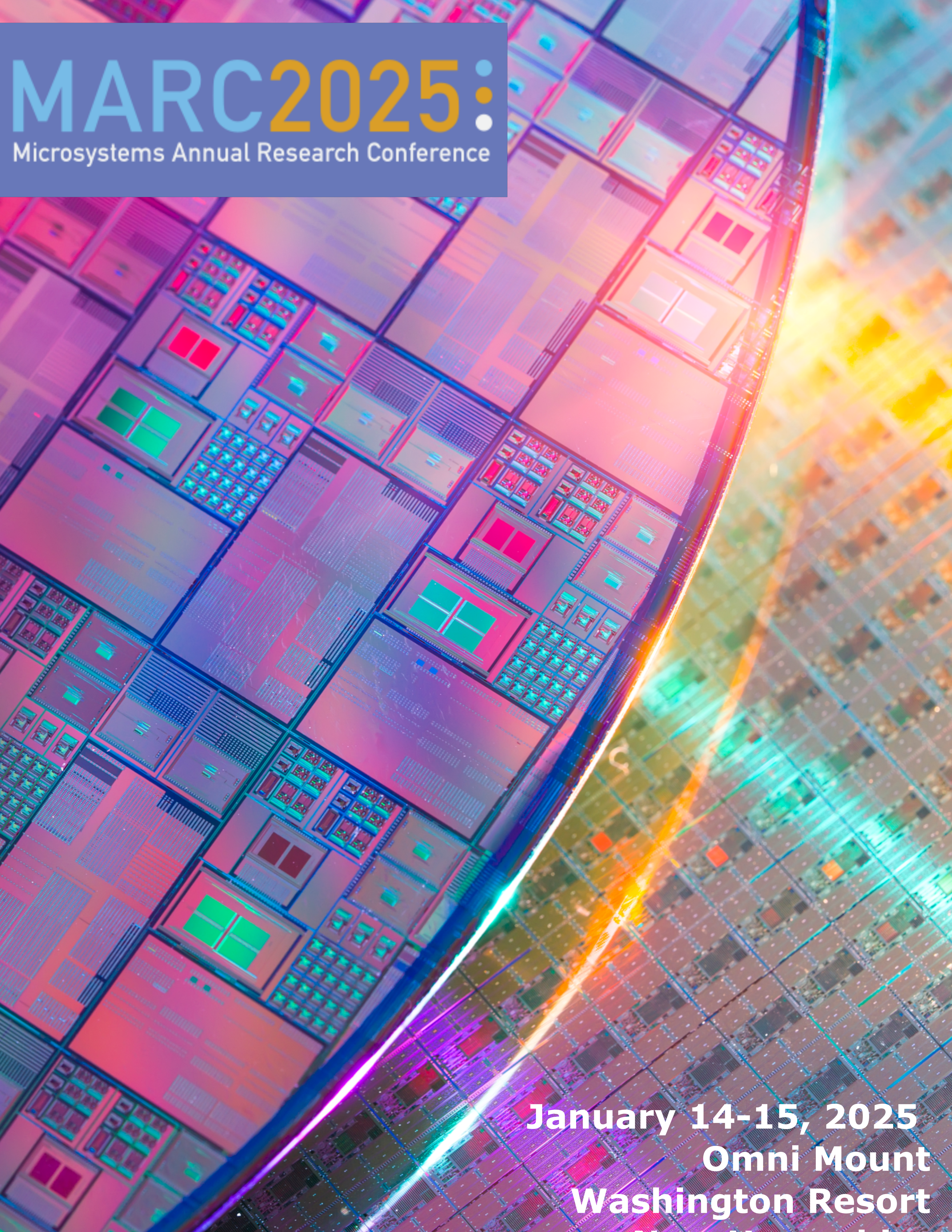

MARC2025:

Microsystems Annual Research Conference

January 14-15, 2025

Omni Mount

Washington Resort

MARC2025:

MICROSYSTEMS ANNUAL RESEARCH CONFERENCE

JANUARY 14–15, 2025 • BRETTON WOODS, NH

Massachusetts Institute of Technology

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CONTENTS

Introduction i
Agenda ii
Keynote - Deirdre Hanford iv
Panelist Speakers v
Industry Consortium (MIG & MAP Members) x
Abstracts vii
- Session 1: Electronic Devices 1
- Session 2: Integrated Circuits & Systems 14
- Session 3: Medical Devices & Biotechnology 23
- Session 4: Energy, Power & Sustainability 35
- Session 5: Materials & Manufacturing 41
- Session 6: Nanotechnology & Nanomaterials 52
- Session 7: Optoelectronics & Integrated Photonics 58
- Session 8: Quantum Technologies 67
- Session 9: Quantum Technologies 75
- Session 10: Quantum Technologies 86
- Session 11: Quantum Technologies 89

Maps 95
Sponsors 97

INTRODUCTION

Dear friends, collaborators, and colleagues,

Welcome to MARC 2025! We are honored to gather once again to celebrate the Microsystems Technology Laboratory's enduring leadership in microelectronics research and innovation. Since first opening its doors in 1984, MTL has consistently pushed the boundaries of knowledge and technology, creating new possibilities in semiconductor discovery, development, and education.

Today, we come together to reflect on the remarkable technological milestones achieved over the past year and to discuss how we, as researchers, participants, and contributors, will continue shaping the future of the semiconductor industry. Building on MTL, we are committed to pushing the limits of scientific inquiry and technological progress, while also educating and inspiring the next generation of innovators. The best is yet to come.

This conference would not have been possible without the tireless efforts of the staff of MTL and MIT.nano, our student committee, as well as MTL Director Prof. Tomás Palacios and MIT.nano Director Prof. Vladimir Bulović. We offer our deepest gratitude to this dedicated team.

This year's conference opens with a convivial social event and a dinner banquet on the first day. We are very pleased to have Prof. Palacios deliver remarks during the banquet, and to hear the insights from seven distinguished panelists on the differences between academia and industry. Our panelists include four MIT professors—Prof. Jelena Notaros, Prof. Song Han, Prof. Joseph Casamento, and Prof. Duane Boning—as well as three industry experts—Esther Jeng of Lam Research Corporation, Dirk Pfeiffer of IBM Research, and Karen Nummy of GlobalFoundries.

On the second day, following an address by Prof. Bulović, we are delighted to welcome our keynote speaker: Deirdre Hanford, Chief Executive Officer & Trustee of Natcast. Hanford's extensive career in semiconductor design and leadership—including executive roles at Synopsys—promises to offer invaluable insights into secure and energy-efficient microelectronics, as well as her personal journey in shaping the semiconductor landscape.

After Hanford's keynote, we are excited to present a panel of four experts from both industry and academia. Representing the world of microelectronic startups, these panelists will share their visions, experiences, and reflections on bridging the worlds of academic research and industrial innovation. The panel includes one MIT professor—Prof. David Perreault—and three industry members—Jan Tiepelt of FabuBlox, Jamie Goldstein of Pillar VC, and Richard Swartwout of Active Surfaces.

This year's MARC has reached an all-time high in attendance, with 273 registered participants. Among them are 228 MIT graduate students, postdocs, and undergraduates representing 59 research groups, plus 5 students and faculty from other academic institutions. We are also joined by partners from 15 companies spanning globally recognized corporations to alumnus-founded startups. Your enthusiastic participation makes this conference unprecedented in scale and richness, and we sincerely thank you for your involvement.

We hope MARC 2025 will inspire you to forge new connections, revisit enduring collaborations, and explore the possibilities that lie ahead. Let us carry forward the pioneering spirit of MTL—innovating, educating, and leading the microelectronics field into the next four decades and beyond.

Thank you for joining us. We wish you a memorable MARC 2025!

Warm regards,

Emma Wawrzynek and Mingran Jia
MARC 2025 Co-Chairs

AGENDA

DAY 1: JANUARY 14

7:00am	**Early Bus Departs MIT** 60 Vassar Street, Cambridge, MA	
10:00am - 4:00pm	**Winter Activities** Bretton Woods, NH	
12:00pm	**Late Bus Departs MIT** 60 Vassar Street, Cambridge, MA	
3:00pm - 5:00pm	**Check-in & Registration** Great Hall Conference check-in @ MARC2025 Registration Desk Hotel check-in @ Hotel front desk *(Rooms available after 4pm)*	
5:00pm - 6:00pm	**Welcome Reception** Conservatory	
6:00pm - 6:30pm	**Opening Remarks** Grand Ballroom	
6:30pm - 7:30pm	**Dinner Banquet** Grand Ballroom *Team Building Activity*	
7:30pm - 8:15pm	**Panel 1: Industry vs. Academia** Grand Ballroom Jelena Notaros, Assistant Professor, MIT Song Han, Associate Professor, MIT Joseph Casamento, Assistant Professor, MIT Duane Boning, Vice Provost for International Activities, Professor, MIT Esther Jeng, Lam Research Corporation Dirk Pfeiffer, IBM Research Karen Nummy, GlobalFoundries	
8:15pm - 8:30pm	**Group Photo** Grand Ballroom	
8:30pm - 12:00am	**Evening Activities** Presedential Ballroom, Washington, Jefferson & Reagan Rooms	
8:30pm - 11:45pm	**Pitch Practice and AV Check** Grand Ballroom	

DAY 2: JANUARY 15

7:00am - 9:00am	**MIG/MAP Networking Breakfast** Main Dining Room
9:00am - 9:15am	**Opening Remarks** Presidential Ballroom
9:15am - 10:15am	**Keynote** Presidential Ballroom Deirdre Hanford Chief Executive Officer & Trustee | Natcast
10:15am - 10:40am	**Morning Refreshments** Presidential Foyer
10:20am - 11:00am	**Poster Pitches (Session 1)** Presidential Ballroom S2 - Quantum Science & Engineering S5 - Electronic, Magnetic, & Spintronic Devices S6 - Medical Devices & Biotechnology S8 - Circuits & Systems S9 - Neuromorphic Devices & AI Hardware Accelerators
11:00am - 12:00pm	**Poster Session (Session 1)** Grand Ballroom • S2, S5, S6, S8, S9
12:00pm - 1:30pm	**MIG/MAP One-on-One Lunch** Main Dining Room
2:00pm - 2:40pm	**Panel 2 - "Academia to Industry"** Presidential Ballroom Jan Tiepelt (FabuBlox) Jamie Goldstein (Pillar VC) Richard Swartwout (Active Surfaces) David Perreault (Ford Professor of Engineering, MIT)
2:40pm - 3:20pm	**Poster Pitches (Session 2)** Presidential Ballroom S1 - Electronic Devices S3 - Photonics and Optoelectronics S4 - Power Devices & Circuits S7 - Nanoscience & Nanotechnology S10 - 3DHI & Additive Manufacturing S11 - MEMS, Field-Emitter, Thermal, Fluidic Devices & Robotics
3:20pm - 4:20pm	**Poster Session (Session 2) / Refreshments** Grand Ballroom • S1, S3, S4, S7, S10, S11
4:45pm - 5:00pm	**Closing Ceremony** Grand Ballroom

KEYNOTE

DEIRDRE HANFORD

Chief Executive Officer & Trustee

Natcast

Deirdre Hanford was appointed Chief Executive Officer and Trustee of Natcast in January 2024. In this role, Hanford leads Natcast as a purpose-built, non-profit entity designated to operate the National Semiconductor Technology Center (NSTC) by the Department of Commerce. Established by the CHIPS and Science Act of the U.S. government, the NSTC is a public-private consortium dedicated to semiconductor R&D in the United States. The NSTC convenes industry, academia, and government from across the semiconductor ecosystem to address the most challenging barriers to continued technological progress in the domestic semiconductor industry, including the need for a skilled workforce.

Prior to Natcast, Hanford served as an executive at Synopsys. Over the span of thirty-six years, Hanford's roles included being Chief Security Officer, Co-General Manager of the Synopsys Design Group, and leader of a variety of customer engagement, applications engineering, sales and marketing groups.

Well known within the semiconductor ecosystem, Hanford has served on many industry advisory boards, including being a leader in the Department of Commerce Industrial Advisory Committee formed through the CHIPS Act.

In July 2024, Hanford was selected to receive the 2025 IEEE Frederik Philips Award "for visionary leadership in electronic design automation for secure and energy-efficient microelectronics." Hanford was additionally awarded the 2024 Brown Engineering Alumni Medal (BEAM) within the Brown University School of Engineering. She has also been named to WomenTech's 2022 list of Women in Tech Leaders to Watch, VLSIresearch's 2017 list of All Stars of the Semiconductor Industry, and National Diversity Council's 2014 list of Top 50 Most Powerful Women in Technology. In 2001, Hanford was a recipient of the YWCA Tribute to Women and Industry (TWIN) Award and the Marie R. Pistilli Women in EDA Achievement Award.

Hanford earned a B.S. Engineering (electrical engineering) from Brown University and an M.S.E.E. from University of California, Berkeley.

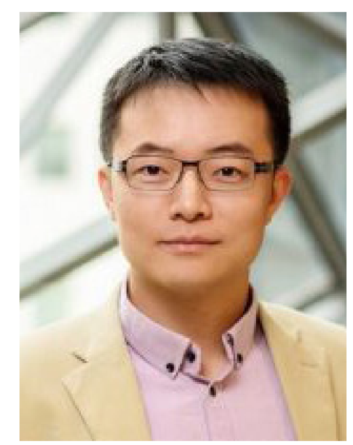
PANELIST SPEAKERS

Panel 1: Industry vs. Academia

JELENA NOTAROS

Assistant Professor, MIT

Professor Jelena Notaros is the Robert J. Shillman Assistant Professor of Electrical Engineering and Computer Science at the Massachusetts Institute of Technology. She received her Ph.D. and M.S. degrees from MIT in 2020 and 2017, respectively, and B.S. degree from the University of Colorado Boulder in 2015. Her research interests are in silicon-photonics devices, systems, and applications. Notaros was one of three Top DARPA Risers, a 2018 DARPA D60 Plenary Speaker, a 2023 NSF CAREER Award recipient, a 2021 Forbes 30 Under 30 Listee, a 2021 MIT Robert J. Shillman Career Development Chair recipient, a 2020 MIT RLE Early Career Development Award recipient, a 2015 MIT Grier Presidential Fellow, a 2015-2020 NSF Graduate Research Fellow, a 2019 OSA CLEO Chair's Pick Award recipient, a 2024 OSA CLEO Highlighted Talk Award recipient, a 2022 OSA APC Best Paper Award recipient, a 2022 OSA FiO Emil Wolf Best Paper Award Finalist, a 2014 IEEE R5 Paper Competition First Place recipient, a 2023 MIT Louis D. Smullin Award for Teaching Excellence recipient, a 2018 EECS Rising Star, and a 2015 CU Boulder Chancellor's Recognition Award recipient, among other honors.



SONG HAN

Associate Professor, MIT

Song Han is an associate professor at MIT EECS. He received his PhD degree from Stanford University. He proposed the "Deep Compression" technique including pruning and quantization that is widely used for efficient AI computing, and "Efficient Inference Engine" that first brought weight sparsity to modern AI chips, making it one of the top-5 most cited papers in the 50-year history of ISCA. He pioneered the TinyML research that brings deep learning to IoT devices, enabling learning on the edge. His team's work on hardware-aware neural architecture search (once-for-all network) enables users to design, optimize, shrink and deploy AI models to resource-constrained hardware devices, receiving the first place in many low-power computer vision contests in flagship AI conferences. His team's recent work on large language model quantization/acceleration (SmoothQuant, AWQ, StreamingLLM) has effectively improved the efficiency of LLM inference, adopted by NVIDIA TensorRT-LLM. Song received best paper awards at ICLR, FPGA and MLSys, faculty awards from Amazon, Facebook, NVIDIA, Samsung and SONY. Song was named "35 Innovators Under 35" by MIT Technology Review for his contribution on "deep compression" technique that "lets powerful artificial intelligence (AI) programs run more efficiently on low-power mobile devices." Song received the NSF CAREER Award for "efficient algorithms and hardware for accelerated machine learning", IEEE "AIs 10 to Watch: The Future of AI" award, and Sloan Research Fellowship. Song's research in efficient AI computing has witnessed successful commercialization and influenced the industry. He was the cofounder of DeePhi (now part of AMD), and cofounder of OmniML (now part of NVIDIA). Song developed the EfficientML.ai course to disseminate efficient ML research.

JOSEPH CASAMENTO

Assistant Professor, MIT

Professor Joseph Casamento's research background and interests are in semiconducting materials and dielectrics, heterostructure design, thin film synthesis, and device fabrication. Specifically, he focuses on nitride semiconductors and related materials, widely used in light-emitting diodes and lasers, RF transistor amplifiers, and acoustic devices.

In his work, Professor Casamento aims to improve the performance and functionality of these devices with novel synthesis approaches, using new materials with emerging phenomena, understanding detailed structure-property relationships, and device simulation. Examples of emerging phenomena in this class of materials include ferroelectricity and superconductivity.

DUANE BONING

Vice Provost for International Activities, Professor, MIT

Duane Boning is the vice provost for international activities, providing intellectual leadership, guidance, and oversight of the Institute's international engagements and policies. As the Clarence J. LeBel Professor in the Department of Electrical Engineering and Computer Science (EECS), his research focuses on machine learning and statistical methods for modeling and control of variation in semiconductor and photonic manufacturing processes, devices, and circuits, with more than 300 journal and conference publications on these topics.

Prior to joining the faculty MIT in 1992, Prof. Boning worked at Texas Instruments from 1991 through 1992. He served as editor-in-chief of the IEEE Transactions on Semiconductor Manufacturing from 2001 to 2011. He has held several leadership positions at the Institute, serving as associate department head of EECS from 2004 to 2011 and as associate chair of the MIT Faculty from 2019 to 2021. Among his previous leadership roles in international collaborations, Prof. Boning served as faculty lead of the MIT/Masdar Institute Cooperative Program and faculty lead of the MIT Skoltech initiative. He is currently the engineering faculty co-director for MIT's Leaders for Global Operations Program and faculty co-director for the Machine Intelligence in Manufacturing and Operations effort. Prof. Boning is a Fellow of the IEEE for contributions to modeling and control in semiconductor manufacturing.

Prof. Boning earned his SB, SM, and PhD degrees from MIT in electrical engineering and computer science.

ESTHER JENG

Senior Manager of Open Innovation, Lam Research Corporation

Dr. Esther Jeng is senior manager of open innovation in the Office of the CTO at Lam Research where she connects emerging technologies to Lam's semiconductor products for manufacturing new generations of chips. She manages a portfolio of exploratory technologies in partnership with the university ecosystem to find solutions to the industry's grand challenges.

Dr. Jeng has held multiple roles at Lam, leveraging 14 years of experience in atomic layer and chemical vapor deposition of thin-film metals. She has collaborated closely with leading-edge customers and led globally located engineering teams to develop products from initial power-up in the lab to high-volume production for logic and memory fabrication. Her areas of expertise include plasma and thermal thin film deposition, chemical process development and precursor handling in vacuum systems, and defect management.

DIRK PFEIFFER

Director, Microelectronics Research Laboratory (MRL),
IBM Research TJ Watson Research Center

Dr. Dirk Pfeiffer is the director of the Microelectronics Research Laboratory (MRL) at the IBM TJ Watson Research Center. The MRL is a semiconductor R&D facility with key capabilities including a 200mm wafer scale fabrication and its mission is to accelerate technologies from early stages of innovation to wafer scale development and manufacturing ("Lab to Fab" prototyping). Its project portfolio include quantum, semiconductor device and materials development, embedded analog devices for memory and AI applications, and others. Dr. Dirk Pfeiffer has 25 years of experience in semiconductor and material process development as well as building and operating semiconductor fabrication facilities. He is author and coauthor of 80 plus patents, publications as well as several IBM outstanding technology achievement awards and has a PhD in Chemistry.

KAREN NUMMY

GlobalFoundries

Karen Nummy was a Distinguished Member of Technical Staff at Globalfoundries, she has over 35 years of experience in semiconductor process development. After her recent retirement, Karen has rejoined Globalfoundries as a consultant helping to foster the relationship between MIT and GF, establishing a partnership to drive solutions to GF's next generation of products. During her career at IBM and Globalfoundries, she worked on a wide range of technologies, including bipolar, CMOS, BiCMOS, SiGe HBTs, eDRAM as well as photonic devices. Karen was the lead integrator for IBM's 45nm eDRAM and 22nm server products. Her most recent role was the lead for Globalfoundries' photonic processes. During her career, Karen was very active as a mentor for women and young engineers. She has authored over 40 patents and numerous papers. Karen received her BS and MS in Material Science from MIT.

Panel 2: Academia to Industry

JAN TIEPELT

FabuBlox

Jan received Bachelor's and Master's degrees in Materials Science from RWTH Aachen in 2013 and ETH Zurich in 2017 before joining MIT to pursue a PhD in Electrical Engineering in 2017. Under guidance of Prof. Marc Baldo his research was focused on the study of degradation phenomena in blue OLEDs before completing his PhD in May 2024. Experiencing bottlenecks in nanofabrication process development, he created FabuBlox with his team of co-founders in 2023 in an effort to provide a platform dedicated to shared database building for the MIT.nano and MTL community. The innovative FabuBlox interface was so well received that the platform now has over a thousand users at about 80 nanofabrication facilities worldwide and FabuBlox recently received a $1.8M pre-seed investment from Pillar VC.

JAMIE GOLDSTEIN

Pillar VC

Jamie Goldstein is the Founding Partner at Pillar VC.

Jamie founded the firm with the ambition to build the next generation of lasting companies in Boston. He has spent over two decades working in venture capital, and his investments include Algorand, PathAI, Asimov, Abridge, Jellyfish and Videa Health, among others.

Prior to Pillar, Jamie was an investing partner for 18 years at North Bridge Venture Partners.

RICHARD SWARTWOUT

Active Surfaces

Dr. Richard Swartwout is the co-founder and CTO of Active Surfaces Inc which is devoted to bringing the next generation of flexible electronics to market. Prior to his current role, he graduated from Rensselaer Polytechnic Institute with his B.S. in Materials Engineering and obtained his M.S. and PhD in Electrical Engineering from MIT in 2021. His PhD research was conducted in the laboratory of Vladimir Bulovic and the innovations developed in third generation solar photovoltaics and roll-to-roll manufacturing form the foundation of Active Surfaces technical thrusts. During his time at MIT he also worked in VC at Safar Partners as a venture investor and after graduating helped establish the START.nano program for startups associated with the MIT.nano cleanroom during his postdoc. Dr. Swartwout brings a deep technical expertise with over 10 years in cleantech and looks forward to the future where every surface can be Active!

DAVID PERREAULT

Ford Professor of Engineering, MIT

David Perreault received the B.S. degree from Boston University and the S.M. and Ph.D. degrees from the Massachusetts Institute of Technology, all in Electrical Engineering. He is presently the Ford Professor of Engineering at MIT. His research interests include design, manufacturing, and control techniques for power electronic systems and components, and in their use in a wide range of applications. Dr. Perreault is a Member of the National Academy of Engineering, a Fellow of the IEEE and is the recipient of awards including the IEEE William E. Newell Award for his work in power electronics. He is co-author of fifteen IEEE prize papers in the area, and of the textbook "Principles of Power Electronics, 2nd Edition" (Cambridge University Press, 2023). Dr. Perreault also co-founded startup companies Eta Devices (acquired by Nokia in 2016) and Eta Wireless (acquired by Murata in 2021).

INDUSTRY CONSORTIUM (MIG & MAP)

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IBM Research
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TSMC
Texas Instruments
Viavi Solutions

From its very inception, MIT has maintained an intimate connection with industry to inform and inspire its research endeavors. The Microsystems Industrial Group (MIG), established in the early '80s, proved to be an effective platform for engagement of industry with the MTL community! The launch of MIT.nano in 2018 defined a new chapter in MIT's history for advancing science and technology at the nanoscale. Since 2020, the flagship Microsystems Annual Research Conference (MARC) has been co-hosted by MTL and MIT.nano. It is our distinct pleasure to welcome all of our industry partners to join us again at MARC2025.

ABSTRACTS

SESSION 1: MATERIALS - SYNTHESIS & CHARACTERIZATION

1.01 Organic Iono-Electronic Semiconductors for In Vivo Detection of Neurotransmitters ... 1
1.02 Precise Angle Measurement for Two-Dimensional Material Stacking via Computer Vision ... 1
1.03 Solid-State Dewetting of Nickel and Copper Thin Films ... 2
1.04 Cross-Correlated AFM and TERS Imaging of Janus Transition Metal Dichalcogenide Monolayers ... 2
1.05 Mechanocaloric Polymer Discovery and Multi-Scale Engineering for Green HVAC Technologies ... 3
1.07 Artificial Intelligence-Assisted Synthesis and Integration Optimization of 2D Materials ... 3
1.08 Fabrication of √Ö-Scale Graphene Pores for Efficient Isomer and Ionic Separation ... 4
1.09 Characterization of Interface-Driven Wake-Up and Fatigue of Ferroelectric Hf0.5Zr0.5O2 for Non-Volatile Memory Applications ... 4
1.10 Ultra-Densification of Vertically Aligned Boron Nitride Nanotubes via Biaxial Mechanical Compression ... 5
1.11 Selective Area Epitaxy of Defect-free III-V Layers on Silicon via Graphene Nanoholes ... 5
1.12 CVD Synthesis of Mono- and Multilayer hBN on Single-Crystal Metal Surfaces ... 6
1.13 Material Characterization of Niobium Nitride Sputtered Thin Films for SNSPDs ... 6
1.14 Metal-Organic Chemical Vapor Deposition-based Synthesis of P-type Tungsten Diselenide ... 7
1.15 Investigation of Novel Atomic Layer Deposited Dielectric Films for High Frequency, High Temperature Gallium Nitride Electronics ... 7
1.16 Maximizing Value from Municipal Solid Waste Incineration Ash,Äî Electrochemical and Chemical Methods for Material Recovery ... 8
1.17 Mechanocaloric Polymer Discovery and Multi-Scale Engineering for Green HVAC Technologies ... 8
1.18 Hybrid Deposition Process of Perovskite Photovoltaics ... 9
1.19 X-ray Induced Relaxation of Nickel and Nickel-based Nanoparticles on Silicon ... 9
1.20 Group-IV-based Nanostructure Materials for Quantum Computing and Photonics ... 10
1.21 Synthesis of Mixed-Dimensional Perovskite Heterostructures ... 10
1.22 Plasma-enhanced ALD Deposition of High Breakdown Field Al(O, N) and Ga2O3 ... 11
1.23 Electron Energy Loss Spectroscopy of 2D Materials in a Scanning Electron Microscope ... 11
1.24 Seeding Promoter Effect on Metal Organic Chemical Vapor Deposition Synthesized Molybdenum Disulfide ... 12
1.25 Uncovering Origins of Poor Photoluminescence Quantum Yield in 2D Hybrid Metal Organic Chalcogenolates (MOCs) ... 12
1.26 Electric Field Tunable Chern Insulators in Tetralayer Rhombohedral Graphene ... 13
1.27 Semi-transparent Perovskite Solar Cells ... 13

SESSION 2: QUANTUM SCIENCE & ENGINEERING

2.01 Diverse Impacts of Spin-orbit Coupling on Superconductivity in Rhombohedral Graphene ... 14
2.02 Q-Pilot: Field Programmable Qubit Array Compilation with Flying Ancillas ... 14
2.03 Spectroscopy Signatures of Electron Correlations in a Trilayer Graphene/hBN Moiré Superlattice ... 15
2.04 Quantum-secure Multiparty Deep Learning ... 15
2.07 Electron Energy Loss Spectroscopy of 2D Materials in a Scanning Electron Microscope ... 16
2.08 Quantum Frequency Conversion for Networking via the Telecom E-band ... 16
2.09 Impact of Junction Oxidation Parameters on the Two-level System Densities in Superconducting Qubits ... 17
2.10 Strain Tuning of Individual Telecom Color Centers in Reconfigurable Silicon Photonics ... 17
2.11 Nanoelectromechanical Cantilever Waveguide Diagnosis via Visible Spectral Domain Optical Coherence Tomography ... 18
2.12 Strong-coupling Theory of Single-photon Detection in Superconducting Nanowires ... 18
2.13 Spectral Methods for Modeling Non-equilibrium Superconductivity ... 19
2.14 Nanoelectromechanical Cantilever Waveguide Diagnosis via Visible Spectral Domain Optical Coherence Tomography ... 19
2.15 Confinement of Hybridized Light Waves for Single-mode Photonics ... 20
2.16 Integrated Photonics for Polarization-Gradient Cooling of Trapped Ions ... 20

2.17 Characterization and Comparison of Energy Relaxation in Planar Fluxonium Qubits ... 21
2.18 Superconducting TiN Through-Silicon Vias for Superconducting Qubits ... 21
2.19 Superconducting TiN Through-Silicon Vias for Quantum Computing ... 22
2.20 Exciton Fine Structure in Two-dimensional Metal-halide Perovskites ... 22

SESSION 3: PHOTONICS AND OPTOELECTRONICS

3.01 High-Resolution, Broadband Integrated Photonic Fourier-Transform Spectrometer ... 23
3.02 Optimized 2D Template for Remote Epitaxy of Efficient Red InGaN ... 23
3.03 Electro-optic Control of AlN Photo-Switch with Sub-Bandgap Illumination and Enhanced Switching Speed ... 24
3.04 Exploring the Potential of 2D Photovoltaic Devices for Biological Applications ... 24
3.05 Exciton Fission Enhanced Silicon Solar Cell ... 25
3.06 Collaborative Robotics for Free-Space Optics. ... 25
3.07 In-situ Core/Shell Perovskite/MoS2 Heterostructure Phototransistor ... 26
3.08 Vertically Stacked Micro-LEDs for XR Displays ... 26
3.09 Fully Integrated, Silicon Monolithic Refractive Index Sensor in CMOS for Hydrogen Sensing ... 27
3.10 A Novel SERS-Based Strategy for Rapid and Sensitive Detection of NRR Products Using Janus WSSe/WS2 Heterostructures ... 27
3.11 Analysis of Purcell-Modulated Exciton Transport in Transition Metal Dichalcogenide Monolayers ... 28
3.12 Spatially and Spectrally Resolved Electric Field Inhomogeneity in Colloidal Cd-Free QD-LEDs ... 28
3.13 Superconducting Feedforward Electronics for Photon-number Discrimination in Quantum Photonic Platforms ... 29
3.14 Integrated Visible-Light Grating-Based Antennas for Augmented-Reality Displays ... 29
3.15 Adaptive Nonlinear Pulse Engineering in Optical Multimode Fiber with Wavefront Shaping and Mechanical Perturbation ... 30
3.16 Spatially-Adaptive Multi-Beam Optical-Phased-Array-Based Solid-State LiDAR Sensors ... 30
3.17 Photoinduced Surface Passivation for Singlet Fission-Enhanced Silicon Photovoltaics ... 31
3.18 Reduced-Crosstalk Optical Antennas for Wide-Field-of-View Optical Phased Arrays for Solid-State LiDAR Sensors ... 31
3.19 Modulating Multimodal Femtosecond Pulse Propagation for Label-free Nonlinear Microscopy ... 32
3.20 Dark Exciton Signatures in Blue OLEDs Probed by Strong Magnetic Fields in Situ ... 32
3.21 Modeling Coupling Between Optically Driven Nanoantennas and Wires in Petahertz Electronic Circuits ... 33
3.22 Integrated Optical Phased Arrays with Visible-Spectrum-Spanning Emission ... 33
3.23 Gold Nanostructures for Mid and Long-Wave Infrared Detection ... 34

SESSION 4: POWER DEVICES & CIRCUITS

4.01 The Analysis and Design of Resonant Capacitively-Isolated Cockcroft-Walton Converter ... 35
4.02 An Electric Field ‚ÄúDeep Bar‚Äù Induction Motor ... 35
4.03 Soft-Switched Pulsed Bias Plasma Supply System ... 36
4.04 A Hybrid Switched Capacitor Converter Enabling Capacitive-Based Wireless Power Transfer for Battery Charging Applications ... 36
4.05 A Literature Review on the Analysis of Resonant Switched-Capacitor Converters ... 37
4.06 Design of Vertical AlN-Channel Power Transistors ... 37
4.07 A Switched-Capacitor Based Slow Charging Solution for Electric Vehicles ... 38
4.08 Improved Piezoelectric-Resonator-Based Power Conversion at High Conversion Ratios ... 38
4.09 TCAD Simulations to Explore Thermal Solutions for GaN-on-Silicon HEMTs ... 39
4.10 Specific Power Increases in DC-DC Power Converters for Electroaerodynamic Aircraft ... 39
4.11 High Performance Scaled p-GaN-Gate HEMTs for Next Generation Medium-Voltage Power Converters ... 40
4.12 Review of Piezoelectric-Based Power Conversion ... 40

SESSION 5: ELECTRONIC, MAGENTIC & SPINTRONIC DEVICES

5.01 Gate Stack Design of p-GaN Gate GaN High Electron Mobility Transistors ... 41
5.03 Electrical-Controlled Magnetism in Rhombohedral Graphene ... 41
5.04 Discrete Domain Switching in Scaled Amorphous Metal-Oxide Channel Ferroelectric FETs ... 42
5.05 Scalable Functionalization of CNFETs Chip for Chemical and Biological Sensing ... 42
5.06 Non-Toxic Solvent System for Ubiquitous Coatings of Perovskite Solar Cells ... 43
5.07 Systematic Study of Dielectric Materials for GaN MISHEMTs ... 43
5.10 Singlet Fission Sensitized Planar Silicon Solar Cells ... 44
5.11 Reconfigurable Two-dimensional Floating Gate Field-effect Transistors for Highly Integrated Electronics Devices ... 44
5.12 Materials Study of Flip-Processed Nitrogen-Polar GaN HEMTs ... 45
5.13 Hafnium-Zirconium-Oxide Ferroelectric Materials for Advanced Logic and Memory Technologies ... 45
5.14 Towards a Ferroelectric High Electron Mobility Transistor for Memory Applications ... 46
5.15 Photon-Assisted Quantum Tunneling in Two-Dimensional NiI2/hBN Heterostructures ... 46
5.16 Refractory T-Gate AlGaN/GaN MISHEMTs with ALD AlON Gate Dielectric ... 47
5.17 Negative Differential Transconductance Device based on the WSe2 / WTe2 Heterojunction ... 47
5.18 Dipole-Engineered Contacts to Two-Dimensional Semiconductors ... 48
5.20 Lateral GaN Superjunction Diodes through Si-ion Implantation into p-GaN ... 48
5.21 Anomalous Hall Effect and Superconductivity in BN-aligned Magic-angle Twisted Bilayer Graphene ... 49
5.22 AFM-Based Alignment of MATBG with hBN ... 49
5.24 Testing the Hypothesized Iodine Redox Cycle in Illuminated P-I-N Metal-Halide Perovskite Solar Cells Under Illumination ... 50
5.25 Clean and Open-Surface Graphene on hBN Enabled by a Flip-hBN Method ... 50
5.26 High-performance Multi-channel MoS2 Transistors for Front-end-of-line Integration Beyond 1 nm Node ... 51

SESSION 6: MEDICAL DEVICES & BIOTECHNOLOGY

6.01 New NMR Probe Configurations for Spectroscopy and Relaxometry of Moving Fluids ... 52
6.03 Predicting Artifacts and Seizures from EEG Data using Pretrained Foundation Models ... 52
6.04 System Prototype for Electromagnetic Breast Cancer Detection ... 53
6.05 Surface Patch Coils and Pulse Sequences for Noninvasive Blood Tests Using Magnetic Resonance ... 53
6.08 Fiberscope: A Miniature Microscope for Behavioral Fluorescence Observation in Mice ... 54
6.10 Prediction of Onset of Action Potentials in Spontaneous Neuron Firings ... 54
6.11 Highly Integrated Graphene-based Chemical Sensing Platform for Structural Monitoring Applications ... 55
6.12 Stimuli-responsive Nanodevices for Application in Tissue Regeneration ... 55
6.13 Ingestible Gastric Electrical Stimulation System Using Bioresorbable Electromechanical Systems. ... 56
6.14 Continuous Adeno-associated Virus (AAV) Production System Using Inertial Microfluidic Device ... 56
6.15 Deep and Dynamic Metabolic and Structural Imaging in Living Tissues ... 57

SESSION 7: NANOSCIENCE & NANOTECHNOLOGY

7.02 Optical Detection of Proximity Effect Between WSe2 and Multiferroic Helimagnet NiI2 ... 58
7.03 Photonics of Life ... 58
7.05 Probing Operational Degradation Mechanism on Cd-free Red and Blue QD-LEDs ... 59
7.06 Fluctuations in Superconducting Nanowires ... 59
7.07 Sliding Ferroelectric Memory Based on Rhombohedral-stacked Molybdenum Disulfide ... 60
7.08 Graphene-assisted Spontaneous Relaxation for Defect-free Heteroepitaxy ... 60
7.10 High-throughput Manufacturing of Ultrathin Epitaxial Membranes Towards Cooling-free Infrared Detection. ... 61
7.11 On-site Growth of Perovskite Nanocrystal Arrays for Integrated Nanodevices ... 61
7.12 Non-epitaxial Growth of Aligned Transition Metal Dichalcogenides at Low Temperature for Silicon Back-end-of-line Integration ... 62
7.13 Optimizing Contact Resistance of GaN p-FET Devices for CMOS Applications ... 62
7.14 Electrical Double layer Force Enabled Wafer-scale Transfer of Van der Waals Materials ... 63
7.15 Localized and Uniform Strain Engineering of 2D Materials for Optical and Electrical Devices ... 63
7.16 Domain-Controlled Growth of Two-Dimensional Tin Selenide ... 64

7.18 Hydrogen Gas Detection with MoS2-based Chemical Sensing Platform ... 64
7.19 Signatures of Chiral Superconductivity in Rhombohedral Graphene ... 65
7.20 Highly Tunable Josephson Junction in Rhombohedral Graphene ... 65
7.21 Molecular Probe Adsorption as a Technique to Elucidate Corona Phase Molecular Recognition (CoPhMoRe) through Structure Property Relationships ... 66
7.22 Laser-induced Graphene Supercapacitors ... 66

SESSION 8: CIRCUITS & SYSTEMS

8.01 Interface Circuits for Analog In-Memory Computing ... 67
8.02 Memory-Efficient Gaussian Mapping on Micro-Robots: Algorithm and Chip ... 67
8.03 Memory-Efficient Gaussian Mapping on Micro-Robots: Algorithm and Chip ... 68
8.05 Efficientvit-SAM: Accelerated Segment Anything Model without Performance Loss ... 68
8.07 Miniaturized Medical Devices for In-vivo Navigation and Monitoring ... 69
8.08 Harmonic-Resilient Low-Power Receiver Architecture with Pipeline Mixing for IoT Applications ... 69
8.09 A Sub-6GHz Configurable Receiver with High-Order Channel Selectivity and Harmonic Rejection ... 70
8.10 An Analog Front-End for Bladder Ultrasound Monitoring: Achieving 75% Reduction in RX Power Consumption through Power Gating for Intra-Image Sparsity ... 70
8.11 Characterizing the Performance of Large-scale Superconducting Integrated Circuits ... 71
8.12 A 28 GHz Coupled PLL-Based CMOS Quadrature Oscillator ... 71
8.13 Design and Modeling of High Temperature Gallium Nitride RF Amplifiers ... 72
8.14 Integrated System to Control and Measure Graphene Field Effect Transistor Arrays ... 72
8.15 Defining and Optimizing Write/Clear Margin for a Nanoantenna-Based Petahertz Electronic Memory Cell ... 73
8.16 Understanding the Relationship Between Environmental Fabrication Conditions and Perovskite Formation, Performance and Stability. ... 73
8.17 A 232-to-260GHz CMOS Amplifier-Multiplier Chain with a Low-Cost, Matching-Sheet-Assisted Radiation Package and 11.1dBm Total Radiated Power ... 74

SESSION 9: NEUROMORPHIC DEVICES & AI HARDWARE ACCELERATORS

9.01 CiMLoop: A Flexible, Accurate, and Fast Compute-In-Memory Modeling Tool ... 75
9.02 Single-Shot Matrix-Matrix Multiplication Optical Processor for Deep Learning ... 75
9.03 Analog Hardware Accelerators for Energy-Based AI Models ... 76
9.04 Development of a Neuromorphic Network using BioSFQ Circuits ... 76
9.05 Stable and Accurate Nano-Resistor for Reliable Fixed AI Inference Tasks ... 77
9.06 Design Considerations of Analog Accelerators for Machine Learning Applications ... 77
9.07 LongVILA: Scaling Long-Context Visual Language Models for Long Videos. ... 78
9.08 QServe: W4A8KV4 Quantization and System Co-design for Efficient LLM Serving ... 78
9.09 LoopTree: Exploring the Fused-layer Dataflow Accelerator Design Space ... 79
9.10 LEGO: Spatial Accelerator Generation and Optimization for Tensor Applications ... 79
9.11 SORBET: Secure Off-chip Memory Interface for Deep Neural Network Accelerators ... 80
9.12 Efficient Sampling from Prior Distributions Using Stochastic Magnetic Tunnel Junctions ... 80
9.13 SVDQuant: Absorbing Outliers by Low-Rank Components for 4-Bit Diffusion Models ... 81
9.14 DuoAttention: Efficient Long-Context LLM Inference with Retrieval and Streaming Heads ... 81
9.16 Quest: Query-Aware Sparsity for Efficient Long-Context LLM Inference ... 82
9.17 Enhanced Weight-Update Characteristics in Neuromorphic Computing Using Vertical Electrochemical Random-Access Memory with PEALD-TiO2 Channels ... 82
9.18 Tailor Swiftiles: Accelerating Sparse Tensor Algebra by Overbooking Buffer Capacity ... 83
9.19 200 mm Wafer Diameter Process of Pd/PSG/WO3 Protonic Synapses for Analog Deep Learning ... 83
9.20 Quantum-noise-limited Optical Neural Networks Using a Few Quanta Per Neuron Activation ... 84
9.21 Hydrogen-based Electrochemical Random-Access Memories (H-ECRAM) with Low Device-to-device and Cycle-to-cycle Variabilities ... 84
9.22 Ultra-low Power Superconducting Electronics for Deep Learning Accelerator Architectures: Evaluating Energy Efficiency and Scalability ... 85

SESSION 10: 3DHI & ADDITIVE MANUFACTURING

10.01 3D Printed Device for Triaxial Electrospray ... 86
10.02 Additive Manufacturing of Hybrid Electrospray Emitter Geometries via Two-Photon Polymerization ... 86
10.03 3D-Integrated Circuits in GaN/Si CMOS/Glass for High Frequency, High Data Rate Applications ... 87
10.04 3D-Printed Hard Magnets ... 87
10.05 Unsupervised Anomaly Detection on Irregular Time Series Data ... 88
10.06 Semiconductor-Free, Fully 3D-Printed Logic Gates ... 88

SESSION 11: MEMS, FIELD-EMITTER, THERMAL, FLUIDIC DEVICES & ROBOTICS

11.01 2-Photon Photolithography Fabrication of “Pixel” Electrospray Thrusters ... 89
11.02 DecTrain: Deciding When to Train a Monocular Depth DNN Online ... 89
11.03 Using Silicon MEMS OIS Chip Set with Integrated Computer for Jitter Removal in Olympic .22 LR Sport Shooting Rounds ... 90
11.04 Aerophilic Debubbling ... 90
11.05 Characterization of Magnetoelectric Devices for Wireless Energy Harvesting ... 91
11.06 Flexible Acoustically Active Surfaces Based on Piezoelectric Microstructures ... 91
11.07 Hybrid Locomotion at the Insect Scale – Combined Flying and Jumping for Enhanced Efficiency and Efficacy ... 92
11.08 GEVO: Memory-Efficient Monocular Visual Odometry Using Gaussians ... 92
11.09 High-Impulse, Modular, 3D-Printed CubeSat Electrospray Thrusters Throttleable via Pressure and Voltage Control ... 93
11.10 Ultra-thin Ruthenium Electrochemical Actuators ... 93
11.14 Anode Engineering to Reduce On-Resistance of Field Emitter Arrays ... 94
11.15 An Electromechanical Approach to High-Sensitivity Hydrogen Detection ... 94

Organic Iono-Electronic Semiconductors for In Vivo Detection of Neurotransmitters

1.01

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Organic Electrochemical Transistors (OECTs) based on Organic Mixed Ionic-Electronic Conductors (OMIECs) are promising candidates for in vivo biochemical monitoring, particularly of neurotransmitters, due to their capacity for simultaneous ionic and electronic conduction. However, performance challenges persist in the biological environment, including limitations in mechanical flexibility, signal stability, and efficient ion-electron coupling. In this study, we present a cleanroom-fabricated, conformable OECT platform using engineered OMIEC materials designed to address these constraints.

Our strategy involved optimizing the OMIEC structure through polymer backbone and side-chain modifications to improve ionic-electronic interactions while preserving flexibility. Additionally, incorporating insulating matrices like polyethylene oxide (PEO) and crosslinking agents such as 3-glycidoxypropyl trimethoxysilane (GOPS) significantly enhanced the transduction efficiency and stability of the devices. To further improve neurotransmitter selectivity, strategies involve functionalizing the gate and optimizing waveforms tailored to specific neurotransmitters.

Our findings demonstrate that material engineering and advanced fabrication techniques can produce robust, sensitive, and selective OECTs suitable for real-time neurotransmitter monitoring. This approach supports the development of next-generation bioelectronic sensors with potential applications in closed-loop neuromodulation and therapeutic systems.

Precise Angle Measurement for Two-Dimensional Material Stacking via Computer Vision

1.02

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2D materials, Artificial Intelligence, Electronic devices, Machine Learning, Lab automation

In the fabrication of heterostructures composed of two-dimensional (2D) materials, it is crucial to stack different 2D materials at a precise rotational angle to achieve desired moiré patterns and quantum valley effects. However, the use of high-precision piezoelectric rotation stages can be cost-prohibitive, and we need a reference to confirm the actual angle rotated. To address this challenge and make material stacking more accessible, we propose a computer vision-based approach to determine small rotational angles (0.1° – 5°) from consecutive microscope images, where the center of rotation (COR) is located at a considerable distance from the image frame. The method involves three key steps. First, extracting and refining the displacement of feature point pairs between the two images using SIFT (scale-invariant feature transform), FLANN (fast library for approximate nearest neighbors), and Lowe's ratio test. Displacements closer to the COR will be slightly smaller than those farther away. Second, proposing initial estimates for the COR and angle of rotation (AOR) based on the extracted displacements. Third, optimize the COR and AOR values using gradient descent to minimize the pixel subtraction result of two images. This computer vision technique can determine the rotational angle between two microscope images with a precision of 0.1°. By reducing reliance on costly hardware and providing a means to verify the angle achieved by piezoelectric rotation stages, this software approach enhances both accessibility and accuracy in the fabrication of heterostructure 2D materials.

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Solid-State Dewetting of Nickel and Copper Thin Films

1.03

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Sponsorship: NSF, SRC/DARPA

Solid-state dewetting (SSD) of thin films has been explored as a low-cost method for producing intricate and controlled nanostructures. Due to the significant impact of small changes in experimental conditions on SSD behavior, achieving precise experimental control and employing complementary surface-evolution simulations are essential. Here, we report the SSD behavior of single-crystal nickel and copper thin films, as well as simulations that capture the effects of strong crystalline anisotropy in epitaxial films. Lithographic pre-patterning, which can bound the film edges along different in-plane crystallographic orientations, was used to initiate edge retraction and facilitate the exploration of various dewetting phenomena. Furthermore, we utilized the level-set method to simulate the surface evolution by SSD, capturing both anisotropic surface energy and diffusivity effects. Integrating insights from experiments and simulations will provide methods for controlling surface properties and the dewetting process.

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2D materials, Displays, Electronic devices, Electronics, Field-Emitter devices, Integrated circuits, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Sensors, Si, SiGe and Ge

Cross-Correlated AFM and TERS Imaging of Janus Transition Metal Dichalcogenide Monolayers

1.04

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Sponsorship: US Department of Energy (DOE), Office of Science, Basic Energy Sciences

Two-dimensional (2D) Janus transition metal dichalcogenides (TMDs) are intriguing material candidates for various applications such as non-linear optics, energy harvesting, and catalysis. These materials are usually synthesized via chemical conversion of pristine TMDs, and reliable and high-resolution characterization of the obtained Janus materials' morphology and composition is highly desired for both the synthesis optimization and device applications.

In this work, we present a cross-correlated atomic force microscopy (AFM) and tip-enhanced Raman spectroscopy (TERS) study of Janus TMD monolayers synthesized by the hydrogen plasma-assisted conversion of $MoSe_2$ and MoS_2, respectively. Effects of strain and substrates during the Janus conversion process on the morphology of resulting Janus TMD materials are revealed. Moreover, the TERS characterization shows nanoscale $MoSe_2$-Janus MoSeS vertical heterostructures (~20 nm sizes) that will become hidden under conventional far-field optical characterization, suggesting the powerfulness of using near-field approaches to avoid misconceptions in the composition of Janus TMDs. Our work indicates that cross-correlated AFM and TERS have great capability for studying nanoscale composition and defects in Janus TMD monolayers. The obtained insights into morphology and composition should be useful for further optimizing the Janus conversion approach towards uniform and wrinkle-/crack-free Janus materials.

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Mechanocaloric Polymer Discovery and Multi-scale Engineering for Green HVAC Technologies

1.05

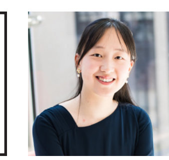
D. Xu, H. Gold, T. Yu, S.V. Boriskina

Sponsorship: SUStech, ONR Global funding, NDSEG Graduate Research Fellowship, PEM Fellowship

Residential thermal management (heating and refrigeration) is one of the most energy-intensive technology sectors, with space cooling alone accounting for nearly 16% of global electricity consumption in the buildings sector in 2021. The direct CO_2 emissions from space and water heating reached a record high of 2.5 G tons in the same year. Solid-state cooling technologies offer a sustainable alternative to conventional HVAC systems, providing opportunities for enhanced energy efficiency and reduced environmental impact.

This work focuses on the AI-driven discovery, testing, and optimization of mechanocaloric (mC) polymers. We use a combination of ab-initio density functional theory and machine-learning surrogate model development to identify most promising polymers and co-polymers for mC applications, a molecular dynamics simulations to evaluate realistic material performance under mechanical deformations, followed by experimental verification and optimization of the most promising materials. Our experimental results show that some of the new materials identified through our discovery pipeline exhibit strong performance, achieving temperature changes exceeding 5 °C under uniaxial strain and up to 20 °C under twisting deformation. Additionally, they exhibit a high coefficient of performance, low actuation stress, and a competitive cost-to-performance ratio, showing promise for scalable applications. Finally, we use macroscopic finite-element mechanical modeling to study the impact of larger-scale structural features, such as fiber plying, braiding and knotting on improving the material performance and fatigue resistance.

Through this multi-scale optimization and testing pipeline, we aim to accelerate the development of durable, high-performance mC materials for scalable and sustainable solid-state cooling and heating technologies.



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2D materials, Nanomaterials, Graphene, Chemical Vapor Deposition

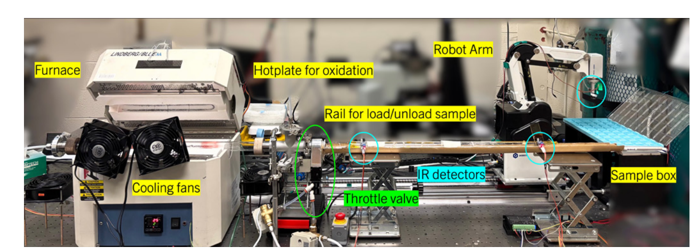
Artificial Intelligence-Assisted Synthesis and Integration Optimization of 2D Materials

1.07

Z. Wang, S. He, A. Lu, J. Wang and J. Kong

Sponsorship: The Semiconductor Research Corporation Center 7 in JUMP 2.0

Chemical vapor deposition (CVD) has developed to be the most efficient and scalable synthesis method for various two-dimensional materials, which hold great promise for advancing the semiconductor technology. However, manual process execution in the CVD synthesis is both time-consuming and labor-intensive. Here, we propose an autonomous CVD system that integrates AI and automation for increased efficiency and high-throughput. To demonstrate this idea, we have built an autonomous graphene CVD system, incorporating stationary robots and automated synthesis. This system can control all the growth parameters including temperature, gas flow, pressure, through input parameters, and handle samples with a robot arm. This autonomous CVD system has the capacity to process up to 50 sets of different growth parameters and synthesize continuously without any manual operation. We have tested the stability of this system with 50 graphene growths within a time period of two weeks, which shows high reproducibility and stability. Enabled by this fully automated system, we plan to incorporate AI into recipe optimization and explore different parameters space of graphene synthesis.



◀ Figure 1: Photograph of the autonomous CVD system for graphene, consists of automated furnace (on the left) and robotic arm for sample handling (on the right)

Fabrication of Å-Scale Graphene Pores for Efficient Isomer and Ionic Separation

1.08

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2D materials, Electronics, Energy, Nanomanufacturing, Nanomaterials, Nanotechnology.

Å-scale pores in monolayer graphene provide spatial confinement for small particles of various sizes, showing great potential in separation science, such as isomer and ionic separation. Conventional top-down methods for fabricating Å-scale pores with high density and uniformity often lack atomistic precision, resulting in large, non-selective pores that cause leakage and reduced selectivity. We previously demonstrated a Cu-ion-sputtering cascade compression approach in Nature that addresses the problem that minimizes the tail-end of the pore size distribution while enhancing pore density. Despite this, it remains challenging to repeatably achieve precise, uniform nanopores for designed separation applications due to the uncontrollable number of Cu ions. Here, we utilize Ar, which delivery is better controlled through a mass flow controller, as an ion source to enhance the reliability of in-situ pore fabrication. By applying voltage within the CVD chamber, Ar gas is ionized into Ar ions through a gas-phase electrochemical reaction and sputters carbon atoms out to create Å-scale pores. As a result, a repeatable production of sub-nanometer pores is implemented by such Ar-cascaded compression, verified by Raman spectroscopy and Conducting-AFM. The resulting Å-scale porous graphene film exhibits remarkable ion-ion selectivity along with high permeance. We plan to collect more data to further verify the repeatability for as-synthesized samples as separation films.

We hope the findings pave the way for Å-scale porous graphene, leading to future sustainable separation technologies.

Characterization of Interface-Driven Wake-Up and Fatigue of Ferroelectric $Hf_{0.5}Zr_{0.5}O_2$ for Non-Volatile Memory Applications

1.09

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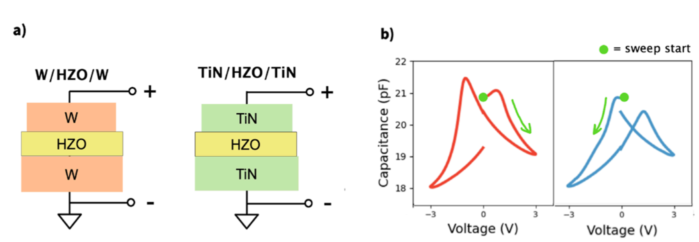
Ferroelectric (FE) memory based on CMOS-compatible $Hf_{0.5}Zr_{0.5}O_2$ (HZO) has emerged as an NVM technology may provide low-voltage operation, fast switching, long data retention, and high device endurance. Plasma-Enhanced ALD has shown enhanced HZO film quality, potentially improving memory. However, certain metal-FE-metal (MFM) capacitive structures show premature breakdown. Endurance characterization shows asymmetric wake-up, indicating unique physics at either metal-HZO interface.

We identify the asymmetric electrical characteristics of W/HZO and TiN/HZO devices that emerge with device cycling. Consistent symmetry patterns across pulsed I-V, DC I-V and C-V measurements indicate interfacial phenomena that eventually lead to device breakdown.

In this work, we show that interface physics are a critical aspect of MFM device endurance: specifically, process conditions and electrode metal are important in realizing high-endurance HZO films and thereby potential NVM applications.



▲ Figure.1: a) Schematic of MFM structures. b) The observed W/HZO C-V characteristic is invariant to sweep direction reversal, indicating device asymmetry.

Densification of Vertically Aligned Boron Nitride Nanotubes via Biaxial Mechanical Compression

1.10

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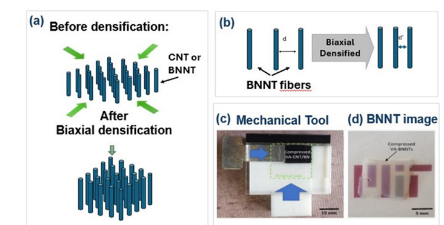
Electronic devices, Energy harvesting devices & systems, MEMS & NEMS, Nanomaterials, Nanotechnology, Quantum devices, Sensors, Transducers

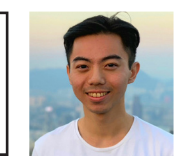
Boron nitride nanotubes (BNNTs) have garnered significant interest due to their one-dimensional structure, piezoelectric properties, superior chemical, and thermal stabilities. All these attributes make BNNTs highly versatile, supporting diverse applications ranging from structural reinforcement to energy storage. However, the synthesized vertically aligned BNNTs have a low volume fraction of around ~1%, which can limit their use in applications like piezoelectric sensor/actuators. In this work, we demonstrate a biaxial densification technique, previously applied to VA-CNTs, that increases the volume fraction of VA-BNNTs by a factor of four.

In this study, the BNNTs were synthesized by coating VA-CNTs with hexagonal boron nitride (VA-CNT/BN), followed by thermal oxidation to remove the CNT scaffold. The work compares three different routes for densifying VA-BNNTs: (1) biaxially densifying the VA-BNNTs directly; (2) biaxially densifying the VA-CNT/BN and posteriorly removing the VA-CNT scaffold; and (3) coating the pre-densified VA-CNTs with BN and subsequently removing the VA-CNT scaffold.

Our results show that method (3) produces a poor BN coating on the CNTs, while method (1) leads to a nonuniformly densified VA-BNNT structure that breaks easily when the densifying forces are released. In contrast, method (2) achieves a uniformly densified VA-BNNT structure after removal of the CNT scaffold. These findings suggest that further densification is feasible with this approach, enabling applications that require a high-volume fraction of BNNTs.



◀ Figure 1: (a,b) Schematic of the biaxial mechanical densification process, (c) Mechanical tool used for compressing VA-CNT compressed, and (d) image of bi-axially compressed VA-BNNT after CNT removal.



Selective Area Epitaxy of Defect-free III-V Layers on Silicon via Graphene Nanoholes

1.11

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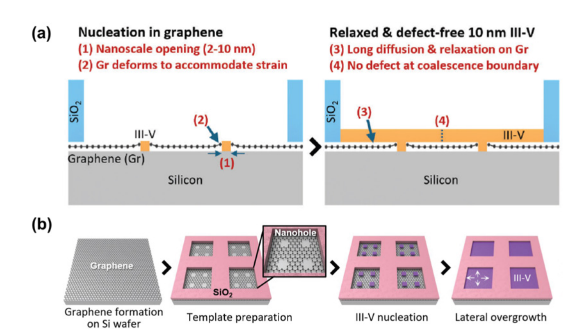
The integration of III-V semiconductors on silicon is a boon for electronic and optoelectronic devices due to their high electron mobility and direct bandgaps. However, their large lattice mismatch often leads to high dislocation densities, severely impacting performance. Standard techniques like graded-buffer layers, epitaxial lateral overgrowth, and aspect ratio trapping have shown limited success, and pseudomorphic growth, while dislocation-free, can result in interface roughening and mobility loss in thin channels.

To address this, I developed a graphene-assisted epitaxy method to achieve dislocation-free III-V growth on silicon. Here, graphene is grown on the silicon surface with nanoholes that expose nucleation sites for III-V growth, while lateral overgrowth over the graphene-covered surface facilitates strain relaxation. This scalable, CMOS-compatible method enables high-quality III-V material integration on silicon for next-generation electronic and optoelectronic devices.



▲ Figure 1: Schematic of the (a) mechanisms and (b) process of graphene-assisted epitaxy to achieve defect-free III-V films on Silicon.

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CVD Synthesis of Mono- and Multilayer hBN on Single-Crystal Metal Surfaces

1.12

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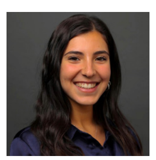
Sponsorship: U. S. Army Research Laboratory, U. S. Army Research Office under contract/grant number W911NF2320057.

Hexagonal boron nitride (hBN) is a crucial material for 2D materials-based field-effect transistors (FETs) due to its outstanding properties as a dielectric substrate and protective layer. However, challenges in synthesizing high-quality, single-crystal hBN films with tunable thicknesses have limited its broader application in nanoelectronics. Here, we demonstrate the scalable synthesis of large-area multilayer hBN films on single-crystal Cu(111) and Ni(111) metal foils prepared through contact-free thermal annealing under atmospheric pressure, yielding uniform crystalline surfaces ideal for hBN growth. Using a thermal chemical vapor deposition (CVD) technique, we synthesize large-area hBN films with various thicknesses. Ongoing studies focus on correlating synthesis conditions with film thickness across different substrates to understand the growth mechanisms of multilayer hBN. Furthermore, we will explore its application as an encapsulation layer to protect air-sensitive transition metal dichalcogenides (TMDs) from degradation, showcasing the potential of hBN to enhance the stability and performance of 2D material-based devices and support their integration into advanced electronic and quantum systems.



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2D materials, Electronic devices, Electronics, Integrated circuits, Lasers, MEMS & NEMS, Nanomaterials, Nanotechnology, Photonic, Quantum devices.

Material Characterization of Niobium Nitride Sputtered Thin Films for SNSPDs

1.13

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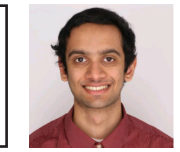
Sponsorship: Darpa Program

Niobium Nitride (NbN) superconducting thin films have garnered significant interest for applications in superconducting electronics, quantum computation, and superconducting nanowire single-photon detectors (SNSPDs). SNSPD performance is highly dependent on the superconducting properties of NbN films, which are primarily determined by the film's microstructure and the substrate on which it is grown. A detailed understanding of the crystallographic structure and chemistry of NbN is essential for evaluating and optimizing device performance. Variations in the phononic spectrum, affected by whether the films are crystalline or polycrystalline, can lead to significant differences in SNSPD characteristics, including thermal conductance, detection efficiency, switching current, depairing current, critical temperature, and diffusion coefficients. This insight enables a direct relationship between crystal structure and device performance, guiding the optimization of NbN-based devices.

In this work, NbN thin films were deposited using sputtering techniques on sapphire, thermally oxidized silicon, and magnesium oxide substrates. The deposition process was analyzed and optimized based on the substrate type. Material and superconducting properties were examined using various techniques, including XRD, XPS, EBSD, ellipsometry, MPMS, and TEM. The critical temperature, crystal structure and orientation, grain dimensions, and optical properties were analyzed and compared across films, with each set of properties related to the achievable device characteristics. Using high-temperature (800 °C) sputtering, we achieved high-quality epitaxial NbN thin films on sapphire, with a critical temperature reaching the bulk value of 16 K, and compared their properties with those of films deposited on other substrates.



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Metal-Organic Chemical Vapor Deposition-based Synthesis of p-type Tungsten Diselenide

1.14

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Sponsorship: Intel

Two-dimensional(2D) materials with their high mobility, excellent gate electrostatic control, and atomically thin nature have emerged as promising channel materials for highly-scaled, energy-efficient electronics. However, most of the previous research focuses on n-type semiconductors, e.g., molybdenum disulfide (MoS_2). P-type 2D materials, e.g., tungsten diselenide (WSe_2), possess equal importance in constituting the complementary electronics circuits, but both the material synthesis and electrical characterizations are less developed.

In this work, using metal-organic chemical vapor deposition (MOCVD), the impact of precursor concentration, seeding promoter, carrier gas and forming gas (H_2) flow on WSe_2 synthesis are systematically discussed, providing insights for obtaining higher-quality materials. Comprehensive material and device characterizations are carried out to evaluate the quality of as-grown WSe_2. This paves the way for our future research on scaling up the material synthesis system to 8" wafer-scale and enabling direct integration of 2D WSe_2 on silicon complementary-metal-oxide-semiconductor (CMOS) circuits.

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Electronic devices, Electronics, GaN, Nanomaterials, Nanotechnology

Investigation of Novel Atomic Layer Deposited Dielectric Films for High Frequency, High Temperature Gallium Nitride Electronics

1.15

J. Kang, J. Niroula, T. Palacios

Sponsorship: AFOSR, SRC Jump 2.0 SUPREME Center

High temperature rated electronics are used in various ways such as hypersonic aircrafts, deep well oil drilling, and exploring Venus. Unfortunately, traditional silicon (Si) devices cannot operate above 250°C due to fundamental limits on its intrinsic carrier concentration. Therefore, semiconductors like silicon carbide (SiC) and gallium nitride (GaN) are more suitable to use for high temperatures because of their wide-band gap and negligible carrier thermal generation at temperatures around 500°C. Currently, plasma enhanced chemical vapor deposition (PECVD) silicon nitride (SiN) is the current state of the art in GaN passivation, but for high frequency devices, thin (<25 nm) passivation layers are needed to minimize parasitic capacitances. Thus, for next generation passivation layers, using Atomic Layer Deposition (ALD) is the preferred deposition method on these devices as ALD allows for atomically precise control of very thin, high quality dielectric layers.

In this project, we investigate the electrical properties of ALD deposited Ga_2O_3, AlN, and Al_2O_3 as future passivation layers for next generation GaN devices. This is done through high temperature (25-300°C) electrical characterization of metal-insulator-metal (MIM) capacitors as well as through current collapse measurements of these films on GaN high electron mobility transistors (HEMTs). ALD grown films provide excellent passivation for silicon surfaces as they exhibit high breakdown voltage, low leakage current, and better thermal conductivity.

Maximizing Value from Municipal Solid Waste Incineration Ash—Electrochemical and Chemical Methods for Material Recovery

1.16

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Sponsorship: ARPA-E (DE-AR0001395), MITEI ExxonMobil

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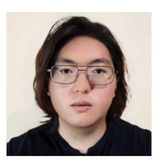
Batteries, Energy, Energy harvesting devices & systems, Fuel cells, Machine Learning, Microfluidic devices & systems, Molecular & polymeric materials, Nanomaterials, Organic materials, Si

In the United States, over 6.6 million tons of hazardous solid residue known as municipal solid waste incineration (MSWI) ash is generated annually by waste-to-energy (WTE) plants. These plants produce electricity and help reduce landfill volume. However, the ash produced is largely unused and typically disposed of in landfills at a cost. The economic viability of MSWI is further challenged by the decreasing price of renewable electricity. Despite this, MSWI ash holds significant potential for valuable element recovery, with an estimated value of $100-400 per ton. We propose an innovative approach to recover valuable materials from MSWI ash using electrochemical and chemical processes. By harnessing electricity generated by WTE plants, our method electrolytically produces acid and base streams to facilitate material recovery and refinement. Our sequential process combines electrochemical extraction with chemical precipitation, enabling the successful recovery of elements such as copper, lead, zinc, magnesium, calcium, iron, and aluminum, along with a purified silica by-product. We have demonstrated the recovery of over 90% of the targeted elements with purities exceeding 90%. Our industry-scale techno-economic analysis indicates that this technology can extract the inherent mineral value from MSWI ash, resulting in net positive returns that far surpass the combined benefits of electricity sales and landfill cost savings.



Mechanocaloric Polymer Discovery and Multi-Scale Engineering for Green HVAC Technologies

1.17

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Residential thermal management (heating and refrigeration) is one of the most energy-intensive technology sectors, with space cooling alone accounting for nearly 16% of global electricity consumption in the buildings sector in 2021. The direct CO2 emissions from space and water heating reached a record high of 2.5 G tons in the same year. Solid-state cooling technologies offer a sustainable alternative to conventional HVAC systems, providing opportunities for enhanced energy efficiency and reduced environmental impact.

This work focuses on the AI-driven discovery, testing, and optimization of mechanocaloric (mC) polymers. We use a combination of ab-initio density functional theory and machine-learning surrogate model development to identify most promising polymers and co-polymers for mC applications, a molecular dynamics simulations to evaluate realistic material performance under mechanical deformations, followed by experimental verification and optimization of the most promising materials. Our experimental results show that some of the new materials identified through our discovery pipeline exhibit strong performance, achieving temperature changes exceeding 5 °C under uniaxial strain and up to 20 °C under twisting deformation. Additionally, they exhibit a high coefficient of performance, low actuation stress, and a competitive cost-to-performance ratio, showing promise for scalable applications. Finally, we use macroscopic finite-element mechanical modeling to study the impact of larger-scale structural features, such as fiber plying, braiding and knotting on improving the material performance and fatigue resistance.

Through this multi-scale optimization and testing pipeline, we aim to accelerate the development of durable, high-performance mC materials for scalable and sustainable solid-state cooling and heating technologies.

Correspondence should be addressed to S.V.B. This work is supported by SUSTech and ONR Global funding. D.X. is supported by the MathWorks MechE Graduate Fellowship. H.G. is supported by the NDSEG and PEM Graduate Fellowships.

Hybrid Deposition Process of Perovskite Photovoltaics

1.18

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Sponsorship: U.S. Department of Energy

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Actuators, Electronic devices, Energy, Energy harvesting devices & systems, MEMS & NEMS, Optoelectronics, Organic materials, Photovoltaics, Si, SiGe and Ge

Halide perovskites have demonstrated remarkably high solar to electrical energy conversion efficiencies and are therefore of great interest for rapid commercialization. Currently, popular fabrication processes involve the hazardous solvent DMF, which is required to dissolve the lead based precursors, such as PbI2. These fabrication routes cannot be readily up-scaled as required. Vapor Transport Deposition (VTD) is an alternative, low-cost manufacturing technique that has been proven before for other solar cell materials.

VTD base process bypasses some solvent related challenges, namely uniform coverage of large areas, chemical compatibility, and toxicity. As a low-cost alternative to thermal evaporation, VTD has the potential to deposit organic and inorganic perovskite precursor materials either sequentially or via co-deposition. Furthermore, VTD potentially offers higher tunability of deposition parameters, to enable film growth with improved composition and microstructure control. In this work, we demonstrate harnessing VTD to deposit the inorganic precursor lead iodide. By that we can eliminate the use of the toxic solvent DMF, and replace it by isopropanol which is considered 40 times less toxic.

We are currently working with a custom-made VTD system, with which we achieved champion FAPI and MAPI cells of 12% power conversion efficiency. We report our progress in investigating the influence of underlying layer, substrate and sublimation temperatures, chamber pressure and flow rate ratios on the morphology and stoichiometry of the forming perovskite film, and in turn, its photo-active and electronic properties.

X-ray Induced Relaxation of Nickel and Nickel-based Nanoparticles on Silicon

1.19

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Sponsorship: MathWorks Fellowship, Startup

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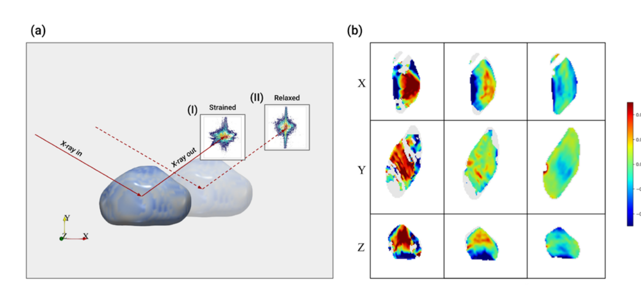
2D materials, Artificial Intelligence, Batteries, Energy, Energy harvesting devices & systems, Machine Learning, Nanotechnology, Photovoltaics, Quantum devices, Si

Nickel and Nickel-Cobalt single crystals are model systems for studying the effects of radiation and corrosion in Light Water Reactor cooling components. While bulk alloys are used in full-scale systems, nanoparticle analogues can accelerate the research and development of bulk materials for use in extreme environments. Their morphologies, formed by dewetting, distinguish them from their bulk forms and influence local mechanical and chemical properties. Utilizing coherent X-rays to resolve strain and defects, Bragg Coherent Diffraction Imaging (BCDI) enables deep insight into single crystal models. In this work, we demonstrate that coherent X-rays can be used to relax highly strained Nickel alloy single crystals on Silicon. Furthermore, we use atomistic density functional theory calculations to show how photo-assisted modulation of charge density at the interface leads to the observed relaxation. Understanding and controlling heteroepitaxy with coherent X-rays will provide deeper insight into the physical chemistry of heterointerfaces while also promoting the use of BCDI to characterize complex models of materials in extreme environments.



◀ Figure 1: (a): Schematic of crystal in initial state (I) and final state (II) with detected diffraction pattern showing changes from highly strained to relaxed state. (b): Crystal cross sections along X, Y and Z directions showing time dependent strain field relaxation under the influence of X-rays.

Group-IV-based Nanostructure Materials for Quantum Computing and Photonics

1.20

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Group-IV semiconductors (Si, Ge, Sn) are key materials for nanoelectronics and show promise for quantum devices. While Si remains the most widely used semiconductor, Ge and GeSn draw interest due to their inherently higher electron and hole mobility. This work explores methods to realize Ge- and GeSn-based nanostructures.

Ge nanowires (NWs) offer a versatile platform for exploring quantum transport phenomena as the 1D charge confinement enables spin-based qubit logic. Despite these convenient properties, NW scalability remains a major challenge. Selective area epitaxy (SAE) offers a scalable solution for achieving horizontal NWs on device substrates. In this work, we advance the SAE of Ge NWs by growing the Ge in a Si V-groove nanomembrane (NM) instead of holes on a planar substrate. This approach confines the NWs fully within the Si V-groove, eliminating the direct interface between the Ge and SiO2 dielectric mask that hinders NW spin-qubit functionality. We present the fabrication of the Si V-groove NM and the temporal evolution of the Ge NW growth using SEM, AFM, and cross-section TEM.

The incorporation of Si V-groove NMs enables precise confinement of Ge nanowires for scalable quantum devices while addressing limitations in spin-qubit functionality. Nonetheless, the indirect bandgap of Ge restricts use in optoelectronics, which can be overcome by leveraging GeSn alloys with direct bandgap properties. GeSn can be monolithically integrated into Si photonics to act as a NIR emitter. We present a novel approach to realize GeSn nanostructures with Sn contents beyond the solubility limit (1%at) via flash annealing. We show the top-down fabrication of GeSn nanostructures and the material properties evaluated using XRD, AFM, Raman spectroscopy, and TEM. Future work focuses on integrating Ge and GeSn nanostructures into optoelectronic platforms to enhance device functionality and scalability.

Synthesis of Mixed Dimensional Perovskite Heterostructures

1.21

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Research Interests:
2D materials, Energy, Lasers, Nanomaterials.

Continued advancements in the synthesis and application of nanomaterials dictate the need for well-developed analysis frameworks that fully capture the fundamentals behind their interactions. Förster theory accurately describes the transfer of excitons between molecules. However, this framework has repeatedly failed to quantitatively predict energy transfer rates between semiconducting nanomaterials, particularly in heterostructure systems that combine nanomaterials of different composition and dimensionality. The shortcomings of Förster theory are exacerbated in the case of lead halide perovskites, offering an optimal platform for pushing past the limits of current energy transfer models. Here, we synthesize mixed dimensional perovskite heterostructures and set the stage for studying energy transfer in these systems using time resolved photoluminescence spectroscopy. We focus on heterostructures combining spheroidal $CsPbBr_3$ quantum dots and two dimensional hybrid organic inorganic perovskite crystals, and aim to contribute to a deeper, quantitative understanding of energy transfer mechanisms in novel nanomaterials, which will inform the design of optoelectronic devices with nanomaterial interfaces.

Plasma-enhanced ALD Deposition of High Breakdown Field Al(O, N) and Ga_2O_3

1.22

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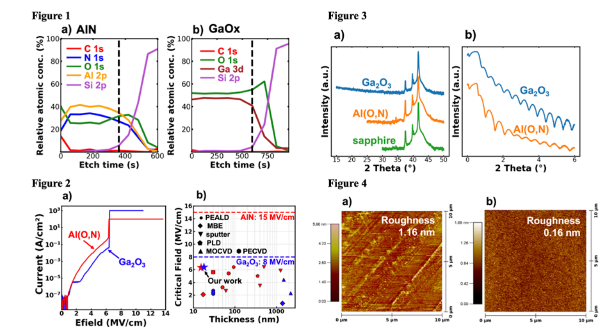
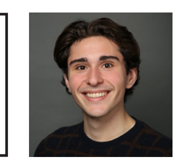
Electronic devices, Electronics, GaN, III-Vs, Integrated circuits

This study investigates PEALD-deposited Ga2O3 and Al(O, N) films on silicon and sapphire substrates. Growth temperature was 250°C, using triethylgallium (TEG) and oxygen plasma for Ga2O3, and trimethylaluminum (TMA) and forming gas plasma for Al(O, N). Growth rates and the film thicknesses were 0.41 Å/min for Ga_2O_3 (18.3 nm) and 0.25 Å/min for Al(O, N) (14.7 nm). Notably, PEALD-grown Ga2O3 films showed undetectable carbon levels via X-ray photoelectron spectroscopy (XPS). The electrical breakdown fields of Al(O, N) and Ga2O3 films were approximately 6.2 MV/cm and 6.3 MV/cm, respectively, among the highest reported for these materials at their respective thicknesses. Leakage current densities below the breakdown voltage are approximately 10^{-2} A/cm^2 for Ga_2O_3 and 10^{-1} A/cm^2 for Al(O, N). X-ray reflectivity (XRR) and atomic force microscopy (AFM) revealed their smooth surfaces with RMS surface roughness of 1.16 nm for Ga_2O_3 and 0.16 nm for Al(O, N). In conclusion, these PEALD-grown films exhibit high breakdown fields, indicating their potential for advanced device applications where efficient passivation is crucial for electric field management.



◀ Figure 1: XPS depth-profile of (a) Al(O, N) and (b) Ga_2O_3 on silicon substrates.
◀ Figure 2: (a) Breakdown field and (b) benchmark figure.
◀ Figure 3: (a) XRD and (b) XRR data of Ga_2O_3 and Al(O, N) films on c-plane sapphire substrate.
◀ Figure 4: 10x10 μm AFM images of ALD-grown (a) Ga2O3 and (b) Al(O, N).



Electron Energy Loss Spectroscopy of 2D Materials in a Scanning Electron Microscope

1.23

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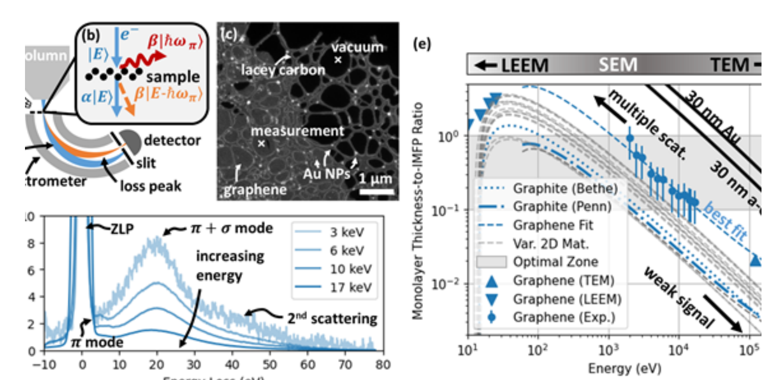
Electronic devices, Electronics, Energy, Energy harvesting devices & systems, Lasers, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Thermal structures, devices & systems.

The use of low energy electrons in a variety of electron microscopy techniques is desirable due to strong electron-photon and electron-matter coupling for low-dose imaging. This work demonstrates electron energy loss spectroscopy (EELS) of 2D materials in a 1-30 keV electron microscope, observing 50-times stronger electron-matter coupling relative to 125 keV transmission electron microscopes, which are historically used for such experiments. We observe for the first time that the universal curve relating beam energy to scattering holds for the transition from bulk graphite to graphene, albeit with a scale factor to account for this transition. We calculate that optimal coupling for most 2D materials and optical nanostructures falls in energy range of scanning electron microscopes, concluding that the spectroscopy of such systems will greatly benefit from use of this previously unexplored energy regime. Specifically, we highlight ultrafast EELS, for this application, which could stand to greatly benefit from the order-of-magnitude performance to resolve previously unobservable ultrafast material dynamics.



◀ Figure. 1. (a) Schematic of our SEM column (b) Rendering of our sample plane, in which our specimen is excited losing ħω$_\pi$ energy. (c) SEM micrograph of our sample. (d) Graphene loss spectrum at various energies. (e) Calculation of the thickness to IMFP (t/ω) versus energy for a variety of 2D materials.

Seeding Promoter Effect on Metal Organic Chemical Vapor Deposition Synthesized Molybdenum Disulfide

1.24

Y. Jiao, J. Zhu, T. Palacios

Sponsorship: Center for Heterogeneous Integration of Micro Electronic Systems (JUMP 2.0)

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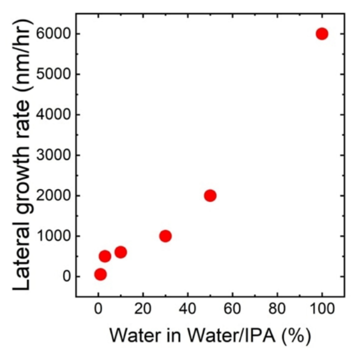
2D materials, Electronic devices, Electronics, Energy harvesting devices & systems, Integrated circuits, Machine Learning, Nanomanufacturing, Nanomaterial, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Si

Two-dimensional (2D) transition metal dichalcogenide (TMD) materials are promising for the next generation electronics thanks to their excellent electronic and photonic properties. Metal organic chemical vapor deposition (MOCVD) can provide excellent uniformity and quality. Seeding promoters, such as sodium chloride (NaCl), have been reported to have significant improvement in the MOCVD growth rate and quality of molybdenum disulfide (MoS_2). Understanding the effect of seeding promoters can benefit overcoming limitations of the large-scale fabrication of 2D electronics.

Here, we quantitatively investigate the concentration dependence of seeding density, and flake quality. We also demonstrate material uniformity across the 200 mm platform and a boost in the average mobility to above 75 cm2/(V·s). This effort has provided insight into the fundamental growth mechanism and heterogeneous integration of TMD material with complementary-metal-oxide-semiconductor (CMOS) technology.



◀ Figure 1: Lateral growth rate change based on NaCl concentration in the saturated water:IPA solution.

Uncovering Origins of Poor Photoluminescence Quantum Yield in 2D Hybrid Metal Organic Chalcogenolates (MOCs)

1.25

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Research Interests:
2D materials, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, Lasers, Light-emitting diodes, Nanotechnology, Optoelectronic, Organic materials, Photonics, Quantum devices

Innovations in blue emitting semiconductors and widespread adoption of light emitting diodes (LEDs) in recent years have drastically reduced global energy consumption associated with lighting. While this reduction is monumental, production and other energy intensive processes associated with LED lighting still contribute significant yearly CO_2 emissions. To reach future sustainability targets, advancements in light emission are essential, driving research interest towards novel materials – particularly ones with more sustainable synthesis pathways.

Our lab investigates metal organic chalcogenolates (MOCs) – novel 2D van der Waals stacking hybrid semiconductors with strong exciton binding energies, in-plane anisotropy, and direct bandgap. Amongst others, these properties make MOCs suitable candidates for applications as LEDs, excitonic switches, and other optoelectronics. Importantly, high-quality millimeter scale single crystals are synthesizable through a simple, ambient single-phase reaction. Covalent intralayer bonding in MOCs bolsters strong environmentally stability and enables property tuning through various functionalizations. Among them, mithrene, $[AgSePh]_\infty$, is of particular interest due to its narrow blue luminescence. However, nonradiative recombination dominates excited state dynamics, limiting its potential to revolutionize future optoelectronics. This work details efforts to uncover the origins of the low photoluminescence quantum yield in mithrene through spectroscopic analysis of defects, physical structure, and brighter MOC variants. Emission is highly impacted by defects, yet impervious to simpler defect-mitigation strategies, forcing exploration of more novel passivation techniques. Despite interest in mithrene's sharp blue emission, future viability of this material class to promote sustainable energy consumption is most dependent on the efficiency of light emission, and is necessary to pursue improvements in both performance and understanding.

Electric Field Tunable Chern Insulators in Tetralayer Rhombohedral Graphene

1.26

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Sponsorship: NSF

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Rhombohedral graphene, characterized by its unique stacking order and flat electronic bands, has emerged as a versatile platform for exploring correlated and topological phenomena. The rhombohedral tetralayer graphene/hBN moiré system has been proposed to host novel superconductivity and topological phases, including the chiral superconductivity and quantum anomalous Hall effect. In this work, we present DC electrical transport measurements in a rhombohedral tetralayer graphene/hBN moiré superlattice. We observed electric-field-induced topological phase transitions of Chern insulators, with the Chern number tunable by displacement field from C=3 to C=4 at the first hole filling of the superlattice. Magnetic hysteresis measurements revealed that these states emerge at extremely low magnetic fields (B=0.1) and exhibit perfect quantization. While the C=4 state aligns with previous prediction and observation of a quantum anomalous Hall state, the C=3 state observed at lower displacement fields is unexpected. Additionally, we identified another C=3 state at filling nu = -2. These findings enrich the topological landscape of this intriguing system. Combined with its unique superconducting properties, rhombohedral multilayer graphene is a promising platform for studying and engineering novel quantum phases of matter.

Semi-transparent Perovskite Solar Cells

1.27

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Sponsorship: MIT EECS, 6.2540 class

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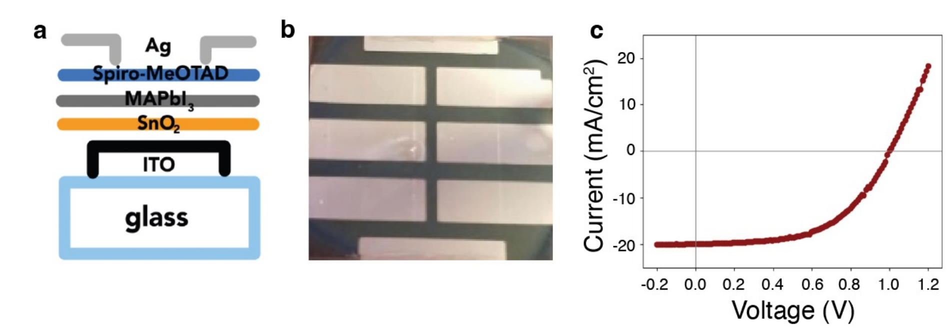
With growing global energy demands, renewable energy sources like solar are more critical than ever. Designing solar cells with a formfactor that allows their ubiquitous integration into the buildings, including windows as energy generating surfaces, can expand access to solar energy. Perovskite solar cells are especially promising due to their high efficiency and thin-film design which can facilitate their manufacturing, enable semi-transparency, and light weight. In this work, we designed and fabricated perovskite solar cells with efficiency as high as 10.7%, and investigated the transparency-efficiency tradeoff in these devices.



▲ Figure 1: a) Schematic illustration of the designed perovskite solar cell. b) Top-view photo of an example fabricated solar cell. c) Example I-V characteristic of a fabricated solar cell with 10.7% efficiency.

Session 2: Quantum Science & Engineering

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2D materials, Artificial Intelligence, GaN, III-Vs, Lasers, Machine Learning, Photonics, Quantum devices, Spintronics.

Diverse Impacts of Spin-Orbit Coupling on Superconductivity in Rhombohedral Graphene

2.01

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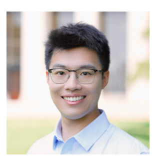
Sponsorship: NSF

Spin-orbit coupling (SOC) has played an important role in many topological and correlated electron materials. In graphene-based systems, SOC induced by transition metal dichalcogenide (TMD) at proximity was shown to drive topological states and strengthen superconductivity, the combination of which was proposed as a viable approach to engineer non-abelian quasiparticles for topological quantum computation. In particular, rhombohedral multilayer graphene with layer number N≥3 is a robust platform of electron topology, exhibiting both integer & fractional quantum anomalous Hall effects. However, superconductivity and the role of SOC in such systems remain largely unexplored. Here we report electron transport measurements of TMD-proximitized rhombohedral trilayer graphene (RTG). We observed a new hole-doped superconducting state SC4 with a transition temperature Tc of 230 mK. On the electron-doped side, we identified a new isospin-symmetry breaking three-quarter-metal (TQM) phase. Near this three-quarter-metal state, the state SC3, very weak in bare RTG, is fully developed into a superconducting state at 110 mK. Both SC3 and SC4 states reside at the phase boundaries between different isospin-symmetry-breaking states, and their observations are aligned with the existing understanding that SOC enhances graphene superconductivity. Surprisingly, the original superconducting state SC1 in bare RTG is strongly suppressed in the presence of TMD, and we cannot find it down to 40 mK— opposite to the effect of SOC on all other graphene superconductivities. Our observations form the basis of exploring superconductivity and non-Abelian quasiparticles in rhombohedral graphene devices, and provide experimental evidence that challenges the understanding of the impacts of SOC on graphene superconductivity.



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Q-Pilot: Field Programmable Qubit Array Compilation with Flying Ancillas

2.02

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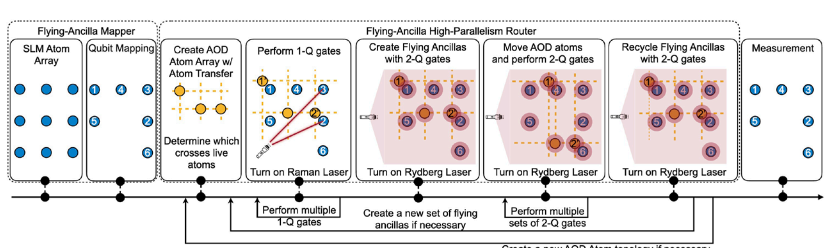
Sponsorship: National Science Foundation

Neutral atom arrays have become a promising platform for quantum computing, especially the field programmable qubit array. The qubit movement ability allows dynamic alterations in qubit connectivity during runtime, which can reduce the cost of executing long-range gates. However, this added flexibility introduces new challenges in compilation. We propose to map all data qubits to fixed atoms while utilizing movable atoms to route for 2-qubit gates between data qubits. Coined flying ancillas, these mobile atoms function as ancilla qubits, dynamically generated and recycled during execution. We present Q-Pilot, a scalable compiler for FPQA employing flying ancillas to maximize circuit parallelism. For two important quantum applications, quantum simulation and the Quantum Approximate Optimization Algorithm, we devise domain-specific routing strategies. In comparison to alternative technologies such as superconducting devices or fixed atom arrays, Q-Pilot effectively harnesses the flexibility of FPQA, achieving reductions of 1.4x, 27.7x, and 6.3x in circuit depth for 100-qubit random, quantum simulation, and QAOA circuits, respectively.



▲ Figure 1: The flowchart of the FPQA compilation framework.

Spectroscopy Signatures of Electron Correlations in a Trilayer Graphene/hBN Moiré Superlattice

2.03

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ABC-stacked trilayer graphene/hexagonal boron nitride moiré superlattice (TLG/hBN) has emerged as a playground for correlated electron physics. We report spectroscopy measurements of dual-gated TLG/ hBN using Fourier transform infrared photocurrent spectroscopy. We observed a strong optical transition between moiré minibands that narrows continuously as a bandgap is opened by gating, indicating a reduction of the single-particle bandwidth. At half-filling of the valence flat band, a broad absorption peak emerges at ~18 milli–electron volts, indicating direct optical excitation across an emerging Mott gap. Similar photocurrent spectra are observed in two other correlated insulating states at quarter- and half-filling of the first conduction band. Our findings provide key parameters of the Hubbard model for the understanding of electron correlation in TLG/hBN.

Quantum-Secure Multiparty Deep Learning in Optical Networks

2.04

K. Sulimany, S. K. Vadlamani, R. Hamerly, P. Iyengar, and D. Englund

Sponsorship: Israeli Council for Higher Education, Zuckerman STEM Leadership Program, DARPA QuANET program

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Secure multiparty computation for deep learning has become a critical challenge as computational workloads are increasingly offloaded to cloud servers, leading to security vulnerabilities. We introduce a quantum-secure protocol using a coherent linear algebra engine based on the quantum properties of light, enabling privacy-preserving multiparty deep learning. We provide a security analysis relying on quantum information theorems to rigorously bound information leakage of both neural network weights and client data.

Applied to the MNIST classification benchmark, our approach achieves over 96% accuracy, setting information leakage upper bounds of 0.1 bits per weight symbol and 0.01 bits per data symbol. Our protocol offers information-theoretic security, unlike classical encryption methods that are dependent on computational complexity. Furthermore, the adaptation of classical encryption methods to machine learning is currently limited due to their computational overhead, which restricts their practical deployment in secure cloud-based inference.

Our protocol achieves physical layer security through an optical matrix-vector multiplication scheme that provides a scalable and efficient solution for real-world deployment. While previous studies have focused on optical AI accelerators to achieve energy-efficient, high-throughput computation, and reduced latency, we leverage optical networks and standard telecommunication components for secure multiparty computation. This work extends the application of optical processors to quantum cryptographic protocols, enabling data security within deep learning tasks.

This advancement paves the way for secure cloud-based artificial intelligence systems with applications in sensitive domains such as healthcare, finance, and more. By integrating a photonic computation architecture, our protocol provides a unique approach to preserving data confidentiality while maintaining strong performance in machine learning.

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Electron Energy Loss Spectroscopy of 2D Materials in a Scanning Electron Microscope

2.07

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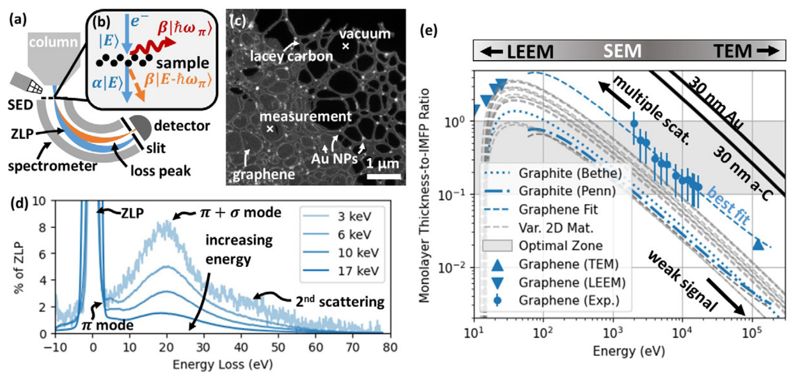
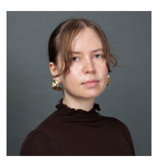
Sponsorship: Department of Energy, National Science Foundation

This work demonstrates electron energy loss spectroscopy (EELS) of 2D materials in a 1-30 keV electron microscope, observing 50-times stronger electron-matter coupling relative to 125 keV transmission electron microscopes, which are historically used for such experiments. We observe for the first time that the universal curve relating beam energy to scattering holds for the transition from bulk graphite to graphene, albeit with a scale factor to account for this transition. We calculate that optimal coupling for most 2D materials and optical nanostructures falls in energy range of scanning electron microscopes, concluding that the spectroscopy of such systems will greatly benefit from use of this previously unexplored energy regime. Specifically, we highlight ultrafast EELS, for this application, which could stand to greatly benefit from the order-of-magnitude performance to resolve previously unobservable ultrafast material dynamics.



▲ Figure 1: Rendering of our experiment. (a) Schematic of experiment, where after interaction (see (b)), measure the beam energy. (c) SEM micrograph of our sample. (d) graphene loss spectrum at various energies. (e) Plot of electron scattering intensity versus energy.



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Quantum Frequency Conversion for Networking via the Telecom E-band

2.08

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Sponsorship: Center for Quantum Networks

High-efficiency quantum frequency conversion (QFC) for group-IV color centers, such as silicon vacancies (SiV), is required for long-distance quantum networking protocols. SiV QFC has previously been demonstrated at external efficiencies of 12% [1] and 30% [2], using periodically poled lithium niobate (PPLN) waveguides of lengths 3.5 and 5 mm, and with efficiencies limited by the available pump power (120 mW and 320 mW, respectively). Here, the efficiency scales with the square of the waveguide length. These results are also obtained with pump wavelength of 1623 nm (L-band), networking the SiV wavelength of 737 nm into the O-band (1350 nm). Here, we improve these results by replacing the pump (L-band in [1],[2]) with a pump with wavelength in the C-band (1561 nm), where (i) high-power erbium-doped fiber amplifiers (EDFAs) are available (ii) SMF-28e fibers have lower losses in the E-band than O-band. Using an EDFA and a 1.5-cm-long PPLN waveguide we measure a maximum external photon conversion efficiency of 43±1.8% (corresponding internal efficiency of 96±1.8%), which we reach at an external pump power of 1.51 W. The external efficiency is limited by waveguide-fiber coupling. As such, we have demonstrated an external efficiency for SiV-telecom quantum frequency conversion exceeding prior results from MIT, Lincoln Labs, and Harvard. To further improve these results in the future, the waveguide will be replaced with a longer one to reduce the power required to reach unit internal efficiency, which further reduces noise. We may also optimize fiber coupling or switch to a free-space-coupled device, which we estimate to increase the external conversion efficiency to approx. 70-80%.

Impact of Junction Oxidation Parameters on the Two-level System Densities in Superconducting Qubits

2.09

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Electronic devices, Electronics, III-Vs, MEMS & NEMS, Nanomaterials, Quantum devices, Si, Spintronics

Superconducting qubits are a promising platform to build large-scale quantum computers. To achieve such scalability, we require the ability to fabricate qubits with low decoherence and perform gate operations with high fidelities. However, superconducting qubits often suffer from the presence of two-level systems (TLSs), which originate from material imperfections and defects induced by various nanofabrication processes. Strongly-coupled TLSs are predicted to arise from defects in the amorphous oxide region of the commonly used Al/AlO_x/Al Josephson junctions. However, a comprehensive understanding of the relation between oxidation conditions, quality of the AlO_x layer and the density of observable defects is currently missing.

Here, we investigate the effects of junction oxidation parameters on the TLS densities and losses observed in transmon qubits containing Al/AlO_x/Al junctions. In this work, we explore how the temperature, pressure, and presence of plasma during oxidation affect the crystalline nature, chemical composition, and defects observed in these junctions. For this we utilize material analysis techniques such as X-ray diffraction, atomic force microscopy and transmission electron microscopy. Finally, we correlate it to the microwave performance of these qubits at cryogenic temperatures.

The views and conclusions contained herein are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Office or the U.S. Government.

Strain Tuning of Individual Telecom Color Centers in Reconfigurable Silicon Photonics

2.10

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Color centers in silicon, such as G and T centers, have gained significant attention as potential candidates for quantum information processing, particularly due to their compatibility with established silicon fabrication techniques and their telecom wavelength operation. Despite their promise, the scalability of such systems depends on the ability to tune single emitters to identical frequencies, enabling multiphoton interference. Although frequency tuning of ensembles has been shown, the controllable and reversible tuning of individual color centers in silicon has not been demonstrated.

In this work, we present a waveguide-integrated device that leverages MEMS photonics to achieve controlled strain tuning of a single G center's emission frequency. By applying a 35 V driving voltage, we demonstrate a tuning range of up to 400 pm. Additionally, we compare these results to a piezospectroscopic model, correlating the tuning behavior with the emitter's position within the waveguide. This milestone is crucial for advancing silicon color center technology, potentially enabling the development of quantum memories and entangling gates for quantum communication and computing.

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Nanoelectromechanical Cantilever Waveguide Diagnosis via Visible Spectral Domain Optical Coherence Tomography 2.11

Y. M. Goh, C. Li, J. Fujimoto, D. Englund
Sponsorship: Department of Energy (DOE) Quantum Systems Accelerator; MITRE

Photonic Integrated Circuits (PICs) in the visible wavelength range are crucial for applications like quantum control and augmented reality/virtual reality (AR/VR). However, the limited tunable range of visible lasers makes high-resolution diagnostic techniques like Optical Frequency-Domain Reflectometry (OFDR) challenging. We demonstrate the use of Optical Coherence Tomography (OCT), a non-invasive imaging method widely used in ophthalmology, for diagnosing photonic circuits. Using a simple OCT A-scan, we characterize a nanoelectromechanical cantilever waveguide—an on-chip beam-steering device—by analyzing waveguide loss mechanisms based on the back reflections from periodic cladding etching near the periphery of silicon nitride waveguides. We validate our approach with both spectral-domain and time-domain OCT, and by imaging multi-layer Scotch tape and unetched bare waveguides. Adopting OCT for nanoelectromechanical photonic circuit diagnostics enables efficient waveguide inspection and allows phase-sensitive measurements even during device actuation.

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Strong-coupling Theory of Single-photon Detection in Superconducting Nanowires 2.12

A. Simon, R. Foster, E. Batson, M. Sahoo, C. Heil, K. K. Berggren
Sponsorship: NSF GRFP and MIT Vanu Bose Presidential fellowship programs, Alan McWhorter fellowship, DARPA DSO

Superconducting nanowire single-photon detectors (SNSPDs) are the preferred technology for single-photon detection in the visible and near-infrared wavelengths. By optimizing design and material properties, SNSPDs have achieved near-unity single-photon detection efficiencies, ultra-low dark count rates, and jitter times of less than 3 ps. However, many applications, including dark matter search, biomedical imaging, and quantum networks, require an increase in the operating temperature or wavelength sensitivity range relative to the current state-of-the-art, without sacrificing detection efficiency or other relevant metrics. To enable these advances, we require a thorough understanding of the detection mechanism and its relation to material parameters to guide the search for new material platforms and device engineering for improved SNSPD performance. However, though its importance is clear, only limited prior work has explored the role of the microscopic quasiparticle and phonon dynamics in the detection mechanism of SNSPDs. Likewise, no study has investigated the effect of the frequency-dependent electron-phonon coupling on detection efficiency and wavelength sensitivity, despite its importance in describing superconductivity in strong coupling superconductors such as niobium nitride. In this work, we develop a theory of SNSPD detection, generalized to the case of strong coupling superconductors, which is suitable to describe SNSPD detection in conventional superconductors. This work provides a theoretical framework to enable the study and exploration of new materials and device engineering for improved performance.

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Spectral Methods for Modeling Non-equilibrium Superconductivity 2.13

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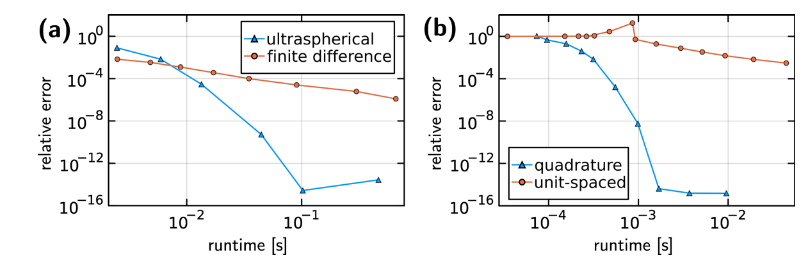
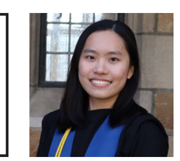
Sponsorship: Alan McWhorter fellowship, NSF GRFP and MIT Vanu Bose Presidential fellowship programs, DARPA DSO

The Usadel equations describe electron correlations in dirty superconductors, where the mean free path is much shorter than the coherence length. This is useful for modeling the microscopic physics of photon absorption in superconducting nanowire single photon detectors (SNSPDs). In this work, we solve the Matsubara formulation of the Usadel equations with a Newton-Krylov method. The differential equation is discretized with an ultraspherical spectral method, and the infinite Matsubara sum is evaluated with a spectrally-accurate summation quadrature technique.



▲ Figure 1: (a) Comparison of ultraspherical and finite difference methods for spatial discretization. (b) Comparison of quadrature and unit-spaced methods for Matsubara sum evaluation.



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Machine Learning, MEMS & NEMS, Nanotechnology, Optoelectronics, Photonics, Quantum devices

Nanoelectromechanical Cantilever Waveguide Diagnosis via Visible Spectral Domain Optical Coherence Tomography 2.14

Y. M. Goh, C. Li, J. Fujimoto, D. Englund.
Sponsorship: Department of Energy (DOE) Quantum Systems Accelerator; MITRE

We present a method for characterizing optical losses in a NEMS-based photonic integrated circuit (PIC) platform designed for efficient photon routing between free space and on-chip photonics. The nitride waveguide is oxide-cladded and suspended on an aluminum nitride (AlN) piezoelectric cantilever, which curls upwards due to intrinsic stress gradient in the layered structure. Operating the device at resonant frequencies enables 2D beam steering and high-speed spot array control. Furthermore, scalable integration of on-chip modulators positions this platform as a critical component for development of quantum repeater networks and cluster state generation. While miniaturized projection capabilities have been demonstrated with this device, optical efficiency, particularly in the complete transfer of amplitude and phase information, remains a bottleneck for quantum information applications involving single-photon level signals. A key source of loss is imperfect fabrication in the initial prototyping stages. Specifically, scattering has been observed at periodic crossbar etch points, which are designed to modulate the waveguide's stiffness and refractive index. To address these issues, we employ Spectral Domain Optical Coherence Tomography (SD-OCT), a non-invasive, high-resolution technique, to characterize and spatially resolve scattering and loss features within the waveguide. By employing a scannable delay line in the reference arm of the SD-OCT setup, we can probe the device with micrometer-level axial resolution over an arbitrary imaging depth by stitching together multiple spectrographs. Our experiment configuration allows us to distinguish between continuous loss and discrete scattering events within the waveguide, as well as scattering from waveguide input and termination ends. This work advances techniques for non-invasive waveguide loss characterization and supports the development of programmable photonic platforms for quantum networking applications. Efficient photon routing, fast qubit addressing, and scalable integration of on-chip modulators position this platform as a critical component for future quantum communication protocols.

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Confinement of Hybridized Light Waves for Single-mode Photonics

2.15

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Wave localization is a central concept in photonics: e.g. waveguides and resonators facilitate the control of light waves necessary for numerous indispensable technologies. Nonlinear optics enables control over the frequency of photons, and is an essential tool for both the design of classical light sources and quantum optics. However, nonlinear-optical processes tend to be multimode, distributing excitations to many modes of the electromagnetic field. Such a lack of confinement in the spectro-temporal degree of freedom can be detrimental, e.g. in experimentally realizing vacuum squeezing – one of the basic operations in the quantum optics toolbox.

In this work, we introduce a wave-trapping mechanism based on the interplay between group-velocity mismatch and mode coupling between suitable pairs of optical modes. Remarkably, it turns out that these hybridized pairs form a supersymmetric relationship, which allows an analytical description of the effective potential. A natural application of this result is to enforce single-mode behaviors in the naturally multimode nonlinear-quantum-optical dynamics needed to implement Gaussian and non-Gaussian interactions. This mechanism may thus provide resolutions to widely recognized challenges in optical quantum science and technologies.

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Integrated Photonics for Polarization-Gradient Cooling of Trapped Ions

2.16

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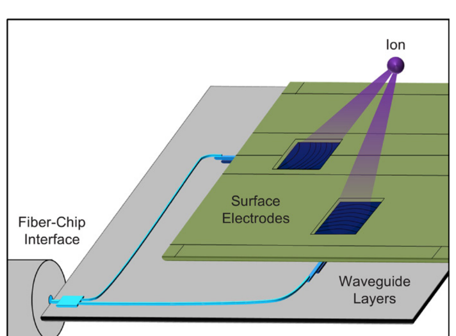
Sponsorship: DOE QSA, NSF QLCI HQAN (2016136), NSF QLCI Q-SEnSE (2016244), MIT CQE (H98230-19-C-0292), NSF GRFP (1122374), NDSEG Fellowship, MIT Cronin Fellowship, and MIT Locher Fellowship

Trapped ions are a promising modality for quantum systems, with demonstrated utility as the basis for quantum processors and optical clocks. However, most trapped-ion systems are implemented using free-space optics, whose large size and susceptibility to vibrations and drift inhibit scaling. Integrated photonics offers a potential avenue to address these challenges.

Motional state cooling is a key optical function in trapped-ion systems. However, to date, integrated-photonics-based demonstrations have been limited to Doppler and resolved-sideband cooling. In this work, we develop and demonstrate a variety of integrated-photonics-based systems for polarization-gradient cooling (PGC), resulting in the first experimental demonstration of trapped-ion PGC by an integrated-photonics-based system. By enabling faster and more power-efficient cooling, this work has the potential to improve computational efficiencies for integrated-photonics-based trapped-ion platforms.



◄ Figure 1: Conceptual diagram of an integrated-photonics-based polarization-gradient-cooling experiment, demonstrating the emission of multiple beams from an ion-trap chip designed to intersect and form a polarization gradient at a target ion location.

Characterization and Comparison of Energy Relaxation in Planar Fluxonium Qubits

2.17

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Sponsorship: Air Force Contract No. FA8702-15-D-0001

Fluxonium superconducting qubits have demonstrated high coherence times and high single and two qubit gate fidelities, making them a promising building block for superconducting quantum processors. In this work, we characterize the energy relaxation times T1 of multiple fluxonium qubits across their tunable frequency range in order to assess the dominant contributors to decoherence. Of the mechanisms considered, a circuit-based model for capacitive loss best captures the trends in the data over the majority of the tuning range. Motivated by this, we also consider modifications to this model accounting for a frequency-dependent effective capacitive quality factor. Furthermore, we use this analysis to bound the contributions of various other loss mechanisms. Finally, we utilize a composite model to compare these loss mechanisms on equal footing across individual qubits, and compare qubits fabricated with different materials processing techniques.

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Quantum devices

Development of TiN Through-Silicon Vias for Superconducting Qubits

2.18

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Sponsorship: National Science Foundation Graduate Research Fellowship under Grant No. (000885616).

Superconducting qubits are a promising platform to realize scalable fault-tolerant quantum computers. However, current architectures use mostly planar elements that make dense integration challenging. The incorporation of non-planar elements, such as through silicon vias (TSVs) and flip-chip bonding, can ease geometric constraints on signal routing and enable the fabrication of such densely integrated large-scale quantum processors. TSVs have been demonstrated to reduce spurious chip modes and can also be used to fabricate novel circuit elements, such as compact qubits and filters. In this work, we show our progress toward fabricating wafer-scale superconducting Titanium Nitride (TiN) TSVs and integrating them into multi-qubit devices. First, we show the fabrication of TSVs on 6" Si wafers using a dry etching (Bosch) technique and characterize the TSV sidewall angle and sidewall smoothness. Next, we explore atomic layer deposition (ALD) as a technique to coat the TSV sidewalls with superconducting TiN. We further characterize the critical temperature of the ALD-deposited TiN on the planar surface and inside the TSV sidewalls. Preliminary electrical data of the TSVs as well as future directions of incorporating them into flip-chip architectures will be discussed.

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Development of TiN Through-Silicon Vias for Superconducting Qubits

2.19

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Sponsorship: National Science Foundation Graduate Research Fellowship under Grant No. (000885616).

Superconducting qubits are a promising platform to realize scalable fault-tolerant quantum computers. However, current architectures use mostly planar elements that make dense integration challenging. The incorporation of non-planar elements, such as through silicon vias (TSVs) and flip-chip bonding, can ease geometric constraints on signal routing and enable the fabrication of such densely integrated large-scale quantum processors. TSVs have been demonstrated to reduce spurious chip modes and can also be used to fabricate novel circuit elements, such as compact qubits and filters. In this work, we show our progress toward fabricating wafer-scale superconducting Titanium Nitride (TiN) TSVs and integrating them into multi-qubit devices. First, we show the fabrication of TSVs on 6" Si wafers using a dry etching (Bosch) technique and characterize the TSV sidewall angle and sidewall smoothness. Next, we explore atomic layer deposition (ALD) as a technique to coat the TSV sidewalls with superconducting TiN. We further characterize the critical temperature of the ALD-deposited TiN on the planar surface and inside the TSV sidewalls. Preliminary electrical data of the TSVs as well as future directions of incorporating them into flip-chip architectures will be discussed.

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2D materials, Electronic devices, Electronics, Energy harvesting devices & systems, Light-emitting diodes, Nanomaterials, Nanotechnology, Optoelectronics, Perovskites

Exciton fine structure in two-dimensional metal-halide perovskites

2.20

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Sponsorship: 2024 Fulbright Junior Research Award by Polish-U.S. Fulbright Commission; Sonata grant no. 2020/39/D/ST3/03000 from National Science Centre Poland

Two-dimensional (2D) lead halide perovskites are a group of hybrid organic-inorganic semiconducting materials, considered an alternative for applications in photovoltaics and optoelectronics. Their structure can be seen as the "natural" quantum wells, where slabs of metal-halide octahedral units are surrounded from both sides by large organic cations, acting as potential barriers. Owing to the possible adjustment of the structure and chemical composition of the crystals, optical properties of 2D perovskites can be tuned over a range unattainable for their three-dimensional counterparts. This makes them not only intriguing in terms of their application potential, but also a very attractive object of fundamental studies. As a result of both quantum and dielectric confinement, exciton binding energy in 2D perovskites is greatly enhanced and can reach up to few hundreds of millielectronvolts. This makes them very attractive materials for the investigation of exciton physics, since their optical properties are dominated by the excitonic effects. It also results in the significant splitting of states within the exciton fine structure, which can have a dramatic impact on the performance of light emitters or other devices based on these 2D materials. Gaining a deeper understanding of the exciton fine structure is therefore very important from the point of view of potential applications.
We combine the optical spectroscopy techniques with the use of magnetic field to investigate the excitonic properties of series of 2D perovskite compounds. We investigate in detail the exciton fine structure as well as the evolution of the optoelectronic properties of 2D perovskites with the change of the confinement strength. Our results provide a further insight into one of the "tuning knobs" of this material system, which is gradual progression of the properties from the 2D limit to bulk.

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Available from May 2026.

Research Interests:
Integrated circuits, Nanotechnology, Photonics, Spintronics.

High-Resolution, Broadband Integrated Photonic Fourier-Transform Spectrometer

3.01

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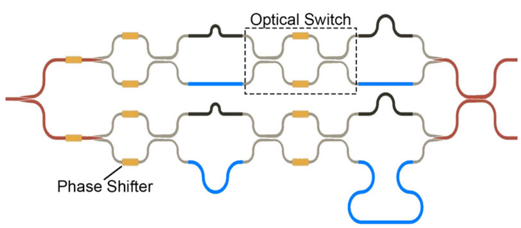
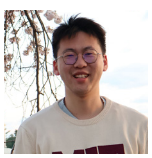
Sponsorship: NSF (Grant No. 2122581), LyteChip Inc., Equinor ASA

Spectrometers are powerful and widely used tools for chemical and biological analysis. Low cost, miniaturized spectrometers enable a wide range of in-the-field, hand-held or point-of-care spectrometer applications. Integrated photonics provides a unique opportunity for small footprint, on-chip spectrometer devices. In recent years, a variety of integrated spectrometer designs have been proposed, however most are limited in either bandwidth or resolution.
In this work, we present a digital Fourier-Transform spectrometer that overcomes the bandwidth-resolution trade-off faced by other integrated devices. The design employs broadband 2x2 optical switches to route light through different optical paths on the silicon-on-insulator chip (Fig. 1), allowing for large optical path length differences and thus high resolution over a broad bandwidth in the near-infrared. Our work shows the potential of the digital Fourier-Transform spectrometer as a broadly applicable miniaturized spectrometer.



◄ Figure 1: A schematic representation of the digital Fourier-Transform spectrometer. Thermo-optic phase shifters (yellow) in the broadband 2x2 optical switches (grey) allow the light to be switched between different waveguides (black and blue, respectively). Each combination of optical switch states results in a unique optical path length difference between the two arms of the spectrometer.



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2D materials, Displays, Electronic devices, Electronics, GaN, Nanomaterials

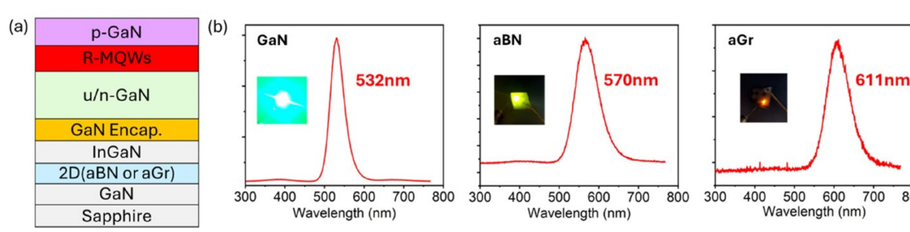
Optimized 2D Template for Remote Epitaxy of Efficient Red InGaN

3.02

J. Feng, J. Kim, Y. Liu, J. Kim

Sponsorship: Samsung Electronics

InGaN-based Micro-LEDs have garnered significant attention for their potential to emit light across the entire visible spectrum. While high external quantum efficiency blue and green InGaN emitters have been achieved, progress in developing high-efficiency red InGaN LEDs remains constrained by the lattice mismatch between III-nitride materials and conventional substrates. This work presents a novel approach using remote epitaxy on 2D materials, such as amorphous graphene (aGr) and amorphous Boron Nitride (aBN), to overcome these challenges by strain relaxation. By directly growing wafer-scale 2D layers on GaN substrates, we enabled relaxed InGaN (up to 100%) with a low dislocation density of $4.4*10^{-8}$ cm^{-2}. Optimized growth conditions via Molecular Beam Epitaxy (MBE) at 550–600°C facilitated the redshift of luminescence to 611 nm (red light) for InGaN grown on aGr/GaN, a notable improvement compared to that grown directly on a GaN template which exhibited 532 nm (green light). These results demonstrate a promising pathway to develop highly efficient InGaN red LEDs for ultra-high-pixel-density micro-LED displays in AR/VR applications, offering a potential alternative to III-As/P-based LEDs.



▲ Figure 1: (a) InGaN red LED quantum well structure and (b) Electroluminescence spectra of InGaN LED on bare GaN, aBN/GaN and aGr/GaN substrate

Electro-optic Control of AlN Photo-Switch with Sub-bandgap Illumination and Enhanced Switching Speed

3.03

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Sponsorship: Advanced Concepts Committee of MIT Lincoln Laboratory

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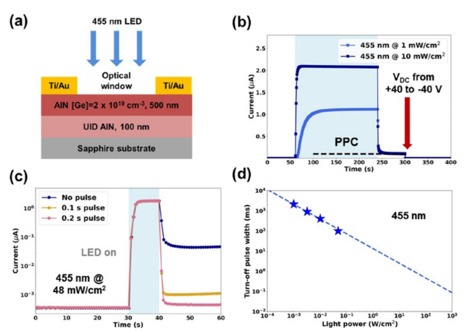
Research Interests:
Electronic devices, GaN, III-Vs, Optoelectronics

AlGaN photoconductive switches may be useful for optical control of power electronics. However, switching the intrinsic photoconductivity of high-Al content AlGaN requires deep ultraviolet (UV) illumination, which compromises system cost and reliability. In this work, we study the extrinsic photoconductivity in Ge-doped AlN with sub-bandgap visible light. Under blue LED with 455 nm center wavelength and irradiance as low as 1 mW/cm^2, the AlN photo-switch achieves 1.1 μA photocurrent, 4 orders of magnitude on/off current ratio and 2.8 A/W optical responsivity. However, turn-off is much slower than turn-on because of persistent photoconductivity (PPC). We show that, in a metal-AlN Schottky junction device, the turn-off speed is limited by charge traps in the space charge region. We demonstrate that electrical bias can annihilate trapped charge on timescales orders-of-magnitude faster than PPC decay. In this way, we remove the limitations of PPC and dramatically improve device response time. The results presented here pave the way for fast switching and high optical gain in high-Al content AlGaN power devices triggered with visible illumination.



◀ Figure 1: (a) Schematic cross-section of sub-bandgap triggered AlN lateral photo-switch. (b) Transient photo response at V_{DC}=40 V. (c) Transient photo response after bias pulse is applied. (d) Width of turn-off bias pulse as function of the light power density.

Exploring the Potential of 2D Photovoltaic Devices for Biological Applications

3.04

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Research Interests:
2D materials, Biological devices & systems, BioMEMS, Nanomanufacturing, Nanotechnology.

This literature review explores recent advancements in two-dimensional (2D) photovoltaic (PV) devices and their promising applications in biological fields. With unique properties such as high surface-area-to-volume ratio, flexibility, and tunable electronic characteristics, 2D PV materials like graphene, transition metal dichalcogenides (TMDs), and perovskites have emerged as viable alternatives to traditional PV materials. These materials demonstrate efficient light absorption and energy conversion at the nanoscale, enabling their use in low-power, bio-compatible energy harvesting applications. The review examines various fabrication methods, device architectures, and performance metrics of 2D PV devices, highlighting their superior optical and electrical properties compared to conventional bulk counterparts.

Another key focus is on the integration of 2D PV devices within biological systems, where their small form factor makes them ideal for powering implantable medical devices, biosensors, and wearable health monitors. Additionally, 2D PV devices show promise in facilitating wireless energy transfer to biological implants, enhancing patient comfort and reducing the need for battery replacement surgeries. The review emphasizes challenges in biocompatibility, stability, and scalability of 2D PV devices, outlining potential solutions to enable their broader adoption in bioelectronics.

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Research Interests:
Displays, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Photovoltaics, Si

Exciton Fission Enhanced Silicon Solar Cell

3.05

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Crystalline silicon (c-Si) photovoltaics, which currently comprise over 90% of the solar cell market, are also among the promising candidates for solar-to-chemical conversion such as water splitting and CO_2 reduction. However, they are nearing the thermodynamic single junction limit, presenting significant challenges for further efficiency enhancements in c-Si photovoltaics. One promising method to exceed this limit involves sensitizing c-Si with organic molecules capable of singlet exciton fission (SF), a process that generates two triplet excitons (electron-hole pairs) from a single photon. Efficient transfer of these triplet excitons to c-Si could potentially enhance photocurrent and power conversion efficiency (PCE). Previous studies have shown coupling between c-Si and the archetypal SF material (tetracene), facilitated by passivating interfacial layers of hafnium oxynitride, as evidenced by magnetic-field-dependent photocurrent measurements. However, the photovoltaic performance did not improve due to insufficient passivation and poor carrier extraction at the surface between tetracene and c-Si. We have developed a novel interfacial heterostructure that effectively passivates surface defects and facilitates intermediate charge separated states necessary for the transfer of triplet excitons from tetracene to c-Si. Utilizing c-Si solar cells with shallow p-n junctions and a microstructured geometry, we demonstrate, for the first time, enhancements in short-circuit current and PCE attributed to SF in tetracene. Singlet fission-enhanced silicon solar cells establish a technological path that can exceed the single-junction efficiency limit.

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2D materials, Artificial Intelligence, Lasers, Optoelectronics, Quantum devices, Quantum Optics.

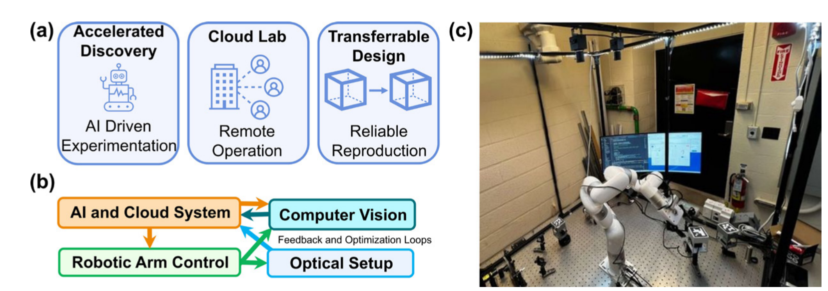
Collaborative Robotics for Free-Space Optics

3.06

S. Z. Uddin, S. Vaidya, S. Choudhary, R. Salib, L. Huang, M. Soljačić

Sponsorship: U. S. Army Research Office through the Institute for Soldier Nanotechnologies at MIT, under Collaborative Agreement Number W911NF-23-2-0121.

Optical beam characterization is essential across multiple fields, from laser development to free-space communication. While traditional manual methods require precise alignment and are prone to human error, collaborative robots integrated with artificial intelligence offer an automated solution for laboratory environments. We present an automation pipeline that combines a robotic arm with AI-driven computer vision and image processing for optical beam characterization. As AI advances, such intelligent systems become crucial for accelerating experimental science through automated decision-making. Our system autonomously handles precision tasks like camera positioning and lens placement, enabling automated collection of 4×4 beam matrix measurements. Through practical implementation, we show how integrating AI, robotics, and computer vision can streamline complex optical measurements, advancing the field toward more efficient and reliable characterization methods.



▲ Figure 1: Overview of AI-driven robotic optics lab. (a) Features: AI experimentation, remote operation, reproducible designs. (b) Architecture: AI control, vision, feedback, robotic arm, optical setup. (c) Physical setup: robot arm on optical breadboard.

In-Situ Core/Shell Perovskite/MoS2 Heterostructure Phototransistor

3.07

J. Sim, S. Ryoo, J. S. Kim, J. Jang, T.-W. Lee, K. Cho, K. Kang, T. Lee

Two-dimensional (2D) transition metal dichalcogenides (TMDCs) are promising materials that can be used in various fields such as low-power devices and optoelectronic devices due to their atomically thin nature, tunable band gap, high on/off ratio, and excellent electrical properties. Photodetectors based on 2D TMDCs can realize high-performance, flexible devices with high integration density. However, their atomic-level thinness results in low light absorption, which hinders sensitive photodetection.

In this study, we address the shortcoming of low light absorption by integrating in-situ core/shell perovskite onto the MoS2 channel. The in-situ core/shell perovskite layer effectively acts as a photosensitive layer, due to its excellent charge transfer and light absorption efficiency. As a result, responsivity and specific detectivity of the hybrid perovskite/MoS_2 device are significantly enhanced compared to the pristine MoS_2 device. Moreover, photodetection performance can be tuned by applying gate voltage, which is explained as a combination of photogating and photoconduction effects. Our research provides a promising approach for a low-cost, highly integrated, and stretchable photodetector based on 2D materials.

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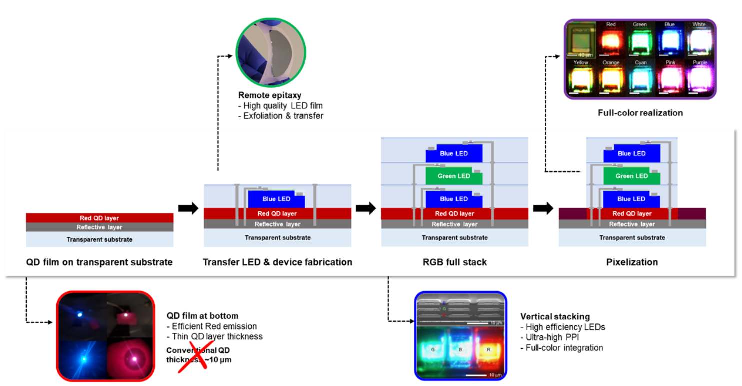
2D materials, Displays, Electronic devices, Electronics, Energy harvesting devices & systems, Field-Emitter devices, Light-emitting diodes, MEMS & NEMS, Molecular & polymeric materials, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors, Si, Spintronics

Vertically Stacked Micro-LEDs for XR displays

3.08

J.-E. Ryu, Y. Jung, J. Kim
Sponsorship: IARPA (6948435)

Extended Reality (XR) displays, encompassing augmented reality, virtual reality, and mixed reality, are poised to succeed smartphones with superior display quality necessitating display elements like resolution and power efficiency. Our research tackles organic light emitting diode stability and resolution challenges by using micro-light emitting diode technology with vertically stacked RGB pixels for enhanced resolution and integrating quantum dot (QD) materials for improved red light emitting diode (LED) efficiency. The overall concept of this research can be seen in Figure 1. We utilize remote epitaxy to grow LED films over 2D materials on substrates, enhancing crystal quality and enabling easy exfoliation. This method supports the production of stacked full-color pixels through simple transfer. Also, collaboration with Professor Bawendi's group focuses on enhancing the thermal stability of QD materials, ensuring their durability during fabrication.



▲ Figure 1: Concept and process of the vertically stacked micro-LED display.

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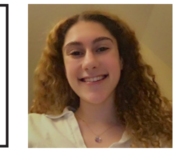
Fully Integrated, Silicon Monolithic Refractive Index Sensor in CMOS for Hydrogen Sensing

3.09

L. S. Hudson, M. de Cea, R. J. Ram
Sponsorship: MITei ExxonMobil



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Electronic devices, Electronics, Integrated circuits, Lasers, Light-emitting diodes, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors, Si, SiGe and Ge, Nonlinear optics, integrated photonics

Fossil fuels produce high carbon emissions; they can be replaced with cleaner energy sources. Energy storage in the form of chemical bonds is considered an optimal scheme. Hydrogen is a low cost, low emission energy carrier; however, it is difficult to contain, highly flammable, odorless, and a short-lived climate forcer. We need an efficient, scalable, and cost-effective mechanism for in-field hydrogen monitoring.

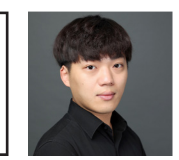
We introduce a fully integrated silicon monolithic refractive index sensor in CMOS for hydrogen sensing. The system consists of a CMOS LED waveguide, a functionalized sensor in the form of a microring resonator, and a CMOS photodetector. The LED waveguide on-chip light source significantly reduces the cost of the device as opposed to an off-chip light source. The waveguide ring is coated with an active material to adsorb and diffuse hydrogen molecules. The ring is exposed to hydrogen molecules and the change in refractive index is extracted. We build a testing setup, evaluate, and characterize discrete components of the system. Then, we characterize the full system and establish the sensitivity of the device. This is done through grating coupling into the device and measuring the relationship between the change in refractive index and the change in detected current. Variations of Palladium and Tungsten Trioxide are examined to determine which chemicals are best suited as an active material for the functionalized sensor through optimizing the ratio of the change in refractive index to the change in concentration of hydrogen.

This system represents the first fully integrated refractive index sensor for hydrogen sensing and paves the way for on-site, affordable, and effective gas sensing in the industry.

A Novel SERS-Based Strategy for Rapid and Sensitive Detection of NRR Products Using Janus WSSe/WS2 Heterostructures

3.10

Y.-R. Peng, T. Zhang, T. H Yang, S.-Y. Tang, S.-M. He, J. Kong
Sponsorship: US Army Research Office grant number W911NF2210023, US Army Research Office through the Institute for Soldier Nanotechnologies at MIT, under cooperative agreement No. W911NF-18-2-0048.



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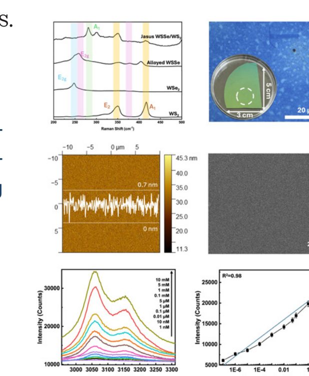
Research Interests:
BioMEMS, Electronics, Medical devices & systems.

Ammonia is a critical feedstock in many everyday products and is considered a crucial energy carrier in the context of the energy transition. Electrochemical nitrogen reduction reaction (NRR) under ambient conditions offers a sustainable alternative to the energy-intensive Haber-Bosch process. However, conventional NRR product detection methods require complex sample preparation and long analysis times. Here, we demonstrate a novel surface-enhanced Raman spectroscopy (SERS) platform based on Janus WSSe/WS2 heterostructures for rapid and sensitive detection of NRR products. The asymmetric structure, featuring an intrinsic out-of-plane electric field and optimized surface chemistry, enables superior SERS performance with an enhancement factor of 10ˆ6. This platform achieves rapid detection of ammonia with concentrations ranging from 1nM to 10mM, demonstrating excellent sensitivity and stability. This work provides a new strategy for rapid NRR product detection and demonstrates the potential of engineered Janus TMD heterostructures for molecular sensing applications.



▲ Figure 1: (Left) Characterization of a Janus WSSe/WS2-based SERS platform. (Right) Raman enhancement performance with varying NH4Cl concentrations and corresponding calibration curve.

Analysis of Purcell-Modulated Exciton Transport in TMD Monolayers

3.11

Mike Dillender, Zhaohan Jiang, Zidong Li, Matthias Florian, Parag Deotare

Sponsorship: Army Research Office (ARO) Award W911NF21-1-0207

Developing methods of directing energy transport of excitons is essential for the creation of energy efficient excitonic devices, however, the neutral charge of these particles has made this difficult. Existing methods for directed transport rely on inefficient use of surface-acoustic wave generators or complex substrate morphologies and transfer methods for strain engineering. In this work, we explore the use of substrate nanocavities to spatially control the diffusive behavior of excitons via spatial-modulation of the Purcell factor.

This work shows various techniques used to design this environment, measure and predict the Purcell factor, and experimentally measure the exciton transport. We show that carefully designed substrate geometries can greatly enhance directed transport of excitons in WSe_2 monolayers, paving the way for efficient excitonic devices.

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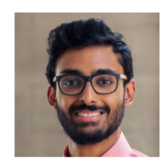
Spatially and Spectrally Resolved Electric Field Inhomogeneity in Colloidal Cd-Free QD-LEDs

3.12

S. Srinivasan, R. Zhang, M. Dillender, T. Nguyen, M. Laitz, Taehyung Kim, M. Bawendi, V. Bulović

Sponsorship: Samsung Semiconductor Co.



Colloidal quantum dots (QDs) are solution-processable emitters with high quantum efficiencies and tunable emission wavelengths. They have emerged as promising materials for electronic displays, solid-state lighting, and optical communication. The demand for QD-based display technologies has necessitated the development of environmentally-benign QD compositions with similar optical properties to high-performing, but toxic, heavy-metal-containing QDs. Using time-resolved confocal micro-photoluminescence and micro-electroluminescence mapping under an applied electric field, we observe direct evidence of inhomogeneity in QD response to the electric field for InP/ZnSe/ZnS quantum dot light emitting diodes (QD-LEDs). By applying a negative bias across the diode while photo-exciting the QDs, the steady-state and time-resolved exciton dynamics are modulated, resulting in photoluminescence (PL) quenching and a decrease in average exciton lifetime. Under confocal micro-PL mapping, intensity hotspots imaged in the QD thin film are found to be less-reactive to the applied electric field, resulting in spatial inhomogeneity in PL quenching after the application of the electric field. These same regions also exhibit limited electroluminescence. We thus hypothesize that the thicker regions of the QD film screen the effective electric field experienced by the dots in that region, leading to limited field-induced modulation. Subsequently, we posit that under positive bias, the same regions that are unresponsive under negative bias also do not contribute to charge injection and electroluminescence, leading to increased field exposure and aging in the surrounding QDs. This work provides a possible mechanism for the accelerated operational lifetime decays observed for InP/ZnSe/ZnS QD-LEDs.

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Displays, Energy, Lasers, Light-emitting diodes, Nanomanufacturing, Optoelectronics, Photonics, Photovoltaics, Quantum devices.

Superconducting Feedforward Electronics for Photon-Number Discrimination in Quantum Photonic Platforms

3.13

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Sponsorship: National Science Foundation (OMA-2137723)

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Research Interests:
Electronic devices, Electronics, Nanomaterials, Nanotechnology, Photonics, Quantum devices, Sensors.

Integrating superconducting nanowire single-photon detectors (SNSPDs) on thin-film lithium niobate (TFLN) circuits is a promising step for miniaturizing and advancing quantum photonic platforms. Recent progress has shown SNSPD fabrication on TFLN waveguides, paving the way for system-level applications. Many quantum photonics protocols require feedforward control, where optical operations depend on prior photon measurement outcomes. Therefore, integrating feedforward electronics with SNSPDs-on-TFLN, to support dynamic detector readout and electro-optics control, is an exciting advancement. This approach could enable optical operations based on the observed photon-number state, by using the photon-number resolution (PNR) of SNSPDs. In SNSPDs, PNR is usually achieved by distinguishing output waveform features (e.g., amplitude) with room-temperature electronics. A practical on-chip approach is using nanocryotron (nTron) electronics, an integrated nanowire-based technology that can reach the half-wave-voltage of TFLN optical modulators.

We propose a nanowire-based system that discriminates photon-number detection events. This system includes an SNSPD with PNR coupled to an nTron current-level discriminator. Higher photon numbers produce larger detector output currents, and the discriminator circuit generates an output pulse only if such currents fall within a specific range (set by two tunable thresholds), thus selectively detecting a target photon-number state while ignoring others. This output pulse can drive electro-optic switches to enable feedforward control.

We fabricated the discriminator on a niobium nitride thin film via electron beam lithography, achieving current thresholds compatible with typical SNSPD output levels, and demonstrated successful current discrimination at 4.2 K with a 1-MHz input square wave. Additionally, we simulated the detector-circuit system in SPICE, showing photon-number recognition at 10 MHz. We aim to fabricate and test this system.

Integrated Visible-Light Grating-Based Antennas for Augmented-Reality Displays

3.14

A. G. Coleto, M. Notaros, J. Notaros

Sponsorship: NSF CAREER Program, DARPA VIPER Program, MIT SoE Mathworks Fellowship, NSF Graduate Research Fellowship

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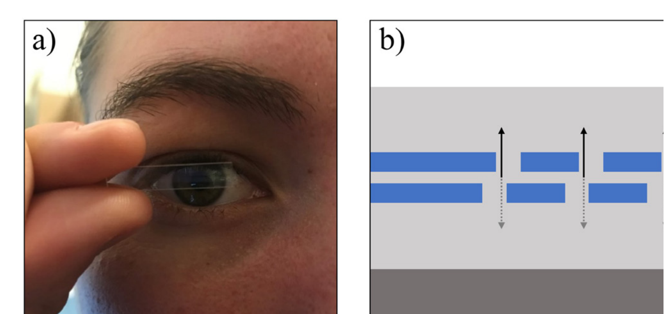
Augmented-reality (AR) displays that display information in the user's field of view have many wide-reaching applications in defense, medicine, gaming, etc. However, current commercial AR displays are bulky, heavy, and indiscreet. Moreover, current AR displays are incapable of producing holographic images with full depth cues; this lack of depth information results in eyestrain and headaches that limit long-term and wide-spread use of these displays.

To address these limitations, we are developing an integrated-photonics-based display that consists of a single transparent chip that sits directly in front of the user's eye and projects holograms that only the user can see. Specifically, in this work, we develop and demonstrate uniformly- and unidirectionally-emitting grating-based antennas that enable this integrated-photonics-based display architecture. This work paves the way towards a highly discreet and fully holographic solution for the next generation of AR displays.



◀ Figure 1: (a) Photograph of a transparent integrated-photonics-based holographic display. (b) Simplified cross-sectional conceptual diagram of a partial section of a dual-layer antenna showing unidirectional emission in the upward direction.

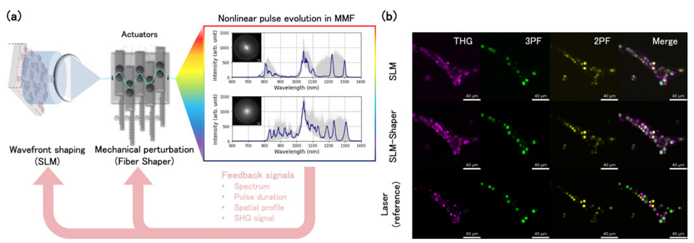
Adaptive Nonlinear Pulse Engineering in Optical Multimode Fiber with Wavefront Shaping and Mechanical Perturbation

3.15

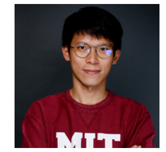
L.-Y. Yu, H. Cao, K. Liu, T. Qiu, S. You

Sponsorship: MIT EECS and RLE startup funds, Jameel Clinic, Chan Zuckerberg Initiative, Radon Institute, Koch Institute, Research Corporation for Science Advancement, Mathwork Fellowship, Claude E. Shannon Fellowship.

Multimode fibers offer a platform to accommodate intricate light-matter interactions with emerging applications in telecommunications, imaging, and sensing. Controlling light with extended frequency ranges and spatiotemporal characteristics usually requires high-performance photonic devices with considerable degrees of freedom, such as spatial light modulators. However, a more efficient control strategy is demanded to exploit the high dimensionality of nonlinear pulses in a multimode fiber. Here, we demonstrate adaptive nonlinear pulse engineering from 650 to 1350 nm by leveraging wavefront shaping and mechanical perturbation. We show two control mechanisms have complementary effects on supercontinuum generation in the spectral, temporal, and spatial domains. We leverage the physics priors to establish an efficient adaptive pulse optimization framework, demonstrating the superior capability of femtosecond pulse tailoring and enhanced signal-to-noise ratio in multiphoton microscopy.



▲ Figure 1: (a) Schematic of adaptive nonlinear pulse optimization in a multimode fiber. (b) Multiplexed multiphoton images of fluorescent beads with an excitation at 1300 nm.



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Spatially-Adaptive Multi-Beam Optical-Phased-Array-Based Solid-State LiDAR Sensors

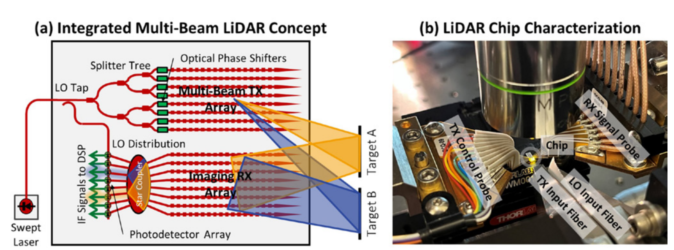
3.16

D. M. DeSantis, B. M. Mazur, M. Notaros, J. Notaros

Sponsorship: SRC JUMP 2.0 CogniSense, MIT Rolf G. Locher Endowed Fellowship, NSF Graduate Research Fellowship

Light detection and ranging (LiDAR) has emerged as a vital and widely-used sensing technology for autonomous systems, such as autonomous vehicles, since it enables 3D mapping with higher resolution than traditional RADAR. However, current commercial LiDAR systems utilize mechanical beam-steering mechanisms that decrease reliability, increase production cost, and limit detection range. To address these limitations, solid-state optical-phased-array-based (OPA-based) LiDAR, which enables low-cost, high-speed, and compact non-mechanical beam steering, has emerged as a promising solution for next-generation LiDAR sensors.

In this work, we propose, develop, and experimentally demonstrate a novel spatially-adaptive solid-state LiDAR system enabled by multiple-beam OPA subsystems and integrated optical-processing devices. This multi-beam adaptability enhances spatial awareness and reduces the back-end data processing traditionally associated with beam-rastering LiDAR.



▲ Figure 1: (a) Conceptual diagram of our solid-state multi-beam LiDAR system illuminating and ranging two targets simultaneously. (b) Photograph of our fabricated solid-state multi-beam LiDAR system chip under test with light coupled in through optical fibers (bottom) and electrical probes landed (left and right).

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Photoinduced Surface Passivation for Singlet Fission-Enhanced Silicon Photovoltaics

3.17

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Sponsorship: U.S. Department of Energy, Office of Basic Energy Sciences

Crystalline silicon (c-Si) photovoltaics (PVs) dominate the global production of renewable energy. Capitalizing on the mature industry by sensitizing single junction c-Si PVs with the exciton multiplication process singlet fission (SF) enables generation of two electron-hole pairs per photon and efficiencies that can surpass the single junction limit. SF-enhanced c-Si PV efficiencies are limited by the interfacial transfer of charge carriers from a SF chromophore coupled to the surface of c-Si due to surface recombination and trap loss pathways. Effective surface passivation is essential for achieving high efficiency c-Si PVs and to maximize the contribution of exciton multiplication. Tunnel-oxide layers based on high-k dielectrics have attracted interest in PV architectures to provide chemical passivation of surface defects and electric field-effect passivation, while maintaining favorable charge tunneling characteristics. This passivation layer must be sufficiently thin for tunneling of electrons and holes from the SF chromophore and sufficiently thick to reduce interfacial recombination loss pathways to successfully enhance the performance of a c-Si PV when coupled to a SF chromophore. In this work we employ a dual-interlayer architecture with an electron donor and a high-k dielectric that enhances the ultra-thin tunnel oxide passivation with a photoinduced charge separation, field-effect passivation contribution while maintaining effective tunneling for charge extraction between the SF chromophore and c-Si surface. Minority carrier lifetime and photoluminescence measurements suggest a reduction in charge recombination loss pathways. Understanding the interplay of charge at the interfaces of SF and c-Si PVs provides a strategic path for employing exciton multiplication in existing PV technology to enhance collection of usable energy from the sun.

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Reduced-Crosstalk Optical Antennas for Wide-Field-of-View Optical Phased Arrays for Solid-State LiDAR Sensors

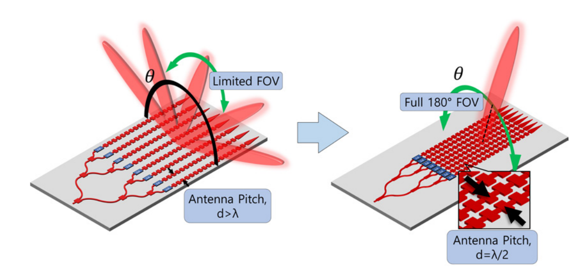
3.18

B. M. Mazur, D. M. DeSantis, A. G. Coleto, J. Notaros

Sponsorship: SRC JUMP 2.0 CogniSense, DoD NDSEG Fellowship Program, MIT Rolf G. Locher Endowed Fellowship, NSF Graduate Research Fellowship

Light detection and ranging (LiDAR) has emerged as a crucial sensing technology for autonomous systems, as it enables 3D mapping with higher resolution and accuracy than RADAR or stereoscopic imaging. Current commercial LiDAR systems rely on mechanical beam-steering mechanisms that decrease reliability, increase production cost, and limit frame rate. To address these limitations, integrated optical-phased-array-based (OPA-based) LiDAR enables low-cost, high-speed, and compact solid-state beam steering, making it a promising solution for next-generation LiDAR sensors.

Despite the many advantages, integrated OPAs typically have a restricted field of view (FOV), limited by grating lobes caused by large antenna pitches. In this work, we develop novel integrated grating-based antennas that mitigate crosstalk to enable a half-wavelength-pitch OPA, allowing for an increased near-180-degree array-dimension FOV.



◄ Figure 1: Diagram depicting an OPA with an array-dimension FOV limited by grating lobes caused by large antenna pitch (left) compared with a full 180-degree array-dimension FOV enabled by achieving half-wavelength-pitch antennas (right).

Modulating Multimodal Femtosecond Pulse Propagation for Label-Free Nonlinear Microscopy

3.19

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Sponsorship: Mathworks Fellowship

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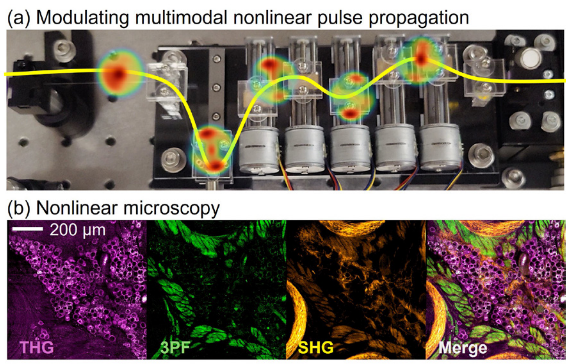
Multimode fibers (MMFs) are of increasing interest for high-power applications, including high-power fiber lasers and bioimaging. However, current methods for controlling light propagation in MMFs, such as input wavefront shaping, have limitations in controlling broadband high-peak-power nonlinear pulse propagation, especially in the femtosecond regime. Here, we present a simple yet effective method for achieving this control by leveraging both spatial and temporal degrees of freedom during multimodal nonlinear pulse propagation in step-index MMFs, using a programmable fiber shaper that introduces time-dependent disorders. The fiber shaper modulates the output field in the spectral, temporal, and spatial domains, resulting in a broadband high-peak-power source. Its potential as a nonlinear imaging source is demonstrated through widely tunable two- and three-photon microscopy. This demonstration provides possibilities for technological advances in nonlinear optics, spectroscopy, and bioimaging.



◀ Figure 1: (a) Device modulating multimodal nonlinear pulse propagation via programmable bending to adjust mode interactions (modes shown over the photo). (b) Label-free nonlinear microscopy image of a mouse whisker pad.

Dark Exciton Signatures in Blue OLEDs probed by Strong Magnetic Fields in situ

3.20

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Understanding the degradation mechanisms of blue organic light emitting diodes (OLEDs) is key to developing the next generation of bright and stable blue OLEDs for applications in phones, TVs and solid-state lighting. Annihilation processes involving dark excitons are thought to be the primary cause of degradation in blue OLEDs, as they form 6 eV states which break carbon-carbon bonds in the host, emitter, and transport layers, creating defect sites which quench the electroluminescence of the device. While these annihilation processes are thought to be ubiquitous, observing them directly has proven difficult through optical means due to their dark nature, and their connection to device degradation has yet to be fully understood.

In this work, the annihilation rates of dark excitons are modulated in blue OLEDs in situ through the application of strong DC magnetic fields. By monitoring the response of the electroluminescence efficiency and stability of blue OLEDs to the applied field, unique signatures of these annihilation events are identified and associated with specific nanoscale processes in the device during normal operation. By measuring device degradation under the magnetic fields associated with each annihilation process, a direct link is established between the annihilation of dark excitons and their impacts on blue OLED performance.

Modeling Coupling between Optically Driven Nanoantennas and Wires in Petahertz Electronic Circuits

3.21

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Sponsorship: NSF career waveguide integrated PHz electronics

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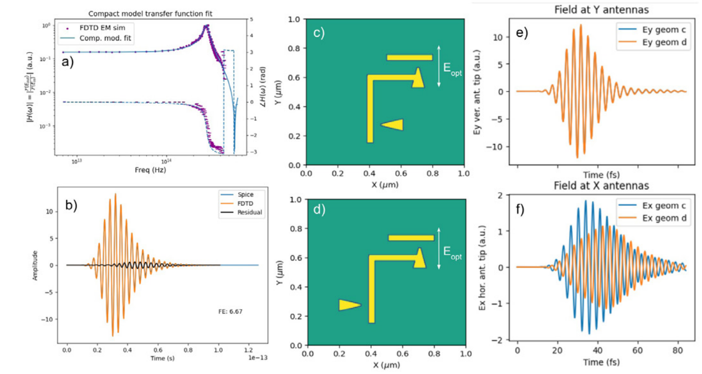
Optically driven nanoantennas leverage geometrical field enhancement, plasmonic resonance, and polarization selection of metallic nanostructures. Their subcycle tunneling current responses to optical inputs make them promising candidate components in petahertz electronic circuits, such as memory cells or logic gates. The computational cost of full electromagnetic and particle tracking simulations makes them an infeasible option for design of nanoantenna circuitry. As an alternative, we developed a compact circuit model describing a nanoantenna which can be simulated efficiently in LTspice, with interconnecting wires modeled as transmission lines.
In this work, we study the coupling between gold triangular nanoantennas and interconnecting wires as well as the free space coupling between neighboring nanoantennas. Describing the wire-mode coupling and distinguishing it from parasitic near-field coupling through free space is essential for reliably simulating nanoantenna circuits in LTspice.



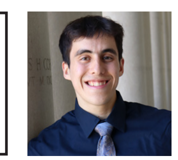
◀ Figure 1: a) Fit of circuit model transfer function to FDTD data. b) Time domain LTspice and FDTD simulation outputs. d-e) Layout of charge coupled devices under Y polarized pulses. e) FDTD simulation of Ey field at vertical antennas. f) FDTD simulation of Ex fields at horizontal antennas.

Integrated Optical Phased Arrays with Visible-Spectrum-Spanning Emission

3.22

H. Crawford-Eng, A. Garcia Coleto, J. Notaros

Sponsorship: AIM Photonics GDP4, NSF CAREER Program, NSF Graduate Research Fellowship, MIT SoE Mathworks Fellowship, and MIT Locher Fellowship



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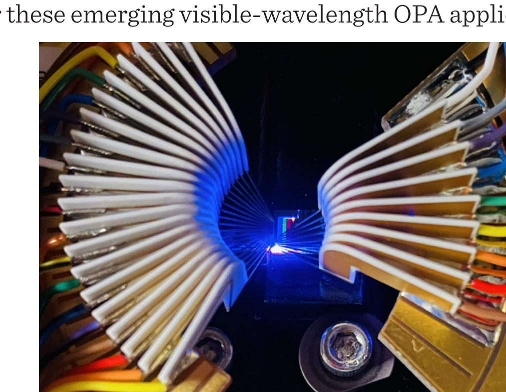
Integrated optical phased arrays (OPAs) have emerged as a promising technology for various applications due to their ability to dynamically control free-space optical beams in a compact and non-mechanical manner. As such, integrated OPAs have gained significant attention due to their already demonstrated impact on applications such as LiDAR for autonomous vehicles and free-space optical communications. However, motivated by these initial applications, integrated OPA demonstrations have mostly been limited to implementations at infrared wavelengths. Advancements in visible-light integrated OPAs have been relatively limited despite their potential benefits for applications such as displays, quantum systems, underwater communications, and optogenetics.

In this work, we design and demonstrate the first integrated OPA system that simultaneously emits beams at red, green, and blue wavelengths, enabling spectrum-spanning functionality for these emerging visible-wavelength OPA applications.



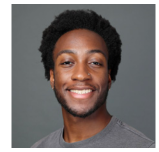
◀ Figure 1:Photograph of the fabricated integrated visible-spectrum-spanning OPA system on an experimental setup.

Gold Nanostructures for Mid and Long-Wave Infrared Detection

3.23

M. A. Sere, M. D. Yeung, K. K. Ryu, I. Prigozhin, K. K. Berggren, P. D. Keathley

Sponsorship: Office of Naval Research, Lincoln Laboratory ACC (Longwave Infrared-Enhanced Electron Emission from Nanoantennas (L-IREEN)), MIT Presidential Fellowship



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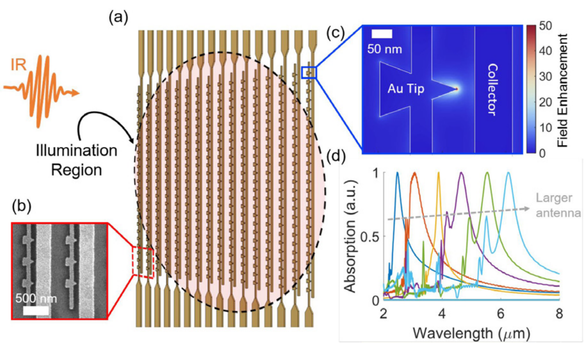
Lasers, Light-emitting diodes,
Nanotechnology, Optoelectronics,
Photonics, Quantum devices,
Spintronics

Mid-wave infrared (MWIR) and long-wave infrared (LWIR) imaging carries numerous applications such as night vision and security, environmental, and industrial monitoring. However, traditional detectors at these wavelengths have a steep tradeoff between Size, Weight, and Power (SWaP) considerations due to cryogenic cooling requirements and performance metrics in speed and sensitivity.

This work investigates the use of Infrared Enhanced Electron Emission from Nanoantennas (IREEN) for MWIR and LWIR detection at room temperature. Gold antennas of varying geometries are deposited onto silicon and silicon oxide substrates to qualify the effect of geometry on the prominence of field-driven vs Schottky-driven electron emission, providing insights on how to design high-performance, low cost MWIR and LWIR detectors.



◀ Figure 1: (a) Nanoantenna array. (b) SEM of nanoantenna. (c) Field-enhancement simulation of nanoantenna design. (d) Simulation showing spectral tuning of nanoantennas.

Session 4: Power Devices & Circuits

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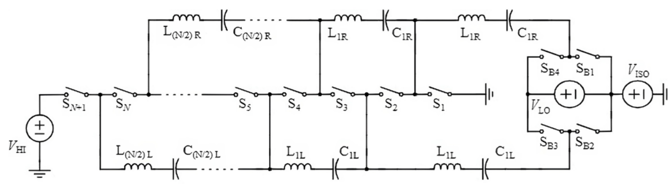
The Analysis and Design of Resonant Capacitively-Isolated Cockcroft-Walton Converter

4.01

E. Rabenold, R. Jerez, S. Coday

Hybrid switched-capacitor converters have been shown to be competitive with traditional magnetics-based converters in both efficiency and passive component volume due to their utilization of energy-dense capacitors for energy processing. However, one important feature that is yet underdeveloped in hybrid switched-capacitor converters is isolation between the input and output voltages, which is a critical feature for performance and safety. Traditional implementations of galvanic isolation employ transformers to create the isolation barrier. However, transformers are costly in both component volume and weight. In applications where passive volume is a key design constraint, the dielectric material of capacitors may instead be used to achieve isolation. This work proposes the introduction of a capacitor-based isolation barrier into the Cockcroft Walton converter to support isolated power transfer in applications that require extreme conversion ratios and output regulation. Generalized equations for mid-range flying capacitor voltages and switch voltages for converters of even level count are detailed. Experimental results for a 6:1 version of the resonant capacitively-isolated Cockcroft Walton are shared, and the viability of capacitive isolation in this topology is demonstrated.



▲ Figure 1: Schematic of an N-level capacitively-isolated Cockcroft-Walton converter.

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An Electric Field "Deep Bar" Induction Motor

4.02

A. S. Miller, J. H. Lang

Sponsorship: NSF Graduate Research Fellowship, Fannie and John Hertz Foundation Fellowship

Electric field-based actuators and machines lead the design space at the nanoscale and in biological systems, while having the potential to be used in favorable macroscale applications which prioritize minimal mass, performance in a vacuum, or performance in high temperatures. Electrostatic induction motors consist of a set of stator electrodes which induce opposite charges onto a movable rotor surface. In earlier work, rotor surfaces for electrostatic induction motors have been made of single continuum materials, which are limited in possible resistivity and circuitry characteristics. Magnetic field induction motors, which are common in machinery, often utilize "deep bar" rotors, consisting of iron bars which decrease the rotor time constant with increasing frequency using the skin depth effect. We propose, analyze and design a macro-scale electric field induction motor which uses circuitry on the rotor surface to emulate the deep bar design, providing improved torque over a wide range of speeds.

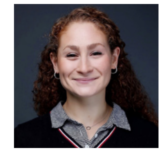
Soft-Switched Pulsed Bias Plasma Supply System

4.03

J. Estrin, A. Jurkov, D. J. Perreault
Sponsorship: MKS Instruments, Inc.

Radio Frequency (RF) generators play a crucial role in plasma-enhanced semiconductor manufacturing, particularly as sources of bias voltage. Employing pulsed waveforms as bias voltage sources offers significant improvements in manufacturing precision. However, producing these waveforms is challenging due to the need for high voltages (in the kV range), high frequencies (hundreds of kHz to low MHz), precise timing, and broadband frequency content. Traditional methods to generate these waveforms are constrained by semiconductor voltage ratings, resulting in either low-voltage outputs or complex circuits to achieve higher pulse voltages.

This work introduces a simple and compact method for generating pulsed bias voltages for plasma processing, enabling reduced loss compared to the more complex systems previously described in the literature. The approach synthesizes the pulsed waveform at a low, convenient voltage and then uses an auto-transformer to step up the voltage to the desired level. A coaxial-cable-based transformer with low leakage inductance has been developed to provide scaling with sufficient fidelity across a wide frequency range. Zero voltage switching (ZVS) is achieved on all devices, ensuring low-loss operation. The proposed system is validated through a lab bench prototype that generates pulses of 2.1 kV at 400 kHz. The proposed system further offers both adjustable pulse duty ratio and slew rate, providing enhanced control and versatility for various applications.



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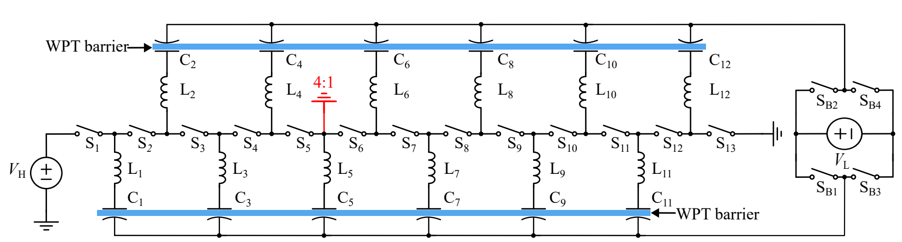
A Hybrid Switched Capacitor Converter Enabling Capacitive-Based Wireless Power Transfer for Battery Charging Applications

4.04

J. Sund, S. Coday

Wireless power transfer is emerging for applications such as autonomous drones, electric vehicles, biomedical implants, and phone charging, where wired charging is inconvenient or impractical. This work investigates the feasibility of employing hybrid switched capacitor converters in wireless battery charging applications to decrease passive component sizing and switch stress. A capacitively-isolated hybrid Dickson converter designed for use in low-power volume-constrained wireless power transfer applications is presented. The converter analysis, operation and design are detailed. Finally, a hardware prototype is presented, and experimental results validate wireless power transfer, across varying load and gap distances.



▲ Figure 1: Capacitively-isolated 12:1 hybrid Dickson converter schematic with WPT barrier shown. The ground connection (red) at the node between S5 and S6 converts the schematic to the 4:1 capacitively-isolated hybrid Dickson converter when S_6–S_{13}, L_5–L_{12}, and C_5 –C_{12} are omitted.

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A Literature Review on the Analysis of Resonant Switched-Capacitor Converters

4.05

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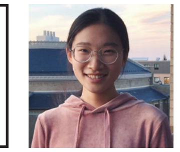

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Mainly focus on the following paper: *A General Analysis of Resonant Switched-Capacitor Converters Using Peak Energy Storage and Switch Stress Including Ripple* (N. M. Ellis, N. C. Brooks, M. E. Blackwell, R. A. Abramson, S. Coday and R. C. N. Pilawa-Podgurski)

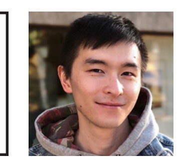
Abstract: This article presents a general analytical framework enabling the large-signal characterization of resonant switched-capacitor (ReSC) power converters that accounts for passive component voltage and current ripple, for operation at and above resonance. From this, appropriate phase durations for minimized rms currents are derived, in addition to expressions for total passive component volume using an intuitive peak energy method. An example hardware prototype validates both the derived waveforms and timings—as well as total passive volume—through three comparable hardware configurations, one of which minimizes passive component volume. In addition, the proposed technique formulates analytical expressions for both rms currents and peak blocking voltages, facilitating refined loss estimation and component selection. Subsequent calculation of the large-signal volt-amp switch stress metric allows a more accurately quantified tradeoff between active and passive components compared to prior work, which has not fully accounted for ripple. Four common ReSC topologies are exemplified throughout, with topology-specific parameters documented for reference.

My Main Takeaways: This paper offers a comprehensive analysis of ReSC converters applicable to various topologies. The proposed analysis method provides an excellent foundation for understanding innovative converters, including both resonant and far-above-resonant performance. Additionally, it sheds light on analyzing converters with varying resonant frequencies across different switching states, which is particularly relevant to my research on input inductor buck converters.

Design of Vertical AlN-Channel Power Transistors

4.06

Z. Zhu, H. Pal, T. Palacios
Sponsorship: Knut and Alice Wallenberg Foundation



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Research Interests:
Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, Microfluidic devices & systems, Nanotechnology, Power management, Quantum devices.

As an ultrawide bandgap (UWBG) semiconductor, aluminum nitride (AlN) is a promising candidate for next-generation high-voltage electronic devices due to its remarkably large breakdown field of 11-15 MV/cm. Moreover, AlN exhibits higher bulk electron mobility compared to other UWBG materials like AlGaN and Ga_2O_3. As a result, Baliga's figure of merit is over 10 times higher in AlN than in conventional wide-bandgap materials such as GaN and SiC. However, AlN faces challenges to achieve high carrier concentration through doping due to the large ionization energy of donors. Forming ohmic contacts is also difficult, as low electron affinity and Fermi level pinning near the charge neutrality level prevent reduction of the potential barrier at the metal/AlN interface. These factors limit the development of AlN-based power switches with high current density.

Here, we propose a heterostructure design of vertical AlN-channel fin field-effect transistors (FinFETs) on a sapphire substrate. A graded $Al_xGa_{1-x}N$ layer on both sides of the AlN channel serves as the source and drain, respectively. Strong polarization at the AlxGa1-xN/AlN interface and within the graded layer forms a three-dimensional electron gas (3DEG), creating a polarization-induced doping region. This leads to an increased carrier concentration in the source and drain access region without compromising mobility from impurity doping, effectively reducing the on-resistance. Technology-Computer-Aided-Design (TCAD) simulation suggests that this device structure could achieve high on-current density above 100 mA/mm at source-drain bias (V_{DS}) of 5 V, approximately three orders of magnitude higher than state-of-the-art lateral AlN transistors. These preliminary simulation results indicate that this vertical heterostructure device architecture may overcome the current obstacles in AlN-based power switches.

A Switched-Capacitor Based Slow Charging Solution for Electric Vehicles 4.07

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Sponsorship: MITEI Future Energy Systems Center

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Research Interests:
Electronic devices, Electronics Energy, GaN, Integrated circuits, Power management, Sensors, Si.

Electric vehicle (EV) market share has greatly increased in recent years. Because of this, there has been considerable effort to decrease EV charging time. This has increased stress on power grids worldwide, causing concern on how quickly the grid will have to grow to meet this demand. To delay this issue, there has been increased focus on slowing down EV charging. Charging vehicles at a lower power would give the grid more time to grow, and can still provide the necessary daily mileage for the average person with just a few hours of charge time. A big impediment, however, is that slow chargers must be very efficient in order to charge within a reasonable amount of time. Using a 120-volt, 20-amp outlet, 30 miles of charge can be achieved in less than 6 hours for a 100% efficient system, but the same outlet would take almost 8 hours for a 70% efficient system. Therefore, there exists a need for a high-efficiency charger that can work at both low power and can also be used for higher power when needed.

In this work, a switched-capacitor based solution for a slow EV charger is developed. The charger is able to provide 30 miles worth of charge within 8 hours, allowing users to plug in their cars while they are asleep or at work. It is important to note that the 95% of Americans drive less than 30 miles every day, and the average American car is parked for 23 hours per day, so these numbers are well within reason for most Americans. The charger is also able to plug into a standard 120-volt outlet, so it does not require the installation of a high-power outlet like most EV chargers do. The charger internally has a switched-capacitor based topology consisting of multiple power converters in parallel. This allows it to activate one module for the low power 120-volt charging mode, or parallelize more modules if the user chooses to plug the charger into an outlet that can provide higher power. The topology also allows for a much more power-dense and efficient solution, meaning the converter is much smaller, lighter, and generates less heat than similar magnetic-based converters. This work also explores solutions for switched-capacitor based isolation solutions that are used within the charger to comply with safety regulations.

This work can be used to make EV's more affordable, as high-power outlets can cost upwards of $2000 to install in a home. It can also increase accessibility of charging, as users can use this charger to plug into any outlet that can be reached from a parking spot, such as those on the walls of parking garages. Future work will investigate solutions for paying for the power used in this way.

Improved Piezoelectric-Resonator-Based Power Conversion at High Conversion Ratios 4.08

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Sponsorship: Texas Instruments, NSF Graduate Research Fellowship

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Research Interests:
Electronic devices, Electronics. Energy, Energy harvesting devices & systems, GaN, Power management.

Power converters are essential components of many electric energy systems, and recent technological advances demand smaller, lighter, and more efficient power converters than those that are currently available. Conventional power converters are rely on magnetic components (inductors and transformers) for energy storage, but these magnetics are bulky, heavy, and lossy. Converters based on piezoelectric elements provide a promising alternative to magnetic-based designs due to their favorable scaling properties as converters are miniaturized; furthermore, current topologies tend to perform best at high load impedances, indicating potential suitability for medium-voltage, low-power applications. However, the switching sequences examined in prior work exhibit poor efficiencies at high conversion ratios. In this work, a new switching sequence is demonstrated which utilizes multiple resonant cycles per switching cycle. With no added circuit complexity, this sequence can significantly improve high-step-down, light-load performance over previous designs, making piezoelectric-based converters viable in a wider range of applications.

TCAD Simulations to Explore Thermal Solutions for GaN-on-Silicon HEMTs 4.09

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Sponsorship: Center 7 SUPREME: SUPeRior Energy-efficient Materials and dEvices, one of the seven centers in JUMP 2.0, a Semiconductor Research Corporation (SRC), Defense Advanced Research Projects Agency (DARPA)

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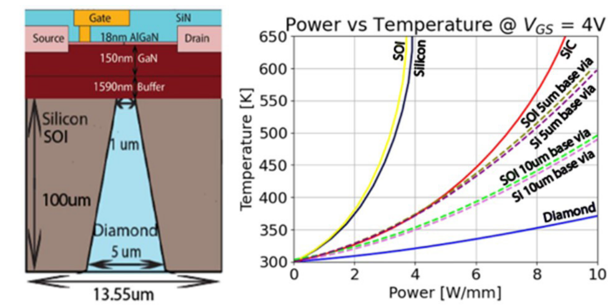
Research Interests:
Electronic devices, GaN, III-Vs, Integrated circuits, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology, Thermal structures, devices & systems.

The wide bandgap and large breakdown voltage of GaN makes GaN HEMTs a key element for the next generation of high-power and high-frequency electronics. Silicon (Si) based substrates allow wafer scaling to 8-12" wafers and the use of state-of-the-art fabrication tools. However, they make thermal management more difficult compared to more commonly used silicon carbide (SiC) substrate.

Thermal management is crucial because the large power density in GaN HEMTs induces extreme self-heating in their conducting channel which leads to reduced current and device degradation. To fully leverage the benefits of Si-based substrates, this work uses TCAD simulations to explore thermal solutions that reduce the peak temperature of GaN-on-Si HEMTs to that of GaN-on-SiC HEMTs.

The simulations are calibrated using transfer-length-method and Hall measurements of fabricated GaN-on-Si HEMTs. Explored solutions include strategically incorporating diamond vias into Si substrate to enhance heat dissipation.

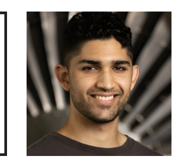


◀ (a) Simulated structure with conical diamond via (not to scale) and (b) Power vs. Temperature curves of GaN HEMTs with various substrates. Shows that the diamond via reduces the peak temperature of GaN-on-Si ~65% to a lower value than GaN-on-SiC.

Specific Power Increases in DC-DC Power Converters for Electroaerodynamic Aircraft 4.10

M. Shevgaonkar, K. Muhammad, D. Perreault

Sponsorship: NASA NIAC Phase 2 (80HQTR23NOA01-23NIAC-A2)



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Research Interests:
Batteries, Electronic devices, Electronics, Fuel cells, GaN, Photovoltaics, Power management.

Electroaerodynamic (EAD) propulsion is a novel form of propulsion that has no moving parts and is almost completely silent. Aircraft powered by EAD propulsion have the potential to perform nearly silent package delivery and surveillance missions. A major component of an EAD aircraft is the high voltage gain DC-DC converter required to drive the high voltage thruster array from a lithium-ion energy source. The endurance of the aircraft is heavily dependent on the efficiency and specific power of the converter. The aim of this research is to design and implement a converter with specific power improvements over the last generation of EAD power conversion designed at MIT. This can be accomplished by utilizing magnetics integration and cooling techniques as well as by changing high level parameters such as power level and output voltage. Magnetics integration involves consolidating several discrete magnetic structures into a single structure that is lighter in weight and more compact. Magnetics cooling techniques involve designing the magnetic structure for effective heat transfer to a forced convection parallel plate heat sink. Modeling suggests that magnetics integration and cooling combined with a higher power level and lower output voltage can result in an increase of specific power from 1.15 kW/kg to nearly 3 kW/kg while maintaining 85% efficiency. Ongoing improvements in the thruster and airframe combined with the aforementioned specific power increases in the converter would enable an endurance increase from from 90 seconds to roughly 10 minutes.

High Performance Scaled p-GaN-Gate HEMTs for Next Generation Medium-Voltage Power Converters

4.11

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Research Interests:
2D materials, Electronic devices Electronics, GaN, III-Vs, Integrated circuits, Nanomanufacturing, Nanomaterials, Nanotechnology, Si.

With the increasing prevalence of artificial intelligence, cloud computing, and internet of things, data centers consume 2% of the world's electricity, a number which is predicted to double by 2026. Key to the efficiency of powering these data centers are high speed and low on-resistance medium-voltage power switches (e.g. for use in 48V-12V DC-DC converters). P-GaN-gate high electron mobility transistors (HEMT) are a promising candidate for these switches due to their high breakdown voltage, high switching speed, low on-resistance, and normally-off operation. However, while >650V p-GaN-gate HEMT power switches have been heavily researched and are already commercially available, not much work has been done exploring the potential of p-GaN-gate HEMTs for low-medium voltage applications (10-100 V).

In this work we demonstrate a scaled p-GaN/$Al_{0.2}$GaN/GaN (80/15/200 nm) HEMT with a p-GaN Mg doping of 3×10^{19} cm^{-3} grown on an 8" Si substrate by SOITEC. To reduce on-resistance and improve the maximum current density, we employ a self-aligned Schottky Tungsten gate first process. Devices with $L_G/L_{SD}/L_{GD}$ = 600/1300/370 nm demonstrated a maximum drain current of 1.07 A/mm, an on-off current ratio exceeding 10^{10}, and a threshold voltage of 0.45 V. Furthermore, these devices exhibit on-resistances as low as 1.6 Ω·mm and breakdown voltages exceeding 125 V which make them highly promising for use as medium-voltage power switches. To the best of the authors' knowledge, the demonstrated devices have the highest Baliga figure of merit (0.3 GW/cm^2) of all medium-voltage (<200V) p-GaN-gate HEMTs reported in the literature. Compared to the current state-of-the-art technology for medium voltage power switches, Si LDMOS, the demonstrated device demonstrates a greater than order-of-magnitude improvement in the specific on-resistance at the given breakdown voltage. This work demonstrates that replacing Si LDMOS switches with p-GaN-Gate HEMTs serves to greatly improve the efficiency of medium-voltage power converters.

Review of Piezoelectric-Based Power Conversion

4.12

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Sponsorship: Texas Instruments, MIT SuperUROP

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Power electronics are critical components of many electric systems. For example, power converters can be found in anything from consumer electronics to renewable energy generation. New applications demand smaller, lighter, and more efficient power converters. However, scaling down these parameters is often bottlenecked by magnetic energy storage elements: not only are they typically the largest element on the circuit, but they are also the least efficient at small volumes. Piezoelectric resonators are a promising alternative energy storage device. Instead of storing energy in a magnetic field, these components store energy in mechanical vibrations. Critically, piezoelectric resonators do not suffer from the same limitations as magnetics do at small scales. Piezoelectric-resonator-based converters can achieve high-efficiency behaviors such as zero-voltage switching and capacitor soft-charging, both without the use of magnetics. In general, utilizing piezoelectric resonators for power conversion enables high power density, high efficiency and favorable scaling properties.

Gate Stack Design of p-GaN Gate GaN High Electron Mobility Transistors 5.01

Y. Yu, J. A. del Alamo

Sponsorship: Texas Instruments

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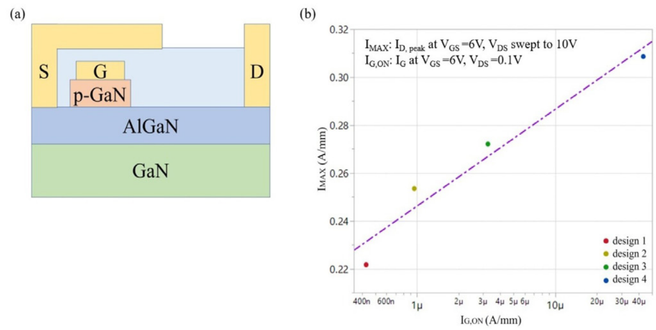
Gallium nitride (GaN) high electron mobility transistors (HEMTs) represent a breakthrough in semiconductor technology, offering superior high-frequency and high-power performance. However, reliability issues, particularly related to p-GaN gate designs, remain a challenge. This study investigates the impact of this design and fabrication on transistor performance, focusing on the trade-off between peak saturation drain current (I_{MAX}) and ON-state current ($I_{G,ON}$). Modest structural design and fabrication process changes have shown significant variations in I_{MAX} and $I_{G,ON}$, highlighting the need for strict process control.

In our work, we are carrying out extensive electrical characterization of prototype industrial transistors. In addition, we are performing Sentaurus TCAD simulations built to model such GaN HEMTs. By comparing experimental and simulated data, we aim to understand the dominant underlying physical mechanisms and refine predictive models for future GaN HEMT designs, ultimately improving device performance and reliability.



▶ Figure 1: (a) Cross-sectional view of p-GaN gate GaN HEMT (S is source, G is gate, D is drain), and (b) trade-off between I_{MAX} and $I_{G,ON}$ of prototype transistors from four differently-designed wafers.

Electrical-Controlled Magnetism in Rhombohedral Graphene 5.03

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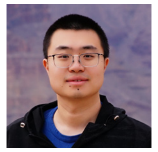
Research Interests:
2D materials, Electronic devices, Electronics, Lasers, Light-emitting diodes, Nanomaterials, Nanotechnology, Quantum devices, Spintronics.

Magnetism typically arises from the alignment of electron spin, which can only be indirectly influenced by an electric field. In contrast, orbital magnetism can be directly controlled by an electric field, enabling faster and more energy-efficient operation. Rhombohedral-stacked multilayer graphene, with its flat electronic bands and concentrated Berry curvature, facilitates the spontaneous ordering of electron orbital motion, resulting in a pure carbon-based orbital magnet. In this study, we investigate orbital magnetism in rhombohedral graphene by measuring the anomalous Hall effect, a Hall effect observed in the absence of an external magnetic field. By applying an out-of-plane magnetic field, we observe a hysteretic Hall resistance loop, providing clear evidence of magnetic ordering. Given graphene's negligible spin-orbit coupling, this anomalous Hall effect must arise from the ordering of electron orbital motion. Remarkably, an out-of-plane electric field can effectively modulate the magnitude of the anomalous Hall effect and magnetic hysteresis loop, demonstrating the electric-field control of magnetism. This control arises from the coupling of the electric field to the electron wave function, underscoring the potential for fast, low-energy magnetic memory and computation applications.



Discrete Domain Switching in Scaled Amorphous Metal-Oxide Channel Ferroelectric FETs

5.04

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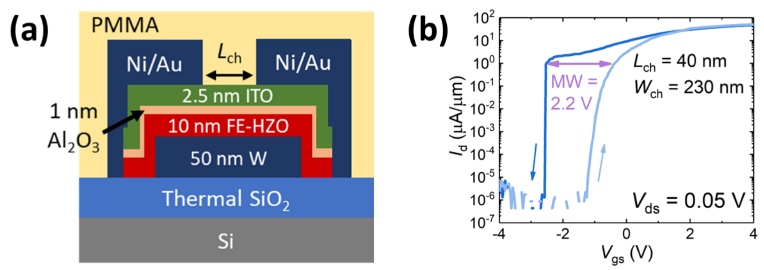
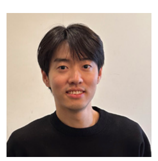
Research Interests:
2D materials, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, III-Vs, Light-emitting diodes, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Photovoltaics, Quantum devices.

Understanding domain structures and domain switching mechanisms in ferroelectric (FE) $Hf_{0.5}Zr_{0.5}O_2$ (HZO) is crucial for its applications in non-volatile memory and analog hardware. Probing the actual size of the elementary regions and mapping their individual polarization switching is challenging, but such information is highly valuable for HZO-based FE device design. In this work, we integrate FE-HZO in CMOS-compatible FE-FETs based on an amorphous oxide-semiconductor (AOS) channel. A large memory window of 2.2 V @ 1 μA/μm is achieved with a channel length of 30 nm. Discrete domain switching is observed in narrow devices with reproducible multi-level erasing/programming operations, whereas gradual switching is apparent in wider ones. Moreover, we show that discrete polarization switching acts as a sensitive probe to study intriguing physics in FE-FETs, such as FE fatigue. This work shows the rich engineering opportunities for AOS-based FE devices.



▲ Figure 1: (a) Schematic of our CMOS-compatible FE-FET. (b) Hysteretic transfer characteristics of a highly-scaled FE-FET.



Highly Sensitive Functionalization of CNFETs Chip Using Conductive Metal-organic Frameworks

5.05

J. Song, D.-H. Kim, J. Tiepelt, Y.-M. Jo, G. McGrath, M. Song, T. Chen, J. Wang, M. Shulaker, M. Dinca, M. Baldo

Sponsorship: Analog Devices Incorporated

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Research Interests:
Artificial Intelligence, Displays, Electronic devices, Machine Learning, MEMS & NEMS, Nanotechnology, Optoelectronics, Organic materials, Sensors.

Practical implementation of gas sensors for general tasks requires room temperature operation of an integrated chip. However, challenges such as integration of multiple sensors and the lack of statistical significance have limited their use in real-world settings.

Here, we present an integrated gas sensing chip comprising 2048 carbon nanotube field effect transistors, functionalized with conductive metal-organic frameworks and metal nanoparticles. Our functionalization method enhances sensor response by up to two orders of magnitude and enables on-chip pattern generation. Additionally, sensor redundancy validates statistical significance. The enhanced response is attributed to the combined effects of increased Schottky barrier height modulation and channel doping. We further demonstrate bacteria and yeast classification based on the gas mixtures generated from cultures grown on agar plates. This demonstration promises convenient, rapid, and cost-effective use of gas sensors for general tasks including medical applications.

Non-Toxic Solvent System for Ubiquitous Coatings of Perovskite Solar Cells

5.06

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Research Interests:
Electronic devices, Energy, Energy harvesting devices & systems, Optoelectronics, Organic materials, Photovoltaics.

Perovskite Solar Cells (PSCs) have the potential to greatly disrupt the solar landscape due to their lightweight form factors as well as their simple manufacturing process. Bottom-up analysis performed on flexible PSC photovoltaics using Monte-Carlo simulation methods shows that, at scale, flexible perovskite modules cost $0.19/W, compared to $0.30/W/module for crystalline silicon. This reduction in cost also requires the lifetime of these modules to only be around 13 years to reach similar LCOE levels, which is in direct contrast with the 25 years required for silicon. From an industrial scalability perspective, the additional air handling costs required to keep toxic solvents under the governmental guidelines for permissible exposure levels increase exponentially with factory capacity. A recent internal study shows that the air handling costs for a DMF-based system, a commonly used solvent in perovskite manufacturing, would account for up to 12.3% of the overall module cost, whereas a less toxic alternative, THF, would only account for about 0.6% of the module cost. However, because the perovskite community has not settled on one particular architecture or deposition technique, it is advantageous to develop a perovskite ink which can be used ubiquitously across device designs. Therefore, in this project we developed a non-toxic solvent system for perovskite manufacturing which can be applied to both PIN and NIP architectures and two different thin film deposition techniques for the SnO_2 ETL in NIP. Thus far we have been able to demonstrate up to 15% power conversion efficiency (PCE) for the archetypical fully slot-die coated NIP stack and greater than 10% PCE for the slot-die coated PIN architecture and chemical bath deposited (CBD) SnO_2. These results demonstrate the first non-toxic ink able to be ubiquitously applied to three different solar cell stacks, and the first scalable demonstration of coating perovskite on an underlying layer grown by CBD.

Systematic Study of Dielectric Materials for GaN MISHEMTs

5.07

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Sponsorship: U. S. Army Research Office (ARO) and AFOSR

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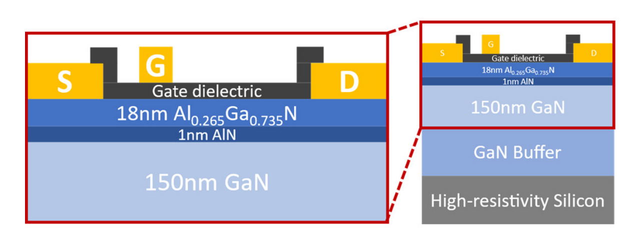
Research Interests:
Electronic devices, Nanotechnology, Photonics, Quantum devices, Spintronics.

Gallium nitride (GaN) heterojunction high-electron-mobility-transistors (HEMTs) are promising candidates for next-generation high-frequency and power electronics due to their superior performance characteristics. While Schottky-gate HEMTs are the current standard for lateral GaN transistors, metal-insulator-semiconductor HEMTs (MISHEMTs) are attractive due to their high on/off ratio and low gate leakage current. A comprehensive review of different insulators is necessary to identify the optimal gate dielectric material for GaN MISHEMTs. In this study, we cover a wide range of insulators, including conventional oxides (SiO2, Al2O3), high-k dielectrics (HfO2, ZrO2), and nitrides (SiNx, AlN), comparing their impact on device characteristics such as gate leakage, threshold voltage shift, and interface quality. By fabricating and measuring hundreds of MISHEMTs, we can systematically evaluate the feasibility of these dielectrics for GaN MISHEMTs.



Dielectric	Deposition technique	t_{ox} (nm)
AlN	PEALD	18
SiN_x	PECVD	18
Al_2O_3	Thermal ALD	15
Al_2O_3	PEALD	18
SiO_2	PECVD	18
HfO_2	PEALD	18
ZrO_2	PEALD	15

▲ Figure 1: Device diagram (enlarged on the left). Source and drain are alloyed metal contacts. Table: Deposition technique and thicknesses of gate dielectrics. PEALD – Plasma Enhanced Atomic Layer Deposition. PECVD – Plasma Enhanced Chemical Vapor Deposition.

Singlet Fission Sensitized Planar Silicon Solar Cells

5.10

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Sponsorship: DOE Materials Chemistry Program and NSF Graduate Research Fellowship

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Research Interests:
Electronic devices, Electronics, Energy, Optoelectronics, Organic materials, Photovoltaics, Si.

Integrating singlet fission materials with silicon solar cells presents a pathway to surpassing the Shockley-Quiesser power conversion efficiency limit for single-junction solar cells. Singlet fission is a spin-allowed process in which one high energy singlet exciton is converted into two lower energy triplet excitons. These triplet excitons can transfer to silicon in a solar cell, enabling external quantum efficiencies over 100% and increasing the photocurrent output for the same incident light. Previous work in our group demonstrated enhanced external quantum efficiency in devices employing tetracene as the singlet fission material and zinc phthalocyanine as a charge transfer layer on silicon microwire cells, a geometry optimized to reduce reflection losses. In this work, we focus on a planar silicon system to further study and optimize the interface between singlet fission materials and silicon for efficient triplet exciton transfer. We examine new singlet fission materials such as rubrene, which introduces an uphill triplet exciton transfer to silicon, as well as more stable tetracene derivatives. Another key consideration is silicon surface passivation: the oxide layer must be thick enough to reduce surface recombination losses but also thin enough to allow efficient triplet transfer from the singlet fission material. This study contributes insights into the interface engineering required to leverage singlet fission in planar silicon solar cells towards the development of high-efficiency photovoltaic devices.

Reconfigurable Two-dimensional Floating Gate Field-effect Transistors for Highly Integrated Electronic Devices

5.11

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Research Interests:
2D materials, Electronic devices.

Recently, machine learning applications, such as artificial intelligence, neuromorphic computing, and autonomous vehicles, have attracted extensive attention. However, the von Neumann architecture consisting of the separated parts of data processing and data storage has a weakness in real-time processing and consumes large power. Therefore, there is needed for energy-efficient electronic hardware that needs no data transport between logic and memory units. In this regard, two-dimensional (2D) materials are considered promising candidates for logic-in-memory devices. Owing to the atomic thickness and electrostatic controllability, the conductance of 2D field-effect transistors (FETs) can be precisely modulated so that they can be used for reconfigurable logic circuits.

Here, we demonstrate reconfigurable floating gate FETs (FG-FETs) that are composed of entirely 2D materials. By using WSe_2 as an ambipolar channel, one single device can exhibit programmable multiple operations of not only transistor mode with n- and p-type polarity control but also memory mode of on and off states. The inverters and circuits based on the WSe_2 FG-FETs show multi-functionality in logic operation with high performance and low power consumption. Our work highlights the great potential of atomically thin semiconductors FG-FETs as necessary components in next-generation electronics.

Materials Study of Flip-Processed Nitrogen-Polar GaN HEMTs

5.12

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Sponsorship: SRC Jump 2.0 SUPREME

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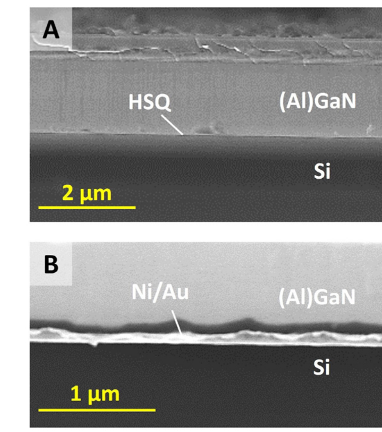
Electronic devices, GaN, III-Vs, Lasers, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Photovoltaics, Sensors, Si, SiGe and Ge.

GaN high electron mobility transistors (HEMTs) are the leading technology for high-power and high-frequency applications thanks to the high breakdown voltages and high electron saturation velocity of GaN. Utilizing wafer bonding, flip processing, and Si substrate removal, we demonstrate a technology for making N-polar devices from Ga-polar GaN-on-Si heteroepitaxy, which provides the flexibility to create innovative gate designs for greater electrostatic control. Here we present an in-depth study of this technology and the resulting N-polar AlGaN/GaN structure. Specifically, we investigate the adhesion between GaN and Si bonded with a hydrogen silsesquioxane (HSQ) interlayer and included back gate metal, looking at thermal compressive bonding variables and particle inclusions in the HSQ layer. Applying this technology for the fabrication of multichannel devices offers a path towards high current densities with superior gate control compared to previously demonstrated architectures.

▶ Figure 1: SEM cross-sections of (A) the bonding interface between the Ga-face GaN and the Si mechanical wafer, and (B) the bonding interface with the included Ni-Au gate metal.



Hafnium-Zirconium-Oxide Ferroelectric Materials for Advanced Logic and Memory Technologies

5.13

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Sponsorship: Research Laboratory of Electronics

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Research Interests:
Artificial Intelligence, Electronic devices, Electronics, Integrated circuits, Machine Learning, Nanomanufacturing, Nanotechnology, Spintronics, Systems.,

Ferroelectric materials as insulating gate stacks in field-effect transistors (FETs) present promising solutions for energy-efficient logic and high-bandwidth memory applications. In negative capacitance field-effect transistors (NC-FETs), the integration of carefully designed ferroelectric-antiferroelectric materials into the gate stack can reduce the effective oxide thickness (EOT) without conventional transport penalties, which thereby lowers the operating voltage and enhances the performance in logic circuits. For memory applications, ferroelectric gate stacks, due to their voltage-tunable polarization state, enable energy-efficient, fast-switching, high-density, high-endurance non-volatile storage in ferroelectric field-effect transistors (FeFETs). Our approach employs hafnium-zirconium-oxide (HZO) -- the same dielectrics used in today's logic transistors and DRAM capacitors -- deposited via atomic layer deposition (ALD) for 3D-conformality, wafer-scale uniformity, and low-temperature processing, which helps accelerate the lab-to-fab translation of ferroelectric technology into prototyping and high-volume manufacturing semiconductor foundries.

Towards a Ferroelectric High Electron Mobility Transistor for Memory Applications

5.14

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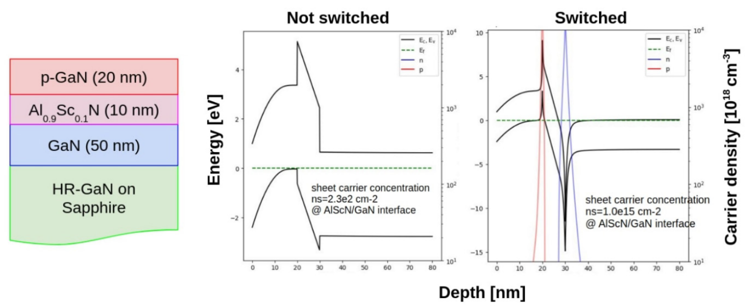
Available from January 2029.

The development of ferroelectric high electron mobility transistors (FeHEMTs) presents a compelling pathway for memory applications. However, current demonstrated devices exhibit limited polarization switching capabilities, a critical feature for memory functionality. This challenge underscores the necessity for further advancements in FeHEMT design.

In this work, I used 1D Poisson simulation software to explore gate stack configurations suitable for a p-type FeHEMT (pFeHEMT) that depletes the two-dimensional electron gas (2DEG) at zero bias. This design strategy aims to achieve an enhancement-mode (E-mode) FeHEMT device controllable by polarization switching, supporting memory-like operation. Following simulation, I attempted device fabrication, but encountered significant challenges with achieving robust ohmic contacts to the 2DEG and demonstrating reliable polarization switching. These issues highlight critical areas for future research.



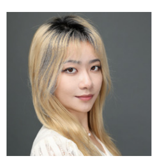
▲ Figure 1: (a) Gate stack design. (b) 1D Poisson band structure simulation showing E-mode behavior and switching capability.

Photon-Assisted Quantum Tunneling in Two-Dimensional NiI2/hBN Heterostructures

5.15

J. Li, R. Comin

Sponsorship: National Science Foundation under Grant No. DMR-2405560



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Research Interests:
2D materials, Electronic devices, Electronics, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Quantum devices, Spintronics.

Quantum tunneling plays a fundamental role in modern physics and technology. Understanding the intricate relationships between quantum tunneling, light, and magnetic ordering expands the frontiers of quantum physics. Here, we demonstrate photon-assisted quantum tunneling in NiI2/hBN heterostructures in the two-dimensional material NiI2. Our measurements reveal a remarkable ten-fold enhancement in tunneling current through the junction at specific photon energies during the multiferroic phase (low-T) compared to the non-multiferroic phase (high-T).

This phenomenon suggests a complex interplay between photonic excitation, multiferroic ordering, and electron tunneling dynamics. Our findings open new possibilities for controlling quantum tunneling through light-matter interactions in multiferroic systems, and paving the way for integration of photonic, spintronic, and electronic quantum devices.

High Temperature RF GaN electronics

5.16

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Sponsorship: Sponsorship: AFOSR (Grant No. FA9550-22-1-0367)

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Research Interests:
Electronic devices, Electronics, Energy, Energy harvesting devices & systems, GaN, III-Vs, Integrated circuits, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Quantum devices, Thermal structures, devices & systems.

High temperature electronics has received much interest recently due to emerging applications in geothermal well exploration, hypersonic flight electronics, and space exploration. GaN based devices are an exciting contender for extremely high temperature environments due to their high mobility, high saturation velocity, especially beyond 250°C, which is the limit of traditional silicon-based devices. In this project we aim to develop a high performing GaN based RF devices that operates at both room temperature as well as 500°C, by developing highly scaled, high temperature refractory tungsten T-gates with AlN gate dielectric that has record current density at 500°C. Such high temperature ready devices will allow high performing RF communication systems operating in the extreme conditions needed to enable the aforementioned applications.

Negative Differential Transconductance Device based on the WSe_2 / WTe_2 Heterojunction

5.17

H. Ahn, J. Kim

Sponsorship: Global Value Innovation Creator (GVIC)

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Research Interests:
2D materials, Electronic devices, Integrated circuits, Nanomaterials.

In the big data era, businesses based on AI and IoT are generating huge amounts of data, and a tremendous amount of energy is consumed for data processing. However, it is predicted that current technologies based on Si CMOS cannot handle the rapid increase in power consumption needed for data processing. In these circumstances, Multi-valued Logic (MVL) circuits have attracted considerable attention because MVL circuits are capable of expressing more than two states ('0', '1', and '2'). Therefore, computers based on MVL circuits require fewer devices to handle the same amount of data, leading to lower power consumption.

Here, we demonstrate devices based on the tungsten diselenide/tungsten ditelluride (WSe_2/WTe_2) van der Waals heterostructure, featuring the negative differential transconductance (NDT) phenomenon. In this NDT device, the NDT phenomenon is realized by modulating the voltages between metal electrodes to control current flow. The proposed NDT devices are expected to enable lower power consumption.

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Research Interests:
2D materials, Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Power management, Quantum devices, Si, SiGe and Ge.

Dipole-Engineered Contacts to Two-Dimensional Semiconductors

5.18

A. S. Gupta, J. Zhu, Y.-R. Peng, J. Kong, T. Palacios

Sponsorship: Army Research Office

Power transistors for fast-switching, high-voltage applications require wide bandgaps to enable large breakdown fields. Emerging ultrawide-bandgap (UWBG) two-dimensional (2D) semiconductors such as hexagonal boron nitride (hBN) and 2D gallium nitride (GaN) have bandgaps above 5 eV and are expected to provide better performance than current WBG semiconductors thanks to their higher critical fields and atomic thinness. However, forming low-resistance contacts to UWBG 2D materials is challenging due to their extreme energy band misalignment with conventional metal contacts and the Fermi level pinning effect, which both contribute to large Schottky barrier heights (SBHs).

Here, we propose using dipoles to reduce the SBH. Inserting a material with an appropriate built-in electric field at the contact interface will enhance carrier injection from the metal to the 2D channel. In this work, we study contacts to MoS_2 with MoSSe, a so-called "Janus" 2D material, which has vertical asymmetry and therefore an inherent dipole. We demonstrate higher current density in Janus 2D material contacts than in conventional MoS_2 contacts to bilayer MoS_2 transistors, confirming the positive impact of dipole-tuned contacts. Future work will focus on contact materials with stronger dipoles, as well as wider bandgap channel materials such as hBN and 2D GaN. Overall, this work is a step towards forming ohmic contacts with WBG and UWBG 2D materials, thus enabling the next generation of power electronic devices with higher operation voltage as well as future integrated circuits with increased functionalities.

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Research Interests:
Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology, Si.

Lateral GaN Superjunction Diodes through Si-ion Implantation into p-GaN

5.20

M. Oh, J. Perozek, Z. Biegler, J. S. Speck, and T. Palacios

Sponsorship: Advanced Research Projects Agency-Energy (ARPA-E)

Gallium Nitride (GaN) based power devices have significantly advanced semiconductor technology thanks to the unique properties of GaN, including a wide bandgap, high breakdown field, and excellent carrier mobility and saturation velocity. A promising device concept in this area is the GaN superjunction diode, which improves electrical performance by incorporating alternating p-type and n-type regions with equal numbers of acceptors and donors, ensuring no net space charge in the fully depleted drift region in reverse bias. This structure enables overcoming the material's tradeoff between on-resistance and breakdown voltage, resulting in faster switching speeds, lower power losses, and enhanced high-voltage operation.

Various methods, including p-GaN regrowth techniques and Mg-ion implantation into n-type GaN, can create these advanced diodes. In this work, we used Si-ion implantation into p-type GaN due to its easier process and dopant activation. Six Si-ion implantations were conducted on 250 nm p-GaN ([Mg] = 1×1019 cm-3) grown by NH3-MBE on a sapphire substrate, creating an interdigitated n-GaN region with a box Si profile, with a concentration of 2×1019 cm-3 and a depth of 250 nm. A 30 sec N2 annealing at 1200 °C was performed with a 200 nm sputtered AlN protection layer to heal lattice damage and activate the Si dopants. A 30 nm Ni/40 nm Au stack was e-beam evaporated and annealed at 550 °C for 30 mins in N2/O2 for p-type ohmic contact, and a 20 nm Ti/100 nm Al/25 nm Ni/50 nm Au metal stack was e-beam evaporated and annealed at 850 °C for 30 s in N2 for n-type ohmic contact.

Hall measurements confirmed successful p-to-n conversion in the implanted region, and TLM results indicated ohmic behavior from both p and n-type contacts. Baseline diodes showed typical pn diode behavior, with a forward voltage of 8 V and a breakdown of 78.5 V. Superjunction diodes showed noticeable enhancement in breakdown voltage, with a maximum value of 176 V; however, this effect was limited in devices with narrower finger widths, and large leakage currents were observed before breakdown. Simulation results suggested that narrowing the finger widths can improve both the leakage current and the breakdown voltage of superjunction diodes.

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Anomalous Hall Effect and Superconductivity in BN-aligned Magic-angle Twisted Bilayer Graphene

5.21

S. V. Rao, A. L. Sharpe, T. Iwasaki, D. Kumawat, L. A. Benitez, K. Watanabe, T. Taniguchi, P. Jarillo-Herrero

Sponsorship: Department of Defense

Magic-angle twisted bilayer graphene (MATBG) hosts many exotic electronic states due to its combination of strong electron-electron correlations and band topology. Results published in 2019 reveal that MATBG, when tuned to a charge carrier density of 3 electrons per moiré cell (ν=+3), exhibits a quantum anomalous Hall effect, but not the canonical superconducting state typically observed near ν=+2. These results are likely explained by the added moiré potential of an aligned BN which breaks inversion symmetry, gapping the otherwise protected Dirac cones of MATBG.

Using atomic force microscopy-based techniques, we verify BN alignment in a MATBG heterostructure prior to device fabrication. Subsequent transport measurements of a fabricated device reveal an anomalous Hall effect when filling 1 electron or hole per moiré cell (ν=±1). The anomalous Hall signal is comparable in both fillings, in contrast to earlier studies showing a strong particle-hole asymmetry. Additionally, we find hints of superconductivity near ν=2 despite the BN-induced inversion symmetry breaking, suggesting superconductivity and the quantum anomalous Hall effect might coexist in the same device. These findings contribute to a deeper understanding of stabilizing Chern bands in mesoscopic moiré systems, a critical step toward realizing novel fractional Chern insulator states that can serve as platforms for topological quantum computing.

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Research Interests:
2D materials, Electronics, Lasers, Optoelectronics, Photonics, Quantum devices.

AFM-Based Alignment of MATBG with hBN

5.22

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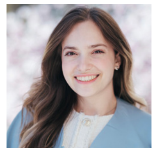
Sponsorship: Department of Defense

In van der Waals heterostructures, two adjacent layers with similar lattice constants and a small angle alignment create a large length-scale moire pattern, changing periodically as the atoms modulate in and out of registry. When two moire patterns are overlaid, a larger supermoire can emerge. This supermoire pattern may be relevant in magic-angle twisted bilayer graphene (MATBG) aligned with hexagonal boron nitride (hBN), where it is possible to observe a quantum anomalous hall effect (QAHE) instead of the canonical superconducting phase. Recent theory papers suggest that quantization relies on the percolation of a well-defined non-zero Chern number throughout the sample, arising precisely when the two moire patterns are commensurate. However, crystal alignment between MATBG and hBN layers at precise angles close to zero degrees is challenging, requiring the identification of crystallographic edges as armchair- or zigzag-type cleavages. We use lateral force microscopy (LFM) techniques to determine the crystal orientation with high precision. We then use torsional force microscopy (TFM) to analyze the supermoire formed by the moire patterns. By constructing devices with well-characterized stacks, we aim to connect the supermoire length scale back to stable Chern insulators in MATBG. Partially filled Chern insulator bands in such moire systems have been suggested to host fractional quasiparticles, which are candidate platforms for topological quantum computation.



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Testing the Hypothesized Iodine Redox Cycle in Illuminated P-I-N Metal-Halide Perovskite Solar Cells Under Illumination

5.24

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Sponsorship: DOE ADDEPT Center

Photovoltaic (PV) cells made from metal-halide perovskites have several advantages over traditional silicon solar cells, including higher efficiency potential, lower production costs, and the ability to be lightweight and flexible. These qualities make them a promising option for next-generation solar energy technology. However, the adoption of perovskite devices has been hindered by their anomalous transient and degradation behavior, which is caused by "ion migration" under external factors like voltage and light. In a recent paper from a collaborator at the ADDEPT center, Prof. Barry Rand summarized emerging research that reveals how photochemical and Faradaic reactions provide a continuous source of migrating ions, offering new insights into the underlying processes of ion migration.

In this work, we run experiments aiming to test the validity of said insights and processes of ion migration taking place within the metal-halide perovskite devices through the use of ICP (Inductively Coupled Plasma) and XRF (X-ray Fluorescence) Spectroscopy.

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Research Interests:
2D materials.

Clean and Open-Surface Graphene on hBN Enabled by a Flip-hBN Method

5.25

W. Xu, T. Han, Z. Wu, S. Ye, L. Ju

The fabrication of clean and open-surface graphene on hexagonal boron nitride (hBN) performs much better than that on silicon dioxide because the mobility is larger. It holds the potential to unlock a variety of high-performance applications, including scanning tunneling microscopy (STM) measurements and other sensitive techniques. However, conventional methods often require extra steps, such as annealing or AFM scratching, which can damage the sample and even change the special order like moire or rhombohedral stackings. In this work, we demonstrate a novel flip-hBN transfer method that enables the monolithic fabrication of pristine graphene on hBN without polymer contamination.

Using this method, hBN is first picked up with a half-polymer layer, next is pickup of graphene. The stack is then transferred onto a similar half-polymer layer before being transferred onto the final silicon chip. This process avoids direct polymer contact with the sample, preserving its cleanliness and structural integrity.

This work represents a significant advancement in the fabrication of clean graphene-hBN systems, made the possibility for scalable production of high-quality samples. The combination of cleanliness, stability, and enhanced mobility makes this method a promising platform for next-generation applications in nanoscale characterization, high-performance electronics, and beyond.

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Research Interests:
2D materials, Artificial Intelligence, Electronic devices, Integrated circuits, Machine Learning, Nanotechnology, Device simulation and modeling.

High-performance Multi-channel MoS_2 Transistors for Front-end-of-line Integration Beyond 1 nm Node

5.26

A. Yao, J. Zhu, Y. Jiao, A.S. Gupta, J. Kong, T. Palacios

Sponsorship: SRC Jump 2.0 SUPREME Center

Front-end-of-line (FEOL) integration of transistors based on two-dimensional (2D) materials, e.g., molybdenum disulfide (MoS2), provide exciting opportunities for device scaling by leveraging the unique material properties of 2D materials, e.g., atomic channel thickness, large band gap, to ensure excellent gate modulation and minimum leakage. The advancements of two-dimensional (2D) materials-based microelectronics have sparked notable efforts for both industry and academic research of novel 2D front-end-of-line (FEOL) device structures such as Gate-All-Around (GAA), stacked nanosheets, multi-channel transistors (MCT), and multi-fin transistors. However, functional multi-channel transistors (2 or more channels) have not been demonstrated, and sacrificial layers (SALs) or suspended structures are also required in previous fabrication flows, which could lead to potential damage and contaminations and more complexity in the fabrication.

Here, we demonstrated double-gate, single-channel MoS_2 transistors based on a novel reduced lithography step, low-temperature, high-quality MoS_2 synthesis. These devices demonstrate a high on-current (I_{ON}) of 386 μA/μm at V_{DS}=1 V, a subthreshold swing (SS) of 85 mV/dec and low drain-induced-barrier-lowering (DIBL) of 28 mV/V, showcasing record performance among 2D GAA transistors and MCTs. Additionally, we presented the first high-performance, functional 2-channel MoS_2 transistor, which achieves 673 μA/μm I_{ON} and 88 mV/dec SS at a channel length (L_{ch}) of 400 nm. Further with design-technology co-optimization (DTCO) analysis, our studies enable projections of 2D MCT scaling, addressing power and performance demands for the "1 nm" technology node and beyond.

Session 6: Medical Devices & Biotechnology

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Research Interests:
BioMEMS, Electronics, Medical devices & systems.

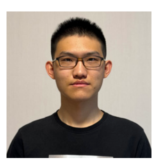
New NMR Probe Configurations for Spectroscopy and Relaxometry of Moving Fluids

6.01

H. Gaensbauer, A. Bevacqua, D. H. Park, J. Han

Sponsorship: Singapore MIT Alliance for Research and Technology, CAMP IRG

Nuclear Magnetic Resonance (NMR) spectroscopy and relaxometry are widely used and well-established techniques that can detect and identify chemical compounds in samples with significant background. Because NMR measurements are nondestructive, they have many applications in industrial process control, where they can be used to track reaction progress, detect contaminants, and provide insight into the quality of the product being produced. However, movement of the sample through the NMR system during the experiment reduces the resolution of NMR spectroscopy and confounds NMR relaxometry measurements. This makes it difficult or impossible to use NMR to continuously monitor flowing fluids in industrial settings, especially when the flow rate is variable or unknown. In this work, we present an RF coil geometry that produces NMR measurements that are completely insensitive to the flow behavior of the sample. We show that these coils can be designed for different ranges of flow rates and demonstrate in-line monitoring of a commercial dairy sample over a period of several hours. These coils enable in-line high resolution spectroscopy and relaxometry for process monitoring applications without needing to control or even know the flow rate, making it possible to retrofit state-of-the-art NMR systems for continuous quality control on a wide range of biomanufacturing and industrial processes that would traditionally require regular invasive sampling.



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Research Interests:
Artificial Intelligence, Biological devices & systems.

Predicting Artifacts and Seizures from EEG Data using Pretrained Foundation Models

6.03

D. Liu, T. I. Ponir

Sponsorship: MIT Media Lab Nano-cybernetic Biotrek Group

EEG (electroencephalography), a technique for measuring electrical activity in the brain via electrodes placed on the scalp, is commonly applied for diagnosing neurological disorders, monitoring brain health, and understanding cognitive processes such as sleep, attention, and memory. However, analyzing EEG data can be difficult due to its high dimensionality, low signal-to-noise ratio, and the need for expert interpretation. This study explores the application of pretrained foundation models in analyzing EEG data to detect artifacts, predict seizure events, and automate report generation. Using a series of tailored prompts, we are trying to fine-tune a model pipeline to distinguish between noise and seizure activity in real-time EEG recordings. By leveraging the rich representational power of foundation models, our approach has the potential to reduce the need for extensive labeled data and significantly improve the generalizability of the model. Furthermore, we aim to enable report generation capabilities based on input prompts, which offers an efficient method for synthesizing EEG analysis into comprehensive, clinician-friendly summaries.

System Prototype for Electromagnetic Breast Cancer Detection

6.04

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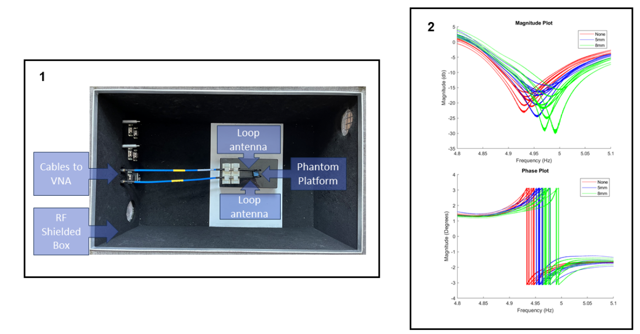
Research Interests:
Communications, Electronics, Integrated circuits, Medical devices & systems.

Breast cancer detection is ideally quick, accurate, and comfortable. An emerging technology to fill the gaps in current diagnostic methods is microwave imaging, which sends and receives microwave signals through the breast in order to detect tumors of various sizes. This method has potential for a more comfortable patient experience at a lower cost than the current standards in breast cancer imaging.

In this work, a prototype system is developed for determining tumor size in breast tissue by utilizing microwave imaging techniques. The system consists of RF shielding components, custom loop antennas, and a vector network analyzer for signal generation and data collection. Additionally, post processing is completed by a ML algorithm to classify tumor sizes. By sending and receiving signals in the GHz range, this system can detect and distinguish between tumors of varying sizes on the millimeter scale within breast phantoms.



▲ Figure 1: 1. System overview 2. Transmission coefficient of various tumor sizes

Surface Patch Coils and Pulse Sequences for Noninvasive Blood Tests Using Magnetic Resonance

6.05

A. Huang, H. Gaensbauer, J. Han

Sponsorship: MIT Research and Innovation Scholars Program, MIT Lincoln Labs

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Traditional blood tests for diseases such as malaria and diabetes require drawing blood, which is painful and time-consuming. Our lab has shown that magnetic resonance (MR) relaxometry can be used to perform these blood tests electromagnetically, opening the door to contact-free, noninvasive diagnostic blood tests. While our low-cost, gradient-free MR systems have been demonstrated in vitro, they have not yet been demonstrated in vivo, due to the movement of blood in the body and the chaotic tissue signal background. In this work, we demonstrate the use of custom surface coils designed for blood signal detection with standard time-of-flight MR pulse sequences to isolate signals from blood and compensate for the blood flow velocity. We go on to perform relaxometry measurements in a model of a human arm. This brings us one step closer to noninvasive blood monitoring with low-cost equipment.

Fiberscope: A Miniature Microscope for Behavioral Fluorescence Observation in Mice

6.08

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Research Interests:
Biological devices & systems, Electronic devices, Electronics, Integrated circuits, Medical devices & systems, Optoelectronics, Sensors, Systems.

Neural activity can be observed through fluorescence microscopy using GCaMP7s-expressing neurons. Traditional fluorescence microscopy, while effective for observing neural activity, is limited to stationary mice, restricting behavioral studies. To study neural activity during specific behaviors, a miniaturized and lightweight system is required, one that can be mounted on a mouse's head without causing a burden. Mice can carry a maximum load of 2.5 g, whereas existing systems are typically only suitable for rats, which can carry loads exceeding 10 g.

In this work, we propose a lightweight system with fluorescence excitation capabilities and wireless imaging to record neural activity in freely moving mice. This system allows for the tracking of single-neuron activity during behavioral experiments with wireless programming capabilities, eliminating the need to shorten behavioral sessions. This tool thus opens new possibilities for studying neural activity in mice under naturalistic conditions.

Prediction of Onset of Action Potentials in Spontaneous Neuron Firings

6.10

S. Yadav, A. Das, M.T. Islam, P. Patel, D. Sarkar

Sponsorship: MIT Media Lab start-up funding

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Research Interests:
2D materials, Biological devices & systems, BioMEMS, Molecular & polymeric materials, Nanomaterials, Nanotechnology, Optoelectronics, Organic materials, Photovoltaics, Sensors.

Precise control of neural activity is crucial for advancing our understanding of brain function and developing therapeutic interventions for neurological disorders. This study presents a novel approach for predicting the onset of action potentials (APs) in spontaneous neuron firings, with potential applications in closed-loop neural inhibition systems.

We employed patch-clamp electrophysiology to record live data from individual neurons and employed real-time short-time Fourier transform (STFT) algorithm for signal processing. Multiple machine learning models were then applied to the transformed data to predict AP onset. Our best-performing model achieved an accuracy exceeding 80% with a latency of more than 100 microseconds.

This predictive capability opens new avenues for the development of closed-loop neural inhibition systems. When combined with existing technologies such as optogenetics or electrical stimulation devices, our approach could enable precise temporal control of neural activity. Such control has implications for both basic neuroscience research and potential therapeutic applications in conditions characterized by aberrant neural firing patterns.

Highly Integrated Graphene-based Chemical Sensing Platform for Structural Monitoring Applications

6.11

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Sponsorship: Ferrovial

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Research Interests:
2D materials, Artificial Intelligence, Electronic devices, Electronics, Energy, Machine Learning, Medical devices & systems, MEMS & NEMS, Nanomaterials, Nanotechnology, Sensors, Spintronics, Density Functional Theory.

Two-dimensional materials, such as graphene, hold promise for sensing applications. Graphene's remarkable surface-to-volume ratio, when employed as a transducer, enables the sensor channel to be readily modulated in response to chemical changes in proximity to its surface, effectively converting chemical signals into the electrical domain. However, their utilization has been constrained due to variations in device-to-device performance arising from synthesis and fabrication processes.

To address this challenge, we employ Graphene Field Effect Transistors (GFETs) in developing a robust and multiplexed chemical sensing array comprising tens of sensing units. This array is coupled with custom-designed high-speed readout electronics for structural monitoring applications.

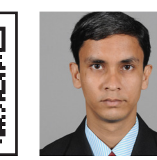
For example, in harsh environmental conditions, structures constructed from reinforced concrete may experience degradation due to corrosion, a chemical process initiated by carbonation and significant fluctuations in temperature and humidity. Under normal conditions, concrete maintains a pH level within the alkaline range of 13 to 14. However, when subjected to carbonation, its pH decreases to values between 8 and 9.

Our platform excels in real-time pH monitoring. By conducting I-V sweep measurements in the sensor channel, we have established a correlation between [H+] concentration and the gate-source voltage (Vgs) at graphene's Dirac point with an accuracy of roughly 98%. This system and correlation allows for the prompt detection of any deviations induced by corrosion within a concrete environment.

Stimuli-responsive Nanodevices for Application in Tissue Regeneration

6.12

M. Saha, D. Sarkar



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Research Interests:
Electronic devices, Medical devices & systems, Nanomaterials Organic materials.

Nanoscale electric fields play a crucial role in modulating the electrophysiological properties of excitable tissues, offering promising therapeutic interventions for various pathophysiological conditions. This bioelectric manipulation can address multiple disease models, including neurodegenerative disorders, cardiac arrhythmias, tissue regeneration, and certain cancers. This work demonstrates the fabrication of magneto restrictive-piezoelectric core-shell nanodevices (MPCND) capable of generating nanoscale electric fields with a tunable parameter upon application of external magnetic fields. This study showed the potential of MPCNDs to interact with cellular components and stimulate them to proliferate. MPCNDs unconditionally increase cell division around the destroyed regions of tissue and fill up the damaged region. This treatment significantly increased colony formation and cellular proliferation in the wound healing assay. Detailed mechanistic investigations explain a novel mechanism of wound healing by increasing growth factors or other bioactive molecules that stimulate specific cellular processes like angiogenesis (new blood vessel formation) and collagen production upon stimulating the MPCND remotely. MPCND's ability to transform low-frequency magnetic fields into localized electric fields provides benefits including wireless treatment with deep tissue penetration, minimal invasiveness, and reduced off-target effects, addressing key limitations of current electro-therapies. These advantages, coupled with its diverse cellular proliferation mechanisms, highlight MPCND's potential as a minimally invasive wound healing treatment with promising translational prospects for human applications.

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Research Interests:
Biological devices & systems, Electronic devices, Medical devices & systems, Microfluidic devices & systems, Systems.

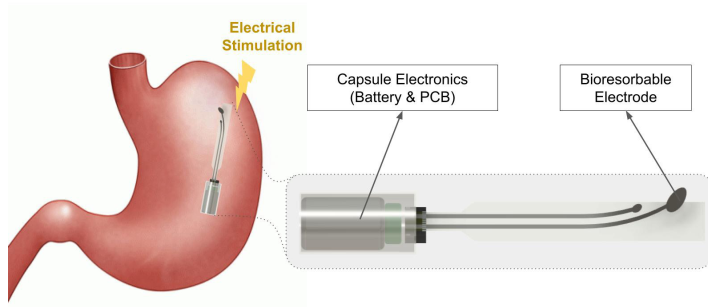
Ingestible Gastric Electrical Stimulation System Using Bioresorbable Electromechanical Systems

6.13

A. O. Erus, M. G. Say, I. Moon, G. Traverso

Sponsorship: ARPA-H

The gut-brain axis, a bidirectional communication network between the gastrointestinal (GI) tract and the central nervous system, regulates various physiological functions via neurohormonal signaling. Electrical stimulation of the GI tract can modulate hormone release, offering therapeutic potential. However, current gastric electrical stimulation (GES) systems require invasive surgery for implantation and removal. To address this limitation, we developed an ingestible GES system composed of a bioresorbable electrode array integrated with capsule-based electronics. The bioresorbable substrate and thin film metal are chosen for their low dissolution rate and high mechanical strength. The electrodes are fabricated using laser systems, offering a faster, cost-effective alternative to traditional photolithography. In vitro testing, including dissolution, stress-strain, and impedance assessments, demonstrates the system's viability, supporting its potential for non-invasive GES.



▲ Simplified schematic of gastric electrical stimulation system (not to scale) in the stomach

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Research Interests:
Biological devices & systems, BioMEMS, Microfluidic devices & systems.

Continuous Adeno-associated Virus (AAV) Production System Using Inertial Microfluidic device

6.14

D. H. Park, A. Ucher, R. Kotin, S. Cecchini, J. Han

Sponsorship: FDA program

Adeno-associated virus (AAV)-based gene therapies have enabled transformative treatments for rare genetic disorders by delivering therapeutic genes that produce essential proteins to correct genetic defects. Since the FDA's first approval of AAV therapy (Luxturna) in 2017, significant efforts have focused on developing gene therapies for various conditions. However, low productivity limits these therapies' accessibility and increases costs. We present a perfusion culture system utilizing an inertial microfluidic cell retention device to culture HEK-293 cells at high densities for efficient AAV production. This system minimizes product loss while supporting high-density cell growth, enhancing AAV yields. We anticipate that this inertial microfluidic-based perfusion culture system will benefit the biopharmaceutical industry by increasing the manufacturing throughput of AAV therapies while lowering associated costs.

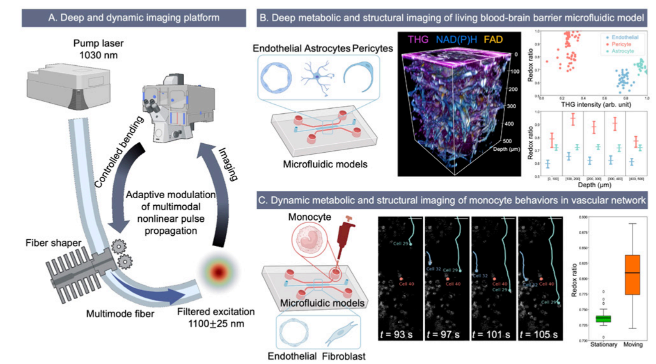
Deep and Dynamic Metabolic and Structural Imaging in Living Tissues

6.15

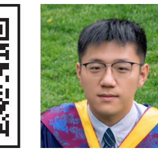
K. Liu, H. Cao, R. Kamm, L. Griffith, F. Wang, T. Qiu, S. You

Sponsorship: Mathworks Fellowship

Label-free imaging through two-photon autofluorescence (2PAF) of NAD(P)H allows for non-destructive and high-resolution visualization of cellular activities in living systems. However, its application to thick tissues and organoids has been restricted by its limited penetration depth, largely due to tissue scattering at the typical excitation wavelength required for NAD(P)H. Here, we demonstrate that the imaging depth for NAD(P)H can be extended to over 700 μm in living engineered human multicellular microtissues by adopting multimode fiber (MMF)-based low-repetition-rate high peak-power three-photon (3P) excitation of NAD(P)H at 1100 nm. This is achieved by having over 0.5 MW peak power at the band of 1100±25 nm through adaptively modulating multimodal nonlinear pulse propagation with a compact fiber shaper. Moreover, the 8-fold increase in pulse energy enables faster imaging of monocyte behaviors in the living multicellular models. These results represent an advance for deep and dynamic imaging of intact living biosystems. The modular design is anticipated to allow wide adoption for demanding in vivo and in vitro imaging applications, including cancer research, autoimmune diseases, and tissue engineering.



◀ Figure 1: (a) Deep and dynamic imaging platform. (b) Deep imaging over the entire depth of 500 μm in the living human blood-brain barrier microfluidic model. (c) Dynamic imaging of monocyte trafficking in vascular network.



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Research Interests:
Biological devices & systems, Machine Learning, Medical devices & systems, Photonics.

Session 7: Nanoscience & Nanotechnology

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Research Interests:
2D materials, Nanomaterials, Photonics, Photovoltaics, Spintronics.

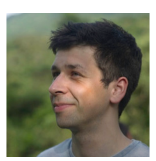
Optical Detection of Proximity Effect Between WSe_2 and Multiferroic Helimagnet NiI_2

7.02

M. Shankar, Q. Song, R. Comin

Sponsorship: National Science Foundation (DMR-2405560) and Peskoff Physics Fellowship

Magnetic proximity effects have been widely investigated in layered heterostructures to imprint the properties of one material to be detected on the other. In many cases, studying the proximity effect of a magnetic material on another material can reveal properties about the former that are not otherwise straightforward to detect. NiI_2 is a type-II multiferroic that exhibits a simultaneous ferroelectric and non-collinear helimagnetic transition at $T_N = 59.5$ K, where the spin helix has propagation vector q = (0.138, 0, 1.457) RLU. It exhibits strong optical linear dichroism related to the ferroelectric transition, but direct optical detection methods of the chirality of the spin helix, which is coupled to the direction of the ferroelectric polarization, have remained elusive. Monolayer WSe_2 is effective for studying a variety of optical phenomena due to its direct band-gap and spin-valley locking, namely exhibiting very strong photoluminescence; thus, putting it in proximity to NiI_2 enables additional optical techniques to interpret properties of the latter. In this study, we report circular dichroism in the photoluminescence of a monolayer WSe_2 and NiI2 heterostructure that switches sign upon reversing the electric polarization of the NiI_2. We attribute the dichroism to the type-II band alignment of the semiconductor-insulator interface and the spin-polarized momentum splitting of the NiI_2 bands along the direction of the spin helix. In addition, we compare the reflective circular dichroism of the heterostructure to the reflective magnetic circular dichroism (RMCD) of the isolated WSe_2 monolayer to estimate the magnitude of the magnetic proximity effect. These results demonstrate a novel optical detection method of magnetic chirality switching in an odd-parity multiferroic, expanding the methods to distinguish symmetry breaking phenomena in unconventional magnetic systems.



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Solid State Solar Energy Storage from Persistently Luminescent Solar Concentrators

7.03

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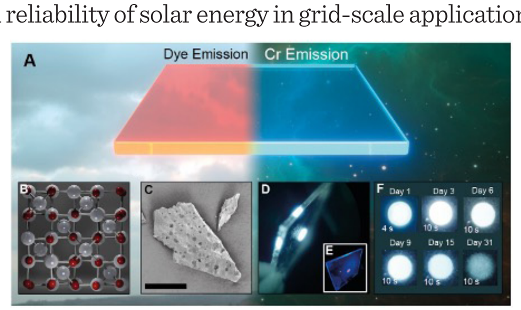
Sponsorship: Schmidt Science Fellowship, Lindemann Trust Fellowship

The remarkable reduction in the levelized cost of energy (LCOE) for solar power has meant that photovoltaics have become increasingly competitive with fossil fuels, yet challenges remain in achieving the widespread adoption necessary to meet global climate targets. One of the primary barriers is the inherent variability of photovoltaic (PV) output, driven by short-term fluctuations in environmental conditions, which undermine the output stability and predictability required in energy markets that rely on spot pricing. We propose an alternative approach to stabilize solar output by artificially delaying the photon flux incident on conventional solar cells using persistently luminescent chromophores within solar concentrator devices. This approach aims to smooth the output power with minimal impact on overall efficiency, providing a pathway to enhance the economic viability and reliability of solar energy in grid-scale applications.



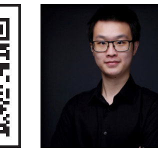
▲ Figure 1: **A** - Cartoon depiction of the two emission modes. Dye emission under bright conditions and long lifetime emission from Cr. **B** – Structure of long-lived emissive crystal determined from XRD. A single unit cell of $Zn_3GaGe_2O_8$, where Zn, Ga and Ge are shown in grey, O is shown in red. Thermal parameters were refined by element and are not shown to scale. **C** - Indicative SEM image of particles. Scale bar is X um. **D** 10 by 10 cm PLSC device photographed 1 hour after illumination in dark conditions in the IR with **E** inset a photo at visible wavelengths under blue illumination. **F** Active area photographed in the IR for a period of a month after illumination with different integration times inset.

Probing Operational Degradation Mechanism on Cd-free Red and Blue QD-quantum Dot LEDs

7.05

R. Zhang, V. Bulović

Sponsorship: Samsung Electronics and MIT 2024 Mathworks Fellowship



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With a variety of emerging display products like AR/VR, smart watch, etc., high quality display materials are required. Cadmium-free colloidal quantum dots have been reported as promising candidates in quantum dot light-emitting diodes (QD-LEDs) due to their tunable optical properties, quantum confinement effects and scale-up capability. However, comparing to the high operational lifetime of red and green QD-LEDs counterparts, the blue QD-LEDs offer a much lower operation lifetime. In this work, we probe the operation degradation mechanisms on both InP/ZnSe/ZnS (red) and ZnSe(Te)/ZnSe/ZnS (blue) QD-LEDs from a perspective of nanoscale device morphology and interlayer elemental tracing. A coarsening and thinning phenomenon is observed in both quantum dots and Mg-doped zinc oxide nanoparticles (ZnMgO NPs) layers after red QD-LED LT-50 aging and blue QD-LED LT-70 aging. An extra oxygen peak shows up in the InP/ZnSe QD layer after biasing the device, where the compositional oxygen level enhances at the Al electrode / ZnMgO NPs junction. Additionally, our findings indicate that long-time high-dose electron beam irradiation contributes to the coarsening of the ZnMgO NP layer, and the presence of hydrogen significantly accelerates the coarsening process under electron beam exposure. This study reveals the morphological thinning and particle coarsening in the electron transporting layer (ETL) and active layer after diode aging, establishing a framework for understanding QD-LED degradation mechanisms during operation.

Spatially-Adaptive Solid-State OPA-Based LiDAR

7.06

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Sponsorship: SRC JUMP 2.0 CogniSense, MIT Rolf G. Locher Endowed Fellowship, and NSF Graduate Research Fellowship

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Research Interests:
Communications, Displays, Electronic devices, Electronics, III-Vs, Integrated circuits, Lasers, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors, Systems, Transducers.

Superconducting nanowire single photon detectors (SNSPDs) provide sensitive, highly efficient detection out into the mid-infrared, suitable for low-signal applications like exoplanet search, quantum networking, and biomedical imaging. However, the physics of these devices is surprisingly complex, and the detection mechanism is not well understood. In this work, we study dark fluctuations in niobium nitride nanowires of various lengths and widths and compare the fluctuation rates to various models of the underlying mechanism. We evaluate whether it is more appropriate to attribute these fluctuations to one-dimensional phase slips or two-dimensional vortices activated by either flux entry or a topological phase transition. We also consider the role of external noise sources such as blackbody radiation or current source noise.

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Research Interests:
2D materials, Electronic devices, Electronics, Integrated circuits, Nanomaterials, Nanotechnology.

Sliding Ferroelectric Memory Based on Rhombohedral-stacked Molybdenum Disulfide

7.07

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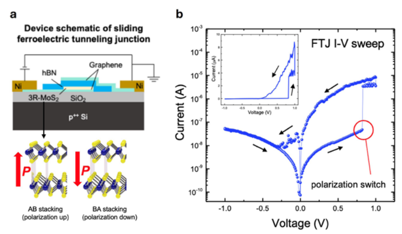
Sponsorship: MIT Lincoln Laboratory through the Advanced Concepts Committee

Ferroelectric memory has been regarded promising for future in-memory computing electronics. However, existing ferroelectric materials tend to require large switching voltages and are challenging to scale down while maintaining ferroelectric polarization. To tackle this issue, sliding ferroelectricity is a novel mechanism observed in certain 2D materials like bilayer hexagonal boron nitride (hBN) and transition metal dichalcogenides (TMDs), where polarization switching is driven by the lateral sliding of atomic layers. This type of ferroelectricity offers ultra-thin, stable polarization at the atomic level, supporting lower power requirements and improved scalability. This unique switching behavior enables faster switching speeds and fatigue-resistant performance, addressing key limitations of traditional ferroelectrics. These characteristics make sliding ferroelectrics especially promising for next-generation non-volatile memory and energy-efficient electronic devices. In our study, we fabricated a prototype ferroelectric tunnel junction (FTJ) based on sliding ferroelectricity in rhombohedral-stacked bilayer MoS_2 (3R-MoS_2), grown through chemical vapor deposition (CVD). We demonstrate that ferroelectric polarization switching in 3R-MoS_2 can be triggered by an external electric field, resulting in a distinct change in current levels in the device. This critical feature enables reliable memory functionality in 3R-MoS_2 FTJs. Furthermore, our devices show excellent retention in performance tests, highlighting their potential for long-term data storage. Our findings underscore sliding ferroelectricity in 3R-MoS_2 as a promising approach for robust, high-performance memory solutions in advanced electronics.



◄ (a) Top, two different stacking configurations of bilayer 3R-MoS_2, corresponding to the polarization up and down state, respectively. Bottom, cross-sectional schematic of a sliding ferroelectric tunneling junction. (b) Representative I-V curves of our 3R-MoS_2 FTJ, where the switching occurs at about 0.7 V. The inset shows the linear scale of the curve.

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Research Interests:
III-Vs, Medical devices & systems, Optoelectronics, Photonics, Si.

Graphene-assisted Spontaneous Relaxation for Dislocation-free Heteroepitaxy of III-Vs on Si

7.08

D. A Kwon, K. Lu, N. M. Han, J. Kim

Sponsorship: DARPA M-STUDIO

Epitaxial thin film heterostructures are promising for monolithic integration of highly lattice-mismatched systems. Although homoepitaxy was adopted to produce high-quality epitaxial films, it is limited to a narrow range of materials. To overcome this limitation, heteroepitaxy has been widely investigated; however, it often leads to strain energy accumulation, producing dislocations that degrade device performance. Here, I describe the innovative approach introduced by Bae et al. They introduce a novel heteroepitaxial film growth technique using a graphene interlayer on the substrate. This interlayer effectively relaxes misfit strain by facilitating interface sliding between epilayers that realizes spontaneous relaxation of accumulated elastic energy without generating misfit dislocations. Furthermore, successful exfoliation of epitaxial overlayers grown on graphene nanopatterns broadens the range of materials that can be integrated, which offers new opportunities for hetero-integrated semiconductor applications.

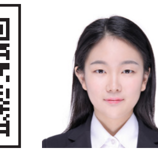
High-throughput Manufacturing of Ultrathin Epitaxial Membranes Towards Cooling-free Infrared Detection

7.10

X. Zhang, O. Ericksen, S. Lee, M. Akl, M-K. Song, H. Lan, J. M. Suh, S. Lindemann, J-E. Ryu, X. Zheng, N. M. Han, B. Bhatia, H. Kim, H. S. Kum, C. S. Chang, Y. Shi, C-B. Eom, J. Kim

Sponsorship: AFOSR

Recent breakthroughs in ultrathin, single-crystalline, freestanding complex oxide systems have sparked industry interest in their potential for next-generation commercial electronic and optoelectronic devices. However, the mass production of these ultrathin complex oxide membranes has been hindered by the challenging requirement of inserting an artificial release layer between the epilayers and substrates. Here, we introduce a revolutionary technique that achieves atomic precision lift-off of ultrathin membranes without artificial release layers. This innovation facilitates the high-throughput production of scalable, ultrathin, freestanding perovskite systems. Leveraging both theoretical insights and empirical evidence, we have identified the pivotal role of lead in weakening the interface. This insight has led to the creation of a universal exfoliation strategy that enables the production of diverse ultrathin perovskite membranes below 10 nm. This technique has significant potential in applications. As an example, our pyroelectric membranes demonstrate a record high pyroelectric coefficient, attributed to their exceptionally low thickness and freestanding nature. Moreover, this method offers a groundbreaking approach to manufacturing cooling-free detectors capable of covering the full far-infrared spectrum, marking a significant advancement in detector technology.



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Research Interests:
Electronic devices, Nanomaterials, Sensors.

On-site Growth of Perovskite Nanocrystal Arrays for Integrated Nanodevices

7.11

P. Jastrzebska-Perfect, W. Zhu, M. Saravanapavanantham, Z. Li, S.O. Spector, R. Brenes, P.F. Satterthwaite, R. Ram, F. Niroui

Sponsorship: National Science Foundation

Known for their superior optoelectronic properties, halide perovskites have been utilized to realize applications such as solar cells, light-emitting diodes, memristors, and single photon-sources. However, integrating halide perovskites in nanoscale devices has remained challenging, given the chemical incompatibilities of these materials with conventional lithographic processing techniques. Here, we introduce a bottom-up approach for precise and scalable formation of perovskite nanocrystals and their integration into functional nanodevices. Our approach uses topographical templates with asymmetric surface wettability to guide the site-selective growth of the perovskite nanocrystals. With this platform, we demonstrate arrays of $CsPbBr_3$ nanocrystals with tunable dimensions down to < 50 nm and placement accuracy < 50 nm. We further apply our approach to develop nanoscale light-emitting diodes (nanoLEDs), highlighting the potential this platform offers for enabling on-chip perovskite nanodevices.

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Research Interests:
Biological devices & systems, Electronic devices, Medical devices & systems, Nanomaterials, Nanotechnology, Optoelectronics.

Non-epitaxial Growth of Aligned Transition Metal Dichalcogenides at Low Temperature for Silicon Back-end-of-line Integration

7.12

D. Lee, K. Kim, S. Seo, J. Shin, H. Ahn, J. Kim

Sponsorship: Samsung

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Research Interests:
2D materials, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, GaN, III-Vs, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Spintronics.

Two-dimensional (2D) transition metal dichalcogenides (TMDs) have been highlighted as a channel material for next generation electronics beyond Moore's law. However, their integration with conventional silicon technology has been a critical hurdle to commercialization because of their high growth temperature.

In previous work, we reported non-epitaxial growth of single-crystalline TMDs below (BEOL) temperature limit by non-epitaxial confined growth method. In that work, although the grown material is single crystal, each domain orientation was random, potentially increasing device-to-device variation due to random channel direction.

In this work, we demonstrate non-epitaxial growth of aligned WSe_2 at low temperature using triangle shaped trench. WSe_2 was nucleated at the corner of triangle trench and their orientation was measured by atomic resolution atomic force microscope (ARAFM). The results confirm that the domains at each corner of triangle trench are aligned with each other, implying that the growth of single-crystalline 2D films on amorphous substrate could be realized with further optimization.

Optimizing Contact Resistance of GaN p-FET Devices for CMOS Applications

7.13

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Sponsorship: Lincoln Laboratory

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Research Interests:
GaN, III-Vs.

Gallium nitride (GaN) transistors have a much higher break-down voltage, switching frequency, and maximum operating temperature than their silicon (Si) counterparts. However, because GaN transistors are largely limited in performance by the Si gate driver and other ancillary chips, GaN transistors need to be integrated with GaN driver chips to fully realize their energy efficiency in power electronics applications and high-temperature environments. The most energy-efficient architecture for integrated circuits and drivers is complementary metal oxide semiconductor (CMOS) circuitry, which requires n-type field effect transistors (n-FETs) and p-type field effect transistors (p-FETs). While GaN n-FETs have been widely demonstrated, GaN p-FETs are traditionally difficult to fabricate with good performance and integrate into CMOS circuits.

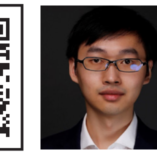
A primary source behind the current density limitations of a GaN p-FET device is the high contact resistance. Prior work in the Palacios group at the Massachusetts Institute of Technology (MIT) has shown record GaN p-FET performance; however, these devices are still largely limited by the contacts. In this project, we will explore different deposition methods and metals for achieving low contact resistance on GaN p-FETs. Ultimately, this work on improving contact resistance of GaN p-FETs will enable a fully integrated GaN-based CMOS platform.

Electrical Double Layer Force Enabled Wafer-scale Transfer of Van der Waals Materials

7.14

X. Zheng, J. Wang, J. Jiang, T. Zhang, J. Zhu, T. Dang, P. Wu, A. Lu, D. Chen, T. H. Yang, X. Zhang, K. Zhang, K. Y. Ma, Z. Wang, Y. Hsieh, V. Bulović, T. Palacios, J. Kong

Sponsorship: US Army Research Office and Air Force Office of Scientific Research (AFOSR) Multi-University Research Initiative



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The transfer and integration of van der Waals (vdW) materials to target substrates is critical to their applications in high-end electronics, optics, moiré electronics, etc. The transfer step typically requires the use of either chemical etchants, electrochemical bubbling, or mechanical strain to detach vdW materials from growth substrate. However, these approaches often have issues regarding contamination, degradation of vdW materials or damage of growth substrates (adding significant cost to the manufacturing process, especially for single crystalline substrates). In this work, we present an electrical double layer (EDL) force enabled transfer method that is etching-free, fast, highly reliable and widely applicable to various types of substrates (e.g., oxide, nitride, etc.) and materials (e.g., carbon nanotube, MoS_2, h-BN, etc.). The unique strategy is to leverage the negative zeta potential of both the substrate and the vdW material in concentrated ammonia solution. With the formation of the EDL, the vdW material is repelled from the substrate by the strong EDL repulsion force. The as-transferred vdW materials show minimized wrinkles, cracks, contaminations, and other transfer-induced defects. The MoS_2 field effect transistors fabricated with EDL transfer show 100% yield, near-zero hysteresis (7 mV) and near-ideal subthreshold swing (65.9 mV/dec), evidencing an ultra-clean interface and minimized damage. The combination of EDL transfer and bismuth contact further enables an ultra-high on-current of 1.3 mA/μm. This EDL transfer approach offers a facile and manufacturing-viable solution for vdW material integration, which will significantly advance the future development of atomically thin electronics.

Localized and Uniform Strain Engineering of 2D Materials for Optical and Electrical Devices

7.15

S. O. Spector, W. Zhu, F. Niroui

Sponsorship: NSF Graduate Research Fellowship

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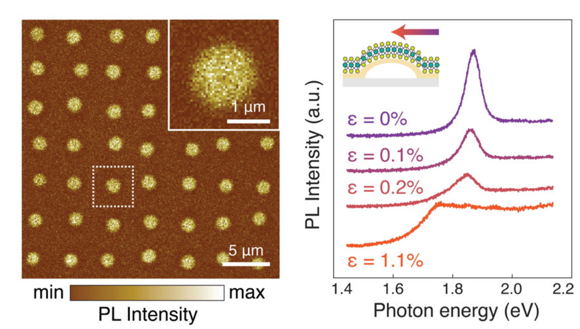
Research Interests:
Electronic devices, MEMS & NEMS, Nanomaterials, Nanotechnology.

Owing to their atomic nature, 2D materials are highly sensitive to lattice perturbations. This enables the use of strain to sensitively engineer their electronic, optical, and magnetic properties, leading to applications in enhanced transistors, sensors, quantum light sources, and memory devices. Despite its promise, strain engineering of 2D materials can be challenging to implement, with current methods often introducing damage to the 2D material while lacking wafer-scale processability and nanoscale precision.

In this work, we introduce a directed bottom-up approach using our nonplanar nanofabrication platform to strain 2D materials precisely and at scale. With our platform, we can achieve localized and uniform straining of a 2D layer, avoiding the common formation of bubbles, wrinkles and tears. We demonstrate controlled straining of monolayer MoS_2 via photoluminescence mapping and Raman spectroscopy, paving the way for enhanced photodetectors, transistors, and tunable light sources.



◄ Figure 1: Left: Photoluminescence (PL) intensity map of periodically strained MoS_2, with a single strain structure at inset. Right: By comparing the PL spectra at a flat vs. maximally strained location of MoS_2, 1.1% tensile strain at the dome apex is shown.

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2D materials, Artificial Intelligence, Electronics, Lasers, Machine Learning, Nanomaterials, Photonics.

Domain-controlled Growth of Two-dimensional Tin Selenide

7.16

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Sponsorship: DOE Basic Energy Sciences under Award

Two-dimensional (2D) van der Waals (vdW) layered materials have become a hot research topic in the fields of condensed matter physics and materials science due to their unique low-dimensional crystal structures and physical properties. 2D tin selenide (SnSe) is a vdW layered material with a strong spontaneous ferroelectric polarization and second-order nonlinear optical response, whose ferroelectric properties and second-order nonlinear optical characteristics are enhanced in its ferroelectric-stacking (FE-stacking) phase, a metastable phase at room temperature. Large-sized ultrathin 2D SnSe crystals have been synthesized via a physical vapor deposition (PVD) approach, but the control of FE-stacking and domain distribution remains a challenge.

In this work, the domain control of 2D SnSe is preliminarily achieved by growth condition modulation and substrate engineering. A PVD growth recipe for 2D SnSe is optimized, that yields the most FE-stacking phase crystals, and a dependence of domain distribution density on substrate condition is identified. A pre-annealing treatment of the mica substrate in air not only improves the 2D SnSe samples' size and distribution on substrate, but also promotes the synthesis of samples with dense FE-stacking domains. The next step is to apply an electric field to the 2D SnSe material during PVD growth, which modulates the energy of the FE-stacking metastable phase compared to the stable phase, providing a possible pathway to achieve the controlled growth of FE-stacking 2D SnSe.

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2D materials, Artificial Intelligence, Biological devices & systems, Electronic devices, Electronics, Integrated circuits, Machine Learning, Medical devices & systems, MEMS & NEMS, Microfluidic devices & systems, Nanomanufacturing, Nanomaterials, Nanotechnology, Sensors.

Hydrogen Gas Detection with MoS_2-based Chemical Sensing Platform

7.18

C. -H. Liu, J. Zhu, C. Lopez Angeles, H. Feng, T. Swagger, J. Kong, T. Palacios

Sponsorship: Palacios Lab

Hydrogen is a promising candidate as a clean energy carrier for its high energy density, clean combustion byproduct, and versatile end use. However, its explosive nature calls for the need for rapid and accurate detection. Two dimensional (2D) materials are ideal candidates for such application thanks to their naturally surface-sensitive properties and large surface-to-volume ratio, providing high sensitivity towards the target gas.

In this work, we developed a field effect transistor-based sensor that employs functionalized molybdenum disulfide (MoS_2) as the channel material. Threshold voltage shift under hydrogen and surface functionalization of the MoS_2 to further enhance sensitivity are demonstrated. Thanks to the 8" low-temperature (< 400 °C) synthesis of high-quality MoS_2, the MoS_2 sensors can be further integrated into a robust sensing array in which each device can be functionalized with different sensing materials and combinations. Future work involves the development of a high-speed readout electronic circuit with a total processing speed below 1 second, establishing an integrated system that can perform rapid measurement, analysis, and real-time chemical recognition.

Signatures of Chiral Superconductivity in Rhombohedral Graphene

7.19

T. Han, Z. Lu, Y. Yao, L. Shi, J. Yang, J. Seo, S. Ye, Z Wu, M Zhou, H. Liu, G. Shi, Z. Hua, K. Watanabe, T. Taniguchi, P. Xiong, L. Fu, L. Ju

Sponsorship: DOE, NSF, NSF

Chiral superconductors are unconventional superconducting states that break time reversal symmetry spontaneously and typically feature Cooper pairing at non-zero angular momentum. Such states may host Majorana fermions and provide an important platform for topological physics research and fault-tolerant quantum computing. Despite intensive search and prolonged studies of several candidate systems, chiral superconductivity has remained elusive so far. Here we report the discovery of robust unconventional superconductivity in rhombohedral tetra-layer graphene. We observed two superconducting states in the gate-induced flat conduction bands with Tc up to 300 mK and charge density n_e as low as 2.4×10^{11} cm^{-2} in three different devices, where electrons reside close to a proximate WSe_2 layer, far away from WSe_2 and in the absence of WSe_2, respectively. Spontaneous time-reversal-symmetry-breaking (TRSB) due to electron's orbital motion is found, and several observations indicate the chiral nature of these superconducting states, including: 1. In the superconducting state, R_{xx} shows fluctuations at zero magnetic field and magnetic hysteresis in varying out-of-plane magnetic field $B_\perp$, which are absent from all other superconductors; 2. one superconducting state develops within a spin- and valley-polarized quarter-metal phase, and is robust against the neighboring spin-valley-polarized quarter-metal state under $B_\perp$; 3. the normal states show anomalous Hall signals at zero magnetic field and magnetic hysteresis. We also observed a critical $B_\perp$ > 0.9 T, higher than any graphene superconductivity reported so far and indicates a strong-coupling superconductivity close to the BCS-BEC (Bardeen-Cooper-Schrieffer - Bose–Einstein condensate) crossover. Our observations establish a pure carbon material for the study of topological superconductivity, and pave the way to explore Majorana modes and topological quantum computing.

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Research Interests:
2D materials, Nanomaterials, Nanotechnology, Optoelectronics

Highly Tunable Josephson Junction in Rhombohedral Graphene

7.20

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Sponsorship: NSF grant DMR-2225925

Rhombohedral graphene, with its unique electronic properties and flat-band structures, has emerged as a promising platform for exploring unconventional superconductivity. Recently, multiple superconducting states have been reported in the rhombohedral graphene system and each exhibits distinct properties that are potentially governed by its pairing symmetries. We observed an unconventional superconducting state in tetralayer rhombohedral graphene which is possibly p-wave superconductor. To investigate these pairing symmetries, we have designed a highly tunable in-plane Josephson junction, which offers precise control over the electric environment and coupling between superconducting regions. We use high precision electrode-free local anodic oxidization to separate the graphite gate so that we can tune the two superconducting regions independently. The gap region is created by atom force microscope, which can reach to less than 50nm wide. This device should serve as a powerful tool for probing the nature of the superconducting phases and their pairing symmetries.

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Molecular Probe Adsorption as a Technique to Elucidate Corona Phase Molecular Recognition (CoPhMoRe) through Structure Property Relationships

7.21

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Sponsorships: National Science Foundation Graduate Research Fellowship Program, Singapore-MIT Alliance for Research & Technology (SMART)

The nanoparticle corona—a molecular layer adsorbed on nanoparticle surfaces—is critical in controlling molecular interactions for applications in catalysis, separations, and sensing technologies like Corona Phase Molecular Recognition (CoPhMoRe). While tailoring the corona has enabled detection of diverse analytes, quantitatively characterizing it remains challenging. Here, we advance Molecular Probe Adsorption (MPA) to address this issue. MPA employs a fluorescent probe quenched upon adsorption to quantify the solvent-exposed surface area via adsorption isotherms. We use MPA to elucidate recognition mechanisms in various corona phases and expand the library by characterizing new CoPhMoRe constructs, enabling comprehensive comparative analyses. We further develop structure–property relationships linking MPA area to adsorption parameters. Additionally, we investigate how polymer stiffness, characterized by persistence length, influences corona formation on single-walled carbon nanotubes (SWCNTs). Contrary to the assumption that stiffer polymers enhance adsorption efficiency, our results indicate that more flexible polymers achieve greater surface coverage, offering new insights for optimizing polymer-based corona phases. We also tackle the inverse problem of predicting analyte binding affinities by integrating MPA with molecular dynamics simulations and thermodynamic modeling, demonstrating that computational CoPhMoRe screening is feasible. This integration paves the way for rational sensor design without extensive experimental screening. Our findings highlight MPA's utility in advancing nanomaterial-based sensing technologies through quantitative corona characterization and provide a framework for the rational design of selective nanosensors.

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Laser-induced Graphene Supercapacitors

7.22

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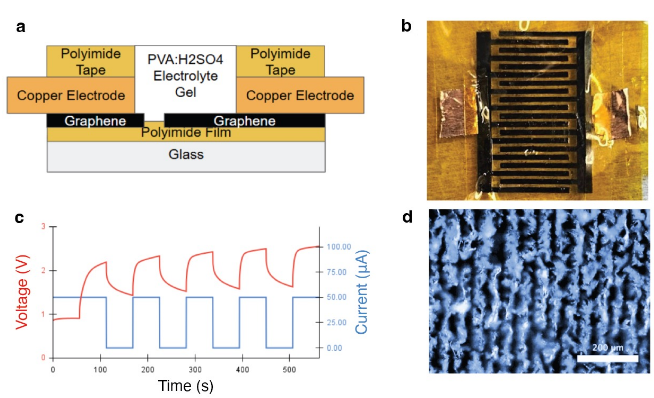
Sponsorship: MIT EECS, 6.2540 class

Supercapacitors, which demonstrate power densities comparable to those of batteries while providing fast charging and discharging capabilities, have gained favor in energy storage applications requiring fast power transfer, like electric vehicles or power grids. To achieve high capacitances, porous electrodes, which maximize electrolyte-electrode interaction, are utilized. For supercapacitors to be generally applied, scalable, repeatable, and cost-effective methods for fabricating such electrodes are required. Here, we demonstrate a method for manufacturing supercapacitors based on high surface area laser-induced graphene electrodes. We use a laser-based fabrication process that enables tuning of the electrode conductivity through empirically-determined power-conductivity relationships. Through optimization of laser power level, substrate choice, and details of the optical setup, we achieve devices with a specific capacitance of 0.7 mF/cm2. This approach provides an accessible and scalable method for manufacturing graphene supercapacitors.



◄ Figure 1: a) Illustration of the designed supercapacitor's cross section. b) Image of a working supercapacitor. c) Charge and discharge curves of a working capacitor when applying pulses of current. d) Microscope image of laser-induced graphene surface.

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Interface Circuits for Analog In-Memory Computing

8.01

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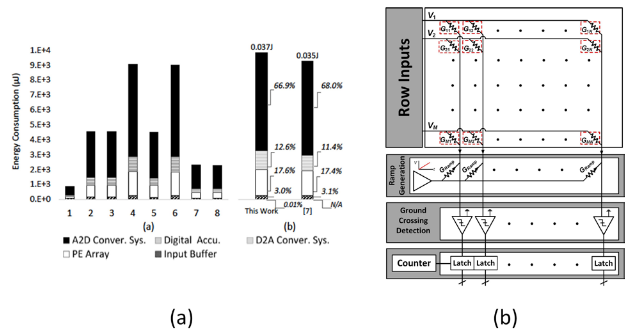
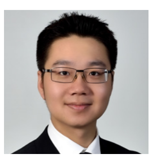
Sponsorship: MIT/MTL Samsung Semiconductor Research Fund

The increased adoption of machine learning (ML) in mobile devices demands high performance at low energy consumption. General purpose hardware is limited in speed and efficiency by the data movement between the memory and the processing unit. Alternatively, compute-in-memory (CIM) accelerators perform the required arithmetic by the integration of memory and processing elements to mitigate this problem. Analog CIM accelerators use voltage and current laws for the parallel generation and addition of partial sums, rapidly and efficiently. However, the read-out circuitry poses a substantial overhead in energy consumption. In this work, we propose single-slope an analog-to-digital converter with non-linear characteristics, which maintains the inference accuracy at a reduced number of bits, to leverage the statistical properties of partial sum outputs to optimize performance and efficiency. This will enable more widespread adoption of ML in more energy-constrained applications.



◄ Figure 1: (a) Energy breakdown in analog CIM systems (b) proposed single-slope analog to digital converter readout circuits for analog CIM



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Memory-Efficient Gaussian Mapping on Micro-Robots: Algorithm and Chip

8.02

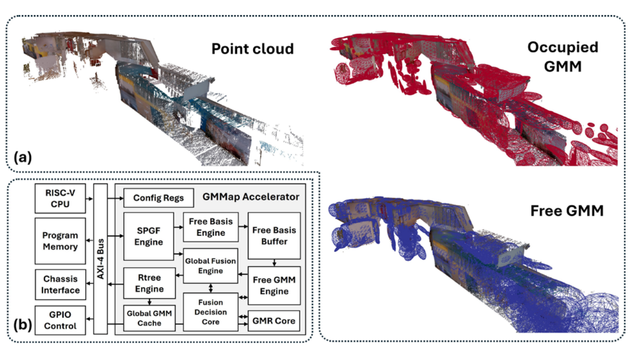
P. Z. X. Li, Z. S. Fu, K. Gupta, S. Karaman, V. Sze

Sponsorship: Amazon, MathWorks Fellowship and National Science Foundation CPS

Constructing a compact map of 3D environments in real-time is essential for enabling autonomy on energy-constrained robots. During construction, the memory usage is not limited to map storage, but also includes overheads for storing the sensor measurements and temporary variables. Prior works reduce the map size while incurring a large memory overhead (MBs) which increases energy consumption and limits throughput.

To reduce memory and energy, we present GMMap, a memory-efficient algorithm that compresses each depth image into Gaussians which are directly fused across multiple images to form a compact 3D map. Using a low-power ARM Cortex-A57 CPU, GMMap can be constructed in real-time with comparable accuracy as prior works while reducing the map size by at least 56%, memory overhead by at least 88%, and energy by at least 69%.

To further reduce energy, we present LEANC, a System-On-Chip with an accelerator for GMMap. On an FPGA, LEANC enables real-time 3D mapping using only milliwatts of power. Thus, LEANC not only enables autonomy on micro-robots but also illustrates the importance of memory-efficient algorithms and specialized hardware design for low-energy applications.



◄ Figure 1: (a) Visualization of the first floor of Stata Center, MIT, and its GMMap representation consisting of Gaussians representing occupied (red) and free (blue) regions. Each Gaussian is visualized as an ellipsoid in 3-D. (b) Hardware architecture of LEANC.

Memory-Efficient Gaussian Mapping on Micro-Robots: Algorithm and Chip

8.03

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Sponsorship: Amazon, MathWorks Fellowship and National Science Foundation CPS

Constructing a compact map of 3D environments in real-time is essential for enabling autonomy on energy-constrained robots. During construction, the memory usage is not limited to map storage, but also includes overheads for storing the sensor measurements and temporary variables. Prior works reduce the map size while incurring a large memory overhead (MBs) which increases energy consumption and limits throughput.

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Efficientvit-SAM: Accelerated Segment Anything Model without Performance Loss

8.05

Z. Zhang, H. Cai, S. Han

Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Segment Anything Model (SAM) has gained widespread recognition as a milestone in the field of computer vision, showcasing its exceptional performance and generalization in image segmentation. SAM defines image segmentation as a promptable task, that aims to generate a valid segmentation mask given any segmentation prompt. SAM has shown its high versatility in a wide range of downstream applications, including image in-painting, object tracking, and 3D generation. Nevertheless, SAM imposes significant computational costs, leading to high latency that restricts its practicality in time-sensitive scenarios and edge devices. In particular, SAM's main computation bottleneck is its image encoder, which requires 2973 GMACs per image at the inference time. To accelerate SAM, numerous efforts (MobileSAM, EdgeSAM, EfficientSAM) have been made to replace SAM's image encoder with lightweight models. While these methods reduce the computation cost, they all suffer from significant performance drops. We introduce EfficientViT-SAM to address this limitation by leveraging EfficientViT to replace SAM's image encoder. Meanwhile, we retain the lightweight prompt encoder and mask decoder architecture from SAM. Our training process consists of two phases. First, we train the image encoder of EfficientViT-SAM using SAM's image encoder as the teacher. Second, we train EfficientViT-SAM end-to-end on the whole SA-1B dataset. We thoroughly evaluate EfficientViT-SAM on a series of zero-shot benchmarks. EfficientViT-SAM provides a significant performance/efficiency boost over all prior SAM models. In particular, on the COCO dataset, EfficientViT-SAM achieves 48.9× higher throughput on A100 GPU without mAP drop compared with SAM-ViT-H. We believe that EfficientViT-SAM enables the segment anything technique to be widely applied in time-sensitive scenarios, such as autonomous driving and robotic manipulation, while also making it easily deployable on edge devices like mobile phones.

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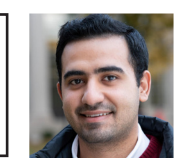
Low-Power and Miniaturized Medical Electronics for In-Vivo Localization and Tracking

8.07

S. Sharma, M. Shapiro, G. Traverso, A. Emami

Sponsorship: NSF, RI2, HMRI

Localization of medical devices inside the body is valuable for several areas—tracking pills in the GI tract, navigating precision surgeries, and guiding endovascular procedures. The current gold-standard solutions are invasive (endoscopy), use harmful X-ray radiation (CT scans), and require clinical evaluation. Here, we present a novel radiation-free system for high-precision 3D localization and tracking of miniaturized wireless devices *in-vivo*, using harmless magnetic field gradients. The gradients encode each spatial point with a distinct magnetic field magnitude, which is measured and transmitted by our wireless microdevices to help decode their location. We demonstrate *in-vivo* system functionality for different clinically-relevant applications.



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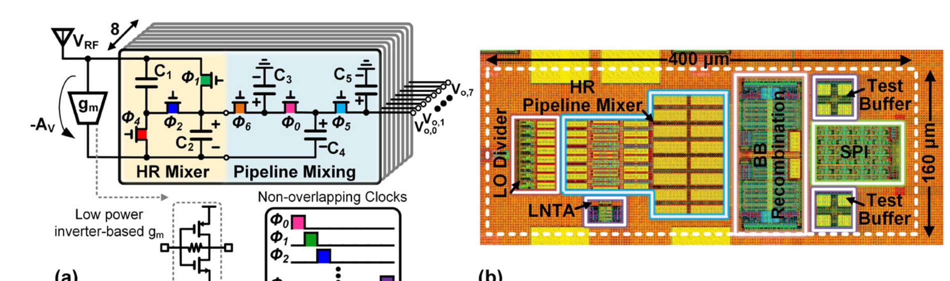
Harmonic-Resilient Low-Power Receiver Architecture with Pipeline Mixing for IoT Applications

8.07

S. Araei, M. Barzgari, and N. Reiskarimian

The rapid growth of Internet of Things (IoT) applications in wearable devices, smart homes, and healthcare demands receivers (RXs) that integrate seamlessly into this expanding network. Achieving low power consumption, high linearity, and wide tunability is crucial for efficient operation in the congested sub-7GHz frequency band. In this work, we present an RX topology tailored for IoT needs, featuring a harmonic-resilient N-path filter embedded within negative feedback to provide robust blocker protection for all active circuits. By leveraging the Miller effect, the proposed RX achieves a reduced capacitor area and minimal dynamic power consumption. Furthermore, the use of pipeline down-mixing eliminates the need for power-hungry baseband amplifiers, enabling passive gain in a low-noise manner. This RX topology consumes sub-mW power, relies solely on switches and capacitors, and is highly scalable, making it an ideal choice for battery-operated IoT devices.

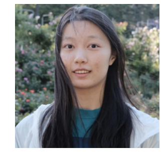


▲ Figure 1: (a) Block diagram of the proposed architecture (b) Chip Layout

A Sub-6GHz Configurable Receiver with High-Order Channel Selectivity and Harmonic Rejection

8.09

H. Yang, S. Araei, M. Barzgari, N. Reiskarimian



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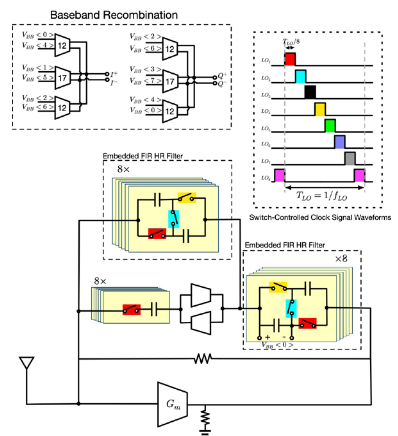
As the sub-6G spectrum becomes increasingly congested with applications such as 5G New Radio, Bluetooth, and wireless local-area networks (WLAN), it is crucial for receivers to exhibit sharp filtering and resilience against out-of-band interference, including both harmonic and close-in blockers. The mixer-first receiver is widely regarded as a competitive solution in this scenario, as its flexibility in carrier frequency and bandwidth also allows it to support multiple communication standards with a single device, such as software-defined radios (SDRs). Although conventional mixer-first receivers offer a surface acoustic wave-less, highly linear, and configurable design, they are vulnerable to harmonic blockers and exhibit a poor noise figure.

Our research proposes a robust sub-6G configurable receiver capable of tolerating both harmonic and close-in blockers. This resilience is achieved by integrating finite-impulse response (FIR) filters and a high-order feedback loop. As shown in Figure 1, the low-noise amplifier (LNA) with the feedback loop, generating two transmission zeros, functions as a high-order filter that effectively rejects close-in blockers. Meanwhile, the FIR filter, responsible for rejecting harmonic blockers, is embedded within this loop as a functional component of the transmission-zero structure. With the topology proposed, the receiver can achieve the high-order channel selectivity and harmonic rejection (HR) at the same time.

In this work, we present a configurable sub-6G receiver resilient to close-in and harmonic blockers, with a competitive noise figure (NF) and linearity, leveraging an N-path structure and making it suitable for wireless communication in interference-rich environments.



▲ Figure 1: Schematic of the proposed receiver.

An Analog Front End with Sparse-Image Capturing for Energy-Efficient Bladder Ultrasound Imaging

8.10

M. Manohara, S. Schoen, D. U. Yildirim, M. Perrot, P. Garcha, A. Samir, A. Bahai, A. P. Chandrakasan

Sponsorship: Texas Instruments

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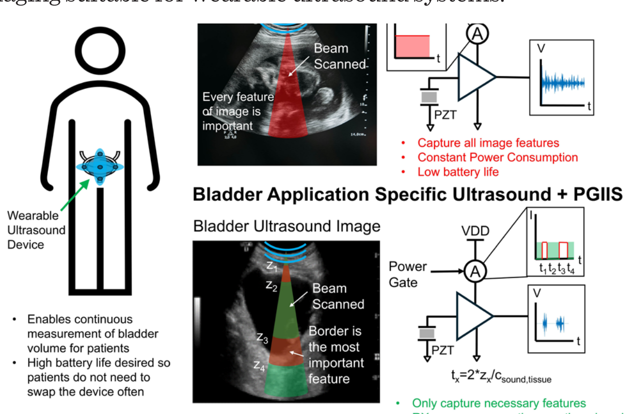
Artificial Intelligence, Communications, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, GaN, Information processing, Integrated circuits, Machine Learning.

Continuous bladder monitoring is important for patients unable to excrete their urine. One method for bladder volume calculation is capturing ultrasound images and utilizing image segmentation algorithms for bladder volume estimation. These algorithms typically search for the boundary of the bladder and ignore other regions of the image. In this work, we design an analog front end (AFE) utilizing an algorithm called Power Gating for Intra-Image Sparsity (PGIIS). This AFE simultaneously generates beamformed TX pulses and amplifies the RX signals with good signal-to-noise ratio. For each TX event, the PGIIS algorithm identifies time intervals corresponding to the bladder boundary and power-gates the RX amplifiers outside of these time intervals, generating a sparse image. The AFE was tested on a custom phantom with a bladder proxy. After calibration, the PGIIS algorithm demonstrated 75% power savings in RX amplification, enabling low-power imaging suitable for wearable ultrasound systems.



◄ Figure 1: Motivation for continuous bladder monitoring and motivation behind Power-Gating for Intra Image Sparsity algorithm.

Characterizing the Performance of Large-scale Superconducting Integrated Circuits

8.11

E. Golden and K. Berggren

Sponsorship: MIT Lincoln Laboratory

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Superconductor circuits can utilize Josephson junctions and nanowires to perform analog, digital, and quantum computation. Superconductor circuits have demonstrated the ability to perform logical operations with speeds and switching energies comparable to CMOS-based circuits. However, very few superconductor large-scale circuits with Josephson junctions have been demonstrated.

In this work, the feasibility of designing and manufacturing large-scale superconducting integrated circuits is evaluated. Measurements of Josephson junction-based circuit sensitivity, speed, and scalability are presented. These results are used to inform the design of large-scale circuits built in this technology.

A 28 GHz Coupled PLL-Based CMOS Quadrature Oscillator

8.12

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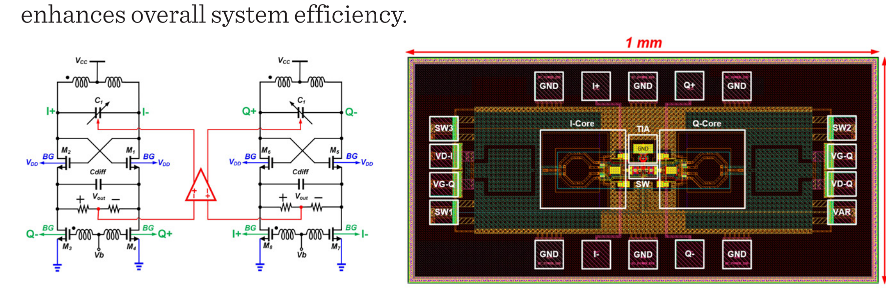
Research Interests:
Electronics, Integrated circuits.

One of the most critical challenges in RF and mm-wave transceivers for the further development of wireless communications is generating quadrature signals for receiver down-conversion. Quadrature voltage-controlled oscillators are among the most promising candidates for 5G/6G frequency bands due to their lower power consumption and reduced area. However, achieving a higher Figure-of-Merit (FoM) for the oscillator while maintaining perfect quadrature accuracy remains a significant challenge.

In this work, a coupled PLL-based approach for generating quadrature signals at the local oscillator (LO) is implemented and fabricated using 22nm fully depleted silicon-on-insulator (FDSOI) CMOS technology. In this approach, each oscillator serves as a reference for the other, and the entire structure functions as a type-II phase-locked loop (PLL). This topology relaxes the trade-off between phase noise and quadrature accuracy while achieving a high FoM. It not only improves the image rejection ratio in mm-wave transceivers but also enhances overall system efficiency.



▲ Figure 1: (a) Simplified schematic and (b) Chip Micrograph.

Design and Modeling of High Temperature Gallium Nitride RF Amplifiers 8.13

A. Goodnight, J. Niroula, M. Taylor, P. Yadav, T. Palacios

Sponsorship: AFOSR (Grant No. FA9550-22-1-0367) and NSF Graduate Research Fellowship

High temperature electronics play an important role in many applications such as space exploration, hypersonic flight, geothermal energy, and automotive industry. However, an RF circuit operating at 500°C has never been demonstrated, which, in part, is due to a lack of sufficient high temperature device modeling and process design kits (PDKs). Such frameworks are critical in designing robust circuits with high first pass yield as they enable accurate estimations of circuit performance and allow exploration of design space parameters.

Over the last couple years, our group has been developing and exercising a CAD framework of gallium nitride technologies. In this work, we expand upon this modeling effort, exploring the design space of high temperature GaN RF HEMTs. We use the MIT Virtual Source GaN FET (MVSG) model to predict the influence of temperatures from a wide temperature range on the electrical and RF device performance. Based on this model, we are developing a PDK for design optimization within industry-standard CAD tools such as Keysight ADS and Cadence. These device characterizations can then be used to investigate different amplifier topologies with a focus on the output power, efficiency, and linearity operating over a wide temperature range from 25°C to 500°C.

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Research Interests:
GaN.

Integrated System to Control and Measure Graphene Field Effect Transistor Arrays 8.14

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Sponsorship: NSF CIQM and NSF Convergence

Two-dimensional materials such as graphene have shown great promise as biochemical sensors. As a zero-bandgap material, graphene field effect transistors (GFETs) exhibit a Dirac point shift when different ions (i.e., dopants) come into contact with the transistor's channel. This shift can be observed from the GFET's I-V characteristics, enabling the detection of changes in chemical environment.

Our group has designed and fabricated a scalable, handheld chemical sensing system with 4096 sensing units, each consisting of a graphene field-effect transistor. While previous research has demonstrated the feasibility of ion detection with electrolyte-gated transistors [1] [2], we propose an integrated system that controls and measures both liquid-gated and gas-sensing transistors. Specifically, the custom-designed printed circuit board (PCB) enables extraction of the electrical characteristics of 4096 functional GFETs individually by multiplexing a single pair of drain and source connections to the measurement circuitry. This PCB facilitates automated, real-time analysis of data regardless of transistor quality, applied dopant, and sensing medium, advancing its potential for use as a portable biomedical diagnostic device.

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Defining and Optimizing Write/Clear Margin for a Nanoantenna-Based Petahertz Electronic Memory Cell 8.15

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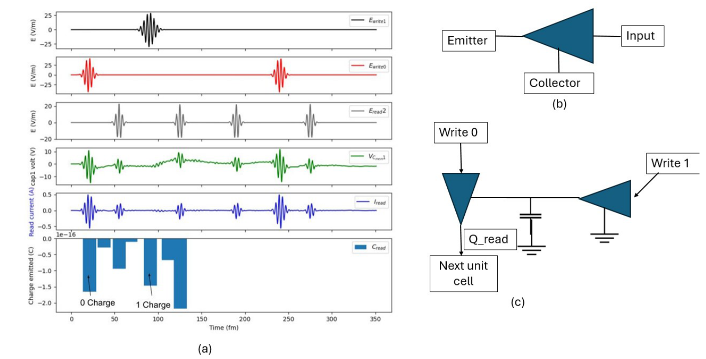
Sponsorship: MIT UROP, NSF, AFOSR

Nanoantennas leverage the unique properties of metallic nanostructures to enable tunneling of low-voltage currents. The compact and integrable design of the nanoantennas makes them a promising approach for realizing ultrafast electronic components. It is possible to construct complex structures using these nanoantennas. One possible structure is a memory cell. In this study, SPICE circuit models will be employed to explore and optimize various parameters, such as input intensity and input signal frequency, in an operational nanoantenna-based memory cell. Performance metrics will be defined and numerical techniques will be applied to refine these parameters, ensuring a robust and clear distinction between the 'write' and 'clear' states for reliable memory cell performance. Modelling the nanoantenna as a circuit component would take significantly less time than traditional physical simulations.



◄ Figure 1: The current model of the nanoantenna has indistinguishable write 1/0 as can be seen from (a). A simplified model of the nanoantenna component (b) can be used to create memory cells (c).

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Understanding the Relationship Between Environmental Control and Perovskite Formation, Performance and Stability 8.16

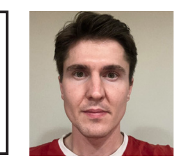
N. Evans, T. Liu, T. Buonassisi

Sponsorships: ADDEPT

To achieve perovskite solar cells with recipes that can transfer from lab-to-fab reproducibly and scale from spin-coating to meniscus coating methods, understanding the impact of environmental variables during the perovskite deposition and drying processes is imperative. These variables, namely the ambient temperature, humidity, solvent flow rate, vapor pressure, and resultant partial pressures, all affect the solvent evaporation rate and in turn the growth and formation of the perovskite. Therefore, in this study we aim to quantify and tune these variables to optimise perovskite solar cell device efficiency.

To do this, as part of this study with the Centre for Accelerated Co-Design of Durable, Reproducible, and Efficient Perovskite-Silicon Tandems (ADDEPT), our team at MIT has designed a setup with which we can control the relative humidity (RH), temperature (T) and solvent partial pressure (SPP) during the deposition and annealing steps of perovskite fabrication. In this work, we have explored the effects of these parameters on the optoelectronic properties of $FAPbI_3$ based perovskite solar cells.

Machine learning technology was employed to map the relationships between these environmental parameters and the electronic characteristics, importantly the power conversion efficiencies (PCE), of perovskite solar cell devices. As expected, our preliminary findings reveal that solvent and water partial pressures both considerably affect perovskite film quality, and consequently prove to have the greatest effect on the PCE of solar cell devices and the repeatability of device performance from batch-to-batch. By tuning these parameters across a range of temperatures, we exhibit how optimising environmental conditions during fabrication can be exploited to repeatably produce high efficiency perovskite solar cells, with recipes that are ultimately reproducible across labs. Understanding the conditions required to achieve repeatably consistent solar cell device performance characteristics is an important step in transitioning to reliable high-throughput printing of perovskite solar cells.



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Organic materials, Photovoltaics, Perovskites.

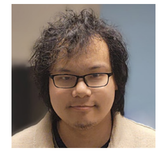
A 232-to-260GHz CMOS Amplifier-Multiplier Chain with a Matching-Sheet-Assisted Radiation Package and 11.1dBm Total Radiated Power

8.17

J. Wang, R. Han

Sponsorship: Intel University Shuttle Program, Jet Propulsion Laboratory Strategic University Research Partnerships Program

Terahertz (THz) signal sources and radiators are essential for a variety of future applications, such as high-resolution radar imaging, molecular spectroscopy, and clocks, as well as high-speed or miniature-platform communications. For over a decade, the growing interest in complementary metal-oxide semiconductor (CMOS) compact THz radiation sources has been driven by their small form factor and integration with other analog/digital systems. However, the total radiated power of prior CMOS THz sources was still only several mW, not only due to the limited fmax and breakdown voltages of the CMOS transistors, but also due to the inefficient on-chip radiation approaches. Due to the large dielectric constant contrast between the silicon and air, the radiated waves undergo strong reflection at the silicon-air interface, and with a small outward angle, total internal reflection occurs. To alleviate this problem, cm-sized, high-resistivity silicon lenses affixed to the chip back have been used. However, they dramatically increase the cost and size of the overall assembly. In this work, we introduce a CMOS THz amplifier-multiplier chain array generating radiation between 232 and 260GHz. Instead of using a silicon lens, a patterned dielectric matching sheet is applied onto the flipped-chip back, which enhances the wave coupling from silicon to air and enables low-cost and planar packages. That, in conjunction with broadband gain-peaking power amplifiers built with a high-power radio frequency FinFET transistor technology in the CMOS process, enables a measured peak total radiated power of 11.1dBm.



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Session 9: Neuromorphic Devices & AI Hardware Accelerators

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CiMLoop: A Flexible, Accurate, and Fast Compute-In-Memory Modeling Tool

9.01

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Sponsorship: Ericsson, TSMC, the MIT AI Hardware Program, MIT Quest, Samsung Semiconductor Fellowship, Siebel Scholars Fellowship

Compute-In-Memory (CiM) is a promising solution to accelerate Deep Neural Networks (DNNs) as it can avoid energy-intensive DNN weight movement and use memory arrays to perform low-energy, high-density computations. These benefits have inspired research across the CiM stack, but CiM research often focuses on only one level of the stack (i.e., devices, circuits, architecture, workload, or mapping) or only one design point (e.g., one fabricated chip). There is a need for a full-stack modeling tool to evaluate design decisions in the context of full systems (e.g., see how a circuit impacts system energy) and to perform rapid early -stage exploration of the CiM co-design space.

To address this need, we propose CiMLoop: an open-source tool to model diverse CiM systems and explore decisions across the CiM stack. CiMLoop introduces (1) a flexible specification that lets users describe, model, and map workloads to both circuits and architecture, (2) an accurate energy model that captures the interaction between DNN operand values, hardware data representations, and analog/digital values propagated by circuits, and (3) a fast statistical model that can explore the design space orders-of-magnitude more quickly than other high-accuracy models. Using CiMLoop, researchers can evaluate design choices at different levels of the CiM stack, co-design across all levels, fairly compare different implementations, and rapidly explore the design space.

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Single-Shot Matrix-Matrix Multiplication Optical Processor for Deep Learning

9.02

C. Luan, D. Englund, R. Hamerly

Sponsorship: NTT Research, TSMC, DARPA NaPSAC

The computational demands of modern AI have sparked interest in optical neural networks (ONNs), which offer the potential benefits of increased capacity and lower power consumption. Notable progress includes the demonstration of optical matrix-vector multiplication (MVM) processors based on cascaded Mach-Zehnder interferometer arrays using coherent light as the data carriers and thermo-optic phase shifters as weighting. Broadcast-and-weight MVM optical processors using different wavelengths as data carriers and tunable add-drop micro-ring resonators as weighting elements have also been demonstrated. Recent advancements in delocalized photonic deep learning also shows the advantages of using optical fan-out and analog time integrator based optical MVM processors on the Internet's edge. So far, limited by the low parallelism, most existing systems operate vector-vector multiplication (VVM) or MVM with O(N) or $O(N^2)$ scaling in system throughput. To fully unlock the potential of optical computing, a parallel matrix-matrix multiplication (MMM) processor will allow better throughput and efficiency scaling than ordinary MVMs, but its realization is challenging due to the 3D data structure and high parallelism requirements.

In this work, we propose and experimentally demonstrate a 3D grating-based ONN architecture using time-wavelength-spatial domain data flows with parallel operations in 16 space-degrees of freedom to improve the output capacity and energy efficiency. We experimentally demonstrate a parallel matrix-matrix multiplication processor using 4x4 input and output fiber arrays with 16 channel frequency comb lines of 7 different wavelengths, 32 broadband $LiNbO_3$ intensity modulators for weight matrix and input matrix encoding, a blazed reflective grating for low loss beam routing, and 16 analog time integrators for signal accumulation and network scaling, yielding a total operation-throughput of 64 MACs/shot with a high bit precision of 8-bits.

Analog Hardware Accelerators for Energy-Based AI Models

9.03

M. Bacvanski, D. Krotov, D. Englund

Analog computation offers the potential for rapid, energy-efficient inference beyond the capabilities of conventional digital neural networks, yet it has faced significant challenges in achieving the scale and performance of modern AI systems. In this work, we introduce an analog hardware model for implementing Energy-Based Models (EBMs) that can match the representational power of modern AI architectures, including transformers, associative memories, and diffusion models, while adhering to the practical physical realizability of analog circuits. We have developed a functional model of this system using analog electronics capable of accelerating the dense associative memory EBM. This class of EBMs are modeled with recurrent nonlinear differential equations, and are realized in hardware by combining linear circuit components with nonlinear amplification. These systems can achieve rapid, constant-time scaling of convergence by leveraging continuous, parallel parameter evolution. Our hardware design is grounded in electronic circuitry but is readily extensible to alternative computational platforms, including photonics. Ultimately, systems like this can be scaled to thousands of neurons, presenting an expressive and energy-efficient alternative to digital neural network inference hardware.

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Development of a Neuromorphic Network using BioSFQ Circuits

9.04

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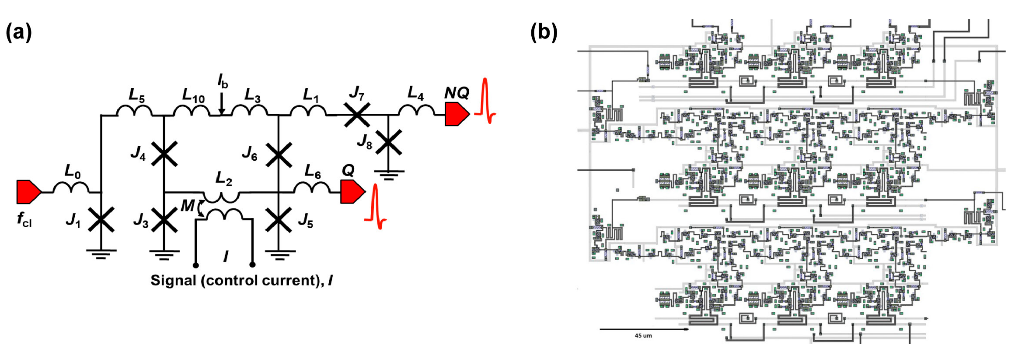
Sponsorship: Air Force Contract

Superconducting single-flux quantum (SFQ) circuits are promising candidates for neuromorphic hardware accelerators. They are extraordinarily fast and energy-efficient and use asynchronous pulse-rate data encoding, much like biological neurons. BioSFQ is an SFQ-based family that uses these neuromorphic features of SFQ circuits to process mixed analog/digital logic. BioSFQ circuits are also programmable, enabling mixed modes of operation and resilience to fabrication variation and flux trapping.

In this work, we design, fabricate, and measure a 3x3 network of bioSFQ comparators, the fundamental building block of bioSFQ circuits. We also demonstrate novel techniques for network calibration, integrating on-chip memory, and image processing using this 3x3 network.



▲ Figure 1: (a) Schematic of a bioSFQ comparator and (b) layout of the 3x3 comparator network.

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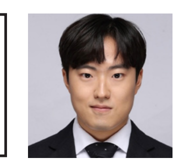
Stable and Accurate Nano-Resistor for Reliable Fixed AI Inference Tasks

9.05

G. Lee, M. Song, K. Kwon, J. Kim

Sponsorship: Samsung Semiconductor Fellowship

As artificial intelligence (AI) technology continues to advance in everyday applications, there is a rising demand for seamless, private, and sophisticated AI functionalities. On-device AI solutions, embedded within commercial mobile devices, eliminate the need for external server communication, thereby enhancing response times and data privacy. However, existing on-device AI technologies are limited by substantial power consumption and insufficient computational capacity to support advanced generative AI models. Memristor-based analog AI accelerators have emerged as a potential solution to the von Neumann bottleneck, a major limitation in achieving greater speed and energy efficiency in AI computing. Despite their promise, memristors are hindered by issues with conductance state stability and the complexity of required programming algorithms and circuitry, which constrains their widespread adoption in industry. In this study, we introduce an ultra-reliable nano-resistor array that enables robust analog AI inference for specific tasks, minimizing the dependence on complex circuitry. Conductance states are fixed and geometrically defined through a single micro-nano patterning process, removing the need for stochastic programming and reducing the complexity of programming circuits typically required in memristor-based accelerators. We achieved 6.8-bit programming accuracy and stable 8-bit conductance levels. Additionally, experimental results from multiply-accumulate (MAC) operations show the feasibility of achieving 8.2-bit accuracy in a passive 28x28 array with simple circuit-level compensation. This nano-resistor array offers a reliable and precise platform for AI computing, tailored for daily AI tasks while reducing peripheral circuitry.



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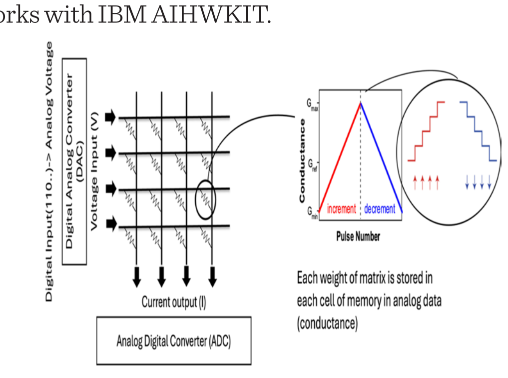
Design Considerations of Analog Accelerators for Machine Learning Applications

9.06

J. Lee, J. A. del Alamo

Sponsorship: IBM and Ericsson

Recently, there has been tremendous progress in machine learning, leading to a dramatic increase in its applications, such as image classification and natural language processing. As a result, there has been an explosion in demand for Graphics Processing Units and various accelerators that perform the computation required for machine learning training and inference. The widespread use of currently dominant digital accelerators requires a massive amount of energy, which is becoming a significant global issue. In response, analog computing using devices such as protonic synapses and ReRAM has been proposed as an alternative that can significantly enhance energy efficiency. Analog devices still face issues such as nonlinearity, asymmetry, and noise. Moreover, their performance heavily depends on components like Analog-to-Digital Converters (ADCs) and Digital-to-Analog Converters (DACs). In this work, we investigate how non-idealities degrade the performance of analog computing. We also evaluate different analog algorithms that mitigate performance degradation in several tasks such as Convolutional and Recursive Neural Networks with IBM AIHWKIT.



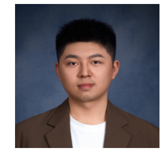
◀ Figure 1: Schematics of analog computing with analog crossbar array consisted by non-volatile memory cells.

LongVILA: Scaling Long-Context Visual Language Models for Long Videos

9.07

Q. Hu, H. Tang, S. Yang, S. Han

Long-context capability is critical for multi-modal foundation models, especially for long video understanding. We introduce LongVILA, a full-stack solution for long-context visual-language models by co-designing the algorithm and system. For model training, we upgrade existing VLMs to support long video understanding by incorporating two additional stages, i.e., long context extension and long video supervised fine-tuning. However, training on long video is computationally and memory intensive. We introduce the long-context Multi-Modal Sequence Parallelism (MM-SP) system that efficiently parallelizes long video training and inference, enabling 2M context length training on 256 GPUs without any gradient checkpointing. LongVILA efficiently extends the number of video frames of VILA from 8 to 2048, MM-SP is 2.1x - 5.7x faster than ring style sequence parallelism and 1.1x - 1.4x faster than Megatron with a hybrid context and tensor parallelism.



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QServe: W4A8KV4 Quantization and System Co-design for Efficient LLM Serving

9.08

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Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Quantization can accelerate large language model (LLM) inference. Going beyond INT8 quantization, the research community is actively exploring even lower precision, such as INT4. Nonetheless, state-of-the-art INT4 quantization techniques only accelerate low-batch, edge LLM inference, failing to deliver performance gains in large-batch, cloud-based LLM serving. We uncover a critical issue: existing INT4 quantization methods suffer from significant runtime overhead (20-90%) when dequantizing either weights or partial sums on GPUs. To address this challenge, we introduce QoQ, a W4A8KV4 quantization algorithm with 4-bit weight, 8-bit activation, and 4-bit KV cache. QoQ stands for quattuor-octo-quattuor, which represents 4-8-4 in Latin. QoQ is implemented by the QServe inference library that achieves measured speedup. The key insight driving QServe is that the efficiency of LLM serving on GPUs is critically influenced by operations on low-throughput CUDA cores. Building upon this insight, in QoQ algorithm, we introduce progressive quantization that can allow low dequantization overhead in W4A8 GEMM. Additionally, we develop SmoothAttention to effectively mitigate the accuracy degradation incurred by 4-bit KV quantization. In the QServe system, we perform compute-aware weight reordering and take advantage of register-level parallelism to reduce dequantization latency. We also make fused attention memory-bound, harnessing the performance gain brought by KV4 quantization. As a result, QServe improves the maximum achievable serving throughput of Llama-3-8B by 1.2x on A100, 1.4x on L40S; and Qwen1.5-72B by 2.4x on A100, 3.5x on L40S, compared to TensorRT-LLM. Remarkably, QServe on L40S GPU can achieve even higher throughput than TensorRT-LLM on A100. Thus, QServe effectively reduces the dollar cost of LLM serving by 3x.

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LoopTree: Exploring the Fused-layer Dataflow Accelerator Design Space

9.09

M. Gilbert, Y. Nellie Wu, V. Sze, J. Emer

Sponsorship: MIT AI Hardware Program

Superconductor circuits can utilize Josephson junctions and nanowires to perform analog, Deep neural network (DNN) accelerators often process DNNs one layer at a time, keeping intermediate data in off-chip DRAM. However, DRAM data transfers consume more energy than on-chip transfers and may increase latency due to limited DRAM bandwidth. Recent work has proposed fused-layer accelerators, which do not transfer intermediate data to/from DRAM but must recompute or retain data on-chip. This retention-recomputation trade-off results from the order of operations (dataflow) and the data tiles retained on-chip (partitioning). However, prior work has only explored a subset of this design space. We propose (1) an expanded design space, and (2) a model, LoopTree, to evaluate the latency and energy consumption of accelerators in this design space. We validate LoopTree against prior architectures (worst-case 4% error). Finally, we show how exploring this larger space results in more efficient designs (e.g., up to 10× buffer capacity reduction to achieve the same off-chip transfers).

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LEGO: Spatial Accelerator Generation and Optimization for Tensor Applications

9.10

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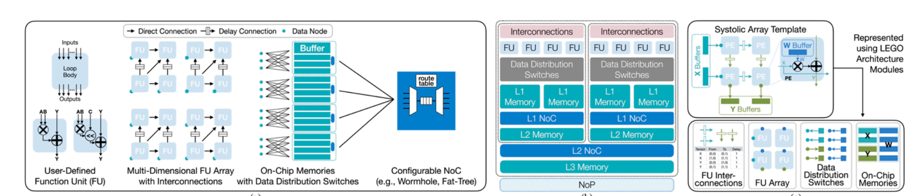
Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Modern tensor applications, especially generative AI applications require multiple input modalities, which increases the demand for flexible accelerator design. Existing frameworks suffer from the trade-off between design flexibility and productivity of RTL generation: either limited to few hand-written templates or cannot automatically generate the RTL. We propose the LEGO framework which automatically generates spatial architecture and outputs synthesizable RTL code without templates. From the affine-transformation-based architecture representation, LEGO frontend finds connections between function units, synthesizes the memory system, and fuses different spatial dataflow designs. LEGO backend uses linear programming to optimally insert pipeline registers and reduce the overhead of unused logic when switching dataflows. LEGO achieves 3.2× speedup and 2.4× energy efficiency over Gemmini, and can generate one architecture for diverse foundation models in generative AI applications.



▲ Figure 1: a) LEGO Spatial Architecture decouples computation logic, data path topology, and memory system. (b) LEGO modules are assembled hierarchically. (c) An example of representing a conventional systolic array template using LEGO modules.

SORBET: Secure Off-chip Memory Interface for Deep Neural Network Accelerators

9.11

K. Lee, G. Das, D. Han, A. P. Chandrakasan

Sponsorship: Samsung Electronics

As deep neural networks (DNNs) are deployed in high-stakes applications, ensuring their confidentiality and integrity becomes crucial. Trusted execution environments (TEEs) offer a potential solution by cryptographically encrypting and authenticating all data traffic to and from DNN accelerators without relying on off-chip hardware or system software to provide security. However, hardware memory encryption and authentication for DNN accelerators is challenging due to the large memory footprints of DNNs and the impact of cryptographic operations on the data access pattern of the accelerators. To address these challenges, we present SORBET, a secure off-chip memory interface for DNN accelerators. SORBET efficiently manages the altered data access patterns resulting from cryptographic authentication and leverages lightweight cryptography to minimize overhead. Also, we designed our DNN accelerator to support fused-layer processing, a technique that reduces the overall off-chip data traffic, to alleviate pressure on the cryptographic engine. Our implementation of a secure DNN accelerator equipped with SORBET supports memory encryption and authentication with only 1-22% performance overhead, 5.6-7.9% of the chip area, and 18.4% energy overhead. These results are verified with an ASIC implementation using TSMC 28nm technology. Overall, we show that memory security of TEEs can be practically achieved for resource-constrained DNN accelerators.

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Efficient Sampling from Prior Distributions Using Stochastic Magnetic Tunnel Junctions

9.12

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Sponsorship: MIT-HPI Design for Sustainability Award

Uncertainty quantification is critical in machine learning (ML) for enhancing model reliability and robustness in real-world applications. Bayesian learning offers a powerful framework for this purpose, but the high computational cost of algorithmic random number generation (RNG) presents a significant barrier to practical implementation. This work proposes an energy-efficient alternative to algorithmic RNG by harnessing the stochastic behavior of nanoscale two-dimensional (2D) magnetic materials, enabling scalable Bayesian learning. Based on ultrathin magnetic devices that exhibit probabilistic switching, we have designed Bernoulli distribution sampling devices (BSDs) that can produce binary states stochastically, with their Bernoulli parameter tunable through a current bias across the device. Building on this, we devised a theoretical framework to generate uniform distributions from BSDs, which can be adapted to form arbitrary posterior distributions for Bayesian neural networks. Benchmarking results indicate up to a 5000-fold improvement in energy efficiency compared to traditional RNG methods. This approach paves the way for a new class of stochastic computing devices, providing a pathway to energy-efficient AI/ML applications and enhancing the practical viability of Bayesian learning.

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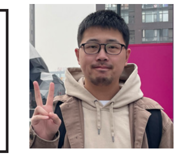
SVDQuant: Absorbing Outliers by Low-Rank Components for 4-Bit Diffusion Models

9.13



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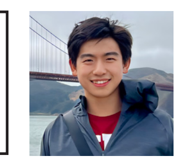
Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Diffusion models have been proven highly effective at generating high-quality images. However, as these models grow larger, they require significantly more memory and suffer from higher latency, posing substantial challenges for deployment. In this work, we aim to accelerate diffusion models by quantizing their weights and activations to 4 bits. At such an aggressive level, both weights and activations are highly sensitive, where conventional post-training quantization methods for large language models like smoothing become insufficient. To overcome this limitation, we propose SVDQuant, a new 4-bit quantization paradigm. Different from smoothing which redistributes outliers between weights and activations, our approach absorbs these outliers using a low-rank branch. We first consolidate the outliers by shifting them from activations to weights, then employ a high-precision low-rank branch to take in the weight outliers with Singular Value Decomposition (SVD). This process eases the quantization on both sides. However, naïvely running the low-rank branch independently incurs significant overhead due to extra data movement of activations, negating the quantization speedup. To address this, we co-design an inference engine Nunchaku that fuses the kernels of the low-rank branch into those of the low-bit branch to cut off redundant memory access. It can also seamlessly support off-the-shelf low-rank adapters (LoRAs) without the need for re-quantization. Extensive experiments on SDXL, PixArt-∑, and FLUX.1 validate the effectiveness of SVDQuant in preserving image quality. We reduce the memory usage for the 12B FLUX.1 models by 3.5×, achieving 3.0× speedup over the 4-bit weight-only quantized baseline on the 16GB laptop 4090 GPU, paving the way for more interactive applications on PCs. Our quantization library and inference engine are open-sourced.

DuoAttention: Efficient Long-Context LLM Inference with Retrieval and Streaming Heads

9.14



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Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Deploying long-context large language models (LLMs) is essential but poses significant computational and memory challenges. Caching all Key and Value (KV) states across all attention heads consumes substantial memory. Existing KV cache pruning methods either damage the long-context capabilities of LLMs or offer only limited efficiency improvements. In this paper, we identify that only a fraction of attention heads, a.k.a, Retrieval Heads, are critical for processing long contexts and require full attention across all tokens. In contrast, all other heads, which primarily focus on recent tokens and attention sinks--referred to as Streaming Heads--do not require full attention. Based on this insight, we introduce DuoAttention, a framework that only applies a full KV cache to retrieval heads while using a light-weight, constant-length KV cache for streaming heads, which reduces both LLM's decoding and pre-filling memory and latency without compromising its long-context abilities. DuoAttention uses a lightweight, optimization-based algorithm with synthetic data to identify retrieval heads accurately. Our method significantly reduces long-context inference memory by up to 2.55x for MHA and 1.67x for GQA models while speeding up decoding by up to 2.18x and 1.50x and accelerating pre-filling by up to 1.73x and 1.63x for MHA and GQA models, respectively, with minimal accuracy loss compared to full attention. Notably, combined with quantization, DuoAttention enables Llama-3-8B decoding with 3.3 million context length on a single A100 GPU.

Quest: Query-Aware Sparsity for Efficient Long-Context LLM Inference

9.16

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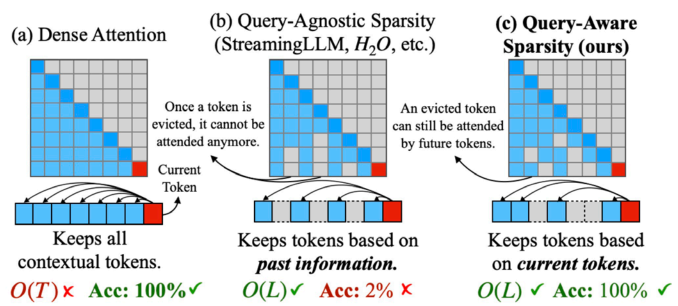
As the demand for long-context large language models (LLMs) increases, models with context windows of up to 1M tokens are becoming prevalent. However, long-context LLM inference is challenging since the inference speed decreases significantly as the sequence length grows. This slowdown is primarily caused by loading a large KV cache during attention. Previous works have shown that a small portion of critical tokens will dominate the attention outcomes. However, we observe the criticality of a token highly depends on the query. To this end, we propose Quest, a query-aware KV cache selection algorithm. Quest keeps track of the minimal and maximal Key values in KV cache pages and estimates the criticality of a given page using Query. By only loading the Top-K critical KV cache pages, Quest significantly speeds up attention without sacrificing accuracy. We show that Quest can achieve up to 2.23x attention speedup, which reduces inference latency by 7.03x with negligible accuracy loss.



▲ Figure 1: Quest Algorithm Overview.

Enhanced Weight-Update Performance in Neuromorphic Computing with Vertical ECRAM Using PEALD-TiO_2-x

9.17

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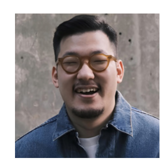
Sponsorship: Samsung Research Funding & Incubation Center for Future Technology



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Cross-point arrays of analog synaptic devices hold promise for energy-efficient neuromorphic computing, outperforming von Neumann hardware in speed and energy consumption. Vertically structured electrochemical random-access memory (VECRAM) is a key candidate due to its CMOS compatibility, minimal cell size, and scalability. To optimize VECRAM performance, conformal thin film deposition along vertical sidewalls using atomic layer deposition (ALD) is essential, yet conventional ALD faces challenges in achieving the desired electronic and ionic properties. In this study, we utilize plasma-enhanced ALD (PEALD) with an additional Ar plasma step to deposit TiO_2-x channels for VECRAM devices. By tuning Ar plasma power and duration, we control the crystallinity and off-stoichiometry of TiO_2 films. Electrochemical impedance spectroscopy reveals improved ionic and electronic transport in PEALD-TiO_2-x compared to conventional ALD films. ECRAM devices with PEALD-TiO_2-x channels exhibit enhanced linearity and reduced weight-update variations, demonstrating superior performance for high-density neuromorphic computing applications.

Tailor Swiftiles: Accelerating Sparse Tensor Algebra by Overbooking Buffer Capacity

9.18

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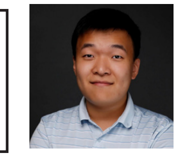
Sponsorship: MIT AI Hardware Program, Mathworks Fellowship, NSERC PGS-D



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Many applications operate on tensor data that has high sparsity (i.e., many zeros) with large variations sparsity between regions of a tensor. Prior sparse tensor algebra accelerators partition the tensor into equal shape tiles that all fit in a buffer, limiting utilization of buffer resources for more sparse tiles. Our key insight is that we can overbook the buffer by allocating tiles that occasionally exceed the capacity of the buffer. We propose to combine a low-overhead data orchestration mechanism, Tailors, with a statistical tiling approach, Swiftiles, in order to support tiles that overbook the buffer and improve utilization of buffer resources and thus improve on-chip data reuse. Across a suite of 22 sparse tensor algebra workloads, we show that Tailors and Swiftiles introduce an average speedup 2.3x over an existing sparse tensor algebra accelerator with optimized tiling.

200 mm Wafer Diameter Process of Pd/PSG/WO3 Protonic Synapses for Analog Deep Learning

9.19

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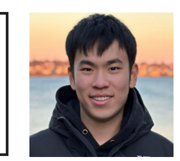
Sponsorship: MIT-IBM Watson AI Lab



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Research Interests:
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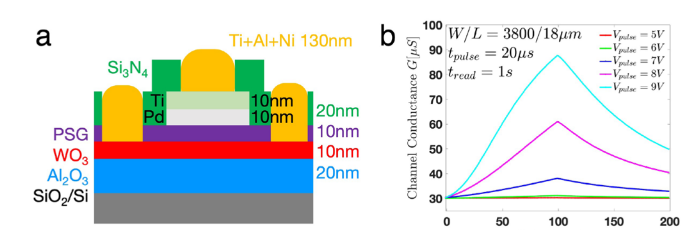
To solve the overcoming computational bottlenecks for deep learning, analog deep learning accelerators process information locally using special-purpose devices for matrix multiplication calculations and outer product updates. Among them, Electrochemical Random-Access Memories modulate channel resistance by ionic exchange between a semiconductor channel and a gate reservoir via an electrolyte. This design aims to enable neural network training with enhanced energy efficiency, non-volatility, and low latency.
Our research focuses on proton-based ionic synapses featuring in-situ hydrogenated H_xWO_3 (as channel) and PdH_y (as gate reservoir), and phosphosilicate glass (PSG) (as electrolyte). In a close collaboration with IBM Research, we have fabricated devices on a 200-mm wafer from IBM Research using a CMOS back-end-of-line compatible process. We have successfully demonstrated linear and symmetrical channel conductance modulation under different voltage pulses across gate and channel.



▲ Figure 1: (a) Schematic of Pd/PSG/WO_3 protonic synapse fabricated in a joint MIT-IBM Research process on 200-mm wafers. (b) Conductance modulation under voltage pulses from 5 V to 9 V with a width of 20 µs that are fired every 1 s.

Quantum-noise-limited Optical Neural Networks Using a Few Quanta Per Neuron Activation

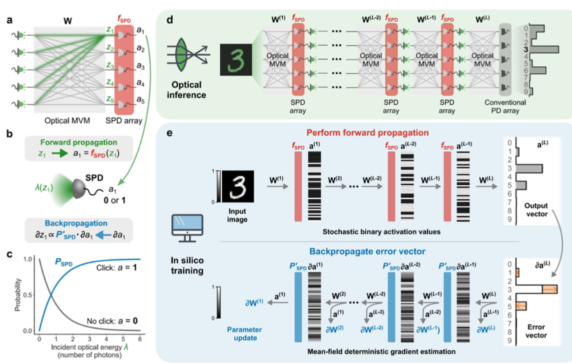
9.20

Y. Lin, Z. Zhang, and S. Han

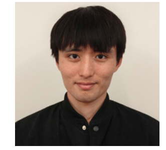
Sponsorship: National Science Foundation, MIT-IBM Watson AI Lab, MIT AI Hardware Program, Amazon, Samsung, Hyundai

Analog physical neural networks offer the potential for significant energy and speed advantages over digital counterparts. However, fully realizing these advantages requires addressing the inherent challenge of low signal-to-noise ratio (SNR) in analog signals, where physical limits become a critical factor.

In this presentation, we explore the implementation of optical neural networks at the fundamental limit: utilizing only a single photon to cause a neuron activation. In this quantum-noise-limited regime, the measurement outcome will be highly stochastic (SNR ~ 1), which challenges traditional noise-aware training algorithms. The key idea in our work is to embrace the inherent stochasticity of the system rather than trying to shape it as a deterministic network with restricted precision. We adopt methods from machine learning research on stochastic neural networks, employing a physics-based model to effectively capture and utilize the system's natural stochastic behavior.



◄ Figure 1: a-c, Diagrams of a layer, the activation function fSPD,the mean-field function PSPD. d, Optical inference. e, In silico training. MVM: matrix-vector multiplier; W : weight matrix; z: pre-activation value; a: activation value; PD: photodetector; C: cost function; ∂x: gradient ∂C/∂x.



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Research Interests:
Artificial Intelligence, Biological devices & systems, Communications, Displays, Electronic devices, Information processing, Machine Learning, Medical devices & systems, Optoelectronics, Photonics, Quantum devices, Sensors, Systems, Transducers.

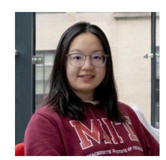
Hydrogen-based Electrochemical Random-Access Memories (H-ECRAM) with Low Device-to-device and Cycle-to-cycle Variabilities

9.21

L. Xu, M. Huang, and B. Yildiz

Sponsorship: Semiconductor Research Corporation(SRC) JUMP 2.0 SUPREME

Programmable resistors with low variability are the key to achieve high training accuracy in hardware neural networks for effective artificial intelligence applications. Traditional candidates for programmable resistors, such as resistive random-access memory (ReRAM), often face challenges with large variability due to their stochastic nature of operation. Electrochemical random-access memories (ECRAMs) are promising three-terminal non-volatile programmable resistors with low variability, which is enabled by the deterministic and controllable dynamic doping of the channel material. However, the device-to-device variation has not been systematically studied. In addition, the effect of extended defects, such as grain boundaries in the channel, on the device-to-device variability is not clear. In this work, we systematically quantified the variability of CMOS-compatible hydrogen-based ECRAMs (H-ECRAMs) with crystalline and amorphous channels, and of various channel sizes. By programming multiple devices with identical parameters and examining their conductance modulation range, we observed very low variations in the low-conductance regime, including approximately 15% device-to-device and less than 2% cycle-to-cycle variation, with an endurance exceeding 10^8 conductance updates. Furthermore, device-to-device variation showed no dependence on whether the channel was crystalline or amorphous, nor on channel sizes ranging from 10 μm to 150 nm . These results demonstrate that ECRAMs meet the variability targets for programmable resistors and possess significant potential for downscaling, making them a promising candidate for use in hardware neural networks.



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Ultra-low Power Superconducting Electronics for Deep Learning Accelerator Architectures: Evaluating Energy Efficiency and Scalability

9.22

L. Camron Blackburn, Evan Golden, Tanner Andrulis, Vivienne Sze, Joel Emer, Neil Gershenfeld, Karl K. Berggren

Sponsorship: MIT Lincoln Laboratory, the MIT AI Hardware Program

Since the invention of the Josephson junction in the 1960s, superconducting electronics have shown promise for high-speed and energy-efficient computing. Since 2013, the Adiabatic Quantum Flux Parametron (AQFP) device has gained popularity for its ultra-low energy dissipation. AQFP inverters dissipate 10^{-21}J per switching event, 100× less than other superconductor logic, and 10^6× less energy than modern-day CMOS transistors or 10^3× when including the cryogenic cooling cost. As Moore's law ends and energy efficiency emerges as a limit on today's computing systems, superconducting AQFP logic is a promising technology to address these energy challenges. Although individual AQFP device performance is impressive, superconducting electronics have failed to replace CMOS systems in the past in part due to the high cost of cryogenic low-noise testing environments and the limitations of superconductor memory scaling. To realize the promise of superconducting electronics, there is a need to architect full systems that can leverage the benefits of the unique superconductor physics (e.g., low-energy logic, low-energy interconnects on zero-resistance wires) while addressing the challenges (e.g., using low-noise cryogenic environments commoditized by the quantum computing industry, constructing a memory hierarchy that addresses the lack of a scalable, high-density superconducting memory). In this work, we extend Timeloop/Accelergy accelerator modeling tools to support superconducting accelerators. This framework explores the design space of deep learning accelerator architectures with a toolbox of superconducting circuits from various logic families. We present results demonstrating the tradeoffs between superconductor vs. CMOS accelerators while running a range of deep learning workloads.

Session 10: 3DHI & Additive Manufacturing

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Research Interests:
Actuators, Artificial Intelligence, BioMEMS, Electronic devices, Electronics, Lasers, Nanomanufacturing, Nanomaterials, Nanotechnology, Photonics.

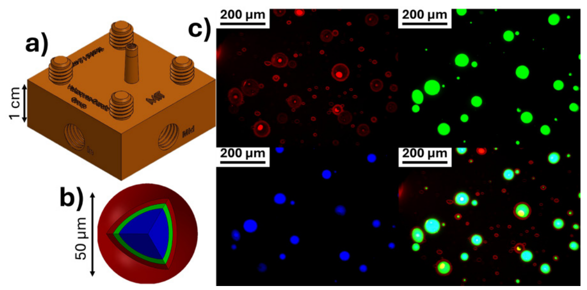
3D Printed Device for Triaxial Electrospray

10.01

B. I. Quintanar, L. F. Velasquez-Garcia

Sponsorship: Monterrey Tec - MIT Nanotechnology Program

Electrospray systems are widely used in targeted drug delivery, mass spectrometry, and nanoparticle synthesis applications. However, it may be expensive and difficult to generate due to the complexity of the electric-microfluidic system. This study presents the design, fabrication, and performance analysis of a triaxial electrospray device developed using 3D resin printing. The device features a three-channel configuration that enables simultaneous, controlled release of multiple solutions through concentric nozzles. Preliminary experiments demonstrate the device's capability to produce a stable, high-precision spray, obtaining a triple encapsulation structure (core-shell-shell), by varying applied voltages and flow rates, characterized with fluorescent microscopy to ensure encapsulation. 3D printing offers significant customization, rapid prototyping, cost reduction, and scalability advantages, making this approach a viable option for versatile electrospray device manufacturing.



◄ Figure 1: (a) Triaxial 3D printed device, b) Core-shell-shell particle model obtained with colors for each fluid, c) Fluorescent particles obtained (red – outside shell, green – middle shell, and blue – core)

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Additive Manufacturing of Hybrid Electrospray Emitter Geometries via Two-Photon Polymerization

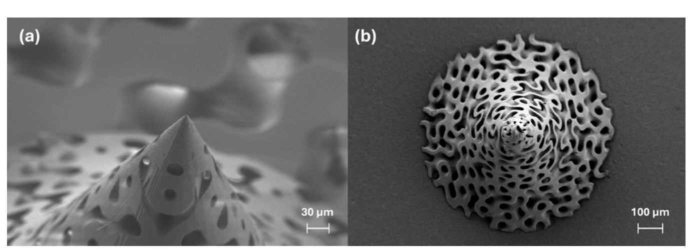
10.02

R.A. Davis, G. D'Orazio, J.H. Fang, S. Sobhani, E. Petro, B.L. Wardle

Sponsorship: NASA Space Technology Graduate Research Opportunities Grant

Electric propulsion provides precise, in-space propulsion with mass savings and high specific impulse. Electrospray propulsion, using microfluidics and electrostatics to accelerate ions and droplets, has low-thrust applications and can scale to larger systems. Key failure modes are dependent on the propellant wetting properties and emitter geometry.

Current manufacturing methods face challenges in creating precise, repeatable emitter geometries, leading to long development times and unstable performance. This work aims to improve individual emitter accuracy with nanoscale additive manufacturing and tailor wetting properties via dielectric atomic layer deposition. Single emitters are printed including triply periodic minimal surfaces (TPMS) to achieve uniform porosity, followed by alumina coating to adjust wetting. Key electrospray performance parameters are estimated, revealing the potential for convenient, repeatable emitter fabrication and tailored geometries for specific applications.



▲ Figure 1: Scanning electron microscope (SEM) images of additively-manufactured (a) Schwarz diamond TPMS electrospray emitter, (b) and alumina-coated gyroid TPMS electrospray emitter.

3D-Integrated Circuits in GaN/Si CMOS/Glass for High Frequency, High Data Rate Applications

10.03

P. Yadav, J. Wang, D. Baig, X. Li, J. Pastrana, J. Niroula, M. Bakir, M. Swaminathan, R. Han, T. Palacios

Sponsorship: SRC JUMP 2.0 (Grant no. 2023-JU-3136) and the National Defense and Science Graduate Fellowship

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Communications, Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, Nanomanufacturing, Nanomaterials, Nanotechnology, Si, Systems.

GaN (Gallium Nitride) transistors are enabling the next generation of high efficiency, high power, and high frequency integrated circuits. Furthermore, demonstrations of low voltage GaN radio frequency (RF) switches for front-end modules (FEM) and low noise figures in GaN low noise amplifiers (LNAs), are broadening the applications of GaN into the mobile, artificial intelligence (AI), and quantum sectors. But this excellent performance comes with a high cost, due to limited wafer sizes and BEOL (back end of line) metallization options. On the other hand, Si CMOS allows access to state-of-the-art 300 mm BEOL and digital circuit design.

To revolutionize GaN chip design, a holistic approach must be taken through integration with Si Complementary Metal-Oxide-Semiconductor (CMOS). In this work, through these two approaches, 3D GaN chips design is made more cost effective while providing orders of magnitude improvement as compared to convention 2D-circuits in Si or GaN-only FEOL (front end of line). With the combination of Si CMOS digital, bias, and matching chips, high frequency GaN dielets are integrated in a highly scaled manner through the use of direct Cu-Cu bonding for several 3D-amplifier first demonstrations. Such integration offers low RF losses as well as near seamless-bonding interfaces. Similarly, glass offers a low-cost packaging option for mutli-chiplet systems. Large substrate sizes and panel thickness down to 30um enables the next generation of packaging for nano-systems at scale, while also allowing for novel thermal cooling solutions such as microfluidic, two-phase vapor, etc. With the lamination of low-loss dielectric ABF (Ajinomoto build-up film) layers in glass, a highly capable package for 3D-RF stacking can be created. In this work, GaN dielets are integrated directly in this glass package for the first time and their properties are studied and quantified.

3D-Printed Hard Magnets

10.04

Z. Bigelow, L. F. Velásquez-García

Sponsorship: Empiriko Corporation

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Hard magnets are extensively used across numerous industries, including electronics, automotive, renewable energy, healthcare, and consumer goods. However, conventional methods for producing these magnets are limited to simple shapes and require assembly, leading to increased production costs and constrained geometries and devices.

We present a novel 3D printing process capable of producing hard magnets using micro- and nano-reinforced materials, thereby expanding the scope of their practical applications. Our research is focused on the fabrication of isotropic magnets at a miniature scale, typically ranging in size from a few millimeters. The material composition utilized in our printing process consists of a blend comprising 75% NdFeB and 25% Nylon 12 by volume. This work demonstrates the feasibility of 3D printing hard magnets and underscores the potential for fine-tuning magnetic properties through additive manufacturing techniques. These advancements offer precise control over magnet geometry and performance, presenting significant opportunities for industries seeking tailored magnetic solutions.

◄ Figure 1: 3D printed 75% NdFeB magnet

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Research Interests:
Information processing, Machine Learning for Time Series in Manufacturing.

Unsupervised Anomaly Detection on Irregular Time Series Data

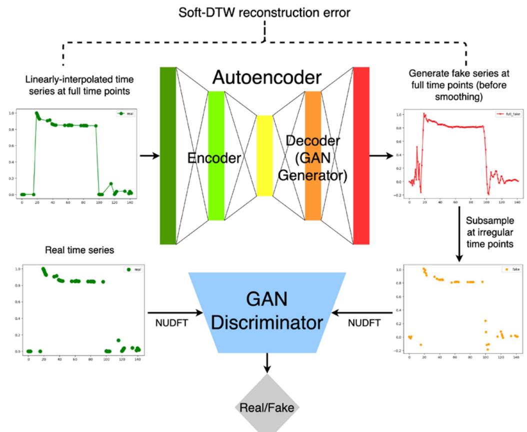
10.05

F. -K. Sun, R. K. Owens, D. S. Boning

Sponsorship: Analog Devices

Anomaly detection in semiconductor manufacturing is essential for maintaining production quality and efficiency. However, data from semiconductor equipment sensors can form irregular (i.e. unevenly-spaced) time series due to sporadic instabilities, which challenge the regularity assumption in most machine learning algorithms.

Our anomaly detection uses an autoencoder as its backbone. To address time shifts commonly seen in signals, we compute the reconstruction error using Soft-Dynamic Time Warping (Soft-DTW), a technique resilient to temporal misalignments. We also employ the Non-Uniform Discrete Fourier Transform (NUDFT) to convert irregular time series into fixed-size representations in the frequency domain, making the data suitable for processing. To further enhance the ability to reconstruct realistic series, even with irregular timing, we integrate a Generative Adversarial Network. This combined approach enables robust anomaly detection in irregular time series without performance degradation.



◄ Figure 1: Overall model architecture

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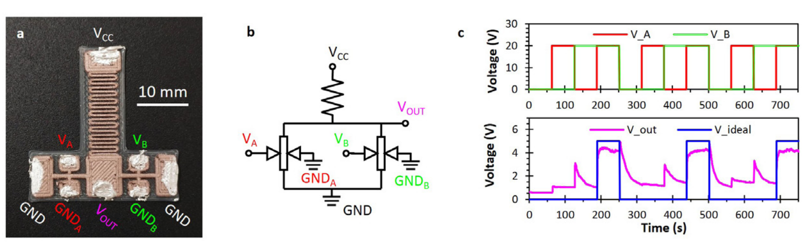
Semiconductor-Free, Fully 3D-Printed Logic Gates

10.06

J. Cañada, B. I. Quintanar, L. F. Velásquez-García

Sponsorship: Empiriko Corporation (Newton MA, USA) and "la Caixa" Foundation (Barcelona, Spain)

Additive manufacturing (AM) has the potential to enable the inexpensive, single-step fabrication of fully functional electromechanical devices. However, while the 3D printing of mechanical parts and passive electrical components is well developed, the fabrication of fully 3D-printed active electronics, which are the cornerstone of intelligent devices, remains a challenge. Existing examples of 3D-printed active electronics show potential but lack integrability and accessibility. This work reports the first instance of active electronics fully 3D-printed via material extrusion, i.e., one of the most accessible and versatile AM processes. The technology is demonstrated through the implementation of the first fully 3D-printed, semiconductor-free, solid-state logic gates. Although the reported devices don't perform competitively against semiconductor-enabled integrated circuits, the customizability and accessibility intrinsic to material extrusion make this technology promisingly disruptive.



▲ Figure 1: Fully 3D-printed AND gate: picture of fabricated device (a), schematic (b), and input-output characteristics with Vcc set to 5 V (c) (J. Cañada and L. F. Velásquez-García, Virtual and Physical Prototyping, 2024).

Session 11: MEMS, Field-Emitter, Thermal, Fluidic Devices & Robotics

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Electronic devices, Electronics, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology.

2-Photon Photolithography Fabrication of "Pixel" Electrospray Thrusters

11.01

C. J. Nachtigal, S. Dhulipala, C. M. Portela, P. C. Lozano

Sponsorship: NSTGRO Grant, AFOSR

Electrospray thrusters (ESTs) are a promising form of electric propulsion in small satellite and deep space applications due to their high specific impulse and low thrust. They consist of an array of micro emission sites where propellant is fed to and propelled from via a voltage application to the emitter with respect to a downstream grounded extractor electrode. ESTs lack in their lifetime, due to electrical shortages at a single emission site causing premature full array shortage. They also lack in their efficiency, due to improper extractor alignment and poor emitter manufacturing precision affecting emission site stability and purely ionic regime emission. To remedy this, an EST design consisting of precise capillary emitters with an integrated extractor array consisting of single extractors connected via fuses to prevent shortage propagation and ensure extractor alignment has been proposed. To realize this design, this work uses 2-photon photolithography to build the emitter capillaries and integrated extractor base, and liftoff of sputter-coated nichrome to pattern the extractors and fuses. We examine the fabrication feasibility on porous glass substrates and on 50 μm diameter etched through-holes in silicon wafers to allow for passive propellant uptake. The contact angle and dielectric breakdown of the structure is determined, and a prototype is designed to be compatible with voltages over 1200 V, which is well within the necessary firing voltage range that is simulated. Further, the design allows for an emitter pitch of less than 80 μm, which can be reduced further in future iterations, greatly densifying arrays and increasing the potential thrust per area of ESTs.

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Research Interests:
Sensors, Systems, Robotics.

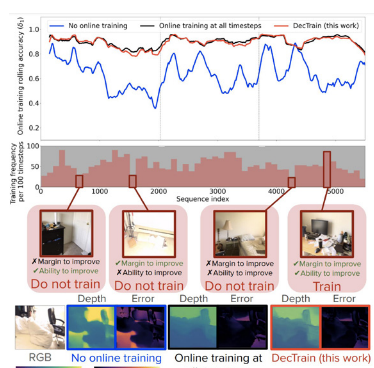
DecTrain: Deciding When to Train a Monocular Depth DNN Online

11.02

Z.-S. Fu, S. Sudhakar, S. Karaman, V. Sze

Sponsorship: National Science Foundation, Real-Time Machine Learning program, the MIT-Accenture Fellowship, the Huang Phillips Fellowship, a gift from Intel.

Monocular depth deep neural network (DNN) is useful for 3D reconstruction by predicting per-pixel depth of an RGB image. While using a monocular depth DNN can be more energy efficient and has a smaller form factor than traditional bulky and high-power physical depth sensors, it can deteriorate in accuracy when deployment data differs from training data. While performing online training at all timesteps can improve accuracy, it is computationally expensive. We propose DecTrain, a new algorithm that decides when to train a monocular depth DNN with self-supervision by comparing the cost of training with the predicted accuracy gain. DecTrain maintains accuracy compared to online training at all timesteps on out-of-distribution data, while training only 44% of the time on average. We also compare the recovery of a low inference cost DNN using DecTrain and a more generalizable high inference cost DNN, and find DecTrain recovers the majority (97%) of the accuracy gain of online training at all timesteps while reducing computation compared to the high inference cost DNN which recovers only 66%. DecTrain enables low-cost online training for a smaller DNN to have competitive accuracy with a larger DNN at a lower overall computational cost.



▶ Figure 1: Compared to the baseline of online training at all timesteps (black) or no timesteps (blue), DecTrain (red) maintains the accuracy improvement of adaptation while training on only a subset of the timesteps.

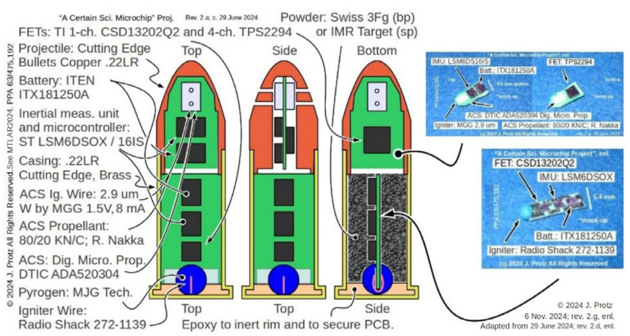
Using Silicon MEMS OIS Chip Sets with Integrated Computers for Jitter Removal in Olympic .22 LR Sport Shooting Rounds

11.03

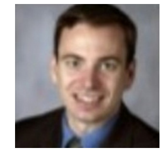
J. Protz, J. Gerson, A. Jain, P. Kelly, A. Lee

Sponsorship: Protz Lab Group, microEngine LLC, Asteria Propulsion LLC

Silicon MEMS propulsion was studied at MIT for two decades. In recent years, the present investigator has been considering a sq. mm -sized MEMS chip that would combine inside one package a CMOS guidance computer, MEMS sensors, and a MEMS solid- or liquid- propellant micro rocket motor and that would serve as a drop-in replacement for a bullet primer cap or model rocket motor igniter. This year, a practical iteration of the concept was considered; it combines on two circuit boards off-the-shelf sensors, computers, and batteries, an SiO2 digital micro thruster, and a micro rocket motor igniter. The design is for a .22 LR bullet useful in NCAA and Olympic -type sport shooting; it uses an off-the-shelf MEMS chip set commonly used for optical image stabilization (OIS) in digital cameras; one board is placed with the propellant, and the other is placed inside the lightly-machined projectile to provide limited in-flight steering. The projectile and casing are also off-the-shelf. A plastic mock-up has been completed; see the accompanying figure. If successful, the project could lead to a class of sport shooting that features teams having both athletes and device engineers like does auto racing.



◀ Figure 1: (left) conceptual design of a .22 LR digital bullet cartridge for NCAA and Olympic -type sport shooting and (right) photographs of plastic mock-ups of parts of the sames; note MEMS OIS chips and thruster array and PCB-type model rocket igniter.



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Biological devices & systems, Energy, MEMS & NEMS, Molecular & polymeric materials, Nanomaterials, Nanotechnology, Sensors, Systems, Propulsion, Vacuum electronics, Econ.

Aerophilic De-bubbling

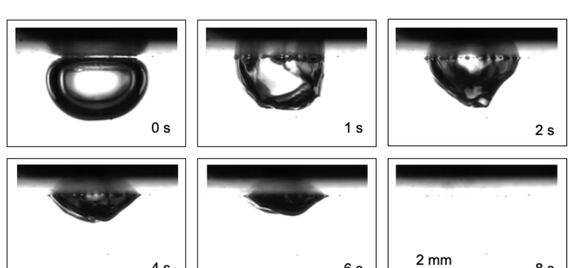
11.04

B. Vandereydt, S. Nath, K. K. Varanasi

Sponsorship: MIT Lincoln Laboratory

From the froth of brewing kettles to the lather of cosmetics, from bioreactors teeming with life to wastewater treatment tanks, foam—or more simply, bubbles—is everywhere. Classical approaches to eliminating bubble populations—through centrifugation, use of vacuum chambers, or incorporation of chemical defoamers—are often highly energy-intensive, may introduce contaminants, and even compromise the pristine nature of the material.

In this work, we show how we can borrow ideas from nature—specifically, the aquatic insect Haemonia mutica—to design an aerophilic solid. This clever little insect under water envelopes itself in a thin layer of air sustained for days using intricate hair-like hierarchical features. We show that engineering such an aerophilic material and perforating it can lead to some spectacular properties in bubble evacuation dynamics from aqueous media, reducing evacuation times from tens of seconds to mere milliseconds! Our experiments exploring the physics of the complex phenomenon of debubbling across a cascade of scales—from population (foam) to single bubble to pore—reveal that the fastest bubble evacuations correspond to an interface that is nearly a liquid, but not quite.



▲ Figure 1: A millimetric underwater bubble contacts an aerophilic membrane and evacuates in 8ms.

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Availavle from June 2025.

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Characterization of Magnetoelectric Devices for Wireless Energy Harvesting

11.05

H. T. Yang, D. Sarkar

Sponsorship: MIT Media Lab Nano-cybernetic Biotrek Group

Micrometer-sized energy-harvesting devices are crucial for advancing microelectronics, particularly in applications such as biomedical implants and wireless sensors. Among various energy-harvesting mechanisms, magnetoelectric (ME) devices are especially promising due to their high efficiency in energy conversion, making them ideal for wireless and battery-free operations. However, characterizing non-resonant ME devices presents challenges, as charge amplifiers often lack the sensitivity needed to detect ultra-low charge outputs. To address this, we fabricated ME devices with dimensions of tens of μm, designed to theoretically generate approximately fC per device—a value below the detection threshold of typical charge amplifiers. Through the microfabrication process, we created an array of hundreds of devices and tested both released and unreleased configurations to minimize external artifacts and isolate direct responses to magnetic fields. By measuring charge generation across varying magnetic field strengths at non-resonant frequencies, we determined the non-resonant magnetoelectric coefficient of single devices. This approach provides a pathway for accurate characterization of ME devices with low charge outputs and their integration into highly miniaturized energy-harvesting systems.

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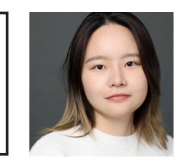
Flexible Acoustically Active Surfaces Based on Piezoelectric Microstructures

11.06

T. Dang, J. Han, Z. Zheng, J.H. Lang, V. Bulovic

Flexible acoustic transducers have gained significant attention due to their diverse applications in modern technologies, including active noise control, human-machine interfaces, ultrasonic imaging, and tactile sensing. Flexible speakers typically utilize electrostatic or piezoelectric effects to generate sound, with piezoelectric loudspeakers standing out for their ease of fabrication and low power consumption. Despite their advantages, most demonstrated flexible speakers show limited performance or require high operating voltages, restricting their practical use in applications involving potential human contact.

In this project, we develop a flexible thin-film acoustic transducer based on an ensemble of free- standing microstructures using a piezoelectric polyvinylidene fluoride (PVDF) sheet, targeting potential wearable applications. The PVDF microstructure arrays are encapsulated between two layers of flexible substrates that not only protect the piezoelectric microstructures but also define their shapes while allowing free vibration. The performance evaluation of these speakers demonstrates excellent sound generation, achieving 60 dB at 1 kHz under 20V excitation. The speakers display broad bandwidths reaching up to 100 kHz, thanks to the high resonant frequencies of the fabricated microstructures. Additionally, the device consumes power at the milliwatt level, offering a substantial efficiency advantage over dynamic and thermoacoustic loudspeakers. Therefore, this lightweight, flexible and low-cost speaker could perform as an innovative interface for acoustic applications.



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Hybrid Locomotion at the Insect Scale – Combined Flying and Jumping for Enhanced Efficiency and Efficacy

11.07

Y.-H. Hsiao, S. Bai, Z. Guan, S. Kim, Z. Ren, P. Chirarattananon, Y. Chen

Sponsorship: National Science Foundation, the MIT MISTI program, and the Research Grants Council of the Hong Kong Special Administrative Region of China

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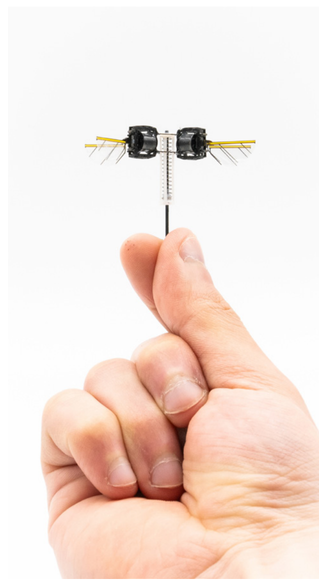
Insect-scale robots hold promise for diverse application such as inspection, and environmental monitoring. However, they face two major locomotive challenges: constrained energetics and large obstacles that far exceed their size. Terrestrial locomotion is efficient yet mostly limited to flat surfaces. In contrast, flight is effective for bypassing large obstacles but consumes high power. Here, we present a hopping design that combines a sub-gram flapping-wing robot with a telescopic leg. Our robot can hop continuously while controlling jump height and frequency in the range of 1.5 – 20 centimeters and 2 – 8.4 hertz. Compared to flight, this design reduces power consumption by 64 percents and increases payload by 10 times. The robot can follow positional setpoints, overcome tall obstacles, and traverse challenging surfaces such as soil and grass. It can also hop on dynamically rotating surfaces, recover from strong collisions, and perform somersaults. These results highlight hopping as an efficient and effective locomotion strategy for microscale robots, opening opportunities for achieving sensing and power autonomy in payload constrained microrobots that often confront large obstacles.



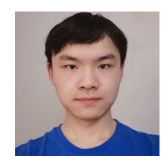
▶ Figure 1: A photograph illustrating a hopping robot module being held in a hand.

GEVO: Memory-Efficient Monocular Visual Odometry Using Gaussians

11.08

D. Gao, P. Z. X. Li, V. Sze, S. Karaman

Sponsorship: Amazon, MathWorks Fellowship, and NSF CPS



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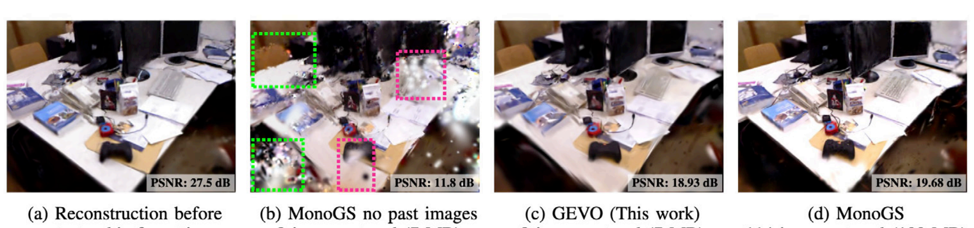
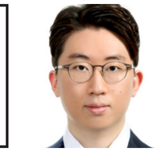
Research Interests:
Artificial Intelligence, Integrated circuits.

High-fidelity 3D scene reconstruction with a monocular camera supports applications on mobile devices like micro-robots and AR/VR headsets, where access to the off-chip memory dominates the compute energy. While Gaussian Splatting (GS) enables detailed reconstruction, existing GS-based SLAM systems are memory-inefficient because they store numerous past images to retrain Gaussians to prevent catastrophic forgetting, leading to excessive memory usage.

Thus, we present GEVO, a GS-based SLAM framework that achieves comparable fidelity as prior works by rendering (instead of storing) them from the existing map. Novel Gaussian initialization and optimization methods are proposed to delay the degradation of the rendered images over time. In various environments, GEVO achieves comparable map fidelity with up to 94x lower memory overhead than prior works. Ultimately, GEVO facilitates the design of ASIC accelerators for real-time, high-fidelity, and low-energy reconstruction on mobile devices.



▲ Figure 1: The region (a) catastrophically forgets (b) when no past images are used to retrain. GEVO (d) maintains high fidelity with significantly lower memory overhead for storing images compared with prior work (c).



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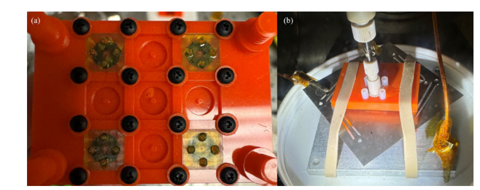
High-Impulse, Modular, 3D-Printed CubeSat Electrospray Thrusters Throttleable via Pressure and Voltage Control

11.09

H. Kim, and L. F. Velásquez-García

Sponsorship: MathWorks fellowship and the NewSat project. The NewSat project is co-funded by the Operational Program for Competitiveness and Internationlisation (COMPETE202), Portugal 2020, the European Regional Development Fund (ERDF), and the Portuguese Foundation for Science and Technology (FTC) under the MIT Portugal program.

This study presents a proof-of-concept for a novel droplet-emitting electrospray emitter array, designed for CubeSat thrusters. Traditionally, the fabrication of electrospray thrusters has been conducted in semiconductor cleanrooms to achieve precise microscale features. However, this manufacturing process is expensive and time-consuming due to its numerous individual steps. To address these challenges, the electrospray thruster developed in this study was 3D printed for a cheaper and faster fabrication. The thruster design is modular and features micro- and meso-scale components that allow for low power consumption while increasing thrust. Two different printing technologies, digital light processing and two-photon polymerization, were used to create these features. The device has optimized microfluidic channels to ensure uniform operation of emitter arrays. Testing demonstrated stable and uniform performance in a vacuum for the first time as a 3D-printed droplet-emitting electrospray emitter array. Both pressure and voltage were evaluated as ways to control the emitted current and thrust, with voltage control proving to be simpler and more effective approach, despite being less explored in the literature. The results show that this manufacturing approach could be a promising method for creating efficient electrospray thrusters for space propulsion.



◀ Figure 1: (a) Photograph of the device having 4 emitter modules and (b) triode configuration of the device tested in a vacuum chamber.

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Research Interests:
Actuators, Electronic devices, Electronics, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology.

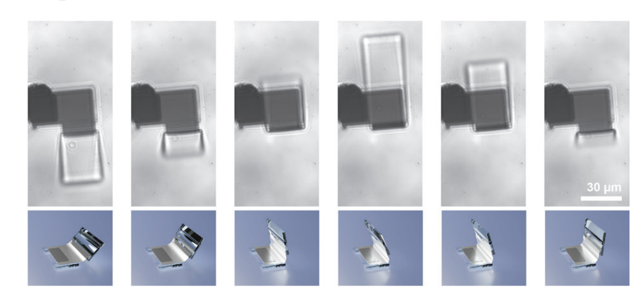
Ultra-thin Ruthenium Electrochemical Actuators

11.10

Z. Zheng, M. F. Reynolds, J. Clark, S. Norris, Q. Liu, N. L. Abbott, I. Cohen, and P. L. McEuen

Sponsorship: Cornell Center for Materials Research (DMR-1719875)

Electrochemical micro-actuators are essential components in micro-robotics, micro-fluidics, and biomedical devices. The surface electrochemical actuator (SEA) platform was developed by our group with atomic layer deposited (ALD) platinum and shown to provide locomotion in CMOS integrated micro-scale robots. Prior to the SEAs, there had been a lack of micron-scale actuator systems that can be processed with the standard semiconductor technology and well-integrated with on-board CMOS for control. Besides platinum, materials with similar properties have the potential to accomplish comparable functions and may possess advantageous properties like higher force output or better durability. In this work, we investigate such actuators of nano-scale thickness fabricated with ALD ruthenium. Similar to the platinum version, these actuators operate at low-voltages, low-power, with high durability, and ample force output, while being entirely compatible with industrial standard microelectronics processing. Distinguishingly, though, these actuators show atomic layer etching (ALE) when driven at certain higher voltages, which allows us to have special control over the precise thickness and thereby motions of these actuators. Thus, we show ruthenium as a viable option for electrochemical micro-actuators with unique additional features.



◀ Figure 1: A sequence of optical images and schematics showing an actuator's motion in a 1 Hz sweep cycle between +0.4 and -0.8 V.

Anode Engineering to Reduce On-Resistance of Field Emitter Arrays

11.14

Y. Shin, W. Chern, N. Karaulac, A. Akinwande

Sponsorship: AFOSR

Field emitter arrays (FEAs) are promising electron sources for high-power and high-frequency devices such as power switches and electric jet propulsion. The property of ballistic transport and high breakdown field make FEAs capable of low switching losses and on-resistance. However, prior optimization methods fail to account for changes in electrostatics along the vacuum channel due to the anode geometry and position, causing unfavorable phenomena in device characteristics.

In this work, we attempt to engineer the anode of FEAs, specifically for anodes configured with anode-to-emitter distances of 100m, using a MEMS fabricated silicon anode for on-chip integration. We find that the geometry and position of the anode improves the space charge limited (triode) regime of the FEA output characteristics, achieving lower on-resistance. These results pave a way to integrate FEAs into compact high-power switches for megawatt operation with comparable on-resistances with GaN and SiC.

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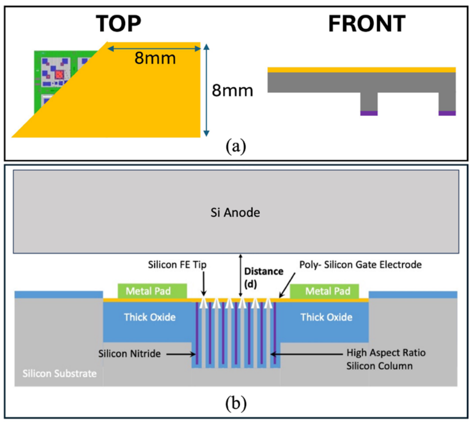
Research Interests:
Electronic devices, Field-Emitter devices, Nanomanufacturing, Nanotechnology, Si.



◄ Figure 1: (a) Anode design of three layers consisting of silicon oxide (purple), silicon (gray), and TiAu (gold). The relative size of the flat anode is compared to a sample device chip. (b) Schematic of the experimental setup relative to the device.

An Electromechanical Approach to High-Sensitivity Hydrogen Detection

11.15

M. Andrade, H. Kim, F. Niroui, J. Lang

Sponsorship: ExxonMobil

Hydrogen gas is considered as a promising source of environmentally friendly and sustainable energy towards global decarbonization. However, given the flammable and explosive nature of H2, highly sensitive and selective detection systems with fast response are needed to enable leakage monitoring to ensure safe deployment and use. To address this need, we propose an electromechanical platform for H2 sensing with the aim of achieving sub-ppm sensitivity. In our approach, an electromechanical structure is made composed of H2-responsive palladium (Pd) features. Once exposed to H2, the gas molecule will diffuse through Pd causing lattice expansion which translates into deflection of the mechanically-mobile feature, in particular a cantilever. The deflection can be measured using electrical and optical means to enable high-accuracy detection and quantification of H2 as will be shown in this project through a combination of modeling and experimental characterization. With this new sensor, H2 concentration can be monitored with high sensitivity and selectivity, providing a novel approach for H2 detection and quantification across the hydrogen supply chain.

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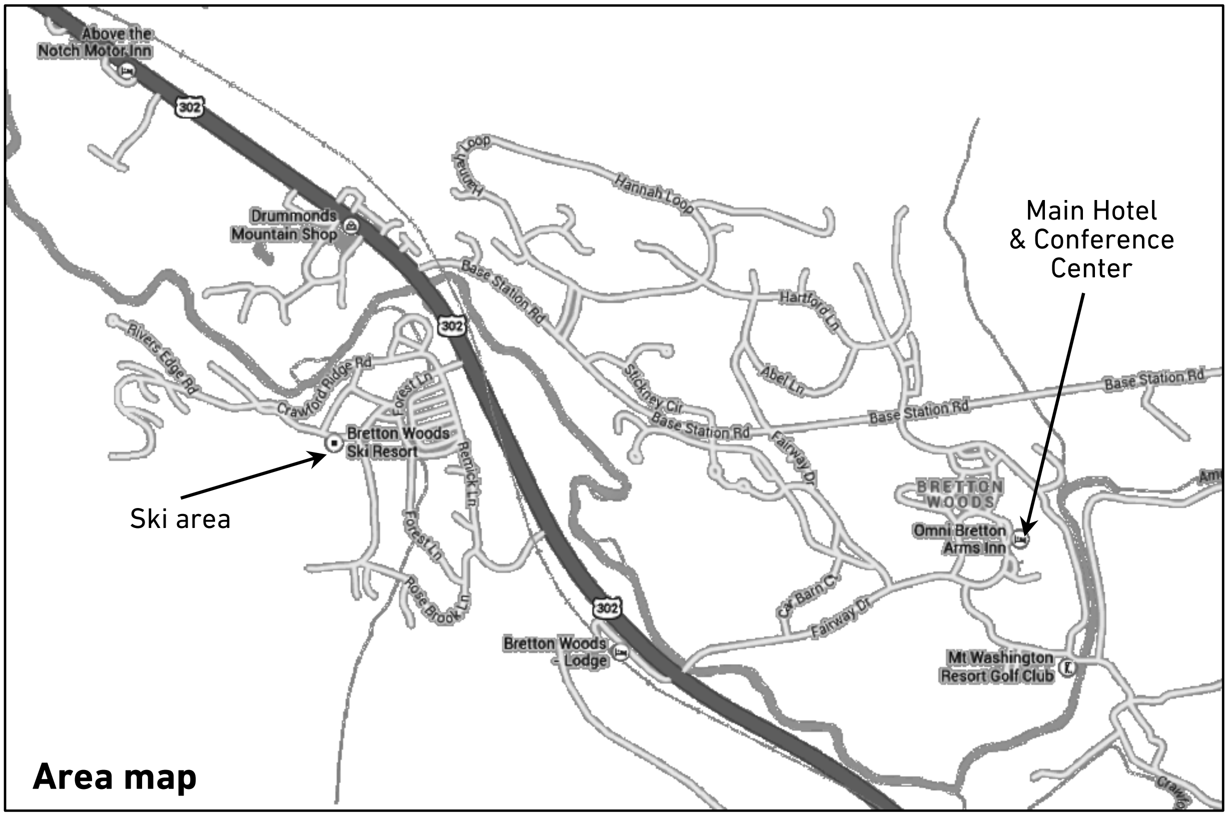
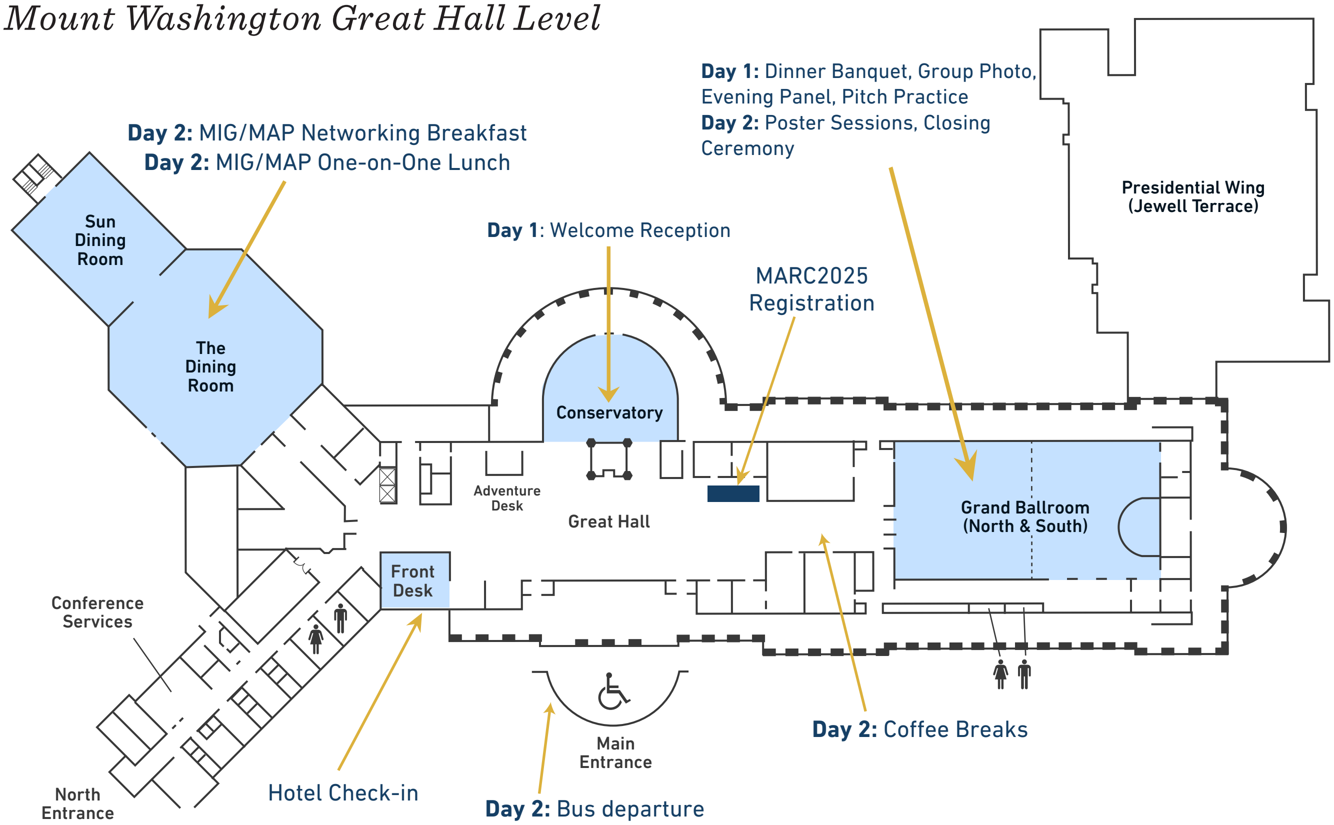
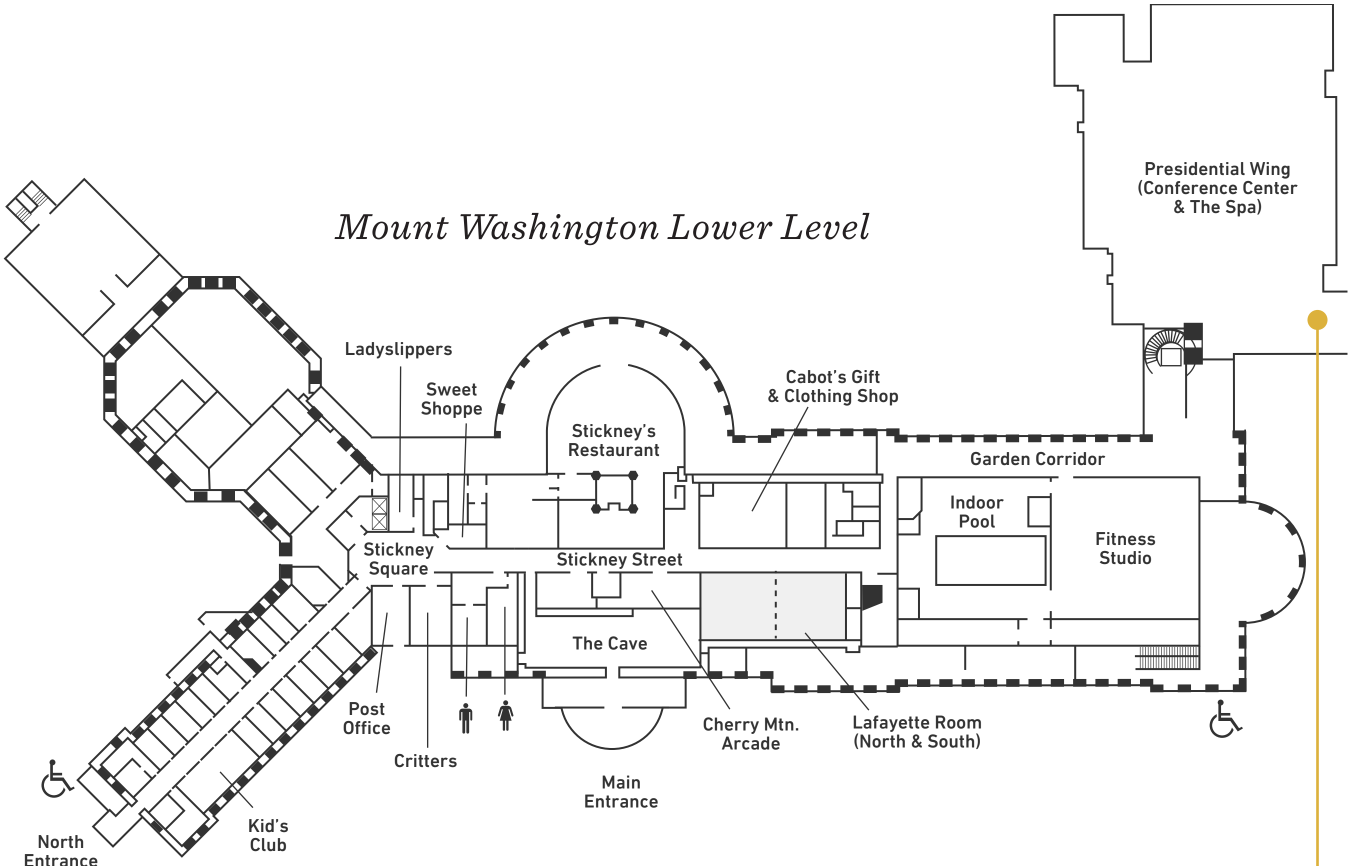
MAPS

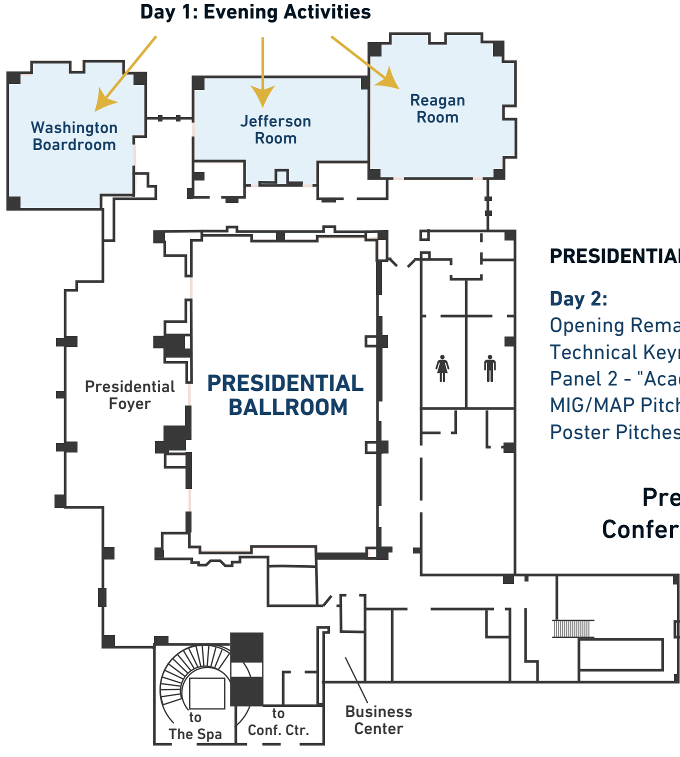


Mount Washington Great Hall Level



DAY 1 & 2: LOWER LEVEL





PRESIDENTIAL BALLROOM

Day 2:
Opening Remarks
Technical Keynote
Panel 2 - "Academia to Industry"
MIG/MAP Pitches
Poster Pitches

Presidential Wing Conference Center Level

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