MARC2026:

Microsystems Annual Research Conference

PROCEEDINGS

January 27-28, 2026
Omni Mount Washington Resort

Massachusetts Institute of Technology

MTL: MICROSYSTEMS TECHNOLOGY LABORATORIES

MARC2026:

MICROSYSTEMS ANNUAL RESEARCH CONFERENCE

JANUARY 27–28, 2026 • BRETTON WOODS, NH

Massachusetts Institute of Technology

MTL: MICROSYSTEMS TECHNOLOGY LABORATORIES

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Kelly Gavin, MIT.nano
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Jami Mitchell, MTL

PDF version, January 2026

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CONTENTS

INTRODUCTION

Dear friends, collaborators, and colleagues,

Welcome to MARC 2026! We are delighted to gather once again to celebrate the Microsystems Technology Laboratory's continued leadership in microelectronics research, education, and innovation. Since its founding in 1984, MTL has remained at the forefront of semiconductor discovery, fostering a community that bridges fundamental science, emerging technologies, and real-world impact.

This year, MARC 2026 introduces an updated conference format designed to encourage deeper engagement across academia, industry, and entrepreneurship. The conference opens with opportunities for informal connection and reflection, followed by a restructured technical program that emphasizes interaction, discussion, and visibility across the breadth of research represented within the MTL community.

Our opening evening features a dinner banquet followed by a Shark Tank–style panel that brings together leaders from venture capital, industry, and academia to discuss innovation, commercialization, and the pathways from research to impact. We are pleased to welcome our panelists: Richard Collins (Engine Ventures), Lisa DeCrescente (Revvity, Inc.), Rahul Meka (Playground Global), Vera Schroeder (Safar Partners), and Vladimir Bulović (MIT). Their diverse perspectives promise a dynamic discussion on translating cutting-edge research into real-world technologies.

On the second day, we are honored to welcome our keynote speaker, Myung-Hee Na, Vice President and Semiconductor Technologist at Intel. With extensive experience spanning advanced semiconductor technologies and industrial leadership, Dr. Na will share insights into the evolving semiconductor landscape and the challenges and opportunities shaping the future of the field.

Following the keynote, MARC 2026 features poster pitches and extended poster sessions designed to foster meaningful technical exchange among students, faculty, and industry participants. Dedicated networking opportunities further support one-on-one conversations and collaboration, reinforcing MARC's role as a nexus for research, mentorship, and innovation.

This conference would not be possible without the tireless efforts of the MTL and MIT.nano staff, our student organizing committee, and the broader MTL community. We are deeply grateful to everyone who contributed their time and energy to making MARC 2026 possible.

We hope MARC 2026 inspires new connections, strengthens existing collaborations, and sparks ideas that will shape the future of microelectronics. Thank you for joining us, and we wish you a memorable and rewarding MARC 2026.

Warm regards,

Stella Lessler and Hyeonsok Kim
MARC 2026 Co-Chairs

DAY 1: JANUARY 27

10:00 AM – 4:00 PM	**Winter Activities**
1:00 PM - 5:00 PM	**Faculty/Industry Lunch & Workshop** *Jefferson Room*
3:00 PM – 5:00 PM	**Check-in & Registration** *Great Hall* **Conference Registration:** *Registration Desk* **Hotel Check-in:** *Hotel Front Desk*
5:00 PM – 6:00 PM	**Welcome Reception** *Conservatory*
6:00 PM – 6:30 PM	**Opening Remarks** *Grand Ballroom*
6:30 PM – 7:30 PM	**Dinner Banquet** *Grand Ballroom* **Team Building Activity**
7:30 PM – 8:45 PM	**Shark Tank & Shark Panel** *Grand Ballroom*
8:45 PM – 9:00 PM	**Group Photo** *Grand Ballroom*
9:00 PM – 12:00 AM	**Evening Activities** *Presidential Ballroom,* *Washington, Jefferson, Reagan Rooms*
9:00 PM - 11:45 PM	**Pitch Practice & AV Check** *Grand Ballroom*

DAY 2: JANUARY 28

7:00 AM – 9:00 AM	**Breakfast** **Faculty/Industry Breakfast**	*Main Dining Room* *Jefferson Room*
9:00 AM – 9:15 AM	**Opening Remarks**	*Presidential Ballroom*
9:15 AM – 10:15 AM	**Keynote Address** **Myung-Hee Na** **Semiconductor Technologist & Vice President, Intel**	*Presidential Ballroom*
10:15 AM – 10:40 AM	**Morning Refreshments**	*Presidential Foyer*
10:20 AM – 11:00 AM	**Poster Pitches (Session 1)** Session 3 - Materials - Synthesis & Characterization Session 6 - Nanotechnology & Nanomaterials Session 8 - Photonics and Optoelectronics Session 10 - Quantum Science and Engineering	*Presidential Ballroom*
11:05 AM – 12:35 PM	**Poster Session 1/Demos** Sessions 3, 6, 8 and 10	*Grand Ballroom*
12:40 PM – 2:10 PM	**Lunch**	*Main Dining Room*
1:30 PM – 2:10 PM	**MIG One-on-One Meetings**	*Presidential Ballroom*
2:15 PM – 2:55 PM	**Poster Pitches (Session 2)** Session 1 - Circuits & Systems Session 2 - Electronic, Magnetic & Spintronic Devices Session 4 - Medical Devices & Biotechnology Session 5 - MEMS, Field-Emitter, Thermal Fluidic Devices & Robotics Session 7 - Neuromorphic Devices & AI Hardware Accelerators Session 9 - Power Devices and Circuits	*Presidential Ballroom*
3:00 PM – 4:30 PM	**Poster Session 2** Sessions 1, 2, 4, 5, 7 and 9	*Grand Ballroom*
4:15 PM – 4:40 PM	**Afternoon Refreshments**	*Grand Ballroom Lobby*
4:45 PM - 5:00 PM	**Closing Ceremony**	*Grand Ballroom*

KEYNOTE

Myung-Hee Na

Vice President and General Manager of Technology Research

Intel

Myung-Hee Na is currently the Vice President and General Manager of Technology Research in Intel. Over 20 years, she has been known as the semiconductor technologist and held various executive positions in global semiconductor companies including US, Belgium and Korea. She has been very diverse and deep semiconductor experiences from device to designs including logic and memory technologies over 20 years. Prior to joining Intel in April 2024, over the past three years she was Vice President of the Revo-lutionary Technology Center in SK Hynix, Korea. In this role she was responsible for multi-decade semi-conductor research roadmaps and strategies for memory centric and emerging computing domains such as emerging memory, and beyond memory.

From 2019-2023, Myung-Hee also worked at imec in Belgium where she was Vice President, Technology Solutions and Enablement. In this role she was responsible for overall 10-year research strategies for CMOS pathfinding and emerging computing domains such as edge computing. After completing her Ph.D. in Physics, Dr. Na started her career at IBM in 2001, where she held various technical, managerial and executive roles until early 2019. During that time, she was promoted to Distinguished Engineer and Technical Executive. At IBM Research, she successfully led Research and Development for multiple gener-ations of semiconductor technologies, including high-K metal gate, FinFET, and Nanosheet development. Moreover, she has co-authored numerous research papers and U.S. and international patents.

PANELIST SPEAKERS

Shark Tank Panel

RICHARD COLLINS

Engine Ventures

Richard is Senior Director of Research at Engine Ventures, a venture capital firm spun out of MIT that invests in the next generation of Tough Tech founders. He leads the firm's research function, generating insights that guide new investments and support the portfolio. He brings deep experience in strategic consulting on emerging technologies and holds a PhD in Inorganic Chemistry from the University of Oxford.

VERA SCHROEDER

Safar Partners

Vera Schroeder is a Partner and Investment Committee Member at Safar Partners. Vera brings broad experience in the fields of chemistry, nanoscience, and materials science to the Safar team. As a graduate student, she worked in the laboratory of Professor Tim Swager at MIT focused on carbon-nanotube-based chemical sensing. While at MIT, she also spent her time at Sloan and HBX learning about venture creation and strategy, as well as interning at MP Healthcare Venture Management fund. She holds a BS and MS in Chemistry from RWTH Aachen University and a Ph.D. in Chemistry from MIT.

RAHUL MEKA

Playground VC

Rahul joined Playground in 2023 and focuses on deep tech investing across decarbonization, automation, and AI.

Rahul's professional journey began at Magna International, where he focused on electrification, autonomy in mobility, and other aspects of manufacturing and robotics. Following his tenure at Magna, he contributed his expertise to Akasha Imaging, which was later acquired by Intrinsic, an Alphabet company based out of Google X. At Intrinsic, Rahul furthered his exploration of computational imaging and related technologies.

Rahul holds an MBA in Finance and Strategy from the University of Chicago, complemented by an MSc. in Mechanical Engineering from Columbia University and a B Engg. in Mechanical Engineering from Birla Institute of Technology and Science.

When he is not busy sourcing deals and supporting companies, Rahul enjoys studying watches and playing soccer.

VLADIMIR BULOVIĆ

MIT.nano

Vladimir Bulović is a Professor of Electrical Engineering at the Massachusetts Institute of Technology, holding the Fariborz Maseeh Chair in Emerging Technology. He directs the Organic and Nanostructured Electronics Laboratory, co-leads the MIT-Eni Solar Frontiers Center, leads the Tata GridEdge program, and is the Founding Director of MIT.nano, MIT's new 200,000 sqft nano-fabrication, nano-characterization, and prototyping facility that opened in the summer of 2018. He is an author of over 250 research articles (cited over 45,000 times) and an inventor of over 100 U.S. patents in areas of light emitting diodes, lasers, photovoltaics, photodetectors, chemical sensors, programmable memories, and micro-electro machines, majority of which have been licensed and utilized by both start-up and multinational companies. The three start-up companies Bulović co-founded jointly employ over 400 people, and include Ubiquitous Energy, Inc., developing nanostructured solar technologies, Kateeva, Inc., focused on development of printed electronics, and QD Vision, Inc. (acquired in 2016) that produced quantum dot optoelectronic components. Products of these companies have been used by millions. Bulović was the first Associate Dean for Innovation of the School of Engineering and the Inaugural co-Director of MIT's Innovation Initiative, which he co-led from 2013 to 2018. For his passion for teaching Bulović has been recognized with the MacVicar Fellowship, MIT's highest teaching honor. He completed his Electrical Engineering B.S.E. and Ph.D. degrees at Princeton University.

LISA DECRESCENTE

Revvity, Inc.

Lisa DeCrescente is an experienced Patent Attorney, currently serving as Intellectual Property Counsel at Revvity, Inc. At Revvity, Lisa manages an extensive patent portfolio of over 3,000 patents covering a broad array of technologies, including microfluidics, mechanical and electrical devices, medical devices, next generation sequencing, and chemical compounds. In her role, she also evaluates third party IP, conducts trademark and patentability analyses, evaluates and maintains trade secrets, and litigates IP matters. Lisa has a Juris Doctor with honors in Intellectual Property from Quinnipiac University School of Law, where she served as Editor-in-Chief of the Quinnipiac Law Review, and a Bachelor of Science in Biomedical Engineering from Rensselaer Polytechnic Institute, where she was a research assistant in microfluidics in the Massachusetts General Hospital Cancer Research Center.

MTL MICROSYSTEMS INDUSTRIAL GROUP (MIG)

Analog Devices, Inc.
Applied Materials
Edwards
Ericsson
GlobalFoundries
Hitachi High-Tech
IBM Research
Intel
Lam Research Corp.
Lockheed Martin
MuRata
NEC Corporation
Soitec
TSMC
Texas Instruments

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!

It is our distinct pleasure to welcome all of our industry partners to join us again at MARC2026.

ABSTRACTS

SESSION 1: CIRCUITS & SYSTEMS

SESSION 2: ELECTRONIC, MAGNETIC & SPINTRONIC DEVICES

SESSION 3: MATERIALS - SYNTHESIS & CHARACTERIZATION

SESSION 4: MEDICAL DEVICES & BIOTECHNOLOGY

SESSION 5: MEMS, FIELD-EMITTER, THERMAL, FLUIDIC DEVICES & ROBOTICS

SESSION 6: MEDICAL DEVICES & BIOTECHNOLOGY

SESSION 7: NEUROMORPHIC DEVICES & AI HARDWARE ACCELERATORS

SESSION 8: PHOTONICS AND OPTOELECTRONICS

SESSION 9: POWER DEVICES & CIRCUITS

SESSION 10: QUANTUM SCIENCE & ENGINEERING

LEDRO: LLM-Enhanced Design Space Reduction and Optimization for Analog Circuits

1.01

D. Kochar, H. Wang, A. Chandrakasan, X. Zhang

Sponsorship: MIT-IBM Watson AI Lab

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Research Interests:
Artificial Intelligence
Electronics
Integrated circuits
Machine Learning
Si
Systems
AI for Chip Design

Traditional approaches for designing analog circuits are time-consuming and require significant human expertise. Existing automation efforts using methods like Bayesian Optimization (BO) and Reinforcement Learning (RL) are sub-optimal and costly to generalize across different topologies and technology nodes.

In our work, we introduce a novel approach, LEDRO, utilizing Large Language Models (LLMs) in conjunction with optimization techniques to iteratively refine the design space for analog circuit sizing. LEDRO is highly generalizable compared to other RL and BO baselines, eliminating the need for design annotation or model training for different topologies or technology nodes.

We conduct a comprehensive evaluation of our proposed framework and baseline on 22 different Op-Amp topologies across four FinFET technology nodes. Results demonstrate the superior performance of LEDRO as it outperforms our best baseline by an average of 13% FoM improvement with 2.15x speed-up on low complexity Op-Amps and 48% FoM improvement with 1.7x speed-up on high complexity Op-Amps. This highlights LEDRO's effective performance, efficiency, and generalizability.

In conclusion, the generalizability and adaptability with other optimization techniques marks an advancement in the field, offering a solution for complex analog circuit design challenges.

A Microwave Microfluidic Sensor for Highly Sensitive Permittivity Measurements

1.02

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Sponsorship: Draper Scholars

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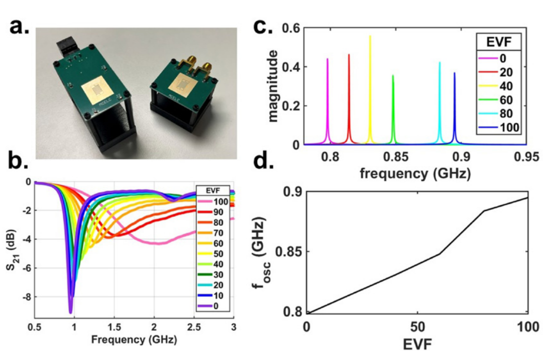
Research Interests:
Communications
Electronics
Integrated circuits
Medical devices & systems

Microwave resonators can detect changing permittivity values in liquid samples, paving the way for a new approach to material sensing. As the liquid changes in the microfluidic channel above the resonator, a shift in resonant frequency occurs. While these resonators can achieve high sensitivity when coupled to a transmission line that is excited by a vector network analyzer (VNA), this approach is impractical due to the large size and expensive cost of a VNA.

In this work, a meandering complementary electric LC resonator is optimized for high sensitivity. This resonator is integrated into a Colpitts oscillator, effectively converting the resonant frequency into an oscillation frequency that is directly correlated to liquid permittivity. The system is tested with varying volume fractions of ethanol (EVF) in water, spanning a wide permittivity range of 10 to 80. This approach eliminates the need for a VNA and demonstrates the potential for a portable low-cost liquid sensor.



◄ Figure 1: a. Fabricated resonator and oscillator b. Measured resonator S21 parameters for 0-100% EVF c. Simulated oscillator output frequency spectrum for 0-100% EVF d. Simulated oscillation frequency vs EVF.

Scalable Superconducting Multilayer Process for Digital Imager Readout with Nanocryotrons

R. A. Foster, D. J. Paul, F. Incalza, E. Batson, O. Medeiros, K. K. Berggren

Sponsorship: The material is based upon work supported by NASA under award No(s) 80NM0018F0610.

1.03

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Research Interests:
Electronic devices
Electronics
Nanotechnology

Multiplexing superconducting photon detectors for imagers is a challenge. The largest-scale demonstrations to date use time-of-flight or frequency-multiplexing schemes that require complex, power-hungry readout electronics. Digital solutions, such as those based on single-flux-quantum (SFQ) exist, but magnetic flux trapping and interfacing with the high-impedance of CMOS persist as problems for SFQ. Instead of SFQ, current-controlled superconducting switches known as nanocryotrons offer a promising alternative; their high impedance allows driving of high-impedance loads, and they can be tuned to be insensitive to ambient magnetic fields. Several prior works have demonstrated basic building blocks for nanocryotron circuits using electron-beam lithography, the majority of which are fabricated on a single superconducting layer. In this work, we develop a scalable fabrication process based on photolithography for multilayer superconducting nanocryotron circuits. Initial cryogenic testing shows a relative variation in switching current less than 19% for the narrowest nanocryotron gate width of 300 nm, comparable to that of 30 nm gates fabricated with electron-beam lithography. Superconducting vias that allow zero-resistance connections between the superconducting layers exhibit less than 23% variation in switching current. We are currently investigating thermal crosstalk and maximum switching speed of the nanocryotrons. This fabrication process will enable fabrication of nanocryotron circuits to perform low-power digital readout of superconducting photon detector arrays.

Interface Circuits for Analog In-Memory Computing

M. A. G. Elsheikh, H. -S. Lee

Sponsorship: MIT/MTL Samsung Semiconductor Research Fund

1.04

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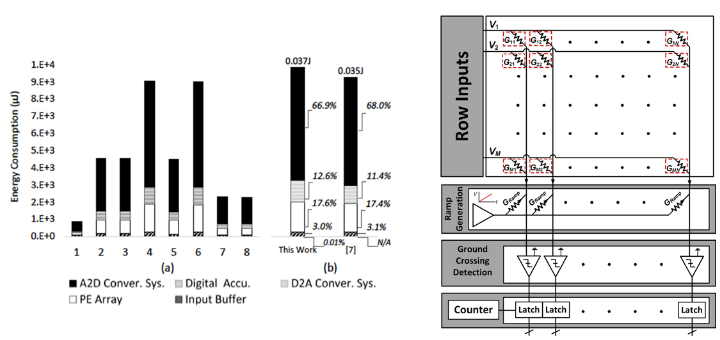
Research Interests:
Communications
Energy harvesting devices & systems
GaN
Integrated circuits
Lasers
Machine Learning
Medical devices & systems
Photonics
Systems

Machine learning (ML) applications have found their way into energy-constrained environments, which requires special attention to the speed and the energy efficiency of the compute systems. Performing the computations in memory alleviates the substantial energy overhead from data movement between the memory and the processing elements. Moreover, analog compute-in-memory (CIM) is a promising alternative to digital implementations as multiplication and addition are two operations that dominate ML, and which are highly parallelized in analog implementations. However, the energy bottleneck in analog CIM comes from the read-out peripherals, as the analog outputs need to be digitized. In this work, we propose a ramp analog-to-digital converter with programmable non-linear quantization profiles. This maintains the accuracy at fewer quantization levels and optimizes the read-out speed and energy efficiency. This will enable the deployment of ML applications in more mobile environments.



(a) (b)

◀ 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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Research Interests:
Artificial Intelligence
Batteries
Energy
Energy harvesting devices & systems
Fuel cells
Microfluidic devices & systems
Nanotechnology
Thermal structures, devices & systems

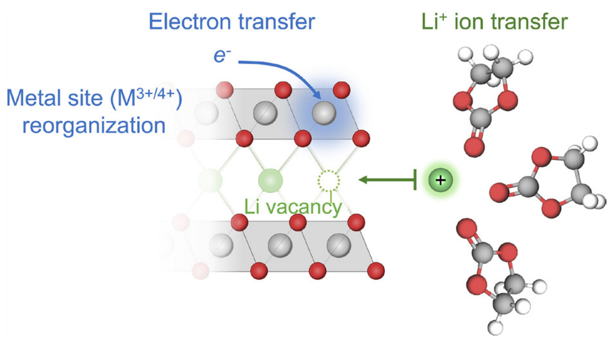
Lithium-ion Intercalation by Coupled Ion Electron Transfer

1.05

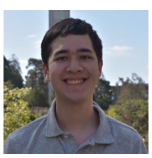
S. Pathak, Y. Zhang, D. Fraggedakis, T. Gao, D. Zhuang, C. Grosu, Y. Samantaray, A.R.C. Neto, S.R. Duggirala, B. Huang, Y.G. Zhu, L. Gordano, R. Tatara, H. Agarwal, R.M. Stephens, M.Z. Bazant, Y. Shao-Horn
Sponsorship: Shell International Exploration and Production Inc., Toyota Research Institute

Understanding intercalation kinetics is central to design and operation of lithium-ion batteries that power today's devices and transportation. There are predictive models of intercalation, but its fundamental mechanism remains poorly understood. We hypothesize that lithium intercalation proceeds by coupled ion-electron transfer (CIET).

To test our hypothesis, we measured intercalation kinetics for common electrodes in a number of electrolytes and temperatures. We found that CIET theory fits the data well, collapsing hundreds of data points onto a universal current-voltage curve with only a small set of intrinsic material parameters. This presents a unified framework for lithium intercalation based on CIET, supported by evidence across a wide range of common electrodes, electrolytes, and operating conditions. By linking interfacial electrochemistry with electrode performance, CIET theory may catalyze new strategies to develop faster-charging, higher-power energy storage technologies.



◀ Figure 1: Schematic of lithium-ion intercalation by coupled ion electron transfer.



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Research Interests:
Communications
Electronic devices
Electronics
Integrated circuits
Molecular & polymeric materials
Photonics
Quantum devices
Si

Simultaneous Phase and Amplitude Sensing in Molecular Clocks

1.06

T. Weigand, R. Han
Sponsorship: Jacobs Presidential Fellowship

Molecular clocks based on the sub-terahertz rotational spectroscopy of gas molecules have demonstrated a potential for cheap, compact clocks with comparable long-term Allan deviation to chip-scale atomic clocks (CSACs). Previous molecular clock designs have relied on amplitude sensing to lock onto the rotational absorption line. However, thus far the long-term stability still trails CSACs, with a major limiting factor being the slope of the absorption line. For an amplitude sensing based molecular clock, the slope of the rotational absorption line determines the frequency sensitivity and thus the clock stability. The slope can be increased by reducing the pressure and temperature of the gas, but this requires larger gas cells and active cooling equipment, increasing size and cost.

In this work, we investigate the potential to increase molecular clock performance by simultaneously sensing both the absorption and phase shift of the gas. From the Kramers-Kronig relations, we know that for narrow absorption lines there also exists a corresponding change in the index of refraction. This results in a gas cell phase shift that is dependent on the frequency, which we can exploit to increase the frequency sensitivity of the clock. We present a novel method of utilizing an IQ plane to analyze the amplitude change and phase shift induced by the gas cell, allowing us to calculate the frequency sensitivity of both phase and amplitude sensing. This analysis also reveals that we can simultaneously utilize phase and amplitude sensing to further increase the clock stability beyond what is possible with only amplitude sensing. Finally, we discuss the required circuits and locking algorithm for implementing phase and amplitude sensing into a molecular clock.

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Accelerating Large-Scale Reasoning Model Inference: Self-Speculative Decoding with Sparse Attention

1.07

Y. Zhao, J. Tang, K. Zhu, Z. Ye, C. Chang, C. Lin, J. Park, G. Xiao, M. S. Abdelfattah, M. Gao, B. Kasikci, S. Han, I. Stoica

Reasoning language models have demonstrated remarkable capabilities on challenging tasks by generating chain-of-thought solutions. However, such lengthy generation shifts the inference bottleneck from compute-bound to memory-bound. To generate each token, the model applies full attention to all previously generated tokens, requiring memory access to an increasingly large KV cache. Consequently, longer generations demand more memory access for every step, leading to substantial pressure on memory bandwidth. To address this, we introduce SpecGen, a speculative decoding framework that reuses the same model as the draft and target models. SpecGen features a novel sparse attention mechanism PillarAttn as the draft model, which accurately selects critical tokens via elegantly reusing information from the verification stage.

Furthermore, SpecGen co-designs self-speculation with three system innovations:
(1) a unified scheduler to batch token drafting and verification,
(2) delayed verification for CPU/GPU overlap, and
(3) dynamic KV cache management to maximize memory utilization.

Across various models and datasets, SpecGen outperforms state-of-the-art solutions, with an up to 2.13x throughput speedup.

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Research Interests:
Artificial Intelligence
Integrated circuits
Machine Learning
Medical devices & systems

In Vivo Demonstration of Ultra-Low-Power Post-Quantum Secure Wireless Ingestible Capsule in Swine

1.08

H. S. Lee, S. Jang, G. Traverso, A. P. Chandrakasan
Sponsorship: ARPA-H (6951485)

Wireless Ingestible Capsules (WICs) are emerging as one of the next-generation healthcare technologies due to their minimally invasive operation and powerful capabilities. Their application area ranges from monitoring the gastrointestinal (GI) tract to diagnostics and drug delivery. Many of their applications include wireless communication with external devices which could be vulnerable for sensitive medical information leakage.

In this work, we demonstrate an ultra-low-power post-quantum secure communication protocol for WICs in swine. A 4-layer custom printed circuit board (PCB) was designed with a microcontroller, a 915 MHz antenna, and a 50 mAh Li-ion battery. A custom designed package was fabricated using a resin 3D printer with biocompatible PolyJet material. The in vivo experiment successfully demonstrated the functionality of the capsule and validated the proposed protocol. These results show that our prototype provides a practical demonstration of energy-efficient and secure data transfer, an essential capability for future ingestible systems.

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Research Interests:
Integrated circuits

Delay Line Design in High Bandwidth Continuous-Time Pipelined ADC

1.09

H.-F. Hung, H. S. Lee

Sponsorship: Shillman Fellowship - LMR

Analog to digital converters (ADC) with increasingly high bandwidth are in high demand since they can directly serve as the front-end of an RF block. Pipelined ADCs using time-interleaving and digital calibration have been proven to achieve high resolution. A continuous-time pipelined ADC combines the inherent anti-aliasing benefits of continuous-time front-ends and a resistive input impedance that is easy to drive.

One of the major challenges in designing a continuous-time pipelined ADC is constructing a good delay line that matches the signal path to the magnitude and phase of the interleaved ADC-DAC path. Delay lines are important because they subdue the residue signal to ensure that the backend ADC will not saturate and improve SNR. Previous efforts to construct delay lines used cascaded RC or LC lattices and series resistance to achieve the delay necessary within the ADC bandwidth. While RC lattices offer worse overall matching, they consume less area, making them an appealing option over LC lattices in lower bandwidth applications. Systems previously built with these lattices offered good matching until 1-1.5GHz bandwidth. However, matching beyond such frequencies tail off. Given that the bandwidth of the ADC we are constructing is 5GHz, new delay lines need to be designed.

Our new method allows the ADC bandwidth to be extended to 5GHz. This involves combining RC and LC lattices into the same delay line, in addition to adding a new high-pass path that compensates for the sharp magnitude and phase differences at higher frequencies (3-5GHz). Currently, the new delay line could achieve a worst-case residue of 18% post-amplification across the entire 5GHz bandwidth, which is sufficient for the ADC's operation. Future goals involve tuning the delay line to account for PVT and constructing other blocks such as a highly interleaved first stage Flash-ADC, DAC, high bandwidth TIA, and backend ADC to finish the entire system.

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Research Interests:
Actuators
Systems
Robotics

Aerobatic Maneuvers in Insect-scale Flapping-wing Aerial Robots via Deep-learned RobustTube Model Predictive Control

1.10

N. Y. Hsiao, A. Tagliabue, O. Matteson, S. Kim, T. Zhao, J. P. How, and Y. Chen

Sponsorship: NSF (FRR-2202477, FRR-2236708), MathWorks

Aerial insects exhibit agile maneuvers such as sharp braking, saccades, and body flips under disturbances; in contrast, insect-scale aerial robots are limited to tracking smooth trajectories with small acceleration. To achieve similar flight capabilities, insect-scale robots require a robust and computationally efficient controller. Here, through designing a deep-learned robust tube model predictive controller, we showcase exceptional flight agility in a 750-milligram flapping-wing robot. Our neural network controller can track aggressive trajectories and run at a high rate on a compute-constrained system. The robot demonstrates saccades with lateral speed and acceleration of 197 centimeters per second and 11.7 meters per second square, representing an improvement of 447% and 255% over prior results. The robot also performs saccades under 160 centimeters per second wind disturbance and completes 10 consecutive somersaults in 11 seconds. These results represent a milestone in achieving insect-scale flight agility and inspire future investigations on sensory and compute autonomy.

Sub-THz Transceiver with Sub-Millimeter Ranging Accuracy for Distributed Apertures

1.11

N. Lee, R. Han

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Communications
Electronic devices
Electronics
Integrated circuits
Sensors

Distributed apertures (i.e., distributed phased arrays) offer exceptional beamforming capability and scalability for next-generation communication and sensing systems. To achieve precise open-loop coordination of spatially separated antennas, the distance between them must be known with sub-wavelength accuracy, translating to the sub-millimeter scale for mm-Wave and sub-THz operations. Accuracies of existing ranging techniques rely on large bandwidth and heavy digital processing, which complicate hardware implementation and make deployment of such architectures in distributed nodes challenging.

In this work, we suggest a sub-THz transceiver pair that exchanges multi-tone continuous wave (CW) signals to perform precise ranging. Returned waves are processed with respect to their phase to retrieve distance information. A binary quantization procedure, which resembles the operation of a pipelined analog-to-digital-converter (ADC), provides a systematic approach to achieving sub-millimeter ranging accuracy. The narrowband nature of tone signals simplifies hardware design and allows for simultaneous ranging and distributed beamforming operation. Simulation results demonstrate the accuracy and practicality of the proposed architecture. The collaborative operation of distributed apertures enabled by this technology opens new paradigms for miniature wireless systems, as individual nodes will no longer be constrained in size due to their physical apertures.

EARL: Entropy-Aware RL Alignment of LLMs for Reliable RTL Code Generation

1.12

J. Shi, Z. Gao, C. Ko, and D. Boning

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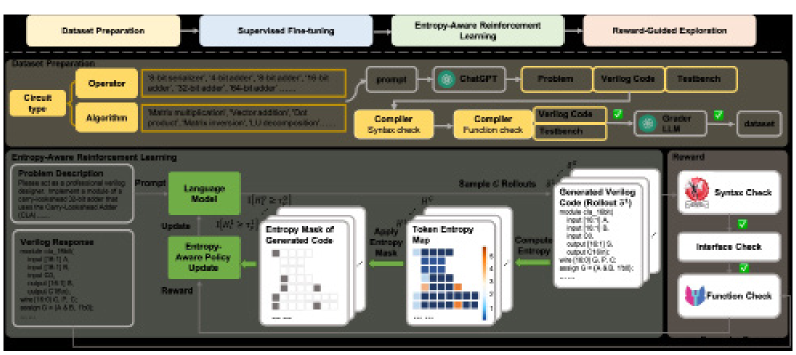
Recent advances in large language models (LLMs) have shown promise for synthesizing Register-Transfer Level (RTL) code from natural language. However, practical RTL generation remains challenging due to syntax errors, functional hallucinations, and weak alignment with designer intent. Reinforcement Learning with Verifiable Rewards (RLVR) offers a principled way to address these issues by leveraging executable and formally checkable hardware feedback during training. Yet, in long and highly structured RTL sequences, applying RL uniformly across all tokens is inefficient, as many tokens have little impact on functional correctness. We propose EARL, an Entropy-Aware Reinforcement Learning framework for Verilog generation. EARL performs policy optimization with verifiable rewards while using entropy-guided selective updates to focus gradient learning on high-entropy, functionally critical tokens. Experiments show that EARL improves pass rates by up to 14.7% over prior LLM baselines, while improving training stability and reducing unnecessary updates.



◀ Overview of the EARL framework for Verilog generation. The top panel presents the end-to-end pipeline. The bottom panel details the three core components.

Development of Superconducting Nanowire Josephson Junctions and Circuits

1.13

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Research Interests:
Artificial Intelligence
Electronic devices
Electronics
Information processing
Integrated circuits

Josephson junctions are a unique superconducting circuit element that can be used for high-speed, energy-efficient digital or quantum logic. Josephson junctions can be formed in a wide variety of geometries, including superconducting nanowire constrictions. These devices offer simplified fabrication and compact feature sizes but haven't been developed beyond few-junction circuits due to the intrinsically large critical current variation.

In this work, we introduce a process for fabricating nanowire Josephson junctions and constructing digital logic circuits that mitigate the detrimental impact of critical current variation. Varying junction geometries and materials are characterized using time-dependent Ginzburg-Landau model. Simulations of variation-tolerant circuits demonstrate the viability of developing large-scale computing circuits using this technology.

Integrated CMOS Microwave Control for Scalable Neutral Atom Quantum Computing

1.14

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Sponsorship: MIT Jacobs Presidential Fellowship

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Research Interests:
Communications
Electronics
Integrated circuits
Photonics
Quantum devices
Sensors
Si
Systems

Cold atom-based qubits have emerged as a leading modality for universal quantum computing, offering key benefits such as long coherence times, reconfigurable and scalable form factors, and the ability to operate in room-temperature vacuum environments. Despite these advantages, the transition to large-scale atom qubit arrays is constrained by the limited scalability of bulky microwave equipment and free-space bulk optics required for coherent, high-density qubit control. As such, there is a critical need for integrated electronic-photonic solutions to bridge this gap.

In this effort, we propose a monolithic microwave CMOS controller featuring a scalable array of high-speed IQ modulators, co-designed and heterogeneously integrated with a photonic controller. The architecture will support the generation of precise optical sidebands capable of driving both single-photon and two-photon Raman transitions for individual atom control. Future efforts will also explore architectures to enable purely microwave-driven transitions within the Rydberg manifold at scale, bypassing intermediate electro-optic modulation. These advancements pave the way for high-fidelity, scalable local addressing, essential for large-scale neutral atom quantum computing.

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Research Interests:
Artificial Intelligence
Time Series

Chameleon: Channel-Dependent State-Space Model for Multivariate Time Series Forecasting

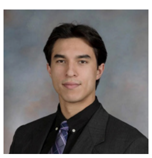
1.15

Y. Wu, D.S. Boning

Accurate multivariate time series forecasting (MTSF) is essential for decision-making in complex, interconnected systems. While channel-independent (CI) strategies provide strong baselines by emphasizing temporal dynamics, they inherently overlook informative cross-variable correlations. In contrast, existing channel-dependent (CD) architectures often sacrifice sequential modeling fidelity to incorporate global channel mixing.

This work introduces Chameleon, a novel CD state space model (SSM) that unifies stable temporal learning with dynamic cross-series calibration. Building on GatedDeltaNet as the intra-series backbone, it draws a theoretical connection between modern SSMs and the Kalman filter. Chameleon implements a dual-role mechanism in which each input patch token simultaneously acts as a control input for the temporal prediction step and as a measurement signal for a multivariate correction step. By refining hidden states with a learned correlation matrix at every step, Chameleon adaptively corrects predictions using instantaneous cross-series information.

Preliminary results on standard benchmarks show that Chameleon outperforms state-of-the-art CI baselines, establishing a scalable and theoretically grounded framework for MTSF.



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Research Interests:
Artificial Intelligence
Batteries
Electronic devices
Electronics
Energy
Systems

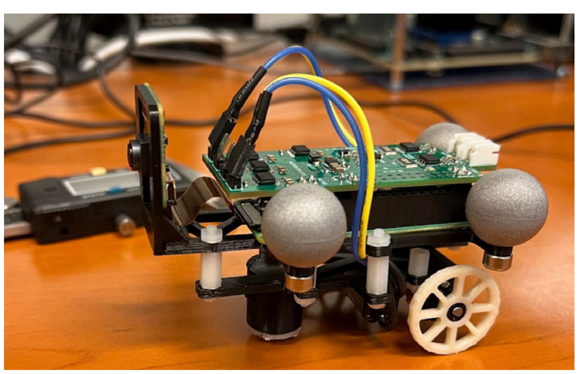
Energy-Constrained Autonomous Robotic Platform for Hardware-Software Co-Development: Enabling Perception

1.16

N. Wiley, S. Sudhakar, Z.-S. Fu, V. Sze, and S. Karaman
Sponsorship: MIT SuperUROP

Advances in edge computation enable the possibility of autonomy on small mobile robotics. However, the desire for autonomy shifts energy requirements such that the computation energy required to make these robots autonomous can be of a similar magnitude to their actuation energy. While recent works offer significant energy reductions using both hardware and software, many demonstrations and experiments have been limited to highly specific testbeds.

This work presents an open-source, palm-sized energy-constrained robotic testbed designed for hardware-software co-development. Unlike existing platforms, we provide flexible interfaces for running compute-intensive perception processes. We successfully demonstrate simultaneous localization and mapping (SLAM) and monocular depth estimation on our platform, delivering an accessible toolchain for researchers to rigorously evaluate energy optimizations for modern autonomy workloads.



◀ Figure 1: Low power car test platform with camera module, custom PCB, and motion detection markers that we will use to demonstrate and analyze perception and motion planning algorithms.

A TDD-Enabled FMCW Radar System with Self-Interference Mitigation for Vital Sign Detection

1.17

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Research Interests:
Artificial Intelligence
Biological devices & systems
Communications
Electronic devices
Integrated circuits
Machine Learning
Medical devices & systems

Continuous, in-home healthcare monitoring is essential for the elderly and patients with chronic illnesses. Advances in wireless sensing have enabled contactless detection of vital signs such as respiration and heart rate using FMCW (Frequency Modulated Continuous Wave) radar. However, conventional FMCW radar suffers from Tx-to-Rx (transmit-to-receive) self-interference due to concurrent operation of Tx and Rx chains. This paper presents a novel TDD (Time Division Duplex) enabled FMCW radar system that mitigates self-interference. In the proposed TDD FMCW, the Tx and Rx chains operate in non overlapping slots to eliminate self-interference at the source. An adaptive TDD FMCW scheme optimizes the TDD transmit and receive time slots based on the detected target distance, maximizing the SNR. A software testbench is developed in MATLAB to model a 60 GHz TDD-FMCW system with a human target, and signal processing algorithms are implemented to extract vital signs from simulated radar data. Finally, a novel TDD-enabled FMCW technique is proposed (US Patent Pending #63/869,497) and a 60 GHz RF front-end integrated circuit that mitigates Tx-to-Rx self-interference is designed, simulated, laid out, and taped out. The link budget analysis and software simulations demonstrate that the proposed TDD-FMCW system enhances detection sensitivity, extends the operational range of the radar, and minimizes the size and cost of the radar system.

High-Resolution and Multi-Modality Sense of Touch: Compact Terahertz Tactile Chip System for Advanced Robotic Training and Manipulation

1.19

K. Pochana, R. Han

Sponsorship: Analog Devices and National Science Foundation Graduate Research Fellowship

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Actuators
Artificial Intelligence
Communications
Electronic devices
Electronics
Energy harvesting devices & systems
Integrated circuits
Machine Learning
Medical devices & systems
MEMS & NEMS
Microfluidic devices & systems
Nanomanufacturing
Nanomaterials
Optoelectronics
Photonics
Power management
Quantum devices
Sensors
Si, Systems

Robotics is rapidly building towards Large Behavior Models (LBMs), akin to Large Language Models (LLMs), that enable robots to interact cooperatively with humans in the real world and in uncontrolled or unseen environments. For these interactions, tactile sensors provide critical information about the objects being interacted with. However, the current reliance on optical tactile sensors adds bulk, increases the difficulty of learning methods with human teachers, and misses information prior to object contact.

In this work, we instead design micro-radar-cells in CMOS to gather precise range information and form a 2D array of these cells to generate a range 'image' to objects being manipulated. Due to the radar sensing method, the sensor provides information both during and before object contact. We additionally develop packaging methods to realize a thin sensor form factor, enabling integration into robotic manipulators such as humanoid hands. The final sensor system represents a new modality of tactile sensing that provides more information and allows usage in more robotic form-factors.

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Research Interests:
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Electronic devices
Machine Learning
Medical devices & systems
Nanomaterials

Balancing Defect Passivation and Ion Migration with Thermal Annealing in Metal Halide Perovskite Thin Film Transistors

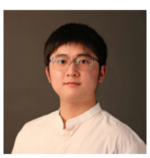
2.01

T. Kong, Y. Kim, J. Cho, H. Choi, Y. Zhang, H. Ahn, J. Woo, D. Kim, J. Lee, H. Sirringhaus, T. Lee, K. Kang
Sponsorship: Samsung Research Funding and Incubation Center of Samsung Electronics, National Research Foundation of Korea (NRF) grant, BrainLink Program

Metal halide perovskites (MHPs) are widely adopted in electronics and optoelectronics like TFTs and solar cells due to their excellent charge transport and scalable processing. Triple-cation systems such as CsFAMAPbI3 offer enhanced stability. However, thermal annealing (TA), a step essential for film crystallization, raises high degree of complexity in these multi-component materials by the differing thermal behaviors of the cations, which can lead to degradation of device performance.

We systematically studied the effect of TA duration on CsFAMAPbI3 films. We identified two key processes: (1) the elimination of intermediate phases, which directs a surface-to-bulk crystallization pathway, and (2) the decomposition of organic cations, which yields PbI2 phase.

Correlating these findings with TFT performance, we discovered a dual function for PbI2 phase: an optimal TA duration creates a beneficial level of PbI2 that passivates defects and boosts performance. In contrast, extended TA results in excessive PbI2, which encourages detrimental ion migration and degrades the device. This work offers a mechanistic framework for TA-driven phase evolution, providing clear design principles for advanced metal halide perovskite devices.



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Research Interests:
2D materials
Artificial Intelligence
Electronic devices
Integrated circuits
Nanomaterials
Nanotechnology
Quantum devices
Spintronics
Neuromorphic computing

A Room-temperature Cavity-magnonic Source of Correlated Microwave Pairs

2.02

Q. Wang, A. Karthigeyan, C.-T. Chou, L. Liu
Sponsorship: NSF, DOE-BES, and NSF Research Experience for Undergraduate (REU) Program

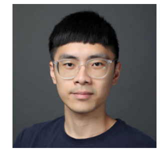
Correlated microwave photon sources are key enablers for technologies in quantum-limited sensing, signal amplification and communication, but the reliance on milli-Kelvin operating temperature limits their scalability for broader applications. Here at room-temperature, we demonstrate strong correlated microwave signals emitted from a hybrid magnon-photon platform. Different from traditional parametrically induced magnons with degenerate frequencies, we achieve non-degenerate excitations by coupling magnon modes simultaneously with two cavity photon modes. Through the magnon - photon interactions in the corresponding linear and nonlinear regimes, one input microwave photon is enforced to split into a pair of magnon polaritons that possess distinct frequencies but maintain strong inter-mode correlations. Based on this magnon polariton source we demonstrate a microwave communication experiment that achieves both physical layer security from the verified true randomness of the signals and communication efficiency from the robust correlation. This work establishes cavity magnonics as a versatile and compact platform for generating correlated multi-mode microwave signals, opening new avenues for applications in classical and quantum domains.

Interfacial Dielectric Relaxation in Metal-$Hf_{0.5}Zr_{0.5}O_2$-Metal Structures in the GHz Regime

2.03

J. C.-C. Huang, Y. Shao, E. R. Borujeny, J. Grajal, D. Antoniadis and J. A. del Alamo

Sponsorship: Semiconductor Research Corporation



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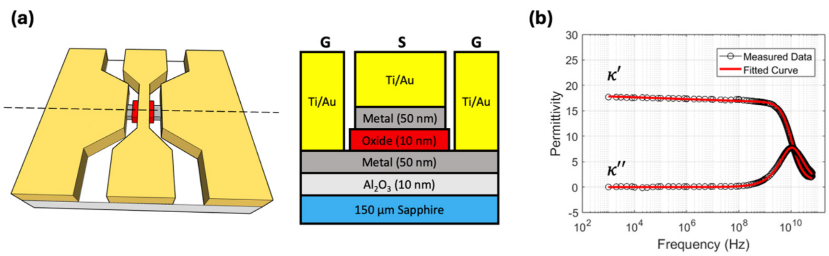
Research Interests:
Electronic devices
Electronics
Nanomaterials
Nanotechnology
Spintronics

Despite its strong ferroelectric properties and CMOS compatibility, the practical application of $Hf_{0.5}Zr_{0.5}O_2$ (HZO) is limited by an incomplete understanding of metal–oxide interfaces and defect physics. Our group previously performed capacitance characterization up to 10 GHz, revealing new aspects of defect behavior in FE-HZO.

In this work, we perform extensive impedance characterization from 1 kHz to 65 GHz on HZO-based metal/FE/metal capacitors. A pronounced dielectric relaxation is observed in the GHz regime, accompanied by a sharp capacitance drop. By comparing devices with different oxides and metals, we attribute this relaxation to the metal–oxide interface. The behavior is well captured by the Maxwell–Wagner model, enabling extraction of interfacial properties. The asymmetric voltage dependence reflects intrinsic asymmetry between the two interfaces. This study provides an effective electrical methodology to probe interfacial phenomena and their interplay with FE behavior.



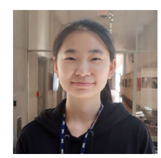
▲ Figure 1(a) Schematic of a metal-oxide-metal capacitor integrated in coplanar waveguide structures and its cross-sectional plot. (b) Permittivity of TiN/HZO/

Field-free Switching of Perpendicular Magnetization in a Ferrimagnetic Insulator with Spin Reorientation Transition

2.04

Y. Song, T. Nguyen, M. Li, C. A. Ross, and G. S. D. Beach

Sponsorship: NSF ECCS 2232830, DMR 2323132, DE-SC0020148, NSF DMREF DMR-2118448, DMR 1419807



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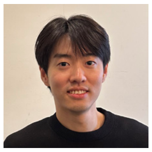
Research Interests:
Nanotechnology
Spintronics

Writing magnetic bits through spin-orbit torque (SOT) switching is promising for fast and efficient magnetic random-access memory devices. While SOT switching of out-of-plane (OOP) magnetized states requires lateral symmetry breaking, in-plane (IP) magnetized states suffer from low storage density. Here, we demonstrate a field-free switching scheme using a 5-nanometer europium iron garnet film grown with a (110) orientation that shows a spin reorientation transition from OOP to IP above room temperature. This scheme combines the benefits of high-density storage in the OOP states at room temperature and the efficient field-free SOT switching in the IP states at elevated temperatures. While conventional switching of OOP bits faces the dilemma that high OOP anisotropy is required to improve bit stability and low OOP anisotropy is required to lower switching current density, this scheme disentangles this interdependence, allowing for low switching currents to be possible without sacrificing the bit stability, offering opportunities for future memory devices.



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

Machine Learning-driven Robust Microelectronic Gas Sensors Beyond Non-idealities

2.05

J. Song, T. Baikie, T. Kong, M. Shulaker, and M. Baldo
Sponsorship: Analog Devices Incorporated (6935641)

Practical implementation of gas sensors for general tasks requires robustness against non-idealities encountered in real-world settings. The non-idealities such as device-to-device variation and varying humidity, however, have been considered difficult to address inconventional gas sensing. Here, we employ foundry-derived random-network carbon nanotube field effect transistors (CNFETs) and apply machine learning techniques such as long short-term memory (LSTM) for gas sensing with real-world non-idealities considered. CNFETs are understood to have complex reaction sites each governed by distinct transduction mechanisms, enabling multi-gas classification even without any functional components. We show that mutual information, which is model-independent, can be used to facilitate better sensing design by identifying the most informative features. Furthermore, we demonstrate that a machine learning model trained in dry air can be transferred to classify gases in humid conditions through domain adaptation techniques. The combination of complex yet consistent sensors, machine learning models, along with information theory, paves the way for implementation of microelectronic gas sensors in real-world settings.

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

Correlated Boson Physics in Rhombohedral Graphene Double Layers

2.06

E. Aitken, T. Han, S. Ye, L. Ju
Sponsorship: NSF

Rhombohedral multilayer graphene (RMG) has proven to host an array of phenomena for electronic devices, but is an unexplored front for bosonic devices. Using a double layer structure, a bound electron and hole pair, or an exciton, can form across an insulating layer (hBN) that is sandwiched between RMG sheets. This allows two band gaps to open on either side of the hBN creating interlayer Coulomb interactions between the RMG sheets. To create this device tape exfoliation of graphite, laser cutting, and dry transfer methods were used to carefully align the top graphite gate, top layer of RMG, thin hBN, bottom layer of RMG, and a bottom graphite gate. In order to tell whether or not the rhombohedral stacking order was preserved, near-infrared imaging from an InGaAs camera was used to differentiate between bernal and rhombohedral flakes. Tuning gate voltages of the two RMG layers results in a suppressed kinetic energy of the electrons and holes. From this, the binding energy of the excitons dominates the system, and at low enough temperatures they condense into a phase-coherent quantum matter known as the Bose-Einstein Condensate (BEC). However, the rhombohedral state of graphene is metastable previously preventing the community from making this double layer structure. In this project, I've successfully created such a device with intent to measure this exotic state, the BEC. Such bosonic devices have applications in the manipulation of qubits.

Turing Instability and Current-Driven Self-Sustained Waves in Dirac Fluids

2.07

P. Liong, A. Melnichenka, A. Bukhtatyi, A. Bilous, L. Levitov

Viscous films flowing down an incline can form self-sustained running waves, known as Kapitsa roll waves. Here we describe an analogous electron-hydrodynamic instability that produces similar running waves in Dirac materials such as graphene mono- and multilayers. It arises when carrier kinetics near charge neutrality make current dissipation strongly density dependent. As the flow velocity exceeds a critical value, the system transitions to a state with coupled spatial and temporal oscillations. Experimentally, the instability should manifest as (i) a nonanalytic behavior characteristic of a second-order transition—an abrupt increase in time-averaged current—and (ii) narrow-band emission at the characteristic "washboard" frequency. This behavior parallels the AC and DC transport of sliding charge-density waves, but here it originates from a distinct, intrinsic mechanism unrelated to disorder. Estimates indicate that the emission frequency, tunable by current, spans a broad range, highlighting Dirac bands as a promising platform for high-frequency electron-fluid dynamics.

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Research Interests:
2D materials

Designing Planar Silicon Solar Cells for Singlet Fission Sensitization

2.08

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Sponsorship: NSF Graduate Research Fellowship (2141064)

Singlet fission (SF)-sensitized silicon (Si) solar cells offer a path towards surpassing the Shockley-Queisser efficiency limit for single-junction solar cells. However, realizing efficient charge transfer from the SF material to Si remains a significant challenge that requires careful interface engineering. Prior work showed that Si microwire cells sensitized with tetracene and a zinc phthalocyanine donor layer can boost photocurrent and external quantum efficiency. Planar devices are simpler to fabricate than microwire devices and reproduce the planar geometry of optical test samples to connect studies of the interface to device performance. We developed a fabrication process for planar cells comparing varied oxide passivation layer growth conditions and surface treatments, Si(100) versus Si(111) orientation, and junctions formed by diffusion doping versus ion implantation. A drift–diffusion model shows that the diffusion doping emitters reduce surface recombination rates compared to ion implantation emitters. We also show that a positive fixed charge density at the surface enhances short wavelength EQE, with the effect strongest for Gaussian emitters. These results provide practical design rules for planar SF-sensitized Si cells and the study of charge transfer at organic-Si interfaces.

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Research Interests:
Electronic devices
Energy
Optoelectronics
Organic materials
Photovoltaics
Si

Magnetic Transistors with Strong Magnetoelectric Coupling and Spin–Orbit–Coupling Induced Nonreciprocity

2.09

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Sponsorship: SRC, DARPA, NSF (DMR-2104912), DOE (DE-SC0026239)

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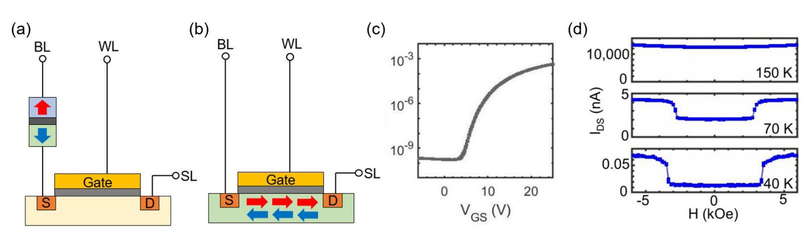
Research Interests:
Spintronics

Magnetic control of electronic transport is central to spintronics and magnetic-memory technologies. However, today's magnetic memories predominantly rely on tunneling magnetoresistance, where the multilayer architecture of magnetic tunnel junction limits its design flexibility. Here, we demonstrate a new type of magnetic device—a magnetic transistor—that operates simultaneously as a MOSFET and a magnetic memory. Using the magnetic semiconductor CrSBr as channel material, the device directly links electronic conduction to the material's magnetic order. Strong magnetoelectric coupling in CrSBr enables low-energy magnetic control of the channel, while gate-tunable spin-orbit coupling in combination with magnetism produces strong nonreciprocal transport responses that could be used for nonlinear optics. This device concept provides an alternative to multilayer magnetic-memory stacks, integrating logic-like gating and magnetic functionality into a single, energy-efficient architecture.



▲ Figure 1: (a)-(b), conventional MRAM structure (a) vs. proposed magnetic transistor-based MRAM (b). (c)-(d), gate voltage control (c) and magnetic control (d) of the magnetic transistor.

Frequency-Dependent Wake-Up in Ferroelectric Hf0.5Zr0.5O2 Devices

2.10

T. E. Espedal, Y. Shao, J. C-C. Huang, E. R. Borujeny, Dimitri A. Antoniadis, J. A. del Alamo.

Sponsorship: MIT UROP, Semiconductor Research Corporation, MIT AI Hardware Program.

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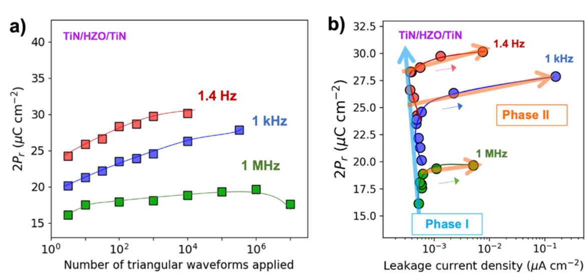
Electronics
GaN
Lasers
Nanomanufacturing
Nanomaterials
Nanotechnology
Optoelectronics
Photonics
Quantum devices
Si
SiGe and Ge
HZO
Ferroelectrics

Ferroelectric (FE) memory based on CMOS-compatible $Hf_{0.5}Zr_{0.5}O_2$ (HZO) has emerged as a promising non-volatile memory (NVM) technology due to its potential for low-voltage and fast switching, long data retention, and high memory endurance. A drawback of this technology is the need for device wake-up, typically requiring >10^3 bipolar cycles to wake up MFM capacitors. The frequency dependence of this wake-up cycling is poorly understood, but it is of great relevance for device performance and reliability.

In this work, we systematically investigate the wake-up behavior of TiN- and W-based FE-HZO capacitors under repeated triangular sweeps at frequencies ranging from 1.4 Hz to 1 MHz. Our detailed experiments allow us to compare stress time with the number of cycles applied, from which we find evidence of a decoupled evolution of wake-up and device degradation. Importantly, our findings show more effective wake-up with low frequency cycling, providing guidance for optimizing FE HZO device preparation.



◀ Figure 1: a) Frequency-dependence of 2Pr with number of applied triangular waveforms, measured in capacitors with TiN electrodes. b) The evolution of 2Pr vs. DC I-V leakage current reveals two distinct stages or "phases" of device wake-up.

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Electronic devices
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Integrated circuits
Machine Learning
Nanomanufacturing
Nanotechnology
Spintronics
Systems

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

2.11

D. Koh, and S. S. Cheema

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.

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Research Interests:
Electronic devices
Energy
Energy harvesting devices & systems
Optoelectronics
Organic materials
Photovoltaic

Scalable Self-Assembled Monolayer as Anchoring Molecule for Ion Migration Buffer for Perovskite Solar Cells

2.12

K. Yang, R. Patidar, V. Bulovic

Sponsorship: Tata Power, Petroliam Nasional Berhad (Petronas)

Perovskites are hybrid organic-inorganic materials which have been explored extensively as a potential next-generation solar cell active material over the past decade; however, they exhibit markedly degraded stability in comparison to their silicon counterparts. This is partially due to their high halide ion mobility causing ion migration both between layers and effusion of ions out of the lattice, causing lattice defects and degraded electronic performance. We thus deposit a self-assembled monolayer (SAM) called 5-AVAI between the perovskite and an ultra-thin layer of Al_2O_3 layer via Atomic Layer Deposition (ALD) to protect the underlying perovskite surface while offering the ALD precursor a reactive -OH group to bind with to initiate conformal Al_2O_3 growth. The ultra-thin Al_2O_3 layer thus serves as an impenetrable barrier to prevent iodine effusion out of the perovskite layer. Further, we mix 5-AVAI directly into the perovskite precursor solution. Because 5-AVAI is too bulky to reside within the perovskite structure, it is forced to segregate to the top and bottom of the perovskite layer during crystallization where it self-assembles on the top surface of the perovskite, forming a thin, uniform film. This then allows us to blade coat the perovskite precursor without adding an additional fabrication step, pushing the entire fabrication process closer to industrial relevance. This method of incorporating the 5-AVAI into the perovskite precursor solution and its subsequent blade coating is one of the first demonstrations of an industrially scalable method of ion diffusion mitigation and is a potential significant step towards full industrial compatibility of the perovskite solar cell fabrication process.

Characterization of Thermal boundary Conductance in Superconducting Nanowire Single-Photon Detectors

2.13

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Sponsorship: National Research Foundation of Korea, Sejong Science Fellowship

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Research Interests:
Electronic devices
Electronics
Nanomaterials
Nanotechnology
Quantum devices
Thermal structures, devices & systems

Superconducting nanowire single-photon detectors (SNSPDs) operate by distinguishing between the superconducting and resistive states of a nanowire, with the transition triggered by photon-induced hotspot formation. Due to their high detection efficiency, SNSPDs have been widely applied to space communications, quantum photonic circuits, and related technologies. Because the switching behavior of SNSPDs is governed by thermal physics, which is determined by both nanowire geometry and material properties, it plays a crucial role in overall device performance. Despite this importance, comprehensive studies on the thermal properties of SNSPDs remain limited. In this work, we estimate the thermal boundary conductance between the nanowire and its underlying substrate and provide experimental validation of the extracted values. The characterized material properties and device geometries highlight opportunities for optimizing SNSPD performance in applications such as data communication and space-based photon detection.

Chiral Superconductivity in Rhombohedral Hexalayer Graphene

2.14

Z. Hua, S. Ye, F. Pattanakanvijit, T. Han, G. Shi, H. Liu, J. Guo, K. Xiao, K. Watanabe, T. Taniguchi, L. Ju, P. Xiong, and Z. Lu

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Rhombohedral multilayer graphene has recently emerged as a versatile platform for exploring unconventional superconductivity. In particular, chiral superconductivity arising from a spin valley polarized quarter metal phase has been observed in tetra and pentalayer rhombohedral graphene, opening a pathway toward realizing Majorana fermions and establishing an important platform for topological physics and fault-tolerant quantum computing. However, the influence of detailed band-structure evolution with layer number, including the shape of the Fermi surface, lifting of spin and valley degeneracies, and the evolution of these symmetry broken states within the chiral superconducting phase, remains unresolved. Here, we report the observation of robust chiral superconducting phases in electron doped rhombohedral hexalayer graphene under a large displacement field, in the absence of moiré superlattice effects. Similar to the tetra and pentalayer cases, the longitudinal resistance in both chiral superconducting regimes exhibits magnetic hysteresis upon sweeping the out-of-plane magnetic field B . Moreover, the superconductivity is remarkably robust against exceptionally high critical fields in both in-plane and out-of-plane directions. These observations reinforce the universality of chiral superconductivity in the rhombohedral multilayer graphene family and establish this system as an ideal platform for realizing and studying exotic phases of matter.

From High-κ Dielectrics to Negative-κ Ferroelectrics: Atomic-Scale Gate Stack Design for Advanced Logic Transistors

2.15

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Research Interests:
Electronic devices
Electronics
Integrated circuits

As logic technology scales toward gate-all-around (GAA) and nanosheet architectures, continued improvement in electrostatic control requires aggressive reduction of the effective oxide thickness (EOT). However, conventional high-κ materials, while successful for more than a decade, now face a fundamental limitation: further thinning of the physical dielectric increases tunneling leakage faster than it improves capacitance, preventing meaningful EOT scaling. This bottleneck motivates new gate-dielectric platforms capable of enhancing electrostatics without relying solely on geometric thinning. Fluorite-structured oxides such as HfO_2–ZrO_2 offer such a pathway. Their coexistence of ferroelectric (FE) and antiferroelectric (AFE) phases, and the formation of polar–nonpolar domain boundaries, can give rise to negative-κ behavior. At these boundaries, polarization frustration and local free-energy curvature enable an effective capacitance enhancement, allowing the gate stack to achieve sub-nanometer EOT without the leakage penalty that constrains traditional high-κ dielectrics.

In this work, we investigate how superlattice-engineered HfO_2–ZrO_2 thin films stabilize these FE/AFE configurations in the ultrathin regime. Rather than relying on uniform mixtures, we employ atomic-scale superlattice engineering of gate stacks to control fluorite polymorph formation, which give rise to polar–nonpolar phase boundaries. This design strategy enables stable FE/AFE ordering down to thicknesses approaching ~1.2 nm, compared to the ~9.5A EOT typically achieved with homogeneous HfO_2 stacks. The resulting domain-wall–mediated negative-κ behavior supports capacitance-boosted EOT scaling that is inaccessible with conventional high-κ dielectrics. These results position the ZrO_2-based gate-stack platform for future logic transistors. Further atomic-scale engineering with atomic layer deposition (ALD), including dopant incorporation, vacancy control, and carefully designed interfaces, offers additional levers to tune FE/AFE domain configurations and amplify negative-κ effects. Such approaches may extend EOT scaling beyond current limits and advance both energy efficiency and electrostatic performance in next-generation logic technologies.

From High-k Dielectrics to Negative-k Ferroelectrics: Reliability of HfO2-ZrO2 Gate Stacks for Advanced Logic Transistors

2.16

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Research Interests:
Electronic devices
Electronics
Si

Since the transition from SiO_2 to high-k metal-gate (HKMG) technology, further advances in effective-oxide-thickness (EOT) scaling have been stalled. The negative permittivity (negative-k) effect, a phenomenon in ferroelectric materials that allows the series capacitance of a composite stack exceeds that of its individual layer, can be promising as an alternative EOT scaling route. Recently, leveraging the negative permittivity effect in a 2 nm ALD HfO2-ZrO2-HfO2 superlattice has enabled a record-low EOTs down to 6.5 Å. In this work, we assess the reliability of both conventional high-k dielectrics (HfO_2) and negative-k ferroelectric stack (HfO_2–ZrO_2–HfO_2). With the SiO_2/HfO_2 interface held constant, we demonstrate that these ultrathin EOT stacks do not exhibit additional reliability degradation. Low-frequency noise (LFN) and time-dependent dielectric breakdown (TDDB) measurements reveal comparable interface properties in both stacks, indicating that further EOT scaling enabled by ferroelectric negative permittivity effect can be achieved without compromising reliability.

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Research Interests:
Information processing
Lasers
Nanomanufacturing
Nanomaterials
Nanotechnology
Spintronics

Stabilizing and Steering Multi-Skyrmion Bags

2.17

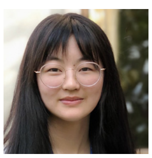
L.-M. Kern, V. M. Kuchkin, V. Deinhart, C. Klose, T. Sidiropoulos, M. Auer, S. Gaebel, K. Gerlinger, R. Battistelli, S. Wittrock, T. Karaman, M. Schneider, C.M. Günther, D. Engel, I. Will, S. Wintz, M. Weigand, F. Büttner, K. Höflich, S. Eisebitt, B. Pfau and G.S.D. Beach

Sponsorship: German Research Foundation (Grant No: 546268067).

Topologically non-trivial magnetic solitons such as skyrmions are complex spin textures with particle-like properties. While unit-charge (π) skyrmions have been widely explored for their potential in spintronic applications, higher-order topological textures—such as skyrmion bags—have remained largely theoretical due to challenges in experimental realization.

We have recently demonstrated the controlled formation and stabilization of isolated higher-order skyrmion configurations in ferromagnetic thin films. Specifically, we achieve the nucleation of skyrmionium (2π-skyrmion), target skyrmion (3π-skyrmion), and tunable-charge skyrmion bags through the introduction of localized anisotropy defects via focused ion irradiation. These engineered defects act as preferential sites for the generation of these complex topological textures. In addition, we compare two formation pathways—magnetic fields and ultrafast laser pulses—and find that laser pulses produce a significantly higher conversion rate of π-skyrmions into higher-order skyrmion bags. High-resolution x-ray magnetic circular dichroism (XMCD) imaging enables direct observation of the stabilized textures. Micromagnetic simulations further reveal that defect geometry, especially diameter, plays a key role in stabilizing closed-loop spin structures.

These findings provide a practical approach for their controlled generation in a scalable material platform. Skyrmion bags show exciting potential: their response to currents or laser pulses could trigger internal motion, shape changes, or oscillations. These dynamic effects could be ideal for energy-efficient neuromorphic computing and future applications in sensing and complex data processing.



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

Ferroelectric Optimization On-Demand: In-Situ Annealing of HfO_2-ZrO_2 using Micro-heaters

2.18

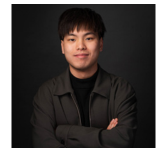
Q. Xue, Z. Xu, D. Koh, K. Dao, J. Hu, and S. Cheema

Hafnium Zirconium Oxide ($Hf_{0.5}Zr_{0.5}O_2$) has emerged as a premier candidate for next-generation non-volatile memory and ferroelectric field-effect transistors (FeFETs) due to its high scalability and CMOS compatibility. Achieving the optimal orthorhombic phase for ferroelectricity typically requires precise thermal processing. However, conventional rapid thermal annealing (RTA) relies on global heating of the entire chip, which lacks spatial resolution and restricts the ability to decouple thermal effects from electrical field cycling dynamics during phase crystallization.

In this work, we demonstrate a localized, in-situ annealing platform utilizing doped silicon microheaters vertically integrated with HZO capacitors. By leveraging a standard DC probe station, this setup enables precise, voltage-controlled Joule heating of individual devices within an array. This allows for simultaneous application of thermal stress and electric biasing, distinct from standard furnace methods. We report on the ferroelectric behavior of HZO under these tailored "on-demand" annealing conditions. This site-specific approach provides new insights into the interplay between temperature and applied electric field, enabling the optimization of wake-up characteristics and reliability for advanced memory applications.

High Performance Hydrogen Gas Detection with MoS_2-based Chemical Sensing Platform

2.19



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Sponsorship: ExxonMobil

Hydrogen is a promising clean energy carrier candidate for decarbonizing the global power grid. However, its flammable nature calls for the need for rapid and accurate detection. Two dimensional (2D) materials are ideal candidates for such application owing 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 transistor-based sensor that employs molybdenum disulfide (MoS_2) as the channel material. The high sensitivity of the monolayer MoS_2 is further enhanced by functionalization of palladium-based nanostructures, achieving parts per million (ppm)-level detection of hydrogen in ambient atmosphere. Strategies such as alloying and morphology modifications were also investigated to optimize sensor kinetics and sensitivities. The advantage in scalability of 2D materials can be leveraged by integrating the MoS_2 sensors into a robust sensor array, in which individual devices can be customized with different functional materials and expanding the scope beyond single-gas detection. Future work involves the development of a high-speed readout electronic circuit, establishing an integrated system that can perform rapid measurement, analysis, and real-time chemical recognition.

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Research Interests:
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

High Capacitance Ferroelectrics for BEOL MIM Capacitors

2.20

B. J. Luijten, S.S. Cheema

The leading bottleneck in computation is power delivery, both through the cumulative power draw of the world's utilization and on chip, where performance is throttled by inefficient power delivery. The collective power of computation exceeds 10% of the world's demand and is predicted to be supply-constrained within 5 years. In microprocessors, the operating speed and computational accuracy is limited by the stability of the power delivery network. Given the global reliance on computation, the development of more power-efficient computing is imperative. A significant portion of the power loss and performance degradation originates from voltage drops across the power delivery network and long vias. While these losses could be reduced by up to 40% through simple decoupling capacitors, limitations in capacitance density require expensive trenches as opposed to direct integration between metal layers.

In this work, recent capacitance enhancements are exploited by integrating mixed-ferroelectric superlattices compatible with Complementary Metal-Oxide-Semiconductor fabrication to scale capacitance density so that the need for trenches is eliminated and manufacturing costs of effective decoupling capacitors can be greatly reduced.

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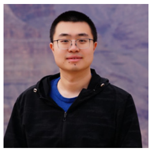
Research Interests:
Electronic devices
Electronics
Energy
Integrated circuits
Nanomaterials
Nanotechnology
Ferroelectrics



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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

Back-end Device Integration Platform Enabled by Amorphous In_2O_3 and Ferroelectric $HfZrO_2$

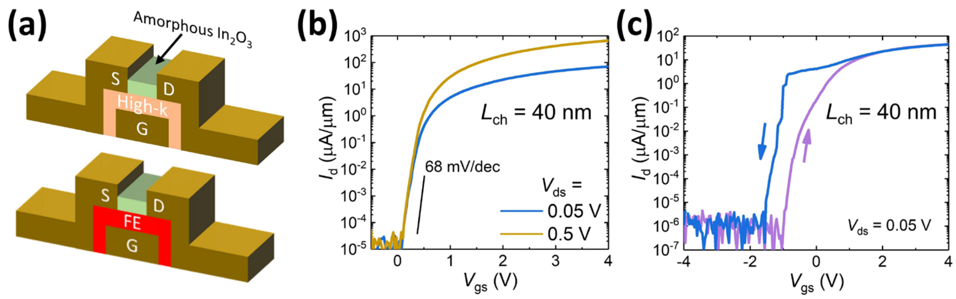
2.21

Y. Shao, J. C.-C. Huang, E. R. Borujeny, T. E. Espedal, H. Choi, D. A. Antoniadis and J. A. del Alamo

Sponsorship: Intel Corporation, Semiconductor Research Corporation

The explosive growth of artificial intelligence (AI) comes at the cost of exponential energy consumption increase in computation. It is clear that the future progress of AI cannot be made possible without the advancement of extremely energy-efficient electronics. Monolithic electronic device integration has emerged as a promising path forward, in which logic and memory devices are fabricated at the CMOS back-end to minimize data movement between computation and storage units. However, realizing such an integration platform requires the development of high-performance devices with a strict CMOS-compatible thermal budget (≤ 400 °C).

In this work, we investigate an emerging material, amorphous In_2O_3, for high-performance enhancement-mode field-effect transistors (FETs), and further integrate ferroelectric (FE) $Hf_{0.5}Zr_{0.5}O_2$ in the gate stack to build embedded non-volatile memory. This work shows the rich opportunities of monolithic 3D integration based on our advanced technology platform.



▲ Figure 1: (a) Schematic of our transistors. Transfer characteristics of highly-scaled (b) FET and (c) FE transistor.

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Research Interests:
Electronic devices
Electronics
Energy
Nanotechnology

Ferroelectric HZO Capacitors for CMOS-Compatible On-Chip Energy Storage and Power Delivery

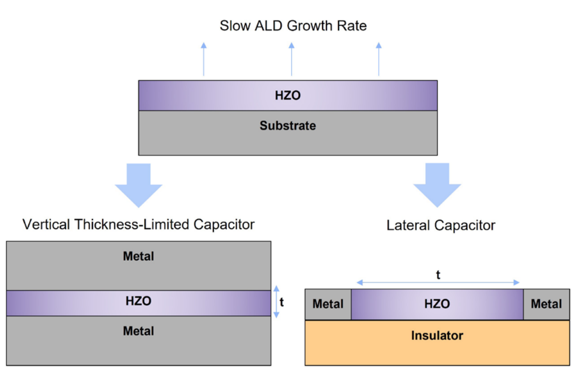
2.22

M. Czajka, B. Luijten, J. Schaadt, J. Kim, S. Cheema

Sponsorship: Grass Instrument Company Fellowship

Ferroelectric HfO_2–ZrO_2 (HZO) capacitors offer a promising route to energy- and power-dense, CMOS-compatible components for next-generation on-chip power delivery systems in AI and data-center hardware. These include on-chip power converters, backside power delivery networks for IR-drop suppression and sub-nanosecond current bursts, and decoupling layers for power transient stabilization. However, the slow deposition rate of atomic layer deposition (ALD) limits practically achievable film thickness, preventing ALD-grown metal–insulator–metal capacitors from spanning the full voltage range required by data-center power delivery.

In this work, HZO films are integrated into lateral capacitors with lithographically defined electrode separation, enabling operating voltage tunability for all stages of on-chip power conversion. This approach provides a scalable path toward higher-efficiency power delivery, addressing the rapidly growing energy demands of AI and data-center systems.



◀ Figure 1: Schematic illustrating how the slow ALD growth rate limits vertical metal–insulator–metal capacitor thickness, while lateral capacitors bypass this constraint by defining the electrode spacing t lithographically, enabling greater voltage scalability.

Measuring Changes in Electric Fields Really Quickly; an Ultrafast-Kelvin Probe

2.23

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Sponsorship: Schmidt Science Foundation

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Characterizing charge carrier dynamics in photoactive materials requires measurement techniques capable of resolving processes over vast time scales. We present advancements in "ultrafast-KP" (Transient Surface Photovoltage) instrumentation, enabling the precise tracking of surface potential changes from the nanosecond regime to seconds. Traditional Kelvin Probe methods are often limited by mechanical constraints and RC time constants; however, by utilizing ultra-low bias current high-impedance buffers and optimized fixed-capacitor geometries, we overcome these bandwidth limitations. A critical challenge in ultrafast measurements is the presence of parasitic LCR damped oscillations arising from the measurement loop, which can obscure the true signal onset. I will show instrumental ringing can be suppressed, allowing for signal resolution down to $<$ 1 ns. These engineering and analytical improvements provide a robust methodology for investigating transport mechanisms and defect states in emerging semiconductor materials.

Unraveling Electrochromic Polymers–Ion Interactions in for their Implementation in Organic Electrochemical Synaptic Devices: Leveraging Optical Switching in Electrochemical Switching

2.24

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Sponsorship: Abdul Latif Jameel Water and Food Systems (JWAFS) Lab at MIT

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Owing to low-power, fast and highly adaptive operability, as well as scalability, electrochemical random-access memory (ECRAM) technology is one of the most promising approaches for neuromorphic computing based on artificial neural networks. Despite recent advances, practical implementation of ECRAMs remains challenging due to several limitations including high write noise, asymmetric weight updates, and insufficient dynamic ranges. Here, inspired by similarities in structural and functional requirements between electrochromic devices and ECRAMs, high-performance, single-transistor and neuromorphic devices based on electrochromic polymers (ECPs) are demonstrated. To effectively translate electrochromism into electrochemical ion memory in polymers, this study systematically investigates polymer–ion interactions, redox activity, mixed ionic–electronic conduction, and stability of ECPs both experimentally and computationally using select electrolytes. The best-performing ECP-electrolyte combination is then implemented into an ECRAM device to further explore synaptic plasticity behaviors. The resulting ECRAM exhibits high linearity and symmetric conductance modulation, high dynamic range ($\approx$1 mS or $\approx$6x), and high training accuracy ($>$84% within five training cycles on a standard image recognition dataset), comparable to existing state-of-the-art ECRAMs. This study offers a promising approach to discover and design novel polymer materials for organic ECRAMs and demonstrates potential applications, taking advantage of mature knowledge basis on electrochromic materials and devices.

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

Engineering GaN-on-Si for RF and Beyond

2.25

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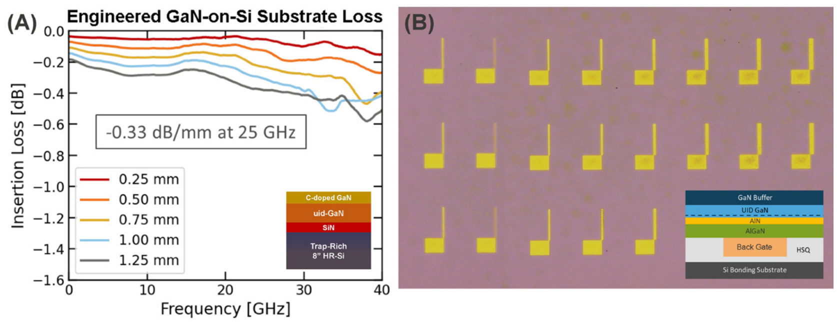
Sponsorship: SRC Jump 2.0 SUPREME, SOITEC

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. GaN-on-SiC has been widely used in 5G commercial applications, but Si substrates offer certain practical and economic advantages that make it a promising alternative. To push the potential of GaN-on-Si technology beyond its cost, substrate size, and CMOS-compatibility advantages, we engineer GaN devices from the substrate up. We characterize loss mechanisms of engineered substrates and buffers with coplanar waveguide measurements. We leverage GaN-on-Si substrates to fabricate double-gate HEMTs using wafer bonding, flip processing, and substrate removal to create innovative gate designs for greater electrostatic control. This work aims to address some of the main challenges facing GaN-on-Si technology and lead to improved output power, linearity, short channel effects, and overall functionality.



▲ Figure 1: (A) Engineered GaN-on-Si substrate demonstrates a line loss of -0.33 dB/mm at 25 GHz. (B) Microscope image of buried back gate metal as seen from the N-polar GaN surface after wafer bonding and substrate removal.

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

Charge Balance in Ion-implanted Lateral Gallium Nitride Superjunction Diodes

2.26

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

Gallium Nitride (GaN) power devices exploit a wide bandgap, high breakdown field, and superior electron transport, yet still face a tradeoff between on-resistance and breakdown voltage. GaN superjunction devices mitigate this by using alternating, charge-balanced p- and n-type regions to achieve high breakdown voltage with low resistance. This work demonstrates Si-ion implantation into p-GaN to realize superjunction p-n diodes with ~8x higher breakdown voltage than conventional p-n diodes and presents combined theoretical and experimental optimization of charge balance.

Six Si-ion implantations were performed into 250 nm p-GaN ([Mg] = $1{\times}10^{19}$) grown by MBE on semi-insulating GaN/sapphire, creating interdigitated n-GaN regions with a boxed Si profile, a Si concentration twice the Mg concentration, and a depth of 250 nm. A 1 μm SiO2 implant mask set the p- and n-type finger widths between 150 nm and 500 nm. After implantation and mask layer etching, devices were annealed at 1200 °C in N2 for 30 s with a 300 nm sputtered AlN cap for damage recovery and dopant activation, followed by AlN removal in a TMAH-based developer. P- and n-GaN ohmic contacts were formed using Ni/Au and Ti/Al/Ni/Au alloyed metal stacks, respectively.

As a result, successful p-type to n-type conversion was confirmed via the Van der Pauw method. A baseline diode without the finger structure exhibited conventional pn diode behavior with a breakdown voltage of -115 V. Most superjunction diodes showed higher breakdown voltages, with a maximum of -887 V when p-type and n-type finger widths were 180 nm and 150 nm, respectively. Breakdown voltage mapping revealed that enhancement was greatest when p-type fingers were 20-30 % wider than n-type fingers, implying a 20-30 % higher activated dopant concentration in the n-type region compared to p-type. This work demonstrates the potential of GaN superjunction diodes using ion implantation for high power applications.

Reliability Study of MoS_2 Transistors with Channel Length Scaling and Sub-1-nm EOT

2.27

A. Yao, D. Erus, Z. Zhu, J. Zhu, Y. Jiao, J. Kong, T. Palacios

Sponsorship: SUPREME Center of SRC JUMP 2.0, MIT-Army Institute for Soldier Nanotechnologies, U. S. Army Research Office (ARO)

Front-end-of-line (FEOL) integration of transistors based on two-dimensional (2D) materials, e.g., molybdenum disulfide (MoS_2), provide exciting opportunities to continuing 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.

In this project, we conducted a systematic reliability study of monolayer MoS_2-channel MOSFETs with a scaled EOT (~0.8 nm) and channel length (Lch) down to 40 nm. By carefully engineering gate and drain bias conditions, we correlate VT instability with Lch and identify a transition in dominant degradation mechanisms from long-channel to short-channel devices. TCAD simulations validate the experimental results, revealing a strong coupling between bias-temperature instability (BTI) and hot-carrier injection (HCI) under simultaneous gate/drain stress, primarily induced by non-uniform electrical field distribution in the channel and gate dielectric. Our findings demonstrate that highly scaled MoS_2 transistors exhibit reliability metrics — such as PBTI and HCI degradation — comparable to those of planar Si CMOS with similar channel lengths.

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

In Situ 3D Printing and Magnetization of Strontium Ferrite Composites

2.28

Z. Bigelow, L. F. Velásquez-García

Sponsorship: Empiriko Corporation

Hard magnets are essential in electronics, renewable energy, and robotics, but traditional methods are limited by fixed geometries and post-processing magnetization. We demonstrate a 3D printing process for Strontium ferrite composites that enables in situ magnetization during fabrication. Strontium ferrite's high remanence and low coercivity allow easy magnetization during printing. Using an extrusion printer, we placed a strong NdFeB magnet beneath the bed, producing a field of 0.2 T at bed level. Printed samples showed remanent magnetization of 90 mT at the bottom and 60 mT at the top, reflecting a vertical field gradient. This proof-of-concept demonstrates that embedded magnets can be magnetized during printing, circumventing the need for post-processing. Future work will integrate magnetizers with the extruder to achieve uniform fields across complex geometries.

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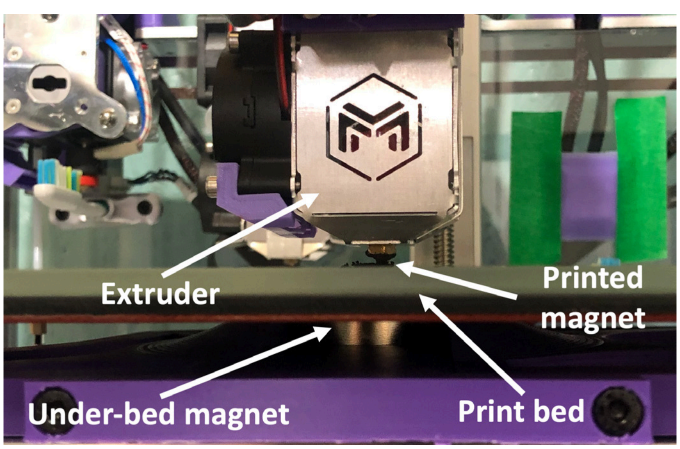
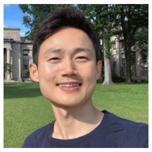


◀ Figure 1: 3D printed Strontium ferrite magnet



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Research Interests:
2D materials
Electronic devices
Electronics
Energy
Energy harvesting devices & systems
III-Vs
Nanomaterials
Nanotechnology
Organic materials
Photovoltaics

Nanoporous Graphene via Nanoparticle-Assisted Carbon Oxidation

3.01

J. Kim, R. Karnik
Sponsorship: DARPA

Nanoporous graphene has emerged as a promising platform for water desalination, gas separation, and antimicrobial filtration. Conventional pore-generation methods such as e-beam lithography, laser ablation, and ion bombardment enable nanoscale patterning but rely on high-energy, high-cost instrumentation and often offer limited control over pore dimensions. Therefore, there is a need for low-cost, scalable pore-generation method with precise size control. In this work, we present a cost-effective, vacuum-free, and solution-processable strategy for producing few-nanometer pores in graphene through nanoparticle-assisted carbon oxidation. Metal oxide nanoparticles act as localized etching catalysts, creating vacancies in graphene through controlled thermal oxidation. The pore size is controlled by the nanoparticle diameter, allowing for predictable and tunable nanoscale porosity. We demonstrate pore formation down to a few nanometers using this method, which is much high resolution compared to the scale from the conventional methods. The simplicity, scalability, and energy efficiency of this approach establish a practical platform for manufacturing nanoporous graphene membranes suitable for a broad range of applications such as separation, filtration, and semiconducting material growth.

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Research Interests:
2D materials
Nanomanufacturing
Nanomaterials
Nanotechnology
Organic materials

Thermogravimetric Analysis of 2D Polyaramids Nanoplatelets

3.02

S. Amirabadi, Z. Wei, M. Quien, M. S. Strano
Sponsorship: Soldier Nanotechnologies under Cooperative Agreement and Center for Enhanced Nanofluidic Transport (CENT)

Two-dimensional (2D) polyaramids (2DPAs) have recently emerged as a new class of organic 2D materials, exhibiting exceptional mechanical strength and gas barrier properties. However, their characterization remains challenging due to their unique hybrid molecular structure, combining features of conventional 2D inorganic materials with those of organic polymers, resulting in limited solvent dispersibility. Herein, we show that thermal degradation, monitored by mass spectrometry (MS) in the form of thermogravimetric analysis (TGA-MS), can provide chemical insight into the end group and nanoplatelet molecular structure of 2DPAs. We find that distinct thermal gravimetric loss regimes correlate with the ratio to aromatic-to-end group proton peak integrations from 1H NMR, or 'r' value. This then informs the end-group chemical composition, which can be linked to a consistent set of mechanistic steps for thermal degradation. Kinetic parameters, including activation energies, are determined using the Coats–Redfern method. This study establishes the utility of TGA and TGA-MS as a versatile characterization tool for 2D polyaramids with distinct terminal groups, allowing measurement and therefore control of nanoplatelet functionalization, and molecular weight.

Stretchable Organic Transistors for Soft Electronics

3.03

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Sponsorship: K Lisa Yang Brain-Body Center, MIT HEALS Graduate Fellowship

Soft and stretchable electronics offer a route toward wearable, implantable, and conformable systems that can interface seamlessly with dynamic surfaces. Yet, high-performance organic transistors are often brittle and incompatible with large strains, limiting integration with soft substrates and biological tissues.

We present a fully stretchable organic electrochemical transistor (OECT) platform engineered for mechanical compliance, robust mixed ionic/electronic transport, and stable performance under deformation. The platform integrates two key components: (1) ultrathin, exponentially stacked Au nanomembranes interleaved with porous polyisobutylene (PIB), and (2) a stretchable OECT channel composed of Pg2T-T blended with the same PIB elastomer. The exponential-stacking architecture provides mechanically resilient source, drain, and gate electrodes, while the Pg2T-T/PIB composite enables elastic deformation and efficient mixed conduction through nanoscale phase separation. We further show how semiconductor microstructure, including horizontal versus vertical phase separation, influences mechanical durability and electrical performance.

This strategy establishes a generalizable platform for fully stretchable, high-performance OECTs. It enables soft sensing, conformable signal amplification, and integrated electronics for wearable health monitors, epidermal devices, and soft robotics, where devices must reliably deform with their environment.

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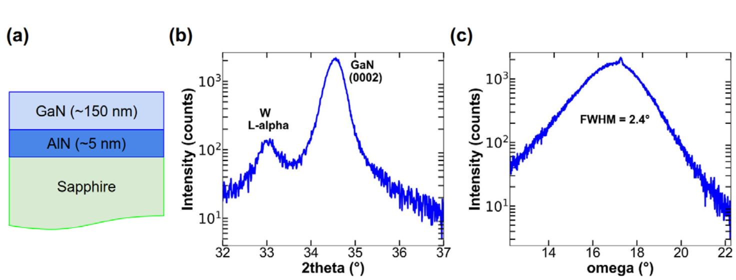
Research Interests:
Actuators, Artificial Intelligence
Biological devices & systems
BioMEMS, Communications
Displays, Electronic devices
Electronics, Energy
Energy harvesting devices & systems, Light-emitting diodes
Machine Learning
Medical devices & systems
MEMS & NEMS
Molecular & polymeric materials
Nanomanufacturing
Nanomaterials, Nanotechnology
Optoelectronics, Organic materials
Photovoltaics, Sensors
Transducers, Neurotechnology, Neuroengineering, Sensors

Low Temperature Deposition of GaN by Reactive Sputtering

3.04

L. Talli, D. Kang, J. Casamento

Achieving high crystalline fidelity GaN at low temperatures is critical toward diversifying the integration capabilities of GaN-based technologies. Conventional epitaxial GaN growth by metalorganic chemical vapor deposition (MOCVD) requires temperatures above 1000 °C, limiting integration with silicon-based technologies. This work explores an alternative pathway using ultra-high vacuum (UHV) reactive sputtering of GaN, with growth temperatures below 400 °C. Crystalline GaN films grown at 300 °C on c-plane sapphire substrates are demonstrated using an AlN seed layer, achieving a full-width at half-maximum (FWHM) value of the (0002) peak in X-ray Diffraction (XRD) as low as 2.4°. These results indicate the onset of oriented crystal growth at temperatures compatible with back-end-of-line (BEOL) processes. The next phase of this research focuses on correlating plasma conditions and adsorbed atom energy with film crystallinity, defect density, and growth rate to establish a pathway toward electronic-grade GaN suitable for power devices and RF transistors. This low-temperature sputtering approach offers a potential foundation for scalable, energy-efficient semiconductor manufacturing.



◄ Fig 1 a) Schematic of the heterostructure grown at 300 °C. b) Theta-2thera (θ-2θ) scan for this structure. The Tungsten L-alpha (W L-θ) peak does not originate from the sample. c) Omega (θ) scan for this structure.

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Generating Photodegradation ‘Spectra’ of 2D Bue-emitting Semiconductor Mithrene (AgSePh)

3.05

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Sponsorship: NSF Graduate Research Fellowship, U.S Army Research Office

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

Innovations in blue emitting semiconductors and widespread adoption of light emitting diodes (LEDs) 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 sustainability targets, advancements in light emission are essential, driving research interest towards novel materials – particularly ones with more sustainable synthesis pathways.

Our lab investigates silver phenylselenide, known as “mithrene” (AgSePh), a novel 2D van der Waals stacked organic-inorganic semiconductor with strong exciton binding energy, in-plane anisotropy, and direct bandgap. Covalent intralayer bonding bolsters environmentally stability and enables property tuning through various functionalizations, where high-quality millimeter scale single crystals are synthesizable through a simple, ambient reaction. Mithrene is of particular interest due to its narrow blue luminescence; however, nonradiative recombination dominates excited state dynamics and strong photodegradation is observed, limiting its potential. We hypothesize that poor photoluminescence (PL) quantum yield (QY) is the result of Auger recombination enhanced by carrier generation during material degradation. Here, we present x-ray photoelectron spectroscopy (XPS) and PL microscopy experiments done to uncover the origins of the low PLQY in mithrene through spectroscopic and chemical analysis of material photolysis and defect generation. Future viability of this material class to promote sustainable energy consumption is strongly dependent on the efficiency of light emission, and is necessary to pursue improvements in both performance and understanding. Facile synthesis, blue-emission, and structural tunability make mithrene a suitable candidate for applications as LEDs, excitonic switches, and other sustainably manufactured optoelectronics, but more must be understood about the material’s underlying photophysics to realize these goals.

Heterostructures of Lead Halide Perovskite Quantum Dots and Exfoliated WS_2: Characterization and Spatially-Resolved Energy Transfer

3.06

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

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Research Interests:
2D materials
Energy
Lasers
Nanomaterials

Lead halide perovskite nanomaterials hold immense promise for use in optoelectronic devices. In excitonic devices such as LEDs, designing efficient devices is dependent upon our knowledge of the exciton transfer process. Although Förster theory is the default framework for describing exciton transfer, it inaccurately describes energy transfer in many semiconducting nanomaterials. In particular, perovskites exhibit energy transfer rates that not only exceed Förster theory predictions, but outstrip all other semiconducting nanomaterials by 1-2 orders of magnitude. These discrepancies underscore a significant gap in our understanding of the exciton transfer mechanism in semiconducting materials. To understand why perovskites and other semiconducting nanomaterials diverge so strongly from the Förster framework, we synthesize heterostructures of $CsPbBr_3$ quantum dots and WS_2 exfoliated to 1-5 layers, and study interfacial energy transfer in this system. Here, we present spectroscopic characterization of the heterostructures via spatially-resolved Raman and photoluminescence spectroscopy. We share our initial energy transfer results calculated from the radiative lifetimes of each material. In future work, we will measure heterostructures of $CsPbBr_3$ quantum dots and 2D lead halide perovskite crystals, thus providing a direct comparison between the behavior of well-studied WS_2 and novel 2D perovskites. Using findings from these two systems, we will develop a framework building upon Förster theory to accurately describe energy transfer in semiconducting nanomaterials, informing the design of efficient optoelectronics and bridging the gap to the next generation of devices.

Sodium Free Synthesis of Monolayer Molybdenum Disulfide for Heterogeneous Integration with Si-CMOS

3.07

Y. Jiao, T. Palacios

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

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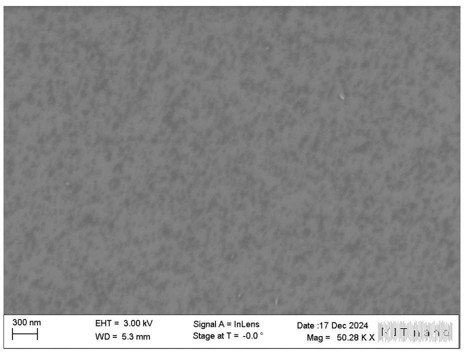
2D materials
Electronic devices
Electronics
Energy harvesting devices & systems
Integrated circuits
Machine Learning
Nanomanufacturing
Nanomaterials
Nanotechnology
Optoelectronics
Photonics
Quantum devices
Si

Two-dimensional (2D) transition-metal dichalcogenides (TMDs) are leading candidates for next-generation electronic technologies owing to their exceptional electronic and optoelectronic properties. Metal–organic chemical vapor deposition (MOCVD) has emerged as a scalable route for wafer-level synthesis, enabling films with high uniformity and material quality. Conventional seeding promoters such as sodium chloride (NaCl) facilitate high-quality molybdenum disulfide (MoS_2) growth; however, the presence of alkali-metal ions poses significant reliability risks for dielectric layers and is incompatible with complementary metal–oxide–semiconductor (CMOS) fabrication standards. Consequently, alkali-free nucleation strategies are required to advance CMOS-compatible 2D material integration.

In this work, we systematically evaluate alkali-metal-free seeding promoters and demonstrate the successful MOCVD growth of monolayer MoS_2 using crystal violet (CV). These findings elucidate key aspects of TMD nucleation chemistry and support the development of heterogeneous integration pathways for CMOS-compatible 2D electronics.



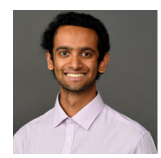
◄ Figure 1: SEM Image of monolayer MoS_2 synthesized with CV as seeding promoter.

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

3.08

S. Chakravarthi, H. W. Lee, Y. Jiao, X. Zheng, J. Kong, T. Palacios

Sponsorship: SRC Jump 2.0 SUPREME Center



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Research Interests:
2D materials
Electronic devices
Electronics
Nanomaterials
Nanotechnology

Two-dimensional(2D) materials with their high carrier mobility, excellent gate electrostatic control, and atomically thin nature have emerged as promising channel materials for highly-scaled, energy-efficient electronics. However, while n-type 2D semiconductors like MoS_2 have achieved reliable synthesis with strong device performance, p-type materials like WSe_2 remain underdeveloped. This imbalance critically limits the realization of monolithic 2D complementary metal-oxide-semiconductor (CMOS) technology.

In this work, we employ metal-organic chemical vapor deposition (MOCVD) to systematically investigate the impact of precursor concentration, seeding promoter incorporation, carrier gas flow rates, and hydrogen reducing environment on monolayer WSe_2 synthesis. Through methodical parameter optimization, we identify growth recipes that yield centimeter-scale, continuous monolayer films on both sapphire and silicon/silicon dioxide substrates. Comprehensive characterization using Raman spectroscopy, scanning electron microscopy (SEM), atomic force microscopy (AFM), and X-ray photoelectron spectroscopy (XPS) provides a thorough assessment of the as-grown film's uniformity, quality, and stoichiometric accuracy. Device-level characterization via fabrication of p-type field-effect transistors validates the electronic quality of the grown material. This work establishes the foundation for future efforts in scaling WSe_2 synthesis to 8-inch wafers and enabling direct, low-temperature integration of p-type WSe_2 on silicon CMOS circuits.

Low-Temperature Growth of AlN by Ultra-High-Vacuum Sputtering: Crystallinity and Thickness-Driven Relaxation Mechanisms

3.09

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Research Interests:
Electronic devices
Electronics
GaN
III-Vs
Integrated circuits

Low-temperature growth of AlN is required for GaN device integration and reduced thermal budget processing, motivating a systematic investigation of how growth parameters control the material's properties. This study investigates structural evolution and sputter-parameter dependence of ***c***-axis AlN grown by ultra-high vacuum reactive magnetron sputtering at 300 °C and at room temperature. At 300 °C, a N_2/Ar ratio of ~1.5 and high Al target power (>800 W) yield the narrowest out-of-plane mosaicity, while N-rich or low-power conditions broaden the AlN (0002) X-ray diffraction peak. Thickness-dependent study shows coherent nucleation, strain relaxation by misfit dislocations, and subsequent columnar coarsening on ***c***-plane sapphire, whereas room-temperature growth produces more weakly textured films with broader mosaicity on both sapphire and Si (111) substrates. These results show progress toward the utilization of low-temperature sputtered AlN as a passive layer for GaN-based power and RF systems.

Figure 1

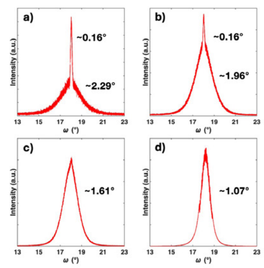
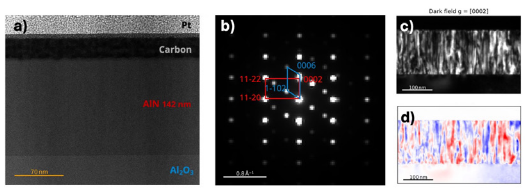


Figure 2



◀ Figure 1: XRD ω-scan of AlN (0002) with different thicknesses.

◀ Figure 2: (a) HAADF, (b) nano-beam diffraction, (c) dark field, and (d) g=[0002] difference map of AlN.

Ultra-High-Vacuum Sputtering of Ferroelectric $Al_{1-x}Y_xN$ and $Al_{1-x}Sc_xN$

3.10

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Available from September 2030.

Ferroelectric wurtzite nitrides offer nonvolatile functions in GaN power and RF platforms, and ultra-high vacuum (UHV) sputtering provides a low-temperature, scalable route to incorporate Y and Sc into AlN for ferroelectric, metastable nitride thin films while preserving the wurtzite framework. This study investigates the structural evolution and the ferroelectric response of UHV-sputtered $Al_{1-x}(Y,Sc)_xN$ on Si-doped GaN and ***c***-Al_2O_3. Films grown at 400 °C show a (0002) X-ray diffraction peak shift with increasing Y/Sc flux, confirming c-axis expansion, while the narrow rocking-curve width indicates retention of wurtzite texture under cation incorporation. Frequency-dependent P-E measurements confirm switchable polarization in sputtered $Al_{1-x}Y_xN$. X-ray photoelectron spectroscopy reveals oxygen ingress even in vacuum-sealed samples, underscoring the need for ***in-situ*** capping. These results provide a combined experimental basis for integrating ferroelectric nitride thin films into GaN-based RF and power devices.

Figure 1

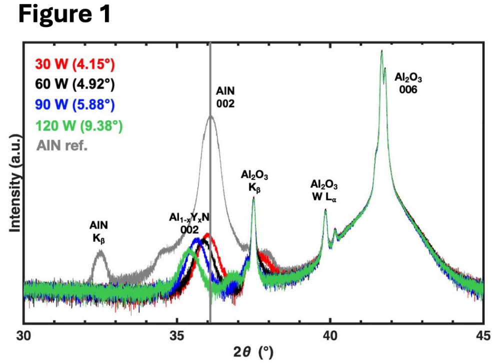
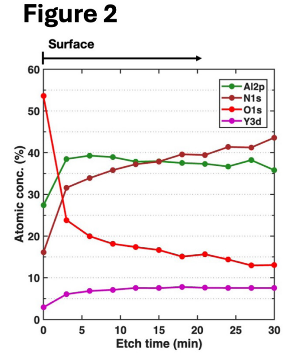


Figure 2



◀ Figure 1. XRD of Al1-xYxN on c-Al2O3 with corresponding rocking-curve widths.

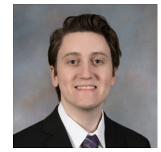
◀ Figure 2. XPS depth profile analysis of Al1-xYxN film.

Preparing High-coverage Self-assembled Monolayers for Perovskite Solar Cells

3.11

J. E. Griffith, W. A. Tisdale

Sponsorship: NSF Graduate Research Fellowship, U.S. Department of Energy, Office of Science, Basic Energy Sciences



Self-assembled monolayers (SAMs) are commonly featured as hole transport layers in high-performance perovskite solar cells. During device fabrication, SAMs are typically deposited on hydrophilic substrates through spin-coating from polar solvents such as ethanol. However, the polar nature of the deposition solvent can lead to SAM molecules forming micelles in solution or being blocked from adsorbing onto the substrate, both of which can lead to the formation of voids in the resulting monolayer. Such voids can reduce device efficiency and stability by increasing nonradiative recombination and causing harmful perovskite-electrode reactions, respectively. In this work, the effect of tuning the solvent environment on the coverage of 2PACz SAMs is studied through contact angle measurements, X-ray photoelectron spectroscopy (XPS), and cyclic voltammetry (CV). In particular, it is found that utilizing lower-polarity solvents such as diethyl ether can improve SAM coverage, as demonstrated by increased contact angle, XPS coverage factor, and CV peak separation. This improvement is believed to arise from reduced micelle formation and competitive adsorption in the lower-polarity solvent environment. Furthermore, the impact of SAM coverage on the subsequent perovskite crystallization process is explored, revealing a potential route to improve perovskite crystallinity.

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Research Interests:
Energy
Photovoltaics

Optimizing the Fabrication of Electroluminescent Quantum Dot Light-emitting Devices

3.12

S. Martin, M. Dillendar, J. Park, S. Shrinivasan, K. Yang, R. Zhang, J. Zhang, V. Bulovic

Sponsorship: Samsung Advanced Institute of Technology

Electroluminescent quantum dot light-emitting devices (QDLEDs) show large potential for next-generation display technology due to their high efficiency, controllable band-gap, narrow spectral emission, wide gamut, and cost-effective scalable processing. To better understand and improve QDLED technology, laboratory-scale fabrication efforts are required. This project aims to classify and resolve defects that emerge from devices made from spin-coating, namely organic crystallite formations, ring trenches, film rupture, and particle contamination. The electrical consequences of such defects are not well understood; they may increase leakage current and turn-on voltage, decrease external quantum efficiency (EQE), and produce dark regions that make current-density comparisons difficult. Preliminary results show organic ligand concentration contribute to crystallite formation, spin technique contributes to ring trenches and film striations, and cathode deposition is responsible for film rupture. Additionally, devices with an electron transport layer of evaporated 2-Phenyl-4,6-bis(3-(triphenylsilyl)phenyl)-1,3,5-triazine (mSiTrz) instead of conventional colloidal zinc magnesium oxide (ZMO) nanoparticles are presented with comparable EQE and improved defectivity. Process engineering of each QDLED layer is of critical importance, and larger studies are enabled by development of a repeatable and reliable fabrication recipe.

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Metal Organic Chalcogenides as Chiral Semiconductors

3.13

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Sponsorship: MIT School of Science MathWorks Fellowship

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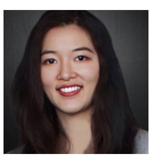
Research Interests:
2D materials
Lasers
Light-emitting diodes
Nanomaterials
Organic materials

Chirality refers to the property of the non-superimposability of an object onto its mirror image, endowing chiral objects with a "handedness." Due to chiral materials' asymmetric light and spin interactions, interest in chiral semiconductors has grown in recent years in pursuit of the implementation of chiral systems to control spin-selective transport and to interact uniquely with circularly polarized light. In this work, a new target material is proposed: chiral metal organic chalcogenides (MOCs). The canonical MOC, silver phenylselenide (AgSePh), is an attractive candidate for the development of novel semiconductor species, as a blue-emitting direct gap semiconductor. In particular, this material appeals because its bandgap has been shown to be highly susceptible to tuning via modification of its organic ligands, indicating its relevance for applications in circularly polarized light detection.

This work presents a synthetic scheme toward the development of chiral MOCs, employing an atypical route to arrive at substituted diphenyl diselenide synthons, to accommodate a range of chiral substituents. Current research includes the optimization of synthetic routes to such designer ligands, while future work will involve chiroptical characterization. This work will ultimately serve in the pursuit of novel optoelectronic and chiroptical devices.



Harnessing Mining Waste for Sustainable Steel Manufacturing and Rare Earth Element Extraction

3.14

D. Zhang, Y.M. Chiang

Sponsorship: MITEI-ExxonMobil Fellowship, ARPA-E

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

Rare earth elements (REEs) are essential for advanced energy and defense technologies. However, U.S. production remains limited due to the scarcity of high-grade deposits and the difficulty of extracting REEs from abundant low-grade ores and tailings. In these materials, REEs are chemically locked within iron-oxide–rich matrices, where nanoscale surface chemistry and morphology hinder conventional separation.

We propose a materials-driven extraction strategy that uses micro- and nano-structured electrochemical interfaces to unlock REEs from mining waste. By engineering the electrode morphology and surface chemistry, our process directs the selective electro-metallurgical reduction of iron oxides. This controlled interfacial transformation exposes REE-bearing phases and modifies mineral microstructure, enabling high-efficiency downstream leaching. Coupled hydro-metallurgical steps then dissolve aluminum phases and isolate REE concentrates. The products are close to 100% pure iron, aluminum, and the rare earth element concentrations are increased up to 4000 times.

Throughout the process, we apply advanced characterization, including electron microscopy, XRD, XRF, and ***in situ*** electrochemical probes to correlate surface structure, reaction pathways, and extraction efficiency. The approach simultaneously produces emissions-free iron metal, REE mixtures, and supplementary cementitious materials, supporting decarbonization of the steel, REE, and cement industries.

By integrating materials synthesis, surface science, and comprehensive characterization, this method transforms mining tailings into valuable materials, offering a sustainable and scalable pathway for domestic critical mineral recovery.

Ferroelectric Capacitors By Design: A Versatile Platform for On-Chip Energy & Power

3.15

J. Schaadt, S. Cheema

The exponential rise of Internet-of-Things (IoT) and edge devices (nearing 1 trillion) [IEEE-2019] demands a reexamination of one of the most fundamental components of modern integrated circuits – the capacitor. Dielectric materials in electrostatic capacitors play a key role in enabling edge technologies, with low-loss, high permittivity (κ) dielectrics serving as the basis for wireless communications, power delivery, and signal stability. With the increasing importance of miniaturization, on-chip integration, and extreme-environment adaptability, dielectric materials that maintain (or even enhance) their properties at the nanoscale with dynamic control are urgently needed. However, to develop high-performance dielectrics, a combination of high permittivity, large breakdown field, and low loss is required.

My research focuses on overcoming the tradeoffs plaguing traditional dielectrics by exploiting (i) new physical phenomena in ferroelectric dielectrics, (ii) new materials design strategies to enhance performance across small-large scales, and (iii) new capacitor architectures to maximize performance for on-chip applications.

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Research Interests:
Electronic devices
Electronics
Energy
MEMS & NEMS
Microfluidic devices & systems
Nanomaterials
Nanotechnology
Thermal structures, devices & systems

Wurtzite Nitride Ferroelectricity: New Opportunities via Atomic Layer Deposition

3.16

G. M. Muha

Wurtzite nitride ferroelectrics represent an emerging class of materials distinguished by their large spontaneous polarization, exceptional thermal stability, and compatibility with existing III–V semiconductor platforms. Aluminum scandium nitride (AlScN), the first experimentally demonstrated nitride ferroelectric, highlights the potential of this material family, and Atomic Layer Deposition (ALD) offers a promising route to advance it further by providing self-limiting growth that enables conformal, ultrathin films with atomic-scale thickness control, even on complex three-dimensional structures. In addition, ALD supports low-temperature deposition (<300 °C) while still achieving high crystalline quality, including the possibility of epitaxial growth on III-V semiconductors. To broaden the understanding and optimization of ALD-grown ferroelectric nitrides, this work employs structural characterization (XRD) alongside electrical measurements (Current-Voltage, Capacitance-Voltage, PUND). Together, these approaches confirm the ferroelectric behavior of ALD-grown AlScN and highlight the expanded opportunities of ALD for future device applications.

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Research Interests:
2D materials
Electronic devices
Electronics
Energy harvesting devices & systems
GaN
III-Vs
Integrated circuits
Nanomanufacturing
Nanomaterials
Nanotechnology
Power management

Progress Toward Microwave Sensing of 2D Semiconducting Transition Metal Dichalcogenides

3.17

W. Cai, Z. Ji

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Research Interests:
2D materials

Microwave sensing provides a powerful route to probe the frequency-dependent complex conductivity, closely linked to a material's band structure and low-energy dynamical properties. However, in 2D semiconducting transition-metal dichalcogenides (TMDs), efficient microwave coupling is often hindered by non-Ohmic metal–2D interfaces, and impedance mismatch introduced by vias and interconnect geometries. To address these challenges, we use a contact-free capacitive coupling scheme: a coplanar waveguide (CPW) with a small series gap, where a 2D flake (future gated TMD channel) is placed above/below the gap and isolated by a dielectric spacer to form a strong coupling capacitance.

In this work, we report initial progress toward microwave sensing of 2D TMDs, including electromagnetic simulations of device–waveguide coupling and preliminary device fabrication aimed at enhancing coupling and reducing parasitic, with low S11 and large, clean S21 modulation (high contrast). By using contact-free capacitive coupling, we minimize artifacts from non-Ohmic contacts, and use electromagnetic/circuit simulations to identify the gate-tunable operating regime where the TMD impedance produces the strongest change in S21, enabling rapid integration of gated TMD devices for subsequent extraction of microwave-frequency transport dynamics.

Defect-free III-V on Silicon via Holes on Graphene

3.18

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

Sponsorship: DARPA M-STUDIO

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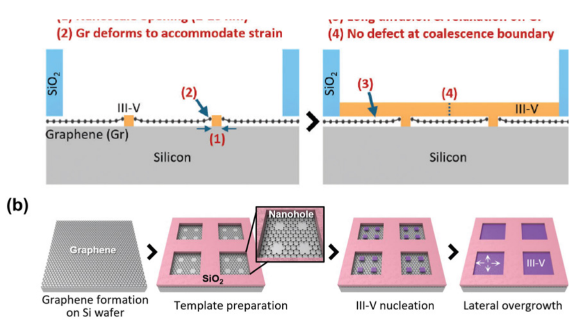
Research Interests:
2D materials
Biological devices & systems
Displays
Electronic devices
Electronics
GaN
III-Vs
Information processing
Integrated circuits
Lasers
Light-emitting diodes
Medical devices & systems
Nanomaterials
Nanotechnology
Optoelectronics
Photonics
Photovoltaics

Integrating III-V semiconductors on silicon is hindered by lattice mismatch that generates dislocations and degrades device performance. Conventional approaches such as graded buffers, ELO, and aspect-ratio trapping only partially suppress defects, while pseudomorphic growth is unsuitable for ultrathin channels.

We present a graphene-assisted selective-area epitaxy method that enables dislocation-free III-V growth on silicon. A thin GaP layer is first formed on Si, followed by patterned graphene with nanoscale holes that expose controlled nucleation sites. III-V islands initiate inside these apertures and laterally overgrow the graphene, filtering defects and relaxing strain during coalescence. This approach provides a scalable, CMOS-compatible route for integrating high-quality III-V materials 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.

Session 4: Medical Devices & Biotechnology

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

Volumetric Imaging of Live Biological Systems via an UltrafastSelf-localized Pencil Beam

4.01

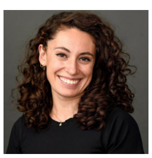
H. Cao, S. Spitz, L. Yu, K. Liu,S. Kulkarni, R. D. Kamm, S. You

Sponsorship: Mathworks Fellowship

High-speed volumetric imaging of live biological systems remains challenging due to the trade-offs between resolution, imaging depth, and speed. We introduce a self-localized ultrafast pencil beam generated in a standard multimode fiber via nonlinear spatiotemporal localization near the critical power. This beam forms a sidelobe-suppressed, Bessel-like profile with exceptional axial confinement, low noise, and resilience to tissue-induced aberrations.

By integrating this beam into a conventional multiphoton microscope, we achieve over 10-fold increased axial excitation range and ~25-fold faster volumetric imaging with reduced photodamage. We benchmark performance in two biological models: (1) two-photon imaging of the intact mouse enteric nervous system, where the localized beam maintains subcellular resolution over large 3D volumes, and (2) real-time imaging of transferrin uptake in a live human blood-brain barrier model. This approach uncovers inter- and intra-cellular heterogeneity in receptor-mediated transport across endothelial, pericyte, and astrocyte populations that are not accessible with conventional endpoint assays.

Our platform combines fiber-based nonlinear optics with advanced biological imaging, offering a scalable and hardware-efficient solution for dynamic 3D bioimaging. The technique holds promise for studying tissue physiology, disease models, and therapeutic delivery in complex multicellular environments. We demonstrate resolution and signal enhancement in multiphoton imaging with the MMF under nonlinear localization, compared to the generally speckled MMF output, by characterizing the 3D point-spread function. We expect our work to provide physical insights and a strategy for creating robust ultrafast pencil beams, thereby enabling new applications in biomedical imaging and endoscopy.



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Research Interests:
Actuators, Batteries, Electronics, Energy, Energy harvesting devices & systems, Machine Learning, Photonics, Sensors.

The UmboMic: Biocompatibility and Testing of a Middle Ear Microphone for Fully Implanted Cochlear Implants

4.02

E. F. Wawrzynek, J. Z. Zhang, J. G. Arenberg, D. B. Welling, I. Kymissis, E. S. Olson, J. H. Lang, H. H. Nakajima

Sponsorship: National Institutes of Health/National Institute on Deafness and Other Communication Disorders, the National Science Foundation (NSF) Graduate Research Fellowships Program (GRFP)

Realizing a fully-implanted cochlear implant depends on the development of an appropriate microphone. We present advancements of the UmboMic, a piezoelectric sensor and amplifier implanted in the middle ear to detect motion of the umbo. The UmboMic functions as a microphone by transducing the umbo's vibration into an electrical signal. Our prior experiments on the bench and in human cadaveric ears demonstrate the UmboMic's excellent signal-to-noise ratio and linearity over a wide dynamic range. We now report a new method of UmboMic fabrication, which achieves a fully biocompatible sensor. Despite the use of new materials, the biocompatible UmboMic has similar performance on the bench.

UmboMic sensors are fabricated in the cleanroom at MIT.Nano using photolithography and thin-film deposition techniques. The active layers of the sensor are two polarized sheets of piezoelectric PVDF. Finished UmboMic sensors are tested in an electrically- and acoustically-isolated sound chamber. UmboMic sensors are first evaluated on the bench using an "artificial umbo," and next tested in human cadaveric temporal bones.

Bench and cadaveric experiments demonstrate that the previous non-biocompatible UmboMic has a low noise floor of approximately 62E-18 C from 200 Hz to 20 kHz, and a maximum sensitivity of about 230E-15 C/Pa at 2 kHz. The UmboMic also shows a linear response over a dynamic range of 35 to 115 dB SPL. The fully-biocompatible UmboMic sensors perform similarly to the previous non-biocompatible versions on the bench, with comparable sensitivity, noise floor, and linearity.

This work demonstrates the success of an UmboMic sensor comprising fully biocompatible materials. Developing a biocompatible UmboMic sensor is critical to achieving a chronically safe fully-implanted cochlear implant.

Single Shot, 3-photon Fluorescence Lifetime Imaging for Deep and Fast Metabolic Microscopy

4.03

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

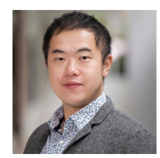
Fluorescence lifetime imaging microscopy (FLIM) has shown promise in metabolic imaging applications, but it suffers from several drawbacks, including limited imaging depths, and demanding photon budgets. This project seeks to address these shortcomings with a two-pronged approach. We first utilize three-photon excitation to simultaneously obtain lifetime images at increased depths. To relieve the burden of photon starvation in conventional FLIM, we develop a physics-based learning algorithm to extract lifetime information from the directly sampled output of the photomultiplier tube (PMT) in both low- and high-flux scenarios. By examining the arrival time of several photons simultaneously, we avoid the dead-time based limitations which slow conventional FLIM methods, enabling lifetime estimation after just a single laser pulse period. By addressing the issues of imaging depth and speed, this work will enable new translational applications for live-tissue metabolic microscopy such as drug screening in living organoids and real-time dermatology assessment.

Understanding the Molecular Effects of Antiviral Compounds on Enterovirus 71 (EV71) capsid

4.04

K. Wang, H. Shi, J. Yeo, E. Spero, and C. Ortiz

Sponsorship: MIT Novo Nordisk Artificial Intelligence Postdoctoral Fellowship



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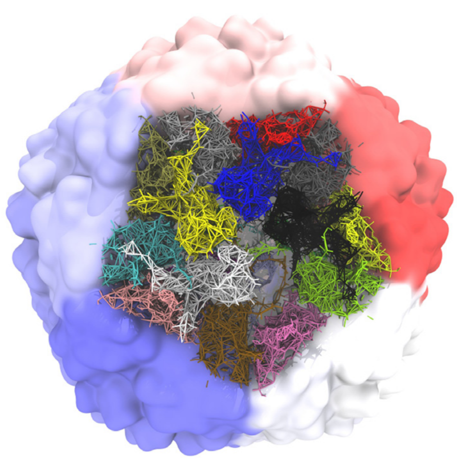
Research Interests:
Biological devices & systems, Energy, Energy harvesting devices & systems, Integrated circuits, Power management.

Human Enterovirus 71 (EV71) is a major pediatric pathogen causing neurological disease. We investigate how chemical environments reshape its capsid by combining atomistic and coarse-grained (CG) molecular dynamics. Building on prior machine learning–guided all-atom simulations, we first show how urea disrupts key structural motifs through changes in solvent-accessible surface area, residue fluctuations, and native contacts. We then highlight that fully atomistic simulations, while mechanistically rich, are restricted to small subsystems such as a single capsid pentamer. To overcome this limit, we build a CG model of the full EV71 capsid using the Martini 3 force field. The CG model captures large-scale capsid flexibility and enhanced dynamics near the pore region under denaturing (urea) conditions. Finally, we outline strategies for refining this CG framework into a predictive platform for screening antiviral candidates at biologically relevant scales.



◀ Figure 1: Coarse-grained MD model of the EV71 protein capsid with elastic networks to account for long range interactions

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Research Interests:
Biological devices & systems
BioMEMS
Machine Learning
Microfluidic devices & systems
Molecular & polymeric materials
Nanomaterials
Nanotechnology

Quantifying Red Blood Cell Sickling Dynamics in Sickle Cell Disease by Microfluidics Combined with AI-driven Tools

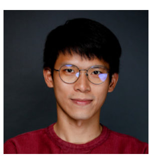
4.05

J. Zheng, M. Dao

Sponsorship: NIH R01HL154150 & R01HL158102, and Global Blood Therapeutics (acquired by Pfizer)

Sickle cell disease (SCD) is an inherited blood disorder caused by a single-point mutation in the β-globin gene, leading to the production of sickle hemoglobin (HbS). Under deoxygenated conditions, HbS polymerizes to form rigid fibers that deform red blood cells (RBCs) into a sickled morphology. These biomechanical alterations drive vaso-occlusion, stroke, and progressive organ damage. Although curative options such as gene therapy and stem cell transplantation are available, their high cost, donor-matching constraints, and uncertain long-term risks underscore the need for pharmacological strategies, including polymerization inhibitors like osivelotor (currently in Phase II/III clinical trials). However, patient responses to anti-sickling therapies vary widely due to substantial heterogeneity across RBC subpopulations, complicating drug evaluation and limiting accurate prediction of pain crises.

To overcome these challenges, we developed a microfluidic assay integrated with an AI-driven image analysis pipeline to quantitatively characterize sickling dynamics at the single-cell level. This combined platform enables high-throughput phenotyping of diverse RBC subpopulations, offering deeper insights into cell classification and the biophysical heterogeneity of SCD, and supporting the development and evaluation of more effective therapeutic strategies.



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Research Interests:
Biological devices & systems
Photonics
Nonlinear microscopy,
Computational imaging
Fiber optics

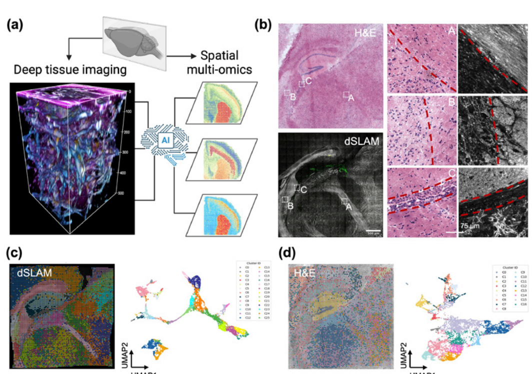
Spatial Transcriptomics-informed, AI-empowered Multimodal Label-free Microscopy for Mouse Brain Imaging

4.06

L. Yu, Y. Kim, Z. Bai, S. Sinha, S. You

Sponsorship: NSF CAREER Award (2339338), the CZI Dynamic Imaging program via the Chan Zuckerberg Donor Advised Fund (DAF) through the Silicon Valley Community Foundation (SVCF), the Claude E. Shannon Award, the MathWorks Fellowship.

Understanding the spatial molecular landscape of the brain is essential for unraveling the cellular mechanisms of neurological disorders. Although current spatial omics technologies are transformative, they require destructive tissue sectioning, preventing live or longitudinal analysis. In contrast, deep-tissue, multimodal label-free nonlinear microscopy (dSLAM) enables real-time interrogation of tissue architecture without labeling or damage, but it lacks direct molecular specificity. We introduce an AI-driven framework that bridges spatial omics with non-invasive, label-free deep-tissue imaging. Our model learns to correlate spatially resolved gene expression profiles with microenvironments, linking molecularly defined cell identities with cellular morphology, metabolism, and extracellular matrix features. The rich biological contrasts captured by dSLAM improve gene-level prediction and cell-type classification compared with conventional histology and facilitate downstream analyses.



◄ Figure 1: (a) Schematic of an AI-driven framework for integrating dSLAM with spatial omics. (b) H&E and dSLAM images from a sagittal section of the mouse brain. (c-d) Gene prediction and clustering performed using dSLAM images (c) and H&E images (d).

Ultrasound-based Gaseous Emboli Detection and Sizing

4.07

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Sponsorship: 'la Caixa' Fellowship Foundation, Boston Children's Hospital Anesthesia Foundation

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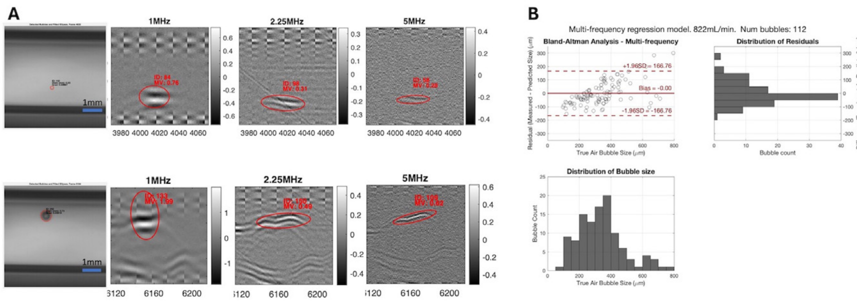
Research Interests:
Artificial Intelligence
Biological devices & systems
Electronic devices
Medical devices & systems
Transducers

Neurologic injury affects one in four pediatric patients supported with Extracorporeal Membrane Oxygenation (ECMO), and gaseous and solid emboli generated within the ECMO system are believed to contribute to this problem. Current methods for emboli monitoring rely on visual inspection with a flashlight. This is inefficient and highly subjective. Ultrasound-based approaches for cerebral emboli monitoring and in-line embolus detection have not achieved clinical translation due to technical limitations.

In this work, we propose an ultrasound-based system for gaseous emboli monitoring within the ECMO circuit. Single-element pulse-echo transducers at 1, 2.25, and 5 MHz are synchronized with high-speed videography to detect, count, and size gaseous emboli in a controlled flow phantom. Using a multi-frequency regression model, 58% of bubbles were sized within ±20% of their true diameter (n=112), and 76.8% were sized within ±100 μm absolute error.



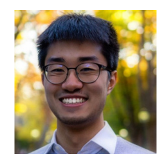
▲ Figure: A: Two bubbles of different sizes with synchronized high-speed video and ultrasound signals (1, 2.25, and 5 MHz), including detection and voltage extraction. B: Bland-Altman plot for the multi-frequency regression model used for air-bubble sizing.

Silicon Nitride Metalens for Scintillation-based Imaging

4.08

J. Chen, S. Pajovic, S. Vaidya, W. Michaels, S. Choi, J. Hu, M. Soljacic

Sponsorship: NSF, DARPA



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Research Interests:
Machine Learning
Nanotechnology
Photonics
Nanophotonics

Scintillators are widely used to convert X-rays into visible light for medical imaging modalities such as radiography and computed tomography (CT). However, in conventional systems the scintillator must be several millimeters thick to absorb high-energy X-rays, and the resulting isotropic light emission and Beer's-law attenuation cause strong blur: most X-ray energy is deposited near the entrance facet while the detector is attached to the back, leading to a fundamental thickness–resolution trade-off and typical resolutions on the order of hundreds of microns to millimeters in CT detectors. Recent work on nanophotonics and photonic crystals has shown that structuring scintillators can enhance light extraction and control emission, suggesting that metasurfaces could be used to reshape scintillation light and overcome this limitation.

In this work, we integrate a silicon nitride metalens directly on the back facet of a 1 mm-thick YAG:Ce scintillator and use it to refocus blurred scintillation light back toward the high–energy-deposition region near the entrance facet. We design the metalens (NA = 0.45) using the local periodic approximation and rigorous coupled-wave analysis. Experiments on a Zeiss Xradia Versa 620 micro-CT system show an 8.8× improvement in spatial resolution, from 202.2 μm for a bare scintillator to 22.9 μm with the metalens, as quantified by edge-spread and line-spread function measurements. This metalens-integrated scintillator architecture provides a path toward micron-scale X-ray resolution in thick scintillators compatible with high-energy CT applications.

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Visiting affiliate supervised by Luis Fernando Velasquez-Garcia.

Research Interests:
Biological devices & systems
Medical devices & systems

Finite Element Evaluation of WE43 Magnesium Scaffolds fabricated by JS-LMSW for Biodegradable Orthopedic Implant Applications.

4.09

H. J. Grijalva, L. D. Cedeño-Viveros, C. A. Rodríguez, L. F. Velasquez-Garci2 , E. Vázquez-Lepe, E. García-López

Sponsorship: Secretaría de Ciencia, Humanidades, Tecnología e Innovación (SECIHTI) (1276197) and Tecnológico de Monterrey

The demand for biodegradable implants in orthopedic applications has increased due to their potential to eliminate the need for secondary surgeries and reduce long-term complications. This study investigates the mechanical behavior of WE43 magnesium scaffolds fabricated via joining stacking-based laser micro-spot welding (JS-LMSW) through linear finite element analysis (FEA). Two simplified FEM models, assembly and solid, were developed to simulate the scaffold's elastic response under vertical and horizontal compression loads. The numerical results were validated against experimental data, showing good correlation in stress distribution and deformation patterns. The simulation confirmed suitable mechanical strength and uniform load transfer, demonstrating the viability of using JS-LMSW magnesium structures in orthopedic implant applications. As future work, a new composite scaffold design combining magnesium and nitinol will be developed to enhance both mechanical stability and functional performance. This approach aims to exploit the biodegradability of magnesium and the superelasticity of nitinol, achieving improved load sharing, deformation recovery, and long-term structural integrity. Finite element simulations and experimental testing will be conducted to assess the mechanical behavior and potential biomedical applications of this composite system.

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Research Interests:
Transducers

Determining Which Blood Biomarkers are Detectable in Non-invasive Biofluids and How theirLevels Correlate Across Sweat, Saliva, and Tears

4.10

I. Canas, M. Muntada-Segura, CH. Liu, C. Lopez-Angeles, T. Palacios, M. Balcells-Camps

Sponsorship: ASISA Foundation scholarship

Inflammatory cytokines and kynurenine-pathway metabolites play key roles in immune regulation and are increasingly investigated as clinical indicators associated with various pathologies and comorbidities. However, it remains unclear which of these blood biomarkers can also be reliably detected in non-invasive biofluids such as sweat, saliva, and tears, and whether their concentration patterns correlate across these fluids.

To address this question, we are developing two types of biosensors based on graphene and molybdenum disulfide field-effect transistors. These sensors are capable of detecting biomarker concentration changes with high specificity and sensitivity by transducing biomarker binding events into measurable variations in channel conductivity. The long-term objective is to determine the biomarker profiles associated with different pathologies and to integrate this technology into wearable medical devices for continuous, real-time monitoring, such as minimally invasive patches or wrist-worn systems.

High-speed Micromotor Imaging Catheter for Intravascular Cardiac Optical Coherence Tomography

4.11

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Sponsorship: National Science Foundation Graduate Research Fellowship Program; National Institutes of Health (R01EB033306, P41EB015903).

Intravascular OCT (IV-OCT) provides valuable information for the characterization of vulnerable coronary plaques in the heart, however cardiac imaging catheters are severely limited in their beam scanning speed. Current clinical hardware utilizes an external rotary junction and torque coil which cannot transmit rotation above ~160 Hz due to friction-induced heating and non-uniform rotation. Modern MHz-rate OCT lasers can support imaging speeds more than an order of magnitude faster, which is especially important when imaging in the dynamic environment of the heart, motivating the development of a faster scanning catheter.

This work introduces a distally actuated micromotor catheter designed for high-speed, low-distortion rotation. It uses the optical fiber as the motor shaft, enabling stable rotation within a 2.4 Fr (0.74 mm) diameter. A two-pole rotor and an ultra-thin flexible-circuit stator electromagnetically drive the rotation of an angled mirror while maintaining a clear optical path. Precision two-photon-polymerized components and new micro-scale assembly techniques enable integration of the magnet, windings, optics, and fiber shaft within the tight device envelope. Preliminary benchtop testing results demonstrate the viability of distally actuated beam scanning in a clinically compatible form factor for the next generation of IV-OCT systems.

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Research Interests:
BioMEMS
Medical devices & systems
Optoelectronics
Sensors

Smart Sensing Platform Based on 2D Materials for Healthcare Diagnosis

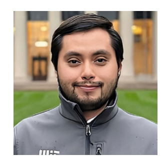
4.12

Applications C. Lopez Angeles, C.-H. Liu, D. I. Erus, S. Bae, T. Palacios

Sponsorship: Exxon Mobil and NSF Convergence

This work introduces a highly integrated platform for breath analysis, leveraging a 4096-sensor array of graphene and MoS_2 back-gated field-effect transistors. Designed for the recognition of volatile organic compounds (VOCs) and inorganic gases from human breath, the platform employs functionalized graphene channels and MoS_2 transistors to enable high sensitivity and selectivity. This system lays the groundwork for applications in detecting biomarkers associated with respiratory conditions, cancer, diabetes, and neurodegenerative diseases like Parkinson's.

The platform integrates printed circuit board (PCB) electronics for data readout and is designed to generate large datasets for analysis. Proposed approaches include incorporating deep learning algorithms, such as convolutional neural networks (CNNs), to enable robust pattern recognition and predictive diagnostics. Measurements to date include transfer characteristics (IV curves), distribution of gate-source voltage (Vgs) at the Dirac point, and resistance changes. This platform represents a significant step toward scalable, non-invasive diagnostics using cutting-edge electronic nose technology.



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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

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Research Interests:
2D materials
Biological devices & systems
Electronic devices
Energy harvesting devices & systems
Medical devices & systems
Nanotechnology
Optoelectronics
Organic materials
Photovoltaics

Autonomous Bioelectronic Implants Enable Surgery-free Focal Neuromodulation

4.13

S. Yadav and D. Sarkar

Sponsorship: MIT Media Lab start-up funding

Traditional bioelectronic implants for treating brain disorders require invasive neurosurgery, limiting accessibility and increasing risks. Here, we present "Circulatronics" technology that enables surgery-free implantation of functional neuromodulation devices through immune cell–electronics hybrids.

Our approach leverages subcellular-scale, wireless photovoltaic electronic devices that harvest optical energy with high power conversion efficiency. By covalently integrating these nanoelectronics with immune monocytes, we create biologically intelligent hybrids that can be delivered intravenously and autonomously navigate the vasculature to target inflamed brain regions.

In murine models of brain inflammation, we demonstrate: (1) successful self-trafficking of hybrids to target sites without external guidance or imaging, (2) autonomous implantation within inflamed regions, and (3) focal wireless neuromodulation with 30-μm spatial resolution around the therapeutic target.

By fusing the electrical functionality of miniaturized electronics with the biological transport and targeting capabilities of living cells, Circulatronics circumvents the need for neurosurgery while enabling focal brain stimulation. This platform technology addresses a critical unmet need in neuromodulation and establishes a new foundation for the autonomous implantation of bioelectronic devices to treat neurological disorders.

Session 5: MEMS, Field-Emitter, Thermal, Fluidic Devices & Robotics

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Research Interests:
Actuators
Electronic devices
MEMS & NEMS
Nanomaterials
Nanotechnology
Sensors

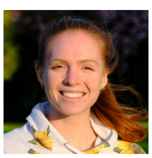
Flexible Acoustically Active Surfaces Based on Piezoelectric Microstructures

5.01

T. Dang, 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. The growing industrial and consumer demand for sound-based sensing and actuation has driven the development of scalable, cost-effective, and high-performance loudspeakers. 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 are not readily scalable or show limited performance, restricting their practical use in large-area, low-power applications.

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. 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 and sensing capabilities, along with high sensitivity and broad bandwidths.



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

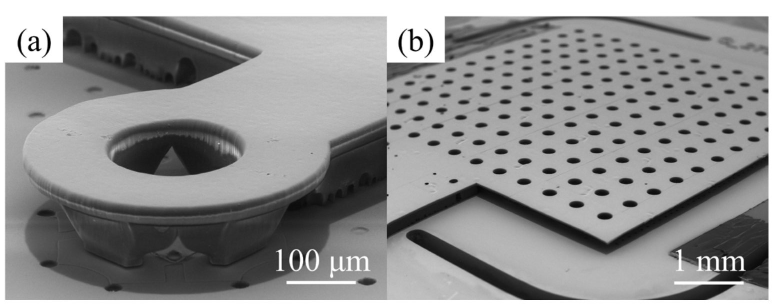
Fabrication of Electrospray Thruster Extractors with 2-Photon Polymerization

5.02

C. J. Nachtigal, L. Parameswaran, P. C. Lozano

Sponsorship: NSTGRO Grant (80NSSC23K1174), AFOSR (FA9550-19-1-0104)

Electrospray thrusters (ESTs) are compact, scalable propulsion systems that can allow for high efficiency thrust, making them good candidates for CubeSat and small spacecraft missions. ESTs operate as an array of tens or hundreds of emitters, which are fed conductive propellant to accelerate and generate thrust. ESTs operate by applying a high voltage to the emitter tip site and grounding a manually aligned downstream extractor grid. They lack reliability and lifetime due to poor extractor alignment and electrical shortages. In this work, 2-photon polymerization (2PP) is used to make extractor grids on Lincoln Laboratory EST emitter arrays. These grids are directly printed and do not require manual alignment, reducing intercepted current and handling that can cause electrical shortages. A selective metal assisted chemical etching (MACE) process is also developed to control the chip wetting and prevent shortages. A 13x13 array is tested, generating over 30 µA of current as would be expected by such an array, with improved grid alignment and little intercepted current. This work can increase EST reliability and lifetime, increasing their use in satellites.



◄ Figure 1: Lincoln Laboratory (a) single emitter and (b) 13x13 EST array with integrated 2PP metallized extractor.

Temperature Effects on Electrical Resistivity of Selected Ceramics for High-temperature Packaging Applications

5.03

T.M. Deucher, R.S. Okojie

Sponsorship: NASA Lewis' Educational & Research Collaborative Internship Program, NASA Hypersonic Technology Project

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Available from September 2029.

Research Interests:
2D materials
Communications
Electronics
Energy harvesting devices & systems
Lasers
MEMS & NEMS
Nanomaterials
Photonics
Thermal structures, devices & systems

The upper operating temperature of semiconductor sensors is often limited by packaging, contact metallization, and intrinsic thermal properties of the material. NASA Glenn Research Center demonstrated 4H-SiC piezoresistive pressure sensors and integrated circuits functioning above 800 °C, but signal instabilities emerged at higher temperatures. One proposed cause is increased leakage through ceramic packages as their electrical resistivity drops with temperature.

We characterized the high-temperature bulk and surface resistivities of several candidate packaging materials—aluminum nitride (AlN), silicon nitride (Si_3N_4), beryllium oxide (BeO), yttrium oxide (Y_2O_3), and silicon dioxide (SiO_2). Samples were thermally cycled twice to 1200 °C in nitrogen while resistivity was measured in situ, providing comparative data for identifying viable packages for next-generation high-temperature SiC electronics.

Although the resistivity values of all samples dropped with increasing temperature, BeO maintained the relatively highest bulk and surface resistivity values at 1200°C of 28 and 34 kΩ cm, respectively, while AlN had the lowest values at 6.8 and 0.64 kΩ cm. In terms of viability for packaging SiC sensors for >800°C operation, AlN and Si_3N_4 are the choice candidates due to their lowest mismatches in the coefficient of thermal expansion with SiC. However, the relative resistivity stability of Si_3N_4 over AlN makes it a promising candidate, even with its lower thermal conductivity relative to AlN.

An All-Electrical Biomolecular Sensing Platform with Ion-Sensitive Field Effect Transistors (ISFETs)

5.04

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Sponsorship: Texas Instruments

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Research Interests:
Biological devices & systems
BioMEMS
Electronic devices
Electronics
Medical devices & systems
Microfluidic devices & systems
Molecular & polymeric materials

Ion-sensitive field-effect transistor (ISFET)–based biomolecular sensors offer several advantages over conventional biosensing techniques, including compatibility with standardized semiconductor manufacturing, structural simplicity and ease of miniaturization, material robustness, and high sensitivity. However, their high sensitivity—enabled by the strong binding affinity of surface-immobilized capture molecules—often comes at the expense of low dissociation rates. This limits surface regeneration, complicates the detection of decreasing analyte concentrations, and hinders long-term continuous measurements.

In this work, we investigate surface regeneration strategies for an ISFET-based all-electrical biomolecular sensing platform. The system explores the use of electrical and/or thermal stimuli to promote the dissociation of non-covalently bound targets, thereby enabling surface regeneration and sensor reuse. Non-functionalized ISFETs are incorporated as on-chip references for drift compensation and signal normalization. Signal differences upon analyte spikes between functionalized ISFETs and reference ISFETs have been detected.

This platform aims to enable reusable, continuous-monitoring biomolecular sensors capable of tracking both rising and falling analyte concentrations in real time. Such a system could facilitate long-term monitoring of clinically relevant molecules—ranging from small metabolites such as glucose and lactate to larger biomolecules like cytokines—providing valuable insights into disease progression and physiological dynamics.

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Research Interests:
Electronics
Energy harvesting devices & systems
Machine Learning
MEMS & NEMS
Microfluidic devices & systems
Molecular & polymeric materials
Nanomanufacturing
Nanomaterials
Systems
Thermal structures, devices & systems

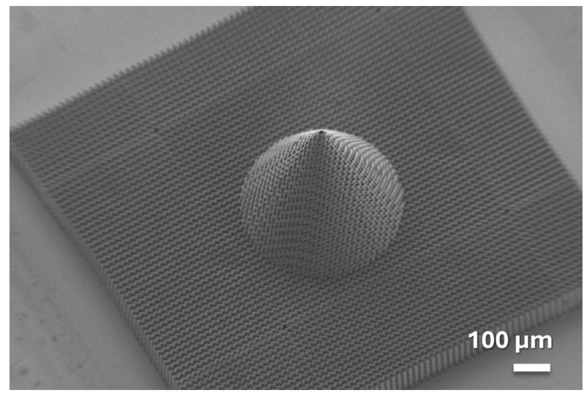
Characterization of An Additively-Manufactured Microporous Electrospray Single Emitter

5.05

R.A. Davis, B. Kingsley, Z. Ulibarri, P. Lozano, S. Sobhani, E. Petro, B.L. Wardle
Sponsorship: NASA Space Technology Graduate Research Opportunities Grant

Electrospray thrusters employ microfluidics and an electric field to extract and accelerate ions or charged droplets, with the goal of producing thrust for small spacecraft. Key failure modes are dependent on the wetting properties of the propellant and the emitter geometry. An approach to optimizing the emitter geometry employs two-photon polymerization, which through the two-photon absorption principle can additively manufacture with achievable resolution below 100 nm. Applying this technology to manufacture emitters has led to satisfactory ion emission; however, the two-photon polymerization process leaves uncured resin trapped in the pores of the emitter resulting in current degradation.

In this work, the additive manufacturing and characterization of a single emitter is presented. The print repeatability and trapped resin are characterized through imaging. The effect of trapped, uncured resin on the ion emission of the emitter is presented and compared to numerical modeling.



▶ Figure 1: Scanning electron microscope (SEM) images of the additively-manufactured electrospray single emitter containing a gyroid TPMS porous network and integrated capillary channels.

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Research Interests:
Biological devices & systems
BioMEMS
Electronic devices
Electronics
MEMS & NEMS
Microfluidic devices & systems
Nanotechnology

Rapid Microfluidic Point-of-care Immune Cell Monitoring for Sepsis

5.06

C. Hsu, J. Voldman
Sponsorship: MIT Portugal Program

Sepsis is an excessive dysregulated immune response to infection that can lead to substantial morbidity and even death within hours. In addition to vital signs, blood tests are commonly used to monitor the progression and resolution of sepsis. However, current blood testing is used infrequently, much slower than the underlying dynamics of the disease. To better understand sepsis progression and resolution, there is a critical need for integrated tools that can rapidly deliver essential clinical information to support timely treatment decisions. Previously, we have reported on a fully automated, label-free leukocyte activation analysis platform for monitoring immune responses in sepsis by integrating an inertial microfluidic sample preparation sub-platform with an iso-dielectric separation (IDS) sub-platform. While this system provides rapid assessment of leukocyte biophysical properties, further characterization of immune cell function and system automation would improve the effectiveness of the platform. To address this need, we have been developing improvements in the fabrication, automation, and integrated analysis of the platform. These operational and functional extensions, combined with our existing biophysical analysis, strengthen our ability to capture both the physical and functional signatures of immune dysregulation, advancing the development of a comprehensive, point-of-care tool for sepsis monitoring.

Sensing Autonomy of Insect-Scale Flapping-Wing Aerial Robots

5.07

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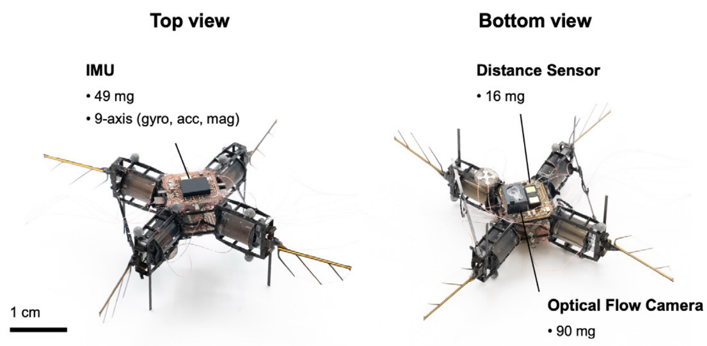
Available from May 2030.

Research Interests:
Systems
Robotics

Recent research has shown that insect-scale, flapping-wing aerial robots can be remarkably robust and agile, capable of precise trajectory tracking and acrobatics. However, their operation relied on external motion tracking systems, precluding autonomous flight in real-world environments and limiting their practical applications. Here, we present an integrated sensor package measuring 1 cm x 1 cm and weighing 0.24 grams. This package enables full onboard estimation of position, attitude, velocity, and angular velocity, with attitude tracking achieving an RMS error of less than 2 degrees compared to a motion capture system. Using this sensor package, our robot achieved 10 seconds of stable hovering flight, a fourfold increase over the current state-of-the-art. This result represents a critical step toward fully autonomous micro-robots, paving the way for diverse applications such as 3D reconstruction in narrow spaces, search and rescue, and environmental monitoring.



▲ A photograph illustrating the sensor package mounted on the robot.

Experimental Negative Differential Resistance of Field Emitter Arrays for Different Anode Geometries

5.08

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Sponsorship: Xcimer Energy Corporation

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

Field emitter arrays (FEAs) are promising electron sources for high-power and high-frequency devices such as compact power switches and pulsed power systems for electron accelerators. The property of ballistic transport and high breakdown field make FEAs capable of high voltage switching >40kV at operating frequencies of >10kHz. Recent work has revealed negative differential resistance (NDR) in the device output characteristics using flat anode geometries. The study concluded that different anode geometries can negatively impact electron transport mechanisms, limiting electron collection at the anode in the space charge limited (triode) operating regime. However, the NDR phenomenon has yet to be demonstrated for anodes other than the flat geometries, leaving speculation on the underlying relationships between electrostatics and the emitter-gate-anode geometries of FEAs.

In this work, we show the occurrence of NDR utilizing a ball anode on a set of FEAs with larger emitter tip radii and wider gate apertures, producing wider electron beam spread. The appearance of the NDR signifies the role of the emitter-gate geometries as NDR has not previously occurred for ball anodes on FEAs with smaller tip radii and apertures. The behavior of the NDR in these set of experiments behaves identically to prior work, gradually disappearing when the anode-to-emitter distance is either increased vertically or horizontally. This implies that despite the electrostatics applied by the anode geometry, the beam spread of initial electron trajectories must be small to encourage collection at the anode. These experimental results solidify understanding of the NDR phenomenon as a product of the electrostatics across the vacuum channel combined with the initial trajectory of the electrons determined by the emitter-gate geometries.

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

A Microelectromechanical-Cantilever Hydrogen Sensor with Palladium-Driven Bending and Piezoresistive Readout

5.09

Z. Zheng, H. Kim, F. Niroui, J. H. Lang

Sponsorship: ExxonMobil

The hydrogen economy is a promising vision for a clean and renewable energy system, where hydrogen is the primary agent in energy storage and delivery. A major technical challenge that currently hinders this vision is the lack of adequate hydrogen sensor technology that can protect against the danger of hydrogen leakage in practical settings. Many researchers have developed hydrogen sensors of various genres in the past, but they suffer from various drawbacks ranging from low sensitivity to high cost and power consumption. Micro-electro-mechanical systems (MEMS) with piezoresistive cantilevers provide a promising sensing platform that can be robust, sensitive, while maintaining low manufacturing cost and low operating power. We show recent developments of MEMS cantilevers based hydrogen sensors with palladium driven bending and piezoresistive readout, which is projected to reach the goal of achieving sub 1 part-per-million (ppm) sensitivity, while remaining unaffected against other environmental factors.

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Research Interests:
2D materials
MEMS & NEMS
Nanomaterials
Nanotechnology
Optoelectronics
Sensors

A High-sensitivity Nanoelectromechanical Hydrogen Sensor

5.10

H. Kim, J. Zheng, J. Lang, F. Niroui

Sponsorship: ExxonMobil

Hydrogen gas is a critical component of emerging decarbonized clean-energy systems. However, its flammability necessitates highly sensitive and reliable leakage detection for safe deployment and use. Commercial H_2 sensors typically exhibit sensitivities limited to the few-ppm range, and many of them rely on optical transitions that are difficult to implement in automotive or outdoor environments. As a result, there remains a need for hydrogen sensors that are both highly sensitive and easily deployable. To address this challenge, we present a sensitive and fast nanoelectromechanical sensing platform. Specifically, our device is composed of mechanically compliant, hydrogen-responsive palladium (Pd) structures. In this design, gas absorption induces physical displacement, the extent of which is electrically measured to characterize the H_2 concentration. The structure is optimized through a combination of theoretical and experimental studies to maximize its mechanical response to gas. With this approach, we have demonstrated sensors with a sub-ppm (<1 ppm) limit of detection and fast response. This enables high-sensitivity, selective monitoring of H_2 concentration and provides a novel approach for H_2 detection and quantification across the hydrogen supply chain.

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Research Interests:
Nanotechnology
Quantum devices
Superconductivity

Dark Count Origins in Niobium Nitride Nanowires

6.01

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Sponsorship: NSF Graduate Research Fellowship, DARPA (HR0011- 24-9-0311)

Superconducting nanowire single photon detectors (SNSPDs) are of interest for their high efficiency, low noise sensitivity for single photons well into the infrared. They are used in fields from quantum networking to biomedical imaging. However, SNSPD dynamics are not fully understood. Dark counts, or detections observed in the absence of signal light, are thought to result from thermal activation of vortex crossings. Yet prior data cannot be fully explained by existing models of this process.

In this work, we carefully measure dark count events in nanowires under a range of bias conditions. We demonstrate that some previously unexplained deviations from theory can result from systemic issues in the temperature bias condition, while others can result from incorrect normalization of the current bias condition. With our corrections, our data better agrees with existing models, shedding light on the importance of correct bias control to achieve consistent operating conditions for SNSPDs.

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

Injectable Sub-Cellular Photovoltaic Devices for Wireless Neuromodulation

6.02

P. Patel, S. Yadav, and D. Sarkar
Sponsorship: MIT Media Lab, K. Lisa Yang Bionic Center

Neuromodulation technologies that provide control over neural activity offer therapeutic solutions for neurological disorders, chronic pain, and other conditions. Current approaches face a fundamental trade-off: invasive technologies like deep brain stimulation provide high spatial resolution but require surgery for electrode implantation, while non-invasive modalities such as transcranial magnetic stimulation (TMS) and focused ultrasound avoid surgery but suffer from poor spatial resolution (~1cm). Intermediate approaches using optogenetics or implanted devices with wireless actuation show promise, yet face limitations including genetic modification requirements, potential toxicity, and tissue damage from chronic implants. This work presents wireless, injectable photovoltaic devices with sub-cellular dimensions (10-40 μm) that bridge this gap, offering minimally invasive delivery through injection while achieving single-cell spatial resolution for neuromodulation.

The devices convert near-infrared light (785-895 nm) (NIR) into localized electrical signals through layered semiconductor materials, enabling wireless activation with deep tissue penetration. Fabricated using standard cleanroom processes, these substrate-free devices are small enough to target individual neurons. In-vitro validation using hippocampal rat neurons demonstrates successful neuromodulation, with NIR illumination effectively modulating neuronal membrane potential in cultured neurons, confirming their capability for wireless optical control of neural activity. These freestanding devices can be administered via injection in a drug-like manner, offering unprecedented spatial resolution at the single-cell level. This injectable electronics platform represents a transformative approach to bioelectronic medicine, with potential applications in treating neurological disorders and chronic pain.

BEOL-Compatible Passivation for Reliable In-Based Oxide Semiconductor Transistors

6.03

H. Choi, Y. Shao, J.C.C. Huang, and J. A. del Alamo

Sponsorship: Samsung Electronics

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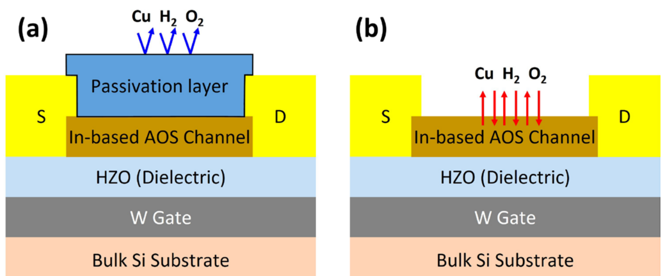
Research Interests:
Artificial Intelligence
Electronic devices
Electronics
MEMS & NEMS
Nanomanufacturing
Nanomaterials
Nanotechnology
Ferroelectric

Indium-based amorphous oxide semiconductors (AOS) enable high mobility and low-temperature uniform deposition, making them attractive channel materials for transistor integration at the back-end-of-line (BEOL). In combination with low-temperature ferroelectrics, these materials are promising for multi-level synaptic devices. Yet BEOL applicability hinges on reliability under environmental/electrical stress and on blocking Cu inter-diffusion from interconnects. Here we experimentally evaluate a BEOL-suitable passivation over the exposed AOS channel. We track threshold-voltage (Vth) shift, hysteresis, and subthreshold swing (SS) under positive/negative bias stress and illumination, versus unpassivated devices. Passivated devices show smaller Vth shift, reduced hysteresis, and stabilized SS across conditions. These results show that engineered passivation mitigates environment-, bias-, and Cu-induced instabilities, enabling reliable BEOL-integrated In-AOS transistors for neuromorphic elements.



▲ Figure 1: Simplified schematic comparison of (a) passivated / (b) unpassivated In-based AOS transistor (not to scale)

Molecular Doping for High Performance P-type WSe_2 Device

6.04

H. W. Lee, Y. M. Jo, M. Dincă, J. Kong, and T. Palacios

Sponsorship: Intel (ISRA)

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Research Interests:
2D materials
Electronic devices
Electronics
Energy
Energy harvesting devices & systems
Integrated circuits
Nanomanufacturing
Nanomaterials
Nanotechnology
Optoelectronics

Two-dimensional (2D) semiconductors are promising candidates for extending device scaling beyond Moore's law due to their atomically thin structure and diverse electronic and optical properties. Advances in 2D material research have elevated 2D semiconductor applications from the academic research level to the industrial level for the next generation of electronics. Thanks to extensive community efforts, the state-of-the-art performance of 2D devices is now comparable to that of silicon devices and even surpasses them in certain aspects. However, substantial challenges remain for realizing 2D complementary metal–oxide–semiconductor (CMOS) technology at an industrial scale. Among these, the most critical barrier is the limited performance of p-type 2D semiconductors such as tungsten diselenide (WSe_2), where reducing the contact resistance at the metal/semiconductor interface is essential for enabling high-performance p-type transistors.

In this work, we study molecular doping techniques based on electron-acceptor molecules, tris(pentafluorophenyl)borane (BCF) and tetracyanoquinodimethane (TCNQ). TCNQ is widely utilized in organic semiconductors for its strong charge-transfer capability. We further enhance its electron-withdrawing strength by forming a BCF:TCNQ complex, then apply to p-type WSe2 transistors. After molecular doping, the on-current of WSe_2 devices increases by more than 200×, reaching the hundreds-of-μA/μm regime. The BCF:TCNQ complex not only injects hole carriers into the channel but also significantly lowers the contact resistance which is confirmed by transfer length method. Finally, the doping effect is spatially uniform and temporally stable, highlighting the potential of this molecular approach for universal implementation in 2D semiconductor devices.

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Research Interests:
Nanomaterials
Nanotechnology
Photonics

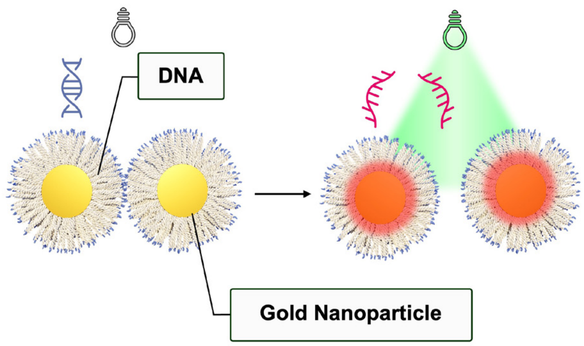
Plasmon-Driven Spatiotemporal Control of Colloidal Crystallization

6.05

S. Woo, T. Hueckel, G. A. Hernandez-Mendoza, A. Alexander-Katz, and R. J. Macfarlane

Sponsorship: AFOSR, Natural Materials and Systems Program (FA9550-23-1-0210); DON, Office of Naval Research (N00014-19-1-2213); ARO, Institute for Collaborative Biotechnologies (W911NF-19-2-0026)

DNA hybridization provides programmable and reversible bonds for self-assembly. Grafting DNA to inorganic nanoparticles yields programmable atom equivalents (PAEs) that form superlattices analogous to atomic crystals. DNA can organize photonic, magnetic, or catalytic behaviors of individual particles and couple them to create emergent properties. Yet DNA primarily controls local interactions, large-scale order remains challenging. Integrating these materials with nanotechnology and devices requires better methods to pattern and place on a substrate. Here we introduce plasmonic thermalization to achieve spatiotemporally resolved PAE crystallization. In situ optical microscopy maps light-to-heat conversion versus intensity, exposure, and pulse frequency. This control decouples nucleation from growth, tunes nucleation density, enables local melting, and yields large single crystals. Light-programmable crystallization offers a general route to hierarchically patterned plasmonic crystals.



◀ Photothermally responsive PAEs: gold nanoparticle core with DNA ligands. Illumination induces plasmonic thermalization, modulating hybridization to drive localized heating and light-controlled assembly.

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Research Interests:
2D materials
Artificial Intelligence
Electronics
Lasers
Machine Learning
Nanomaterials
Photonics

Plasma-assisted Conversion of Janus Transition-Metal Dichalcogenides and their Excitonic Studies

6.06

Y. Zhu, T. Zhang, T. Yang, B. Lawrie, Y. Wu, and J. Kong

Sponsorship: Air Force Office of Scientific Research under award number FA2386-24-1-4049

Two-dimensional Janus transition-metal dichalcogenides (TMDs) have recently emerged as a powerful platform for exploring excitonic physics and nonlinear optical phenomena, owing to their broken out-of-plane symmetry, intrinsic dipole moment, and strain-tunable properties. In this work, we applied a room-temperature method for converting monolayer MX_2 (M = Mo, W; X = S, Se) into Janus MXY (X, Y = S, Se) structures by selectively substituting the top chalcogen layer using a remote hydrogen-assisted plasma process. Room-temperature Raman and photoluminescence (PL) spectroscopy confirm complete conversion to the Janus phase, accompanied by clear shifts in the optical bandgap relative to the pristine TMDs.

To enable detailed excitonic characterization, we further fabricate hexagonal boron nitride (hBN)-encapsulated devices from the converted monolayers. Low-temperature PL measurements reveal the emergence of defect-related excitons following Janus conversion, whose spectral signatures depend sensitively on the charge-doping level of the materials. Moreover, pronounced differences in the excitonic behavior of MoSSe and WSeS highlight intrinsic distinctions in their band structures, underscoring the potential of Janus TMDs as a tunable material family for excitonic, quantum-optical, and nonlinear applications.

Fast-Recovery Epitaxial NbN Superconducting Nanowire Single-Photon Detectors with Saturated 1550 nm Efficiency in Liquid Helium

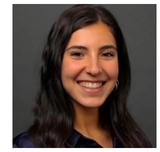
6.07

F. Incalza, M. Castellani, D. J. Paul, A. Simon, E. Batson, D. Mondin, O. Medeiros, and K. K. Berggren

Sponsorship: Darpa (HR0011-24-0311)

Niobium nitride superconducting thin films are widely used in superconducting electronics, quantum computation, and superconducting nanowire single-photon detectors (SNSPDs) due to their high superconducting transition temperature and fast response time. The performance of SNSPDs is highly dependent on the superconducting properties of NbN films.

We report the fabrication and characterization of SNSPDs based on epitaxial NbN thin films deposited via DC magnetron sputtering on c-cut sapphire substrates. High-quality epitaxial growth enables strong electron-phonon coupling and preserves a low electron diffusion coefficient, resulting in a high critical temperature and efficient hotspot formation in the dirty-limit. Structural analysis using X-ray diffraction and transmission electron microscopy reveals well-defined twin domains within the films. 20 nm-wide nanowires exhibit saturated internal efficiency at 1550 nm wavelength at 4.2 K, consistent with hotspot confinement and reduced cross-sectional area, and short reset time enabled by the epitaxial lattice match and high thermal conductance of the sapphire interface. We quantitatively reproduce the experimental photon count rate curves with an ab initio model, informed by detailed material characterization, confirming that the detector performance is driven by the optimized properties of the epitaxial NbN films. These results demonstrate a path toward reproducible high-performance SNSPDs, enabling scalable architectures for quantum information and sensing technologies.



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Research Interests:
2D materials
Electronic devices
Electronics
Integrated circuits
Lasers
MEMS & NEMS
Nanomaterials
Nanotechnology
Photonics
Quantum devices

Dynamically Tuning Lattice Symmetries using Nano-Acoustic Modes

6.08

R. Sane, J. Pettine, J.B. Maier, and N. Gedik

Sponsorship: Gordon and Betty Moore Foundation

Light-induced lattice distortions offer a promising route to tune quantum material properties by dynamically altering atomic spacings and spatial arrangements. However, established methods based on optically-driven phonons can only generate certain types of distortions, restricted by the underlying lattice symmetry. Here, we circumvent these constraints by directly structuring thin quantum materials with high-precision nanolithography. Collective vibrational modes of the nanostructures are then triggered by impulsive ultrafast laser heating, imparting the structural symmetry down to the atomic lattice scale through > 0.1% strain fields. We monitor these nano-acoustic modes and the corresponding lattice distortions in different materials and nanostructure geometries through transient optical reflectivity and time-resolved second harmonic generation. Once fully established, this capability for designer ultrafast symmetry control will open new pathways for tuning quantum interactions, correlated phases, topology, and nonlinear responses of emerging materials.

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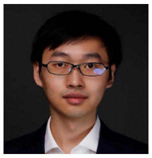
Research Interests:
2D materials
Nanomaterials
Nanotechnology
Quantum devices
Spintronics



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Electrostatic-repulsion-based Transfer of Van der Waals Materials

6.09

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

Sponsorship: US Army Research Office grant number W911NF2210023 and Air Force Office of Scientific Research (AFOSR) Multi-University Research Initiative FA9550-22-1-0166

Van der Waals (vdW) materials offer unique opportunities for 3D integration of planar circuits towards higher-density transistors and energy-efficient computation. Owing to the high thermal budget and special substrate requirement for the synthesis of high-quality vdW materials, an advanced transfer technique is required that can simultaneously meet a broad range of industrial requirements, including high intactness, cleanliness and speed, large scale, low cost and versatility. However, previous efforts based on either etching or etching-free mechanisms typically only improve one or two of the aforementioned aspects and a comprehensive and systematic solution remains lacking.

Here we demonstrate an electrostatic-repulsion-enabled advanced transfer technique that is etching free, high yield, fast, wafer scale, low cost and widely applicable, using ammonia solution compatible with the complementary metal–oxide–semiconductor (CMOS) industry. The high material intactness and interface cleanliness enable superior device performances in 2D field-effect transistors with 100% yield, near-zero hysteresis (7 mV) and near-ideal subthreshold swing (65.9 mV dec^{-1}). The combination with bismuth contact further enables an ultrahigh on-current of 1.3 mA μm^{-1} under 1 V bias. This advanced transfer approach offers a facile and manufacturing-viable solution for vdW-materials-based electronics, paving the way for advanced 3D integration in the future.

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

Sliding Ferroelectric Memory based on Rhombohedral-Stacked Molybdenum Disulfide

6.10

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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. 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.

2D Materials-Based MoS_2 NO_2 Gas Sensor

6.11

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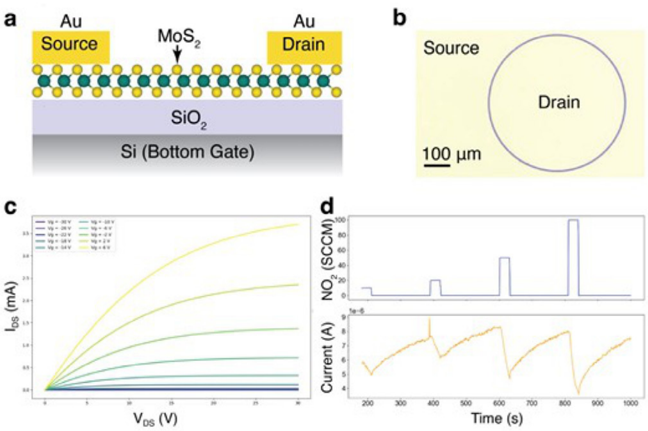
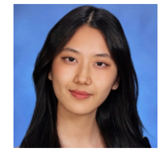
Sponsorship: MIT EECS, 6.2540

Traditional metal oxide semiconductors have been the choice material for gas sensors in the last decades, however they're limited in power consumption efficiency and high operation temperature. 2D materials such as MoS_2 offer a low-power, room temperature solution, as well have a large surface area to volume ratio with good electrical conductivity at an atomically thin thickness limit which miniaturizes devices. Here, we present a ring-shaped sensor on a high-quality monolayer of MoS_2 grown over SiO_2 on silicon substrate. For fabrication, we first synthesized MoS_2 via chemical-vapour deposition in a high-temperature reaction chamber. We then patterned the desired source and drain contacts using photolithography techniques, using electron beam evaporation to deposit gold metal contacts and performed liftoff using NMP solutions, leaving us with a functional NO_2 sensor.



◀ Figure 1: a) Simplified schematic (not to scale). b) Optical microscope image of 4um transistor. c) I-V characteristic of 6um channel length transistors. d) Example sensitivity plot of 8 um channel length sensor



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Ferroelectric Josephson Junctions: A Voltage-tunable Platform for Superconducting Electronics

6.12

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Sponsorship: Lisa Su (1990) Fellowship Fund

Energy efficient computing has become a critical challenge as data center electricity consumption is projected to more than double by 2030 and the computational demands of artificial intelligence continue to grow exponentially. Superconducting electronics offers a promising path forward, providing orders-of-magnitude improvements in energy efficiency and computational density. However, the development of practical superconducting systems has been limited by the absence of compact, low power cryogenic memory elements that can be directly integrated with superconducting logic. Existing memory approaches rely on static currents or magnetic fields, both of which introduce energy overheads and impede scalability.

In this work, ferroelectric Josephson junctions (Fe-JJs) are proposed as a voltage-tunable, nonvolatile memory technology compatible with superconducting circuits and CMOS fabrication. By integrating ultrathin fluorite structure ferroelectrics with superconducting nitrides using low-temperature atomic layer deposition, this platform enables electrostatic control of superconducting transport through polarization-induced modulation of the Josephson critical current. This system represents the first fully CMOS-compatible approach to voltage-programmable superconducting memory based on ferroelectric–superconductor coupling and provides a pathway toward scalable, energy efficient cryogenic computing architectures.

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Research Interests:
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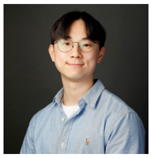
Nanomaterials
Quantum devices
Si



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Research Interests:
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

Broadband Energy Harvesting Using Nonlinear Hall Effect in Weyl Semimetal

6.13

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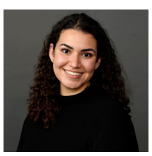
Sponsorship: NSF Convergence Accelerator Award 2345084

Widespread wireless communication has resulted in an abundance of ambient electromagnetic waves, creating opportunities for energy harvesting. Converting this energy into direct current requires an efficient rectifier, yet conventional Schottky diodes are limiting due to low efficiency at low power and operate over a limited frequency range. The nonlinear Hall effect (NLHE) in topological materials enables junctionless rectifiers capable of operating into the terahertz (THz) range, providing a pathway to overcome these limitations. In this work, we present a room-temperature, broadband NLHE rectifier that enables energy harvesting with a flat frequency response across a wide range, from 100 Hz to 20 GHz. By integrating our devices with peripheral circuitry, we confirm the ability to harvest energy in free space. This broadband energy-harvesting platform could open new opportunities for autonomously powered Internet of Things (IoT) devices and other applications in wireless communication.



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Direct Writing of Quantum Dots

6.14

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Sponsorship: NSF Award DMR-2144136

The superior optoelectronic properties of emerging nanomaterials, such as colloidal halide perovskite quantum dots, make these materials attractive building blocks for next-generation quantum technologies. However, integration of such materials into functional devices is hindered by their limited compatibility with conventional top-down fabrication techniques. To address this technology gap, alternative manufacturing platforms are essential. We present a platform for the direct writing of individual perovskite quantum dots as small as ~ 4 nm, with high-accuracy placement within 25 nm of targeted sites. Using this technique, we demonstrate arrays of perovskite nanocrystals with up to 98% single-photon emission purity at room temperature. Furthermore, this technique enables the integration of individual emitters into photonic structures, with successful coupling evidenced by a 3-fold enhancement in radiative lifetimes, a key figure of merit for single-photon emitters. This work represents a crucial step toward overcoming the long-standing integration challenges faced by perovskite quantum dots, enabling their practical use in photonic quantum technologies.

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Medical devices & systems
Sensors

Small-signal is All You Need: Fast and Precise Estimation of Compute-In-Memory Accuracy Loss

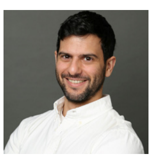
7.01

S. Bae, T. Andrulis, J. S. Emer, V. Sze

As memory access consumes significant energy and latency in Deep Neural Network (DNN) accelerators, analog Compute-In-Memory (CiM) is a promising solution that leverages memory arrays to minimize data movement and perform low-power, high-density computations. However, CiM systems suffer from DNN accuracy loss due to physical non-idealities of analog computing. While various tools can rapidly model the power, performance, and area (PPA) of CiM systems, no existing tool can estimate the accuracy degradation without performing a precise sample-by-sample noise simulation across the entire dataset. There is a need for a methodology to reduce the computational cost of estimating the impact of noise, enabling early-stage evaluation of energy-accuracy trade-offs in the CiM design space.

In this work, we propose a small-signal model for analog noise, which assumes that DNN output error is approximately a linear combination of independent noise sources. Specifically, we demonstrate that (1) for a single noise source, the DNN output error is proportional to the noise magnitude of the source (Scaling), (2) for multiple noise sources, the DNN output error is the sum of error contributions from each source (Addition), and (3) by leveraging these principles, we drastically reduce the number of simulations required to measure the accuracy loss across the entire design space by evaluating only a selected subset of hardware configurations.

Using our open-source tool, researchers can efficiently explore the CiM design space, identify hardware configurations with significant accuracy degradation (e.g., >5%), and quickly evaluate energy-accuracy trade-offs to guide early-stage design decisions.



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Information processing
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Machine Learning
Nanotechnology
Optoelectronics
Photonics
Quantum devices

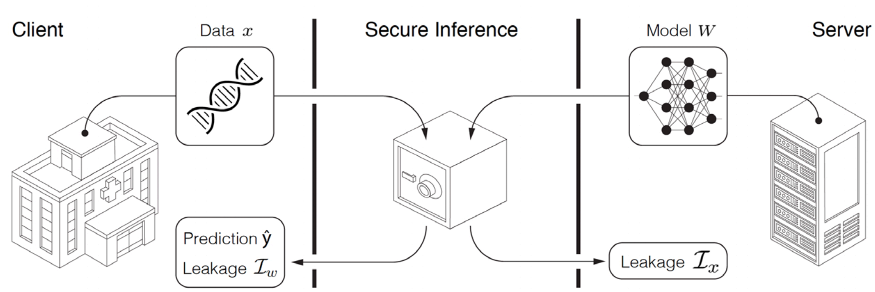
Quantum-Secure Multiparty Deep Learning

7.02

K. Sulimany, S. K. Vadlamani, R. Hamerly, P. Iyengar, and D. Englund
Sponsorship: Marie Curie Individual Fellowships

Cloud deep-learning inference can expose both user data and proprietary models. Current secure multiparty computation and homomorphic-encryption solutions are impractical at scale due to compute and latency overheads and reliance on computational assumptions.

We present an information-theoretically secure protocol based on a coherent optical linear-algebra engine [1]: the server encodes weights in weak coherent states; the client computes matrix-vector products and returns a residual optical state that lets the server certify weight leakage. Quantum-information bounds then limit leakage of both weights and inputs, enabling double-blind inference. On the MNIST classification benchmark, we reach >95% accuracy while bounding leakage to <0.1 bits per weight and per data element, below the precision typically needed for accurate quantized inference. Using telecom-grade components and optical networks, this work suggests a deployable path to privacy-preserving cloud AI in sensitive domains.



▲ Figure 1: In multiparty deep learning inference, a client such as a hospital wishes to classify a patient's confidential data x using a confidential deep learning model W belonging to the server.

Oxide-semiconductor Ferroelectric FETs for Charge-Domain In-Memory Computing

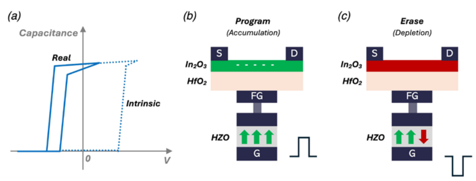
7.03

H. Ning, Y. Shao, J. Kong and J. A. del Alamo

Sponsorship: MIT-Novo Nordisk Artificial Intelligence Postdoctoral Fellowship

The ferroelectric field-effect transistor (FeFET) based on an oxide-semiconductor (OS) channel is a promising candidate for Back-End-of-Line (BEOL) integration. It can serve as an on-chip non-volatile memory for in-memory computing (IMC) in the charge domain, which requires a large capacitive On/Off ratio. However, its performance is hindered by the well-known Full-Program–Partial-Erase (FPPE) issue, arising from insufficient electric field for complete domain reversal when the channel is depleted. Consequently, the memory window and On/Off ratio of FeFETs are significantly reduced from its intrinsic design.

In this work, we systematically investigate the FPPE phenomenon using a Metal–Ferroelectric–Metal–Insulator–Semiconductor (MFMIS) structure, which allows complete decoupling between the ferroelectric and the semiconductor channel. This configuration enables the direct extraction of an asymmetric ferroelectric voltage loop under symmetric voltage sweep. Furthermore, we propose a novel device architecture that effectively overcomes the FPPE problem and demonstrates a record-high capacitive On/Off ratio along with an ultra-symmetric memory window. These results suggest a state-of-art device element for charge-domain in-memory computing.



▲ (a) The extrinsic C-V curve resulting from the FPPE problem. (b-c) Corresponding operation schematics of MFMIS-structure OS-FeFET in (a) programming case where ferroelectric domains all fully polarized up, and (c) erasing case where only a few ferroelectric domains are polarized down. G: Gate; FG: Floating gate; HZO: $Hf_xZr_{1-x}O_2$.

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Nanotechnology
Photovoltaics

2D Simulation Insights into Protonic ECRAM Dynamics

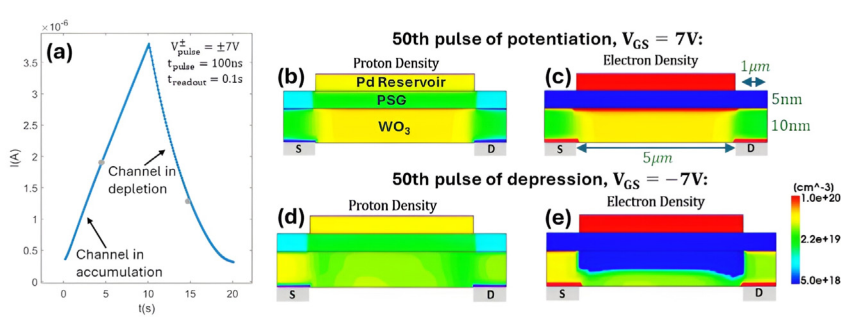
7.04

S. Bitton and J. A. del Alamo

Sponsorship: MIT-IBM Watson AI Lab, Fulbright- ISEF Fellowship, Zuckerman STEM leadership program, Schmidt Israeli Women's Postdoctoral Fellowship

Electrochemical Random Access Memory (ECRAM) is a promising candidate for in-memory computing, offering deterministic programming and low energy consumption. Such memory devices could reduce dramatically the energy consumption of AI hardware, but their inner physical mechanisms are not yet fully clear.

This work presents a 2D simulation study of protonic ECRAM dynamics, utilizing TCAD Sentaurus to model devices with a Pd proton reservoir, WO3 channel, and PSG electrolyte. The simulations solve Poisson and continuity equations for electrons, holes, and protons, incorporating a Field-Induced Activation Energy Lowering model for proton diffusion. Our results reproduce experimental findings and analyze the ECRAM response to trapezoidal gate pulses and for potentiation and depression pulse trains. Our findings offer crucial insights for enhanced ECRAM stability and performance.



▲ Figure 1: (a) ECRAM current response to potentiation and depression pulse trains. (b-c) Proton and (d-e) electron distributions under (b,d) potentiation and (c,e) depression pulses.

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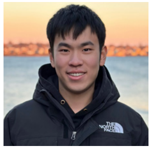

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GaN
Integrated circuits
Machine Learning
Nanomanufacturing
Nanomaterials
Nanotechnology
Quantum devices
Sensors
Systems

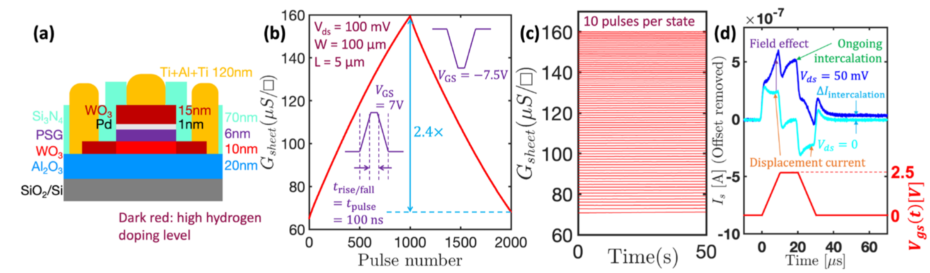
In-Situ Hydrogenated CMOS-Compatible W03/Pd/PSG/ W03 Protonic Electrochemical Random-Access Memory

7.05

Sponsorship: MIT-IBM Watson AI Lab

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, with high energy efficiency and low latency. Among them, Electrochemical Random-Access Memories (ECRAM) modulate channel resistance by ionic exchange between a semiconductor channel and a gate reservoir via an electrolyte.

Our research focuses on protonic ECRAM featuring WO_3 (as channel), in-situ hydrogenated H_xWO_3 and PdH_y (as gate reservoir), phosphosilicate glass (PSG) (as electrolyte), and Si_3N_4 (as encapsulation) with fully CMOS back-end-of-line compatible process. The devices achieve >10-bit analog precision, >2.4× linear dynamic conductance range, and symmetric conductance modulation using 100 ns pulses, with impulse-like non-volatile conductance update transient and >50 s retention, thus showing promising applications in deep learning accelerators.



▲ Figure 1: (a) Cross section of WO_3/Pd/PSG/WO_3 protonic ECRAM structure. (b) Conductance modulation characteristics. (c) Retention behavior over 50 s at different conductance levels. (d) Source current transients under a trapezoidal voltage pulse drive.

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Machine Learning
Systems

Taming the Long-Tail: Efficient Reasoning RL Training with Adaptive Drafter

7.06

Q. Hu, S. Yang, J. Guo, S. Han

The emergence of Large Language Models (LLMs) with strong reasoning capabilities unlocks new frontiers in complex problem-solving. However, training these reasoning models with Reinforcement Learning (RL) faces major efficiency challenges. RL training processes often exhibit a long-tail distribution, where a few extremely long responses dominate runtime and increase costs.

We introduce TLT, a system that accelerates reasoning-focused RL training without loss of accuracy through adaptive speculative decoding. Applying speculative decoding in RL is challenging due to dynamic workloads and the evolving nature of the models. TLT overcomes these obstacles with two key components: a lightweight assistant model that learns to accelerate generation using spare computational power, and an adaptive engine that intelligently manages system resources to maximize efficiency. TLT delivers 1.7–2.1× end-to-end speedups while preserving accuracy and producing a high-quality draft model for deployment.

Taming the Long-Tail: Efficient Reasoning RL Training with Adaptive Drafter

7.07

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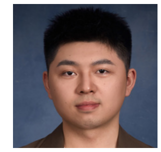

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Research Interests:
Machine Learning
Systems

The emergence of Large Language Models (LLMs) with strong reasoning capabilities marks a significant milestone, unlocking new frontiers in complex problem-solving. However, training these reasoning models, typically using Reinforcement Learning (RL), encounters critical efficiency bottlenecks: response generation during RL training exhibits a persistent long-tail distribution, where a few very long responses dominate execution time, wasting resources and inflating costs. To address this, we propose TLT, a system that accelerates reasoning RL training losslessly by integrating adaptive speculative decoding. Applying speculative decoding in RL is challenging due to the dynamic workloads, evolving target model, and draft model training overhead. TLT overcomes these obstacles with two synergistic components: (1) Adaptive Drafter, a lightweight draft model trained continuously on idle GPUs during long-tail generation to maintain alignment with the target model at no extra cost; and (2) Adaptive Rollout Engine, which maintains a memory-efficient pool of pre-captured CUDAGraphs and adaptively select suitable Speculative Decoding (SD) strategies for each input batch. Evaluations demonstrate that TLT achieves end-to-end RL training speedup over state-of-the-art systems, preserves the model accuracy, and yields a high-quality draft model as a free byproduct suitable for efficient deployment.

Optimizing Mixture of Block Attention

7.08

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Machine Learning

Large language models (LLMs) are increasingly required to process very long contexts, but the quadratic cost of standard attention mechanisms makes this computationally expensive. Mixture of Block Attention (MoBA) has emerged as a promising approach to address this challenge by allowing each query to selectively attend to only a small subset of relevant blocks, substantially reducing computation while preserving model quality. Despite this promise, the factors that determine MoBA's effectiveness remain unclear, and the lack of efficient GPU support has limited its practical use.

In this work, we provide a clearer understanding of how MoBA works and how its performance can be improved. We develop a simple statistical framework that explains MoBA's behavior and highlights the importance of accurately identifying which blocks are most relevant for each query. This analysis reveals that MoBA's effectiveness depends strongly on how well the routing mechanism separates useful information from irrelevant context. Guided by these insights, we propose design improvements that increase routing accuracy, including using smaller block sizes and lightly aggregating key information to better capture relevant signals.

Although these design choices improve accuracy, they are typically inefficient on modern GPUs. To overcome this limitation, we introduce FlashMoBA, a hardware- aware CUDA implementation that enables MoBA to run efficiently with the recommended configurations. Experiments with LLMs trained from scratch show that our optimized MoBA models achieve performance comparable to dense attention while offering substantial computational savings. Overall, our results demonstrate that a better theoretical understanding of MoBA can directly translate into practical, efficient attention mechanisms for long-context language models.

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Research Interests:
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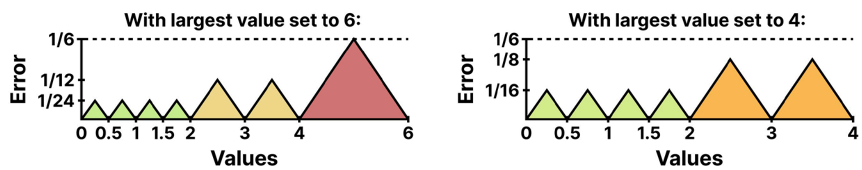
Four Over Six: More Accurate FP4 Quantization with Adaptive Block Scaling

7.09

J. Cook

As large language models have grown larger, low-precision numerical formats such as NVFP4, NVIDIA's block-scaled 4-bit floating point format, have become increasingly popular due to the speed and memory benefits they provide. However, to accelerate computation with NVFP4, all matrix multiplication operands--weights and activations in the forward pass, and weights, activations, and gradients in the backward pass--must be quantized to NVFP4, often leading to divergence during training and performance degradation during inference. To address this issue, in this work we introduce Four Over Six (4/6), a modification to the NVFP4 quantization algorithm that evaluates two potential scale factors for each block of values. Unlike integer formats, floating-point formats such as FP4 have the most quantization error on near-maximal values in each block, which we find to be primarily responsible for downstream performance degradation. We find that for some blocks, scaling to smaller FP4 values makes the distribution of representable values more uniform, improving representation of near-maximal values. Importantly, 4/6 can be implemented efficiently on NVIDIA Blackwell GPUs, making it viable to use while training LLMs with NVFP4. In pre-training experiments with transformer and hybrid model architectures, we find that 4/6 prevents divergence in several cases, bringing training loss significantly closer to BF16 compared to models trained with current state-of-the-art NVFP4 training recipes. We also find that 4/6 can be easily incorporated into many different post-training quantization methods and generally improves downstream accuracy. We hope this inspires future work in training and deploying models with NVFP4.



▲ When FP4 blocks are scaled by a factor of 6, the quantization error on values between 4 and 6 may be very large. Scaling some blocks by a factor of 4 reduces the worst-case quantization error, offering improved representation of outlier values.

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Energy
MEMS & NEMS
Nanomanufacturing
Nanomaterials
Nanotechnology
Neuromorphic computing

Quantification of Variability and Symmetry of Protonic Electrochemical Random-access Memory for Hardware Neural Network Training

7.10

L. Xu, M. Huang, S. D. Funni, J. Cha, and B. Yildiz

Sponsorship: SRC JUMP 2.0 SUPREME center, task no. 3137.017

Electrochemical Random-Access Memory (ECRAM) is a novel programmable resistor candidate powering hardware neural networks (HNNs) based on cross-bar arrays, targeting fast and energy-efficient AI training. Low device variability and good symmetry are crucial to low-loss and high-accuracy training in HNNs. Traditional candidates like resistive and phase-change memory, suffer from high variability due to stochastic operation nature. ECRAMs are promising three-terminal non-volatile programmable resistors with expected low variability, enabled by the deterministic dynamic doping of channel. Some possible intrinsic and extrinsic sources, such as the material microstructure and non-ideal fabrication artifacts, can introduce variations in ECRAMs.

This work systematically quantified the variability of CMOS-compatible protonic ECRAMs with WO3 channel, HfO_2 or Y-ZrO_2 electrolyte and PdH_x gate/reservoir. We observed that the conductance modulation is highly uniform in the low-conductance regime, with low cycle-to-cycle variation (3%), low device-to-device variation (15 - 21%) and stable operation over extensive programming cycles. The device-to-device variation showed no dependence on channel microstructure (crystalline vs. amorphous) in the channel size range of 10^2 μm^2 to 150^2 nm^2. Furthermore, different retention, symmetry and cycling stability were observed comparing the amorphous and polycrystalline channels, indicating the microstructure effects. Meanwhile, source/drain contact with the channel was investigated as a possible variation source.

These findings suggest ECRAM shows low variability and good symmetry and demonstrates strong potential for downscaling, indicating it can be a promising candidate for programmable resistors. The results also emphasize the importance of microstructure and contact resistance control for consistent, low-variability operation.

LoopForest: Leveraging Hybrid Fused Mappings to Reduce Data Movement and Memory Usage

7.11

M. Gilbert, T. Andrulis, V. Sze, J. Emer

Sponsorship: MIT AI Hardware Program

When designing a deep neural network (DNN) accelerator, it is important to optimize the mapping, which is how computation and data movement are scheduled onto the accelerator to minimize latency and energy. A significant contributor to energy and latency is data movement between off-chip memory and on-chip memory. To reduce data movement from off-chip memory, data that are shared by multiple layers can be fetched on-chip once and reused for the processing of those layers. This optimization is referred to as fusing the layers. Because on-chip memory capacity is limited, data in DNN layers are often partitioned to be processed one piece at a time (i.e., tiled), and tiled fusion refers to the reuse of these tiles across multiple layers.

In this work, we show how to tile DNN data and schedule the processing of those tiles to significantly increase data reuse by leveraging diversity in the number of times each data can be reused (i.e., the reuse opportunity). Layers in a DNN are not all identical, and data reuse opportunities vary across layers. Thus, we can use on-chip memory more efficiently by keeping larger tiles from data that have more reuse opportunities and smaller tiles from data that have less reuse opportunities (i.e., hybrid tiling). Moreover, we schedule the processing such that data tiles with less reuse can be released from memory as soon as possible to make room for data with more reuse. Using this technique, we show up to 1.5x and 1.6x reduction in latency when processing layers in GPT-3 and MobileNet respectively compared to prior work. In summary, the mapping techniques described in this work enables low-latency and energy-efficient DNN processing by efficiently using available memory capacity to significantly reduce data movement.

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Research Interests:
Artificial Intelligence
Electronic devices
Electronics
Energy harvesting devices & systems
Information processing
Integrated circuits

7.12

Fast and Fusiest: A Fast and Optimal Fusing Mapper for Tensor Algebra Accelerators

T. Andrulis, M. Gilbert, V. Sze, J. S. Emer

Sponsorship: MIT AI Hardware Program, MIT ISN

Deep Neural Networks include many computation steps such as matrix multiplications and convolutions. While many works focus on optimizing individual computation steps—such as building macros to execute matrix multiplications, or tiling to reuse data in convolutions—there are many opportunities when we look at multiple computation steps together. Considering multiple computation steps opens a broad space of optimizations, such as fusion (running multiple computation steps at once without communicating intermediate data off-chip), multi-accelerator parallelism (executing computation steps across multiple accelerators), and heterogeneous systems (using multiple accelerators, specialized for a different type of computation step). However, despite the exciting opportunities, it is a challenge to find programs that leverage multi-computation-step opportunities because the number of combinations of choices increases exponentially with the number of computation steps.

In this work, we address this challenge with Fast and Fusiest, a framework that can quickly explore the design space of multi-computation-step optimisations. Fast and Fusiest shrinks the search space by pruning partially-completed programs (pmappings) that apply to only some computation steps in the workload. It then joins the optimal pmappings to optimally program all computation steps in the workload. This allows us to reduce search time by orders of magnitude, making it feasible to generate energy-optimal programs for multi-computation-step workloads on accelerators.

We integrate these methods into a new set of open-source tools, which allow users to model a diverse range of accelerator designs, explore a novel space of optimizations, and rapidly generate programs to run workloads on these accelerators.

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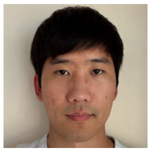

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Research Interests:
Biological devices & systems
BioMEMS
Electronic devices
Electronics
Medical devices & systems
Nanotechnology

Ferroelectric High Bandwidth Memory: Evaluating All-Ferroelectric Logic+Memory FETs for AI Workloads

7.13

M. U. Lee
Sponsorship: DARPA

Modern computing systems increasingly face a bottleneck not in computation, but in memory access. As data-intensive workloads such as real-time sensing, autonomous systems, and edge artificial intelligence continue to scale, the energy and latency of moving data between processors and memory dominate overall system performance. Even compact neural networks repeatedly access weights and activations, limiting gains from compute-core scaling alone.

Conventional DRAM architectures worsen this challenge due to refresh overhead, long interconnect distances, and high activation energy. These limitations are especially critical for defense and embedded AI systems, where low latency, high bandwidth, and strict energy budgets are required.

This project investigates a monolithic three-dimensional ferroelectric high-bandwidth memory (Fe-HBM) architecture that integrates memory and peripheral logic using emerging ferroelectric transistors. Ferroelectric field-effect transistors (FeFETs) enable compact, nonvolatile, capacitor-less storage compatible with low-temperature processing, while negative-capacitance FETs (NCFETs) provide ultra-low-voltage peripheral circuits. Because both devices can be fabricated in the back-end-of-line, multiple ferroelectric memory tiers can be vertically stacked above NCFET-based periphery using fine-pitch vertical inter-vias, reducing interconnect length, RC delay, refresh overhead, and access energy compared to planar DRAM.

We develop calibrated FeFET and NCFET compact models and perform SPICE-level simulations of activation, sensing, write, and full row-cycle operations. Extracted DRAM-style timing parameters (tRCD, tRP, tRAS, tWR, tRC) are integrated into vertically aware architectural templates to evaluate multi-tier Fe-HBM organizations in terms of latency, bandwidth, and energy efficiency.

This work provides a device-to-architecture framework for assessing scalable, low-energy, high-bandwidth memory systems for next-generation AI workloads.

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Research Interests:
Batteries
Energy
Nanomaterials

Impact of Electrolyte Proton Conductivity on Protonic ECRAM

7.14

J. Meyer, B. Yildiz
Sponsorship: DOE EFRC Hydrogen in Energy and Information Sciences (HEISs)

Three-terminal electrochemical random-access memory (ECRAM) devices have demonstrated low energy, reversible, and symmetric switching behavior through the electrochemical insertion of ions into a channel material such as WO_3. Protonic ECRAM devices can have very fast operation using protons, but achieving nanosecond operation requires a high write voltage, which is undesirable for neuromorphic computing. A key kinetic bottleneck is the proton transport across the thin film solid-state electrolyte, which sets a target for high proton conductivity in the material.

Our work studies the effect of electrolyte modification in protonic ECRAM. We measured the proton conductivity of a phosphosilicate glass electrolyte (PSG) used in protonic ECRAM devices. The PSG proton conductivity increased by up to 3 orders of magnitude with increasing phosphorus content in the bulk. PSG was also doped locally with a P_2O_5 layer, and this was compared to the effect of a proton-blocking layer of Y_2O_3 in protonic ECRAM devices. We observed faster device kinetics with the P_2O_5 layer and reduced electrolyte impedance, which comprises the major device impedance under electrochemical impedance spectroscopy. These results emphasize room to improve on the performance of the PSG electrolyte to lower write voltage down to 1 V or less.

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Photonic Probabilistic Computing Using Quantum Vacuum Noise

8.01

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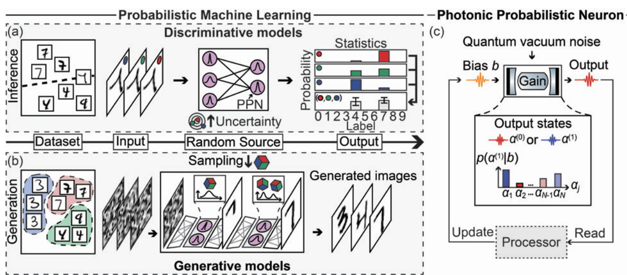
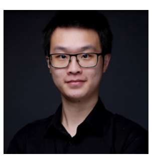
Sponsorship: U. S. Army Research Office through the Institute for Soldier Nanotechnologies at MIT, under Collaborative Agreement Number W911NF-23-2-0121

Probabilistic machine learning relies on controllable random sources to enable probabilistic inference and generative modeling. Although the pure randomness of quantum vacuum noise originating from fluctuating electromagnetic fields has shown promise for high-speed, energy-efficient stochastic optical elements, the development of photonic probabilistic computing hardware leveraging these stochastic elements has been limited. Here, we implement a photonic probabilistic computer utilizing a controllable stochastic photonic element – a photonic probabilistic neuron (PPN). We implement PPN in a bistable optical parametric oscillator (OPO) with vacuum-level injected bias fields. We then program a measurement-and-feedback loop for time-multiplexed PPNs with electronic processors (FPGA or GPU) to solve probabilistic inference and image generation of MNIST-handwritten digits, showcasing how controllable quantum random sources can encode uncertainty and enable statistical sampling.



◀ Figure 1. Probabilistic machine learning with stochastic photonic elements. (a,b) We implement probabilistic computers that solve inference and generation tasks using physical random sources. (c) Schematics of photonic probabilistic neurons (PPNs).



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Morphological and Chemical Changes in Cd-free Colloidal QD-LEDs During Operation

8.02

R. Zhang, V. Bulović

Sponsorship: Samsung Electronics

Heavy-metal-free quantum-dot light-emitting devices (QD-LEDs) demonstrate high brightness, saturated color, and high efficiency, yet their operational lifetimes remain limited, with the underlying degradation mechanisms not fully understood. Here, we show that InP/ZnSe/ZnS (red-emitting) and ZnTeSe/ZnSe/ZnS (blue-emitting) colloidal QD-LEDs undergo nanoscale morphological changes during operation. Interparticle coarsening and layer thinning are observed in the core functional layers, accompanied by the generation and diffusion of compositional-oxygen and hydrogen across the device, with oxygen accumulating at the Al electrode/ZnMgO electron-transport layer (ETL) interface. In-situ transmission electron microscopy reveals that electron beam exposure, in presence of reactive hydrogen species, accelerates ZnMgO nanoparticles coarsening. To mitigate these degradation pathways, we show that acrylate-based resin-encapsulation can stabilize the ETL and QD layers by suppressing radical formation and halting morphology changes. This approach achieves an 8-fold and 5000-fold lifetime improvement on InP/ZnSe/ZnS and ZnTeSe/ZnSe/ZnS QD-LEDs, respectively. Our findings establish the causal relationships between morphological degradation, interlayer radical dynamics, and QD-LED instability, providing new insights into the acrylate encapsulation treatment that enables efficient and long-lived QD-LEDs.

Transparent and Flexible Wafer-Scale Silicon-Photonics Fabrication Platform

8.03

T. Sneh, A. Coleto, T. Dyer, M. Notaros, K. Fealey, and J. Notaros

Sponsorship: NSF CAREER Program (2239525), DARPA VIPER program (FA8650-17-1-7713), NSF Graduate Research Fellowship (2141064), and MIT SoE MathWorks Fellowship

Silicon photonics has benefited greatly from the advanced processes and very-large-scale integration enabled by wafer-scale fabrication. To date, these fabrication processes have occurred primarily on silicon substrates that result in opaque and rigid photonic wafers and chips. Nevertheless, there are many applications that would benefit from transparent and flexible photonic chips, such as discrete wearables and transparent pliable displays. However, prior demonstrations of photonic chips that are both transparent and flexible have been limited to chip-scale fabrication, limiting process complexity and scalability.

In this work, we develop and characterize the first 300-mm wafer-scale platform and fabrication process that results in transparent and flexible silicon-photonics wafers and chips. This work introduces a scalable platform for transparent and flexible silicon-photonics systems, opening up novel applications areas, including transparent pliable displays and discrete wearables.

Image Caption: Photographs of (a) a fabricated transparent and flexible silicon-photonics wafer, and a transparent and flexible silicon-photonics chip (b) on the experimental setup and (c) undergoing bend durability testing.

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Research Interests:
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Displays
Integrated circuits
Lasers
Light-emitting diodes
Nanotechnology
Optoelectronics
Photonics
Quantum devices
Si
Silicon Photonics

Restoring Clarity in Depth with Learned (De)scattering Functions

8.04

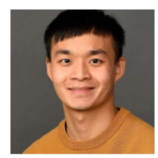
C.-E. Huang, H. Cao, J. Han, S. You

Sponsorship: MIT Presidential Fellowship; Manton Foundation; NSF Career

Understanding biological systems requires visualizing cells within their physiological context. Multiphoton microscopy is the premier tool for this, yet its utility is limited to superficial depths by photon scattering. This deflection causes a catastrophic loss of signal-to-noise ratio deep in tissue, obscuring fine details. Consequently, researchers are left with shallow images insufficient for many biological questions.

To overcome this limitation, we developed a generalizable deep learning de-scattering platform. Our approach involved training an efficient deep-learning model on a novel dataset of co-registered, paired image stacks acquired at both a short, high-scatter wavelength and a long, low-scatter wavelength. By using the high-fidelity long-wavelength image as the ground truth, the model learns to computationally remove scattering artifacts from the corresponding short-wavelength image, restoring its structural fidelity.

A key innovation of this “paired-wavelength” training paradigm is its inherent flexibility, which sets it apart from conventional approaches. Unlike methods like multi-channel confocal microscopy, which are rigidly constrained by specific labels and wavelengths, our label-free method is data-independent. We can train the engine using diverse data pairs—not just two different wavelengths, but potentially even different imaging modalities. This strategy allows us to build a truly robust and generalized de-scattering model. The focus is therefore not on a single biological correction, but on creating a powerful computational tool that can restore clear, sharp, and vivid images from many different deep-tissue imaging experiments. Our future goal is to apply this engine to critical, high-impact research areas where scattering is the primary roadblock, enabling new biological discoveries and therapeutic research at tissue depths previously inaccessible.



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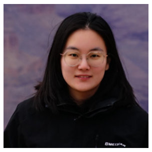
MEMS & NEMS
Microfluidic devices & systems
Photonics



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Electronic devices
Nanomaterials
Sensors

Ultrathin Freestanding Single-Crystalline Lithium Niobate for Advanced Integrated Photonics

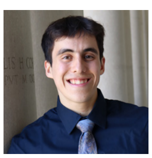
8.05

X. Zhang, Y. J. Yoo, J. H. Ko, A. Buzzi, L. Follet, D. Englund, J. Kim

Sponsorship: NSF

Lithium niobate (LN), first grown 70 years ago, remains an essential material in photonics due to its outstanding electro- and nonlinear-optic properties, wide transparency window and relatively high refractive index. It is the cornerstone of various technologies such as high-speed optical communications and frequency conversion in nonlinear and quantum optics. The recent emergence of thin-film lithium niobate (TFLN) has renewed interest in LN, as it offers superior performance over bulk crystals through tight mode confinement, ultralow optic loss and high index contrast. However, the manufacturing of TFLN via the smart-cut process imposes a minimum thickness limit of ~300 nm, hindering its application in next-generation quantum photonics devices that require ultrathin films.

In this work, we present an atomic lift-off technique to obtain ultrathin, freestanding, single-crystalline LN membranes with high throughput and tunable thicknesses ranging from several hundred nanometers down to below 10 nm. By epitaxial growth on sapphire substrates with varied orientations, we achieve control over the crystallographic orientation of the LN films. Lithium accumulation at the interface is observed, which induces local strain and defect formation, thus weakening interfacial bonding, and promotes crack propagation during delamination with a nickel stressor layer. The electro-optic coefficient r33 of the freestanding z-cut LN membrane is characterized to be 21 pm/V using a Fabry-Pérot cavity structure. These ultrathin LN membranes can be transferred onto arbitrary substrates, holding significant potential for integration into large-area quantum photonic platforms.



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Reduced-Crosstalk Grating-Based Antennas for Wide-Field-of-View Integrated Optical Phased Arrays

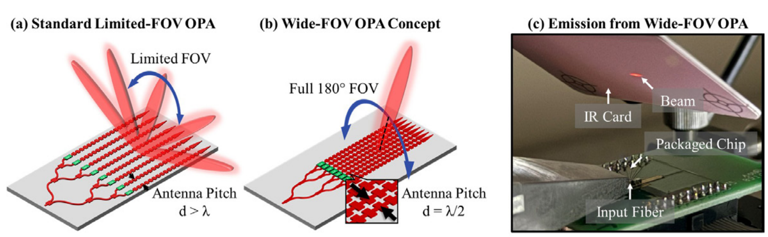
8.06

H. Crawford-Eng, A. Garcia Coleto, B. M. Mazur, D. M. DeSantis, T. Sneh, and J. Notaros

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

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. Typically, these OPAs have undesired grating lobes that restrict the field of view (FOV) and decrease the signal-to-noise ratio (SNR) of the system. These grating lobes can be removed by placing the OPA antennas at a half-wavelength pitch; however, tight antenna pitches lead to inter-antenna crosstalk that lowers the SNR.

In this work, we develop and experimentally demonstrate for the first time a set of integrated grating-based antennas with reduced inter-antenna crosstalk. We then use these antennas to develop and experimentally demonstrate a half-wavelength-pitch reduced-crosstalk integrated OPA with grating-lobe-free and wide-FOV functionality. This work enables high-performance OPA systems that can achieve wide FOVs while maintaining high SNRs.



▲ Figure 1: Simplified conceptual diagram of (a) a typical limited-FOV integrated OPA versus (b) a wide-FOV integrated OPA. (c) Photograph of the fabricated wide-FOV integrated OPA emitting a single beam onto an infrared-detecting card.

Core and Cladding Contributions to Fluorescence and Raman Emission in Integrated Photonic Waveguides

8.07

A. Garcia Coleto, H. Crawford-Eng, N. Tyndall, A. Antohe, S. Kar, L. Carpenter, T. Stievater, and J. Notaros

Sponsorship: AFRL AIM Photonics; MIT SoE MathWorks Fellowship; NSF Graduate Research Fellowship; MIT Rolf G. Locher Endowed Fellowship

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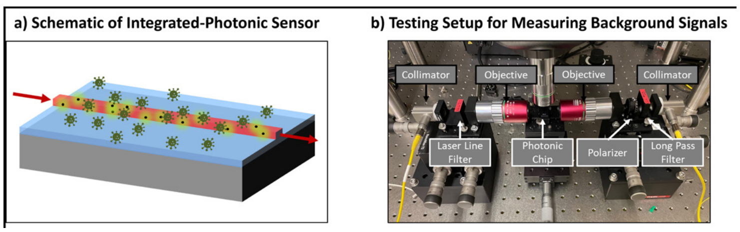
Minimizing background optical emission originating from waveguides is critical for achieving high-sensitivity performance in integrated photonic platforms, particularly for applications in biological, chemical, and quantum sensing. These background signals, often stemming from intrinsic fluorescence or Raman scattering in the waveguide core or cladding, can obscure weak optical signals and limit the accuracy of integrated photonic sensors.

In this work, we introduce a novel parameter-extraction technique that quantitatively separates waveguide losses and background-generation efficiency, and identifies the individual contributions of the waveguide core and cladding to the total background signal. We utilize the method to characterize nine wafers fabricated at AIM Photonics. The method provides a tool for quantifying, diagnosing, and reducing loss and background signals in integrated photonic waveguides, enabling more effective development of low-noise and low-loss platforms.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: (a) Conceptual diagram of a typical integrated-photonic sensor, showing the sensed element (green) and the background-generating defects (yellow) in the waveguide (red). (b) Photograph of the setup used to measure background signals.

Rapid Prototyping of Micro-Structured Chalcogenide Surfaces Using Two-Photon Polymerisation Printing and Imprint Transfer

8.08

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Sponsorship: Samsung

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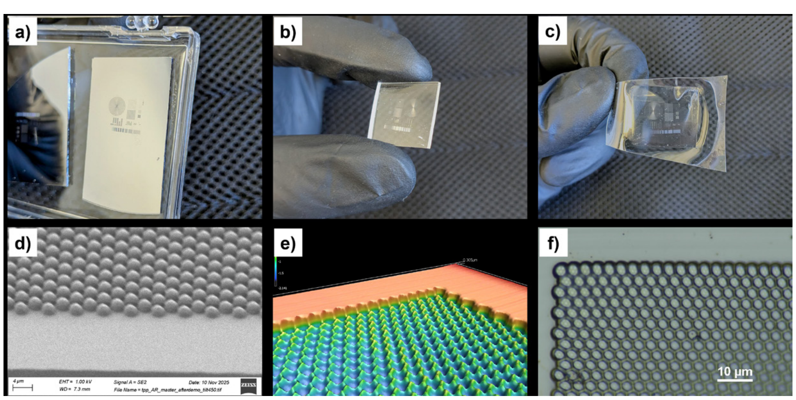
Research Interests:
Communications
Organic materials
Photonics

Surfaces with microscale features can control infrared light for sensing and imaging. Chalcogenide glasses are useful for this because they absorb little in the IR, but limits in standard fabrication make it hard to rapidly prototype, test, and scale complex 3D features on them. Here, we show a process to create and transfer free-form 3D microstructures onto chalcogenide films deposited on various substrates. We print master structures with two-photon polymerization on silicon, form flexible PDMS molds, and imprint the shapes. Feature sizes range from 2–300 µm, and the molds replicate them with sub-micron accuracy. Initial FTIR measurements show clear transmission changes when such microstructures are added. This method enables fast testing of IR micro-optical designs and supports future microsystems with engineered surfaces.



▲ Figure 1: a) TPP-fabricated master on Si substrate. b) PDMS mold by dropcasting. c) PVC imprint; same method applies to chalcogenide glass. d) SEM of master microstructure. e) 3D profilometry of PDMS mold. f) Microscopy image of chalcogenide imprint.

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2D materials
III-Vs
Lasers
Light-emitting diodes
Nanomaterials
Nanotechnology
Optoelectronics
Organic materials
Photonics
Sensors

A Thermally-Assisted Tunneling Model of Blue Quantum Dot Light-Emitting Diodes

8.09

M. Dillender, J. Zhang, H. Chung, T. Nguyen, S. Srinivasan, R. Zhang, V. Bulović

Sponsorship: Samsung Advanced Institute of Technology

Modern quantum dot light-emitting diodes (QD-LEDs) suffer from inefficient charge injection and poorly understood subthreshold behavior, both arising from the intrinsically large energy barriers imposed by their core/shell nanostructure. We report a combined experimental and theoretical study of blue ZnTeSe QD-LEDs in which impedance spectroscopy, EQE analysis, and thickness-dependent current–voltage measurements reveal that devices operate in three distinct regimes: (i) defect-mediated hopping conduction at low bias, (ii) a field-limited transition regime in which interfacial charge buildup controls carrier tunneling, and (iii) a diode regime dominated by thermally assisted tunneling (TAT).

By extracting the effective capacitor thickness from voltage-dependent capacitance measurements, we show that the subthreshold electrostatics are determined almost entirely by the hole-transport layer (HTL), which remains effectively insulating until ~2 V. Above this threshold, rapid field buildup at the HTL/QD interface enables tunneling of holes into the QD core, after which electron injection is Coulomb-assisted. A WKB-based tunneling model incorporating Gaussian disorder in the HTL density of states quantitatively reproduces the temperature-independent slope of log(J)–V and the linear decrease in turn-on voltage with temperature.

Finally, temperature-dependent EQE roll-off yields an activation energy of ~70 meV, consistent with thermally activated leakage of electrons into HTL tail states—identifying leakage, not Auger recombination, as the dominant droop mechanism. Together, these results unify subthreshold conduction, diode behavior, and efficiency roll-off within a single thermally assisted tunneling framework, and provide quantitative design targets for next-generation high-efficiency blue QD-LEDs.

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BioMEMS
Electronic devices
MEMS & NEMS
Microfluidic devices & systems
Nanomanufacturing
Systems

Development of UVC Microscopy for Auto-fluorescent Bioimaging

8.10

Y. Park, and J. Han

Sponsorship: National Research Foundation, Prime Minister's Office, Singapore under its Campus for Research Excellence and Technological Enterprise (CREATE) programme, through Singapore MIT Alliance for Research and Technology (SMART): Critical Analytics for Manufacturing Personalised-Medicine (CAMP) Inter-Disciplinary Research Group.

Fluorescence imaging is central to biomedical research, yet conventional fluorescent labeling can alter the native properties of sensitive biomolecules, creating challenges for applications that require precise separation, purification, or functional characterization. Many biological samples, however, possess intrinsic autofluorescence arising from aromatic amino acids that are strongly excited in the UVC range (260–280 nm). Exploiting this native optical response enables truly label-free detection. In this work, we developed a compact deep-UV fluorescence microscope that employs 265 nm and 280 nm LEDs in combination with UV-compatible optical components. The system is constructed entirely from readily available parts, requires minimal optical alignment, and is designed for straightforward operation by non-experts. Despite its simplicity, the platform delivers robust, high-contrast autofluorescence imaging and provides a practical, accessible alternative for studies involving dye-sensitive or labeling-limited biological samples.

Design and Demonstration of Visible-Wavelength Integrated-Photonics Devices

8.11

A. Garcia Coleto, H. Crawford-Eng, M. Shapiro, T. Dahl, M. Schnuck, and J. Notaros

Sponsorship: AFRL AIM Photonics (FA8650-21-2-1000); MIT SoE MathWorks Fellowship; NSF Graduate Research Fellowship (1122374); MIT Rolf G. Locher Endowed Fellowship

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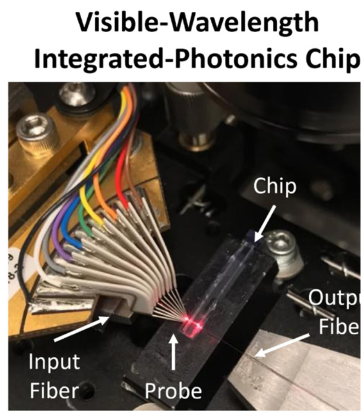
Electronic devices
Integrated circuits
Machine Learning
Photonics
Sensors

Current developments in integrated visible-light photonics have led to advancements in applications such as augmented-reality displays, 3D printing, quantum systems, and biophotonics. However, the development of crucial integrated-photonics devices has predominantly focused on the infrared spectrum, leaving a gap in visible-wavelength technologies, where platform development remains limited by fabrication complexity, elevated material losses, and challenges associated with characterizing devices across broad spectral bands.

In this work, we advance the development of visible-wavelength integrated-photonics platforms by designing and testing a diverse set of visible-wavelength integrated-photonics devices. This work provides key functionality for visible-wavelength integrated photonics, including low-loss waveguide routing, optimized passive devices, and active modulation for operation across the visible spectrum. Together, these capabilities enable emerging integrated-photonics applications that require operation in the visible-wavelength regime.



▶ Figure 1: Photograph of a fabricated visible-wavelength integrated-photonics chip on an experimental setup.

Spatial-Temporal-Resolved Off-Axis Holography for Investigation of Multimodal Nonlinear Pulse Propagation

8.12

J.-C. Chang, H. Cao, L.-Y. Yu, S. You.

Sponsorship: NSF CAREER Award (2339338), the CZI Dynamic Imaging program via the Chan Zuckerberg Donor Advised Fund (DAF) through the Silicon Valley Community Foundation (SVCF), NIA R01AG66768, R21AG072107, the Diacomp Foundation (Pilot Award, Augusta University), a Pilot Grant from the Harvard Digestive Disease Core (SK)

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Research Interests:
Lasers
Machine Learning
Photonics

Multimode fibers (MMFs) support a rich range of intermodal interactions, offering a compact platform for generating structured ultrashort pulses. However, the intertwined spatial, spectral, and temporal degrees of freedom make pulse characterization challenging. Here, we present a spatiotemporally resolved off-axis holography method for characterizing ultrashort pulses propagating through MMFs. By incorporating a delay line into a standard off-axis holography setup, the full spatiotemporal interferogram is recorded. The spatial and temporal complete complex light field can be reconstructed with 0.09-µm spatial and 0.3-fs temporal resolution by incorporating spatial and temporal filtering and demodulation, which is practical for high-resolution laser beam characterization. Using modal decomposition, we further analyze the resulting space–time coupling in a modal basis, providing a potential solution for studying intricate multimode dynamics such as modal dispersion and multimode solitons.

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Electronic devices
Electronics
Nanotechnology
Optoelectronics
Photonics
Quantum devices

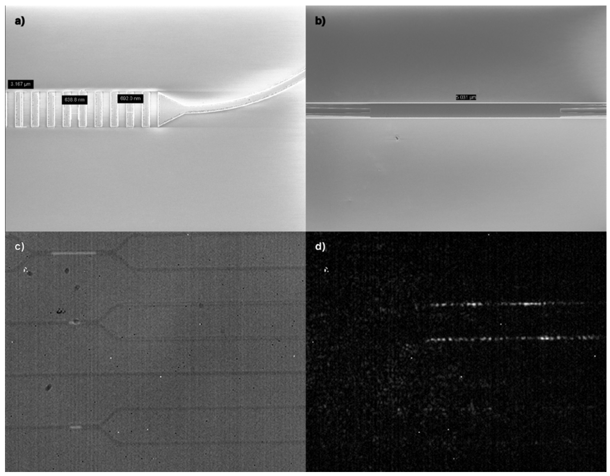
Silicon Photonics at MIT.nano

8.13

D. Dimitrov, K. Chap, S. Corsetti, V. Hariprasad, H. Kim, and X. Zheng

Sponsorship: MIT EECS, 6.2540 class

The field of silicon photonics leverages CMOS fabrication techniques to enable chip-based optical microsystems that have facilitated revolutionary advances for applications ranging from optical communications to quantum computing. Fabricating these microsystems requires developing and refining processes for the formation of nanometer- to micrometer-scale devices. In this work, we fabricate silicon-photonic components at MIT.nano. First, we explore substrate selection and acquisition. Then, we design several devices, such as waveguide splitters and grating-based antennas. Finally, we discuss three separate processes for silicon-photonics fabrication, including step-by-step recipes and suggestions for future work. Finally, we present results from device testing, including successful antenna emission and waveguide splitting. Through this work, we aim to enable further silicon-photonics prototyping at MIT.nano.



◀ Figure 1: a) SEM image of an antenna. b) SEM image of a splitter. c) IR image of splitters with no input. d) IR image of splitters with 1550-nm-wavelength input.

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Research Interests:
Field-Emitter devices
Lasers
Light-emitting diodes
Nanotechnology
Optoelectronics
Photonics
Quantum devices
Spintronics

Schottky Emission from Nanoantennas for Mid-Infrared Detection

8.14

M. A. Sere, K. K. Berggren, P. D. Keathley

Sponsorship: Office of Naval Research (N000142412350), Lincoln Laboratory ACC (Longwave Infrared-Enhanced Electron Emission from Nanoantennas (L-IREEN)), MIT Presidential Fellowship

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 seeks to leverage optically-induced localized plasmonic heating of metallic nanoantennas to detect MWIR through temperature-dependent Schottky emission. We explore antenna designs balancing optical and thermal properties to demonstrate this photodetection mechanism and evaluate its potential performance metrics. This CMOS-compatible approach shows promise for high-speed, room temperature use, allowing for widespread deployment of infrared sensors in military, security, and industrial applications.

Green Solvent Processing of Perovskite Solar Cells

8.15

R. Patidar, K. Yang, V. Bulovic

Sponsorship: Tata Power, Petronas

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Available from May 2026.

Research Interests:
Batteries
Displays
Light-emitting diodes
Photovoltaics

Over the past decade and a half, metal halide perovskite solar cells (PSCs) have attracted tremendous interest from researchers worldwide, driven by their rapid rise in power conversion efficiency to over 27%, now comparable to established crystalline silicon photovoltaics. In addition to their high efficiency, PSCs can be fabricated via low-temperature solution processing, avoiding the slow and energy-intensive manufacturing routes needed for Si PV and offering a route to high-throughput, potentially low-cost production. However, this solution processing typically relies on highly toxic polar aprotic solvents, most notably N,N-dimethylformamide (DMF). While most efforts in the field have focused on improving efficiency and stability of PSCs, the toxicity of these solvents and the engineering controls required to use them safely poses a serious challenge for large-scale manufacturing. In an internal study, we showed that the use of a toxic solvent such as DMF can contribute up to 12.3% of the overall module cost purely through air-handling requirements needed to keep the factory environment safe for workers, which is a significant burden for a commodity PV business. It is therefore essential to develop alternative solvent systems with higher workplace exposure limits and reduced EHS (environment, health, and safety) impact. In this work, we investigate γ-valerolactone (GVL), a greener solvent with more favorable workplace exposure limits, for the solution deposition of $FAPbI_3$ perovskite. Using a GVL-based solvent system, we demonstrate $FAPbI_3$ devices with power conversion efficiencies exceeding 12%. These results show that reasonably efficient PSCs can be fabricated using a lower-toxicity solvent system, providing a concrete step towards environmentally and economically sustainable PSC manufacturing and helping to align high-efficiency PSC technology with the practical realities of industrial PV production.

Progress Towards Directional Transport Mapping Using Metsurface Based Photocurrents

8.16

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Research Interests:
2D materials
Artificial Intelligence
Nanomaterials
Photonics
Quantum devices
Sensors

Photocurrent represents a versatile probe for spatially dependent transport properties of materials. However, photocurrent generation relies on broken symmetry, either intrinsic to the sample, or brought in using an AFM tip. These limitations mean that there is no on-demand way to spatially map in-plane transport properties in any direction. By using a gold metasurface on top of our samples and using a polarized laser, we are able to engineer broken in-plane symmetry and generate a photocurrent in any direction. We present a novel technique for spatially mapping directional transport. As a test case, we demonstrate patterning gold nano-triangles onto the graphene, exploiting their C3 symmetry to probe directionally dependent electronic properties. Electrodes are positioned to collect currents in both the x and y directions, enabling the capture of anisotropic behaviors. Varying the polarization of an incident laser allows the nano-triangles to generate photocurrents in multiple directions, testing the isotropy of graphene's electronic response. Our results reveal how the spatially varying electronic environment, characterized by features in our sample, interacts with the patterned structures, providing a window into graphene's spatially and current direction-dependent electronic behavior. This technique is a powerful tool for understanding spatial inhomogeneities in graphene and other two-dimensional materials.

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Research Interests:
Electronic devices
Electronics
III-Vs
Integrated circuits
Lasers
Light-emitting diodes
Medical devices & systems
Photonics

High-efficiency On-chip Waveguide-detector Coupling

8.17

P. Vemparala, A. Buzzi, D. Englund
Sponsorship: DARPA INSPIRED

Efficient optical coupling between photonic circuits and detectors is critical for scalable photonic systems. Conventional edge coupling methods suffer from mode-size mismatch, alignment sensitivity, and reflection losses, often yielding poor efficiency. This work presents a suspended lithium niobate waveguide structure designed to evanescently couple light directly into a detector The waveguide is fabricated on a $LiNbO_3$-on-SiO_2 platform and suspended. Strain due to underetching causes the waveguide to lift and bend, enabling direct contact with the detector die. The design achieves adiabatic coupling, resulting in a strong overlap and minimal scattering Theoretical modelling predicts over 90% coupling efficiency. Loopback structures with varying etch lengths resulting in different contact lengths to detector are designed to calibrate for insertion and propagation losses during transmission and estimate efficiency. Next steps include optimizing coupling efficiency by testing the coupling structures across geometries, integrating membrane photodetectors directly onto the chip for fully on-chip detection, and benchmarking performance across these structures to enable scalable, integrated photonic detection architectures.

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Distinguishing Biological Fluorescence by its Spectral and Temporal Properties in Multiphoton Microscopy

8.18

F. Presutti, J. Tomkiewicz, S. You
Sponsorship: Novo Nordisk

Fluorescence lifetime imaging is a form of microscopy that maps out the variation in the photon emission decay rate across a sample, which depends on the fluorescing molecules involved and their microenvironment. Label-free microscopy relies on the signals from naturally occurring molecules, fundamental in cases where artificial staining for specific biomarkers is not possible. Increasingly, multiphoton microscopy is used in conjunction with lifetime imaging or for label-free imaging, as it enables high resolution, deep volumetric imaging for the study of tissues, cells, and organelles in biological specimens. Problematically, endogenous molecules tend to be broadband, and their spectral overlap may result in poor contrast and ambiguity of what is being observed.

In this work, we develop a laser-scanning microscope capable of wavelength-band resolved, direct-time sampling of fluorescence signals. By time multiplexing the readout from a series of detectors, we can compare the nanosecond-scale photon-arrival-time traces in different wavelength bands of interest. These fluorescence decay profiles, sampled over a broad optical spectrum, provide clues of the underlying composition, allowing us to disambiguate signals from different biomarkers, informing studies of ex vivo and in vivo samples for biomedical research.

Robotically Assembled 2D Materials for Next Generation Optoelectronics

8.20

A. Mukherjee, Z. Hennighausen, M.G. Blevins, J. Kong, and S.V. Boriskina

Sponsorship: NF MURI (GW911NF-19-1-0279) and MIT MathWorks Engineering Fellowship

Van der Waals heterostructures built from 2D materials enable engineered band structures, strong light-matter coupling, and ultra-compact optoelectronic devices. Many of the most promising architectures—tunable photodetectors, quantum emitters, and moiré superlattices—require precise, multi-layer stacks with controlled strain and interfaces. However, manual stacking of 2D materials is slow, inconsistent, and unscalable, bottlenecking systematic design and deployment of these devices. We present a material stacking machine (MSM) as a fully automated platform for rapid, precise assembly of complex 2D heterostructures. The MSM enables the scalability of heterostructures far beyond bi-layer or tri-layer stacks, reaching 100+ layer stacks of CVD-grown monolayer graphene in a time span of merely 6 hours, and enabling 16-layer spiral WS_2 heterostructures that engineer crystal symmetry for enhanced nonlinear optical responses. We also show deterministic transfer of exfoliated materials onto patterned substrates to impose nanoscale strain gradients, producing spatially localized, strain-modulated optoelectronic responses mapped via scanning photocurrent microscopy. Together, these results move 2D optoelectronics from artisanal assembly toward scalable, programmable manufacturing, opening a path to high-throughput discovery and deployment of strain- and moiré-engineered heterostructures for next-generation photonic and quantum devices.

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Optoelectronics
Photonics
Si

Session 9: Power Devices & Circuits

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

High Voltage Linear Optocoupler Inverter for Electrostatic Machines

9.01

G. C. Jurgiel, A. S. Miller, J. H. Lang
Sponsorship: MIT UROP Office, Space Grant

Electrostatic machines present the possibility of significant torque density benefits over magnetic machines since their flat electrodes can pack more efficiently than the heavy core and coils in magnetic machines. Improved drive circuits are required to realize these benefits. Electrostatic machines require high voltages at low current, something conventional switching devices are poorly suited for. Transistors that operate at this voltage are uncommon, expensive, and complicated to control. We demonstrate a linear six phase inverter using optocouplers as active elements. The inverter produces pure sine wave outputs with a low component count. The design improves on similar work by driving the optocouplers linearly with feedback instead of as PWM. We achieve a larger bandwidth and lower harmonic distortion without worse power efficiency. This design improves the viability of electrostatic machines by providing simpler methods of achieving the necessary output.

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Research Interests:
Batteries
Electronic devices
Electronics
Energy
GaN
Power management
Power Electronics

Characterizing Dynamic Coss Losses in GaN Switches at 13.56 MHz in Class-D Amplifier

9.02

A. Garg, M. Joisher, D. J. Perreault
Sponsorship: CICS, Applied Materials

Applications of power electronics, such as wireless power transfer, and semiconductor processing, require inverters operating at frequencies in the MHz range. Power electronics circuits rely on switches and historically, such high frequencies were limited by the switching capabilities of Si MOSFETs. Introduction of new wide-bandgap GaN devices has allowed designers to overcome this barrier. However, loss associated with the output capacitance (Coss) of GaN devices becomes significant at these frequencies. This dynamic Coss loss arises from the hysteretic, nonlinear behavior of the device capacitance and depends on device structure, frequency, applied voltage, and waveform shape. Because dynamic Coss loss has only recently been formalized, its behavior remains poorly characterized. This work investigates multiple GaN device families operating at 13.56 MHz in a Class-D amplifier and aims to characterize their associated Coss losses.

Valley-mode Current Control of Hybrid Switched Capacitor Converters Operating Above Resonance

9.03

M. Lopes, S. Coday

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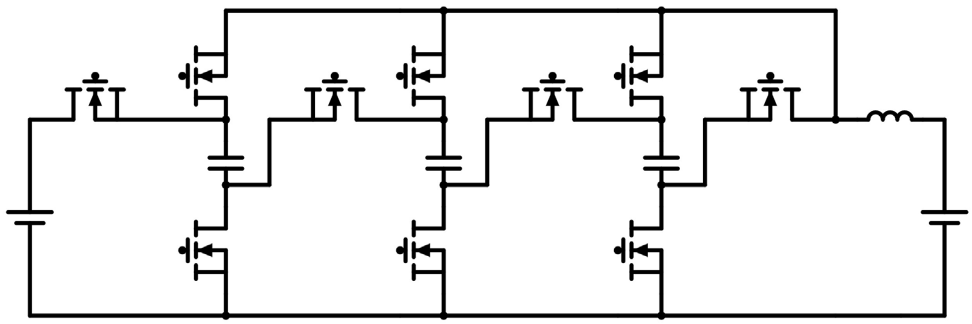
Worldwide investments in electrification demand high energy density solutions, making switched capacitor topologies promising due to their ability to avoid magnetic components, which typically dominate converter scaling. Hybrid designs use small inductors to enable capacitor soft charging and efficiency improvements. However, above-resonance control has not been thoroughly explored in literature, and the specific conditions that allow balanced operation remains an active research area. This project examines this operating region for the hybrid series-parallel converter and introduces methods to maintain balance without requiring detailed component characterization. We demonstrate sensing and control approaches through simulations, ensuring the converter remains within a predictable performance range. This work advances the scalability of hybrid switched-capacitor converters by increasing tolerance to unit-to-unit variation, a vital property for eventual widespread implementation.



▲ Figure 1: 4-level hybrid series-parallel converter.

Design of a Bridgeless Multilevel Coupled Inductor Condensed Buck-Boost Converter for Power Factor Correction

9.04

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Research Interests:
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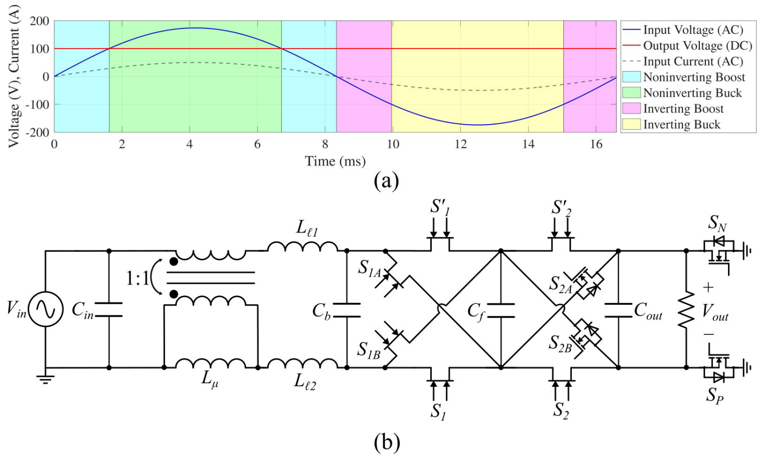
Electronics
Energy
Fuel cells
GaN
Thermal structures, devices & systems

To meet international electromagnetic compliance (EMC) standards, AC/DC converters must be designed with power factor correction (PFC) to reduce harmonic distortion introduced to the grid. In many applications, the desired DC output voltage may be lower than the peak input voltage. However, buck-type PFC converters inherently have discontinuous input current, which causes significant distortion. As a result, boost PFC converters are typically used, requiring a bulky and inefficient second stage with a high conversion ratio. To directly output a lowered voltage without adding distortion, a buck-boost topology is required.

This project presents a novel PFC converter topology based on the condensed buck-boost (CoBB) converter, which uses monolithic bidirectionally blocking switches to improve multilevel scaling and achieve higher power densities. Additional switches are introduced to enable inverting operating modes, eliminating the need for a rectifier.



◄ Figure 1: Proposed topology modes of operation (a) and three-level schematic (b). SN and SP are active during inverting and noninverting modes respectively, while the remaining switches are controlled to provide buck or boost functionality.

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Batteries
Energy
Energy harvesting devices & systems
Nanomaterials
Photovoltaics
Sensors

Electrochemically Resolved Acoustic Emissions for Detecting Degradation in Li-ion Batteries

9.05

Y. Samantaray, D. A. Cogswell, A. E. Cohen, and M. Z. Bazant

Sponsorship: Toyota Research Institute through D3BATT: Center for Data-Driven-Design of Li-ion Batteries, the Center for Battery Sustainability, the NSF Graduate Research Fellowship (2141064), and the National Defense Science & Engineering Graduate (NDSEG) Fellowship Program.

New methods of operando non-destructive evaluation (NDE) are needed to better assess the health and safety of Li-ion batteries. Acoustic emission (AE) testing is a widely used NDE technique in civil engineering, but has yet to provide reliable assessments in battery applications. Here, we show that various electro-chemo-mechanical processes in battery electrodes (graphite and nickel-manganese-cobalt oxides, NMC) can be reproducibly identified by electrochemically resolved AEs, after eliminating electromagnetic interference and applying wavelet-based signal processing. First, we perform "acousto-voltammetry" to correlate acoustic activity with specific electrochemical processes, such as ethylene gas generation and NMC particle fracture, as confirmed by gas detection and ex-situ SEM imaging, respectively. Next, we demonstrate that AEs can be distinguished using wavelet-transform features. Electrochemically resolved AEs provide a new window into quantitatively monitoring battery degradation, offering insights into electro-chemo-mechanical processes and potential advantages over conventional methods for assessing state-of-health, remaining useful life, and safety risks.

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Electronics
Energy
Energy harvesting devices & systems
GaN
Integrated circuits
Machine Learning
Power management

Extreme Step-Down High-Frequency DC-DC Conversion: Topological Study and Hybrid Electronic and Magnetic Integration

9.06

G. Park, and D. J. Perreault

Sponsorship: MIT-Tata Alliance

Multi-kW isolated DC-DC converters with extremely high step-down ratios (up to 60:1) and wide operating voltage ranges are increasingly critical in real-world systems such as on-board converters for battery packs in electric vehicles and high-current power delivery in data centers. However, achieving high efficiency and power density under these conditions is challenging, as large conversion ratios complicate transformer optimization and hinder scalable miniaturization.

This work presents a design study that addresses these challenges through two complementary approaches. First, we use 650-V GaN HEMTs to enable MHz-class switching, increasing power density. Second, we apply magnetics-oriented strategies such as hybrid magnetic-electronic integration to improve transformer performance under extreme conversion ratios. Incorporating these approaches into the circuit topology, we aim to construct high-efficiency and high-density power conversion system for extreme step-down applications.

An Isolated Piezoelectric-Based Power Converter for High Conversion Ratios

9.07

A. K. Jackson, D. T. Brown, J. H. Lang, D. J. Perreault

Sponsorship: Texas Instruments, NSF Graduate Research Fellowship (Grant No. 2141064)

Power electronics are key components of electric energy systems, and new applications require power converters that are smaller, lighter, and more efficient than can be achieved with conventional designs. Conventional power converters rely on magnetic components for energy storage, but these magnetics are often the bottleneck to achieving high power density, high efficiency, and light weight. Power converters that use piezoelectric components for energy storage are a promising alternative to magnetic-based converters, particularly for miniature, power-dense designs. One natural application for piezoelectrics is in isolated converters; due to their electromechanical nature, piezoelectric components can be used to create galvanically isolated converters without the use of any magnetic components. Previously demonstrated isolated piezoelectric-resonator-based converters have performed well, but their topologies are best suited for modest conversion ratios. This work presents a new topology of isolated piezoelectric-based converter that operates with high efficiency for large variable conversion ratios < 0.5, enabling the use of piezoelectric-based designs in a wider set of applications.

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

Soft-Switched Pulsed Bias Plasma Supply System

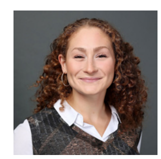
9.08

J. Estrin, A. Jurkov, D. Perreault

Sponsorship: MKS Instruments

Radio Frequency (RF) generators are essential as bias voltage sources in plasma-enhanced semiconductor manufacturing processes. Employing pulsed waveforms to generate plasma 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 having low leakage inductance is 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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Research Interests:
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Electronic devices
Electronics
GaN
III-Vs
Integrated circuits
Nanomanufacturing
Nanomaterials
Nanotechnology
Si

Self-Aligned p-GaN-Gate HEMTs with Regrown Contacts and an All-Refractory Metallization for Next Generation Low-Voltage Power Converters

9.09

P. Darmawi-Iskandar, J. Niroula, C.R. Neve, J. Strate, and T. Palacios
Sponsorship: Samsung Electronics Co., Ltd. (033517-00001), National Defense Science and Engineering Graduate Fellowship

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/$Al_{0.2}Ga_{0.8}N$/GaN (80/15/100 nm) HEMT with a p-GaN [Mg] doping of $3x10^{19}$ cm^{-3}, and a 100 nm $Al_{0.08}Ga_{0.92}N$ back barrier grown via metal organic chemical vapor deposition (MOCVD) on an 8-inch Si substrate by SOITEC. This work features several novel process modules to maximize performance as a scaled power device: 1) a self-aligned Schottky tungsten gate to maintain alignment between the gate and the p-GaN island which is increasingly difficult at scaled gate lengths 2) regrown contacts with a self-aligned source to minimize LGS and contact resistance 3) a back barrier to minimize short channel effects and 4) an all-refractory CMOS compatible metallization for robust fabrication and operation with a high thermal budget. Devices with $L_G/L_{SD}/L_{GD}$ = 575/2000/1075 nm demonstrated a maximum drain current of 1.15 A/mm, an on-off current ratio exceeding 10^8, a threshold voltage of 0.97 V, on-resistances as low as 1.1 Ω·mm, and breakdown voltages exceeding 140 V which make them highly promising for use as medium-voltage power switches.

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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

Gallium Nitride Heterojunction Bipolar Transistors for Radio-Frequency Power Amplifiers

9.10

A. S. Gupta, J.-H. Hsia, and T. Palacios
Sponsorship: Murata Manufacturing Co., Ltd., and NSF Graduate Research Fellowship

The next generation of wireless communications systems targeting the upcoming FR3 band (~7-24 GHz) will require transistors that support higher current densities (>60 kA/cm^2) and maximum operating frequencies (50-100 GHz), as well as improved device linearity and thermal management. Gallium nitride (GaN) is suited to meet these requirements due to its wide bandgap and high electron saturation velocity. While GaN high electron mobility transistors (HEMTs) provide excellent channel conductivity because of their 2D electron gas, they suffer from reduced device linearity at high power levels. In contrast, heterojunction bipolar transistors (HBTs), already implemented in SiGe, GaAs, and InP, offer superior current drive, threshold uniformity, linearity, and high-frequency performance.

Progress in GaN HBTs has been limited by the difficulty of activating and contacting Mg-doped p-GaN, leading to increased base access resistances. Consequently, only four reports of RF performance exist to date. In this work, we fabricate InGaN/GaN double HBTs and AlGaN emitter HBTs. We investigate Mg diffusion to realize ohmic contacts to p-GaN and extract hole concentration and mobility using TLM structures, gated Hall measurements, and diode CV profiling. Additionally, we assess how different etching techniques, including atomic layer etching, and multiple passivation materials impact the minority carrier lifetime of electrons in p-GaN. These results demonstrate a viable pathway towards high-power, high-frequency GaN HBTs, establishing their potential as a competitive device technology for future FR3 power amplifiers.

Optically-Controlled GaN Power finFET

9.11

J.-H. Hsia, M. Oh, A. Gupta, Z. Zhu, J. Park and T. Palacios

Sponsorship: Office of Naval Research, ARPA-E, Tata-MIT Alliance

In recent years, the boost in consumer electronics and data centers has increased the electricity demand. The delivery and transformation of power through electric grids requires many efficient power converters and electronics that can withstand high current and voltages. However, traditional power electronics are mostly electrically triggered, which can complicate the circuitry design and cause electromagnetic interference (EMI). The use of optically triggered devices will simplify the circuitry design, reduce EMI and potentially increase the operating frequency. In this work, we have demonstrated a fully vertical, optically controlled GaN transistor with high optical responsivity and on-off ratio, that could be triggered by low-cost LEDs to enable future multilevel converters.

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III-Vs
Nanomaterials
Nanotechnology
Optoelectronics
Photonics
Power management

Optimization of Class-E Power Amplifier for High-Frequency Applications

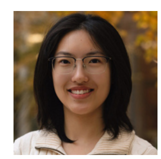
9.12

M. V. Joisher, J. Wang, D. J. Perreault

Sponsorship: MKS Instruments

High-frequency inverters operating in the HF (3-30 MHz) and VHF (30-300 MHz) ranges enable a wide range of applications such as wireless power transfer, plasma generation, and induction heating. However, losses in switching devices at these frequencies significantly limit the performance of switched-mode power converters. As a result, linear power amplifiers are used in this frequency range despite their low efficiency. In addition, these inverters are often required to operate across a wide load range, which further complicates the design space and makes soft-switching operation challenging.

This work investigates Class-E inverter architecture utilizing gallium nitride devices to enable soft-switching operation at HF/VHF frequencies. The ground-referenced switch configuration of Class-E simplifies high-frequency gate driving and makes the topology well suited for operation in this regime. Using experimentally characterized loss models for these devices, we optimize the device choice together with the input voltage, duty cycle, and resonant network parameters to establish operating conditions that preserve soft switching and maximize efficiency. We demonstrate that a 25 % on-duty cycle, rather than the conventional 50 %, achieves a peak efficiency of 89 % for a 500 W design at 30 MHz with less device losses. With reduced losses per device, the optimized design can lead to lower temperature rises across devices and improved thermal performance than its 50 % on-duty cycle counterpart. This result highlights the potential of optimized Class-E architectures to serve as compact and highly efficient power sources for next-generation HF/VHF applications.



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Research Interests:
Actuators
Biological devices & systems
Electronic devices
Electronics
Energy
Energy harvesting devices & systems
GaN
Information processing
Integrated circuits
Medical devices & systems
Power management
Sensors
Transducers

High-Frequency Characterization of GaN Dynamic RdsON and Coss Losses Using SCPI-Based Automation

9.13

M. Joisher, M. De Jesus, C. Sanchez , D. Perreault.

Sponsorship: MKS Instruments, Center for Integrated Circuits and Systems

Gallium nitride (GaN) transistors are enabling higher power density in next-generation power electronics, but unmodeled loss mechanisms such as dynamic on-resistance (RdsON) and output capacitance (Coss) losses can limit their performance, especially at multi-megahertz frequencies. Capturing these losses requires repeatable device characterization across wide ranges of voltage, duty cycle, frequency, and temperature, which is challenging to execute manually with sufficient precision and consistency.

To address these challenges, this work provides a detailed experimental characterization of dynamic RdsON and Coss losses for several commercially available GaN devices. Measurements span duty cycles of 25% and 50%, switching frequencies up to 30 MHz, peak voltages from 200–400 V, and case temperatures up to 80 °C, enabling clear identification of trends relevant to high-efficiency converter design. Second, we introduce an automated SCPI-based characterization platform that standardizes timing, embeds safety interlocks, and implements a cloud-linked data pipeline for logging waveforms, operating conditions, and derived metrics. This automation significantly improves reproducibility, reduces operator overhead, and supports rapid exploration of device behavior at a large number of test points.

Together, the resulting dataset and automated workflow form a scalable foundation for future wide-bandgap device research, enabling more accurate device models and faster development of optimized high-frequency power conversion systems.

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Research Interests:
Batteries, Communications, Displays, Electronic devices, Electronics, Energy, GaN

High Performance P-channel GaN FinFETs for Complimentary Logic Applications

9.14

J. Park, J. Hsia, Z. Zhu, A. Goodnight, T. Palacios

Sponsorship: Lockheed Martin Corporation, MIT Lincoln Laboratory, NSF Graduate Research Fellowship

Gallium nitride (GaN) power transistors boast high breakdown voltages, switching frequencies, and operating temperatures, but are limited in performance by the silicon ancillary chips required to modulate them. Although GaN complementary metal oxide semiconductor (CMOS) technology has been demonstrated as a promising solution, the current challenge lies in p-channel GaN transistors, which have on-state current densities two orders of magnitude lower than their n-channel counterparts. By introducing novel dielectric materials and device geometries, we can modulate p-channel transistors while significantly enhancing their current density.

In this work, we demonstrate a scaled p-channel GaN FinFET that has a higher on-state current density (ION) compared to p-channel transistors with a gate-recessed structure. To maximize ION, we fabricate devices with various fin device geometries and investigate how ION scales as a function of the number of fins. Through TCAD device simulations supported by experimental data of metal-insulator-metal (MIM) capacitors and transistors, we identify how the fin width and gate dielectric can be leveraged to finely tune the threshold voltage. This work explores how different parameters in p-channel FinFETs can be tuned to maximize performance, pushing the limits of p-channel transistors for CMOS applications.

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Research Interests:
GaN
III-Vs

CMOS-Compatible Enhancement-Mode Gallium Nitride MISHEMTs for RF Switching

9.16

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Sponsorship: GlobalFoundries, NSF Graduate Research Fellowship

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GaN

Gallium nitride (GaN) high electron mobility transistors are the current state-of-the-art RF device technology, exhibiting impressive performance with high power densities, frequencies, mobilities, and critical electric fields. These advantages provide superior performance in modern 5G communication systems. However, challenges achieving low-power, enhancement-mode operation and CMOS-compatibility persist. By analyzing the material composition and modifying the geometrical structures of these devices, we can achieve improved performance using GaN metal-insulator-semiconductor high electron mobility transistors (MISHEMTs).

We investigate Au-free metallization for the gate and ohmic contacts, gate recess etching technologies, and dielectric and passivation schemes for GaN MISHEMT devices. To achieve E-mode operation, we compare traditional reactive-ion etching (RIE) to digital etching and atomic layer etching, two approaches for smooth and controlled layer-by-layer removal. By fabricating metal-insulator-metal (MIM) capacitors and MISHEMTs with various dielectric films, CV measurements and pulsed I-V techniques examine the trapping, interface quality, and leakage current for reliable performance. This work aims to explore innovative device processing techniques in order to push the boundaries of CMOS-compatible GaN MISHEMTs for RF switching applications.

A New Class of Topologies for Isolated Piezoelectric-Based Power Conversion

9.17

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Sponsorship: Texas Instruments, MIT SuperUROP

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Electronic devices
Electronics
Energy
Power management

Power electronics are integral to modern electric energy systems—such as electric vehicles, renewable power generators, and consumer electronics—driving a continuous need for lighter, more compact power converters. The main bottleneck to the miniaturization of these converters are magnetic components, whose maximal energy density decreases as their volume decreases. Piezoelectric resonators—components that store energy in mechanical vibrations instead of magnetic fields—are a promising alternative to magnetics, since their energy density fundamentally increases as their volume decreases. Piezoelectric-resonator-based converters can achieve resonant soft switching and capacitive soft charging without the use of magnetics.

This work presents a novel method for constructing galvanically isolated dc-dc piezoelectric-based converter topologies. A hardware prototype experimentally achieves a peak piezoelectric-component power density of 209 W/cm3 and demonstrates peak efficiencies above 95% for conversion ratios between 0.6 and 0.9.

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2D materials
Batteries
Energy
Energy harvesting devices & systems
Fuel cells
Machine Learning
Nanomaterials

9.18

Understanding the Role of Interfacial Bonding and Defects at Diamond/c-BN Interface: A First-principles Study

S. Saini, K. Klyukin, M. B. Liu, M. J. Polking, and B. Yildiz

Sponsorship: MIT Lincoln Laboratory for c-BN/Diamond Heterostructures for High-Power RF Electronics

Diamond and cubic boron nitride (c-BN) are promising materials for high-power and high-frequency devices due to their exceptional thermal conductivity, breakdown field, and carrier mobility. Realizing such devices requires a better understanding of the interface electronic structure. Here, using first-principles calculations based on hybrid density functional theory, we investigate the role of interfacial bonding and antisite point defects on the two-dimensional carrier gas formation at (111) diamond/c-BN heterointerfaces. We identify four distinct interfacial bonding configurations arising from B- and N-terminated c-BN surfaces, in which a B (or N) atom bonds to either one or three C atoms. Our results show the formation of the two-dimensional hole gas (2DHG) at C–B bonded interfaces and the two-dimensional electron gas (2DEG) at C–N bonded interfaces, driven by the electron-deficient and electron-rich nature of the interfacial bonding, respectively. Interfaces where B (or N) bonds to three C atoms exhibit approximately three times higher carrier density than those bonded to one C atom, due to the higher density of interfacial C–B or C–N bonds. We further show that n-type antisite defects stabilize C–B bonded interfaces, while p-type antisite defects stabilize C–N bonded interfaces. These defects reduce the carrier density by ~25% and ~8% for interfaces with one and three C bonds, respectively. Nevertheless, the carrier density remains high (~10^{14}–10^{15} cm^{-2}). These results highlight the importance of interfacial bonding and defects in tuning both stability and carrier density at (111) diamond/c-BN interfaces and provide guidance for interface engineering toward p-type or n-type conduction.

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

Integrated Photonics for Polarization-Gradient Cooling of Trapped Ions

10.01

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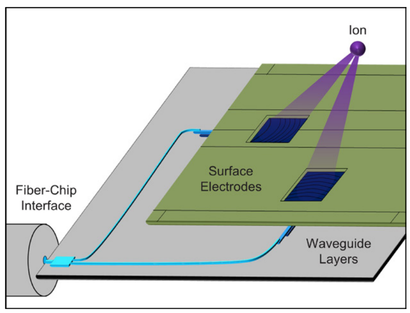
Sponsorship: DOE Office of Science Quantum Systems Accelerator, NSF QLCI HQAN (2016136), NSF QLCI Q-SEnSE (2016244), MIT CQE (H98230-19-C-0292), NSF GRFP (1122374), NDSEG Fellowship, MIT Cronin Fellowship, and MIT Locher Fellowship

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.

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Electronics, Energy harvesting devices & systems, Machine Learning, MEMS & NEMS, Microfluidic devices & systems, Molecular & polymeric materials, Nanomanufacturing, Nanomaterials, Systems, Thermal structures, devices & systems.

Reinforcement Learning-Guided Optimization of Critical Current in High-Temperature Superconductors

10.02

M. Cheng, Q. Wan, B. Yu, E. Rha, M. J. Landry and M. Li

Sponsorship: U.S. Department of Energy, National Science Foundation

High-temperature superconductors (HTSs) are key to future energy, magnet, and quantum-technology systems, where their usefulness is determined by the critical current density J_c, the maximum current the material can carry without losing superconductivity. In practical devices, J_c is limited by the motion of magnetic vortices; pinning these vortices with defects is essential for maintaining zero resistance, while the ultimate upper bound is set by the depairing limit, where Cooper pairs themselves break apart. Designing defect landscapes that maximize J_c is extremely challenging because the effectiveness of vortex pinning depends not only on defect type and density but also on their spatial correlations.

In this work, we present an integrated workflow that combines reinforcement learning (RL) with time-dependent Ginzburg–Landau (TDGL) simulations to autonomously identify optimal defect configurations that maximize J_c. In our framework, TDGL simulations generate current–voltage characteristics to evaluate J_c, which serves as the reward signal that guides the RL agent to iteratively refine defect configurations. We find that the agent discovers optimal defect densities and correlations in two-dimensional thin-film geometries, enhancing vortex pinning and J_c relative to the pristine thin-film, approaching 60% of the theoretical depairing limit with up to 15-fold enhancement compared to random initialization. This RL-driven approach provides a scalable strategy for defect engineering, with broad implications for advancing HTS applications in fusion magnets, particle accelerators, and other high-field technologies.

Through-Silicon Vias (TSVs) for High-Coherence Superconducting Qubit Devices

10.03

G. D. Cutter, F. H. Bijarbooneh, A. Goswami, J. A. Grover, W. D. Oliver

Sponsorship: U.S. Army Research Office under Award No. W911NFF-23-1-0045; in part by the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers, Co-design Center for Quantum Advantage (C2QA) under contract number DE-SC0012704; and in part by the U.S. Department of Energy, Office of Science, National Quantum Information Science Research Centers, Quantum System Accelerator (QSA).

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

Densely packed arrays of superconducting qubits, each requiring multiple control and readout lines, encounter routing congestion in planar architectures. The inclusion of air bridges and flip-chip techniques have alleviated some of this crowding, and high-coherence qubits have been demonstrated alongside their fabrication. Much work remains to be done to establish the same for superconducting through-silicon vias (TSVs), which hold potential for quantum-coherent vertical interconnects. TSVs are used widely in high-density classical microelectronic systems and present a similarly promising route toward 3D-integrated, multi-stack superconducting devices and packaging.

In this work, we target high-aspect-ratio TSVs of varying geometries at the wafer-scale and integrate them with a superconducting process. We investigate the parameters that determine performance of superconducting TSV devices. We also examine compatibility with our flip-chip process to enable vertically stacked dies for complex signal routing.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.

Evidence of Electron Crystal in Crystalline Rhombohedral Graphene

10.04

T. Han, J. Butler, Z. Hadjri, S. Ye, Z. Hua, Z. Wu, E. Aitken, Z. Lu, W. Xu, L. Shi, J. Yang, J. Seo, R. Ashoori, L. Ju

Sponsorship: DOE DE-SC0025325

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Electrons self-organize into a crystal when Coulomb repulsion becomes much larger than their kinetic energy, known as a Wigner crystal. Zero-magnetic-field Wigner crystals demand ultraclean samples and have usually offered only a single tuning knob, the carrier density, in past realizations. Crystalline rhombohedral multilayer graphene provides a clean and highly tunable platform to explore these electron crystals, as its gate-tunable flat electronic band structure allows control not only of carrier density but also of the underlying band dispersion. Here we show evidence of a Wigner crystal in crystalline rhombohedral graphene devices, revealed through transport and capacitance measurements. I will also discuss a distinct state that emerges near the melting transition of the crystal.

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Imperfect Suppression of Quasiparticle-Induced Dissipation in Fluxonium Qubits

10.05

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Sponsorship: Lincoln Laboratory, MIT, RLE

Nonequilibrium quasiparticles generated by stray infrared and ionizing radiation present a challenge to the coherence and scaling of superconducting-qubit-based quantum processors. Standard models of quasiparticle-induced errors typically assume that the characteristic energy of the quasiparticles and the qubit frequency are small relative to the superconducting gap. Under these assumptions, flux tunable qubits such as fluxonium would exhibit suppressed sensitivity to quasiparticle loss at specific bias points. Motivated by the notion that these assumptions would not hold during error "burst" events caused by ionizing radiation, we numerically study the rate of quasiparticle-induced qubit errors in fluxonium qubits for arbitrary quasiparticle energy distributions. We find even away from burst events, with typical qubit frequencies and "cold" quasiparticles, the aforementioned assumptions do not necessarily hold, necessitating a reevaluation of quasiparticle protection in various qubit circuits. This presentation will discuss the interplay of various assumptions in the theory of quasiparticle-induced errors and describe experimental prospects for validating this theory.

This material is based upon work supported under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the U.S. government or the U.S. Air Force.

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Magnetic Field-Enhanced Graphene Superconductivity with Record Pauli-Limit Violation

10.06

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Sponsorship: ONR through Grant number N00014-25-1-2294, National Research Foundation of Korea (RS-2024-004447252), MIT Portugal Program

In modern condensed matter physics, many exciting quantum phenomena are driven by electron correlations, including the long-sought spin-polarized superconductivity. Different from their conventional counterparts that are driven by phonons, spin-polarized superconductors provide a unique platform to examine and manipulate electronic correlation effects, and could possibly host non-Abelian quasi-particles for fault-tolerant topological quantum computers. However, few candidate systems have been experimentally confirmed to date. Here, we report the observation of a spin-polarized superconducting state, denoted SC5, in WSe_2-proximitized rhombohedral trilayer graphene. At in-plane magnetic field $B_{||} = 0$ T, SC5 has a critical temperature of 68 mK and an out-of-plane critical magnetic field of only 12 mT. Surprisingly, these values are significantly enhanced as $B_{||}$ increases, and the superconductivity persists to $B_{||} = 8.8$ T. This value corresponds to a record high Pauli-limit violation ratio of at least 80 among all superconductors, while the true critical field is beyond the limit of our instrument. We conclude that SC5 experiences a canting crossover from Ising-type to spin-polarized superconductor with increased $B_{||}$. Our work forms the basis of exploring unconventional superconductivity and non-Abelian quasi-particles in rhombohedral graphene.

Nano-Engineering Symmetries and Emergent Phases of Quantum Materials

10.07

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

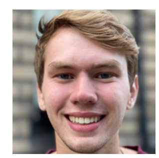
Fine tuning interactions and quantum phenomena in materials has been a longstanding challenge, with recent advances in stacked and twisted van der Waals crystals as well as light-driven transient phases. Yet intrinsic lattice symmetries still fundamentally constrain the accessible phases in these systems. The ability to further design these symmetries therefore represents an exciting frontier for controlling both the static properties and ultrafast responses of quantum materials. Although directly engineering the atomic lattice remains a significant challenge, we can nevertheless nudge the symmetries of a material through high-precision nanolithography. Here, we present recent progress along several directions, including tuning electronic structure via two-dimensional superlattice strain on ultra-fine lithographic arrays and directly patterning thin crystals to induce symmetry-tailored dynamical strain fields through ultrafast nano-acoustic modes. Special attention is given to the photocurrent responses that emerge in centrosymmetric materials when patterned with symmetry-broken metasurfaces. These hybrid systems enable nearly arbitrary control over nanoscale vectorial current and offer a new time-, space-, and angle-resolved local transport probe of electronic anisotropy. Upon ultrafast excitation, they also act as efficient sources of tunable terahertz vector radiation, simultaneously probing the collective material dynamics.

Designer Electronic Structure and Topology in Periodically Nano-Strained Graphene

10.08

C. Glass, J. Pettine, S. Sarkar, S. Rao, X. Wang, K. Sun, S. Lin, P. Jarillo-Herrero, N. Gedik

Sponsorship: Gordon and Betty Moore Foundation



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Graphene has drawn immense interest over the past two decades due to the rich variety of novel electronic and topological properties, particularly within moiré systems. However, the scalability of twisted graphene is limited by strain and disorder, while the triangular superlattice geometry is constrained by the underlying honeycomb lattice. Here, we explore new routes toward highly scalable and geometrically tunable graphene superlattices utilizing high-precision nanolithography to pattern periodic nano-strain. On the experimental front, we demonstrate the high-resolution lithography of spin-on glass with periodicity below 30 nm approaching the magic-angle moire scale. We also show topographical maps of successful initial graphene transfers. Crucially, even at these ultra-fine scales, we achieve triangular nanopillar perturbations that break C_2z symmetry and thereby gap the graphene Dirac cone. On the theoretical front, continuum model calculations of fully relaxed overlaid graphene with arbitrary straining substrates unlock a vast search space to tune electronic structure, topology, and strong correlations. In triangular, kagome, square, Lieb, and other superlattice motifs, we find exceptional flatness and nonzero Chern numbers across a ladder of minibands, suggesting exciting next steps for experimental exploration.

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

Material Design for a RF-transparent Top Gate for Scanning Probe Microscopy of 2D Materials

10.09

S. Jung, Z. Ji

Unlike modulation-doped 2D electron gases (2DEGs) embedded deep within semiconductor heterostructures such as GaAs, atomically thin 2D materials can be efficiently and continuously tuned in-situ using proximitized electrostatic gates. This makes them exceptionally versatile platforms for investigating emergent quantum phenomena, including topological superconductivity. In scanning probe microscopy, however, implementing a top gate presents a fundamental geometric obstacle: the gate physically blocks the probe's access to the sample. Although the probe itself can act as a local gate when biased, the resulting highly nonuniform electric field often destabilizes or complicates the fragile correlated phases of interest.

At the same time, the RF regime has risen to prominence in the 2D-materials community, as GHz–THz excitations may couple directly to exotic quasiparticles such as anyons, excitons, and Cooper pairs.

In this work, we identify and realize a top-gate architecture that simultaneously (i) provides low-frequency electrostatic control of an underlying 2DEG and (ii) transmits THz radiation from a proximal probe with minimal distortion. Achieving this dual functionality requires a gate material whose plasma frequency remains in the sub-THz range even under electrostatic doping. We demonstrate that controlled carrier depletion in a semimetal offers a practical and robust pathway to meeting this requirement.

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Superconducting Nanowire Thin-Film Characterization for Universal Scaling Law

10.10

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Sponsorship: Harold E. "Doc" Edgerton Memorial Fund Fellowship, DARPA (HR0011-24-0311)

Superconducting nanowire single-photon detectors (SNSPDs), first developed by Gol'tsman et. al., can be made sensitive to single photons with near-unity detection efficiency, ultra-low dark-count rates, and sub-nanosecond timing over a broad wavelength range. These characteristics make SNSPDs vital for quantum communication, deep-space optical links, and photonic sensing. However, these performance metrics trade off with each other and with device operating conditions. The superconducting material used to fabricate SNSPDs has a significant impact on the resulting device's performance. Thus, a better fundamental understanding of material parameters and their effects on SNSPD performance is required. We report a comprehensive characterization of superconducting NbN on four different substrates (MgO, SiO2, Al2O3, and a stacking of Nb on Al2O3) with varying thicknesses. We measure their superconducting critical temperature, sheet resistance, magnetic diffusivity, grain boundary size, and residual resistance ratio to determine the fit to the thin-film scaling law given by Ivry et. al. We hope to use this information to develop a connection between Ivry's universal scaling law and McMillan theory of superconducting thin films.

Frequency Comb Stabilization in an Yttrium Iron Garnet Thin-Film Delay-Line Oscillator

10.11

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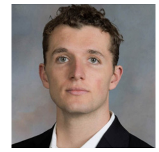
Sponsorship: Under Secretary of War for Research and Engineering under Air Force Contract No. FA8702-15-D-0001 or FA8702-25-D-B002.



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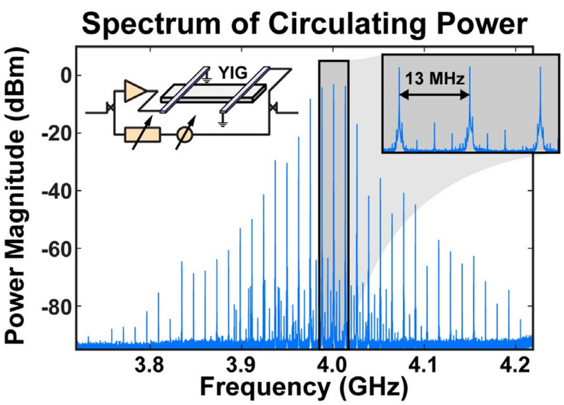
Research Interests:
Communications, Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, Nanomanufacturing, Nanomaterials, Nanotechnology, Si, Systems.

Yttrium iron garnet (YIG) feedback oscillators are promising components for high performance AC magnetometry. We construct a delay-line oscillator by using microwave transducers to launch and receive spin waves in a YIG thin film device. To minimize phase noise and thus optimize sensitivity, it is desirable to operate with high sustaining power, where the nonlinear interactions of spin waves become relevant. At sufficiently high power, two modes become self-sustaining, and four-wave mixing produces a frequency comb with spacing determined by the Barkhausen condition. Using a perpendicularly-biased 10-micron YIG film, we observe a frequency comb centered at 4 GHz with 13 MHz spacing and at most 4 kHz linewidth. The envelope of the comb can be tuned by sustaining power and external phase and can span up to one octave from 2.5 to 5.5GHz. We investigate how to stabilize the comb with an aim to perform demodulation for magnetic field readout.



◂ The YIG delay-line oscillator consists of a thin-film YIG with two transducers and an amplifier within the feedback loop. At high powers, the device generates a microwave frequency comb centered at 4 GHz with 13 MHz spacing.

Foundry-Patterned Diamond Quantum Microchiplets for Scalable Nano-photonics

10.12

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Sponsorship: U.S. DOE C2QA (DE-SC0012704)

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Scalable quantum photonic hardware requires fabrication methods that combine high device quality, high yield, and compatibility with semiconductor manufacturing. Diamond color centers offer excellent spin and optical coherence, but the nanophotonic structures needed to interface with these emitters are typically patterned by electron-beam lithography directly on diamond chips, limiting throughput, uniformity, and reproducibility across large areas.

We present a foundry-compatible approach for fabricating diamond quantum microchiplets (QMCs) using suspended silicon hard masks patterned in parallel on commercial silicon-on-insulator (SOI) wafers. After membrane release, micro-transfer printing is used to place the patterned masks onto bulk diamond substrates, eliminating lithography on diamond and shifting pattern definition to a reproducible upstream step. Using this method, we define arrays of nanobeam waveguides and photonic crystal cavities with high fidelity and achieve large-area patterning of more than 15 × 8 chiplets per membrane. Optical characterization reveals cavity quality (Q) factors of 3,000–4,000 at room temperature and narrow spatial variations in resonance wavelength.

Gas tuning enables deterministic alignment of cavity modes to tin-vacancy (SnV) color centers and yields a fourfold Purcell enhancement. To understand fabrication variability, we combine scanning electron microscopy (SEM)-based computer vision with finite-difference time-domain (FDTD) simulations and a surrogate model to extract distributions of hole radius, waveguide width, and thickness across the sample.

Together, this process demonstrates a reproducible and scalable route to patterning high-quality diamond nanophotonic structures using industrial lithography infrastructure. The chiplet architecture further enables post-fabrication selection, replacement, and heterogeneous integration with photonic integrated circuits or complementary metal–oxide–semiconductor (CMOS) backends, establishing a practical path toward large-scale quantum networks and hybrid quantum–classical systems.

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Universal In-Plane Field Induced Superconductivity River In Rhombohedral Graphites

10.13

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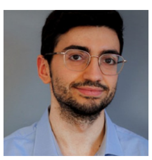
Sponsorship: Office of Naval Research N00014-25-1-2294

Graphene is a natural platform for exploring superconductivity, because it provides an exceptionally clean and low-disorder electronic environment, allowing subtle interaction-driven phases to emerge. Its phase diagram is remarkably rich: in a single device, one can access superconductivity, correlated insulators, and even fractional quantum anomalous Hall states. Looking forward, the ability to integrate superconductivity with topological phases such as the quantum anomalous Hall effect offers a promising route toward next-generation quantum computing building blocks.

Among graphene systems, rhombohedral multilayer graphene has recently emerged as a particularly powerful setting for studying these correlated states—including fractional quantum anomalous Hall phases, unconventional superconductivity, and correlated insulators. In this work, we report our recent study on the low-temperature transport properties of multilayer rhombohedral graphene. Notably, applying an in-plane magnetic field induces a superconducting phase. Remarkably, the superconductivity exhibits an unexpected enhancement under moderate in-plane magnetic fields, it suggests that the underlying pairing symmetry—the spatial and spin structure of how electrons form Cooper pairs—may be nontrivial. This superconducting state displays exotic behavior under the in-plane field, indicating that the pairing mechanisms, meaning the interactions responsible for binding electrons into pairs, likely involves a complex interplay between spin, valley, and orbital degrees of freedom.

Furthermore, this phenomenon appears to be generic across samples with very different layer numbers. These results not only establish rhombohedral graphene as a versatile system for investigating unconventional superconductivity emerging from flat-band correlated physics, but also point toward its potential as a foundation for future superconducting quantum architectures.



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Enhancing Quantum Computing through EDA: a Full-Stack Perspective

10.14

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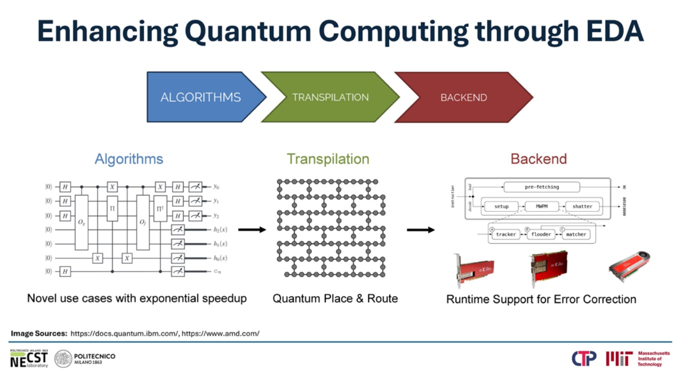
Recently, Quantum Computing (QC) has been emerging as a novel paradigm of computation, promising to achieve exponential speedup compared to classical computing. Yet, current architectures are affected by strong limitations in terms of reliability and availability of hardware resources, introducing unbearable noise during computation and preventing users from successfully accelerating real-world tasks.

This research project aims to enhance current quantum technologies by exploiting expertise and toolkits coming from Electronic Design Automation (EDA), a well-established research area with decades of exploration and analysis to increase the efficiency and reliability of computing architectures. Doing so, it contributes to the low-level execution environment of QC, to the higher-level compilation toolchain, and to the logical-level quantum algorithms, thus offering a full-stack perspective of the benefits of EDA for quantum computation.



◀ Figure 1: (a) Description of the involvement of EDA in the full stack of QC. EDA offers use cases that achieve exponential speedup via quantum algorithms; circuit transpilation can benefit from EDA's place & route. Finally, EDA toolchains generate hardware accelerators for faster error decoding.

Digital-Twin–Enabled AI-Driven Robotic Manipulation of Optical Systems for Quantum Experiments

10.15

M. Mazaheri, F. Belemkoabga, Q. Ding, L. K. N. Kana, P. Anand, A. Martinez de laVilla, D. Englund

Sponsorship: Center for Quantum Network (CQN), NSF FuSe2

Autonomous manipulation of optical systems, when coupled to a physics-based digital twin of the experiment, offers a powerful route to safely explore, optimize, and scale complex quantum-optics setups beyond what is feasible manually. We present a digital-twin-enabled, AI-driven robotic platform for autonomous manipulation of optical systems in quantum information experiments. The system combines a Franka robot with vision-based feedback and reinforcement learning to perform precision alignment, calibration, and component assembly on optical tables. A high-fidelity digital twin in NVIDIA Omniverse provides a physics-aware environment for safe motion planning, optical ray tracing, and virtual validation of procedures. This integration of robotics, AI, and digital-twin simulation enables reliable, repeatable configuration of quantum-optics setups with minimal human supervision, paving the way toward scalable and reproducible autonomous quantum laboratories.

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

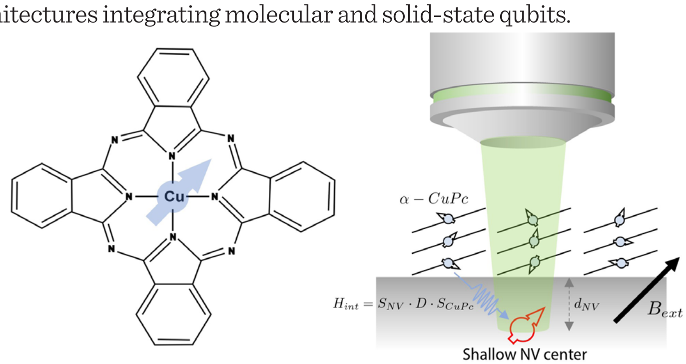
Linking Solid State Qubits (NV-Center in Diamond) to Molecular Spin Qubits

10.16

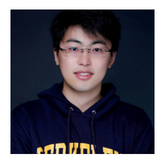
B. Li, X. Li, Y. Quan, G. Wang, R. G. Griffin, A. Harutyunyan, P. Cappellaro

Sponsorship: Honda Research Institute, Inc., U.S.A..

Molecular materials hosting quantum spins are promising components for future quantum technologies, offering chemically tunable qubits that operate at room temperature. However, many molecular spins lack optical addressability, limiting fast, local control. Here we address this challenge by coupling molecular spin qubits to a single NV center, demonstrating a practical and scalable hybrid quantum platform. By monitoring changes in the NV T_1 relaxation when its transition matches hyperfine-resolved molecular transitions, we provide direct evidence of NV–molecule coupling. A quantitative model enables extraction of key molecular parameters, including nanosecond spin coherence and molecular orientation, and also allows nanometer-precision determination of NV depth using purely optical measurements. These results establish a robust pathway for nanoscale molecular spin characterization and open opportunities for hybrid quantum architectures integrating molecular and solid-state qubits.



▲ Figure 1: (a) Copper phthalocyanine (CuPc) molecule. An electron spin is hosted by the Cu^{2+}. (b) A shallow NV center in diamond is optically manipulated. CuPc thin film is deposited on the diamond surface. The NV center couples with the electron spin of CuPc molecules via magnetic dipolar interaction.



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

Fabrication of Amorphous Silicon TWPAs

10.17

E. Bui, K. Peng, A. Lombo, J. Wang, K. O'Brien

A Josephson traveling-wave parametric amplifier (JTWPA) enables quantum-limited amplification of weak microwave signals for large scale superconducting qubit and sensor readout. We present the design and fabrication of a compact JTWPA architecture enabled by low-loss amorphous-silicon (a-Si) parallel-plate capacitors. The use of a-Si dielectric films provides an ultralow loss tangent and high capacitance density, allowing precise dispersion engineering without relying on large-area lateral Josephson junctions. By transitioning from lateral geometries to vertically integrated parallel plate capacitors, we significantly reduce the physical footprint of each nonlinear element while maintaining high impedance and robust phase-matching. This approach enables a substantial scaling improvement: current 5 × 40 mm JTWPA chips created at MIT.nano can be condensed to approximately 5 × 5 mm without compromising gain, bandwidth, or dynamic range.

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Research Interests:
2D materials
Artificial Intelligence
Electronic devices
Machine Learning
Quantum devices
Spintronics

Signatures of Singular Superconductivity in a Bulk Moiré Metal

10.18

A. Chen, K. P. Nuckolls, N. Paul, F. Gaggioli, A. Auslender, J. A. Gardener, A. Akey, D. Graf, R. Nowell, T. Suzuki, L. Fu, D. C. Bell, J. G. Checkelsky

Sponsorship: Gordon and Betty Moore Foundation EPiQS Initiative (GBMF9070), US Department of Energy (DE-SC0022028), Office of Naval Research (N000142412407), Army Research Office (W911NF-24-1-0234)

Superconductors may show anisotropic properties that reflect the symmetry of the material's crystal lattice or of the order parameter of its ground state. Notable examples are quasi-two-dimensional superconductors with structurally decoupled superconducting layers, which exhibit enhanced resilience to B-fields directed between the 2D layers of their lattices and are platforms for studying interactions otherwise inaccessible in conventional superconductors. Here we report the observation of superconductivity in an atomically incommensurate material derived from lattice-mismatched atomic layers in a naturally grown, exfoliatable van der Waals superlattice crystal. This new bulk material consists of superconducting transition metal dichalcogenide (TMD) monolayers in an alternating manner such that the incommensurate sublattices generate a moiré superlattice akin to those found in 2D heterobilayers. Using high-angular resolution magnetotransport measurements, we study the superconductivity and find an unusual form of anisotropic superconductivity with sharply enhanced resilience to B-fields pointing along a narrow angular range within the crystal's ab-plane, a phenomenon we term 'singular superconductivity.' Our work shows how natural heterostructure design in bulk superlattice compounds can modify the superconducting state and uncover new ways in which moiré incommensurability can support novel material properties.

Plan for Scalable Quantum Photonics

10.19

B. Sailors, K. Chen, J. Klein, F. Ross

Sponsorship: NSF Trailblazer Award Number 2421694 and DOE-BES Award Number DE-SC0025387

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Research Interests:
2D materials
Artificial Intelligence
Electronic devices
Electronics
Energy
Energy harvesting devices & systems
Fuel cells
GaN
III-Vs
Machine Learning
MEMS & NEMS
Nanomanufacturing
Nanomaterials
Nanotechnology
Optoelectronics
Photonics
Quantum devices
Spintronics

The grand challenge in quantum information science is to create quantum systems made up of large numbers of qubits. We propose to develop an innovative architecture which overcomes scalability hurdles to realize a spectrum of quantum photonic applications. Utilizing an electron microscope with innovative new techniques, we ultimately aspire to develop a process by which we can create vast entangled photonic states.

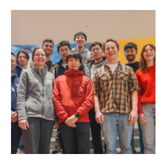
We first propose to understand the physics that underpins atomic motion, defect formation, and the resulting photonic properties. This will be done through STEM imaging and simultaneous optical measurement of atomic lattices under different beam irradiation. We will then develop a suite of electron microscopy techniques to construct and verify quantum defects in tailored patterns, developing a system that will enable the correlation of structure and properties. Finally, we will integrate defect complexes into photonic circuits to create entangled states of light that will demonstrate on-chip photonic quantum systems on the pathway toward practical devices and applications.

Polarization Transfer and Many-Body Spin Dynamics in the NV–P1 Spin Bath

10.20

K. Zhong, J. Yoon, B. Xing, B. Li, G. Heller, P. Cappellaro

Sponsorship: NSE Founder's Fellowship, Korean Research Foundation



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Controlling polarization transfer between nitrogen-vacancy (NV) centers and their environment is important both for improving NV-based sensing and for studying many-body spin relaxation in solids. In diamond, the dominant environment is often a dense ensemble of substitutional nitrogen impurities, known as P1 centers, whose electronic spins form a disordered "P1 spin bath" coupled to nearby NV centers. This project investigates polarization transfer and many-body spin dynamics between NV centers and the P1 bath. We realigned the magnetic field and recalibrated optically detected magnetic resonance (ODMR) on a new high-pressure high-temperature (HPHT) bulk diamond sample and on a nanodiamond platform, comparing line shapes and asymmetries at different laser powers and scanning both resonant and off-resonant fields around the excited-state level anti-crossing near 512 G, where optical pumping is known to strongly enhance NV polarization and spin mixing with nearby defects. Our measurements reveal reproducible changes in the NV longitudinal relaxation time T1 at several far off-resonant fields and for microwave pulse sequences with durations tp = 10–1000 microseconds, providing clear signatures of polarization transfer from NV centers to the surrounding P1 bath. We further estimate the P1 concentration and compare it with the vendor's specification, which constrains future quantitative modeling. These results establish an experimental basis for exploring many-body spin dynamics and polarization accumulation using two-channel control schemes such as double electron-electron resonance (DEER) and Hartmann–Hahn matching.

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Research Interests:
Nanomanufacturing
Quantum devices
Superconducting Circuits

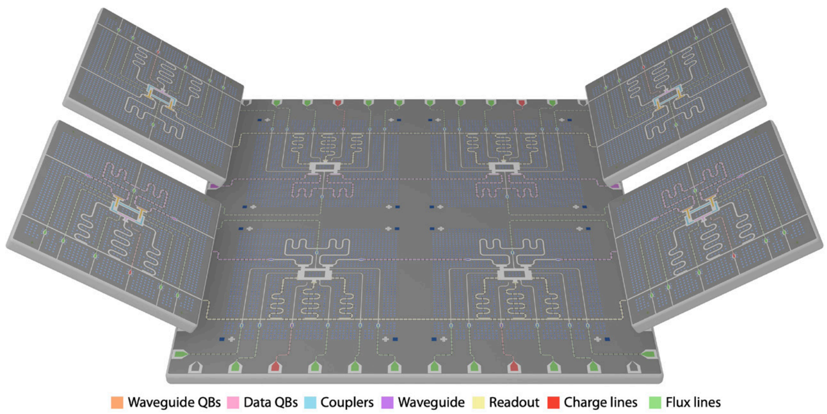
Multi-Module Chiral Waveguide Quantum Electrodynamics

10.21

A. Rommens, B. Yankelevich, A. Almanakly, M. Hays, J. Grover, W. Oliver

Sponsorship: US Army Research Office, AWS Center for Quantum Computing

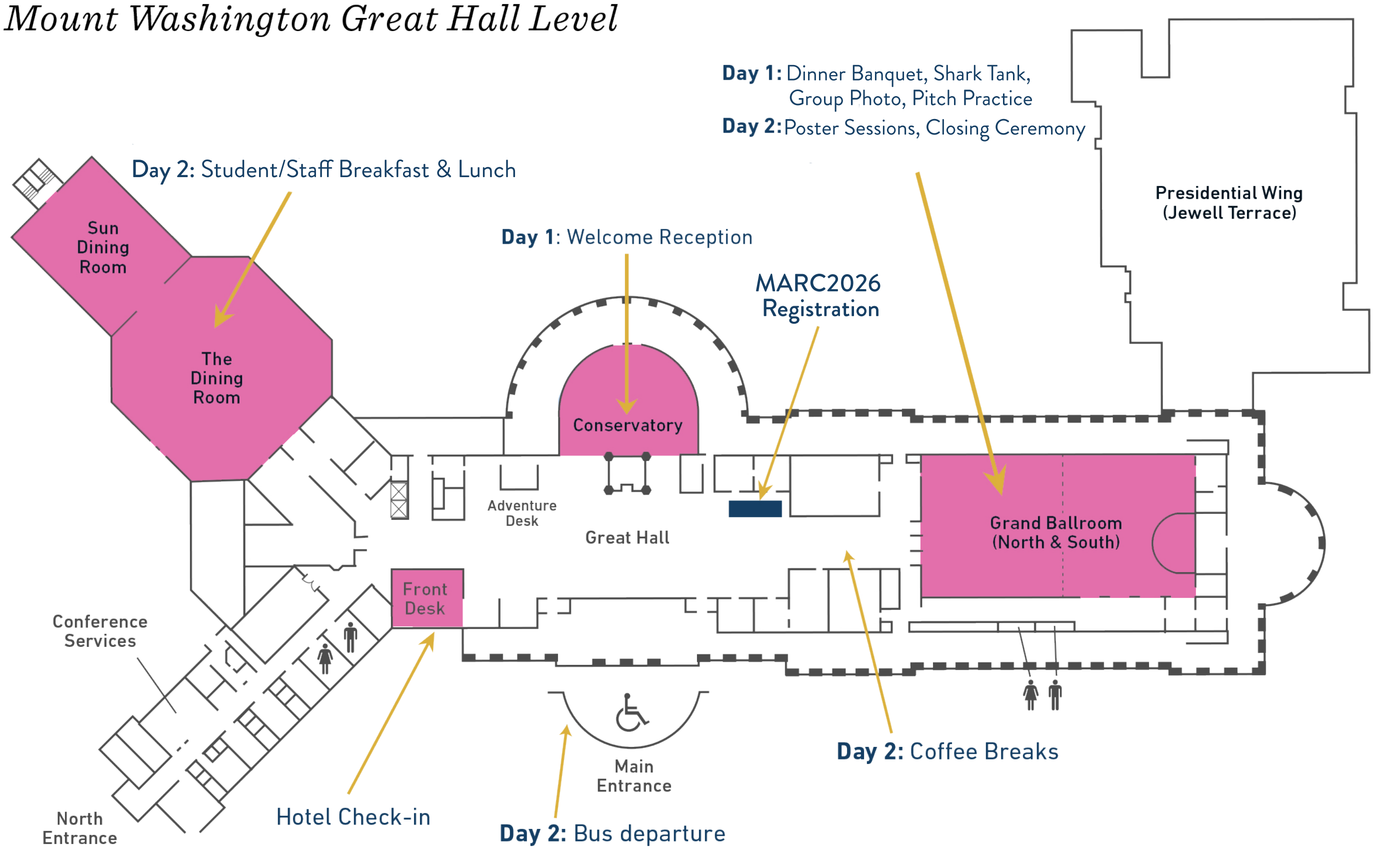
Modular superconducting processors require robust interconnects for entanglement distribution. We propose a scalable Waveguide Quantum Electrodynamics (wQED) framework using itinerant photons to link physically distinct modules. The architecture features a three-qubit unit cell: a data qubit coupled to two emitters via tunable couplers designed to facilitate state transfer, shield against waveguide dissipation, and suppress unwanted coupling. A geometric phase delay between emitters enables directional emission via interference. We integrate these unit cells as chiplets along a shared waveguide to establish remote entanglement through controlled photon exchange. We employ master equation simulations to investigate protocol fidelity, analyzing loss channels and impedance matching to maximize transfer efficiency. This design offers a pathway toward high-fidelity, all-to-all connectivity in extensible quantum networks.



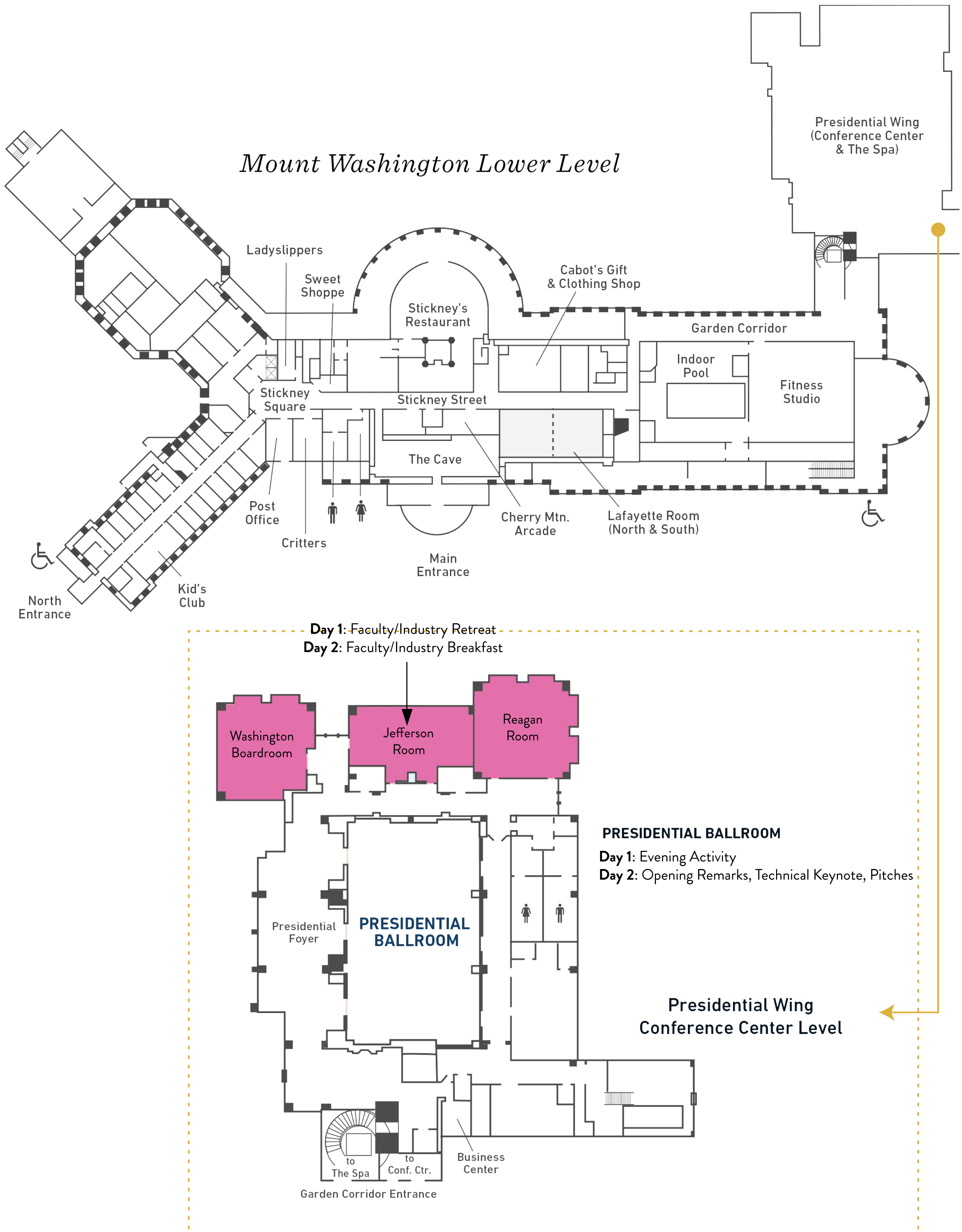
▲ Figure 1: Four wQED modules, hosting data (pink) and emitter (orange) qubits mediated by tunable couplers (blue). The shared waveguide (purple) routes signals between modules, either remaining on the carrier or bump-bonding up to the chiplets.

MAPS

Mount Washington Great Hall Level



DAY 1 & 2: LOWER LEVEL



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