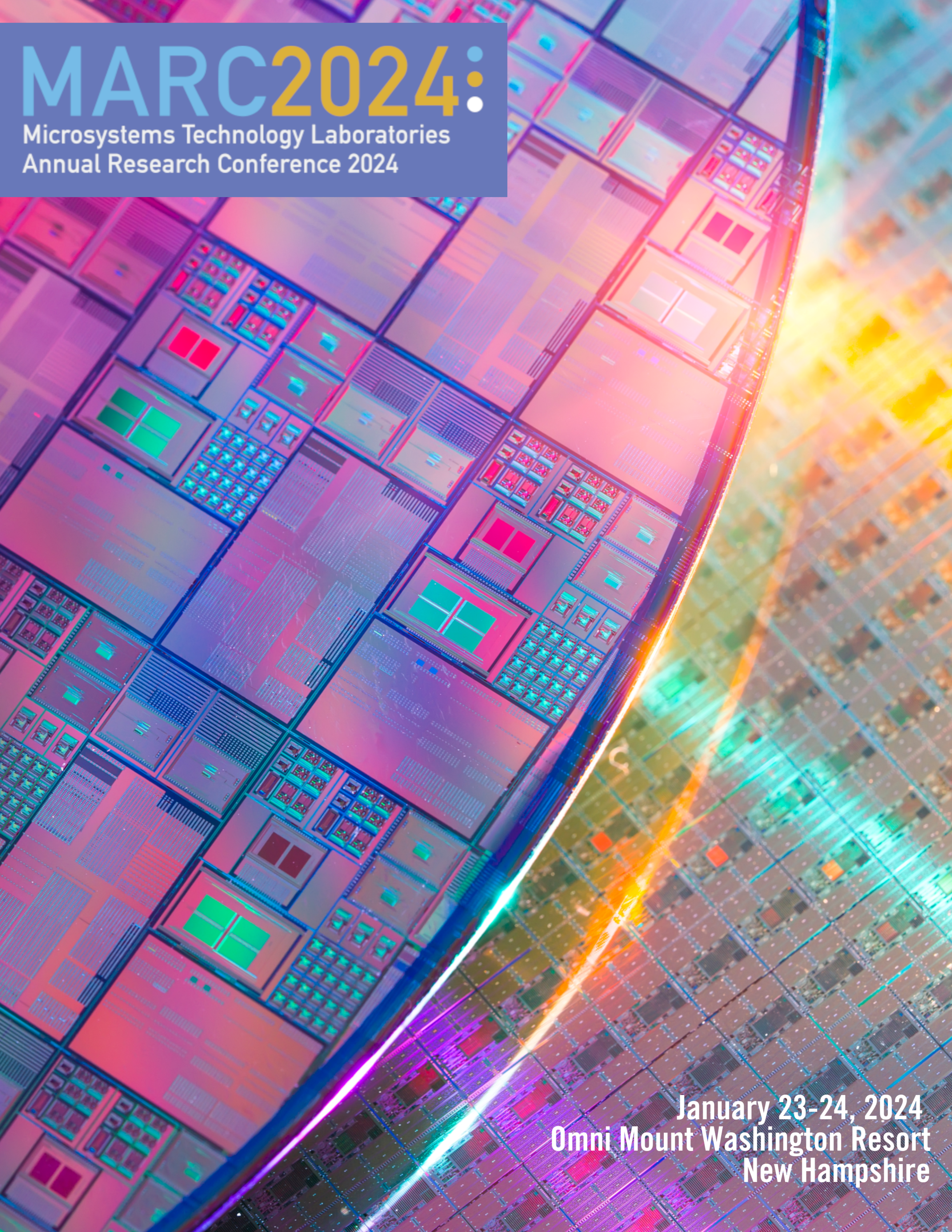

MARC2024:

Microsystems Technology Laboratories Annual Research Conference 2024

January 23-24, 2024
Omni Mount Washington Resort
New Hampshire

MARC2024:

MICROSYSTEMS ANNUAL RESEARCH CONFERENCE

JANUARY 23–24, 2024 • BRETTON WOODS, NH

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PDF version, January 2024

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CONTENTS

INTRODUCTION

Dear friends, collaborators, and colleagues,

Welcome to MARC 2024! We're honored to have you join us this year in a remarkable showcase of the past, present and future of MTL. This year marks the 40th Anniversary of the Microsystems Technology Laboratory. First opened in 1984, MTL has been leading the microelectronics revolution for the past 4 decades. We stand today in awe of what we have accomplished since the opening of MTL, to take inspiration from the scientists and engineers whose discoveries have made way for the research we conduct today, and to celebrate this community made up of our time's brightest and most brilliant minds.

With the mainstream spotlight that the CHIPS Act has brought to our community, the time has never been more critical for us to work together to advance the next generation of semiconductor research, development, and infrastructure. It is our responsibility to advance the next 40 years of microelectronics. We must continue our efforts to discover life-altering innovations that result in true societal change. In addition, we must educate, not only ourselves,but the researchers that will come after us. Like our microelectronics forefathers, wecannot let the momentum stop with us. The best is yet to come.

This conference would not have been possible without the relentless efforts of our student committee, MTL and MIT.nano staff, the director of MTL, Prof. Tomás Palacios and, MIT.nano director Prof. Vladimir Bulović. We extend our heartfelt thanks to this team.

With that, it is our honor to introduce MARC 2024. After a brief social activity and dinner banquet, we are excited to welcome our first keynote speaker. Ted Letavic is corporate fellow and senior vice president of technology innovation at GlobalFoundries. His keynote will bring 30+ years of semiconductor industry insight and personal lessons he has learned as a researcher and leader.

On our second day, we are excited to welcome 8 industry panelists whose expertise in the semiconductor and nanotechnology spans the entire chip continuum. The first panel pays homage to the growth of the semiconductor industry and seeks to peer into the future- titled, "40 Years: Reflections on the Past and Visions for the Future" , the panel features speakers from Applied Materials, IBM, Texas Instruments and Ericsson. Our second panel focuses on the bridge between academia and industry and is titled "Navigating the Transition from Academia to Industry: My Personal Journey" with speakers from Upnano, Analog Devices, Lam Research and Soitec.

MARC 2024 is the largest MARC to date, featuring over 130 student abstracts with nearly 250 attendees. On the morning and afternoon of the second day, students will present their research in technical blocks consisting of 60-second pitches and poster sessions. During lunch, we will feature MIG/MAP member pitches and offer students time to interact 1-on-1 with MIG/MAP members.

We would like to thank our member companies, as well as the abstract authors, attendees, MTL staff, and volunteers for their sponsorship and support of our event. We wish you an enjoyable MARC2024! We hope that you will take this opportunity to rekindle old bonds, strengthen collaboration, and let this year's conference theme guide your future endeavors: MTL @ 40 - Manufacturing Technology Leadership for the next 40 years.

Best,

Pradyot Yadav and Sharon Hsia
MARC2024 Co-Chairs

AGENDA

DAY 1: JANUARY 24

7:00am	**Early Bus Departs MIT** 60 Vassar Street, Cambridge, MA
10:00am - 4:00pm	**Winter Activities** Bretton Woods, NH
12:00pm	**Late Bus Departs MIT** 60 Vassar Street, Cambridge, MA
3:00pm - 5:00pm	**Check-in & Registration** Great Hall Conference check-in @ MARC2023 Registration Desk Hotel check-in @ Hotel front desk *(Rooms available after 4pm)*
5:00pm - 6:00pm	**Welcome Reception** Conservatory
6:00pm - 6:30pm	**Opening Remarks** Grand Ballroom
6:30pm - 7:30pm	**Dinner Banquet** Grand Ballroom *Team Building Activity*
7:30pm - 8:45pm	**Evening Keynote: Ted Letavic** Grand Ballroom Corporate Fellow and Senior Vice President of Technology Innovation at GlobalFoundries
8:45pm - 9:00pm	**Group Photo** Grand Ballroom
9:00pm - 12:00am	**Evening Activities** Presedential Ballroom, Washington, Jefferson & Reagan Rooms
9:00pm - 11:45pm	**Pitch Practice and AV Check** Grand Ballroom

DAY 2: JANUARY 25

7:00am - 9:00am	**Mentorship & Diversity Breakfast** Main Dining Room
9:00am - 9:15am	**Opening Remarks** Presidential Ballroom
9:15am - 9:30am	**MIG/MAP Pitches** Presidential Ballroom
9:30am - 10:15am	**Panel 1** Presidential Ballroom • Michael Haverty, Applied Materials • Dirk Pfeiffer, BM TJ Watson Research Center • Michael Perrott, Texas Instruments • Fredrik Dahlgren, Ericsson Research
10:10am - 10:40am	**Morning Refreshments** Presidential Foyer
10:20am - 11:00am	**Poster Pitches (Session 1)** Presidential Ballroom • S1 - Electronic Devices • S2 - Integrated Circuits & Systems • S3 - Medical Devices & Biotechnology • S4 - Energy, Power & Sustainability
11:00am - 12:00pm	**Poster Session (Sesson 1)** Grand Ballroom • S1, S2, S3, S4
12:00pm - 2:00pm	**MIG/MAP Networking Lunch** Main Dining Room
2:00pm - 2:45pm	**Panel 2** Presidential Ballroom • Paul Ferguson, Analog Devices • Erika Bechtold, Upnano • Esther Jeng, Lam Research • Ionut Radu, Soitec
2:45pm - 3:20pm	**Poster Pitches (Session 2)** Presidential Ballroom • S5 - Materials & Manufacturing • S6 - Nanotechnology & Nanomaterials • S7 - Optoelectronics & Integrated Photonics • S8 - Quantum Technologies
3:20pm - 4:20pm	**Poster Session (Session 2) / Refreshments** Grand Ballroom • S5, S6, S7, S8
4:30pm - 5:00pm	**Closing Ceremony** Presidential Ballroom

DAY 1: KEYNOTE

TED LETAVIC

Corporate Fellow and Senior Vice President
of Technology Innovation
GlobalFoundries

Ted Letavic is a Corporate Fellow and Senior Vice President of Technology Innovation at GlobalFoundries. He is a group leader with technical roadmap responsibility for solution architecture and semiconductor innovation in market segments that include compute and datacenter, wired and wireless infrastructure, mobility, industrial/IoT/ATV, and high speed communications. His recent research interests include silicon photonics, sub tera-Hertz semiconductor devices, analog compute-in-memory, and quantum systems. He has over 60 US patents granted, has authored over 70 reviewed scientific papers, and serves on numerous academic and industrial advisory boards. He received a PhD in Electrical Engineering from Rensselaer Polytechnic Institute.

DAY 2: MIG/MAP PANELIST SPEAKERS

Panel 1: 40 Years: Reflections on the Past and Visions for the Future

MICHAEL HAVERTY

Applied Materials

Michael Haverty is a Director and Distinguished Member of Technical Staff at Applied Materials with degrees in Materials and Computer Science from Johns Hopkins and Stanford. He began his career as an intern as Intel's first Materials modeler during the first internet boom in 2001 and now leads one of the largest atomic-scale modeling teams in the semiconductor industry. He's worked with some of the earliest developing software companies in the field, in the startup world as a VP of Science, his own modeling consulting firm, and advising new start-ups in the area. He has a wide range of 30+ granted and in-process patents, funded and collaborated with academics through SRC and direct funding research projects, and obtained and worked on multiple US and European government funded grant projects. Now leading the Materials Design team at Applied he focuses the team on discovering, screening, and designing new materials, precursor chemistries, and manufacturing strategies to extract tangible value for their experimental partners.

DIRK PFEIFFER

IBM

Dr. Dirk Pfeiffer is the Director of the Microelectronics Research Laboratory (MRL) at the IBM TJ Watson Research Center in Yorktown Heights, NY. The MRL is a state of the art 200mm wafer scale nanofabrication facility, offering a wide range of design and fabrication services, ranging from novel devices fabrication to packaging, test, design, characterization, electronics, system integration and assembly. The laboratory supports a broad range of prototyping and "lab to fab" projects to develop new computing technologies for IBM including quantum computing, neuromorphic devices for AI based computing architectures, Semiconductor device and unit process development and other. Dr Pfeiffer has been with IBM Research for 23 years and has a Ph.D. in Chemistry.

MICHAEL PERROTT

Texas Instruments

Michael H. Perrott has focused on development of new mixed-signal architectures for high performance timing circuits, including analog and digital fractional-N synthesizers, hybrid analog/digital clock and data recovery circuits, and MEMS based timing solutions. Additional areas include VCO-based analog-to-digital conversion, high resolution temperature sensing, and high SNR, wide dynamic range MEMS digital microphones. He is the developer of the widely used CppSim simulation package for phase-locked loop circuits. He is an IEEE Fellow and has served the IEEE SSCS society as a Distinguished Lecturer and as an elected member of AdCom, where he helped launch the SSCS Webinar Program.

FREDRIK DAHLGREN

Ericsson

Fredrik Dahlgren is Head of Device Platform Research at Ericsson Research, a unit he started in December 2017, and which now consists of 30 researchers (more than 50% of whom hold a PhD). He is also an Adjunct Professor at Chalmers University of Technology. Before this, he was Director of WARA, the Research Arenas of the Wallenberg Autonomous Systems and AI research program, during 2016-2017, and in that role he was also a Guest Professor at Linköping University.

Fredrik Dahlgren has a PhD in Computer Architecture from Lund University in 1994. He was a visiting scientist at MIT 1995/1996 after which he became an associate professor at Chalmers. From 1999, he has been with Ericsson Group in various leading positions, including Head of Research at Ericsson Mobile Platforms, Head of Technology Management in the CTO Office (ST-Ericsson), and system architecture program manager for highly integrated multi-core and multimedia-centric smartphone platforms at ST-Ericsson.

Panel 2: Navigating the Transition from Academia to Industry: My Personal Journey

PAUL FERGUSON

Analog Devices

Paul Ferguson graduated from Dartmouth College with a Bachelor of Arts in Engineering Sciences in 1984, and received is MSEE from MIT and joined Analog Devices in 1986. He started in converters and became a pioneer in Delta Sigma Converters before taking a sabbatical to pursue a PhD under Professor Gabor Temes at Oregon State University in the mid-90s. Paul completed all but the thesis writeup before returning to Analog Devices to lead the Analog Circuit Design team in the handset group, where Paul became an ADI Fellow. When Paul's mentor professor suddenly retired at Dartmouth, he stepped in as Adjunct Professor to teach the Analog Integrated Circuits class for several years. Meanwhile, the handset team was very successful and when the industry consolidated, Analog Devices sold the team (and Paul) to MediaTek in 2008, where Paul continued as ACD lead until returning to ADI in 2013. Paul has had several roles at ADI since 2013, but a side project founding ADI Technical University is most relevant here. Today, Paul works in the CTO office leading a small advanced power architectures team and reviewing and connecting horizon 3 projects across the company.

ERIKA BECHTOLD

UpNano

Erika Bechtold is currently leading US commercial activities as the VP of US Operations. Erika brings 10+ years of early-stage startup and commercial experience, holding a variety of roles at Boston-area Universities as well as at a previous Boston-based biotechnology company Sofregen Medical Inc., a Tufts University spin-out developing injectable products for soft tissue augmentation.

Prior to Erika's role at UpNano, she was the Director of Technology Commercialization at Harvard University's Office of Technology Development, supporting the Wyss Institute for Biologically Inspired Engineering. At the Wyss Institute, she worked closely with the faculty, staff, and business teams at the Institute to commercialize their ideas and inventions through strategic partnerships and licensing agreements with academic, venture and industry partners. She additionally supported key spinoffs from the Institute, as well as strategic initiatives for the executive team of the Wyss and the Chief Technology Development Officer at Harvard.

ESTHER JENG

Lam Research

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

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

Dr. Jeng's first immersion into engineering was at MIT where she learned to foster technical discourse and execution at all levels, from the use of liquid nitrogen to make the smoothest ice cream to the development of fluorescent carbon nanotube sensors. She believes that the most robust solutions are developed from open discussions that support everyone to contribute. Dr. Jeng earned B.S. and Ph.D. degrees from MIT and an M.S. from the University of Illinois Urbana-Champaign in chemical engineering and has authored several papers and patents. She enjoys exploration: from cities worldwide to seedlings sprouting in her backyard.

IONUT RADU

Soitec

Ionut Radu is Senior Director, Innovation at Soitec being responsible for path finding and worldwide partnerships with industrial and academic innovation platforms supporting strategic developments of substrate technologies for semiconductor industry.

Dr. Radu obtained his B.S. in physics from University of Bucharest in 1999 and Ph.D (Dr. rer. nat.) in physics from Martin-Luther University Halle-Wittenberg in 2003. He has co-authored more than 100 papers in peer-reviewed journals, conference proceedings and reference handbooks and holds more than 80 patents in the field of semiconductor technologies. Dr. Radu has been elected IEEE fellow effective January 2024 and serves as Vice-President of the IEEE-EDS France chapter since 2018. Ionut was keynote and invited speaker at major international conferences, such as IEDM, ECS, ICICDT, VLSI Symposium, IEEE VLSI-TSA, etc.

INDUSTRY CONSORTIUM (MIG & MAP)

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Viavi Solutions

From its very inception, MIT has maintained an intimate connection with industry to inform and inspire its research endeavors. The Microsystems Industrial Group (MIG), established in the early '80s, proved to be an effective platform for engagement of industry with the MTL community! The launch of MIT.nano in 2018 defined a new chapter in MIT's history for advancing science and technology at the nanoscale. Since 2020, the flagship Microsystems Annual Research Conference (MARC) has been co-hosted by MTL and MIT.nano. It is our distinct pleasure to welcome all of our industry partners to join us again at MARC2024.

ABSTRACTS

SESSION 1: ELECTRONIC DEVICES

SESSION 2: INTEGRATED CIRCUITS & SYSTEMS

SESSION 3: MEDICAL DEVICES & BIOTECHNOLOGY

SESSION 4: ENERGY, POWER & SUSTAINABILITY

SESSION 5: MATERIALS & MANUFACTURING

SESSION 6: NANOTECHNOLOGY & NANOMATERIALS

SESSION 7: OPTOELECTRONICS & INTEGRATED PHOTONICS

SESSION 8: QUANTUM TECHNOLOGIES

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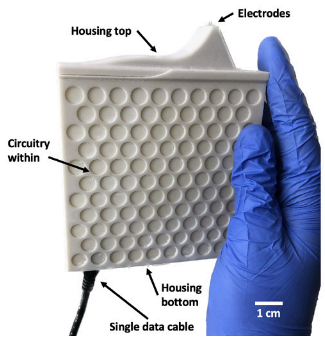
Available from November 2026.

Miniature 3D-Printed Super Sensor: Multi-Langmuir Probe Device for CubeSat Ionospheric Plasma Diagnostics

1.01

Z. Bigelow, L. F. Velásquez-García
Sponsorship: MIT Portugal, NewSat Flagship Project

The ionosphere is a plasmic part of Earth's atmosphere which affects climate change. Studying it requires satellite based in-situ measurements and the versatility of Langmuir probes make them ideal for this. We report the design, fabrication, and characterization of a compact, fully 3D printed, multi-Langmuir probe (MLP) for use on CubeSats. The MLP has low-power, compact electronics and is fully 3D printed, to be compatible with in-space manufacturing. The MLPs are made via vat photopolymerization of vitrolite for the dielectric parts and binder jetting SS 316L for the conductive parts. The MLP uses three different Langmuir probe arrangements (single, dual, and triple) to measure a wide range of plasma properties with redundancy. The MLP was tested in a helicon plasma chamber, showing good agreement across the different configurations. This MLP enables cheaper CubeSat plasma sensors and aims at improving our understanding of the ionosphere and its effects on climate change.



◀ MLP device fully assembled, with relevant parts labelled.

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Research Interests:
2D materials, Artificial Intelligence, Integrated circuits, Medical devices & systems, Nanomanufacturing, Nanomaterials, Nanotechnology.

Analysis of Memristor Device Requirements and Update Thresholding Strategy for Precision Programming of Neuromorphic Memristor Arrays

1.02

G. Lee, J. Kim

Neuromorphic computing, inspired by neural systems, presents advantages such as minimized data transmission, reduced power consumption, and parallel computation, spanning applications in artificial intelligence (AI), scientific computing, and security. Neuromorphic computing, specifically with a memristor crossbar array, shows promise as an AI inference accelerator, demonstrated through on-chip deep neural network inferences comparable to software-based methods. Despite the prevalent one-transistor one-resistor (1T1R) system ensuring precise memristor programming and overcoming sneak path issues, it compromises power, speed, and design simplicity. For these reasons, the simplest one-resistor (1R) system that can accurately program memristors and minimize the sneak path problem would be the ultimate solution. However, precise conductance adjustments at cross-points remain challenging due to asymmetry, poor selectivity, sneak paths, and stochasticity.

This study introduces the simplest automatic programming algorithm, employing iterative conductance reads and updates. It analyzes memristor requirements for high programming accuracy, establishing relationships with array size and parameters like interconnect-to-memristor conductance ratio. Selectivity is identified as enhancing convergence speed. Notably, update asymmetry hampers programming, which is addressed by an update event thresholding algorithm, significantly improving accuracy. This analysis and programming strategy hold the potential to aid the 1R memristor array system in overcoming programming challenges, realizing an ideal AI inference accelerator.

Silicon Solar Cell Quantum Yields Approaching 100% Due to Sensitization by Singlet Exciton Fission

1.05

N. N. Wong, C. F. Perkinson, K. Lee, A. Li, M. A. Baldo, M. G. Bawendi, W. A. Tisdale, K. Seo

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

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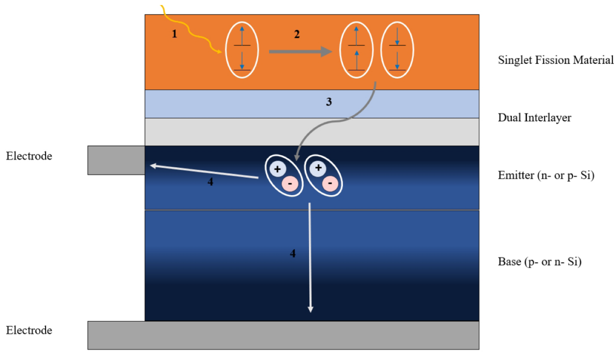
Research Interests:
Energy, Energy harvesting devices & systems, Nanomaterials, Optoelectronics, Photovoltaics, Si.

Crystalline Silicon based solar cells currently dominate the global industry, but for single junction devices, the efficiencies are approaching the Shockley-Queisser limit. Sensitizing silicon to organic molecules that undergo the carrier multiplication process singlet exciton fission (SF), could provide a facile method to generate two electron-hole pairs per photon and improve efficiencies beyond the industry standard. Surface and bulk charge recombination and surface trap loss pathways have inhibited the transfer of energy from a SF material to silicon and decreased the overall performance. Herein, we employ a dual interlayer system to facilitate interfacial charge transfer states and surface passivation of trap states with a shallow junction device architecture for efficient carrier separation and extraction. We have demonstrated short circuit current from triplet excitons of tetracene and an enhancement to the external quantum efficiency of silicon solar cells.



◄ Figure 1: Simplified schematic of a SF sensitized silicon solar cell device: (1) photoexcitation, (2) generation of two triplet excitons, (3) charge transfer into the surface of silicon, and (4) electron and hole separation to the electrodes.

Magnesium Fluoride as a Thin Film Electrolyte in Mg-based Electrochemical Ionic Synapse (EIS) Devices

1.06

M. L. Schwacke, J. A. del Alamo, J. Li, B. Yildiz

Sponsorship: Semiconductor Research Corporation (Task ID: 3010-001) and MIT Quest

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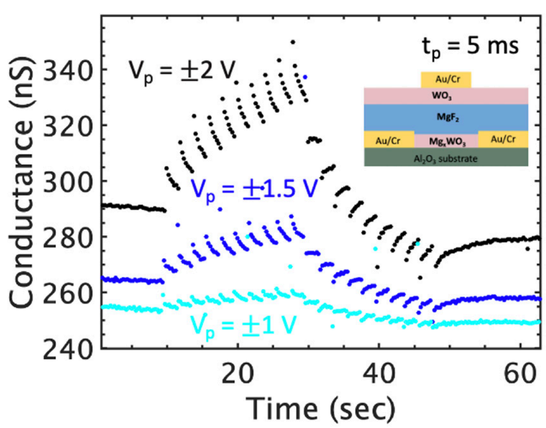
Research Interests:
Batteries, Electronic devices, Energy.

Dynamic doping by electrochemical ion intercalation is a promising mechanism for modulating electronic conductivity, allowing for energy-efficient, brain-inspired computing hardware. Programmable resistors which operate by this mechanism are called electrochemical ionic synapses (EIS). Use of Mg2+ as the working ion in EIS allows for both low energy consumption (compared to O-EIS) and good retention in ambient air (compared to H-EIS). However, while Mg-EIS devices based on organic electrolytes have provided a promising proof-of-concept; inorganic, thin film Mg electrolytes are needed for compatibility with CMOS processing. Here we report development of MgF2 as a thin film electrolyte for Mg-EIS. We investigate how deposition technique (RF sputtering, electron beam evaporation) affects the MgF2 film properties and by extension device characteristics. We show that Mg-EIS with MgF2 electrolyte films are promising for CMOS-compatible EIS with long-term retention and low energy consumption.



◄ Channel conductance of Mg-EIS device with MgF2 electrolyte (schematic shown in inset) in response to 10 positive followed by 10 negative voltage pulses.

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Research Interests:
Electronic devices, Nanomaterials, Sensors.

Epitaxial Perovskite Ferroelectric Based Capacitive Memory

1.07

X. Zhang, M-K. Song, C. S. Chang, S. Lee, J. Kim

Sponsorship: IARPA MicroE4AI program

Nowadays, development of artificial intelligence requires more power efficient memory devices. Compared to the conventional resistive memory, capacitive memory device is quite promising as it eliminates static power consumption and prevents IR drop by leveraging charge transfer. However, the widely used $Hf_{0.5}Zr_{0.5}O_2$ (HZO) is polycrystalline and has high coercive field, resulting in significant variations when scaled to nanoscale and high write energy. On the other hand, single-crystalline perovskite ferroelectric oxides like $BaTiO_3$ (BTO) have better uniformity and a coercive field 2~3 orders of magnitude lower than HZO. Furthermore, 100 times higher dielectric constant can also enlarge the memory window. Previous study uses buffer layer for silicon compatibility, resulting in poor performance. This project investigates epitaxial perovskite ferroelectric material for energy-efficient, high performance and CMOS compatible capacitive memory devices. Freestanding single-crystalline BTO is obtained by chemical lift-off technique using $Sr_3Al_2O_6$ as the sacrificial layer, then transferred onto polymer-coated silicon and fabricated into capacitors. Polarization switching in BTO film leads to a butterfly-like shape capacitance-voltage curve with 1.5V switching voltage. Asymmetric electrodes are designed to achieve curve shift with an on/off ratio of 272% at zero bias. Both coercive voltage and memory window of our proposed devices are better than HZO-based devices. It also shows stable performance with more than 1000 cycles of endurance and more than 1000 s of retention. This capacitor memory device with low-power consumption and CMOS compatibility, serves as a good element in crossbar array for next generation in-memory computing.

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Research Interests:
Batteries, Energy, Nanomaterials.

Sub-Nanometer Interface Modifications for Conductance Modulation in Proton-Based ECRAM Devices

1.08

J. Meyer, M. Huang, B. Yildiz

Sponsorship: DoD NDSEG Fellowship (2022 Fellow), DOE EFRC Hydrogen in Energy and Information Sciences (HEISs)

Three-terminal electrochemical random-access memory (ECRAM) devices have gained interest for use as resistive elements in energy-efficient neuromorphic computing architectures. ECRAM devices display promising non-volatility, reversibility, and symmetric switching operations through solid-state ion intercalation of a channel material, typically WO3. However, these devices remain limited in energy-efficiency and programming speed, displaying operating voltages above 1 V and programming on the order of microseconds. Advances in thin high ionic conductivity electrolytes have decreased the operating voltage required for switching, but as electrolyte thickness approaches a few nanometers, other optimizations are required.

The structure of ECRAM devices is similar to solid-state lithium-ion batteries, for which electrode-electrolyte interfaces can be significant impedances to ion transport. For proton-based ECRAM, much less is known about proton transport across solid-state interfaces. This work chemically modifies the electrolyte-channel interface in a proton-based ECRAM device with sputtered metals and metal oxides. Differences in conductance modulation across interface-modified devices are presented. Surface-modified WO3 films are examined with X-ray photoelectron spectroscopy. An electrochemical impedance spectroscopy setup is also used to separate the impedance contributions of electrolyte and interface in the devices. In doing so, we demonstrate some tunability of ECRAM device operation with sub-nanometer interface modifications. These results suggest modifying the electrolyte-channel interface in ECRAM devices may be another route to achieve faster neuromorphic computing with lower operating voltages.

Polaronic Carrier Mobility in Channel Materials for CMOS-compatible ECRAM

1.09

P. Žguns, B. Yildiz

Sponsorship: SRC JUMP 2.0 SUPREME Center

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Research Interests:
Batteries, Electronic devices, Energy, Energy harvesting devices & systems, Fuel cells, Machine Learning.

Neuromorphic computing hardware based on electrochemical random access memory (ECRAM) enables low-energy computing and nanosecond timescale operation. In these devices, the electrochemical intercalation of hydrogen modulates the electronic conductivity of the channel material, where high sensitivity of conductivity to hydrogen insertion is needed for high energy efficiency. Therefore, to select promising channel materials, the impact of hydrogen on carrier mobility needs to be understood. Here, we computationally study hydrogenated, CMOS-compatible channel materials H_xWO_3, $H_xV_2O_5$, and H_xMoO_3. We apply the DFT+*U* method to describe the electronic structure and polaron localization in the host oxide lattice. We identify the ground state configurations of the proton–polaron pairs and probe microscopic factors that control polaron mobility, *viz.* the polaron migration barriers in pristine lattice and proton–polaron association energy (i.e., the energy required to break the pair). The polaron migration barriers are comparable to the polaron–proton association energies (which are on the order of 0.1 eV–0.2 eV), highlighting that the attraction between polarons and protons plays an important role in polaron mobility. These computational findings will help us to identify the most suitable CMOS-compatible oxide channel material for low-power ECRAM devices for neuromorphic computing applications.

Understanding the Role of Defects at Diamond/cBN Interface: A first-principles study

1.10

S. Saini, K. J. Tibbetts, M. J. Polking, B. Yildiz

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

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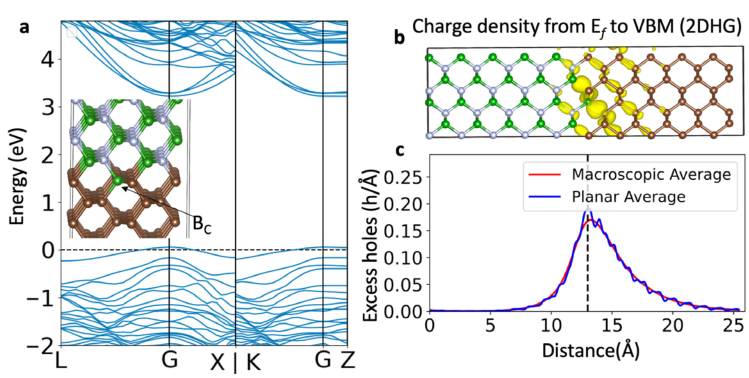
Available from December 2024.

Research Interests:
2D materials, Batteries, Energy, Energy harvesting devices & systems, Fuel cells, Machine Learning, Nanomaterials.

Diamond and cubic boron nitride (c-BN) stand out in high-power electronics due to their wide band-gap, and high thermal conductivity. Despite advancements in epitaxial c-BN growth on diamond, optimizing carrier mobility at the c-BN/diamond interface is impeded by a limited knowledge of the impacts of defects. Our first-principles study investigates the diamond/c-BN interface, focusing on crystal orientation, defects, and doping effects on electronic properties. We found that intrinsic defects, BC and CN, induce p-type doping and lead to 2D hole gas (2DHG) formation, BC case is shown in Fig.1. The electron-deficient nature of these defects and the type-II band alignment are crucial for 2DHG formation. Our work highlights the importance of defect engineering in enhancing the performance of diamond-based electronic devices.



◀ Fig.1 (a) Electronic band structure of BC defect at the diamond/c-BN(110) interface. (b) Charge density distribution, and (c) excess holes from Fermi level to valence band maximum.

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

A Superconducting Bridge Rectifier Using the Asymmetric Surface Barrier Effect

1.11

M. Castellani, O. Medeiros, A. Buzzi, R. A. Foster, M. Colangelo, K. K. Berggren

Sponsorship: Department of Energy, National Laboratory LAB 21-2491 Microelectronics Grant

Superconducting nanowire single-photon detectors (SNSPDs) arrays are currently being explored for quantum communication, bio-imaging, and space exploration. To enhance the scalability of such arrays based on niobium nitride (NbN) thin films, on-chip integration of nanowire-based control electronics is essential. In particular, a superconducting diode can be helpful for signal rectification and biasing. The superconducting diode effect (SDE) has been demonstrated with several technologies but integrating them into NbN-based systems can be challenging due to platform incompatibility. The asymmetric Bean-Livingston surface barrier effect in thin-film micro-bridges under external magnetic fields provides a potential solution. The effect has been observed in NbN wires with limited reproducibility. Moreover, half-wave rectification at more than 100 kHz and multi-diode circuits have never been shown. Overcoming these limitations would make it easier to construct more complex structures, like an AC-to-DC converter. The latter can assist in lowering the number of cables exiting the cryostat by frequency multiplexing the bias levels of several superconducting devices on chip.

We fabricated superconducting diodes by creating a lithographic triangular defect on one side of 1-µm wide NbN micro-bridges. By applying a 4-mT magnetic field, we observed the SDE with a 42% rectification efficiency at 4.2 K. We used these devices to demonstrate a bridge rectifier for full-wave rectification of 3-MHz sinusoidal signals, and AC-to-DC current conversion at 50 MHz, with an estimated 50% power efficiency. Additionally, we simulated a bias distribution network for SNSPDs with frequency-multiplexed bias levels by exploiting AC-to-DC converters based on the superconducting bridge rectifier. This proof-of-concept work demonstrates the possibility of designing complex circuits with superconducting diodes, paving the way for the scalability of SNSPD arrays and other superconducting systems.

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

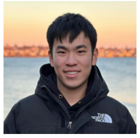
Compact Multi-terminal Nano-electromechanical Relay

1.12

T. Dang, J. Han, V. Bulović, J. H. Lang

Sponsorship: Analog Devices Graduate Fellowship

Nano-electromechanical (NEM) relays have emerged as promising candidates for complementing CMOS technology because of their superior characteristics, including zero leakage, steep sub-threshold slope, high on-off current ratio, and robustness in harsh environments. However, current implementations of NEM relays typically require intricate fabrication and large device active area due to their complicated design and structure, which brings significant challenges for their scaling, versatility, and monolithic integration with CMOS circuits. Therefore, a multi-terminal NEM relay with a simple structure, lateral layout, compact design, ease of processing, and high performance would be greatly beneficial. In this work, a nanoscale multi-terminal electromechanical relay with compact and simple device structures is fabricated with a single lift-off process, thereby allowing versatile implementations for ultra-low-power digital logic. The relay can achieve bistable switching behavior using a pair of gate/drain electrodes, as well as sub-1V actuation voltage with a pre-biased gate electrode, making it advantageous for use in energy-efficient and radiation-hardened electromechanical computing and storage. The lateral design is favorable for further scaling and is compatible with monolithic 3D integration to enable reconfigurable CMOS-NEM hybrid circuits. Together, these features enable the relay to perform as a key component for zero-standby-power electromechanical computing/storage and CMOS-NEM integration.



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Research Interests:
Artificial Intelligence, Batteries, Electronic devices, Integrated circuits, Machine Learning, Nanomanufacturing, Nanomaterials, Nanotechnology, Quantum devices.

Symmetric PSG/WO3 Protonic Synapses for Analog Deep Learning

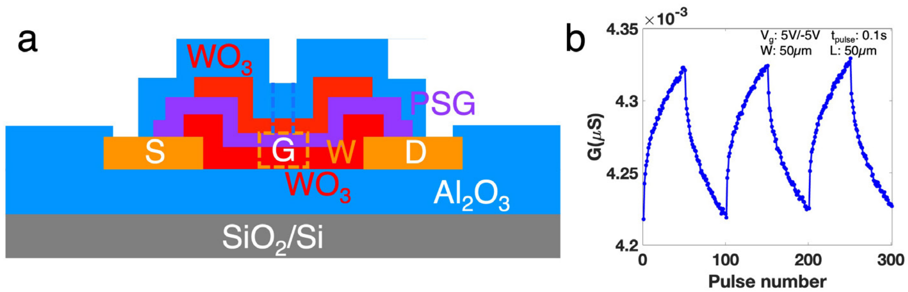
1.13

D. Shen, J. A. del Alamo

Sponsorship: MIT-IBM Watson AI Lab

To solve the overcoming computational bottlenecks for deep learning, analog deep learning accelerators process information locally with specific devices for matrix multiplication calculations and outer product updates. Among them, electrochemical RAMs modulate channel resistance by ionic exchange between the channel and a gate reservoir via an electrolyte.

This study focuses on proton-based ionic synapses featuring in-situ protonated HxWO3-x as both channel and gate reservoir, and phosphorus-doped silicon dioxide (PSG) as electrolyte. This design aims to enable neural network training with enhanced energy efficiency, non-volatility, and low latency. We have experimentally implemented this design in a CMOS and back-end-of-line compatible process. Our protonic synapse with a vertically symmetric structure enables non-volatile and repeatable channel conductance modulation under voltage pulses across gate and channel, thus showing promising applications in deep learning accelerators.



▲ Figure 1: (a) Schematic of symmetric WO3-based protonic synapse with tungsten contacts, PSG electrolyte and Al2O3 encapsulation, fabricated in a lift-off-free and in-situ protonation process. (b) Conductance modulation under voltage pulses shows repeatable control.

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Research Interests:
Electronic devices, Electronics, Nanomaterials, Nanotechnology, Spintronics.

Temperature-Dependent Impedance Characterization of Ferroelectric $HfZrO_2$ Thin Films

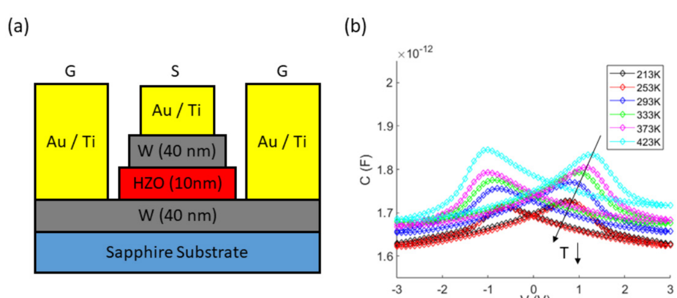
1.14

J. C.-C. Huang, Y. Shao, T. Kim, E. R. Borujeny, J. A. del Alamo

Sponsorship: Ericsson, Semiconductor Research Corporation

The discovery of ferroelectricity in $HfZrO_2$ (HZO) has made it an attractive material due to its CMOS-compatibility, strong ferroelectric (FE) properties, and its potential application in electronic devices. Impedance measurements constitute an underexploited but powerful method to provide insight in FE properties. Recent work in our group has demonstrated impedance characterization of metal/FE/metal structures (MFM) over a broad frequency range up to 10 GHz and has shed light on the role of defects in the dynamics of these structures.

In this work, we have extended this research and performed temperature-dependent impedance characterization of HZO MFM structures. Our results reveal that lower temperature leads to smaller frequency dispersion of the capacitance-voltage (CV) curves and the convergence of the butterfly peaks towards zero volts. Our experiments will be crucial in developing detailed physical understanding of switching mechanisms of HZO-based structures and devices.



▲ (a) Schematic diagram of a W/HZO/W coplanar waveguide device. (b) Capacitance-voltage curves of W/HZO/W measured at 1.9 GHz at various temperatures.

CMOS-compatible Ferroelectric Memory for Analog Neural Network Accelerators

1.15

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

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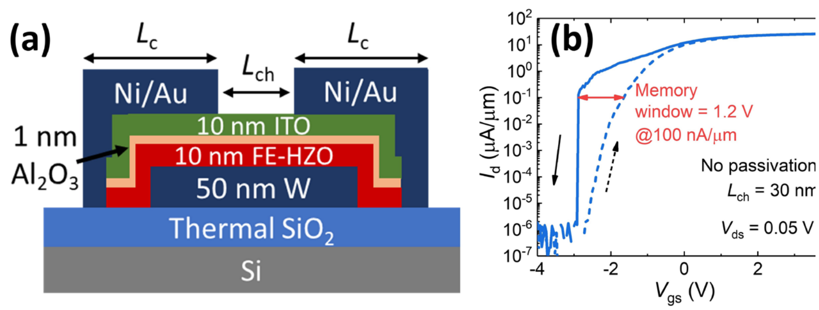
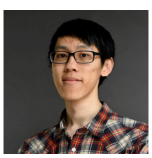
Research Interests:
2D materials, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, III-Vs, Light-emitting diodes, Nanomaterials.

Artificial intelligence has irreversibly changed the way information is stored and processed. However, the huge energy consumption and enormous computation time required for training modern deep learning models highlights the urgent need of energy- and time-efficient hardware uniquely designed to implement AI algorithms. Recently, analog computing has been proposed as an alternative to the digital counterpart. In an analog neural network accelerator, core computations are carried out in the analog domain, exploiting unique device properties and fundamental physical laws.

In this work, we examine the potential of ferroelectric field-effect transistors (FE-FETs) as the core device for analog accelerators. We have fabricated FE-FETs using FE-$Hf_{0.5}Zr_{0.5}O_2$ and a metal oxide channel, within a CMOS-compatible thermal budget. Currently, we are exploring analog FE polarization switching. This work shows the great potential of FE-FETs in both embedded NVM technology as well as analog computing.



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



Tunneling Magnetoresistance in Antiferromagnetic Tunneling Junctions

1.16

C.-T. Chou, B. C. McGoldrick, T. Nguyen, S. Ghosh, K. A. Mkhoyan, M. Li, L. Liu

Sponsorship: SRC, DARPA, NSF (DMR-210491, DMR-2011401), DOE (DE-SC002014), NNCI (CCS-2025124)

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Research Interests:
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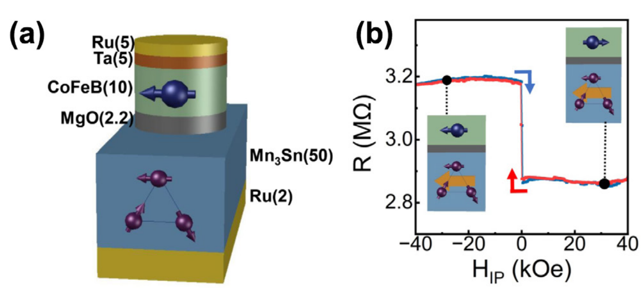
Achieving a high tunneling magnetoresistance (TMR) in junctions with antiferromagnetic (AFM) electrodes has been an enthusiastically pursued goal in spintronics, with the prospect of employing AFMs as next-generation memory and spin-logic devices. High TMR in antiferromagnetic tunnel junctions have been reported in the literature, but the underlying mechanism for the TMR is still not fully understood. In this work, we study Mn_3Sn/MgO/CoFeB tunnel junctions where AFM Mn_3Sn and FM CoFeB serve as fixed layer and free layer, respectively. Large TMR ratios up to 49% are observed in these junctions are comparable to that in conventional FM tunnel junctions. The large TMR suggests the effective spin polarization in AFMs can be as large as that in FMs when proper tunneling barrier and counter FM electrode are selected. The new physical mechanisms revealed by our results are critical for understanding spin polarized tunneling in AFM tunnel junctions.



▲ Figure 1: (a) Schematic of the antiferromagnetic tunnel junction structure and (b) tunneling magnetoresistance at 10K. Inset: schematics of magnetic moments of the CoFeB and Mn_3Sn layers.

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

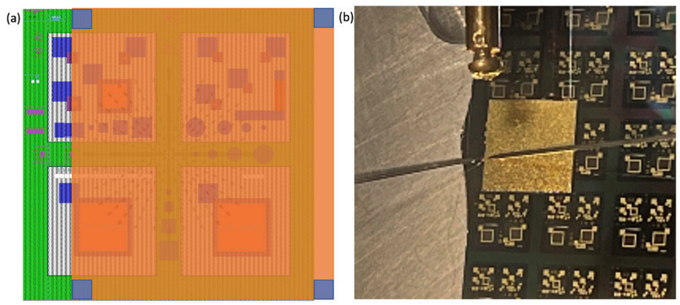
Field Emitter Arrays Device Characteristics – A Closer Look at Space-Charge

1.17

Y. Shin, W. Chern, N. Karaulac, A. Akinwande
Sponsorship: AFOSR

Field Emitter Arrays (FEAs) - based cold cathodes have shown promise as electron sources in devices capable of high power and high frequency operation for a variety of applications such as microwave power amplifiers, pressure sensors, x-ray sources and high-power excimer lasers. Limited work has been done exploring the device characteristics using well defined cathode to anode separation. Consequently, FEAs lack a physics-based compact model.

In this work, a flat stand-off anode was placed on the FEAs, which guarantees the anode distance and the parallel condition. The I-V characteristics in the space charge limit show an unexplained, yet reproducible Negative Differential Resistance (NDR) region. These results imply that the development of a model for FEAs will need to account for additional phenomena affecting electron transport in the space between the anode and the gate electrode. The resulting FEA model opens new avenues of applications including oscillators and amplifiers.



▲ Figure 1: (a) Top view of experimental configuration and (b) photograph of the physical experimental setup.

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

Design-technology Co-optimization of 2D Electronics

1.18

A. Yao, J. Zhu, T. Palacios
Sponsorship: SRC Jump 2.0 SUPREME Center

With 2D electronics becoming more mature in both material synthesis and device integration techniques, Design-technology Co-optimization (DTCO) has been used in designing complex electronic devices based on 2D materials and optimizing device performance and material properties. However, there still lacks an efficient electrical characterization method to provide real-time evaluation and accurate feedback for every process step from material growth to device fabrication. Meanwhile, it is also critical to conduct compact, accurate device modeling especially for high-performance transistors with scaled channel length.

In this project, we investigated fast electrical characterization methods based on circular transmission line model (CTLM) structure. We developed a parameterized cell(PCell) to aid CTLM layout design and fabricated global back-gated devices with both transferred and directly-grown 2D thin films. The convenience of only one lithography step allows seamless switches between different combinations of dielectric layers, metal contacts and passivation layers. The samples were examined by scanning electron microscope (SEM) and contour detection algorithms were used to identify the fabrication-induced variation, domain size, effective channel length and width. These data offered experimental calibration for precise device modeling, which later contributed to design and performance predictions based on TCAD simulation. Simulation models were further studied focusing on highly-scaled transistors with channel length below 10 nm. We expect this fabrication, characterization and modeling pipeline to ultimately facilitate future DTCO processes with improved efficiency and accuracy for novel materials and devices.

Ohmic Contacts to Ultrawide-Bandgap Two-Dimensional Semiconductors

1.19

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Sponsorship: Army Research Office (ARO)

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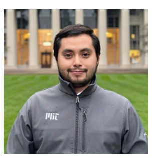
Research Interests:
2D materials, Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Power management, Quantum devices.

Power transistors for fast switching high voltage applications require wide bandgaps to enable large breakdown fields. Silicon carbide (SiC) and gallium nitride (GaN) thus offer advantages over silicon for high-voltage devices and circuits. However, these materials still have limited bandgaps (~3.5 eV) and are difficult to integrate with circuits based on other material systems. The emerging ultrawide-bandgap (UWBG) two-dimensional (2D) semiconductors, which have bandgaps above 5 eV, are expected to provide even better performance thanks to their wider bandgaps, higher critical fields, and atomic thinness. However, forming ohmic contacts to UWBG 2D materials such as hexagonal boron nitride (h-BN) and 2D GaN is very challenging due to their extreme band misalignment with metal contacts, difficulties in realizing substitutional doping, and the Fermi level pinning effect.

Here, we investigate potential approaches to forming ohmic contacts to UWBG 2D semiconductors. Modulation doping can be used to introduce more carriers to the transistor channel without significantly deteriorating carrier mobility. Dipole moments, graded 2D heterostructures, and highly-doped UWBG oxides, are all investigated to tune both the contact metal work function and the band edge of UWBG semiconductors. A combination of these techniques can be used to form ohmic contacts to UWBG 2D materials, thus enabling the next generation of power electronic devices with higher operation voltage as well as future integrated circuits with increased functionalities.



Highly integrated graphene-based chemical sensing platform for structural monitoring applications

1.20

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Sponsorship: Ferrovial

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

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

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

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

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

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

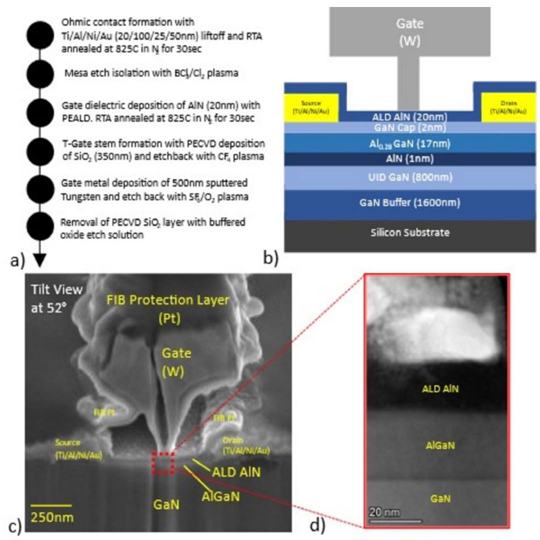
High Temperature RF GaN Electronics

1.21

J. Niroula, Q. Xie, E. Daye, T. Palacios

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

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



◀ Figure 1. (a) Device fabrication process flow (b) Cartoon schematic of device structure (c) Fabricated device SEM cross section (d) TEM view of inset shown in (c)

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2D materials, Displays, Electronics, Field-Emitter devices, GaN, III-Vs, Light-emitting diodes, Nanotechnology.

High Al-content AlGaN Transistors

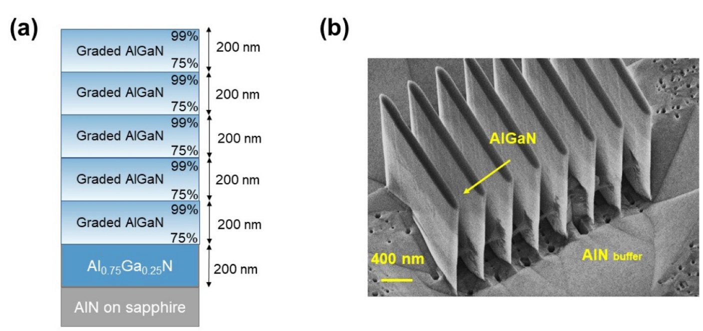
1.22

H. Pal, J. Niroula, Q. Xie, T. Palacios

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

As high frequency electronics is becoming increasingly important for today's commercial, military and space communication needs, power amplifiers need to provide high power density, gain, efficiency, and linearity. Although GaN-based HEMTs have demonstrated excellent results, the use of ultra-wideband gap semiconductors such as AlGaN could enable an even higher Johnson figure of merit due to its superior breakdown electric field (> 8 MV/cm), and subsequently higher power densities and efficiencies beyond 30 GHz.

In this work, we propose a multi-channel epitaxial structure with polarization induced electron doping together with a FinFET architecture to demonstrate AlGaN transistors with high power density. We developed a process technology to obtain high-aspect ratio Al-rich AlGaN fins with smooth and vertical sidewalls which is critical for FinFETs. This work paves the way for the demonstration for our future novel high aspect ratio AlGaN FinFETs for mm-Wave applications.



▲ Figure 1: (a) Epitaxial structure (b) SEM image of fabricated AlGaN fins of aspect ratio 15:1 with smooth and vertical sidewalls.

Large-signal TCAD Simulation of Polarization Switching in Ferroelectric Devices

1.23

J. Navarro, Y. Shao, J. A. del Alamo

Sponsorship: Technical University of Madrid (UPM), Semiconductor Research Corporation

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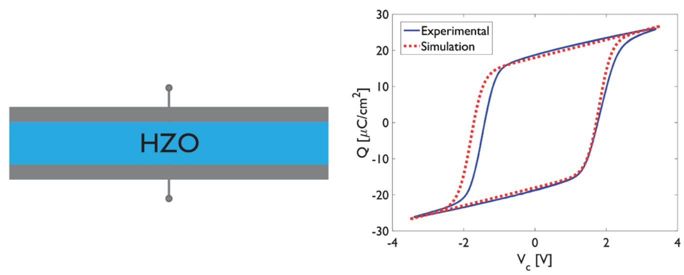
Research Interests:
Electronic devices, Electronics, Energy, III-Vs, Nanotechnology, Power management.

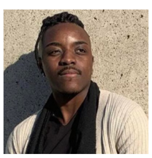
Ferroelectric materials enjoy spontaneous and non-volatile charge polarization with an orientation that can be switched by the application of a voltage. Recently, the discovery of ferroelectricity in HZO (Hf0.5Zr0.5O2) thin films, compatible with current CMOS fabrication processes, have made ferroelectric field-effect transistors (FE-FETs) attractive as low power, nonvolatile memory devices for neuromorphic computing. However, the physics behind HZO polarization switching, especially in FE-FETs, are not widely understood.

In this work, we carry out TCAD simulations on FE capacitors and FE-FETs under large-signal operation. We have employed the Preisach model to reproduce the experimental polarization-voltage hysteresis loop, including transient behavior for low-frequency signals. Currently we are studying the nonvolatile memory behavior in FE-FETs. These results allow us to study how current physical models differ from experimental data, providing insights on the essential FE physics.



(a) (b)

▲ Figure 1: (a) FE Capacitor structure (MFM) and (b) experimental and simulated polarization-voltage (P-V) hysteresis loops



FPGAs for Electrical Characterization of Superconducting Nanowire Based Circuits

1.24

S. Kandeh, R. A. Foster, O. Medeiros, K. K. Berggren

Sponsorship: DOE FNAL Microelectronics, DoD NDSEG Fellowship, Alan L McWhorter Fund Fellowship

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Research Interests:
Communications, Electronic devices, Electronics, Information processing, Integrated circuits, Nanotechnology.

Superconducting nanowire-based computing devices [1] have the potential to play a crucial role in environments that demand extreme power efficiency, radiation hardness, and resilience to magnetic fields. Memory is a critical component of any computing system; thus, the current lack of scalable high-performance superconducting memory is a critical challenge to overcome. Superconducting Nanowire Memory (nMem) technology is a promising solution to this problem.

Current efforts to improve nMem designs and operation rely on expensive arbitrary waveform generators (AWGs) and oscilloscopes that are not well suited for parallelized memory cell tests or quickly providing high resolution analyses. Testing often involves large parameter space searches that take hours. Furthermore, the low memory capacity of the AWG greatly limits the resolution of our search space. Here, the AWG acts as the principal bottleneck.

An FPGA provides the necessary performance to increase parallelism without a proportional increase in cost, greatly improving testing resolution and speed and reducing test time from hours to seconds. In this project, we have developed a custom analog frontend to interface the FPGA with superconducting nanowires. Importantly, the flexibility of this system allows for a generalized application to any electronic system that demands a specialized testing procedure involving arbitrary signal processing and generation. The money, time, and energy that this innovation will save on validating cryogenic electronics in general will significantly improve our progress in developing these technologies.

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Research Interests:
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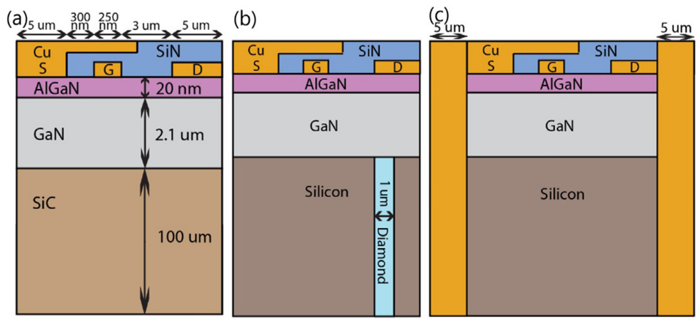
Thermal Management in GaN High Electron Mobility Transistors (HEMTs) 1.25

D. Erus, T. Palacios

Wide bandgap of GaN make GaN HEMTs a key building block for the next generation of high-power and high-frequency electronics. However, the large power density in these devices induces harsh self-heating.

GaN-on-Si structure enables the use of state-of-the-art fabrication tools which reduces defects and increases the yield. However, due to the lower thermal conductivity of Si compared to SiC, GaN-on-Si HEMTs have a higher peak temperature than the commonly used GaN-on-SiC HEMTs at the same power dissipation level.

In this work, the same Silvaco TCAD simulation framework is used to find thermal solutions that decrease the peak temperature of GaN-on-Si HEMTs. Making a 1 um diamond via under the drain of the GaN-on-Si HEMT decreases its thermal resistance 38%. Covering the sides of the HEMT with Cu decreases its thermal resistance 70%, which is lower than the thermal resistance of the GaN-on-SiC HEMT. This work proposes a viable solution for thermal management in GaN-on-Si HEMTs.



▲ Figure 1. (a) GaN-on-SiC HEMT structure; b) GaN-on-Si HEMT with 1 um diamond via; c) GaN-on-Si HEMT with copper covered sides.

Two-dimensional MoS_2 transistors 1.26

B. Hanly, L. Ospina, S. Seshan, D. J. Paul, R. Ram, T. Akinwande, F. Niroui

Sponsorship: MIT EECS, 6.2540

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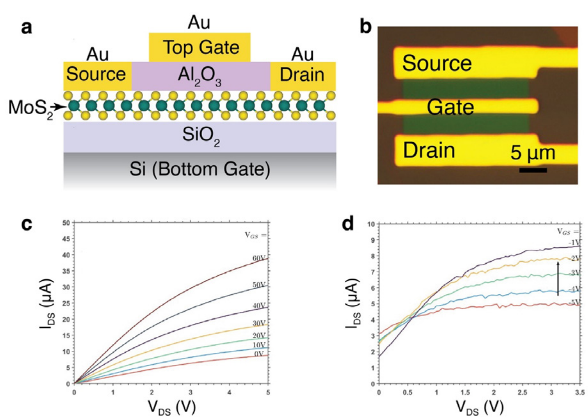
As we reach the limits of traditional silicon-based transistors, we look to other materials to potentially improve performance and expand usage to non-traditional digital systems, such as flexible and thin electronics. The advent of 2D semiconducting materials, such as MoS_2, has led to expansive research on the development of such devices. Here, we present a transistor based on MoS_2 monolayers with both a bottom gate and a top gate. To fabricate the device, we first used a gold-mediated transfer, to place a large area MoS_2 monolayer from its source natural crystal on to a silicon oxide-on-silicon substrate. We then patterned the desired gate dielectric, source, drain and top gate electrodes lithographically forming the final structure shown in Figure 1a-b. Figure 1c and 1d show a representative performance for a bottom-gated and top-gated device, respectively.



▲ Figure 1: a) Schematic illustration of the MoS_2 transistor designed. b) Optical micrograph of an example working transistor. c) Example I-V characteristic of a bottom-gated transistor. d) Example I-V characteristic of top-gated transistor.

Halide Perovskite Memristors Toward Neuromorphic Computing

1.27

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Sponsorship: MIT EECS, 6.2540

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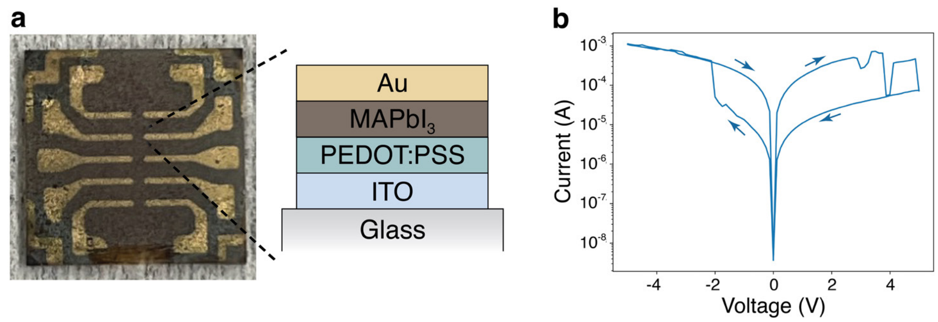
Recent advances in artificial intelligence have necessitated efficient processing of vast amounts of data. Neuromorphic computing networks aim to accomplish this goal using artificial neurons based on memristors. Halide perovskites have been demonstrated to have unique electrical properties, including ionic conduction, making them promising materials for memristive devices. Here, we demonstrate a memristor based on a halide perovskite thin film, as shown in Figure 1a. We used spin coating to deposit a PEDOT:PSS layer and a methylammonium lead iodide (MAPbI3) thin film on a patterned ITO on glass substrate. We then patterned gold electrodes on the film using thermal evaporation. Our memristor displays a hysteresis loop when a voltage sweep is applied, as shown in Figure 1b. This resistive switching behavior suggests that our memristor could be extended to develop neuromorphic devices.



▲ Figure 1: (a) Schematic of the MAPbI3 memristor structure. (b) An example I-V characteristic of the memristor, demonstrating hysteresis.

Automated Measurements and Modeling of RF GaN Electronics for High-Temperature Applications

1.28

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

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Electronic devices, Electronics, GaN, III-Vs, Integrated circuits, MEMS & NEMS, Nanotechnology.

High temperature rated electronics are needed for many emerging applications including hypersonic aircrafts, deep well oil drilling, and exploration of Venus. However, traditional Si devices cannot operate beyond 250°C which is significantly below the typical temperature range required for these applications. Wide-band semiconductors such as SiC and GaN are well suited for high temperature operation because of their wide-band gap and negligible carrier thermal generation at these temperatures (around 500°C). In spite of offering significant advantages in a wider range of applications from power and RF to MEMS and digital circuits, their use in high temperature analog and digital circuits remains relatively unexplored. In this project, we have developed a robust experimental characterization and modeling framework for the characterization and simulation of AlGaN/GaN High Electron Mobility Transistor (HEMT) devices across a wide temperature range from 25°C to 500°C. The project involved the following subtasks: 1) Development of automated analysis code based on automatic DC-IV measurements that show device performance metrics across entire sample area; 2) Development of automated model extraction routine based on DC-IV measurements; and 3) physics simulations of device in TCAD software to estimate projected performance based on changes in device design.

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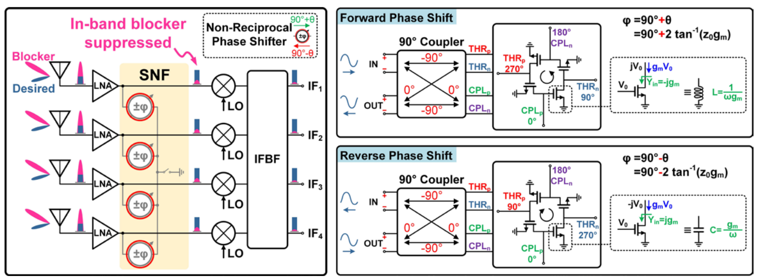
Electronics, Integrated circuits, RF and mm-wave IC.

A Blocker-Tolerant mm-Wave 4-Element MIMO Receiver with Spatial Notch Filtering Using Non-Reciprocal Phase-Shifters for 5G

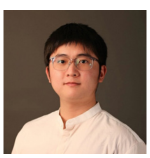
2.01

S. Mohin, S. Araei, N. Reiskarimian

Digital multiple-input multiple-output (MIMO) receivers (RXs) generate multiple data streams and offer flexible calibration. Compared to hybrid beamformers, digital ones are smaller and use less power. However, they are vulnerable to blocker signals, which can limit their dynamic range and linearity performance. This work introduces a mm-wave MIMO RX with spatial notch filter (SNF) to enhance its resilience to spatial blockers. This is achieved by establishing an SNF at the earliest stage in the receiver chain, specifically at the outputs of the Low-Noise Amplifiers (LNAs). We further propose a low-loss non-reciprocal phase-shifter (NRPS) that enables the implementation of this SNF across a full field of view. Notably, unlike traditional mm-wave SNFs, NRPSs are situated in auxiliary paths, allowing them to be disabled when no blockers are present to reduce noise and power consumption. Incorporating NRPSs in digital beamformers makes them attractive for 5G and beyond-5G applications.



◀ Figure 1: Block diagram of the proposed architecture



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Research Interests:
Artificial Intelligence, Electronic devices, Electronics, Energy harvesting devices & systems, Information processing, Integrated circuits, Machine Learning, Systems.

A Massively Parallel In-memory-computing Architecture Using Stochastic Computing

2.02

Q. Wang, B. C. McGoldrick, M. A. Baldo, L. Liu
Sponsorship: SRC, Mathworks

The potential of in-memory computing (IMC) to circumvent the inefficiencies of traditional computing architectures has been widely recognized in the field of machine learning. Despite this potential, current IMC models are hampered by the difficulty of embedding complex arithmetic operations on-site, and the lack of capability for large-scale yet versatile parallel computation, which significantly diminish the applicability of IMC in scenarios demanding high computational throughput and intricate mathematical processing. Confronting these limitations, the research introduces a novel IMC architecture that utilizes stochastic MTJs to streamline in-memory operations. Beyond mere energy and space efficiency, this architecture innovates with a hierarchical approach that emulates the structure of biological neural networks, offering a solution to the scalability challenge. Within this hierarchy, local computations are performed by densely connected neuron-like nodes, enabling rapid data processing and communication for simpler tasks. Meanwhile, more complex and distant interactions are managed via a Network on Chip (NoC), facilitating efficient communication across the larger neural network. This dual-level organization allows for both intensive local computation and broader inter-neuron communication, effectively mirroring the parallelism and connectivity of the brain, and unlocking new potentials for IMC in supporting sophisticated and large-scale parallel machine learning workloads.

An Enhanced Harmonic-Tolerant Mixer-First Receiver Employing Concurrent Top and Bottom-Plate Mixing for 5G NR Applications

2.03

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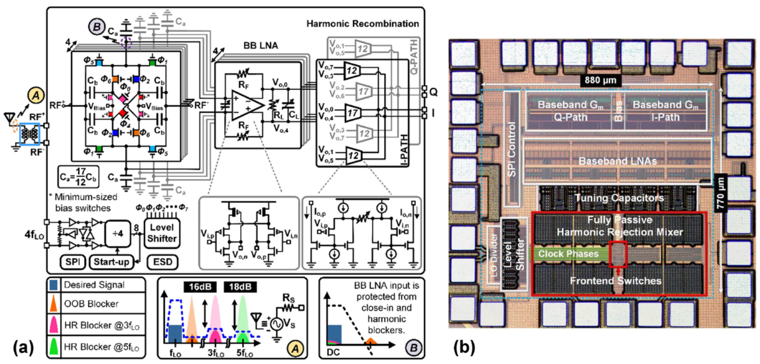
Research Interests:
Communications, Electronics, Integrated circuits, Systems.

The demand for stringent linearity in modern receivers, crucial for supporting 5G New Radio (NR), along with the aspiration to eliminate the reliance on off-chip Surface Acoustic Wave (SAW) filters, drove the preference for mixer-first receivers over the past decade. These structures, however, are vulnerable to harmonic blockers, posing a significant challenge to their design. In this work, we introduce a low-loss fully passive harmonic rejection (HR) mixer that concurrently uses top and bottom-plate mixing linked with a readout switch. The LO filtering in this design not only delivers HR at the mixer's output but also promptly suppresses harmonic blockers at the antenna interface, ensuring high linearity. Moreover, this HR technique requires only a few switches and capacitors, making it scaling-friendly and leading to extended frequency operation and superior noise performance compared to existing state-of-the-art HR mixers, positioning it as a strong candidate for 5G NR applications.



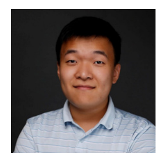
▲ Figure 1: (a) Block diagram of the proposed architecture (b) Die Micrograph

Tailor Swiftiles: Accelerating Sparse Tensor Algebra by Overbooking Buffer Capacity

2.04

Z. Y. Xue, Y. N. Wu, J. S. Emer, V. Sze

Sponsorship: MIT AI Hardware Program



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Tensor algebra describes a class of applications that are increasingly being used in fields such as machine learning, data science, graph analytics, scientific simulations, and engineering modeling. Although many of these applications operate on tensor data that has very high sparsity (i.e., many zeros), exploiting this sparsity to save both computation and memory is challenging. Prior sparse tensor algebra accelerators have explored splitting tensors into tiles to increase exploitable data reuse and improve throughput, but typically allocates tile size in a given buffer for the least sparse tile and thus limits utilization of available memory resources when sparsity varies between different regions of a tensor.

This paper proposes a speculative tensor tiling approach, called overbooking, to improve buffer utilization by taking advantage of the distribution of nonzero elements in sparse tensors to construct larger tiles with greater data reuse. We propose a low-overhead hardware mechanism, Tailors, that can tolerate data overflow by design while ensuring reasonable data reuse and introduce a statistical tiling approach, Swiftiles, that ensures high buffer utilization by picking a tile size so that tiles usually fit within the buffer's capacity, but can potentially overflow, i.e., it overbooks the buffers. Across a suite of 22 sparse tensor algebra workloads, we show that our proposed overbooking strategy introduces an average speedup of 52.7x and 2.3x and an average energy reduction of 22.5x and 2.5x over an existing sparse tensor algebra accelerator without and with optimized tiling, respectively.without and with optimized tiling, respectively.

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A Scalable Cryogenic Phased Array Feed for Radio Astronomy with Integrated Continuous Calibration

2.05

D. Sheen, F. Lind, R. Han

Sponsorship: NSF SpectrumX (SII-2132700), Intel University Shuttle Program

The rapid growth of mobile communications platforms poses an increasing challenge for radio astronomy and radio science instruments. As broadband communications technologies push into mmwave, scientific receivers that once operated in clear spectrum must now contend with sources orders of magnitude stronger than the signals they are designed to observe. The next generation of radio telescopes and radiometers need to be dynamic instruments capable of adaptive spatial and spectral filtering of measurement data while maintaining calibration in a strong signal environment. Phased arrays can offer these capabilities, but their noise performance and cost scaling with aperture size render them impractical for microwave radio astronomy.

In this work, we propose a hardware architecture for a new generation of scalable high dynamic range phased array feeds for reflector telescopes to address theses challenges. This approach promises to overcome many of the scaling limits of traditional phased arrays. A technology demonstration is planned for the Westford Radio Telescope.

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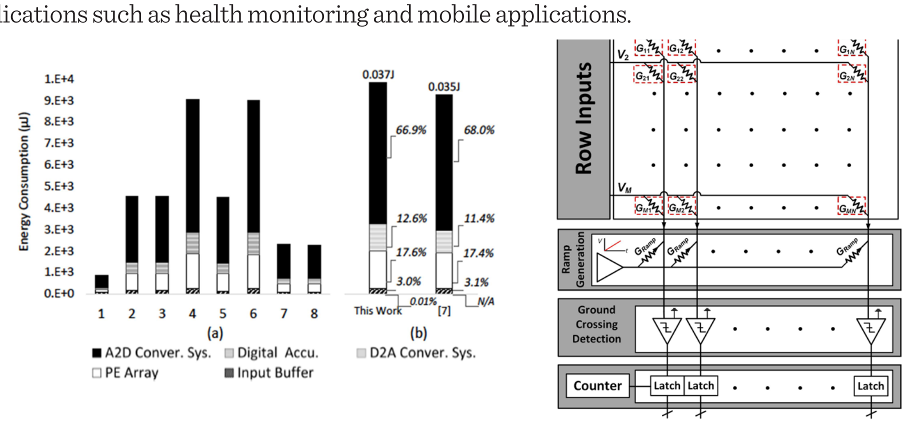
Interface Circuits for Analog In-Memory Computing

2.06

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

Sponsorship: MIT/MTL Samsung Semiconductor Research Fund

Machine learning (ML) has found its way into our daily lives in applications including image processing, voice recognition and healthcare. The energy and speed bottlenecks in ML stem from data movement back and forth between the memory and the processing element. Analog compute in-memory (CIM) presents an alternative where the processing is done locally within the memory, and the analog nature of it allows the parallelization of a significant number of multiply-and-accumulate operations. However, current read-out circuits of CIM circuits are energy and area hungry leading a slow-down and energy inefficiency in the overall accelerator performance. In this work, we proposed a new design for interface circuits using single-slope analog to digital converters that exploit the typical statistics of neural network outputs to optimize speed and efficiency. This paves the way for the incorporation of CIM accelerator in low-power applications such as health monitoring and mobile applications.



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

RAELLA: Reforming the Arithmetic for Efficient, Low-Resolution, and Low-Loss Analog PIM: No Retraining Required!

2.07

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

Sponsorship: Ericsson, MIT AI Hardware Program, MIT Quest

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Processing-In-Memory (PIM) accelerators have the potential to efficiently run Deep Neural Network (DNN) inference. By computing directly inside memory, PIM accelerators avoid expensive off-chip movement of the DNN weights. Furthermore, PIM accelerators often utilize Resistive-RAM (ReRAM) devices and ReRAM crossbars for dense and efficient analog compute.

Unfortunately, while ReRAM crossbars can compute efficiently and with high density, overall PIM accelerator energy is often dominated by the analog-to-digital converters (ADCs) that read computed analog values from crossbars.

Some prior works attempt to reduce this ADC overhead by changing or pruning DNN weights. This reduces computations and ADC converts required, but also introduces accuracy loss. Other works use efficient lower-resolution ADCs to process high-resolution analog values from crossbars, but the resolution difference introduces error and also leads to accuracy loss. Unfortunately, this accuracy loss require costly DNN retraining to compensate for, which is not always possible.

To address high ADC costs without requiring retraining, we propose the RAELLA architecture. RAELLA adapts the architecture to each DNN; it lowers the resolution of computed analog values by encoding weights to produce near-zero analog values, adaptively slicing weights for each DNN layer, and dynamically slicing inputs through speculation and recovery. Low-resolution analog values allow RAELLA to both use efficient low-resolution ADCs and maintain accuracy without retraining, all while computing with fewer ADC converts.

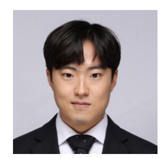
Compared to other low-accuracy-loss PIM accelerators, RAELLA increases energy efficiency by up to 4.9× and throughput by up to 3.3×. Compared to PIM accelerators that cause accuracy loss and retrain DNNs to recover, RAELLA achieves similar efficiency and throughput without expensive DNN retraining.

Analog In-memory Computing with Protonic Synapses

2.08

J. Lee, J. A. del Alamo

Sponsorship: IBM Watson



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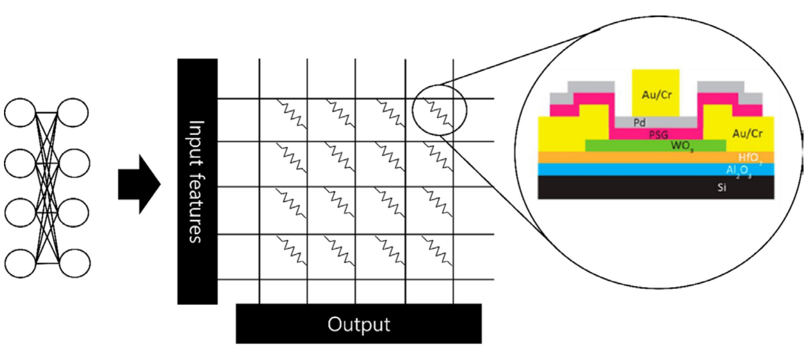
Electronic devices, Integrated circuits, Nanotechnology.

Though demand for computation in neural networks is skyrocketing, conventional computing resources are still constrained by their limited energy efficiency. One of the most promising solutions to this is analog in-memory computing (AIMC). In AIMC, synaptic weights of neural networks are encoded into the conductance of devices which are then configured into cross-bar-arrays that perform the matrix-vector multiplication operation. Recently, protonic synapses were demonstrated with suitable properties for AIMC such as linear and symmetric conductance modulation. To study this, we have built a simulation model for protonic synapses and simulated a crossbar-array operation using IBM's AIHWKIT. AIMC with protonic synapses showed 97.1% accuracy in MNIST classification with a linear-4-layer network. This is comparable to a digital chip accuracy of 98%. We also tested the Tiki-taka algorithm that compensates for device non-idealities and identified the relation between the conductance modulation shapes and the performance of algorithm.



▲ Figure 1: Schematic of cross-bar array with protonic synapses

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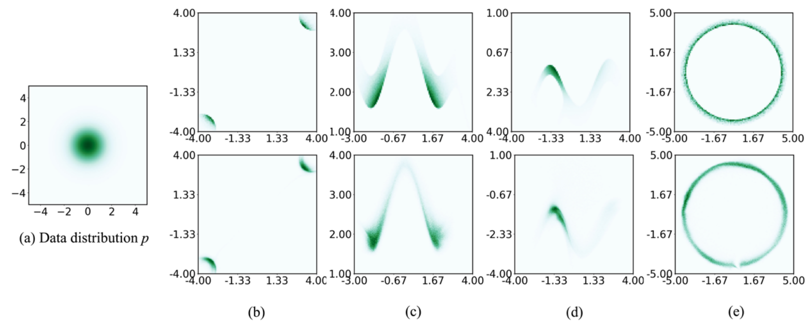
Rare Event Probability Learning by Normalizing Flows

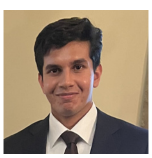
2.09

Z. Gao, L. Daniel, D. S. Boning

A rare event is defined by a low probability of occurrence. In semiconductor manufacturing, accurate estimation of such small probabilities (e.g., the rare failure rate of a process, a device, or a circuit system) is of utmost importance. Conventional Monte Carlo methods are inefficient, demanding an exorbitant number of samples to achieve reliable estimates. Inspired by the exact sampling capabilities of normalizing flows, we propose normalizing flow assisted importance sampling, termed NOFIS. NOFIS first learns a sequence of proposal distributions associated with predefined nested subset events by minimizing KL divergence losses. Next, it estimates the rare event probability by utilizing importance sampling in conjunction with the last proposal. The efficacy of our NOFIS method is substantiated through qualitative visualizations, affirming the optimality of the learned proposal distribution, as well as a series of quantitative experiments, which highlight NOFIS's superiority over baseline approaches.



▲ Figure 1: (a) The heatmap represents the data generating distribution. (b)-(e) The top row displays the theoretically optimal proposal distribution, while the bottom row illustrates the learned proposal distribution learned by our Algorithm.



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

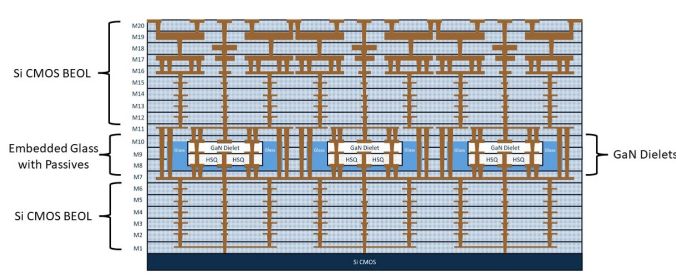
Development of a GaN and Si CMOS Stacked-3DIC Platform for W-G Band Applications

2.10

P. Yadav, J. Niroula, Q. Xie, T. Palacios

Sponsorship: AFOSR (Grant no. FA9550-22-1-0367) , SRC JUMP 2.0 (Grant no. 2023-JU-3136), Lockheed Martin Corp. (Grant no. 025570-00036), and ARPA-E (Grant no. DE-AR0001591), and the National Defense and Science Graduate Fellowship

With data rates pushing into the Tbps for augmented/virtual reality, there is an urgent need for the use of sub-terahertz RF front ends and transistors. Gallium Nitride (GaN) transistors are an ideal candidate for the front-end-of-line (FEOL) as they push the limits of high-power density, high frequency semiconductor devices. Furthermore, silicon is an ideal candidate for the back-end-of-line (BEOL) due to ease of manufacturing and access to complementary logic technology for digital circuits. In this system, 3D-stacked GaN dielets, connected via highly-scaled interconnects in the Si BEOL, will be optimally placed to ensure uniform and minimal thermal degradation in the system. CTE-matched glass will also be embedded in the silicon to allow for passive fabrication. This approach will yield a bespoke chip design, tailor-made for the given high-speed application. To design the most efficient high data rate communication systems, we must embrace a design/system-technology co-optimization (DTCO/STCO) approach, that combines innovative GaN dielets with state-of-the-art Silicon (Si) bias and control circuitry, and passives in glass via advanced heterogeneous integration.



◀ Figure 1: (a) Single chip 3DIC with multiple GaN dielets leveraging Si BEOL and embedded glass for passives

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Communications, Electronics, GaN, Integrated circuits, Quantum devices, Sensors, Si.

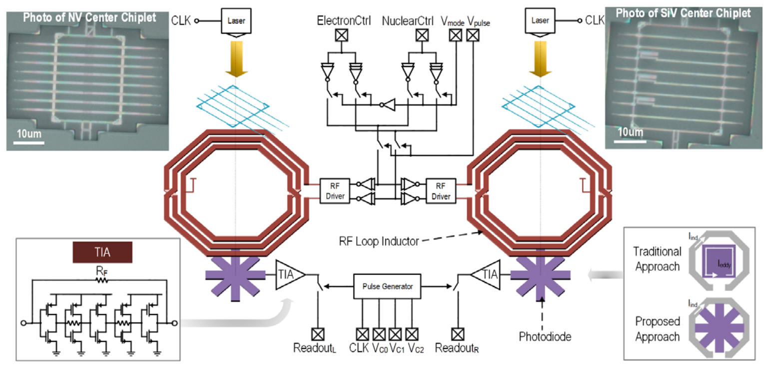
A CMOS-Integrated Color Center Pulse-Sequence Control and Detection System

2.11

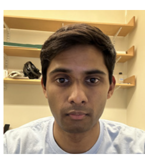
J. Wang, I. B. Harris, X. Chen, D. R. Englund, R. Han

Sponsorship: Intel University Shuttle, Jet Propulsion Laboratory

We introduce a CMOS-integrated control and detection system capable of functioning at both room and cryogenic temperatures, for accommodating general color centers. The chip encompasses a radio frequency driver comprising two inductors, designated for electron/ nuclear spin within two diamond samples. The chip incorporates readout circuitry equipped with photodiodes fashioned in the shape of Union Jack patterns to reject the eddy current. To facilitate fluorescence detection while mitigating the impact of passivation fluorescence and laser excitation, a tunable pulse generator is implemented within the readout system. This configuration enables the acquisition of fluorescence data of color centers in the time domain subsequent to the deactivation of the laser pulse. Since the lifetime of the red fluorescence emitted by the passivation layer is much shorter than that of any types of color centers, the chip no longer requires post-processing such as reactive-ion etching to remove the passivation.



▲ Figure 1: Block Diagram of Control and Readout Circuit



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Artificial Intelligence, Machine Learning.

A Biologically-Inspired Neuromorphic Circuit for Efficiently Training Wide Neural Networks

2.12

A. Boopathy, I. Fiete

Sponsorship: NSF Graduate Research Fellowship (2021310453)

Artificial neural networks are typically trained by gradient descent implemented by backpropagation. However, on neuromorphic hardware, backpropagation can be computationally inefficient in terms of time and memory. Inspired by the brain's ability to efficiently learn without backpropagation, we introduce a introduce a novel backpropagation-free learning rule tailored for wide neural networks (i.e. neural networks with many neurons in each layer). We theoretically demonstrate that this learning rule is *equivalent* to backpropagation in the limit of infinite-width networks: the trained networks are equally capable under the two rules. Moreover, we empirically show its effectiveness in large, finite-width networks, especially in low data regimes.

Building on this insight, we propose an efficient neuromorphic circuit to train wide neural networks. Key practical advantages relative to backpropagation include 1) asynchronous updating of weights at different layers of a network, allowing for greater time efficiency 2) reduced memory costs from having to store intermediate layer activation values, 3) reduced synaptic wiring in the feedback path, enabling better use of physical circuit space. Our empirical results underscore the potential of high-performing, efficient neuromorphic circuits for wide neural networks, an increasingly common class of networks found in settings such as large language models.

Session 3: Medical Devices & Biotechnology

A Conformable Ultrasound Patch for Cavitation Enhanced Transdermal Cosmeceutical Delivery

3.01

A.Shah, C. Yu, N. Md Osman Goni, C. Marcus, C. Dagdeviren, A. Kumar-Bhayadiya

Sponsorship: MIT Media Lab Consortium, K.Lisa Yang Bionics Fellowship, MIT Presidential Fellowship, NSF CAREER, 3M Non-Tenured Faculty Award, NSF

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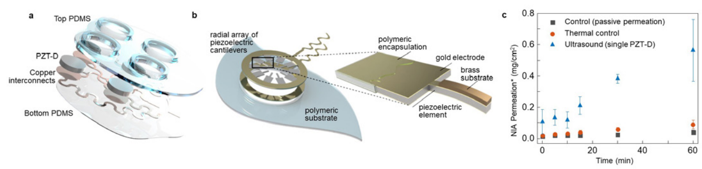
Research Interests:
Actuators, Biological devices & systems, Sensors, Systems, Transducers.

Growing interest in skin health necessitates an effective method for enhancing the transdermal absorption of therapeutic cosmeceuticals such as niacinamide (122 $gmol^{-1}$). The challenge arises due to the limited permeation of such small-molecule drugs (<500 $gmol^{-1}$) through the stratum corneum barrier. We report a conformable ultrasound patch (cUSP) that employs intermediate-frequency sonophoresis to improve the transdermal transport of niacinamide. The cUSP, featuring bulk piezoelectric transducers within a soft elastomer, creates localized cavitation pockets (0.8 cm^2, 1 mm deep). Multiphysics simulations, acoustic spectrum analysis, and high-speed videography characterize transducer deflection, acoustic pressure fields, and cavitation bubble dynamics. In vitro testing on porcine skin demonstrates a 26.2-fold increase in niacinamide transport with a 10-minute ultrasound application. To further enhance portability, we propose miniaturizing the transducer footprint using piezoelectric unimorph cantilever structures to create a seamless conformable interface for patients suffering from skin conditions and premature skin aging.



▲ Figure 1: Simplified schematic, (not to scale) of the a, bulk and b, unimorph embodiments of the cUSP interface. c, In vitro skin permeation results obtained with the bulk interface demonstrating a 19.2-fold enhancement in the total of niacinamide delivered in 60 minutes after 10 minutes of ultrasound application.

Stochastic Regulator with Estimation Filter Implementable Using Bio/Nano Chemistry and Useful for "Intelligent Design"

3.02

J. M. Protz, A. Jain, A. Y.-H. Lee

Sponsorship: Protz Lab Group and the former BioMolecular Nanodevices, LLC

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

Signal processing using polymers has been a focus of the authors for two decades and has recently become of greater interest at MIT. Their present effort explores chemical and biological implementation of a stochastic linear regulator. It builds on a conceptual reaction mixture considered by the performer two years ago: "PROM" -type "junk DNA" in a plasmid transcribes into mRNA strands that are attacked by exonucleases coded for in a "BIOS" region of said plasmid; the activity of the nucleases depends jointly on the species of nucleotide being removed and on peptides pulled from polypeptides present alongside the plasmid; this causes the mix of surviving mRNA to depend on the polypeptide composition; the surviving mRNA reverse-transcribes into DNA that overwrites partly a "RAM" region of coding DNA in the plasmid, evolving it from a "prior estimate" of the environmental state to an "updated estimate" of the environmental state; said DNA expresses phenotypically as "actuator" proteins that are assembled by ribosomes from the free peptides and that "actuate" the surrounding environment; separately, a "sensor" reaction uses proteases and environmentally-sensitive peptide ligation reactions to recycle used "actuator" proteins back into free peptides that are then assembled into the aforementioned "sensor measurement" -storing polypeptides. One period of this cycle represents one update interval for an estimation filter. If implemented in a cell or organism, with the "sensor measurement" -storing polypeptides doubling as, e.g., a yolk, the lifetime of one cell or organism could constitute one update cycle of a stochastic regulator implemented by way of a cell line, organism family line, or society. Progress of the effort may allow the engineering of cell lines that evolve themselves and their environment deterministically and robustly according to "intelligent design" and may also explain the existence of aging, death, reproduction, and variable life expectancy.

Ingestible Electronics for High Quality Gastric Neural Recordings

3.03

A. Gierlach, S. S. You, P. Schmidt, G. Selsing, I. Moon, K. Ishida, J. Jenkins, W. Abdalla M. Madani, S-Y. Yang, H-W. Huang, S. Owyang, A. Hayward, A. P. Chandrakasan, G. Traverso

Recent advances in understanding gastrointestinal dysmotility, the gut-brain axis, and gastric stimulation therapies have highlighted the importance of the electrical signals that regulate the gastrointestinal (GI) tract. However, current tools that can measure these small, slowly oscillating potentials deep within the GI tract either involve acute, invasive procedures for high quality measurements or long-term cutaneous recordings that are highly attenuated and restrict patient movement. Here we introduce a non-invasive system for long term gastric recordings known as Multimodal Electrophysiology via Ingestible Gastric Untethered Tracking (MiGUT). Validated using the gold standard, MiGUT is able to record the gastric slow wave in-vivo in pigs, measure the expected response of prokinetic agents, while also directly observing signals from nearby organs such as the heart rate and respiratory rate. During multi-day measurements of freely-moving subjects, MiGUT measured changes in the slow wave during different behaviors and was not impacted by ingestion or high activity events. This work demonstrates new capabilities of ingestible devices, enabling long-term, at home, personalized diagnostics and detailed study of gastric electrophysiology.

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Available from June 2026.

Research Interests:
Artificial Intelligence, Biological devices & systems, Electronic devices, Machine Learning, Medical devices & systems.

Tracking Neurocognitive Decline via Abnormalities in Eye Movements Recorded on Mobile Devices.

3.04

J. Koerner, V. Sze, C. Sodini, T. Heldt

Sponsorship: Aging Brain Initiative

The aging brain inevitably manifests in a decline of mental abilities. However, it is often difficult to discern age-related decline in neurocognitive performance from a decline due to neurodegenerative disease processes, especially early in the disease process when disease-modifying interventions are thought to be most effective. To this end, certain features of eye movements have been shown to be sensitive and specific markers of neurodegenerative disease progression. However, their quantitative measurements and assessments have hereto required dedicated staff time and high-end equipment and hence are only conducted during specialized neurological examinations. To close this diagnostic and clinical monitoring gap, this work proposes a novel approach for tracking neurocognitive decline in the elderly by transitioning eye movement measurements from high-end, specialized medical equipment to low-cost ubiquitous consumer electronics, such as smartphones or tablets. Specifically, our approach displays eye movement tasks on iPads and uses the integrated selfie-camera to record videos of subjects completing these tasks on a daily basis. From the recordings, we extract eye movement features, identify and track eye movement abnormalities, and correlate them with neurocognitive decline. Our approach promises to enable continual and personalized tracking of neurocognitive decline from home. This will dramatically increase the granularity of assessment, thereby assisting doctors to discern normal, age-related neurocognitive decline from that seen in neurodegenerative diseases and providing an avenue for the development of more effective treatment plans and helping advance research into new treatment strategies.

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Research Interests:
Artificial Intelligence, Machine Learning, Medical devices & systems.

Electrophoretic Quality Assessment of Adeno-associated Virus (AAV) by Microfluidic Ion Concentration Polarization

3.05

Y. Park, M. Cui, J. Han

Sponsorship: U.S. Food and Drug Administration (FDA, 1R01FD007226-01), Singapore MIT Alliance for Research and Technology, CAMP IRG.

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Adeno-associated virus (AAV) is widely used as a viral vector in gene therapies as well as genetic manipulation of various cells. The demand for high-quality AAVs is increasing alongside the growth of gene therapy. Still, there is a critical lack of reliable tools to assess the general quality of AAV capsids produced in biomanufacturing. However, AAV manufacturing in HEK293 always produces a very impure population, where only <30% of produced AAV particles typically have all the genes that make the particle functional in vivo [1]. Moreover, a large number of them are partially filled with genes that are not functional but have the potential to be immunogenic in vivo [2]. Therefore, detecting and potentially removing empty and partially filled AAV capsids is an important quality-control step in AAV biomanufacturing. This study tried to address this critical challenge by introducing a microfluidic device with the ion concentration polarization (ICP) effect. The ICP effect-based microfluidic device is fabricated based on previous research utilizing Nafion resin solution to make cation exchange membranes [3]. The device was tested using a reference AAV capsid to differentiate fully packed AAVs from empty AAV samples. The result was analyzed and quantified based on fluorescence intensity values of labeled AAV. The technique used in this study was able to distinguish a 5% content difference in each empty AAV composition ratio, suggesting a potential to be used as a tool for quantitative analysis in various studies like purification of particles with a similar size but different electric charge.

Inertial Microfluidic Cell Retention Device for Perfusion Culture

3.06

D. Park, A. Bevacqua, J. Han

Sponsorship: FDA program (1R01FD007480-03) and NIIMBL program (PC5.2-105)

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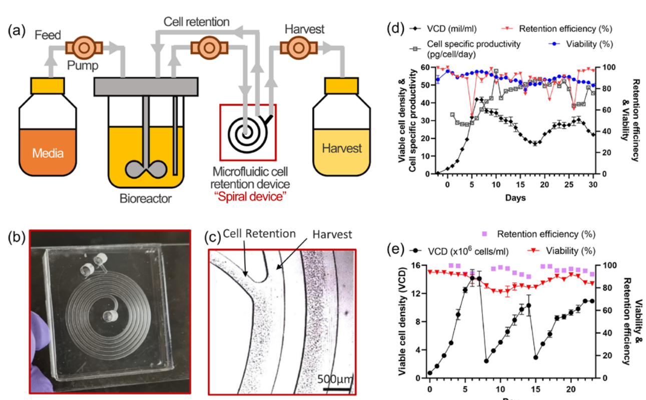
Research Interests:
Biological devices & systems, BioMEMS, Microfluidic devices & systems.

In the bioprocessing industry, perfusion culture is expected to enhance productivity with the advantages of consistent product quality and high productivity. The cell retention device is the essential component of perfusion culture, represented by hollow fiber membrane-based systems. However, Porous membranes frequently encounter membrane fouling, resulting in reduced product yield. Here, we introduce a perfusion culture system using an inertial microfluidic cell retention device. Using the device, we demonstrated antibody production by culturing adalimumab-producing CHO cell line and interval HEK 293 cell production for potential use for AAV production within a 500 ml mini-bioreactor (working volume: 350 ml). With the advantages of no product loss and dead cell removal, we expect the inertial microfluidic device-based perfusion culture system to be used in bioprocessing industries with high product recovery efficiency and high-quality culture conditions.



◄ Figure 1: (a) Schematic diagram of the perfusion culture system. (b) A microfluidic cell retention device. (c) Separation of focused cell stream and media at the branch of channel. Results obtained from (d) CHO and (e) HEK 293 cell culture.

High Throughput Electrokinetic Concentrator with Polydopamine DNA Capture Substrate

3.07

E. M. Wynne, M. Cui, J. Han

Sponsorship: SMART CAMP

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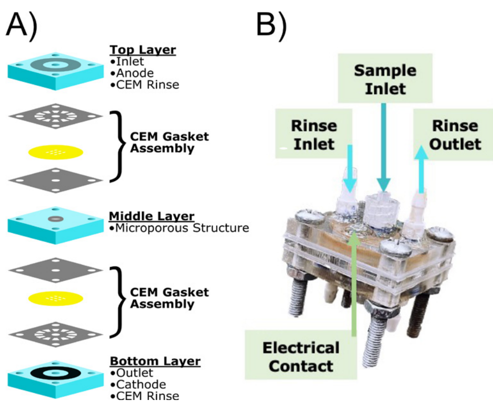
Research Interests:
Biological devices & systems, BioMEMS, Medical devices & systems, Microfluidic devices & systems.

Technologies such as next-generation sequencing are able to detect small amounts of genetic material, making low abundance detection of pathogens a possibility. These technologies can only process volumes on the scale of tens of microliters at time, limiting the utility of these methods when trying to process large volumes such as liters of bioreactor supernatant. Electrokinetic concentration devices could elevate these sensing technologies by reducing large sample volumes to a scale more compatible with these technologies.

We demonstrate an EK concentration device operating at flowrates up to 50 microliters per minute, and characterize the performance when adjusting voltage, flowrate, and buffer composition. We incorporate a polydopamine (PDA) coated substrate that binds DNA, increasing the concentration factor. After removing the PDA substrate from the device, we demonstrate a method for releasing the DNA such that it can quantified by methods other than fluorescence microscopy.



◄ Figure 1: A) A blown up schematic of the electrokinetic concentration device. B) A photograph of the device fully assembled.

Progress on an Implantable Microphone for Cochlear Implants

3.08

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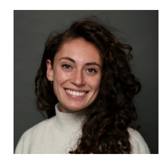
Sponsorship: NIDCD/NIH R01DC016874, NSF GRFP Grant No. 1745302, NSF GRFP Grant No. 2141064



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Research Interests:
Biological devices & systems, BioMEMS, Medical devices & systems, Sensors.

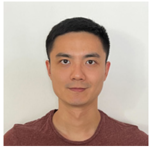
Cochlear implants are devices that can restore hearing loss to people with sensorineural hearing loss. Despite their name, cochlear implants rely on an external electret microphone which poses many lifestyle restrictions on the users. We present the fabrication and testing of an implantable microphone as an important step towards a totally implanted cochlear implant.

The piezoelectric microphone is made from titanium and thin film polyvinylidene fluoride (PVDF), is shaped like a triangular cantilever, and has a differential output. It is inserted through the facial recess and contacts the manubrium's umbo. We target the umbo because its uni-directional motion produces a well-represented sound signal. As the umbo moves, it displaces our piezoelectric sensor, resulting in a charge accumulation that we amplify with a custom differential charge amplifier.

We use photolithography and thin film deposition to fabricate our sensors in a nano-microfabrication facility at the Massachusetts Institute of Technology. We have tested eight sensors at Mass Eye and Ear via bench testing and human cadaveric experimentation.

The eight sensors behave comparably during bench testing and in five distinct human temporal bones. Our microphones show a flat frequency response, high sensitivity, good linearity, and an equivalent input noise comparable to commercial hearing aid microphones.

Our prototype demonstrates the feasibility of a PVDF-based microphone and is an important step towards developing a totally implantable cochlear implant.



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

Engineering High-throughput Electrokinetic Filtration for Nucleic Acid Enrichment

3.09

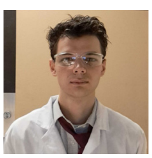
M.Cui, E.M. Wynne, J. Han

Sponsorship: U.S. Food and Drug Administration (FDA, 1R01FD007226-01)

Rapid and reliable ultralow-abundance molecular detection is of great interest in biomedical research and clinical trial. Quantitative polymerase chain reaction, a widely used nucleic acid quantification method, has multiple inherent issues, including tedious sample preparation, non-specific amplification, limited detection range, etc. Besides, there is no existing amplification method for protein, which restricts the development of protein-based diagnosis. Thus, there is a critical unmet need for a universal amplification or preconcentration of molecules.

Previously, our group developed a high-throughput electrokinetic filtration for biomolecule concentration.[1][2] Although the flow rate is extremely high, the sample recovery rate is only 40% - 60%. Furthermore, the optimization of this concentrator is complicated because the device is not designed for microscopy. Herein, we propose a microscopic version of high throughput concentrator. This device allows imaging of concentration region, which provides a quantitative assessment of device performance. With the assistance of microscopy, we optimized the device, including minimizing downstream pore size on cation exchange membranes (CEMs) to ~150 μm in diameter to effectively generate ion depletion zones (IDZs), inserting ~35 μm porous polyethylene (PE) in front of IDZs to increase the electric intensity, adding ~25 μm porous filter paper near IDZs to compress instability of vortex. The operating flow rate can also be easily determined by downstream imaging. In summary, the microscopic device provides not only straightforward assessments of concentration but also operation at a high flow rate.

We used fluorescent-tagged DNA (ssDNA-647) in 0.1X phosphate buffer saline to test the performance of the device. With the assist of microscopic device, a flow rate up to 50 μL/min is achieved without significant leakage at 50 V. A 1 mL sample can be concentrated to a final volume of 50 μL, with a concentration factor of 20. We will further test the concentration performance of protein and bacteria.



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

Continuous In-line Monitoring of Perfusion Culture Viability with Contact-Free Magnetic Resonance Relaxometry

3.10

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

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

Bioreactors produce a wide array of critically important therapeutic products, from insulin to the viral vectors for gene therapies. Frequent, low-latency measurements of bioreactor culture growth are critical for maximizing culture efficiency and viability. Typical cell density and viability measurements are made by removing a sample from the culture, but this approach carries an elevated risk of contamination and wastes valuable cells, making it impossible to take measurements more than two or three times per day. In this work, we use magnetic resonance relaxometry measurements taken through the walls of the bioreactor tubing to monitor the cell density in near real time. The relaxometer detects drops in cell density caused by the manual removal of cells and problems with the cell retention device within minutes, enabling rapid intervention to save the culture that would be impossible with the infrequent measurements taken by a traditional system. This improvement in culture monitoring helps facilitate increased productivity of bioreactor perfusion cultures, and ultimately results in cheaper, higher-quality theraputic products.

Rewiring Photosynthesis

3.11

T. Baikie

Sponsorship: The Lindemann Fellowship

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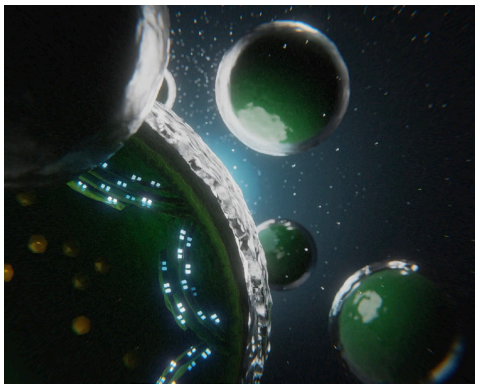
Available from December 2024.

Photosystems II and I (PSII, PSI) are the reaction centre-containing complexes driving the light reactions of photosynthesis. The impressive efficiencies of the photosystems have motivated extensive biological, artificial and biohybrid approaches to 're-wire' photosynthesis for higher biomass-conversion efficiencies and new reaction pathways. Electron extraction at earlier steps, perhaps immediately from photoexcited reaction centres, would enable greater thermodynamic gains; however, this was believed impossible with buried reaction centres. We demonstrate extraction of electrons directly from photoexcited PSI and PSII. Our results challenge previous models of photoexcited reaction centres and opening new avenues to study and re-wire photosynthesis for biotechnologies and semi-artificial photosynthesis. Here, we demonstrate, using in vivo ultrafast transient absorption (TA) spectroscopy, extraction of electrons directly from photoexcited PSI and PSII at early points (several picoseconds post-photo-excitation) with live cyanobacterial cells or isolated photosystems



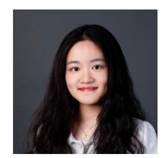
▲ Figure 1: Artists impression of cell environment

A Compact Hydraulic Head Maintainer for Constant Gravity-Driven Flow in Microfluidic Designs

3.12

F. Xue, U. Lee, J. Voldman

Sponsorship: National Institutes of Health award 1R21NS120088 and the MIT School of Engineering Postdoctoral Fellowship Program for Engineering Excellence.



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Research Interests:
Microfluidic devices & systems.

Gravity-driven flow is a widely employed passive flow technique in microfluidics due to its inherent advantages, including compactness, portability, simple fabrication, and minimal operational skill requirements. However, a significant drawback arises as the hydraulic head driving the flow diminishes over time, resulting in a gradual reduction in flow rate. This limitation poses a considerable challenge in applications requiring sustained and constant fluid flows.

In this study, we address this challenge by introducing a novel self-operational hydraulic head maintainer designed to sustain the fluid level at the inlet port of gravity-driven flow systems. The miniaturized device is specifically crafted to seamlessly integrate into a standard 96-well plate, facilitating its adoption in cell studies and high-throughput applications. This innovation aims to enhance the reliability and longevity of gravity-driven flow systems, expanding their utility in various scientific contexts. Our compact design enables long-term constant gravity-driven flow for microfluidic systems with simple and low-cost fabrications.

An implantable device for in-situ ultrasound-enhanced drug delivery

3.13

J. F. Hou*, S. B. Ornellas*, M. O. G. Nayeem, C. Dagdeviren

Sponsorship: Media Lab Consortium Funding

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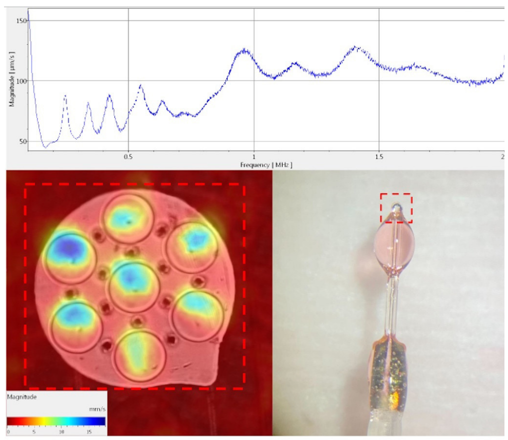
Current intratumoral drug delivery strategies enable delivery of mRNA therapeutics but have poor tissue specificity and a need for repeated doses. Microfluidic devices enable targeted and controlled drug delivery, and ultrasonic cavitation has been used to reversibly modulate the permeability of tissue. A combined effect allows delivery of a drug payload to our target and enhanced penetration with an array of ultrasound transducers.

In this work, we create a novel piezoelectric Micromachined Ultrasonic Transducer (pMUT) with a microfluidic channel for in-situ drug delivery. Our device is based on an array of lead-free potassium sodium niobate (KNN) thin films and is transfer-printed on a flexible SU-8 substrate. The biostable nature of our devices enables chronic and responsive delivery for the treatment of intracranial tumors, and our results highlight the microfabrication and early characterization of the device performance in-vitro.



◀ Figure 1: Laser doppler vibrometer measurement of average velocity of transducer at various frequencies (Top), Relative magnitude of velocity over the array (Bottom left), Full scale device with water injected through the microfluidic channel (Bottom right)

Robust DNA-patterned Glass Surfaces with Micrometer Features by Photolithography and Click Chemistry.

3.15

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Sponsorship: Media Lab Consortia

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The ability to precisely pattern DNA onto glass is paramount for various bio-analytical applications, including DNA microarrays, biosensors, microfluidics, next-generation sequencing, and lab-on-a-chip. Contemporary fabrication techniques often employ printing technologies such as inkjet, piezoelectric, and contact printing for precise droplet placement followed by chemical immobilization. Alternatively, photolithographic exposure can activate or deactivate custom-designed regions of the surface to be patterned with biomolecules. DNA immobilization unto the glass is commonly achieved by Streptavidin-Biotin interactions or the use of Silanized surfaces. Both methods are well established yet carry certain disadvantages and complexities, specifically when combined with advanced microfabrication processes to generate micron and submicron patterns.

In this work, we propose a novel method to fabricate robust DNA-patterned glass surfaces with micron-scale features. The innovation in this approach is the combination of Copper-free Click chemistry with a biocompatible photolithographic process. Copper-free Click chemistry is based on the reaction of diaryl cyclooctene (DBCO) with an Azide-labeled reaction partner. In our process, Azide-coated glass is first masked by direct-write photolithography followed by plasma ashing, to generate reactive Azide regions underneath the photomask. Room-temperature suspension of DNA molecules modified with DBCO leads to covalent attachment of DNA strictly to the active regions. Our preliminary results show this process generates patterned surfaces with a very high signal-to-noise ratio compared to standard techniques, as well as stability and resistance to denaturing conditions. Our method could appeal to researchers interested in custom in-house fabrication of pristine DNA-coated surfaces.

Chamber Design and Airflow Optimization for E-Nose Technology

3.17

M. Grande, C. Lopez Angeles, T. Palacios
Sponsorship: Universidad Politecnica de Madrid (UPM)

Electronic nose (E-nose) technology has been explored for years. However, it has not yet achieved the digitization of the sense of smell with high accuracy. Various concepts of E-nose have been proposed, such as individual semiconductors-based sensors that respond to a certain chemical stimulus. However, their use has been limited due to variability on device-to-device performance resulting from nanofabrication processing. Moreover, when it comes complex environments, such as the human breath, where there are many gases in low concentrations involved, a more robust and accurate sensing approach is needed. In this context, we are designing an E-nose system based on multiple Graphene-Field Effect Transistors (G-FET) sensors arranged in an array. Each sensor chip is equipped with a thousand sensing units, aiming for enhanced precision in measurements.

These sensors, integrated with a PCB system and an external computer, will enable the detection of biomarkers in exhaled breath. So far, a good chemiresistive response of metal NPs functionalized graphene sensor to a 10,000 ppm H_2, 100 ppm NH_3, 10 ppm H_2S,100 ppm NO_2 in dry air at room temperature has been achieved. To optimize the performance, these devices are housed in an engineered-designed chamber, ensuring efficient airflow for detection. Furthermore, simulations of airflow with finite element modeling method utilized to enhance sensing module performance. The air samples can be obtained either by exhaling into the chamber or by activating a vacuum extraction pump to capture ambient air. This research represents a significant step toward achieving a practical E-nose system for diverse applications, including disease diagnosis.

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Research Interests:
2D materials, Biological devices & systems, BioMEMS, Electronic devices, Electronics, Medical devices & systems, Sensors.

Piezoelectric Single Crystal-Based Ultrasound Patch for Breast Imaging

3.18

W. Du, L. Zhang, E. Suh, D. Lin, C. Dagdeviren.
Sponsorship: This work was supported by NSF CAREER: Conformable Piezoelectrics for Soft Tissue Imaging (grant no. 2044688), NSF Graduate Research Fellowship Program under grant no. 2141064.

Ultrasound is pivotal for breast cancer diagnosis, but challenges limit its integration with wearables, especially for large curvilinear organs. We've introduced a breakthrough: the cUSBr-Patch, a conformable ultrasound breast patch. This wearable offers standardized, reproducible image acquisition across the entire breast, reducing operator reliance and transducer compression. The honeycomb-shaped patch, guided by an easy-to-use tracker, enables large-area, deep scanning, and multiangle breast imaging. Using a piezoelectric crystal [Yb/Bi-PIN-PMN-PT], our in vitro and clinical trials achieved a contrast resolution of ~3 dB and axial/lateral resolutions of 0.25/1.0 mm at 30 mm depth. This allows the observation of small cysts (~0.3 cm) in the breast. Our technology provides a noninvasive method for real-time tracking of dynamic soft tissue changes, marking a significant advancement in ultrasound for breast tissue scanning within a compact wearable form.substrate. The biostable nature of our devices enables chronic and responsive delivery for the treatment of intracranial tumors, and our results highlight the microfabrication and early characterization of the device performance in-vitro.

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Research Interests:
Actuators, BioMEMS, Electronic devices, Energy harvesting devices & systems, Medical devices & systems, MEMS & NEMS, Sensors, Transducers, Other Research Interests, Ultrasound transducers.

A Quantum Tunneling-based Breathalyzer

3.19

J. O'Leary, C. Davis, M. Andrade, E. Andrews, D. J. Paul, R. Ram, A. Akinwande, F. Niroui

Sponsorship: MIT EECS, 6.2540 class

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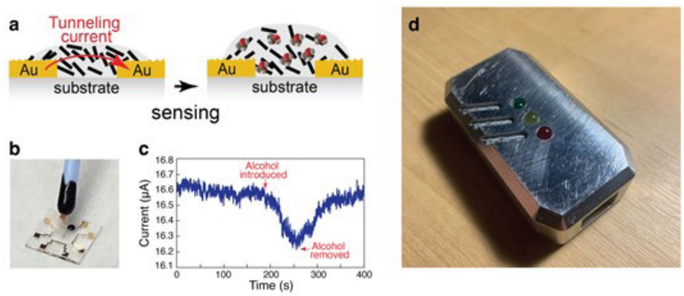
Many students at MIT, and in college more broadly, overconsume alcohol and social events. There are limited ways for these young adults to get a quantitative indicator of their level of intoxication. Therefore, in this project, we developed a compact handheld breathalyzer using a sensor that operates based on modulation of quantum tunneling current. The device is composed of a composite made out of graphene nanoplatelets dispersed in a matrix of ethyl-cellulose. The composite is dispensed through drop-casting onto a lithographically patterned interdigitated electrode and then annealed. Once exposed to alcohol, the polymer matrix will swell, increasing the distance between the neighboring graphene platelets, causing an increase in the tunneling distance and hence a decrease in the tunneling current (Figure 1a-b). This decrease in current corresponds to the detection of the analyte of interest. Once the analyte is removed, the current recovers. An example is shown in Figure 1c. These changes in current allow us to detect the presence of alcohol, which we indicate to users with status LEDs. We then packaged the sensor into a handheld system, housed in a machined aluminum case and controlled using an Arduino. The fully packaged system is shown in Figure 1d.



◀ Figure 1: a) Schematic illustration of the tunneling alcohol sensor and its mechanism of operation. b) Photo of a fabricated sensor. c) Example current-time trace of a sensor detecting alcohol. d) Photo of the fully packaged breathalyzer.

Continuous Lentiviral Vector Harvesting from HEK 293 Perfusion Culture using Spiral Inertial Microfluidic Technology

3.20

A. Bevacqua, F. Liu, D. H. Park, J. Chen, J. Han

Sponsorship: Food and Drug Administration (1R01FD007480-03) and NSF Graduate Research Fellowship

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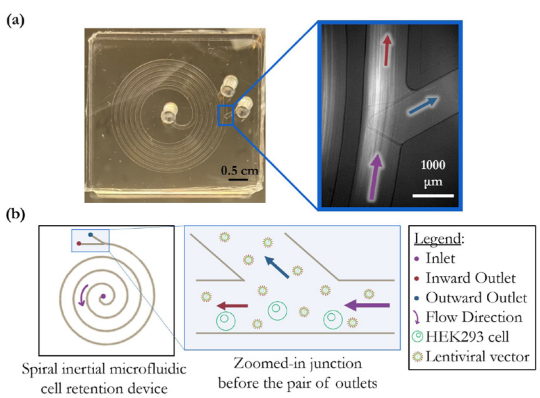
Research Interests:
Biological devices & systems
BioMEMS, Microfluidic devices & systems.

Lentiviral vectors are popular gene delivery tools used to create gene and cell therapies. With these therapies costing patients over $400,000 per dose, research to develop high-concentration, high-yield viral vector manufacturing strategies has a pivotal role in advancing therapy commercialization efforts and lowering costs. Viral vectors are manufactured in HEK 293 cell perfusion culture and a cell retention device is used to separate viral vectors from cells. Many membrane-based cell retention devices used in industry struggle to maintain high product recovery over long production runs. We used a spiral inertial microfluidic cell retention device to carry out high-recovery harvesting from perfusion culture. We achieved 7 days of continuous lentiviral vector production and harvesting with a peak, unconcentrated, functional titer of 10^8 transducing units/mL, with a high recovery throughout production. Advancing viral vector harvesting strategies will expand treatment accessibility.



◀ Figure 1: (a) The spiral inertial microfluidic device inertially focuses cells to the spiral's inward outlet (red arrow). (b) Viral vectors are continuously harvested through the outward outlet (blue arrow), since their motion is unbiased by inertial focusing.

Session 4: Energy, Power & Sustainability

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Research Interests:
Batteries, Electronics, Energy, Power management, Power electronics and Magnetics.

High-Performance High-Power Inductor Design for High-Frequency Applications

4.01

M. V. Joisher, R. S. Bayliss, M. K. Ranjram, R. S. Yang, A. S. Jurkov, D. J. Perreault
Sponsorship: MKS instruments, Inc.

Magnetic components significantly impact the performance and size of power electronic circuits. This is especially true at radio frequencies (rf) of many MHz and above. As operating frequencies rise, the impact of losses in both copper and core becomes a substantial hurdle. Hence, in the high-frequency (HF, 3-30 MHz) range, coreless (or "air-core") inductors are conventionally preferred over cored magnetics. These inductors have typical Q (Quality factor: a measure of an inductor's efficiency) of 200-500 and are often the major contributor to a system's overall loss and size. Even when they can achieve high-Q, air-core inductors can induce electromagnetic interference (EMI) and eddy current loss in surrounding components, thus limiting system miniaturization. With recent advances in high frequency magnetic materials, there is interest in the design of cored inductors to achieve improved combinations of size and loss. This work investigates an approach to achieving high power, high-frequency, high-Q cored inductors. The proposed design approach leverages high-frequency magnetic materials, core geometry, quasi-distributed gaps, and a shield winding to realize high-frequency inductors that emit little flux outside their physical volume. Design guidelines for such inductors are introduced and experimentally verified with a 500 nH inductor (Q = 1150) designed to operate at 13.56 MHz with a peak ac current of up to 80 Amps. Such high-Q inductors can enhance the performance of the overall circuit and enable space-efficient designs for high-frequency high-power applications (e.g. rf plasma generation, HF wireless power transfer).

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Research Interests:
2Electronic devices, Electronics, Energy, Field-Emitter devices, GaN, Integrated circuits, Power electronics.

High-Speed Controllable Transformation Matching Network for Enhanced RF Power Delivery in Semiconductor Plasma Processes

4.02

K. N. Rafa Islam, D. J. Perreault
Sponsorship: Confidential

Efficient and controlled delivery of radio-frequency (rf) power for semiconductor plasma processing typically relies upon tunable matching networks to transform the variable plasma load impedance to a fixed impedance suitable for most rf power amplifiers. Plasma applications require fast tuning speed from the matching networks while operating at high frequency range. However, it is difficult to meet the requirements for many semiconductor plasma applications with conventional impedance matching solutions due to their limited response speeds. This slow speed comes from the presence of mechanical components in the matching network, since they can be tuned only mechanically. This work introduces a novel Controllable Transformation Matching Network (CTMN) intended to address the need for high-speed, tunable impedance matching. Here we show a controllable switching network at the core of the CTMN, leveraging switched-mode energy processing to provide high efficiency and exceptional control speed over a wide operational range.

The CTMN's design employs a two-port switching network coupled with a high-Q passive network, enabling rapid voltage adjustments and dynamic reactance tuning to swiftly accommodate both resistive and reactive load variations. Control strategies are introduced to maintain zero-voltage switching within the CTN as needed to minimize switching losses. This approach is substantiated through simulations, which indicates the CTMN's capability to achieve precise impedance matching with the potential for substantially faster response times (microseconds range) than traditional systems. It is anticipated that the proposed approach will enable ultra-fast, high-efficiency tunable impedance matching to address the needs of modern plasma systems.

On-the-Fly Learning for DNN Monocular Depth Estimation

4.03

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

Sponsorship: This work was funded by the National Science Foundation, Real-Time Machine Learning program grant no. 1937501, the MIT-Accenture Fellowship, the Huang Phillips Fellowship, and a gift from Intel.

Monocular depth estimation with deep neural networks (DNNs) is critical for resource-constrained robots to avoid using power-hungry depth sensors. Since DNNs are known to perform poorly when the deployment environment is different from its training environment, we design a computation-efficient framework where the robot can adapt a monocular depth estimation DNN to a new environment on-the-fly. This form of training is compute and storage-limited, online (sequential video inputs), and self-supervised, making it challenging to accomplish with conventional training practices. As training on every image is computation-intensive, we propose using a novel acquisition function to select a subset of images for the DNN to train on. This function for training data selection is based on a unique combination of uncertainty, diversity, and self-supervised loss quality. With reducing the frequency of training to only 2.5% of the time instead of at every timestep as is conventionally done, leveraging our acquisition function achieves 5.6% higher accuracy on the explored dataset and 3.6% higher accuracy on the unexplored dataset compared to a fixed-periodic image selection strategy using the same number of training images. In addition, we require a buffer capacity of only 9 images, making it more suitable for storage-limited platforms compared to existing works that require two orders of magnitude more capacity. Finally, we deploy MC-dropout on the final layer of the DNN to efficiently estimate the uncertainty term in the acquisition function, which reduces the computational cost of the acquisition function by up to 9.1× compared to the traditional ensemble method.

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Large-Signal Characterization of Piezoelectric Resonators for Power Conversion

4.04

A. K. Jackson, J. W. Perreault, J. H. Lang, D. J. Perreault

Sponsorship: Texas Instruments, NSF Graduate Research Fellowship

As the world moves towards increased electrification and integration of renewable energy sources, there is a need for smaller, lighter, and more efficient power converters. Magnetics are key components of conventional power converters, but they are often the bottleneck to achieving high power density due to their size, weight, and poor performance at small sizes. Piezoelectric devices, when operated in their inductive regime, can serve a purpose similar to that of magnetic components and offer favorable scaling properties as components are miniaturized. Several sources have demonstrated the viability of piezoelectric-based power converters, but selection of the optimal material and component size is limited by a lack of data on the performance of these materials at high drive levels. This work aims to fill that gap by collecting data to examine the variation in resonator quality factor, a geometry-independent metric for the power processing efficiency. The quality factor is measured across a range of drive levels for multiple resonator sizes, frequencies, and materials. By normalizing the collected data against resonator geometry, material trends are derived that can predict resonator losses under high drive levels, offering more insight into realistic converter operation than the currently available small-signal data sheet values. Based on these trends, implications for converter efficiency and selection of material and dimensions are discussed.

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Low-Leakage Transformer Design for High Voltage Pulse Generation

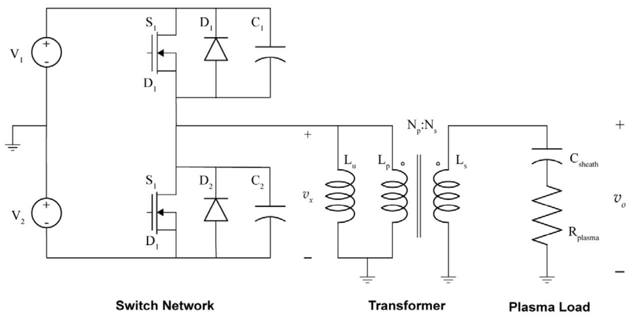
4.05

J. Estrin, D. J. Perreault

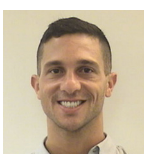
Sponsorship: MKS Instruments Inc.

There is growing interest in employing pulsed waveforms, rather than sinusoidal, for capacitively coupled plasma generation for semiconductor manufacturing, enabling improved etching and plasma-enhanced chemical vapor deposition. These high-voltage, high-frequency waveforms are traditionally built with stacked devices or multilevel inverters, which are bulky and demand complex control.

In this work, a simpler approach is developed, in which a single-level inverter is used to realize a pulsed waveform at a convenient voltage level, and then stepped up using a transformer, enabling the use of fewer, low-voltage devices. The transformer must provide scaling with sufficient fidelity across the wide frequency bandwidth comprising the pulsed waveform. A transmission line-based transformer is developed that minimizes parasitics, particularly leakage inductance, by optimizing the structure for minimum leakage fields. This simple, small design enables easy adoption in plasma chambers.



◄ Figure 1: The circuit topology for the bias supply drives, with low voltage devices used as an inverter, an autotransformer, and an equivalent plasma load.



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In-situ Monitoring of GaN Power Transistor Parameters Under Continuous Hard-switching Operation

4.06

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Sponsorship: Analog Devices

Gallium Nitride (GaN) transistors have garnered attention in the field of power electronics due to their high-speed switching capabilities, low on-resistance, and excellent thermal properties. GaN devices are commonly used in applications like power supplies, electric vehicles, and Radio Frequency (RF) amplifiers. However, their switching reliability is a crucial consideration.
There are many challenges to be addressed to improve GaN switching reliability, including robust gate drive circuitry, effective thermal management, and protection against voltage and current spikes during switching events. Additionally, GaN transistors can be sensitive to voltage and temperature stresses, requiring careful consideration in design and application.
The aim of our work is to devise techniques to continuously monitor GaN Power transistor parameters under hard-switching operation, and to investigate the role of switching transitions on device parameter drift. To this end, we have constructed a unique experimental setup while taking thermal management into account. The setup is capable of repeating the Double-Pulse Testing Technique multiple times and measuring device parameters in-situ as well as maintaining device temperature to avoid self-heating.

In summary, GaN transistors offer significant advantages in terms of switching reliability, especially in high-frequency and high-power applications. However, their successful deployment demands proper design, thermal management, and protection measures to ensure long-term performance and reliability in various electronic systems.

Next-Generation High-Performance GaN Complementary Technology

4.07

P. K. Darmawi-Iskandar, Q. Xie, J. Niroula, T. Palacios

Sponsorship: Samsung Electronics Co., Ltd. (033517-00001), Qualcomm Inc. (MAS-492857), and National Defense Science and Engineering Graduate Fellowship

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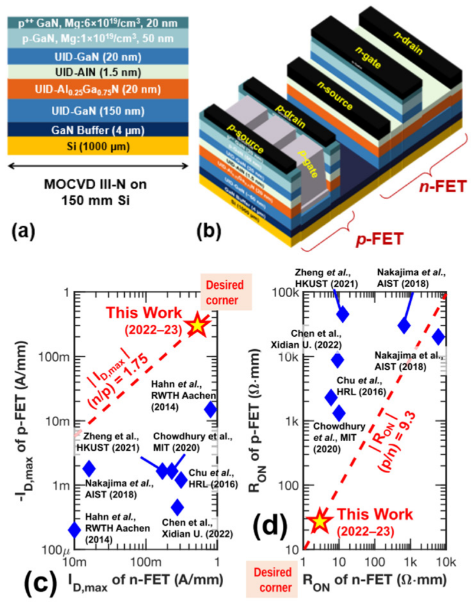
Research Interests:
2D materials, Electronic devices Electronics, GaN, III-Vs, Integrated circuits, Nanomanufacturing, Nanomaterials, Nanotechnology, Si.

Gallium Nitride (GaN) complementary technology (CT) has the potential to offer record levels of efficiency, power, and compactness for data centers, power adapters, electric vehicles (EVs), and 5G/6G telecommunication systems. Over the years, significant research has been conducted on GaN-CMOS at MIT and worldwide, especially for high-voltage power management applications. However, the scaling limits of GaN CMOS for lower voltage applications have not been fully explored. Understanding the scaling limit of GaN is important for low voltage power management, mixed-signal IC, and RF amplifier applications.

This work seeks to explore the low voltage scaling limits of enhancement-mode n-channel p-GaN-gate HEMTs, through the combination of the following approaches: (1) material epitaxy, especially the polarization-inducing barrier; (2) novel transistor architecture to ensure good gate control at short channels; (3) improved processing to achieve aggressive scaling in these transistors.



▲ Figure 1: Highly scaled GaN complementary technology (CT). (a) Epitaxial structure. (b) Device structures of p-FET and n-FET based on the same GaN-on-Si platform as illustrated in Fig. 1(a). (c)(d) Benchmark of GaN CT transistors.

First Demonstration of Optically Controlled Vertical GaN Power finFETs

4.08

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Sponsorship: Office of Naval Research (Grant No. N00014-22-1-2468)

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Research Interests:
Electronic devices, Electronics, GaN, III-Vs, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Power Management.

In recent years, the boost in consumer electronics and data centers has increased the electricity demand. The delivery and transformation of power though electric grids require 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, which can lead to more reliable systems with reduced costs. However, most optically triggered devices require the use of complex and expensive UV lasers due to low optical responsivities. In this work, we have demonstrated optically controlled vertical GaN transistors with $J_{DS} > 90 A/cm^2$ at $V_{DS} = 3V$ under an illumination intensity of 1W, which translates into a high optical responsivity $> 10^5$ A/W, allowing such devices to be triggered by light emitting diodes. The initial results have demonstrated potential of these devices for future high-power electronics.

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Research Interests:
Energy, Power Management.

Low-Power Robot Platforms for Development of Energy-Efficient Algorithms for Pose Estimation, Mapping, and Activity Planning

4.09

J. Posada, S. Sudhakar, S. Karaman, V. Sze
Sponsorship: MIT Department of Aeronautics and Astronautics

Small-form autonomous robots are becoming quicker and more performant, giving them the potential to change the way we approach missions like environmental monitoring, search and rescue, and medicine. However, in order to enable long-duration missions, these robots must be extremely energy-efficient to compensate for their small batteries. Unlike in larger robotic systems, the energy spent sensing, mapping, estimating pose, and motion planning on small-form robots is comparable to energy spent on their actuators. In this work, we have used a small robotic car to begin collecting real-time computation and actuation power data using onboard power sensors and real-time pose data using a motion capture system. We have set a power consumption baseline for this autonomous robot of 0.41 W over a 0.60 W idle when moving at 0.32 m/s that will be used to compare the power consumption of different path-planning algorithms on a common platform. We will also test early-termination algorithms that stop computation on a path-planner early based on estimated energy consumption over execution of the path. Future work includes experiments using different path-planning and early-termination algorithms, and work on including computation energy in mapping and pose estimation algorithms optimized for total energy consumption. This research is novel in considering the energy consumption of computing hardware when optimizing path-planning algorithms for total energy consumption, and aims to demonstrate a new method for increasing the lifetime of severely energy constrained autonomous robots.

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Research Interests:
Nanomaterials, Nanotechnology, Photonics, Photovoltaics.

Optimization Strategies of Photovoltaics-powered Green Hydrogen Production

4.10

X. Wang, X. Liu, L. Zhang

Green hydrogen production powered by photovoltaics provides a clean solution for energy conversion and storage. The key parameter of photovoltaic electrolysis (PV-EC) system is the solar-to-hydrogen (STH) efficiency. Previous studies have been mostly focused on improving the efficiency of each system individually using multi-junction PV materials, catalysts and electrolytes. However, the coupling between photovoltaic and electrochemical devices is still elusive to achieve high STH efficiency in a system level. In our study, the optimization strategies of PV-EC systems are demonstrated to approach thermodynamic limit (26.6%) for green hydrogen production. First, we list three design parameters for modeling, namely number of PV, number of EC and the area ratio between PV and EC. Then we model the crystalline silicon PV coupled with a real EC system. The STH efficiency varies under different PV and EC combinations. The STH efficiency map clearly defines three regions indicating the engineering space for PV-EC coupling, Tafel slope and area ratio. The optimization strategies presented in this study can lead to further advancements in coupled PV-EC systems with well-controlled performance for different conditions.

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Research Interests:
2D materials, Artificial Intelligence, Electronic devices, Machine Learning, Lab automation.

AI-Empowered Automatic 2D Material Image Sampling and Scoring System

5.01

M.-C. Chen, A.-Y. Lu, S. Liu, J. Kong
Sponsorship: SRC JUMP 2.0 SUPREME Center

As the miniaturization of transistors progresses, the inherent physical limitations of silicon-based semiconductors, including leakage current, short-channel effect, and carrier mobility, are beginning to surface. Two-dimensional (2D) materials present a promising solution for further downsizing while preserving control over electronic properties. In the development of 2D materials, precise process control of chemical vapor deposition (CVD) is critical to the outcome, and our group has leveraged machine learning (ML) to expedite the process in several aspects, including literature text mining, recipe optimization, and unraveling correlation between Raman and photoluminescence spectra. For recipe optimization of our autonomous CVD synthesis platform, it is important to provide reliable feedback of CVD results to the recipe optimization algorithm. In this project, we aim to design an AI-empowered automatic 2D material image sampling and scoring system that can capture optical images of the 2D materials from CVD substrates, thereby avoiding human bias in selecting better crystals. The scope of this automated system starts at navigation of the linear motion stage to transferring the sample under the microscope, perform fine autofocus along the z-axis, taking images according to strategically designed sampling pattern and executing vignetting correction and stitching, all the way through image recognition with FastSAM, pattern statistics, and generating a final single score for each experimental result. Multiple independent functions including linear stage control, sample edge and angle detection, image processing, and FastSAM crystal recognition have been completed, and we are currently working on system integration. This system will enhance the integration of automatic characterization branch for our autonomous CVD platform and accelerate the further development of 2D materials.

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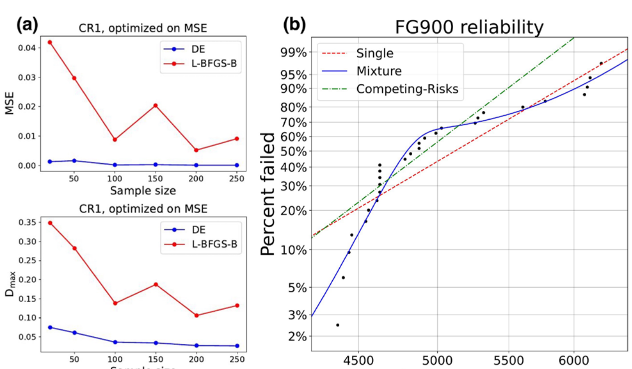
Research Interests:
Machine Learning, Photonics, Quantum devices, Reliability, Packaging and Heterogeneous Integration.

Identification of Multiple Failure Mechanisms for Device Reliability using Differential Evolution

5.02

U. Chakraborty, E. Bender, D. S. Boning, C. V. Thompson
Sponsorship: SRC

Assessing the reliability of electronic devices, circuits and packages requires accurate lifetime predictions and identification of failure modes. However, the common assumption of a single failure mechanism usually leads to inaccurate reliability estimates. In this work, we demonstrate a new method for extracting underlying failure mechanism distribution parameters from data corresponding to a combined distribution of two distinct failure mechanisms. We implement differential evolution (DE) for parameter identification in competing-risks and mixture models and show that it outperforms the best-known method in the literature (L-BFGS-B), especially at small sample sizes. On industrial ball grid array data, our approach provides up to 92% reduction in mean squared error, 7% increase in log-likelihood and 61% decrease in maximum absolute error. Similar improvements are seen on ring oscillator frequency degradation data from lab experiments. Finally, we show how our method can be used to identify specific physical failure mechanisms from the temperature-dependence of the extracted parameters.



◀ Figure 1: (a) Mean squared error of DE vs L-BFGS-B across different sample sizes for a competing-risks model. (b) Single Weibull, mixture, and competing-risks model fits to Xilinx ball grid array failure data.

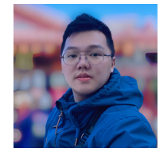
Universal Transferred Process for 2D materials

5.03

S. He, Z. Hennighausen, J. Kong

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

Two-dimensional (2D) materials have garnered significant attention due to their exceptional properties, but preparing with controllable thickness and usable surface area is still challenging. Numerous techniques have emerged for synthesizing high-quality and large-area 2D materials. Among these methods, chemical vapor deposition (CVD) has shown promise, offering superior control over film thickness and uniformity, making it a reliable technology for wafer-scale manufacturing. On the other hand, the typical wet transfer method using PMMA presents a potential solution for transferring 2D materials in large-scale. However, it faces limitations when transferring CVD-synthesized 2D materials from the growth substrate to the target substrate over large areas while maintaining clean surface. To overcome these challenges, we introduce a universal transfer process to keep clean surface using other polymers within a vacuum environment. Comparing wet-transfer and roll-to-roll transfer with vacuum dry transfer. Furthermore, we investigate the different surface situation of 2D materials using different polymers under atmospheric and vacuum environment. Our proposed method opens new possibilities for residue-free 2D materials on a large scale, with potential applications under diverse environments.



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

Controllable Vapor-phase Growth of Multilayer h-BN on Insulator

5.04

K. Zhang, Z. Hennighausen, H. Liu, J. Park, J. Kong

Sponsorship: The U. S. Army Research Laboratory and the U. S. Army Research Office under contract/grant number W911NF2320057.

Multilayer hexagonal boron nitride (h-BN) is highly desirable as an ideal 2D insulator for the fabrication of two-dimensional (2D) van der Waals (vdW) heterostructures and superior electronic/optoelectronic devices. However, achieving controllable synthesis of high-quality, large-area multilayer h-BN films, ranging from a few to dozens of layers, remains a challenge. Here, we employ a vapor-phase growth method to synthesize large-area multilayer h-BN films directly on insulator substrates (such as quartz or sapphire), using a Fe-Ni-B (Fe-B) alloy and nitrogen gas as precursors. The Fe-Ni-B alloy serves a dual purpose: it provides the boron source and catalyzes the reaction with nitrogen to form h-BN at a high temperature. Furthermore, we use an ice-assisted method to transfer the grown multilayer h-BN films onto arbitrary target substrates, thereby avoiding contamination from polymers or chemical agents. The outcome of the research efforts here will enable us to construct large-area, high-performance 2D functional heterostructures and devices.

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Research Interests:
2D materials.

Strain Relaxation Engineering by Thin Amorphous Carbon in the Remote Epitaxy of III-V Materials.

5.05

S. H. Cho, K. Lu, N. M. Han, H. Kim, J. Kim

Sponsorship: AFRL (FA9453-18-2-0017 and FA9453-21-C-0717), DARPA (029584-00001), DOE (DE-EE0008558), LG, Umicore, LG electronics, Rohm Semiconductor

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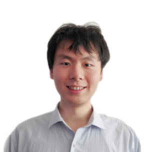
Research Interests:
2D materials, Electronic devices, Electronics, Energy, Energy harvesting devices & systems, GaN, III-Vs, Integrated circuits, Nanotechnology, Photovoltaics.

Remote epitaxy has emerged as a promising method for the fabrication of wafer-scale freestanding membranes of single-crystalline semiconductors. While offering several advantages, it also possesses challenges when compared to direct epitaxy. For growing epitaxial layers on the same or lattice-matched substrates, remote epitaxy still produces lower material quality, with higher defect density, due to the attenuated atomic registry from the substrate. Here, we investigate the impact of thin amorphous carbon (TAC) on the material quality of remote heteroepitaxial InGaAs layers grown on GaAs substrates, and explored the strain relaxation of heteroepitaxial InGaAs on engineered in-situ aGr growth on GaAs substrate. To address this issue, we demonstrated reduction of threading dislocation density by a few orders of magnitude of remote epitaxial layers, by reducing dislocations through strained layer superlattice (SLS) and thermal cycle annealing (TCA). This work aims to achieve high-quality heteroepitaxial single-crystalline membrane by utilizing remote epitaxy, thus expanding its potential applications in the field of semiconductor technology.



Spike timing Dependent Plasticity in Electrochemical Ionic Synapses

5.06

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Sponsorship: MIT Quest for Intelligence program

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Research Interests:
2D materials, Artificial Intelligence, Displays, Electronic devices, Spintronics.

Spiking neural networks (SNNs) have emerged as a promising architecture for machine intelligence due to their potential for highly efficient computation. However, realizing these networks in hardware presents unique challenges, particularly regarding the development of programmable synaptic devices capable of achieving time-dependent weight updates. Electrochemical ionic synapses (EIS) provide a promising solution, with their high energy efficiency, low variability, and rich ionic dynamics. In this work, we leverage the strong nonlinearity of EIS to implement various forms of spike-timing-dependent plasticity (STDP), a fundamental mechanism underlying learning in biological systems. Our results showcase STDP timescales ranging from milliseconds to nanoseconds, enabling high computing throughput. By designing appropriate pre- and post-synaptic neuron signals, we demonstrate that different forms of the STDP function can be deterministically predicted and emulated. Additionally, heterogeneous STDP within an array can be realized, where synapses from a single pre-neuron connecting to different post-synaptic neurons can exhibit distinct learning rules. Furthermore, we observe lower variability compared to existing hardware STDP implementations. Overall, our findings suggest that EIS could enable highly efficient SNN hardware implementations with high throughput. We believe this would further advance the development of bio-inspired computing and intelligent systems.

Laser-assisted Failure Recovery for Robust Dielectric Elastomer Actuators in Aerial Robots

5.07

S. Kim, Y.-H. Hsiao, Y. Lee, W. Zhu, Z. Ren, F. Niroui, Y. Chen

Sponsorship: NSF(FRR-2202477), MathWorks Engineering Fellowship

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Research Interests:
Actuators, Systems, Robotics.

Insects maintain remarkable agility after incurring injuries while most of the robots lack animal-like robustness against damage. Dielectric elastomer actuators (DEAs) are a class of muscle-like soft transducers that have enabled nimble robotic locomotion. However, unlike muscles, DEAs suffer local dielectric breakdowns that often cause global device failure. These local defects limit DEA performance, lifetime, and size scalability. Here, we developed DEAs that can endure more than 100 punctures while maintaining high bandwidth and power density for supporting flights. We also demonstrated a laser-assisted repair method for isolating the critical defects and recovering performance. These results culminate in an aerial robot that can endure critical actuator damage while maintaining hovering capability. Our work highlights that soft robotic systems can embody animal-like resilience—a critical biomimetic capability for future robots to interact with challenging environments.

◀ Figure 1: A photograph illustrating a damaged biomimetic robot module that landed on a cactus.

Additively Manufactured, Monolithic, Self-Heating Microfluidic Devices

5.08

J. Cañada, L. F. Velásquez-García

Sponsorship: This work was sponsored by the Empiriko Corporation (Newton MA, USA). The project that gave rise to these results received the support of a fellowship from "la Caixa" Foundation (ID 100010434). The fellowship code is LCF/BQ/EU21/11890155.

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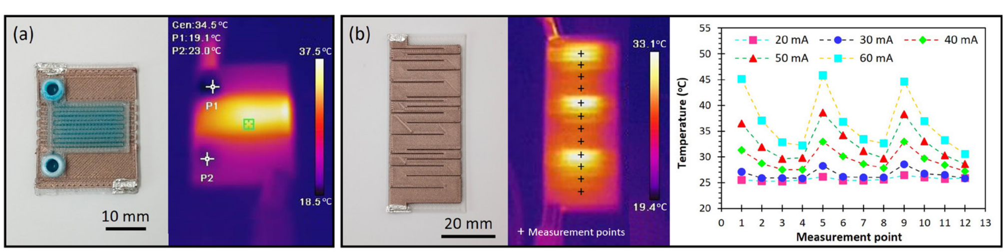
Temperature regulation is critical in many microfluidic applications, e.g., to sustain living organisms, to trigger specific chemical reactions. Temperature regulation techniques often involve the use of bulky equipment, and integrated cooling-heating systems rely on costly fabrication processes.

We propose the use of multi-material extrusion 3D printing to create monolithic, self-heating microfluidic devices. The proof-of-concept devices are fabricated using two polylactic acid-based materials: one dielectric, used to produce the microfluidic channels; and one conductive, used to fabricate heat-generating resistors. The ability of material extrusion to create custom, intricate patterns enables the fabrication of complex, application-specific designs of both the microfluidic structure and the heating system. This technology can greatly impact the yield of microfluidic research by enabling the fast, inexpensive, in-house fabrication of custom, self-heating microfluidic devices.



▲ Figure 1: (a) Optical and thermal images of a 3D-printed, self-heating microfluidic device, and (b) Optical and thermal images, and measured temperature profiles of a custom 3D-printed heater (J. Cañada and L. F. Velásquez-García, PowerMEMS, 2023).

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Research Interests:
Artificial Intelligence, Electronic devices, Electronics, Machine Learning, Nanomanufacturing.

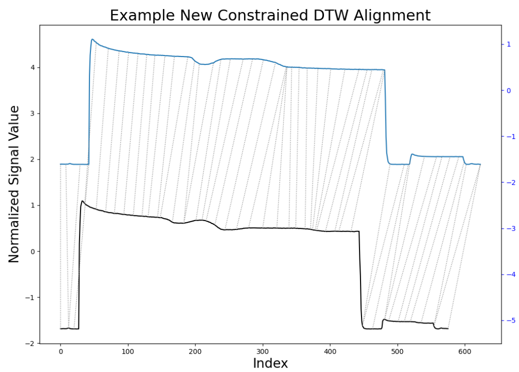
Dynamic Time Warping Constraints for Semiconductor Processing

5.09

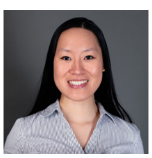
R. Owens, F. Sun, C. Venditti, D. Blake, J. Dillon, D. S. Boning

Sponsorship: Analog Devices, Inc.

Semiconductor fabrication monitoring has become increasingly complex, and nonlinear variations in signal timing have made anomaly detection more difficult. We present a new method for preprocessing semiconductor sensor signals that improves anomaly detection model performance. The proposed method uses dynamic time warping (DTW) and semiconductor processing domain knowledge to address the problem of nonlinear signal alignment. New constraints for the DTW algorithm are developed based on semiconductor processing recipe steps. In tests using the kernel density estimation (KDE) fault detection method on labelled plasma etch datasets, the new constraints consistently outperform comparison methods. This demonstrates the usefulness of DTW, and specifically the new DTW constraints, as a preprocessing method for semiconductor sensor signals used in anomaly detection.



◀ Figure 1: Alignment of two optical endpoint signals. The grey dotted lines indicate mappings between the signals which were generated using the proposed constraints on the DTW algorithm.



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

Development of Ultra-Thin Perovskite Solar Module with Slot-die Printing

5.10

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Sponsorship: Tata Power Company Ltd. and U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy

Owing to their solution-processibility, perovskite solar cells (PSCs) promise to offer a flexible, lightweight, and highly efficient alternative to crystalline silicon solar cells (c-Si). PSCs are able to open markets for solar deployment not accessible with c-Si while maintaining price-competitiveness with existing technologies. However, there are technological challenges to be addressed before PSCs are ready for large scale manufacturing.

In contrast to the majority of research in PSCs which focuses on improving the stability and efficiency of small, spin-coated devices, this work aims to address challenges on the scaling and manufacturing front. Specifically, there exists a "scaling lag" which is seen when technologies are directly transferred from small devices to large area modules and manifests as decreased module efficiency and increased series resistance. In this work, slot-die coating is used to create large, 45cm2 modules on 125um thick polyethylene terephthalate (PET) substrates with 7.5 cm2 mini-modules exhibiting efficiencies of up to 7.4%. This process is the first working demonstration of a flexible, large-area PSC module fabricated with non-toxic solvents and establishes the baseline for the future transition to a 50um peelable module which can be laminated onto transparent fabrics. To demonstrate the economic feasibility of commercial production, a techno-economic analysis is performed using Monte-Carlo simulation techniques to ensure price-competitiveness with current established solar technologies. Levelized Cost of Electricity values for flexible PSCs can be as low as 2.24¢/kWh compared to 3.16¢/kWh currently seen with mono-PERC silicon panels.

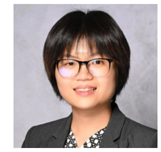
Successful demonstration of a flexible, large-area perovskite solar cell without toxic solvents will accelerate the industrialization of flexible photovoltaics. This would ultimately shift the solar landscape from mainly utility solar farms to a distributed model, further accelerating solar adoption.

Elucidating the Role of MOF Pore Size on OSN Performance of Microporous Polymer-based Mixed-matrix Membranes

5.11

W. Wu, T.H. Lee, G. Dovranova, A. Hernandez, Z. P. Smith

Sponsorship: ExxonMobil



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Organic solvent-based separations are ubiquitous in the chemical industry, but they often rely on energy-intensive processes. Membrane technology provides an energy-efficient alternative to offset the energy cost. However, developing highly selective membranes for organic solvent nanofiltration (OSN) has been a significant challenge due to the poor stability of polymers under aggressive solvent conditions. Mixed-matrix membranes (MMMs) based on fillers such as metal–organic frameworks (MOFs) with well-defined porous structures have shown promise in overcoming these limitations. While material design efforts have improved OSN performance with MMMs, the fundamental mechanisms behind the effects of filler incorporation on solvent transport are not yet fully understood. In this study, we aim to elucidate the effects of MOF pore size on OSN performance for microporous polymer-based MMMs.

A series of MOF nanoparticles with similar chemistry but systematically increasing pore sizes (UiO-6x-NH2 (x=6,7,8)) were chosen for this work. A carboxylic acid functionalized PIM-1 polymer (PIM-COOH) and the MOF nanoparticles were fabricated into thin-film MMMs using a newly developed spin-casting process followed by a crosslinking reaction. Dead-end permeation tests showed lower methanol permeability in all the MMMs compared to their polymer counterparts due to the restricted membrane swelling in the presence of MOF. The molecular weight cutoff (MWCO) of MMMs was probed through the permeation of dyes in methanol, revealing that the highest MWCO values were found for MMM samples with poor interfacial compatibility, indicating that unrestricted polymer swelling and defects need to be carefully controlled to enable MOF-based MMMs for OSN applications. For the MMMs with compatible interfaces, this study provides structure–property guidelines on the role of systematically increased MOF pore apertures and OSN separation performance.

Tungsten Bronzes forNeuromorphoc Computing: Can Lattice Strain Enhance Proton Migration in WO_3?

5.12

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Sponsorship: Max Kade Fellowship 2022 for M. Siebenhofer

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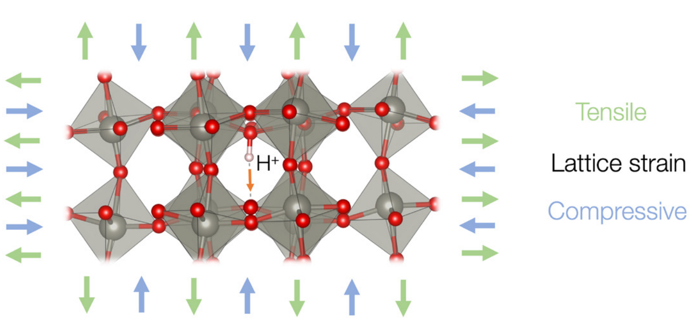
Batteries, Electronics, Energy Energy harvesting devices & systems, Fuel cells, MEMS & NEMS, Nanomaterials, Nanotechnology, Photovoltaics.

Tungsten bronzes are insertion compounds with the general formula M_xWO_3, where M (e.g. H, Li or Mg) is intercalated into WO_3. These compounds have a variety of applications, ranging from superconducting or electrochromic materials to catalysts and analog programmable resistors for artificial neural networks. For its application in neuromorphic computing, where the conductivity of WO_3 is modulated by ion intercalation, fast ion diffusion is key to obtain homogeneous ion distribution and fast switching between distinct resistive states. However, exact migration pathways in WO_3 are not well understood and novel strategies to enhance proton movement are desired. In this contribution, we report the results of ab-initio investigations on proton migration processes in WO_3. We identify favourable binding sites for protons and migration pathways through the lattice. Using the nudged-elastic-band method, we investigate energetic barriers for proton hopping in WO_3 and evaluate their modulation in structures under tensile and compressive strain. If successful, targeted introduction of lattice strain (e.g. by doping) may be essential to improve both neuromorphic and electrochromic devices..



◀ Figure 1: Tensile and compressive lattice strain present a potential tool to modulate proton migration in WO_3.

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2D materials, Artificial Intelligence, Displays, Electronic devices, Electronics, Field-Emitter devices, Integrated circuits, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors.

Defects Break the Self-Limiting Nature of the Room-temperature Atomic-layer Substitution for Growing Janus Monolayer Transition Metal Dichalcogenides

5.13

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Sponsorship: US Department of Energy (DOE), Office of Science, Basic Energy Sciences under Award DE-SC0020042.

Janus monolayer transition metal dichalcogenides (J-TMDs) are gaining an increasing attention because of various intriguing properties that arise from their unique asymmetrical structure. A low-energy-barrier room-temperature atomic-layer substitution (RT-ALS) approach has recently been developed to obtain J-TMDs. This method reliably converts either MS_2 or MSe_2 (M represents a metal atom) into MSSe-type J-TMDs with controlled out-of-plane dipole orientations. Theoretical calculations based on a perfect monolayer TMD lattice model have illustrated that the RT-ALS reaction is self-limiting, in which only the topmost layer of chalcogen atoms is substituted. However, it remains unexplored how the atomic defects in monolayer TMDs affect the RT-ALS reaction pathway and the resulting J-TMDs' crystal quality.

Herein, we studied the role of defects on the RT-ALS process using high-quality and defect-rich $MoSe_2$, synthesized by a recently devised defect-engineered growth approach, as starting materials. Very interestingly, we found that an increased defect density in the starting material breaks the self-limiting nature of RT-ALS, leading to the incorporation of S in the bottom atomic layer of the as-synthesized Janus MoSeS. Our results indicate a positive correlation between the qualities of starting material and resulting J-TMDs, and suggest a defect-mediated atomic substitution pathway that has not been considered before. Our study contributes to the understanding and optimization of J-TMD preparation strategies to make these materials ready for constructing novel electronics, photonics, and Moiré heterostructures in the future.

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2D materials, Microfluidic devices & systems, Molecular & polymeric materials, Nanomaterials, Thermal structures, devices & systems.

Continuum-Scale Modeling Strategies for Microstructure Formation and Evolution

5.14

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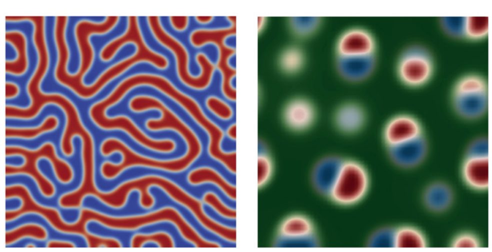
*Sponsorship: A*STAR*

Understanding the formation and evolution of microstructures is of immense interest for engineering the properties and performance of advanced materials in a variety of applications. Phase-field models (PFMs) provide a convenient and extensible framework for studying multiphase and multi-component systems at length and time-scales otherwise inaccessible to meso- and molecular-scale methods such as molecular dynamics. PFMs introduce and track the evolution of one or more auxiliary variables (the phase field) whose values specify which phase is in each spatial location in the system at a given time. Depending on the application, PFMs can be solved by themselves or coupled to additional species, momentum, and energy conservation equations to suitably describe the physics of the process/system. The descriptive capabilities of PFMs have resulted in their widespread use in many areas of science and engineering including fluid dynamics, solidification, fracture mechanics, structure formation, and tumor growth modeling. The use of PFMs across multiple disciplines has resulted in relevant advances often being siloed, taking time to be disseminated across the literature. In this work, a framework for systematically conceptualizing PFMs (and their various extensions) is first outlined to inform their use and development. Subsequently, multiple case studies of increasing physical and computational complexity are presented to demonstrate the capabilities and limitations of using PFMs. All code for numerical simulations and additional details on the mathematics and physics of PFMs will be made available on a public GitHub repository. The developed resources will help accelerate the use of computational methods for developing advanced nanomaterials.



◄ Figure 1: Exemplar phase-field simulations of a binary (Left) and ternary (Right) polymer blends.

Exploring the Limits of Bubble Capture and Transport through Porous Aerophilic Membranes

5.15

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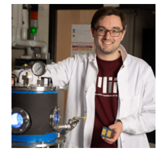
Sponsorship: Lincoln Laboratories



Hydrophobic membranes are a common tool to capture unwanted bubbles in applications ranging from microfluidics, to gas evolving electrochemical systems, to bioreactors for foam prevention. In these, rapid bubble capture on the order of milliseconds is required as longer times will lead to bottlenecks. In this work we seek out the mechanisms behind capillary driven transport of a bubble through a hydrophobic membrane., we fabricate super-hydrophobic nano-structured silicon membranes with a DRIE etching technique with variable hole diameter and spacing. Through altering physical parameters of the membrane, we have identified three different limiting regimes of bubble capture through a membrane. With the use of scaling laws, we can predict the transition between regimes. From this a predictive non-dimensional phase-map is built that can be used to design new membranes. At the high-end, bubble capture times under 1ms have been recorded for millimetric bubbles. This work elucidates the limiting factors behind bubble transport through a membrane, and its results can be translated to applications where bubble capture is required.

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Electric Field-induced Rapid Growth of Single-Crystal Graphene

5.16

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Sponsorship: The Semiconductor Research Corporation Center 7 in JUMP 2.0 (award no. 145105-21913)

Chemical vapor deposition (CVD) has emerged as an effective method for the synthesis of high-quality and large area graphene. However, achieving rapid synthesis of high-quality, single-crystal graphene remains a challenge. Recent studies have shown that the synthesis of single-crystal, high-quality graphene is achievable utilizing 500nm-700nm single-crystal Cu(111) film on sapphire as catalyst and substrate. Nevertheless, the severe evaporation of the thin copper film during high-temperature growth has always been an issue. It has been reported that applying electric field between the copper substrate and a counter electrode could accelerate graphene growth, which can significantly shorten the duration of exposure of thin Cu(111) film to high temperature. In our study, we combined these two methods to use their respective advantages for the rapid synthesis of single-crystal, high-quality graphene. We applied electric field to both low pressure and ambient pressure chemical vapor deposition of graphene, while using single-crystal Cu(111) film on sapphire as the catalyst and substrate. We aim to shorten the growth time for low pressure CVD to within five minutes, and for ambient pressure CVD to within thirty minutes, for growing complete single-crystal graphene film on Cu(111). We believe that this integrated method holds promise for enhancing the efficiency and accessibility of high-quality graphene synthesis.

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Mixed-dimensional Integration of 3D Complex-oxides on 2D Materials via Remote Epitaxy

5.17

J.-E. Ryu, S. Lee, K. S. Kim, X. Zhang, C. S. Chang, M.-K. Song, J. Kim

Sponsorship: IARPA (6948435)

A novel method for growing single crystalline three-dimensional (3D) complex-oxide layers on atomically thin graphene interlayer, known as remote epitaxy, has been proposed as the future of heterogeneous integration strategies. The technique enabled growth of high-quality thin film and perfect transfer of the grown film. However, However, the transfer of graphene, which is a typical process for forming a graphene interlayer on growth substrates, inevitably induces a significant number of unwanted defects such as wrinkles, holes, process residues, and interfacial contamination. Such defects can disturb the remote interaction between the substrate and epitaxial layer through graphene, reducing the crystal quality and exfoliation yield of membranes. Recently, we developed a direct synthesis method for growing alternative two-dimensional (2D) materials, such as transition metal dichalcogenides (TMDs), on growth substrates, which enables the creation of wafer-scale, defect-free 2D interlayers for reliable remote epitaxy of high-quality spinel CoFe2O4 (CFO) and garnet Y3Fe5O12 (YIG) thin films. The atomically clean van der Waals interfaces formed by direct growth of TMDs onto growth substrates serve as an ideal platform for high-throughput production of single-crystalline, freestanding complex-oxide membranes that can be released from substrates, but also for facile fabrication of a new class of mixed-dimensional heterogeneous systems that exhibit emergent physical phenomena at well-defined 3D/2D heterointerfaces. Based on this unique approach to integrating mixed-dimensional heterostructures in a scalable and controlled manner, we demonstrate new device concepts that take advantage of unusual physical coupling or decoupling at exotic 3D/2D interfaces, which are both fundamentally intriguing and practically useful.

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

Low Temperature Wafer-scale Synthesis of 2D TMD Material for Back-end-of-line Heterogeneous Integration

5.19

Y. Jiao, J. Zhu, T. Palacios

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

Two-dimensional (2D) transition metal dichalcogenide (TMD) materials have demonstrated promising future in the next generation of highly scaled microelectronic devices for their excellent electronic and photonic properties such as high mobility, direct bandgap in combination with their atomic scale dimensions. These properties have also made 2D TMD materials ideal candidate for back-end-of-line (BEOL) integration process with silicon front-end integrated circuits (IC). However, the current method of transfer integration of 2D TMD material and Si IC potentially introduces damages and defects to the material, thus greatly impedes the performance of fabricated devices. Direct growth of TMD was proven difficult in BEOL process due to temperature limits (<400°C)

In this work, we explore the low temperature large wafer-scale direct synthesis of high quality 2D TMD (MoS2, MoTe2, WSe2, etc.) which are BEOL compatible. The Metal-Organic Chemical Vapor Deposition (MOCVD) system we designed is capable of direct growth on platforms up to 200 mm in diameter. The BEOL compatibility is achieved through separation of high temperature precursor decomposition region and low temperature deposition region. This enables monolayer TMD materials direct integration with Si front end devices without introducing damage, thus maintaining the optimal device performance. This integration technique shall bring a promising future of heterogeneous integration of TMD with various front-end substrates and applications in flexible electronics, optoelectronics and other monolithic 3D integration electronics.

A Comprehensive Study on Si-ion Implanted Ohmic Contacts on AlGaN/GaN Heterostructure

5.20

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Sponsorship: Advanced Research Projects Agency-Energy (ARPA-E) (grant no. DE-AR0001591)

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

Ohmic contacts to III-Nitride heterostructures pose challenges due to the wide band gap and the limitations of existing methods, e.g. low throughput for MBE regrown contacts, rough surface morphology for alloyed contacts, and the use of metal stacks that are incompatible with Si fabs. In contrast, implanted contacts offer ease of manufacturing with precise doping control and uniformity.

This work delves into Si-ion implanted ohmic contacts on AlGaN/GaN heterostructures. The contact resistance (R_C) of the implanted contacts can be divided in three components: R_{c1}, the resistance between the metal and the implanted region; R_{c2}, the resistance of the implanted region; and R_{c3}, the resistance between the implanted region and the two-dimensional electron gas (2DEG). R_{c1} reached a minimum when the ohmic metals were deposited after etching the entire AlGaN layer. R_{c2} is proportional to the length of the implanted region between the metals and 2DEG, thus can be reduced through precise lithography, such as electron beam lithography. R_{c3} was reduced by employing a dual-path implantation technique that increased the Si concentration at the interface between the implanted region and 2DEG. Both R_{c1} and R_{c2} had minimum values with a middle dose, indicating that a higher dose would lead to an increase in both carrier density and lattice damage, making the optimum value lie in the middle range.

Moreover, this work explores, for the first time, high-temperature Si-ion implantation to form ohmic contacts on AlGaN/GaN heterostructures. Room temperature, 300 °C, and 500 °C were explored in this work, and XRD results demonstrated that less lattice damage was created by the implantation at high temperature. Electrical characterization showed that the higher the implant temperature, the more carriers were activated, resulting in lower R_{c1} and R_{c2} values. Consequently, the lowest R_c (average : 0.20 Ω·mm, minimum 0.14 Ω·mm) was obtained from 500 °C implantation with a dose of 3×10^{15} cm^{-2}.

Advanced Materials issues of GaN-on-Si Transistors for RF and Beyond

5.21

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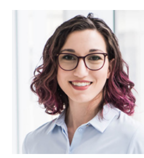
Sponsorship: SRC Jump 2.0 SUPREME Center



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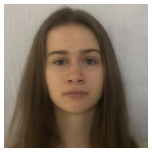
Electronic devices, GaN, III-Vs, Lasers, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Photovoltaics, Sensors, Si, SiGe and Ge.

In an age of ever-increasing demand for high-speed communications, gallium nitride high-electron-mobility-transistors (GaN HEMTs) have emerged as a breakthrough technology to meet the frequency and power demands of modern electronics. Owing to their large breakdown voltages and high electron saturation velocity, GaN HEMTs are the leading technology for power and RF applications. Using Si substrates for GaN heteroepitaxy dramatically increases the cost-efficiency of GaN RF devices, but due to the lattice mismatch and low resistivity and thermal conductivity of Si substrates, GaN-on-Si device performance has lagged SiC, the leading substrate choice for high-frequency GaN devices. Achieving a deeper understanding of parasitics and their causes will enable major improvements to cutoff frequency (f_T) and maximum oscillation frequency (f_{max}) and offer helpful insights for fabricating more advanced device architectures.

Low resistance regrown ohmic contacts will help increase f_{max}. Combining reactive ion etching with novel wet etching techniques during contact fabrication is an effective way to control the sidewall angle and mitigate plasma damage in the recessed GaN, which will improve the regrown GaN/2DEG channel interface and reduce the contact resistance. In this work, we study two wet etching methods to use with inductively coupled plasma dry etching to optimize the interfaces of GaN recesses: (1) KOH and (2) a Digital Etch (DE) that alternates between H_2SO_4/H_2O_2 and dilute HCl. Comparing contact resistance from devices made with each method will help deconvolve the impact of plasma damage and sidewall angle on contact resistance. Furthermore, investigating the role of plasma damage, topology, and interface impurities on channel carrier density and contact resistivity that will facilitate ultralow resistance ohmic contacts that will play a key role in future high-power, high-frequency HEMT architectures.



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Research Interests:
2D materials, Electronic devices, Electronics, GaN, Nanomanufacturing, Nanomaterials, Nanotechnology, Quantum devices, HZO.

Endurance Characterization of Ferroelectric Hafnium Zirconium Oxide for Memory Applications

5.22

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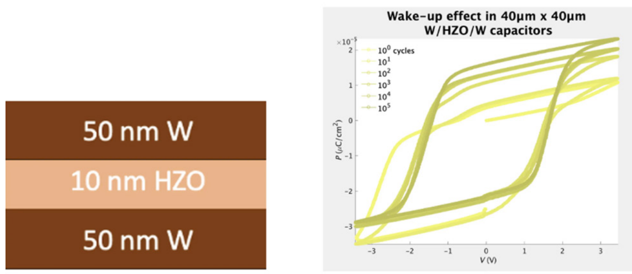
Sponsorship: MIT UROP, Intel Corporation, Semiconductor Research Corporation

To realize on-chip next-generation AI accelerators, 3D monolithic integration of non-volatile memory (NVM) on CMOS is highly favored. Among different NVW technologies, ferroelectric (FE) memory based on CMOS-compatible hafnium zirconium oxide (HZO) has emerged as one of the most promising, as it could potentially provide low-voltage operation, fast switching, long data retention, and high device endurance. Understanding the detailed ferroelectric polarization switching physics in HZO thin films is of great importance for potential memory applications. In working towards developing high-endurance back-end-of-line (BEOL) ferroelectric NVM technology, we investigate the endurance property of HZO in metal/FE/metal (MFM) structures that have been prepared with a variety of material stacks and fabrication parameters. We have studied unique physics in FE-HZO, including wake-up, fatigue, and breakdown, by carrying out repeated polarization-voltage measurements with carefully designed voltage pulse patterns. Through correlation with HZO fabrication parameters and materials characterization, we expect to better predict prospects and limitations of HZO in applications to future FE memory devices.



a) b)

◄ Figure 1: a) Schematic diagram of W/HZO/W structure: 50 nm W / 10 nm HZO / 10 nm W b) Evolution of polarization-voltage (P-V) loop with increasing numbers of switching pulses applied.

Session 6: Nanotechnology & Nanomaterials

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

6.01

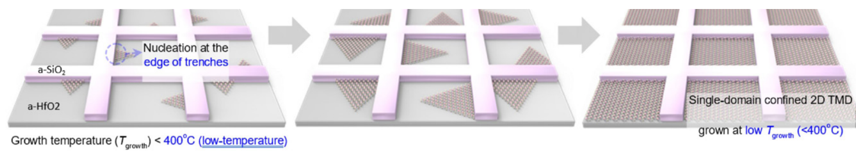
D. Lee, K. Kim, S. Seo, J. Kim

Sponsorship: Samsung

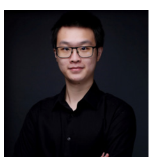
Two-dimensional (2D) Transition Metal Dichalcogenides (TMDs) have been highlighted as a channel material for next generation electronics beyond Moore's law. However, their integration with conventional silicon technology has been a critical hurdle to commercialization because of their high growth temperature.

In addition, even though wafer scale growth of MoS_2 below the back-end-of-line (BEOL) temperature limit has been reported recently, its performance is not comparable to conventional silicon devices because the material is polycrystalline. Furthermore, WSe_2 growth below the BEOL limit has never been demonstrated, which is essential for the p-type devices needed to realize 2D CMOS circuits.

In this work, we overcome those challenges and demonstrate non-epitaxial single-crystalline growth of both MoS_2 and WSe_2 on an amorphous HfO_2 coated substrate below 400°C. We demonstrate that using our technique, their electrical performances are comparable to materials grown at high temperatures.



▲ Figure 1: The dangling bonds at the edge of SiO2 trenches facilitate the nuclei formation even at low growth temperature. In addition, the trenches physically confine the extra lateral growth of single domain TMDs to prevent grain boundaries.



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Predicting Next-Generation Perovskite Solar Cell Performance through Machine Learning Algorithms

6.03

R. Zhang, V. Bulović

Sponsorship: Department of Energy, US, and MIT 2024 Mathwork Fellowship

Organic-metal halide perovskites have promising optoelectronic properties, making them stand out as a potential material for highly efficient next-generation photovoltaic devices contributing to moving towards clean energy. However, most of the laboratory-sized record cells used heavy processes that are not transferrable to an industrial-scale printable method like slot-die coating or roll-to-roll coating. As new fabrication techniques are investigated, it is essential to predict the possible performance beforehand. To better simulate interfacial recombination between layers in the solar cell stack, band-bending, and internal electric fields, models like drift-diffusion are carried out, fitting the experimental data to determine the relevant simulation parameters. Nevertheless, the number of free parameters in these models require extensive measurements and fitting models, hindering their usefulness as a predictive tool. In this project, we overcome this limitation by using machine learning to take the measured physical parameters of the cell as input and directly predict the JV curve, thereby predicting the cell efficiency performance. These black box models allow us to predict the performance of full devices with data that might contain many physical processes which could be too complex to predict accurately with a physics-based model. We consider using percent transmission, spectrum-resolved photoluminescence, and time-resolved photoluminescence as representative characteristics for the algorithm. We have developed various machine learning algorithms that input these three parameters to predict the output values of open-circuit voltage, short-circuit current and fill factors. A less than 10% prediction percent error is reached, with over 65% of the predictions having less than 5% error. Utilizing machine learning in solar technology accelerates the process of clean energy development and opens a new direction in next-generation solar research.

Amorphous 2D Materials – A Novel Platform for Remote Epitaxy and Nanopatterned Epitaxy of III-V Semiconductors with Low Decomposition Temperatures

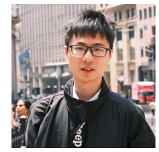
6.04

K. Lu, N. M. Han, H. Kim, Y. Liu, S. H. Cho, J. Kim

Sponsorship: AFRL (FA9453-18-2-0017 and FA9453-21-C-0717), DARPA (029584-00001), DOE (DE-EE0008558), Umicore

Optoelectronic devices based on Indium Phosphide (InP), such as tele-comm lasers, offer outstanding properties that outperform Silicon-based counterparts. However, the cost of InP wafers is considerably higher compared to commonly used semiconductor wafers. While reusing original wafers can effectively reduce costs, traditional techniques for wafer recycling, such as chemical lift-off, introduce significant expenses during fabrication, negating the cost savings achieved through wafer reuse. Consequently, the reuse of InP wafers becomes challenging but with significant opportunity, and new techniques are needed to scalably and cheaply produce InP membranes for optoelectronics.

Remote epitaxy and nanopatterned epitaxy have emerged as novel methods capable of facilitating the growth of InP with high quality, as well as enabling easy exfoliation of the InP films. These breakthroughs offer a promising avenue for cost-effective wafer reuse with the introduction of an interlayer of Two-dimensional (2D) materials between the epilayer and the substrate. Here we report the growth of amorphous boron nitride (a-BN) on InP wafers at low temperature that enabled improved quality of InP epitaxial membranes and their perfect exfoliation. We show fully covered a-BN on InP despite the low decomposition temperatures of InP substrates. The surface of a-BN coated InP substrate remains smooth with a RMS roughness of around 3Å. We also demonstrate 100% coverage of single-crystal InP membranes grown on a-BN, with the film's quality remaining high. Through this low temperature molecular beam epitaxy (MBE) growth approach with remote epitaxy and nanopatterned epitaxy, we successfully demonstrate large-scale flexible InP membrane exfoliation and recycling of InP substrates, which will lead to new opportunities in InP membrane-based optoelectronics and novel heterostructures with significantly reduced cost.



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Research Interests:
2D materials, Electronic devices, III-Vs, Light-emitting diodes, Nanomaterials, Nanotechnology, Optoelectronics, SiGe and Ge.

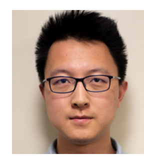
High Indium Content InGaN Strain Relaxation

6.05

Y. Liu, B. Park, J. Kim, J. Kim

Sponsorship: Samsung

Light-emitting diodes (LEDs) are widely used in illumination and displays because of their high efficiency and brightness. Indium gallium nitride (InGaN) has been used as the material to make blue and green LEDs due to its tunable bandgap. However, in order to decrease the band gap of InGaN, more indium has to be incorporated into the material, leading to a high lattice mismatch between the InGaN layer and the GaN substrate. This mismatch decreases the quality of high indium content InGaN, which is an obstacle to the effective use of InGaN as the base material for RGB (red, green and blue) pixels. Here, we propose a method to fabricate high quality LEDs based on InGaN with high indium content using remote epitaxy. Conventionally, when an epilayer is grown on the substrate using epitaxial methods, the lattice structure of the epilayer always perfectly follows the lattice structure of the substrate by forming a covalent bond. Remote epitaxy, on the other hand, provides a way to copy the substrate lattice structure to a freestanding, non-covalently bonded thin film epilayer. When a layer of 2D material is deposited prior to the epilayer, the epilayer grown on the top of the 2D material still follows the crystalline structure of the substrate under the influence of the penetrated potential field from the substrate. However, unlike normal epitaxial methods, the epilayer spontaneously relaxes due to the slippery surface of the 2D material, attached by van der Waals forces rather than covalent bonding. Therefore, high quality InGaN can be obtained with this method. We demonstrate remote epitaxy of high-quality InGaN epilayers based on in-situ MBE-grown amorphous boron nitride (a-BN) as the release layer. By depositing InGaN on a-BN/GaN substrate, the misfit strain can be relaxed from the beginning of the growth regardless of the indium composition, enabling high-quality RGB LED pixels that can be used in superior electronic device displays.



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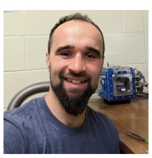
Synthesis of Single-Crystal hBN Multilayers on Ni (111)

6.06

K. Y. Ma, Z. Hennighausen, J. Kong

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

Two-dimensional hexagonal boron nitride (hBN) has been demonstrated to be the "ideal" dielectric substrate for 2D materials-based field effect transistors (FETs) – offering the potential for extending Moore's law using the superior electronic properties of these novel nanomaterials. Although hBN thicker than a monolayer is more desirable as substrate for 2D semiconductors, the growth of highly uniform and single-crystal few- or multi-layer hBN has not yet been demonstrated. Previously, K. Y. Ma et. al [1] developed the epitaxial growth of wafer-scale single-crystal tri-layer hBN by a chemical vapor deposition method. Uniformly aligned tri-layer hBN islands were found to grow on a 2 cm x 5 cm single-crystal Ni (111) at an early stage of growth and finally to coalesce into a single-crystal film. Cross-sectional transmission electron microscopy (TEM) results showed that a $Ni_{23}B_6$ interlayer is formed (during cooling) between the single-crystal tri-layer hBN film and Ni (111) substrate by boron dissolved in Ni (111) and that there is an epitaxial relationship between tri-layer hBN and $Ni_{23}B_6$ and between $Ni_{23}B_6$ and Ni (111). The tri-layer hBN film was found to act as a protective layer that remains intact during catalytic evolution of hydrogen – suggesting continuous and uniform single-crystal tri-layer hBN in large area. This tri-layer hBN was transferred onto the SiO_2 (300 nm)/Si wafer acting as a dielectric layer to reduce electron doping from the SiO_2 substrate in MoS_2 FETs. In this project, we will build upon the previous findings to achieve high-quality few-layer hBN for various applications.



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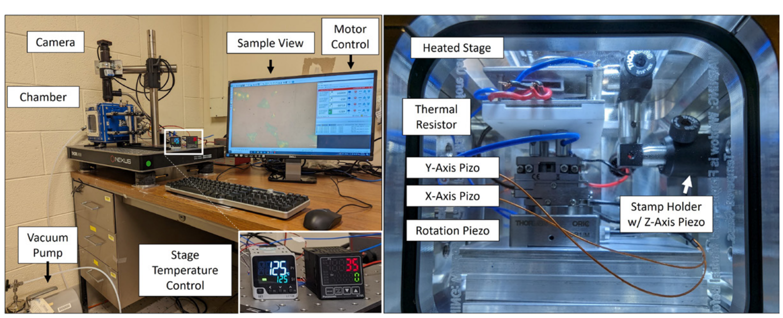
Striving for Rapid Fabrication of Arbitrary, Ultraclean 2D Heterostructures using a Robotic Vacuum Transfer Setup and Automation

6.07

Z. Hennighausen, S. He, J. Wang, X. Zheng, T. Zhang, K. Zhang, K.Y. Ma, Z. Wang, J. Park, J. Kong

Sponsorship: US Army Research Office grant number W911NF2210023, US Army Research Office through the Institute for Soldier Nanotechnologies at MIT, under cooperative agreement No. W911NF-18-2-0048.

Stacking two-dimensional (2D) materials into heterostructures facilitates the emergence of new properties, including superconductivity, interlayer excitons, and ferroelectricity, thereby enabling revolutionary new devices. Specialized transfer setups are required to fabricate 2D heterostructures with clean interfaces. Despite successes of the current technology, they require near-constant user engagement and a large time investment, thereby limiting throughput. To mitigate these challenges, we built a robotic transfer setup that operates in vacuum to reduce gas bubbles and improve interface cleanliness. We plan to identify ideal transfer parameters and fabricate 2D heterostructures with minimal user engagement using automation and machine learning. We plan to synergize the setup with materials grown in our group (e.g., graphene, hBN, TMDs, SnSe) and across MIT to fabricate increasingly complex heterostructures to advance technology in numerous areas (e.g., optics, electronics, qubits).



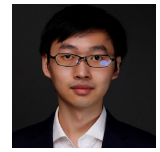
◄ Figure 1: (Left) Image of robotic vacuum transfer setup. (Right) Inside vacuum cube. Piezos enable x, y, z, and twist-angle control.

Formation of Monolayer Metal Oxides via Room Temperature Conversion of Two-Dimensional Transitional Metal Dichalcogenides

6.08

X. Zheng, P. Wu, A. Penn, Z. Wang, T. Zhang, X. Zhong, J. Wang, J. Park, S. Xie, A. Kahn, D. Schlom, J. Kong

Sponsorship: SRC



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Two-dimensional (2D) materials have attracted significant interest due to their ultra-thin thickness and quantum confinement effect. Despite the rich and diverse library of discovered 2D materials, the investigation on 2D oxides has been limited. There is a demand for atomically thin oxides because their band gaps are usually in the range of 3-6 eV, a range less accessible using the most studied 2D materials, such as graphene, transitional metal dichalcogenides (TMDCs) or h-BN. Here, by using 2D TMDCs as templates and converting them to oxide, we show that wafer-scale amorphous oxides can be directly formed at room temperature. The oxidation is enabled by UV light-generated ozone, which is a mild, controllable and homogeneous process. The properties of the as-converted transitional metal oxide monolayers are explored using optical, electrical and electron microscopic approaches. We further explored the potential applications of molybdenum oxide monolayers in two-dimensional field effect transistors. This strategy can be easily extended to a variety of metal oxides, enabling future development of metal oxides in the quantum regime.

Parameters Extraction for a Superconducting Thermal Switch (hTron) SPICE Model

6.09

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Sponsorship: Breakthrough Starshot Initiative, DOE microelectronics

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Superconducting nanowire circuits have shown great potential in photon sensing, demonstrating remarkable efficiency in extreme conditions while having large gains and high fanout. Yet, their integration into complex circuits is not as developed as other superconducting technologies. Their scaling is partly limited by a lack of effective simulation tools for superconducting nanowires, preventing designers from getting behavioral insights prior to fabrication.

As circuits increase in size and complexity, the modeling needs to shift from modeling detailed physical interactions to overall behavior of devices. For example, the multilayered heater-nanocryotron (hTron) device – a superconducting nanowire-based switch [1] – which has demonstrated applications in cryogenic memories, neuromorphic computing, and SNSPD array readout [2], was previously simulated using traditional finite-element modeling (FEM) methods, solving heat diffusion differential equations. However, while FEM techniques simulate individual superconductors accurately, they fall short in simulating larger circuits. Behavioral models are better adapted to that purpose, but require a large number of measurements to accurately reproduce the device's behavior.

In this work, we collect measurement data on the performance of 17 hTron devices and develop a method to extract physical fitting parameters from the measurement curves. Finally, we validate our model by performing the SPICE simulation of a 1:4 hTron-based multiplexer. Our model provides circuit designers with a tool to help understand the hTron's behavior during all design stages, thus promoting broader use of the hTron across various unexplored domains.

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Field-free Deterministic and Non-volatile Switching of van der Waals Ferromagnet Above Room Temperature

6.10

S. N. Kajale, T. Nguyen, N. Li, D. Sarkar
Sponsorship: Nano-cybernetic Biotrek Group

Two-dimensional van der Waals (vdW) magnetic materials are seen as potential building blocks for creating high-density, energy-efficient spintronic devices for data storage and processing. Recent advancements in the discovery of vdW ferromagnets and their spin-orbit torque (SOT) control have paved the way for their potential use in commercial spintronic devices. However, a method for controlling perpendicular magnetic anisotropy (PMA) vdW magnets without the use of a magnetic field, which is crucial for creating compact and thermally stable spintronic devices, has not yet been found. In this work, we report the first demonstration of field-free deterministic and non-volatile switching of a PMA vdW ferromagnet, above room temperature (up to 320 K). We use the unconventional out-of-plane anti-damping torque from an adjacent low-symmetry vdW Weyl semimetal, T_d-WTe_2, to enable such switching with a low current density. We observe the field-free switching exclusively when the charge current is injected parallel to the low-symmetry axis of WTe_2, and not when the charge current is injected parallel to its high-symmetry axis, asserting the role of crystal symmetry in enabling the field-free switching of PMA magnetism. This study exemplifies the efficacy of low-symmetry vdW materials for spin-orbit torque control of vdW ferromagnets and provides an all-vdW solution for the next generation of scalable and energy-efficient spintronic devices.

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Atomically-thin Ferroelectric Transistors made from Rhombohedral-stacked MoS_2

6.11

T. H. Yang, Y. W. Lan, J. Kong
Sponsorship: U. S. Army Research Laboratory, U. S. Army Research Office under contract/grant number W911NF2320057.

Ferroelectric transistors are a promising technology to develop low-power and non-volatile computing-in-memory devices for neuromorphic machine learning architectures that overcome the von Neumann bottleneck. These devices require scaled thickness and ferroelectric channel materials. Two-dimensional high-mobility semiconductors such as molybdenum disulfide (MoS_2) are promising candidates for ultrathin ferroelectric channels due to their sliding ferroelectricity property. However, the realization of switchable electric polarization in epitaxial MoS_2 remains challenging, owing to the absence of mobile domain boundaries, thereby limiting aggressive translation into practical applications. Here, we explore polarity-switchable epitaxial rhombohedral (3R)-stacked MoS_2 as a ferroelectric channel for 2D ferroelectric memory transistors. We find that a shear transformation spontaneously occurs in our 3R-MoS_2 epilayers, producing heterostructures with stable ferroelectric domains embedded in a highly dislocated and unstable non-ferroelectric matrix. This diffusionless phase-transformation process produces mobile screw dislocations that enable collective polarity control of 3R-MoS_2 via an electric field. The polarization-electric field measurement reveals a switching field of 0.036 V nm^{-1} for shear-transformed 3R MoS_2. Individual 'sliding' ferroelectric transistors made of shear-transformed 3R MoS_2 are non-volatile memory units with only two atomic-layer-thickness, exhibiting an average memory window of ~7 V with an applied voltage of 10 V, retention > 10^4 s, and endurance > 10^4 cycles. Our work proves the potential of sliding-ferroelectricity-based transistors in the future ultra-scaled ferroelectric memory-transistor paradigm and provides a straightforward growth strategy for high-throughput manufacturing.

CMOS-Compatible Symmetric Electrochemical Protonic Synapse Device with HfO2 Electrolyte

6.13

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

Sponsorship: SRC JUMP 2.0 SUPREME (3137.017)

Analog programmable resistors, as key components of artificial neural network (ANN) hardware, can help reduce the energy consumption of artificial intelligence training and inference. Proton-based electrochemical synapse devices, as programmable resistors, are operated by the reversible electrochemical hydrogen insertion and extraction to modulate the channel conductance with nonvolatile states. The deterministic electrochemical ion insertion enables deterministic state switch with low variability and without electroforming compared to ReRAMs. Despite good proton conductivity, current organic electrolytes for ionic synapses are not CMOS-compatible, limiting their scalable integration. A CMOS-compatible solid-state proton electrolyte is needed to improve the device speed and push these devices into large-scale fabrication. Meanwhile, achieving linear and symmetric conductance modulation is essential to improve the training and inference accuracy of ANN hardware.

Here, hafnium oxide (HfO_2), a CMOS-compatible material, has been investigated as a proton electrolyte for its low electronic conductivity and high dielectric strength, facilitating good retention and low writing energy. Sputtered HfO_2 is proved to have proton conducting ability, probably originating from the nano-porous structure absorbing water to act as conducting media. The synapse device has WO_3 channel, HfO_2 electrolyte and PdH_x as the hydrogen reservoir. The synapse devices can be programmed with hundreds of conductance states with 1-6 V voltage pulses with tens of microseconds to milliseconds timescale. The conductance modulation exhibits repeatable, symmetric and linear potentiation and depotentiation. The next stage will include improving device performance by engineering HfO_2 proton conduction properties through structure modification. This material could expand the CMOS-compatible proton electrolyte choices and enable the scalable fabrication of ANN hardware for improved machine learning systems.

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2D materials, Artificial Intelligence, Electronic devices, Energy, MEMS & NEMS, Nanomanufacturing, Nanomaterials, Nanotechnology, Neuromorphic Computing.

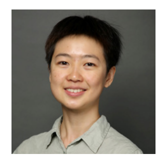
Simultaneous Transport and Capacitance Measurements of a Ferroelectric Graphene Moiré Structure

6.14

X. Wang, Z. Zheng, S. Aronson, K. Watanabe, T. Taniguchi, R. Ashoori, Q. Ma, P. Jarillo-Herrero

Sponsorship: Center for the Advancement of Topological Materials, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science.

2D materials offer many unique advantages for device applications, including miniature size, flexibility, tunability, robustness, and higher quality of various electronic behaviors. In particular, moiré arising from 2D materials brings in more exotic phenomena and functionalities. Unconventional 2D ferroelectricity, for example, was demonstrated recently on a graphene-hBN moiré structure, and was incorporated in a synaptic neuromorphic transistor device that exhibits input specific adaptation, spike-based and spatiotemporal based encoding capabilities up to room temperature. The mechanism of such unconventional ferroelectricity, however, is unclear. Here, I will present simultaneous transport and capacitance measurements of a similar graphene moiré structure that also shows unconventional ferroelectric characters. Our measurements could more directly probe the possible existence of carriers of distinct characters and shed light on their relation with the observed ferroelectricity. With improved understanding of the origin of the 2D ferroelectricity, more versatile and high performance devices can be engineered for more unprecedented functionalities.



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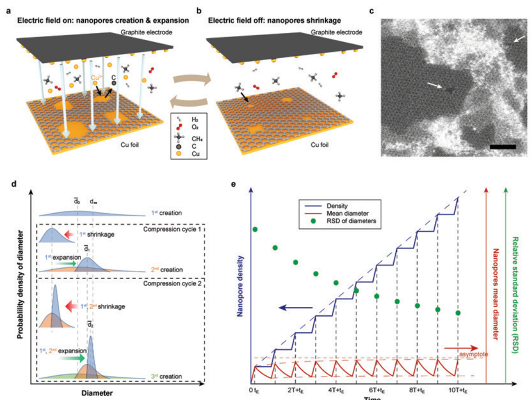
Cascaded Compression of Size Distribution of Nanopores in Monolayer Graphene

6.15

J. Wang, C. Cheng, X. Zheng, T. Zhang, J. Kong

Sponsorship: U.S. Army Research Office, U.S. Department of Energy

Monolayer graphene, featuring nanometre-scale pores and exceptional mechanical properties, is ideal for ion/molecular separations, energy storage, and electronics. Precise engineering of nanopore size and distribution is crucial for these applications. Top-down methods typically result in log-normal size distributions with long tails, especially at subnanometre scales, and a trade-off between nanopore size distribution and density limits their practical use. Here, we report a cascaded compression method for producing graphene nanopores with a narrowed, left-skewed size distribution and ultrashort tail deviation (Fig. 1). This process involves sequential steps where existing nanopores undergo both shrinkage and expansion, simultaneously creating new nanopores and enhancing overall density. The result is graphene nanopores with high density, left-skewed distribution, enabling ultrafast, size-tunable transport of ions and molecules. This technique offers independent control over nanopore density, diameter, deviation, and distribution skewness, potentially revolutionizing nanotechnology.



◄ Figure 1: Cascaded compression cycles. a, Creation & expansion of nanopores by Cu sputter. b, Shrinkage of nanopores by regrowth. c, STEM image of nanopores. Scale bar, 2 nm. The schematic evolution of d, the probability density of diameter, and e, nanopore density, mean diameter, and RSD vs. time.

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Designer Ultrathin Resonators using Delamination Lithography

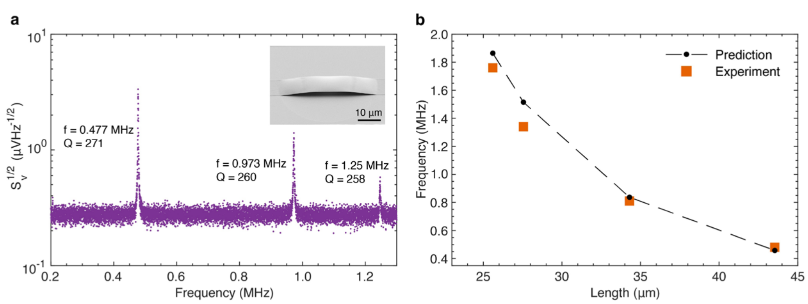
6.16

S. O. Spector, P. F. Satterthwaite, F. Niroui

Sponsorship: NSF Graduate Research Fellowship

Thin-film, suspended mechanical resonators are a crucial component of nanoelectromechanical systems, from frequency conversion for radio signals to mass spectroscopy for biological sensing. Yet, the inherent instability of conventional, top-down fabrication techniques limits how thin these devices can be made, hampering their sensitivity and potential frequency range.

Here, we show that a nonplanar nanofabrication technique can be used to produce stable, ultrathin mechanical resonators (Figure 1a). By engineering surface forces using a molecular monolayer and simultaneously controlling the stress in a thin film, three-dimensional “delamination lithography” is achieved. We demonstrate that these devices, which we can design across a broad range of sizes using simple, wafer-scale techniques, conform to their theoretical and simulated behavior (Figure 1b), suggesting applications in designer resonators across frequency orders of magnitude.



▲ Figure 1: (a) First three vibrational modes of a < 30 nm-thin suspended resonator shown in the inset SEM. (b) The fundamental frequency of the resonator as a function of its length, showing a close match between experimentally-measured and simulated results.

Tunable Mechanical Response of Self-Assembled Nanoparticle Superlattices

6.17

S. Dhulipala, D. Yee, Z. Zhou, R. Sun, J. E. Andrade, R. J. Macfarlane, C. M. Portela

Sponsorship: NSF CAREER Award CMMI-2142460, U.S. Army Research Office under Grant W911NF-18-1-0197, NSF CAREER Award CHE-1653289, Department of the Navy, Office of Naval Research, under ONR award number N00014-22-1-2148

Self-assembled nanoparticle superlattices (NPSLs) are an emergent class of self-architected nanocomposite materials that possess promising properties arising from precise nanoparticle ordering. Their multiple coupled properties make them desirable as functional components in devices where mechanical robustness is critical. However, questions remain about NPSL mechanical properties and how shaping them affects their mechanical response. Here, we perform in-situ nanomechanical experiments that evidence up to an 11-fold increase in stiffness (~1.49 to 16.9 GPa) and a 5-fold increase in strength (~88 to 426 MPa) because of surface stiffening/strengthening from shaping these nanomaterials via focused-ion-beam (FIB) milling. To predict the mechanical properties of shaped NPSLs, we present discrete element method (DEM) simulations and an analytical core–shell model that captures the FIB-induced stiffening response. This work presents a route for tunable mechanical responses of self-architected NPSLs and provides two frameworks to predict their mechanical response and guide the design of future NPSL-containing devices.

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3D-Printed, Non-Planar Electron Sources for Projection Lithography

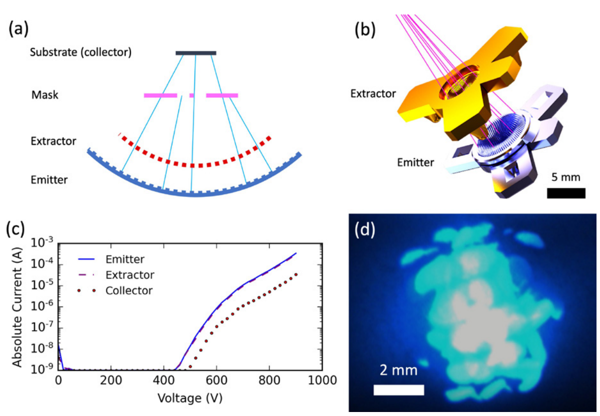
6.18

A. Kachkine, C. E. Owens, A. J. Hart, L. F. Velásquez-García

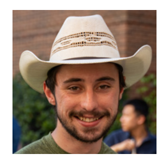
Sponsorship: NewSat Project, COMPETE 2020, ERDF, MIT Portugal Program, Mathworks

Photolithography resolution is diffraction-limited, while electron projection lithography (EPL), though higher resolution, is throughput-limited by electron divergence from planar sources. We report the first non-planar electron sources for EPL, a design paradigm with potential to overcome both limitations.

Fabricated by 3D printing, devices deliver confocal emission, achieving focusing and demagnification. Emission is produced by a concave dish base with an array of carbon nanotube-coated emitters aligned to the apertures of a concave extractor electrode; both are fabricated by vat photopolymerization 3D printing and modified by subsequent coatings. Our prototype device exhibits a startup voltage of 500 V, a peak emission current of 300 μA/cm^2, and a field enhancement factor of 7.8×10^4 cm^{-1}. Phosphor screen imaging of the devices in operation demonstrates that the emission is spatially uniform. Our approach enables compact design at industrial specifications of next-generation EPL systems.



◄ Figure 1: (a) Proposed convex electron source schematic. (b) Device rendering, showing electron paths in pink. (c) Voltage sweep data from device in triode configuration. (d) Phosphor screen image of electron emission.



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Novel Tellurium Contacts for P-type WSe_2 Devices

6.20

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

H. W. Lee, J. Zhu, K. Reidy, F. Ross, J. Kong, T. Palacios
Sponsorship: Intel (ISRA)

Since the first discovery of graphene, extensive research on two-dimensional (2D) materials has opened promising possibilities for elevating 2D semiconductor applications from the academic to the industrial level for the next generation of electronics. Now, 2D semiconductors can be grown at a large scale, processed using CMOS-compatible fabrication techniques, and demonstrate high-performance transistors with low contact resistance. However, these remarkable improvements have mainly been achieved with n-type 2D semiconductors, primarily focusing on molybdenum disulfide (MoS_2). In the case of p-type 2D semiconductors, such as tungsten diselenide (WSe_2), there are still significant challenges in material growth and reducing contact resistance to make them comparable to n-type 2D transistors. These challenges hinder the demonstration of 2D complementary metal-oxide-semiconductor (CMOS) circuits at an industrial level. In particular, reducing the contact resistance between a p-type 2D channel and a metal contact is essential to achieving high-performance p-type transistors.

In this work, we explore the use of semimetal tellurium (Te) as contacts for p-type WSe_2 transistors. Semimetals such as bismuth (Bi) and antimony (Sb) are known to mitigate the Fermi level pinning effect at the interface between the metal and MoS_2, thereby drastically reducing the contact resistance of MoS^2 transistors [1]. We compare the performance of WSe_2 transistors with various contact materials, including Te, palladium (Pd), and platinum (Pt), and observe that Te contacts indeed reduce the Fermi level pinning effect at the interface of WSe_2 and Te. In addition, we enhance the performance of WSe_2 transistors by adjusting the deposition temperature of Te. This research on semimetal Te contacts will serve as an important baseline study for novel contacts for p-type 2D transistors, thereby enabling the next generation of commercialized 2D electronic devices.

Orbital Multiferroicity in Pentalayer Rhombohedral Graphene

6.21

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Available from June 2026.

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

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Sponsorship: NSF (grant no. DMR-2225925), STC Center for Integrated Quantum Materials (NSF grant no. DMR-1231319), USD (R&E) no. FA8702-15-D-0001.

Ferroic orders describe spontaneous polarization of spin, charge and lattice degrees of freedom in materials. Materials exhibiting multiple ferroic orders, known as multiferroics, have important parts in multifunctional electrical and magnetic device applications. Two-dimensional materials with honeycomb lattices offer opportunities to engineer unconventional multiferroicity, in which the ferroic orders are driven purely by the orbital degrees of freedom and not by electron spin. These unconventional effects include ferro-valleytricity corresponding to the electron valley and ferro-orbital-magnetism supported by quantum geometric effects. These orbital multiferroics could offer strong valley–magnetic couplings and large responses to external fields—enabling device applications such as multiple-state memory elements and electric control of the valley and magnetic states.

Here we report orbital multiferroicity in pentalayer rhombohedral graphene using low-temperature magneto-transport measurements. We observed anomalous Hall signals R_{xy} with an exceptionally large Hall angle ($\tan\Theta_H > 0.6$) and orbital magnetic hysteresis at hole doping. There are four such states with different valley polarizations and orbital magnetizations, forming a valley–magnetic quartet. By sweeping the gate electric field E, we observed a butterfly-shaped hysteresis of R_{xy} connecting the quartet. This hysteresis indicates a ferro-valleytronic order that couples to the composite field $E \cdot B$ (where B is the magnetic field), but not to the individual fields. Tuning E would switch each ferroic order independently and achieve non-volatile switching of them together. Our observations demonstrate a previously unknown type of multiferroics and point to electrically tunable ultralow-power valleytronic and magnetic devices.

Session 7: Optoelectronics & Integrated Photonics

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Available from May 2027.

Research Interests:
Displays, Energy, Lasers, Light-emitting diodes, Nanomanufacturing, Optoelectronics, Photonics, Photovoltaics, Quantum Devices.

Plasmonic Nanoparticle Lattices as Optical Cavities for Thin Film Colloidal QD Lasers

7.01

S. Srinivasan, J. Guan, R. Zhang, K. McFarlane-Connelley, M.G. Bawendi, V. Bulović
Sponsorship: Samsung Semiconductor Co., U.S. Department of Energy

Thin film nanoscale lasers have applications ranging from on-chip optical interconnects, virtual and augmented reality displays, and optical wireless communication. To realize these applications, both nanoscale optical cavities and high quantum yield emitters are required. Quantum dots (QDs) are semiconductor nanoparticles with discrete energy levels generated through quantum confinement with size and composition tunable emission. Current thin film lasers utilize molecular beam epitaxy to grow optical cavities and QDs, requiring fabrication with expensive high vacuum systems. To reduce manufacturing costs, both a simple optical cavity and a solution processable gain medium are required. Colloidal QDs are synthesized in solution and are chemically stabilized with organic capping ligands. They have demonstrated synthetically tunable emission and near unity quantum yield. Plasmonic nanoparticle lattices are nanometer spaced arrays of metal nanoparticles that couple local surface plasmon resonance modes of individual nanoparticles with diffraction modes generated by the array. They are fabricated in a single liftoff process, reducing manufacturing complexity. The lattice resonance mode is also easily tunable through control of the lattice geometry, spacing, and surrounding refractive index.

The combination of plasmonic nanoparticle lattices and colloidal quantum dots creates a new paradigm for the fabrication of nanoscale lasers with tunable emission and low pumping thresholds. In this work we demonstrate an optically pumped laser with perovskite colloidal quantum dots integrated into Al-nanoparticle lattices. The lattices were fabricated with a single step electron beam lithography and liftoff process. By varying lattice periodicity, lasing emission directionality was controllable by up to 12 degrees off-normal.

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Integrated Visible-Light Liquid-Crystal-Based Modulators for Augmented-Reality Displays

7.02

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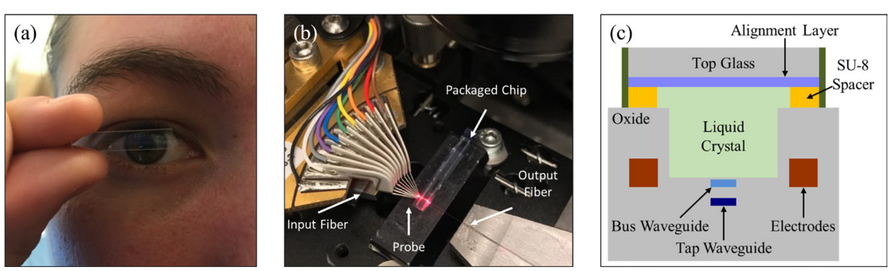
Sponsorship: NSF CAREER Program (2239525), DARPA VIPER Program (FA8650-17-1-7713), MIT SoE Mathworks Fellowship, NSF Graduate Research Fellowship (1122374)

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

To address these limitations, we are developing an integrated-photonics-based display that consists of a single transparent chip that sits directly in front of the user's eye and projects holograms that only the user can see. In this poster, we will discuss the integrated liquid-crystal-based phase and amplitude modulators that enable this integrated-photonics-based display architecture. This work paves the way towards a highly discreet and fully holographic solution for the next generation of augmented-reality displays.



▲ Figure 1: (a) Photograph of a transparent integrated-photonics-based holographic display. (b) Simplified cross-sectional schematic of an integrated liquid-crystal-based modulator. (c) Photograph of an integrated photonic chip packaged with liquid crystal on an experimental setup.

Integrated Photonics for Advanced Cooling of Trapped-Ion Quantum Systems

7.03

S. Corsetti, A. Hattori, M. Notaros, T. Sneh, R. Swint, P. T. Callahan, F. Knollmann, E. R. Clements, D. Kharas, G. N. West, T. Mahony, C. D. Bruzewicz, C. Sorace-Agaskar, R. McConnell, J. Chiaverini, J. Notaros

Sponsorship: 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

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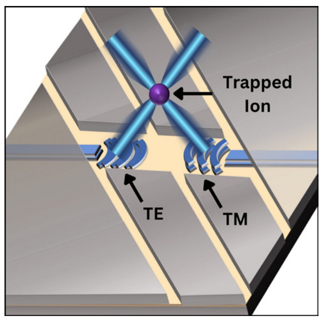
Research Interests:
Electronic devices, Electronics, III-Vs, Integrated circuits, Lasers, Light-emitting diodes, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonic, Si.

Trapped-ion systems are a promising modality for quantum information processing due to their long coherence times and strong ion-ion interactions, which enable high-fidelity two-qubit gates. However, most current implementations are comprised of complex free-space optical systems, whose large size and susceptibility to vibration and drift can limit fidelity and addressability of ion arrays, hindering scaling. Integrated-photonics-based solutions offer a potential avenue to address many of 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 integrated-photonics-based systems and associated devices for two advanced cooling schemes, polarization gradient and EIT. This has the potential to improve cooling performance for trapped ions, enabling scalable quantum systems.



◄ Figure 1: Conceptual diagram of the integrated-photonics-based polarization-gradient-cooling system, demonstrating light of diverse polarizations simultaneously addressing an ion positioned over an ion-trap chip.

Spatially-Adaptive Solid-State OPA-Based LiDAR

7.04

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

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

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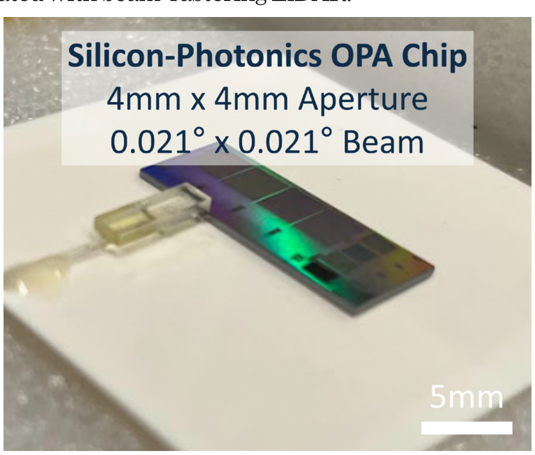
Research Interests:
Communications, Displays, Electronic devices, Electronics, III-Vs, Integrated circuits, Lasers, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors, Systems, Transducers.

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

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



◄ Figure 1: Photograph depicting a large-scale optical-phased-array chip for solid-state beam forming and beam steering.

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

Understanding Ultrafast Energy Transfer in Mixed-Dimensional Perovskite Heterostructures

7.05

M. Chattoraj, W. A. Tisdale

Sponsorship: U.S. Department of Energy, Office of Science, Basic Energy Sciences, award no. DE SC0019345.

Lead halide perovskite nanomaterials are an intriguing class of semiconductors due to their many remarkable optical properties, including long-lived charge carriers and spectrally narrow emission that is synthetically tunable across the visible light spectrum. Perovskites are of interest for many optoelectronic applications ranging from photovoltaics to displays. To increase the efficiency of optoelectronic devices incorporating nanomaterials, a detailed understanding of energy transfer in nanoscale systems is necessary.

Although exciton transfer in colloidal semiconductors has traditionally been described by Förster resonance energy transfer (FRET), this framework does not fully capture exciton behavior in many novel materials. Lead halide perovskites have been shown to exhibit energy transfer rates far exceeding Förster theory predictions, thus posing an intriguing material platform for establishing a more detailed understanding of exciton dynamics. As devices increasingly incorporate nanomaterials such as quantum dots, understanding energy transfer between materials of varying dimensionality becomes crucial. Rigorous characterization of energy transfer mechanisms in perovskite-based heterostructures requires synthesis of high-quality perovskites. Here, perovskites of various dimensionalities are synthesized and combined into heterostructures. In the future, energy transfer in these heterostructures will be studied using time-resolved photoluminescence (TRPL) and ultrafast transient absorption (TA) spectroscopy. Ultimately, we aim to build a thorough, quantitative understanding of energy transfer mechanisms in novel nanomaterials, which will contribute to the development of highly efficient optoelectronic devices including photodetectors, displays, and solar cells.

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Research Interests:
Artificial Intelligence, Information processing, Machine Learning, Quantum devices.

Analog Complex-valued Neural Networks for Quadratic Energy Savings

7.06

M. G. Bacvanski, S. K. Vadlamani, D. R. Englund

Sponsorship: NSF RAISE-TAQS (1936314), NSF C-Accel (2040695), NTT Research Inc

Neural networks (NNs) that are composed of complex weights and operate over complex inputs have demonstrated excellent performance in domains like medical data and signal processing because of their natural ability to manipulate phase and amplitude. However, implementing these complex-valued NNs on conventional digital GPU hardware entails performing several times more multiplication and addition operations than real-valued NNs of the same size. In this work, we propose an AI accelerator that uses standard telecommunications hardware to efficiently implement complex-valued NNs by combining standard modulation schemes with homodyne detection. Through extensive numerical experiments, we demonstrate that these telecom-based analog NNs perform identically to traditional real-valued neural networks on several standard real-valued datasets, while consuming quadratically lower amounts of energy.

Determining Charge Carrier Transport Parameters from Microscopy Data **7.07**

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Sponsorship: Massachusetts Institute of Technology, Department of Chemical Engineering

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Time-resolved microscopy techniques are increasingly used to image the transport of excited charge carriers and excitons in materials. Typically, transport parameters such as diffusivity are extracted by generating a spatially localized population of excited charge carriers, then measuring the growth of the spatial charge carrier profile over time. However, current analysis techniques are highly sensitive to the shape of the initial charge carrier profile, and can result in large errors for even small deviations from an assumed profile shape. Additionally, these measurements may be significantly impacted by shot noise at common experimental conditions. Here, we apply conventional analysis techniques to simulated one-dimensional transport measurements to quantify the effects of non-ideal carrier spatial profiles and shot noise on the diffusivities extracted from microscopy data. We show that non-ideal profile shapes can lead to errors almost as large as 50%. Using these results as a baseline, we then propose an alternate analysis technique that uses convolutions of Gaussian functions with the measured charge carrier spatial profiles to both smooth the effects of shot noise and to measure the growth of the spatial profiles. We demonstrate that this algorithm outperforms traditional analysis techniques at recovering diffusivities from simulated data sets, displaying a slightly reduced sensitivity to shot noise and a significantly lower sensitivity to the shape of the initial charge carrier spatial profile. Finally, we apply this technique to experimental data to illustrate different strategies for extending this algorithm to accurately extract parameters for diffusion that occurs in two or more dimensions.

High Level Intersystem Crossing in Triplet-triplet Annihilation Photon Upconversion Materials Diphenylisobenzofuran and Diphenylisobenzothiophene **7.08**

O. Nix, T.A. Lin, C.A. Kim, C. Perkinson, M. Baldo

Sponsorship: U.S. Department of Energy Office of Basic Energy Sciences (DE-FG02-07ER46474)

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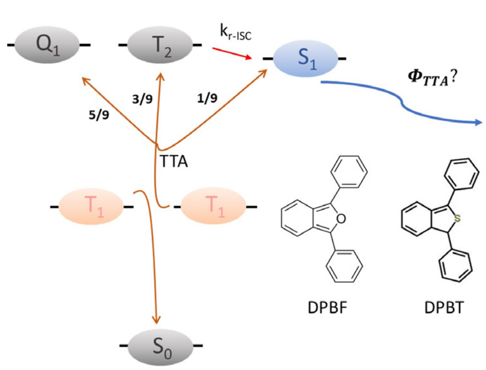
Research Interests:
Energy, Energy harvesting devices & systems, Light-emitting diodes, Nanomaterials, Organic materials, Photovoltaics.

Triplet-triplet annihilation (TTA) presents a promising photon upconverion (PUC) platform that can improve the efficiency and stability of blue organic light emitting devices. TTA is a spin-dependent process that converts two low energy triplet states to a bright singlet state. However, the TTA process can also form dark high energy triplet states that lead to reductions in efficiency and device stability. There is a fundamental limit on the fraction of singlet states that can be produced through TTA, limiting its PUC efficiency.

In this work, tuning reverse intersystem crossing (r-ISC) from dark triplet states to bright singlet states was probed as a strategy for surpassing this limit. TTA materials diphenylisobenzofuran and diphenylisobenzothiophene were modelled to predict their relative r-ISC rates, and were characterized in solutions and spun cast films. Fast r-ISC was inversely correlated with TTA efficiency, suggesting low level r-ISC is a significant loss pathway to TTA.



◄ Figure 1: Schematic of the triplet-triplet annihilation (TTA) process, where two triplet excitons annihilate to form either a bright singlet or dark triplet or quintet state. Increased formation of the bright singlet through r-ISC is investigated in DPBF and DPBT as a strategy for increasing Φ_{TTA}.

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Research Interests:
Communications, Integrated circuits, Lasers, MEMS & NEMS, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Si, SiGe and Ge.

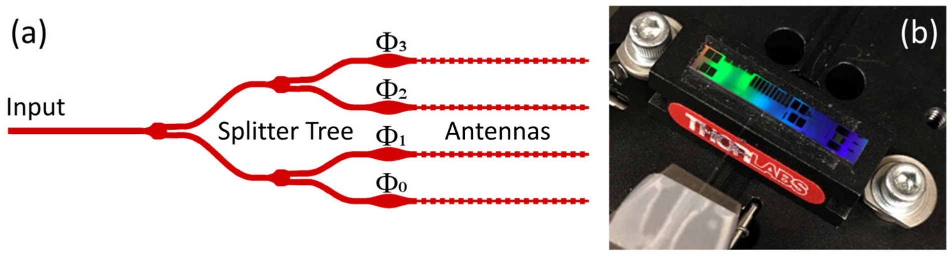
Integrated Beam-Steering Optical Phased Arrays for Solid-State LiDAR Sensors

7.09

B. M. Mazur, D. M. DeSantis, M. R. Torres, M. Notaros, J. Notaros
Sponsorship: SRC JUMP 2.0 CogniSense, MIT Rolf G. Locher Endowed Fellowship, and NSF Graduate Research Fellowship

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

In this poster, we discuss integrated beam-steering OPA architectures and devices for LiDAR sensors, highlighting their design spaces and tradeoffs. Additionally, we propose novel OPA subsystems for spatially-adaptive solid-state LiDAR sensors.



▲ Figure 1: (a) Simplified schematic of an integrated optical phased array. (b) Photograph of a silicon-photonics chip with a large-scale integrated optical phased array.

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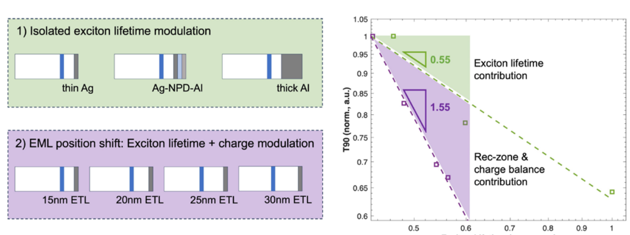
Research Interests:
2D materials, Displays, Electronics, Energy harvesting devices & systems, Light-emitting diodes, MEMS & NEMS, Microfluidic devices & systems, Molecular & polymeric materials, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Organic materials, Photonics, Photovoltaics.

Decoupling the Role of Exciton Lifetime, Charge Carrier Balance, and Dark Excitons in the Degradation of Blue OLEDs

7.10

J. Tiepelt, J. Song, C. Picart, A. Seeglitz, T.-A. Lin, S. Zhu, P. Satterthwaite, J. Li, M. Baldo
Sponsorship: U.S. Department of Energy – Office of Energy Efficiency & Renewable Energy

Organic light-emitting diodes (OLEDs) are the predominant technology for mobile display applications. The greatest remaining challenge is the stability of blue OLEDs, caused by long-lived triplet excitons. The effect of key parameters on OLED stability is not well understood to date. Here, we report a characterization technique that decouples an OLED's electronic properties from modulations of its emission layer's exciton lifetime by means of external plasmonic coupling. We show that the device's operational stability shows a much smaller than expected, square-root, dependence on exciton lifetime. As we only modulate emissive excitons here, it is possible that trapped 'dark' excitons dominate stability. In a second experiment, we vary the position of the emissive layer within the OLED, revealing a super-linear dependence of stability on the variation in charge balance and exciton lifetime. Last, we show strong indication of charge carrier imbalance resulting in trapped dark excitons dominating OLED stability.



▲ Figure 1: Blue OLED stability in dependence of exciton lifetime variation vs. positional shift of the emitting layer. Device stability shown to be dominated by shifts in the recombination zone and charge carrier balance.

Integrated Optical Grating-Based Antennas for Solid-State LiDAR Sensors

7.12

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Sponsorship: SRC JUMP 2.0 CogniSense

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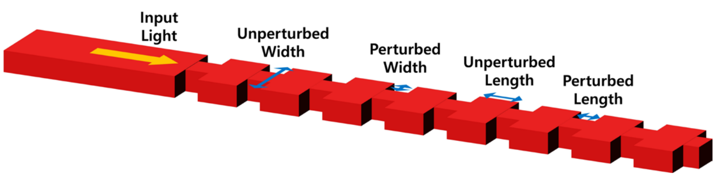
Light detection and ranging (LiDAR) has emerged as a vital and widely-used sensing technology for autonomous systems, such as autonomous vehicles, since it enables 3D mapping with higher resolution than traditional RADAR. However, current commercial LiDAR systems utilize mechanical beam-steering mechanisms that decrease reliability, increase production cost, and limit detection range. To address these limitations, solid-state optical-phased-array-based (OPA-based) LiDAR, which enables low-cost, high-speed, and compact non-mechanical beam steering, has emerged as a promising solution for next-generation LiDAR sensors. In this poster, we develop integrated optical grating-based antennas, a critical device responsible for light emission in these solid-state LiDAR systems. We develop a device synthesis algorithm, design a suite of antennas with varying operating modalities, and discuss their design tradeoffs when applied to OPA subsystems.



◀ Figure 1: Simplified schematic of an integrated optical grating-based antenna with key design parameters labeled.

Session 8: Quantum Technologies

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2D materials, Quantum devices.

Probing Kinetic Inductance in Thin Niobium Diselenide ($NbSe_2$) through Microwave Measurements

8.01

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Sponsorship: MIT RLE, MIT EECS, MIT Lincoln Laboratory, Department of Applied Physics, Harvard University, Research Center for Functional Materials, International Center for Materials Nanoarchitectonics

We developed hybrid superconducting microwave resonators incorporating van der Waals (vdW) superconductors to explore the MW response of superconducting 2D materials in the GHz regime. We first developed a reliable technique to contact thin $NbSe_2$, entirely encapsulated with hexagonal Boron Nitride (hBN), with a coplanar Al resonator. Then we fabricated a hybrid Al-$NbSe_2$ resonator and measured the kinetic inductance of thin NbSe2. We report a kinetic inductance of 5 layers of $NbSe_2$ of 0.3 nH/□. Crystalline 2D superconductors with high kinetic inductance can be used in superconducting quantum devices, photon detection, and other quantum sensors.

This research was funded in part by the US Army Research Office grant no. W911NF-2210023, by the National Science Foundation QII-TAQS grant no. OMA-1936263, and by the Under Secretary of Defense for Research and Engineering under Air Force Contract No. FA8702-15-D-0001. S.Z. acknowledges support from the Schlumberger Foundation Faculty for the Future Fellowship. The views and conclusions contained herein are those of the authors and should not be interpreted as necessarily representing the official policies or endorsements, either expressed or implied, of the US Government.

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

Effects of Helium-ion Exposure on Superconducting-nanowire Single Photon Detectors

8.02

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Sponsorship: NSF CQN Center

Ultra-fast single-photon detectors can be useful for applications including quantum optical communication systems, high-speed communication, lightweight cryogenics for space crafts and biomedical use. In particular, high-temperature superconductors can allow for the development of superconducting-nanowire single-photon detectors (SNSPDs) that can operate at higher temperatures than standard superconductors, enhancing the efficiency, simplicity of use, viability, and affordability of the device. Unfortunately, the fabrication of high-temperature superconducting nanowires damages the material. Moreover, the realization of large and uniform detector arrays formed by hundreds or thousands of detectors is fraught with complexities. As a result, the opportunity to modify the detector metrics through post-processing is attractive.

In this work, the effects of helium ion irradiation on superconductive nanowires single photon detectors are systematically investigated. We exposed NbN single nanowires and SNSPDs with a total active area of 5 x 5 μm^2, 8 x 8 μm^2, 10 x 10 μm^2 to a range of irradiation doses from ~ 10^{14} to ~ 10^{20} ions/cm2 and thus demonstrated the impact of different doses on the target materials as well as improved the detector metrics. With an applied dose of 2.6·10^{17} ions/cm^2, we were able to obtain an increase in the detector count rate of around a factor of 5. These results lead to the possibility of reaching homogeneous detector metrics after fabrication and on the same chip. This capability suggests the potential to achieve uniform and consistent detector performance across an entire chip, offering a solution to the challenge of creating large, high-quality detector arrays.

Optimizing the Radiative Lifetimes of Perovskite Nanocrystals for Quantum Emission Applications

8.03

K. McFarlane-Connelly, N. Brown, M. G. Bawendi

Sponsorship: US Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under award no. DE-SC00216.

Realizing practical quantum computing schemes would fundamentally shift our technological capabilities. Imperative to this innovation is the scalable fabrication of quantum emitters (QEs). Ideal QEs approach the transform-limit ratio where the optical coherence lifetime (T_2) of the emission is twice the radiative lifetime (T_1). Large colloidal semiconductor nanocrystals (NCs) are promising QE candidates, however concrete methods of further minimizing their T_1 lifetimes are necessary. While theories have suggested T_1 values might scale inversely proportional to volume, this hypothesis remains unexplored. This research aims to elucidate the impact of size on the quantum emission properties of weakly confined perovskite nanocrystals. By tuning precursor chain lengths, a size series of highly luminescent $CsPbBr_3$ nanoparticles were prepared with extremely narrow size distributions. Five distinct sizes of nanocrystals were prepared in the weakly confined regime ranging from 16 to 23 nm, with standard distribution of sizes less than 7%. Post synthetic treatments were employed to boost photoluminescence quantum yields to higher than 80% at room temperature for all samples. The radiative lifetimes of these particles were observed under cryogenic temperatures revealing T_1 values that scaled inversely with particle size, providing experimental confirmation of theoretical predictions. These results demonstrate that increasing particle size is a promising route to approaching the ideal transform limit ratio with NCs. This fundamental work aims to enables future optimization of the quantum emission properties of weakly confined nanocrystals in hopes of realizing a path to scalable quantum emitter materials.

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Research Interests:
Energy, III-Vs, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices.

Tailoring Light Emission and Scattering from Atomically Thin Materials with Transferable Nanostructures

8.04

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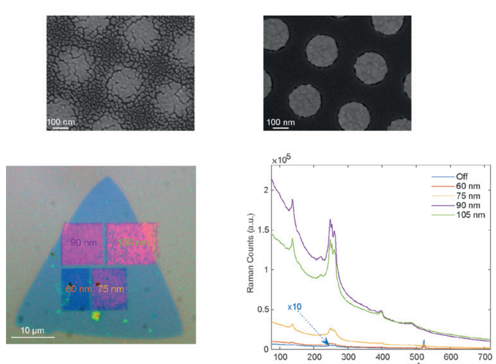
Sponsorship: U.S. Department of Energy, Office of Science National Quantum Information Science Research Center's Co-design Center for Quantum Advantage (C2QA) under contract number DE-SC0012704, Raith VELION FIB-SEM in the MIT.nano Characterization Facilities (Award: DMR-2117609), MathWorks Science Fellowship (Award: 4000182189)

Optical spectroscopy is indispensable for unveiling the unique properties and symmetries of materials in the atomically thin limit. However, the vanishing thickness often leads to a cross section too low for conventional optical methods to work. In this work, we developed a technique, completely dry and simple to implement, to fabricate and transfer high-resolution optical enhancement nanostructures for Raman and PL spectroscopy. We demonstrate orders-of-magnitude increase in the intensities of single-layer WSe_2 phonon modes; enabling the detection of phonon modes of three-layer NiI_2 using non-resonant excitation; and selective Purcell enhancement of the quenched excitons in WSe_2/MoS_2 heterostructures. We also highlight that the method is particularly suitable for optical studies of air-sensitive materials, as the fabrication and transfer can be performed in situ.



▶ Figure 1: Top Panel: Our method provides significant increase in the quality of the nanostructures fabricated without adhesion layers. Bottom Panel: Lack of the adhesion layer enables us to transfer the nanostructures on van der Waals materials, resulting in a large enhancement of the optical signal.

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Elucidating the Dominant Exciton Dynamics in MOCs through Physical, Chemical, and Electrical Manipulation of the Lattice

8.05

N. J. Samulewicz, W. S. Lee, W. A. Tisdale

Sponsorship: NSF Graduate Research Fellowship award no. 1745302, U.S Army Research Office award no. W911NF-23-1-0229

Rapidly expanding integration of semiconductors in consumer electronics up through large-scale supercomputers necessitates substantial quantum efficiency improvements to reduce global electricity consumption. 2D semiconductors, like transition metal dichalcogenides (TMDs) and 2D layered perovskites, have emerged in recent years as strong contenders over silicon and other bulk semiconductors due to their strong exciton binding energy and highly tunable properties.

Our lab investigates metal organic chalcogenolates (MOCs) as 2D semiconductors that can improve upon these existing structures—for example, the layer dependence of TMDs and instability of lead halide perovskites. MOCs are novel van der Waals stacked hybrid organic-inorganic semiconductors with extreme 1D quantum confinement, in-plane anisotropy, and layer independent emission. These properties are promising for applications as light emitting diodes (LEDs), excitonic switches, and a variety of other optoelectronic devices. Silver phenylselenolate, $[AgSePh]_\infty$, is a MOC of particular interest due to its narrow, naturally blue emission (~467 nm), along with its high environmental stability from covalently bonded organic and inorganic atoms. However, its excited state dynamics are still dominated by nonradiative recombination mechanisms, limiting its potential to revolutionize future semiconductor frameworks. This work details plans to perform physical, chemical, and electrical manipulation of MOCs to identify the influence of extrinsic defects and intrinsic material properties on exciton mobility and recombination in 2D hybrid semiconductors.

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Electronic devices, Electronics, Lasers, Nanomanufacturing, Nanomaterials, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Sensors, Si.

Superconducting Nanocryotrons for Single-Photon Detector Readout

8.06

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Sponsorship: DOE FNAL Microelectronics (DE-AC02-07CH11359). A.S. acknowledges support from the MIT Vanu Bose Presidential Fellowship and NSF Graduate Research Fellowship (2141064). O.M. acknowledges support from the DoD NDSEG Fellowship.

Efficient, low-noise single-photon detection is crucial to sensing, communication, and computing applications. To date, superconducting nanowire single photon detectors (SNSPDs) are the most efficient such detectors, with the lowest dark count rates and shortest timing jitter in the ultraviolet to infrared (IR) wavelengths .

Many applications require detection in the mid-IR. However, the read-out signal from SNSPDs produced for these wavelengths is usually weaker than for UV and visible detectors. Consequently, detection at longer wavelengths necessitates a low-noise, low-energy cryogenic amplifier. High-electron-mobility transistors and cryogenic CMOS amplifiers can provide amplification, yet they are not scalable due to substantial power dissipation and a lack of integrability with SNSPDs. In contrast, superconducting nanocryotron (nTron) devices provide gain with minimal power dissipation and are easily integrated on-chip with SNSPDs, making them ideal candidates for these purposes.

To optimally amplify SNSPD pulses, nTron devices must provide consistent and maximal gain. Due to heterogeneous current density across nTrons, the location of the nTron choke is a salient design parameter for determining the device's gain. Thus, to ascertain the best choice of choke offset position we have fabricated a wafer with 350 nTron devices and measured their switching characteristics. We are currently working to determine the gain of each device as a function of the location of the choke to develop a model for the optimal nTron design for SNSPD read-out. This design will then improve performance of SNSPDs in mid-IR and array applications.

High-Temperature Nanowire-Based Superconducting Circuits

8.07

D. J. Paul, D. Santavicca, K. K. Berggren

Sponsorship: NSF Engineering Research Center for Quantum Networks, MIT Lincoln Lab SNSPD Array Program

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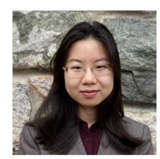
Superconducting electronics are promising for energy-efficient computing beyond CMOS, cryogenic sensor readout, and future quantum computing platforms. Among various families of superconducting circuits, nanowire-based cryotrons have proven to be quite useful in applications, including serving as pre-amplifiers for superconducting nanowire single-photon detector (SNSPD) readout, interfacing JJ-based circuits with CMOS circuits, functioning as digital logic circuits, and superconducting memory cells. These nanowire-based cryotrons are three-terminal devices which are immune to stray magnetic fields and capable of driving high-impedance loads while providing a high fan-out of digital signals. However, their operation has been demonstrated primarily in low-Tc material systems such as NbN, NbTiN, MoN, and WSi, resulting in their operating temperatures usually below 10K. However, in quantum communication and computing, there is a growing need to reduce thermal loads at the 4K or mK stage to accommodate more space for qubits and vacancy centers. This can be achieved by shifting cryogenic logic, memory, and microwave circuits to the 40K stage.

In this work, we investigate the performance of nanocryotrons fabricated on a thin film of YBCO with a critical temperature of 93K. Since the critical temperature of YBCO degrades when exposed to humidity and temperature, fabricating nanowires on YBCO without degrading its superconducting property is quite challenging. Additionally, YBCO does not react to commonly used reactive ion gases employed in etching. We will discuss how to address these challenges in the fabrication process of sub-100 nm width nanowires and present the current-voltage characteristics of the fabricated devices at 40K. Furthermore, we will explore how the device performance changes with increasing operating temperature, and then we will discuss how this work can pave the way for transitioning superconducting nanowire-based devices from sub-4K operation to a more affordable and compact liquid N2 dewar setup.

High Frequency Microwave Packaging for Josephson Traveling Wave Parametric Amplifiers

8.08

J. Wang, A. Yen, K. Peng, W. Van De Pontseele, K. Sliwa, P. Harrington, J. Qiu, K. Serniak, M. E. Schwartz, J. A. Formaggio, W. D. Oliver, K. P. O'Brien



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The detection of single-photon microwave signals above 12 GHz is of significant interest for quantum sensing applications in neutrino mass measurement, dark matter searches, and quantum information processing. Below 12 GHz, quantum-limited amplification can be achieved with high-gain, broadband, and low-noise Josephson traveling wave parametric amplifiers (JTWPAs). However, standard microwave packaging for JTWPAs introduce package modes above 12 GHz, as well as impedance mismatches at the connectors and wirebonding locations that hinder the performance of JTWPAs. Here we present an approach to high frequency microwave package design that optimizes package and connector modes, minimizes wirebonds on interposer chips, and employs signal-line compensation strategies for better impedance matching throughout. The package is modular, easily prototyped, and is well-matched up to 27 GHz. This package will be deployed with a K band JTWPA tailored to the Project 8 neutrino mass measurement experiment, which will enable the detection of cyclotron radiation from single electrons with a signal-to-noise ratio improvement of an order of magnitude compared to current HEMT amplifiers. Since this design features low reflection and minimal spurious modes over a broad range of frequencies, this package can also be tailored to suit a wide range of superconducting quantum devices.

This work is supported by the NSF Graduate Research Fellowship, the US DOE Office of Nuclear Physics (DE-FOA-0002110), the US NSF, the PRISMA+ Cluster of Excellence at the University of Mainz, and internal investments at all institutions. 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. Air Force

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Large Scale Photonics Integrated Circuits for Programmable Nano-photonics Processors and Quantum Information Processing

8.09

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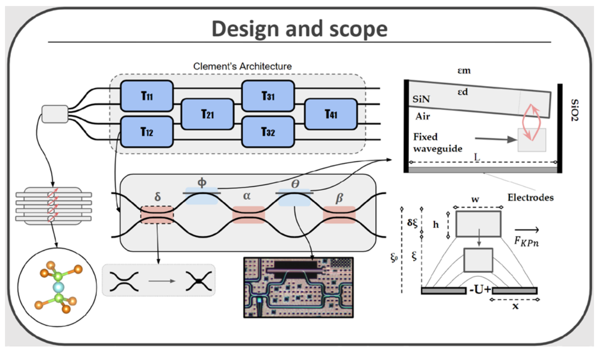
Sponsorship: AIM Photonics and NTT

This study analyzes the benefits of photonics integrated circuits (PICs) in quantum and high-performance computing. It highlights PICs' advantages in data transmission and processing, due to their low-loss, high-bandwidth nature, and their potential in quantum computing through precise photon manipulation. The study proposes novel PIC mesh architectures to minimize error densities, crucial for quantum computation reliability, and discusses PIC compatibility with cryogenic environments, key for quantum systems. Although awaiting experimental confirmation, theoretical models and initial simulations indicate that PICs could effectively operate in cryogenic temperatures, suggesting potential integration with cryogenic MEMS in future quantum computing platforms. This research lays the groundwork for further experimental work and the application of PICs in advanced computing domains.



▲ Figure 1: Large-scale programmable integrated photonics for quantum information processing with artificial atoms

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Integrated Photonics for High-Fidelity Control of Large-Scale Atom Array Quantum Simulator

8.10

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Sponsorship: U.S. Department of Defense (NDSEG Fellowship), MIT (Jacobs Presidential Fellowship), National Science Foundation (DMR-1747426, Graduate Research Fellowship Program), Belgian American Educational Foundation (Fellowship), U.S. Department of Energy (Quantum Systems Accelerator (QSA)), Defense Advanced Research Projects Agency (ONISQ), MITRE Corporation (Moonshot program), Alexander von Humboldt-Stiftung (Feodor Lynen Research Fellowship)

Advances in laser technology have driven discoveries in atomic, molecular, and optical (AMO) physics and emerging applications, from quantum computers with cold atoms or ions, to quantum networks with solid-state color centers. This progress is motivating the development of a new generation of optical control systems that can manipulate the light field with high fidelity at wavelengths relevant for AMO applications. These systems are characterized by criteria: (C1) operation at a design wavelength of choice in the visible (VIS) or near-infrared (IR) spectrum, (C2) a scalable platform that can support large channel counts, (C3) high-intensity modulation extinction and (C4) repeatability compatible with low gate errors, and (C5) fast switching times. Here, we provide a pathway to address these challenges by introducing an atom control architecture based on VIS-IR photonic integrated circuit (PIC) technology. Based on a complementary metal–oxide–semiconductor (CMOS) fabrication process, this atom-control PIC (APIC) technology can meet system requirements (C1)–(C5). As a proof of concept, we demonstrate a 16-channel silicon-nitride-based APIC with (5.8±0.4) ns response times and >30dB extinction ratio at a wavelength of 780 nm. We also present our scheme to merge our atom-control PIC system with arrays of ultracold atomic ensembles.

Magnetic Microwave Pulse Control Schemes for Non-Identical Spin Qubits

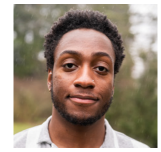
8.11

M. A. Sere, I. Harris, D. Englund

Sponsorship: MIT Lemelson Fellowship, National Science Foundation (NSF), Science-Technology Center (STC), Center for Integrated Quantum Materials (CIQM) (DMR-1231319), NSF Engineering Research Center for Quantum Networks (CQN) (Cooperative Agreement No. 1941583), MITRE Moonshot Program

With the potential for high qubit densities, long coherence times, and relatively high temperature operation, solid state spin qubits are promising candidates for a scalable quantum processor platform. Magnetic microwave pulses can drive the resonances of these qubits, and can therefore be used to control them. However, unavoidable process variation and fabrication errors alter the properties of the defects. Variance in the qubits' resonance frequencies is expected, as is inhomogeneity in the applied magnetic field amplitudes experienced by the qubits.

In this work, we devise methods of mitigating these effects through calibration and magnetic pulse design. Magnetic pulses can be shaped through amplitude and frequency modulation, a method used in NMR spectroscopy. The span of time over which a pulse is applied to specific qubits offers additional tunability. Through these means, pulse sequences and timings can be tailored to high fidelity operations for various ranges of qubit properties. Finally, a calibration step maps qubits to the appropriate pulse parameters. We demonstrate achievable fidelities and highlight system tradeoffs using simulation.



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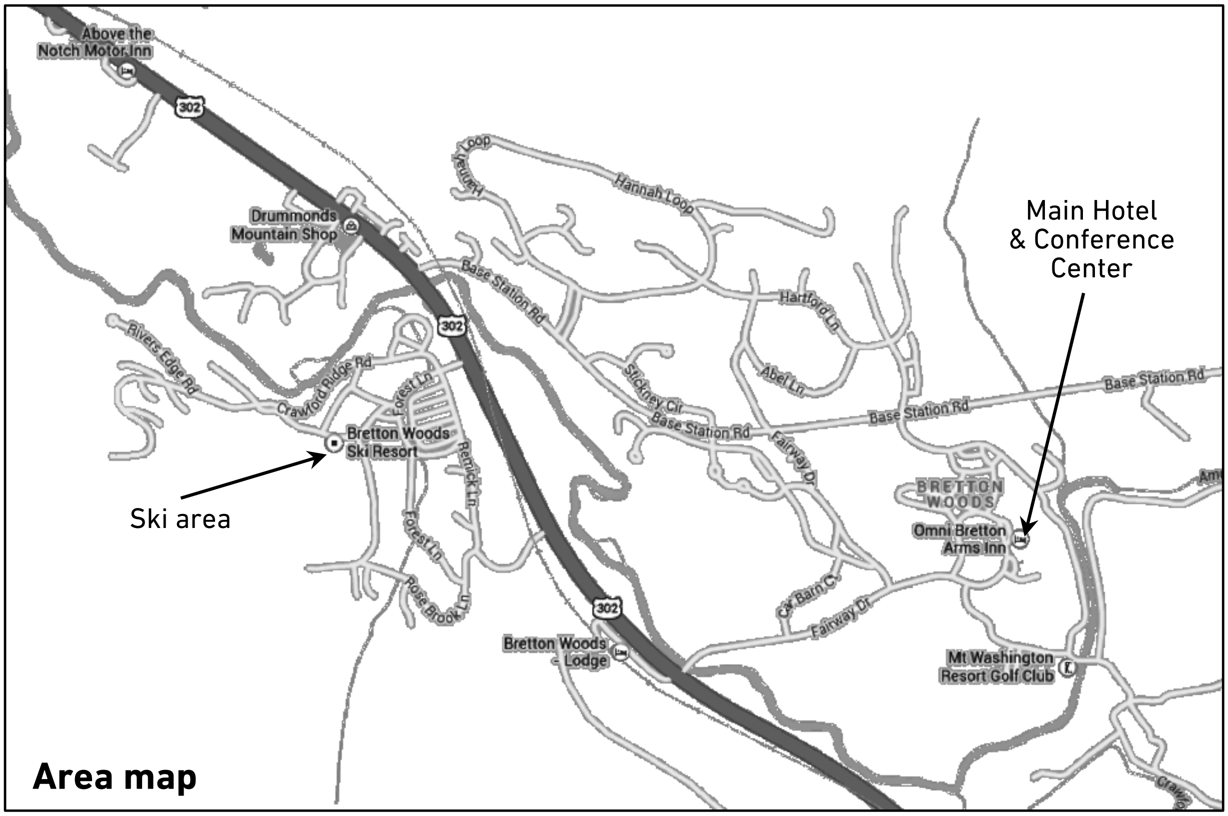
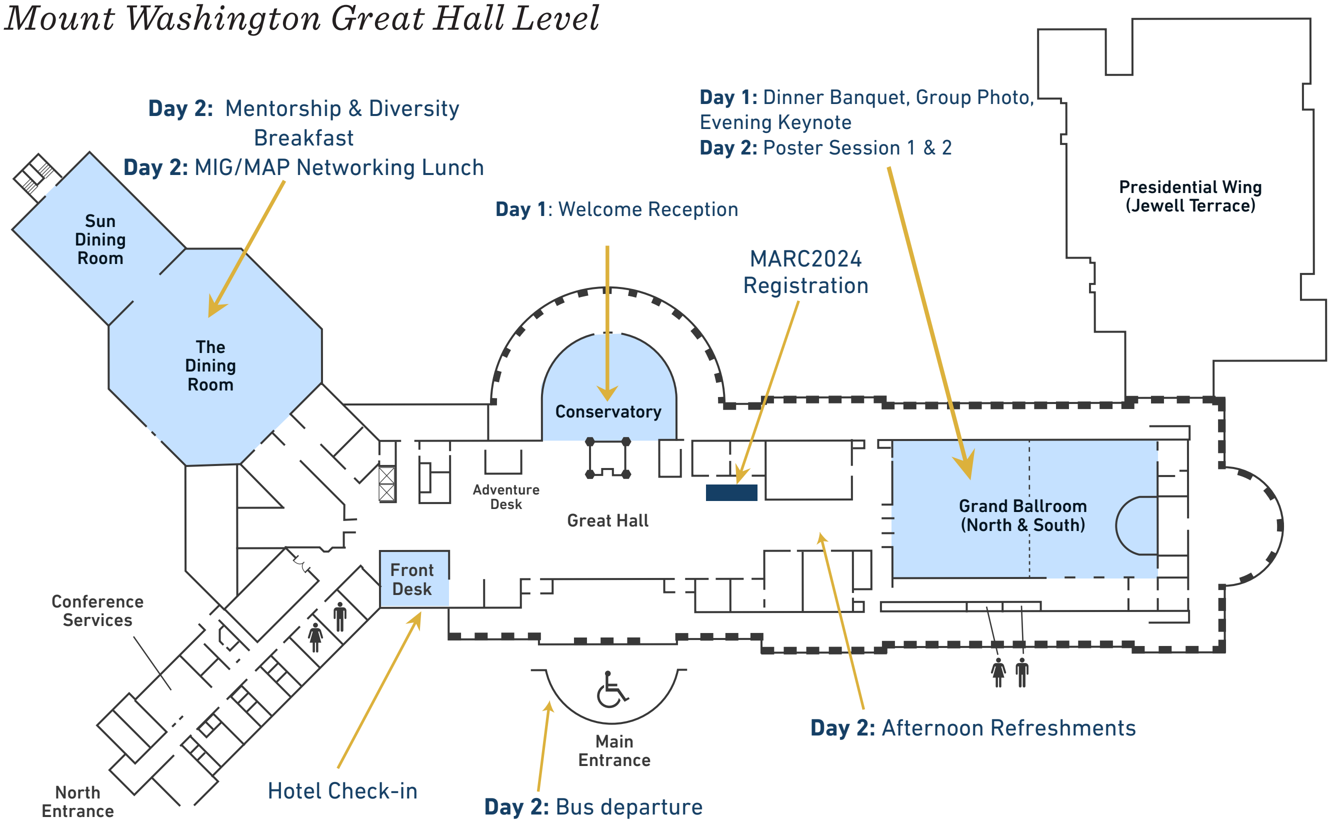
Field-Emitter devices, Lasers, Light-emitting diodes, Nanotechnology, Optoelectronics, Photonics, Quantum devices, Spintronics.

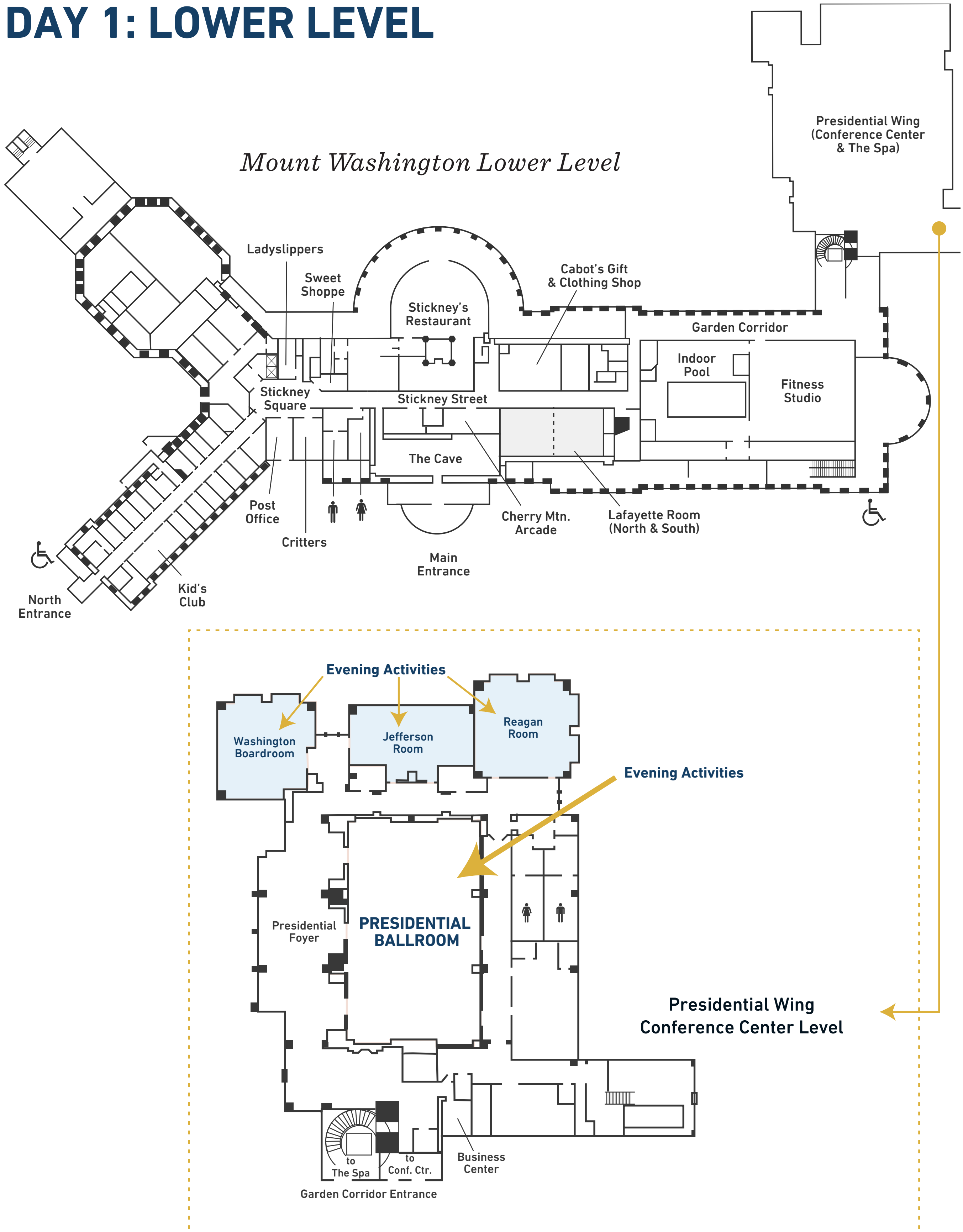
MAPS



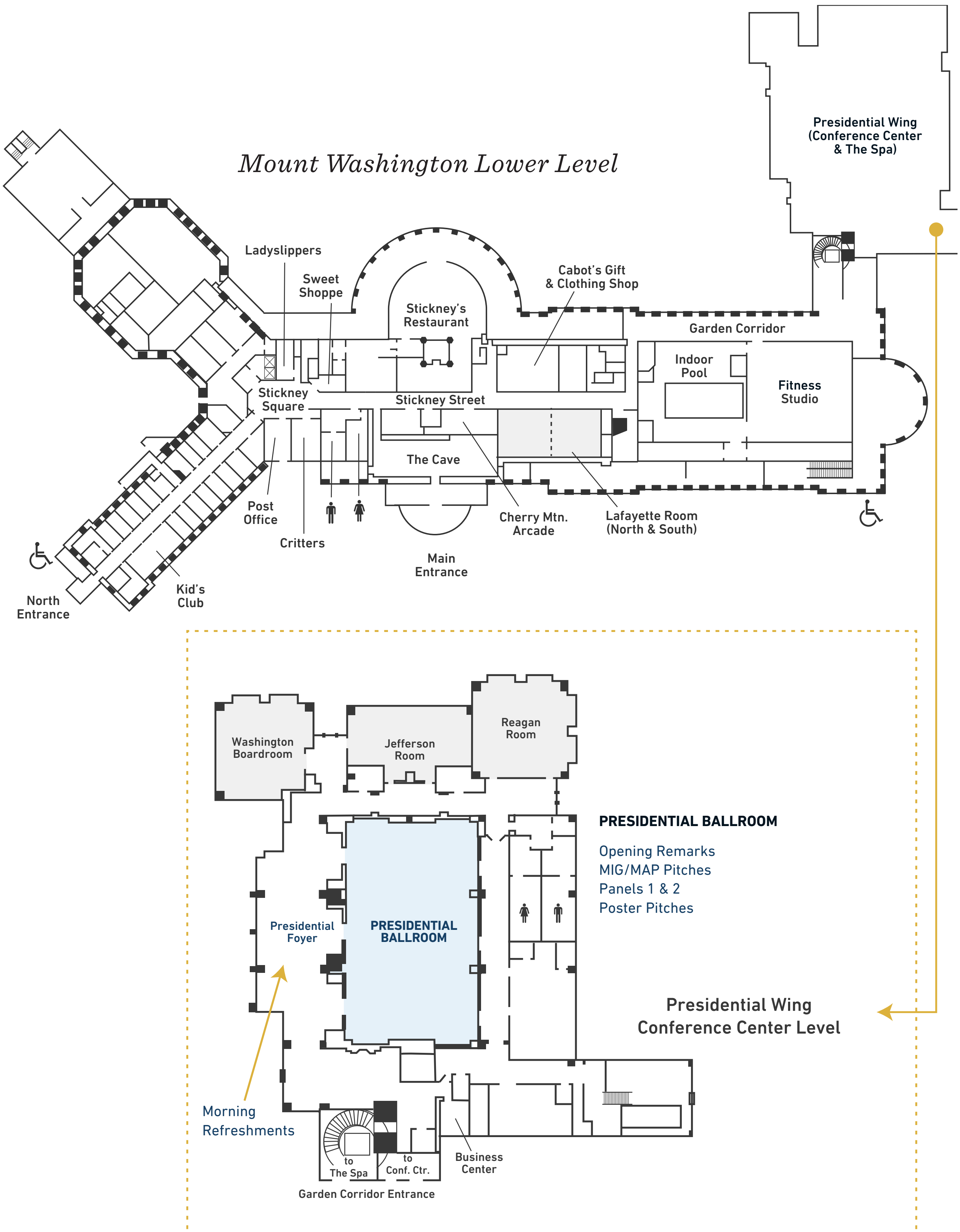
Mount Washington Great Hall Level



DAY 1: LOWER LEVEL



DAY 2: LOWER LEVEL



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