

Spin-orbit torque phenomena in complex oxide heterostructures

Presenter: **Biswajit Sahoo**, Hardware Developer, IBM Research, Albany

Researchers: **Biswajit Sahoo**, **Eric Fullerton**, Endowed Chair Professor, CMRR

Advisor: **Eric Fullerton**, Endowed Chair Professor, CMRR

Energy-efficient magnetic spin orbit torque nano-oscillators and coupled oscillator arrays are being explored for low-power neuromorphic computing systems. Commonly studied oscillator systems are mostly based on metallic bilayers of ferromagnet (FM)/ heavy metal (HM) (FM=CoFeB, Py and NM=Pt, Ta, W). I will discuss recent efforts to replace the metallic layers with complex oxides with coupled spin, electron and lattice degrees of freedom providing opportunity for new device functionality. Large spin-charge conversion, low damping, and small resonance linewidth are essential constituents for the development of energy efficient oscillators. In this regard half-metallic perovskite ferromagnet, La_{0.67}Sr_{0.33}MnO₃ (LSMO) films are studied as the magnetic free layers combined with transition metal oxides such as iridates (e.g. IrO₂ and CaIrO₃) and NdNiO₃ as the spin-orbit torque layer. NdNiO₃ (NNO) exhibits a first-order metal-insulator transition centered near 200K in bulk. We observe thickness and temperature dependent modulation of spin-charge conversion through the phase transition of NNO and harness the disorder in NNO to generate a pronounced enhancement of the inverse spin Hall effect signal at the transition temperature. IrO₂ and CaIrO₃ have topological band structures providing enhanced spin to charge conversion. Finally, progress towards an all-oxide nano-oscillator will be discussed.

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Low Temperature Suppression of Intertwined Orders in $\text{La}_{1/3}\text{Sr}_{2/3}\text{FeO}_3$ Thin Films

Presenter: *Kate Matthews*, PhD Candidate, Dept. of Physics

Researchers: *Mayia A. Vranas*, PhD Candidate, Dept. of Physics

Robin Glefke, PhD Candidate, Dept. of Physics

Xiaoke Li, MS Student, Materials Science & Engineering

Advisors: *Eric Fullerton*, CMRR Director & Endowed Chair

Professor, Dept. of ECE & Nanoengineering

Alex Frañó, Associate Professor, Dept. of Physics

The strong coupling between spin, charge, and lattice degrees of freedom in perovskite oxides can lead to an array of exotic phenomena, such as intertwined orders and coupled phase transitions. This is exemplified by the mixed valence ferrite $\text{La}_{1/3}\text{Sr}_{2/3}\text{FeO}_3$ (LSFO), which exhibits a coupled antiferromagnetic and charge ordering phase transition at 190 K that has been well studied in thin films, single crystal, and polycrystalline samples. However, the low temperature behavior of LSFO thin films below 100 K has not been thoroughly explored. This work uses several X-ray scattering and spectroscopy techniques to directly probe LSFO's magnetic and charge order down to low temperature. Using resonant X-ray scattering, we observe a complete suppression of LSFO's known antiferromagnetic and charge order below ~ 25 K. Further spectroscopy and coherent scattering measurements provide insight into LSFO's electronic structure and domain dynamics in this new low temperature phase, and we propose possible explanations for the observed order suppression based on reduced dimensionality of our thin films. Our findings provide insight into the effects of competing interactions in strongly correlated materials, particularly those with coupled orders.

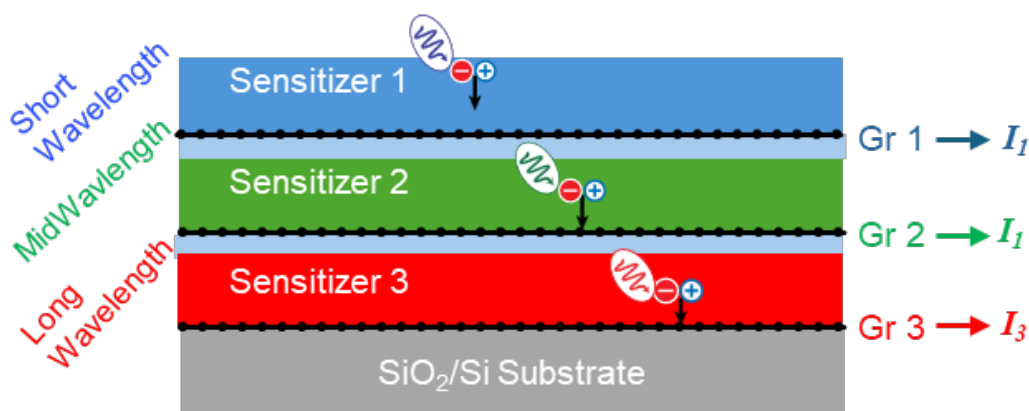


Multispectral Photodetectors based on Vertical Graphene-Quantum Dot Stacks

Presenter: **Prof. Oscar Vazquez Mena**, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Collaborators: **Ju Ying Shang, Freddy Garcia, Suraj Patel, Anthony Monterrosas, Oscar Chen**, Electrical and Computer Engineering, UC San Diego, **Seungbae Ahn**, Division of Electronics and Electrical Information Engineering, Korea Maritime and Ocean University, Busan, Republic of Korea

In this contribution we describe the simulation, fabrication and implementation of photodetectors with multiple spectral detection channels covering from the visible ($\lambda \sim 500$ nm) to the infrared ($\lambda \sim 1800$ nm) range by intercalating single-graphene monolayers as charge collectors with different nanomaterials such as zinc oxide or lead sulfide quantum dots used as light absorbers and photocarrier generators. Our device operation is based on the longer penetration depth of longer wavelengths, with deeper graphene layers sensing longer wavelengths and shallower graphene layers sensing shorter wavelengths. Furthermore, by incorporating quantum dots of different sizes, and therefore bandgaps, each graphene collects photocarriers generated from different light wavelengths determined by the spectral absorption of the films. This technology is pretty compact and encapsulated in a thin film, avoiding dispersive or filtering components that lead to bulky multispectral components or devices. While there is significant overlap between spectral response of Graphene layers, further improvements in technology and design are under investigation to achieve a individual spectral channel for each graphene layer.





Solution-Processed Tellurium Nanocubes and Thin Films for Extended IR Optoelectronic Applications

Presenter: **Suraj Patel**, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Collaborators: **Prof. Kenji Nomura**, **Prof. Yu-Hwa Lo**, Electrical and Computer Engineering, UC San Diego

Advisor: **Prof. Oscar Vazquez-Mena**, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Tellurium (Te) is an emerging p-type semiconductor material with a narrow optical bandgap of 0.3 eV in the far-infrared regime, making it a unique candidate for infrared applications amenable to low-temperature processing. However, unlike other semiconductor producing high-quality Te films has been a challenge as it typically requires high-vacuum techniques like Chemical Vapor Deposition (CVD) or Atomic Layer Deposition (ALD), which yield 2D flakes and hinder scalability. The alternative method of Te film formation is Thermal Evaporation, but the film formed during this process is amorphous in nature, which lacks the desired crystalline quality and stability. This work presents a reliable, solution-based synthesis of single-crystal Te nanocubes and uniform polycrystalline films of pure Te, which exhibit superior quality to the amorphous films obtained by thermal evaporation. While some solution-based methods exist beforehand, they struggle with controlling crystal size, shape, and lacks size uniformity across the substrate. Moreover, a reliable solution-based method for producing uniform Te films has not been demonstrated yet. We used a thiol-amine solution to dissolve the Tellurium, and then, by mixing it with other solutions, we were able to control the shape of the Te crystals. By controlling the solution composition, ambient exposure, and spin-coating parameters, we achieved shape-controlled, monodisperse single crystal nanocubes. The size of the nanocubes can be tuned by annealing temperature and concentration, whereas the shape of the nanocube is dependent on the ambient exposure time. Furthermore, by using two materials having different wettability on the same substrate, we demonstrate that crystal deposition is highly dependent on substrate wettability. This enables us to pre-pattern the substrate to direct the Te crystal growth either on the prepatterns (Au and ITO) or repels from the prepatterned structure (SiO₂), leading to the formation of a patterned Te crystal distribution. Additionally, we demonstrate that our process can be extended by repeating the spin coating cycle multiple times to get a polycrystalline film of Te with the thickness of ~ 500nm. Not only do these films have high uniformity and density, but they also exhibit photoresponse. This robust, low-temperature method provides a cost-effective pathway for producing patterned Te nanostructures and high-quality films, promising for advanced infrared optoelectronic applications.

MemComputing in the age of AI

Massimiliano Di Ventra

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MemComputing is a new physics-based approach to computation that employs memory (*time non-locality*) to both process and store information on the same physical location [1]. I will provide a brief introduction to this computing paradigm and will then discuss how it can be utilized in the field of machine learning, demonstrating its advantages over traditional methods and its usefulness in several science and engineering applications.

[1] M. Di Ventra, *MemComputing: Fundamentals and Applications* (Oxford University Press, 2022).



Biographical Sketch

Massimiliano Di Ventra obtained his undergraduate degree in Physics *summa cum laude* from the University of Trieste (Italy) in 1991 and did his PhD studies at the Swiss Federal Institute of Technology in Lausanne in 1993-1997. Since 2004, he is a professor of Physics at the University of California, San Diego. Di Ventra has worked on a variety of topics in condensed matter physics such as the theory of quantum transport in nanoscale and atomic systems, non-equilibrium statistical mechanics, polymer dynamics/DNA sequencing in nanopores, and memory effects in nanostructures. Recently, he has introduced the MemComputing paradigm of computation. He has been invited to deliver more than 350 talks worldwide on these topics including 20 plenary/keynote presentations. He has published more than 300 papers in refereed journals, 5 textbooks, and has 12 granted patents (7 foreign). He is a fellow of the American Association for the Advancement of Science, the American Physical Society, the Institute of Physics, the IEEE, a member of the National Academy of Inventors and of Academia Europaea. In 2018 he was named Highly Cited Researcher by Clarivate Analytics; he is the recipient of the 2024 Humboldt Research Award, the 2020 Feynman Prize for theory in Nanotechnology, and is a 2022-2023 IEEE Nanotechnology Council Distinguished Lecturer. He is the co-founder of MemComputing, Inc. (<http://memcpu.com/>).



Memory-Induced Long-Range Order Drag

Presenter: *Chesson Sipling*, Graduate Student Researcher, Department of Physics, UCSD

Researcher: *Yuan-Hang Zhang*, Postdoctoral Researcher, Department of Physics, UCSD

Advisor: *Massimiliano Di Ventra*, Professor, Department of Physics, UCSD

Recent research has shown that memory, in the form of slow degrees of freedom, can induce a phase of long-range order in coupled fast degrees of freedom. This phenomenon has been coined “memory-induced long-range order.” [1]

In this talk, I will demonstrate that this phase can be transferred, or “dragged,” in a multilayer system with unidirectional, interlayer couplings. This phenomenon occurs even when subsequent layers are locally interacting and have no memory of their own.

Such behavior could have several important implications, including acting as a design tool for layered, adaptive matter and computational systems and providing key insights into the nature of observed scale-invariant behavior in the layered brain cortex. [2]

[1]: Chesson Sipling, Yuan-Hang Zhang, and Massimiliano Di Ventra, Memory-induced long-range order in dynamical systems, *Phys. Rev. E* 112, 014124 (2025).

[2]: Yuan-Hang Zhang, Chesson Sipling, and Massimiliano Di Ventra, Memory-induced long-range order drag, *New J. Phys.* 28, 025001 (2026).



Scientific Discovery as Meta-Optimization: Application to MemComputing

Presenter: *Yuan-Hang Zhang*, Postdoctoral Researcher, UCSD
Department of Physics

Researcher: *Chesson Sipling*, Graduate Student Researcher, UCSD
Department of Physics

Advisor: *Massimiliano Di Ventra*, Professor, UCSD Department of
Physics

Scientific research is fundamentally an optimization problem over a vast space of theories, experiments, and implementations, evaluated by criteria of quality, novelty, and validity. Large language models (LLMs) now allow this space to be searched at unprecedented scale, but a more subtle question goes unanswered: what should these systems actually optimize?

In this talk I argue that automated research is best framed as meta-optimization: co-evolving solutions and the criteria used to judge them. The core mechanism is consensus objective aggregation: many LLM-generated objectives are combined via correlation-weighted voting with age decay, producing a stable, self-correcting evaluation criterion that adapts as understanding deepens. Using this framework we have been able to discover new types of digital MemComputing solvers for planted 3-SAT problems that reduce the scaling exponent from $N^{2.51}$ to $N^{1.33}$. [1]

I will close with a forward look at a flexible framework that extends these ideas to the full research lifecycle, turning a curated workspace into an open-ended auto-research pipeline.

[1] Y.-H. Zhang, C. Sipling, and M. Di Ventra, Scientific discovery as meta-optimization: a combinatorial optimization case study, Research Square preprint (2026).



Multi-Physics Modeling and Imaging of Nanomagnetic Structures

Presenter: *Vitaliy Lomakin*, Professor, ECE, CMRR

Collaborators: *Jiawei Duan, Egor Savostin, Andrew Parsons, Bill Murray, Oleg Shpyrko, Sergio Montoya, Eric Fullerton*

This presentation summarizes our recent efforts in the computational and experimental study of nanomagnetic and electromagnetic structures, with an emphasis on high-performance multi-physics modeling and advanced imaging methodologies. We have developed scalable micromagnetic, electromagnetic, elastic, and coupled multi-physics solvers optimized for modern CPU/GPU computing architectures. These tools are applied to the investigation of dynamic magnetic phenomena and nanoscale device operation, including synchronization of spin torque oscillators mediated by elastic waves, strain-induced modification of the Dzyaloshinskii–Moriya interaction, magnetization dynamics in soft magnetic materials, and heat-assisted magnetic recording (HAMR) dual-layer media. In parallel, we are developing computational methods for coherent X-ray diffraction imaging to enable high-resolution characterization of nanoscale magnetic and structural dynamics. The presented work highlights the interplay between magnetics, mechanics, electromagnetics, and advanced computational techniques in emerging nanoscale systems.



Enabling Dynamic Geometries, Evolving Materials, and Extreme-Scale Simulation with On-the-Fly Finite Element Micromagnetic Solver

Presenter: *Jiawei Duan*, PhD Candidate, MATS

Advisor: *Vitaliy Lomakin*, Professor, ECE

We present a fully on-the-fly finite element method (FEM) solver for high-performance micromagnetic simulation of dynamically evolving magnetic structures. Conventional solvers typically assume static geometries, fixed material parameters, and precomputed field operators. While effective for standard problems, these assumptions become limiting when structures move, deform, or change material state, often requiring repeated preprocessing, remeshing, or operator regeneration, significantly increasing computational cost.

The key contribution is a fully on-the-fly CPU and GPU formulation that eliminates reliance on fixed preprocessing and auxiliary airbox meshes. All effective magnetic field components are evaluated directly at runtime using the current mesh and geometry. This enables simulation of moving and deforming structures without remeshing or rebuilding field data structures, while maintaining low memory usage and supporting highly complex geometries.

The solver supports dynamic meshes with strong computational efficiency and scalability, making it suitable for motion, deformation, morphology evolution, and reconfigurable magnetic devices. It also incorporates 1D, 2D, and 3D periodic boundary conditions within a unified GPU framework, allowing isolated, film-like, wire-like, and bulk-periodic systems to be handled consistently. Additionally, it supports mixed FEM meshes, including tetrahedrons, hexahedrons, and pyramids of arbitrary order, enabling high accuracy for complex structures. The approach further allows dynamic material properties during simulation. Local magnetic parameters can evolve with temperature, strain, field, phase, or microstructure. Since no precomputed matrices are used, these parameters can be updated directly at runtime. With these capabilities, the solver still achieves high performance with a minimal memory footprint, enabling demagnetizing-field evaluation of up to 1 billion nodes on a single GPU while exhibiting strong scaling across larger GPU configurations as shown in Fig. 1.

Overall, this solver extends micromagnetic simulation beyond static assumptions, providing a practical framework for studying mechanically active magnetic systems, adaptive materials, and next-generation devices driven by motion, deformation, and evolving material states.



Physical Neural Networks from Magnetoelastic Oscillator Synchronization

Presenter: **Egor Savostin**, PhD Candidate, MATS

Advisor: *Vitaliy Lomakin*, Professor, ECE, CMRR

Collaborators: *Andy Kent* (NYU), *Eric Fullerton*, CMRR

The development of energy-efficient and scalable computing architectures has motivated the exploration of physical systems that naturally emulate neural network behavior. In this work, we investigate a hardware-native approach to neural computation based on networks of spin torque oscillators (STOs) coupled through magnetoelastic interactions. Each oscillator acts as a nonlinear dynamical unit, while elastic waves in the substrate mediate long-range coupling between them.

Using a coupled micromagnetic-elastic finite element framework, we model the generation and propagation of strain fields induced by magnetostriction and their feedback on magnetization dynamics. Through phase reduction, the system is shown to map onto a delayed Kuramoto-type model, where synchronization dynamics encode computational states. We demonstrate that different synchronization regimes - such as in-phase, anti-phase, and phase-shifted states - can be interpreted as distinct neural representations.

A key result is the realization of associative memory through physically encoded interactions. Patterns are stored in the system via phase delays and coupling terms, enabling retrieval from corrupted inputs through the natural evolution of the oscillator network. Additionally, we show that geometric arrangement of oscillators directly influences the emergent phase patterns, providing a pathway to encode information in the physical layout itself.

These findings establish magnetoelastic oscillator networks as a promising platform for neuromorphic and wave-based computing. By embedding computation into the intrinsic physics of coupled oscillators, this approach offers a route toward low-power, scalable, and fully physical neural systems with potential applications in signal processing, pattern recognition, and unconventional computing architectures.



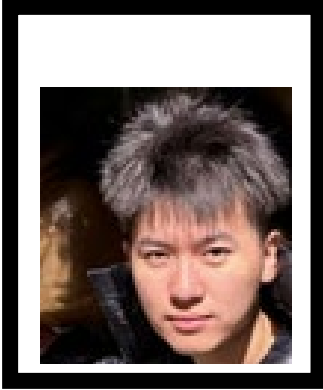
Algorithms for Coherent X-Ray Diffraction Imaging

Presenter: *Andrew Parsons*, Center for Memory and Recording Research

Collaborators: *Bill Murray*, ECE, CMRR, *Oleg Shpyrko*, Physics, CMRR

Advisor: *Vitaliy Lomakin and Sergio Montoya*, Center for Memory and Recording Research

Coherent Diffractive Imaging (CDI) enables high-resolution sample reconstruction without the need for imaging optics whose resolution is limited by lens aberrations and wavelength-scale constraints. While the method has its advantages, there are limitations to it such as the twin-image ambiguity which arises from the inability to distinguish between an object and its inverted complex-conjugate counterpart using Fourier magnitude data alone. Methods such as the use of asymmetric supports show promise in reducing the ambiguity but have their limitations which include a heavy dependence on real-space object geometry and possible suppression of fine structural detail. Dual-axis scanning may provide additional geometric consistency constraints capable of mitigating twin-image ambiguities. In addition to reconstruction fidelity, rapid convergence remains an important practical consideration. One of the algorithms used to reduce convergence time is the Carousel Phase Retrieval Algorithm (CPRA) which has been shown to drastically reduce convergence times for single-axis scan reconstructions. Currently, there is no CPRA-style reconstruction tool for dual axis reconstruction. Given the twin ambiguity, the limited applicability of current mitigation methods, and the speed of CPRA, the proposed work investigates whether consistency constraints between intersecting Fourier-space planes from orthogonal scan axes in a CPRA-style algorithm can improve convergence toward high-resolution reconstructions with suppressed twin-image stagnation under a wider range of reconstruction conditions than current ambiguity mitigation techniques.



The use of MRI and augmented reality in back surgery

Presenters: *Songyuan Lu*, PhD Student, MAE

Steven Hui, Undergraduate Student, BENG

Researchers: *Songyuan Lu*, PhD Student, MAE

Steven Hui, Undergraduate Student, BENG

Isabelle Garlepp, Undergraduate Student, BENG

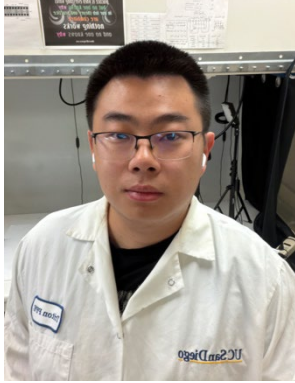
Naina Khanna, Undergraduate Student, BENG

Sherry Huang, Highschool Student

Collaborator: *Farshad M. Ahadian*, MD, Center for Pain Medicine

Advisor: *Frank E. Talke*, PhD, Center for Memory and Recording Research

Chronic back pain is a growing global health concern, necessitating frequent interventions like Radiofrequency Ablation (RFA) and Epidural Steroid Injections (ESI). However, standard procedures currently rely on fluoroscopy, exposing patients and medical staff to harmful ionizing radiation. Our project addresses this challenge by developing a radiation-free Augmented Reality (AR) navigation system tailored for spinal pain management. By integrating high-resolution MRI data with fiducial marker tracking, our system overlays a personalized 3D spine model (constructed from the patient's MRI image) onto the patient's back in real time. Preclinical needle-insertion trials on a 3D-printed lumbar phantom demonstrate that our AR system achieves accuracy within 2mm. This approach not only eliminates radiation risks but also offers a cost-effective solution to advanced surgical navigation, ensuring precise, safe, and accessible care for smaller healthcare facilities.



Modeling of human tissue using composite materials

Presenter: **Brian Li**, Graduate Student Researcher, MATS

Researchers: **Po-Han Chen**, Graduate Student Researcher, CMRR, MAE; **Brian Li**, Graduate Student Researcher, CMRR, MAE

Collaborators: **Jyoti Mayadev**, Professor of Radiation Medicine and Applied Sciences, Department of Radiation Medicine & Applied Sciences; **Milan Makale**, Associate Adjunct Professor, Department of Radiation Medicine & Applied Sciences.

Advisor: **Frank E. Talke**, Professor/Principal Investigator, MAE/CMRR

This project aims to analyze the structure and behavior of complex geometries in composite materials to replicate the mechanical properties of tissue and to provide an accurate model for benchmark testing of medical devices. We have simulated human soft tissue by developing a composite material composed of an elastic, 3D-printed thermoplastic polyurethane scaffold sheet with sinusoidal corrugation embedded within a soft silicone matrix. The strain-stiffening response and the tunability of the mechanical properties of this composite were investigated via uniaxial tensile testing to compare the mechanical characteristics of the novel composite material with the characteristics of porcine vaginal tissue. Digital image correlation was used to analyze strain behavior, and data on true-stress and true-stretch responses were recorded. The soft composite coupon was shown to be tunable and displayed tissue-like strain-stiffening behavior with a distinct initial “toe-region” followed by a stiffer “heel-region” on the stress-stretch plot. The resulting material provides a tunable platform for soft-tissue models in medical device calibration, bench testing, and physician training.

Enabling *next generation* In Memory Computing Systems, through ferroelectric materials based devices



Presenter: **Prab Bandaru**, Professor, Department of Mechanical & Aerospace Engineering (MAE)

Affiliate Professor of Electrical Engineering and Program in Materials Science

Students: *S. Natani* (MAE), *P. Khajanji* (Materials Science)

Ferroelectric (FE) materials can be integrated into non-volatile RAM *as well as* field effect transistors (FETs)/tunnel junctions (TJ) - with the advantages fast switching speeds (< 100 ns) and CMOS compatibility. Such aspect is relevant for in-memory computing (IMC) related to AI applications, involving multi-level storage coupled with high performance in situ computing for future advanced technology nodes.

The basis for IMC is the polarization of a FE, which (a) may be set to an up (/down) state from an applied given electric field yielding for *memory*, and (b) which can also modulate the electrical current in a channel, as is done in transistor logic. While FE based memory devices have been utilized as FERAMs (FE random access memory), FE transistors are not as well known. A major reason is that voltages, and power, is larger than that presently used for silicon based technology.

It has then been indicated that the path forward for the widespread usage of FE materials would be considerably facilitated through the reduction of programming voltages to on-chip logic-compatible values of < 1 Volt. Obstacles involve issues related to the scaling of the FEs to lower thickness as well as the presence of an interfacial layer (IL) between the high-permittivity FE and the substrate - resulting in wasted voltage across the IL. We have shown that lower operating voltages along with a higher tunneling electroresistance (TER) could be achieved through IL engineering. Consequently, it was demonstrated that ultrathin FE films deposited on single-layer graphene/Si can exhibit polarization switching at reduced voltages ~ 0.8 Volt, with significant TER

The overall objectives incorporate scientific, technological, industrial, and collaborative goals, *i.e.*,

- (i) Developing low energy organic and inorganic materials systems for information processing,
- (ii) Heterogeneous integration of two-dimensional (2D) and three-dimensional (3D) materials,
- (iii) Use of quantum mechanical tunneling for achieving low voltage and low power operation,
- (iv) Integration of logic and memory into a single device,
- (v) Incorporation of related devices into semiconductor manufacturing

Towards the ultimate scaling of oxide thin film transistors: Investigation of short channel effects in IGZO

Presenter: *Seongho Yang*, PhD Student, Program in Material Science

Advisors: *Dr Kenji Nomura, Dr Prab Bandaru*

a-IGZO (amorphous Indium Gallium Zinc Oxide), considered superior to a-Si, have been commercialized in TFTs (Thin-Film Transistors)-based high performance displays based on their ultra-low power consumption. There is now the possibility of their usage for *next-generation* memory applications – as access transistors, in DRAM and non-volatile RAM. However, such applications demand the ultimate scaling characteristics of the IGZO TFTs to be well understood – particularly through the short channel effect (SCE). The talk presents an overview of SCE related issues.

Generally, the scaling behavior of a-IGZO TFTs remains unclear to date, *e.g.*, in terms of the threshold voltage (V_{th}) reduction /"roll off", with decreasing channel length, in sub-micron scale devices. Indeed, there seems to be an intriguing aspect where the SCE even seems to be absent. We investigated the V_{th} roll-off in deep sub-micron a-IGZO TFTs by varying the gate length and TFT geometry through (i) overlap, and (ii) offset of metal gate - contact structures. Short Channel a-IGZO TFTs with gate lengths down to 30 nm were fabricated using an ultrathin (~5 nm) a-IGZO active layer and ~15 nm Al₂O₃ gate oxide. A pronounced (/suppressed) V_{th} *roll-off* was observed in the metal gate - contact offset (/overlap) structures with decreasing gate length.

Our results indicate that the device scaling behavior in oxide TFTs is strongly influenced by contact geometry, highlighting the critical role of design in the scaling down of oxide semiconductor devices.



Helimagnetic Properties of Mn-Intercalated Transition Metal Dichalcogenide: First-Principles Calculations and Micromagnetic Simulations

Presenter: *Yun Chen*, PhD student, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Advisor: *Kesong Yang*, Professor, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Mn-intercalated transition metal dichalcogenides (TMDs) are promising candidates for hosting helimagnetism, offering opportunities for next-generation spintronic applications. Despite their potential, key magnetic characteristics, including the intrinsic helix period, the critical magnetic field for phase transitions, and the role of shape anisotropy in modulating the spin textures, remain elusive. In this study, we investigate the helimagnetic properties of $\text{Mn}_{1/3}\text{MX}_2$ ($\text{M} = \text{Nb}, \text{Ta}; \text{X} = \text{S}, \text{Se}$) using first-principles calculations and micromagnetic simulations. Applying a rotation-state method, we extract the critical magnetic interaction parameters and successfully predict their helix period. Incorporating shape anisotropy into our theoretical framework, we elucidate its role in modulating the spin configurations. Furthermore, we propose a new approach to determine the critical magnetic field based on the slope of the magnetization curve in the low-field regime. Our results offer the first quantitative insights into the magnetic behavior of Mn-intercalated TMDs and establish a predictive framework for understanding helimagnetism in this emerging material class.



First-Principles Insights into Strain-Driven Altermagnetism in RuO₂

Presenter: **Shri Vakula**, MATS MS Student, Department of Chemical and Nano Engineering

Researchers: **Shri Vakula**, MATS MS Student, Aiiso Yufeng Li Family Department of Chemical and Nano Engineering

Dr. Kesong Yang, Professor, Department of Chemical and Nano Engineering

Advisor: **Dr. Kesong Yang**, Professor, Department of Chemical and Nano Engineering

Altermagnetic materials combine zero net magnetization with spin-polarized electronic bands, making them promising candidates for next-generation spintronic devices. Rutile RuO₂ has been proposed as a potential altermagnet, but the structural conditions that stabilize its spin-polarized state remain unclear. In this project, we investigate how epitaxial strain controls the emergence of magnetic order in RuO₂ thin films grown on TiO₂ along the (001), (100), and (110) orientations. Using computational, structural, and electronic analysis, we compare unstrained and strained RuO₂ cells by correlating lattice distortion, Ru–O bond-length changes, spin density, magnetic moment, and orbital-resolved density of states near the Fermi level. The results show a strong orientation dependence: the strained (001) configuration remains non-spin-polarized, while the strained (100) and (110) configurations develop spin polarization. The (110) orientation exhibits the largest magnetic moment and a unique local structural distortion, where adjacent RuO₆ polyhedra become geometrically inequivalent and display four distinct Ru–O bond lengths rather than the usual two. These findings suggest that strain does not simply alter magnetism through average lattice compression or expansion. Instead, the symmetry, and local anisotropy of the RuO₆ polyhedra appear to play a central role in modifying orbital hybridization and enhancing spin polarization near the Fermi level.



RIFT: A Training-Free Rank-Aligned Transformation for Learned Indexes

Presenter: *Wenyu Peng*, PhD Student, ECE

Researcher: *Wenyu Peng*, PhD Student, ECE

Advisor: *Paul H. Siegel*, Professor, ECE/CMRR

Learned indexes [1] approximate the cumulative distribution function (CDF) of keys to predict record positions. Recent systems such as NFL [2] improve learned index performance by applying normalizing flows [3] to achieve distribution transformations before indexing. However, these approaches require offline training, introduce neural inference overhead, and optimize probability density rather than rank prediction, creating a mismatch with learned index objectives.

In this research, we propose **RIFT** (Rank-Informed Function Transformation), a training-free and deterministic distribution transformation for learned indexes. RIFT replaces learned normalizing flows with a monotone piecewise-linear approximation of the empirical CDF, directly aligning the transformation with the rank prediction objective. We further optimize evaluation using affine segment computation, grid-based lookup, and batch processing, significantly reducing transformation latency.

We evaluate RIFT in the AFLI pipeline against NFL and state-of-the-art learned indexes across seven datasets. Results show that RIFT eliminates training, substantially reduces transformation latency, and achieves higher throughput than NFL on five out of seven datasets, while maintaining comparable or better backend quality. Our findings demonstrate that deterministic CDF-aligned transformations can effectively replace learned normalizing flows in learned indexing systems.

[1] Tim Kraska, Alex Beutel, Ed H. Chi, Jeffrey Dean, and Neoklis Polyzotis. 2018. The Case for Learned Index Structures. In Proceedings of the 2018 International Conference on Management of Data (Houston, TX, USA) (SIGMOD '18). Association for Computing Machinery, New York, NY, USA, 489–504. doi:10.1145/3183713.3196909.

[2] Shangyu Wu, Yufei Cui, Jinghuan Yu, Xuan Sun, Tei-Wei Kuo, and Chun Jason Xue. 2022. NFL: robust learned index via distribution transformation. Proc. VLDB Endow. 15, 10 (June 2022), 2188–2200. doi:10.14778/3547305.3547322.

[3] Laurent Dinh, David Krueger, and Yoshua Bengio. 2015. NICE: Non-linear Independent Components Estimation. In Proceedings of the 3rd International Conference on Learning Representations (ICLR).



Differential-VT Codebook Sizes and Combinatorial Necklaces

Presenter: *Nithish Suresh Babu*, Graduate Student, CMRR, ECE, UCSD

Researcher: *Nithish Suresh Babu*, Graduate Student, CMRR, ECE, UCSD

Collaborators:

Adi Krishnamoorthy, Undergraduate Student, CSE, UCSD

Prof. Ron M Roth, Professor, CS Department, Technion

Advisor: *Prof. Paul H Siegel*, Professor, CMRR, ECE, UCSD

Differential Varshamov Tenengolts (Differential-VT) codes [1] are a class of non-binary block codes capable of correcting single insertion, deletion or substitution or a burst of insertion or deletion. In this talk, I will be presenting my work [2] on finding a closed form expression for the codebook sizes of Differential-VT codes for generic alphabet sizes (not necessarily binary codes) using techniques from enumerative combinatorics. This work is inspired by the work of Dr. Neil Sloane in his paper “On single-deletion-correcting codes” [3] where he deals with codebook sizes of binary VT codes. Prof. Sloane also discusses several open problems in that paper, one of them being finding a bijection between binary VT codes and binary combinatorial necklaces. In this talk, we will discuss how this open problem extends to bijection between non-binary Differential-VT codes and combinatorial necklaces of same alphabet size.

[1] T. Thanh Nguyen, K. Cai and P. H. Siegel, "A New Version of q-Ary Varshamov-Tenengolts Codes With More Efficient Encoders: The Differential VT Codes and The Differential Shifted VT Codes," in *IEEE Transactions on Information Theory*, vol. 70, no. 10, pp. 6989-7004, Oct. 2024, doi: 10.1109/TIT.2024.3417894.

[2] N. S. Babu, A. Krishnamoorthy, R. M. Roth and P. H. Siegel, "On Differential Varshamov—Tenengolts Codes," *2025 IEEE International Symposium on Information Theory (ISIT)*, Ann Arbor, MI, USA, 2025, pp. 1-6, doi: 10.1109/ISIT63088.2025.11195208.

[3] N.J.A. Sloane, “On single-deletion-correcting codes,” in *Codes and Designs* (conference proceedings), K.T. Arasu, A. Seress (Editors), Ohio State Univ. Math. Res. Inst. Publ. 10, de Gruyter, Berlin, 2002, pp. 273 291.



Stochastic Characterization and Asymptotic Limit Laws for the Labeled Coupon Collector Problem

Presenter: *Andrew Tan*, PhD Student, ECE

Researcher: *Andrew Tan*, PhD Student, ECE

Advisor: *Paul Siegel*, Professor, ECE/CMRR

In the Labeled Coupon Collector Problem (LCCP), subsets of k coupons are drawn from a universe of n items, yielding an unordered set of k unique labels. The objective is to deduce the underlying bijection between coupons and labels. While we previously established the deterministic combinatorial boundaries for this deduction process, this presentation investigates the stochastic behavior of the problem when subsets of size k are sampled uniformly at random.

First, we establish a first-order stochastic dominance ordering of the random waiting times with respect to the system parameters, formalizing how altering n or k impacts separation probabilities. We then derive the exact asymptotic distributions of the number of samples required as $n \rightarrow \infty$. In the fixed-density regime ($k = \rho n$), we utilize the Chen-Stein method for Poisson approximation to prove that the waiting time converges to a standard Gumbel distribution. In the fixed-sampling regime (constant k), we establish a structural equivalence to the classical group drawing CCP, demonstrating convergence to generalized Gumbel limiting laws. Finally, we introduce an exact unidirectional absorbing Markov chain model that enables the precise computation of expected waiting times for small finite values of k , revealing that the asymptotic expectation $\frac{n}{k} H_n$ is a surprisingly tight approximation even for small n .



Frame-Theoretic Constructions of Analog Error-Correcting Codes

Presenter: **Ziyuan Zhu**, Graduate Student, ECE, UCSD

Researcher: **Ziyuan Zhu**, Graduate Student, ECE, UCSD

Collaborators: **Changcheng Yuan**, Graduate Student, TAMU

Anxiao Jiang, Professor, TAMU

Ron M. Roth, Professor, Technion

Advisor: **Paul H. Siegel**, Professor, CMRR, ECE, UCSD

Analog error-correcting codes have been proposed for analog in-memory computing on resistive crossbars, which can accelerate vector-matrix multiplication for machine learning. Unlike traditional communication or storage channels, this setting involves a mixed noise model with small perturbations and outlier errors. Although several analog code constructions have been developed, the range of available code families remains limited. We propose a frame-theoretic approach to analog code design. Our work starts from several highly symmetric geometric constructions, which give rise to structured and analytically tractable code families. Motivated by the geometric regularity of these examples, the work further introduces two general construction methods: an incoherent tight frame construction that prioritizes tightness while seeking unit-norm columns and low coherence, and an incoherent unit-norm frame construction that enforces unit-norm columns and reduces coherence without imposing tightness. The results show that the proposed codes provide strong error-handling capability and often achieve state-of-the-art performance.



Symmetry and Topology in Photonic Nanostructures for sensing and imaging applications

Presenter: *Abdoulaye Ndao*, Associate Professor, ECE Department

The quest for smaller, lighter, and more efficient optical components usually comes at the price of reduced functionalities. In this talk, I will provide an overview of how topological approaches to control light-matter interaction enable novel photonic devices with unique features and enhanced performance. I will discuss our recent breakthrough in demonstrating the first topological light source that unidirectionally outcouples to a waveguide from magnetic biased photonic crystal cavities of arbitrary shape. I will also discuss singularities of non-Hermitian systems and their application in biology and healthcare by detecting attomolar concentrations of anti-immunoglobulin G in both chiral and achiral structures. In the last part of the talk, I will present a premier achromatic broadband metalens that is strategically engineered to span an octave bandwidth with high efficiency and single-shot wavefront sensing and correction paradigm that overcomes the limitations of existing approaches. Central to the approach is the integration of a learned optical phase mask that acts as a physical encoder and is jointly optimized with a neural-network decoder. This encoding removes intrinsic phase ambiguities and significantly enhances sensitivity to weak aberrations. By leveraging this hybrid deep-learning architecture, our method directly and unambiguously retrieves Zernike-based phase distortions from a single focal-plane intensity image, eliminating the need for defocus measurements, or iterative phase reconstruction. Such devices will be suitable for free space and integrated optics and pave the way towards more complex and versatile systems with applications in high-capacity classical and quantum communications, as well as sensing.



Optical Beam Engineering for Magnetic Domain Control in Data Storage Applications

Presenter: **Muhammad Waleed Khalid**, PhD Candidate, Department of Electrical and Computer Engineering

Researcher: **Sergio A. Montoya**, Assistant Research Scientist, Center for Memory and Recording Research

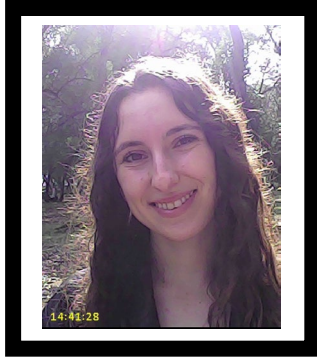
Collaborators: **Mohammed Salah El Hadri**, Principal R&D Engineer, Western Digital Corporation.

Stéphane Mangin, Professor, IJL, CNRS, Université de Lorraine

Eric E. Fullerton, Director and Chaired Professor, Department of Electrical and Computer Engineering & Center for Memory and Recording Research

Advisor: **Abdoulaye Ndao**, Associate Professor, Department of Electrical and Computer Engineering & Center for Memory and Recording Research

Ultrafast all-optical switching (AOS) in ferromagnets has emerged as a promising route toward dense and energy-efficient magnetic memory. However, its implementation has typically been limited by material-specific polarization requirements or by the need for auxiliary exchange coupling and compositional tuning. Here, we demonstrate that deterministic control of AOS can instead be achieved purely through optical engineering. By tailoring the polarization distribution and focusing of the excitation light, we shift the selectivity from intrinsic material properties to external optical beam shaping. In stand-alone [Pt/Co]_N multilayers, this enables direct control over local heating and optical torques, allowing the system to be driven either into helicity-dependent, multishot domain-wall propagation or into helicity-independent magnetization reversal, without material modification or external bias fields. Our results establish optical beam design as a universal control knob for magnetization dynamics in ferromagnetic.



Vapor Deposited ZIF-8 MOF as a Low k Dielectric for Applications in Packaging

Presenter: *Amy E. Ross*, Graduate Student, Department of Material Science and Engineering

Researcher: *Amy E. Ross*, Graduate Student, Department of Material Science and Engineering

Collaborators: *Dipayan Pal, Naeun Yang, Harsono Simka, Jit Dutta, Kesong Wang, Diego Contreras Mora, Jing Mu, Ping-Che Lee, Xinyu Wang, Charles H. Winter*

Advisor: *Andrew Kummel*, Professor, Department of Chemistry

As logic and memory devices continue to scale down, shrinking interconnect dimensions increase parasitic capacitance between nearby wires. This decreases device performance. Low k interlayer dielectrics are therefore needed to maintain device performance and porous materials are especially attractive as air has the lowest dielectric constant. Metal organic frameworks (MOF) are extremely porous materials that can be created entirely in the vapor phase. First ALD ZnO is deposited using diethylzinc (DEZ) and water. By exposing the ZnO to 2-methylimidazole at 160°C, the film is converted to zeolitic imidazolate framework 8 (ZIF-8) MOF in 15 minutes. The resulting expansion factor was maximized at 14x and was able to do a seamless gap fill in patterned features with gaps ranging from 40 to 200 nm. The ZIF-8 films exhibited a k value of 2.6, had low leakage, and experienced dielectric breakdown at 0.7 MV/cm. These results suggest that ZIF-8 MOF is a promising candidate as a low k interlayer dielectric for packaging applications.



Memory effect in exchange bias in disordered hematite

Presenter: *Tianxing Wang*, Graduate researcher, Department of Materials Science and Engineering (UCSD)

Researchers: *J. Andres Hofer, Ali C. Basaran, Javier Rodriguez*. Post-doctoral scholars, Department of Physics (UCSD)

Collaborator: *Yayoi Takamura*, Professor, Department of Materials Science and Engineering (UC Davis).

Advisor: *Ivan K Schuller*, Professor, Department of Physics (UCSD)

Exchange bias is a pivotal effect in modern spintronics, widely employed to stabilize the ferromagnetic reference layer in spintronic devices. This interfacial phenomenon, arising at antiferromagnet/ferromagnet interfaces, has traditionally been considered as a passive element, owing to the antiferromagnet's insensitivity to external magnetic fields. Here, we present a comprehensive exchange bias study in a hematite/ferromagnet heterostructure in which the antiferromagnetic hematite layer undergoes controlled surface disordering via low-energy argon ion bombardment.

The bombardment-induced disorder gives rise to a series of remarkable properties, including a thermal memory effect in the exchange bias and its associated slow dynamics. Furthermore, we observe a purely exponential thermal dependence of the exchange bias — in stark contrast to the power-law of conventional systems — alongside isotropic pinning and asymmetric reversal of the ferromagnetic layer. Together, these features paint a complex picture that is not easily explained by conventional models.

Our findings demonstrate that intentional disordering of the antiferromagnet can produce exchange bias behavior fundamentally distinct from that of archetypal systems, opening new avenues for engineering novel functionalities within this widely applied magnetic effect.

Acknowledgements

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Flexible VO₂ devices for ultra-low power electronics

Presenter: *Juan Andres Hofer*, PhD, Department of Physics

Researchers: *Juan Andres Hofer*, PhD, Department of Physics;
Tianxing D. Wang, PhD Student, Department of Physics

Collaborator: *Ali C. Basaran*, PhD, General Atomics

Advisor: *Ivan K. Schuller*, Professor, Department of Physics

The metal-insulator transition (MIT) in vanadium dioxide (VO₂) thin films is a topic of great interest for applications in memristors and neuromorphic computing. VO₂ thin films are accompanied by substantial changes in the electronic and optical properties across the MIT, and these changes can be induced by external stimuli such as voltage, strain, or temperature. While several studies have shown that flexible and freestanding VO₂ films can be achieved, complex pre- or post-growth processing is required. In this work, we show that direct sputter deposition of VO₂ on flexible Kapton substrates results in a straightforward methodology to achieve flexible MIT films. A pre-deposited Al₂O₃ layer on Kapton enhances film adhesion, and the resulting flexible VO₂ films show up to 4 decades of change in resistance across the MIT. Temperature and substrate-induced strain during growth affect substantially the quality of the films. The resulting VO₂ flexible devices show ultra-low power consumption for resistive switching, up to two orders of magnitude lower than samples grown on conventional substrates. We also demonstrate that the VO₂ MIT characteristics can be governed by mechanical deformation, resulting in a novel method to induce resistive switching and decrease power consumption. This study reveals a straightforward approach for direct growth of high-quality flexible VO₂ films exhibiting robust MIT, with promising applications in tactile sensors and electromechanical devices.

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