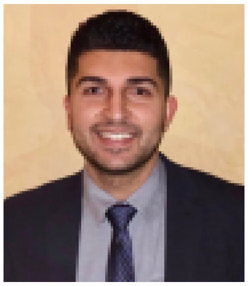
Lab Group		Speakers's Name	Presentation Title
Allen		Taige Wang	Understanding Microwave Impedance Microscopy Images of Quantum Anomalous Hall Insulators
Cauwenberghs			
	1	Stephen Deiss	Reconfigurable Development Platform for Large-Scale Neuromorphic Cognitive Computing
	2	Gopabandhu Hota	Design Optimizations for Large-Scale Reconfigurable Spike-Based Computing using High-Bandwidth Memory
Di Ventra		Yuanhang Zhang	MemComputing Quantum State Tomography
Fullerton			
	1	Yuxuan Xiao	Electrical transport in chemically ordered CrPt3 and FePt3 epitaxial thin films
	2	Jeffrey Brock	Interplay of the half-skyrmion topology and spin-orbit torque on the growth of magnetic stripe domains
	3	Biswajit Sahoo	Efficient charge to spin conversion in 5d transition metal oxide
	4	Ruben Saatjian	Tracking spatiotemporal magnetic domain correlations through a morphological phase transformation
Kummel		Scott Ueda	High Thermal Conductivity Aluminum Nitride Thin Films
Lomakin			
	1	Fangzhou Ai	Synchronization of spin-transfer nano-oscillator
	2	Zhuonan Lin	Nonuniform current density for switching current reduction in magnetic tunnel junctions
	3	Iana Volvach	Spin-transfer torque oscillator based on composite synthetic antiferromagne
	4	Xueyang Wang	Trajectory Sampling Method for Reaction Rate Computation in Micromagnetic Simulations
Nomura		Chi-Hsin Huang	Reconfigurable Artificial Synapses using Ambipolar Oxide Transistor
Schuller			
	1	Ben Erbin Qiu	Unusual phenomena on capacitively coupled stochastic spiking oscillators
	2	Pavel Salev	Magnetoresistance anomaly in a resistive switching system
	3	Henry Navarro	Photo-assisted non-volatile and volatile resistive switching in hybrid CdS/Mott heterostructures
Siegel			
	1	Dongmin Shin	Powerful Error Correction Codes for QLC/PLC NAND Flash Memory
	2	Karthik Nagarjuna	Polar Shaping Codes for Costly Noiseless and Noisy Channels
	3	Omer Sabary	Decoding for Optimal Expected Normalized Distance over the t-Deletion Channel
	4	Simeng Zheng	Modeling Flash Memory Channels Using Conditional Generative Nets
Talke			
	1	Matthew Kohanfars	Design of a detachable bronchoscope
	2	Rafaela Simoes-torigoe	Design and Validation of an Automated Dilator Prototype for the Treatment of Radiation-Induced Vaginal Injury
	3	Bryan Nguyen	Surgical Site Localization with Skin Printed Markers for Pain Management
	4	Alex Phan	Portable Ophthalmic Device for Remote Slit Lamp Examinations and Visual Acuity Screening
	5	Dirk Schuster and Ben Suen	Internet-Enabled Ophthalmic Instruments
Yang		Sicong Jiang	High-throughput Design of Perpendicular Magnetic Anisotropy at Heusler-based Material Interfaces



Design of a Detachable Bronchoscope

Presenter: ***Matthew Kohanfars,*** Graduate Student, CMRR & MAE
Researchers: ***Yu Li***, Graduate Student, CMRR & MAE
Avinash Laha, Graduate Student, CMRR & MAE
Alexander Luke, Graduate Student, CMRR & MAE
Collaborators: ***Dr. Farshad Ahadian*****,** MD, UCSD health system
Advisor: ***Dr. Frank Talke***, Professor, CMRR & MAE

In the process of intubation, a bronchoscope is used to insert an endotracheal tube (flexible plastic tubing) into the trachea to maintain an open airway. In order to properly place an endotracheal tube, a physician must estimate the width of the patient's trachea before intubation. This estimation process is not ideal and never entirely accurate. In situations where a physician estimates the width of the endotracheal tube inaccurately, the entire bronchoscope must be removed, a new endotracheal tube must be added, and the bronchoscope must be repositioned for intubating. This process takes time and puts the life of the patient at risk. Repositioning of the bronchoscope tends to be the most time-consuming aspect of intubation. To speed up the process of intubation, it would be desirable to have a bronchoscope with an easily detachable handle, so that the endotracheal tube can be replaced without losing the position of the tip of the bronchoscope from the trachea. A redesign of the bronchoscope where the control body is detachable will give physicians the opportunity to alter the size of the endotracheal tube easily without needing to remove the bronchoscope. This will in effect reduce the time of intubation.

We have investigated the development of a novel detachable bronchoscope with a 3D printed micro-transmission system. The micro-transmission controls the motion of the tip of the bronchoscope and is embedded in one end of the flexible insertion section of the bronchoscope. The micro-transmission allows manipulation of the distal end through the translation of guide nuts that are connected to the tip of the bronchoscope through so-called “angulation” wires. The displacement of the guide nuts on the left and right-handed screw sections and the control of the distal end of the bronchoscope are investigated. The maximum tensile force on the angulation wire before failure is determined experimentally for different screw pitches.

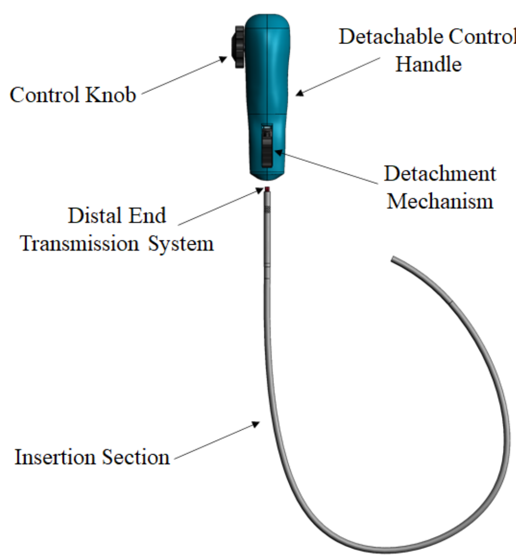


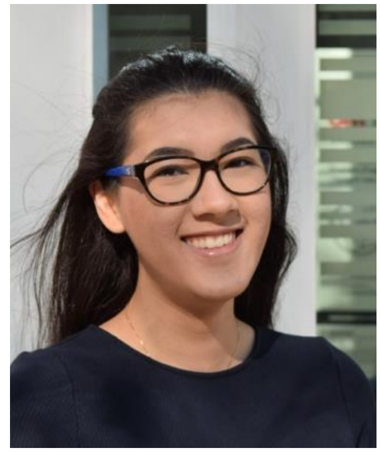
Figure 1: Detachable bronchoscope prototype SolidWorks model

Design and Validation of an Automated Dilator Prototype for the Treatment of Radiation-Induced Vaginal Injury

Presenter: **Rafaela Simoes-Torigoe**, Graduate Student, MAE
Advisor: **Frank E. Talke**, Professor, MAE & CMRR

Researchers:
Po-Han Chen, Graduate Student, MAE
Yu M. Li, Graduate Student, MATS
Shengfan Hu, Undergraduate Student, ECE
Matthew Kohanfars, PhD Candidate, MAE
Karcher Morris, Teaching Professor, ECE

Collaborators:
Jyoti Mayadev, Radiation Oncologist & Professor, Moores Cancer Center
Milan Makale, Assistant Adjunct Professor, Moores Cancer Center
Casey Williamson, Physician, Moores Cancer Center



Radiation-induced vaginal stenosis (VS) is a prominent late complication of cervical cancer radiotherapy that can often be detrimental to patient quality of life. It is characterized by the narrowing or shortening of the vaginal canal. To address this clinical problem, an expandable vaginal dilator was designed for the prevention of VS in cervical cancer survivors. Finite element modeling and benchtop experimentation were used to characterize the relationship between internal dilator pressure, cross sectional expansion area, and the load applied to the simulated vaginal wall. Both experimental and finite element analysis results exhibited shared trends relating pressure, expansion, and applied load to the modeled vaginal walls. Future research will incorporate enhanced Mooney-Rivlin material assumptions, automated inflation benchtop tests, and the design of an assembled system for vaginal stenosis prevention.

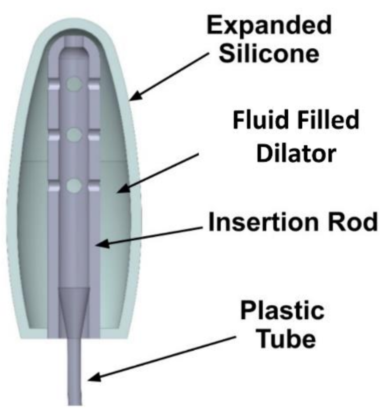


Figure 1: Schematic of the designed vaginal dilator

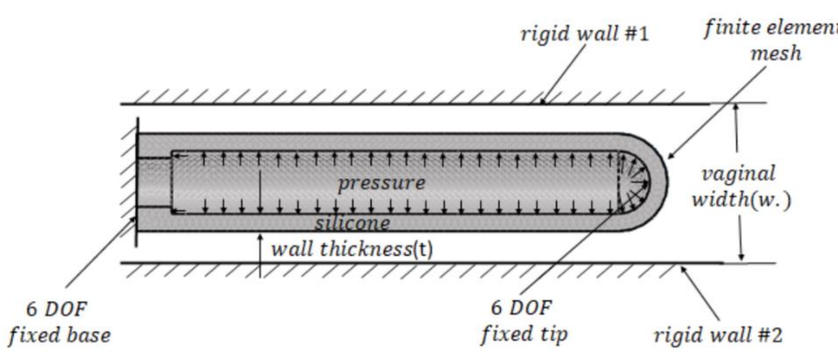


Figure 1: Finite element model of the vaginal dilator including dilator geometry, mesh, and boundary conditions

Surgical Site Localization with Skin Printed Markers for Pain Management

Presenter: ***Bryan Nguyen***, Master's Student, Bioengineering
Collaborators: ***Dr. Farshad Ahadian***, MD, UCSD Health
Advisors: ***Professor Frank Talke***, Professor, Mechanical and Aerospace Engineering, ***Dr. Gert Cauwenberghs***, Professor, Bioengineering

Chronic back pain can be debilitating and significantly impact lives with pain causing an inability to perform jobs or basic physical tasks. It is estimated that the frequency of back pain cases will rise over the coming years due to obesity, physical inactivity, and an increase in aging populations. Since age is correlated with diseases or health complications that arise to changes in anatomy and structural pathology, it is expected that the frequency of complicated cases will substantially rise in the future. It is increasingly important for physicians to have a clear idea of how to navigate a patient's body as they perform interventional pain therapies and carefully guide needles to the targeted areas. A 3D navigation system that interfaces with 3D imaging such as MRI and allows physicians to plan the procedure and determine needle trajectories beforehand would help the physicians perform the procedure with minimal radiation exposure and with increased safety, accuracy, and speed.

The proposed augmented reality navigation system will read coded skin markers that will be placed on the patient's thoracic and lumbar regions and appear in the MRI scans. An example of how the operating room would look like with the markers in use is shown below in Figures 1a-b where during the procedure, a physician will wear the AR heads-up display. During the time period of several days to 1-2 weeks, in between the MRI scan and the procedure, a 3D image of the patient's anatomy will be created from the MRI images. When the patient arrives for the procedure and lays down on the operating table, cameras will locate the markers on the patient's body and match them with those on the 3D image in order to properly overlay the augmented reality through the physician's headset and on top of the patient.

This year we are focusing on creating and testing the coded skin markers, as they are a keystone of the augmented reality navigation system. Therefore, rigorous tests simulating many different conditions such as speed, size, distance, angle, marker material, camera resolution, warping, marker damage, and more will be done to determine the feasibility of the coded skin markers. We will also be attaching the markers to the instruments and needles and seeing whether they can accurately track those items regardless of physician hand movements.

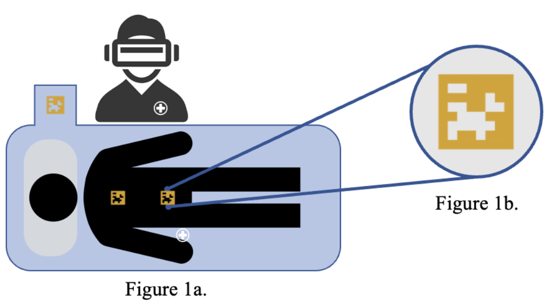
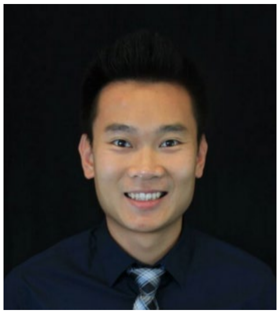


Figure 1a*: A depiction of the operating room with the code skin markers.*
Figure 1b*: A close-up image of one coded skin marker.*



Portable Ophthalmic Device for Remote Slit Lamp Examinations and Visual Acuity Screening

Presenter: ***Alex Phan***, Asst. Project Scientist, CMRR
Researchers: ***Dirk Schuster***, Visiting Graduate Student, TUM
Justin Feng, Graduate Student, ECE
Benjamin Suen, Engineering Aid, CMRR
Zach Daley, Undergraduate Student, MAE
Brian Lee, Undergraduate Student, MAE

Collaborator: ***Gerrit Melles***, Ophthalmologist, NIIOS
Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Currently, standard care in ophthalmology monitors patient eye health through routine follow-up phone calls or in-person office visits. While in-person office visits allow physicians to directly assess the eye health of a patient, routine follow-up phone calls often do not provide sufficient information to determine if an office visit is necessary. This results in unnecessary office visits and limits the patient to infrequent monitoring that can only be performed in-person. As the 2020 COVID-19 pandemic continues to pose challenges for public health, social distancing guidelines and restricted closed-door environments increase the need for the elimination of unnecessary office visits in lieu of at home examinations. In this paper we report on the design and testing of a multi-functional ophthalmic device for remote eye examinations.

We present on the development of internet-enabled instruments for remote self-examination of the eye to address this pressing need. Four miniaturized and portable ophthalmic instruments are under development: a slit lamp, a funduscope, a non-contact tonometer, and a visual acuity device. Each instrument is designed for patients to perform an examination without the assistance of a secondary person or trained medical professional. The results can be captured and sent to the physician remotely for evaluation. We report on the design and clinical testing of each of the devices and discuss future direction of the project.

Internet-Enabled Ophthalmic Instruments

Presenters: ***Dirk Schuster, B.A., B.Sc.***, ***CMRR (UCSD) and MIMED (TUM)***, ***Ben Suen, M.Sc.***, ***CMRR (UCSD)***

Researcher: ***Justin Feng, B.Sc.***

Collaborators: ***Zach Daley***, ***Brian Lee***, ***GSR, UCSD***

Advisors: ***Alex Phan, PhD, Project Leader at CMRR***

Prof. Frank Talke, CMRR

Over half of the visits at an ophthalmologist are routine eye checkups or post-surgery follow-ups, while the majority of patients recovered with no sign of ocular abnormality. Such regular eye checkups are necessary for a suitable and in-time treatment of different eye diseases (Taylor et al. 2004). These include Glaucoma or Diabetic Retinopathy (DR), leading causes of blindness worldwide (Lee et al. 2015 and Resnikoff et al. 2004). Glaucoma is painless, and symptoms occur only at a further course of the disease (Jonas et al. 2017). Consequently, Wensor et al. (1998) shows that about half of glaucoma patients are not diagnosed before symptoms appear. DR is subject to the same issue. Also, a routine eye examination is necessary for the early detection and prevention of blindness, and in the early stages, no visual symptoms occur (Sinshaw et al. 2020). Routine examinations also employ binocular slit lamp examinations to visualize the structure of the anterior chamber of the eye. This is done to detect abnormalities in the anterior chamber such as infections and cataracts.

Routine eye examinations are unavoidable for the optimal treatment of Glaucoma, DR, and other ophthalmic pathologies. Nowadays, three devices are necessary for these examinations: the tonometer, funduscope, and slit lamp. They are bulky, high priced, non-portable, and need professional assistance for an eye examination. Therefore, a doctor’s visit is expensive and time-consuming. Additionally, worldwide there is a growing lack of ophthalmologists (Resnikoff et al. 2012). To guarantee accessible and in-time treatment of glaucoma, DC, and other conditions of the eye, there is a strong need for technology that connects physicians and patients and remotely enables routine eye check-ups. This need increased during Covid-Pandemic. Rural regions with poor medical access also exhibit such a need.

To address the aforementioned issues, we present a trio of internet-connected, low cost, and portable ophthalmic instruments that can be operated by a patient their own home. These instruments provide one with the ability to access frequent ophthalmic screenings.

Synchronization of spin-transfer nano-oscillator

Presenter: ***Fangzhou Ai***, Ph.D. student, Material Science and Engineering Department

Advisor: ***Prof. Vitaliy Lomakin***, Professor, Electrical and Computer Engineering Department

Spin-transfer nano-oscillator (STNO) is a nanomagnetic device that using spin transfer torque converts a DC current into a microwave voltage output, generated by high-frequency magnetization precession. A single STNO can typically generate a very small amount of power and it is susceptible to thermal noise making its linewidth broad. A solution to increasing the output power and reducing the linewidth is to have an array of synchronized STNOs. Synchronizing as large number of STNOs is a difficult task, due to the complexity of their mutual interactions. Here, we designed a chainsaw permalloy plate embedded into a large damping constant base plate (Fig. 1). The STNOs are placed at the necks of the chainsaw. The spin wave generated by the STNO can propagate within the chainsaw plate while they are absorbed by the high-damping (green) region. The neck's widths are smaller than the spin wave wavelength, so that the spin waves are confined to each yellow region. Thus, each STNO will only have nearest-neighbor interaction. In this case we achieve only near-neighbor coupling between the STNOs, which simplifies achieving synchronization. This approach can be extended to 2D arrays of STNOs. These ideas can also be used in neuromorphic applications.

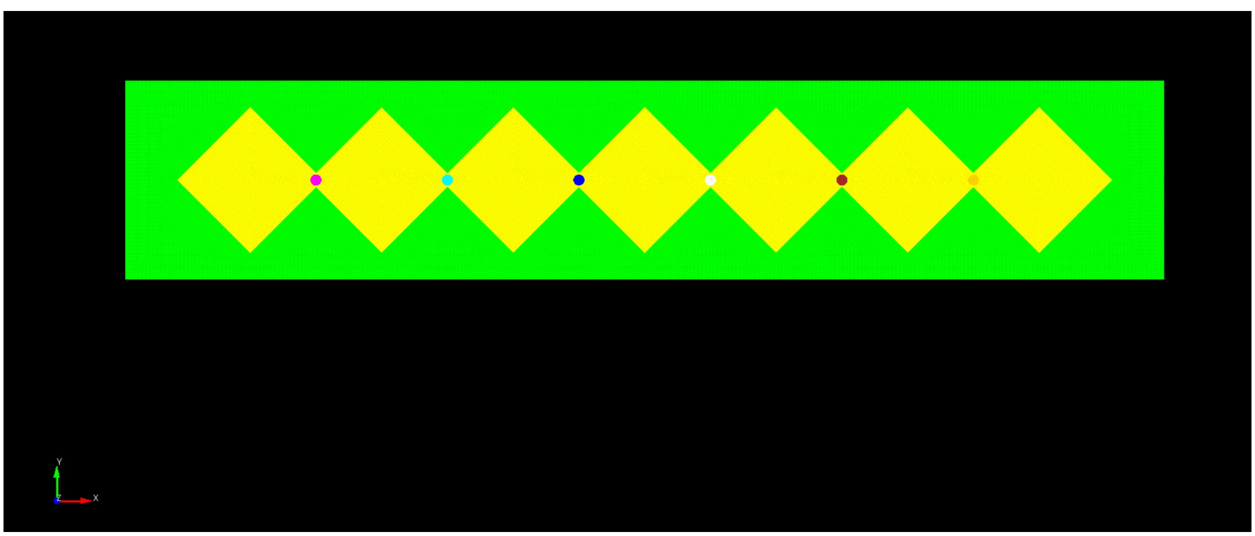


Fig 1. Illustrate of our deign. The yellow chainsaw Py part has small damping constant to allow spin wave to propagate. The green part here as base plate serves as absorbing layer to avoid spin wave reflection at the edge of chainsaw plate. The circle dots here are STNOs which can generate and receive spin wave.

Nonuniform current density for switching current reduction in magnetic tunnel junctions

Presenter: ***Zhuonan Lin***, PhD candidate, Department of Electrical and Computer Engineering

Advisor: ***Dr. Vitaliy Lomakin***, Professor, Department of Electrical and Computer Engineering

We present an approach for minimizing the critical current (CC) for the magnetization switching in magnetic tunnel junctions (MTJs) by optimizing the spatial distribution of the current density (CD). We show that such a minimization is possible because CC is determined by the condition of making one of the magnetization eigenstates grow in time. The excitation of the eigenstates is enhanced when the spatial distributions of the eigenstates and CD overlap. CC can be viewed as a functional of the CD spatial distribution and it can be minimized by optimizing this distribution. Such an optimization results in a major reduction of the CC and increase of the switching efficiency, viz. the ratio between the energy barrier and CC. The minimized CC increases only approximately linearly with the MTJ size, which is much slower than for the case of a uniform CD. The optimized efficiency is approximately a constant as a function of the MTJ size, which is much higher than the decrease of the efficiency as an inverse of the MTJ size for the uniform CD. The presented approach and obtained scaling of the CC and efficiency offer additional opportunities for the MTJ optimization.

Spin-transfer torque oscillator based on composite synthetic antiferromagnets

Presenter: ***Iana Volvach***, Ph.D. student, Material Science and Engineering Department

Advisor: ***Prof. Vitaliy Lomakin***, Professor, Electrical and Computer Engineering Department

We present an antiferromagnetically exchange coupled composite (soft/hard) spin torque oscillator (AF-ECC STO) and demonstrate its operation via an analytical model and micromagnetic analysis. The operation mechanism is based on the exchange field due to the antiferromagnetic coupling between soft and hard sub-layers of the free layer as well as on the easy-plane anisotropy of the soft sub-layer. AF-ECC STO can operate without an applied external field and generate large amplitude magnetization oscillations, which can be tuned over a broad frequency range with precessions mostly generated by the soft layer. We demonstrate that AF-ECC STO offers a flexibility in current control of the oscillation frequency and magnetization angle for realistic material parameters. The modeled STO comprises a cylindrical cross – section stack of diameter D (Fig. 1), including a reference layer and a free layer composed of SAF layers (SL and HL). HL is much harder than SL and the sub-layers are exchange coupled with interlayer exchange energy density J_{ex}. The results are obtained via micromagnetic simulations with the FastMag[1] simulator. The precession frequency of SL is proportional to both J_{ex} and J as shown on the Fig. 1 (a). The magnetization of SL has a much greater in-plane component, i.e., it would generate a much stronger external magnetic field than that of HL. With an increase of J, m_z of the SL changes its sign from being opposite to the HL direction to the same direction and with a further increase of J, the magnetization of SL approaches the perpendicular direction together with that of HL as shown on Fig. 1 (b).

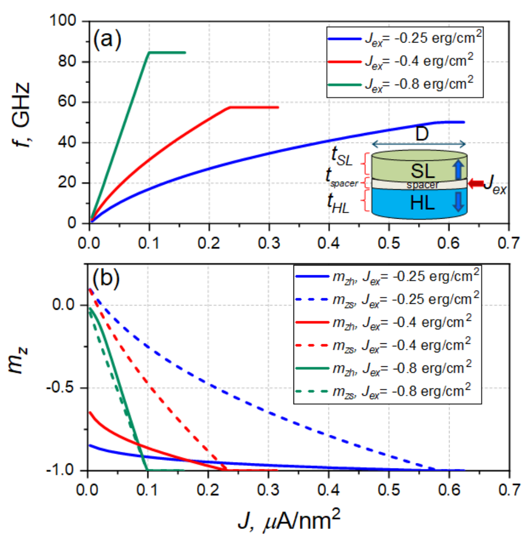


Fig. 1. Inset shows the AF-ECC STO structure. The results obtained via the 2-spin model are shown for (a) f, (b) m_z, and (c) φ as functions of J for different exchange coupling J_{ex} for $D = 20\,\mathrm{nm}$, $t_h = t_s = 0.8\,\mathrm{nm}$, $t_{\mathrm{spacer}} = 0.3\,\mathrm{nm}$, $M_{s,s} = 1350\,\mathrm{emu/cm^3}$, $M_{s,h} = 470\,\mathrm{emu/cm^3}$, $M_s = 1350\,\mathrm{emu/cm^3}$, $K_{u,h} = 4\,\mathrm{Merg/cm^3}$, $K_{u,s} = 1.11\,\mathrm{Merg/cm^3}$, $\alpha_h = \alpha_s = 0.008$.

[1] R. Chang, S. Li, M. V. Lubarda, B. Livshitz, and V. Lomakin, J Appl Phys **109** (3), 07D358 (2011).

Trajectory Sampling Method for Reaction Rate Computation in Micromagnetic Simulations

Presenter: ***Xueyang Wang***, Graduate Student, ECE

Advisor: ***Prof. Vitaliy Lomakin***, Professor, ECE

Collaborator: ***Byron Lengsfield***, Western Digital Corporation

Trajectory sampling methods are widely used in various fields including computational physics, chemistry, and biology. The transition state theory (TST) was developed to describe chemical reaction rates based on the reaction coordinate in energy phase space (minimum energy path). However, such reaction coordinate is hard to locate, while chemical reaction can happen without following reaction coordinates. Transition path sampling (TPS) was then developed based on metropolis Monte Carlo simulation for trajectory sampling and umbrella sampling for separation of phase space. The major advantage of TPS over TST is the ability to run without prior knowledge of reaction coordinates. However, the drastic computation requirement for TPS makes it not feasible for complicated system. A variation of TPS method, transition interface sampling (TIS) method was presented later assuming the system is at the stable state and reaction rate does not change over time. TIS also decreases computation load significantly as compared to TPS. Based on TIS, fast forward sampling (FFS) method was developed by replacing the Monte Carlo trajectory sampling method used in TIS by a direct Langevin simulations that are only forward in time, which eliminates reversable symmetry limitations.

Here, we present an improved trajectory sampling method, which is a modified version of FFS method. The computation stage is divided into two stages: the initial reaction rate computation stage and success ratio computation stage for all interface sections in the phase space. For the initial reaction rate computation stage, the original method presented in FFS suffers from a parameter tuning problem, which may influence accuracy, stability and the efficiency. Our approach combines the above two stages together in a time-weighted manner, which is much more stable, accurate, and efficient. Micromagnetic examples of computing the attempt frequencies in several micromagnetic systems, such as grains of granular media used in magnetic recording will be presented.

High-throughput Design of Perpendicular Magnetic Anisotropy at Heusler-based Material Interfaces

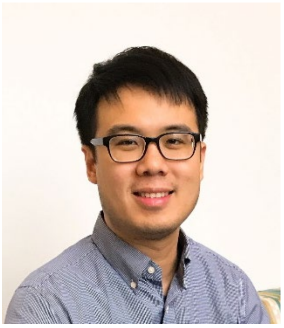
Presenter: ***Sicong Jiang***, PhD student, NanoEngineering

Researchers: ***Sicong Jiang***, PhD student, NanoEngineering

Safdar Nazir, PhD, NanoEngineering

Advisor: ***Kesong Yang***, Associate Professor, NanoEngineering

As one large family of intermetallic compounds, Heusler compounds offer a wide playground for novel materials design because of their wide range of compositions and tunable materials properties. The MgO/Heusler alloy-based magnetic tunnel junctions (MTJs) with perpendicular magnetic anisotropy have attracted extensive interest because of their potential utilization in spin-transfer-torque magnetic random-access memory (STT-MRAM). However, it is challenging to select appropriate combinations of Heusler ferromagnets with the desired interfacial properties. In this study, we present a systematic high-throughput computational design of MgO/Heusler alloy heterostructures. By using a series of descriptors, such as formation energy (ΔE_f), convex hull distance (ΔE_H), magnetic ordering, lattice misfit (f), magnetic anisotropy constant (K_i), and tunnel magnetoresistance (TMR), we successfully selected seven Heusler compounds out of ~2000 X_2YZ and ~1000 XYZ structures. Five full Heusler compounds Co_2FeAl, Co_2CrAl, Co_2HfSn, Fe_2IrGa, Mn_2IrGe, and two half Heusler compounds PtCrSb and PtMnAs were found feasible for future applications in STT-MRAM devices. Meanwhile, we developed a method to predict the disordering properties when we considered the Quaternary Heusler compounds X_1X_2YZ. One could expect the acceleration of the discovery of new materials for spintronic devices by expanding this study to other materials families beyond Heusler compounds.



Reconfigurable Artificial Synapses using Ambipolar Oxide Transistor

Presenter: ***Chi-Hsin Huang***, Ph.D. student, Department of Electrical and Computer Engineering

Advisor: ***Kenji Nomura***, Associate Professor, Department of Electrical and Computer Engineering

Many intelligent behaviors, such as learning and perception, are affected by external environmental stimuli in the human nervous system. Therefore, one of the significant challenges is to develop an artificial synapse device with reconfigurable excitatory and inhibitory responses for artificial intelligence systems with human-like perceptual capability. Since traditional neuromorphic circuits using complementary metal-oxide-semiconductor (CMOS) devices require numerous transistors to realize even one synapse, however, the hardware implementation of an artificial synapse with two response modes in a single electronic device is difficult.

Here, we developed a reconfigurable artificial synapse device using ambipolar oxide thin-film transistors (TFTs) and successfully demonstrated dynamic reconfigurable excitatory and inhibitory synaptic responses in a single device. The ambipolarity, which is characterized by a balance of electron/hole transport, is the key to developing the excitatory and inhibitory responses. Thus, we first developed the boron (B) doped SnO as an ambipolar semiconductor channel and ambipolar TFT with the electron/hole mobilities of ~0.01/~1.3 $cm^2V^{-1}\ s^{-1}$, respectively. We confirmed that the presented ambipolar SnO: B-TFT device imitated both the excitatory and inhibitory synaptic responses using both the n/p-channel mode, and these two response modes were dynamically switched by gate bias. The work demonstrated the high potential of ambipolar oxide-TFT to develop emerging neuromorphic perception and computing hardware for future artificial intelligence robots and systems.

Reconfigurable Development Platform for Large-Scale Neuromorphic Cognitive Computing

Presenter: ***Stephen Deiss, R&D Engr, INC - UCSD***

Researchers: ***S. Deiss, G. Hota, N. Mysore, O. Olajide, B. Pedroni***

Collaborators: ***Q. Wang, M. Lueker-Boden, D. Vucinic, et. al. – WDC, E. Neftci, T. liu – UCI, and A. Majumdar, S. Sivagnanam - SDSC.***

Advisor: ***G. Cauwenberghs, INC, BENG, & CENI - UCSD***

With initial funding from the National Science Foundation and continued support from Western Digital Corporation, the goal of this Community Research Infrastructure (NSF CISE CRI) project is to construct and support a general-purpose neuromorphic cognitive computing platform for research into new forms of brain-inspired computing that are more effective and more efficient in approaching the cognitive capabilities of the human mind. The objective for this CRI is to serve as a very large, versatile, broadly available system that is open to the research community at large. Building on extensive existing network and storage infrastructure for user access and data sharing at the San Diego Supercomputer Center (SDSC), the platform will be hosted and maintained through the Neuroscience Gateway (NSG) Portal.

The CRI infrastructure under development consists of a cluster of 40 field-programmable gate arrays (FPGA) with integrated high-bandwidth memory (HBM), targeting neuroscience models and AI applications with up to 160 million neurons and 40 billion synapses. An early decision was to use commercial off the shelf FPGA-based hardware that is customizable via hardware definition languages such as Verilog, and to deploy in rack mounted servers at SDSC. We have had to develop novel methods for taking incoming network specifications and translating and then partitioning them to fit onto available hardware. We have also developed a novel on-FPGA ‘multicast AHB’ bus architecture for moving spike events between neuron processing core elements on each FPGA. The FPGAs we use have 8GB of DDR4 HBM that we take advantage of with a crafted data structure and processing pipeline. We are also using very high bandwidth interconnects between boards and servers running at up to 100Gbps each to ensure millisecond timing precision in spike inputs and outputs.

The system is nearing completion for rack mounting and integration this year. It consists of 6 dual EPYC CPU servers, each with 1TB SDRAM, and 25 TB SSD, each hosting 8 Xilinx Ultrascale+ FPGA boards that each have multiple 100 Gbps Samtec ‘Firefly’ and 100GigE interconnects. As it will come online for community access through the NSG user interface, the CRI system will provide a powerful platform for exploring novel neuromorphic architectures by neuroscientists, cognitive scientists, machine learning specialists and AI experimenters.

Design Optimizations for Large-Scale Reconfigurable Spike-Based Computing using High-Bandwidth Memory

Presenter: ***Gopabandhu Hota, Ph.D. Student, ECE - UCSD***

Researchers: ***G. Hota, S. Deiss, N. Mysore, O. Olajide, B. Pedroni***

Collaborators: ***Q. Wang, M. Lueker-Boden, D. Vucinic, et. al. – WDC,***

E. Neftci, T. liu – UCI, and A. Majumdar, S. Sivagnanam - SDSC.

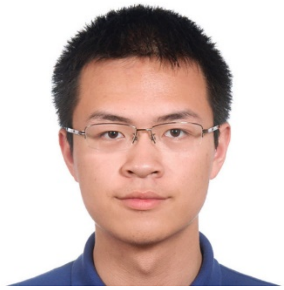
Advisor: ***G. Cauwenberghs, INC, BENG, & CENI - UCSD***

Our group in the Cauwenberghs Lab, in collaboration with researchers at UC Irvine Cognitive Science, San Diego Supercomputer Center (SDSC), and Western Digital Corporation, has been developing a hardware-software-firmware system for large-scale neural emulation to be hosted through the SDSC Neuroscience Gateway (NSG). Initial funding for the project was provided by the NSF CISE Program for Community Research Infrastructure, or CRI, with continued support provided by Western Digital Corporation.

Our system consists of 8 Alpha-Data boards in each of 5 servers, 40 total, with each board equipped with 8GB of High-Bandwidth Memory (HBM) for synaptic storage and Xilinx Virtex Ultrascale+ field-programmable gate array (FPGA) for neuromorphic computing. Each FPGA comes equipped with a PCIe interface to host processor, which is used as a network I/O interface, as well as for model parameters, synapse weights, and initial membrane potential configuration. Our hardware-software partitioning approach ensures the compute balanced and memory efficient partition of neural network workloads into the hardware resources for high-throughput implementation. The software compiler running inside the host servers also handles the placement of neurons into compute cores and an optimal placement of synaptic weights into HBM. Such hardware-software co-design optimization approach leads towards a simplified, yet efficient and reconfigurable hardware architecture.

Each FPGA can fit up to 32 cores, with 128k spiking neurons and 4M dynamical synapses per core. Neuron membrane potentials and spike events are stored locally using on-chip SRAM memories. Each core in FPGA consists of several submodules (axon processor, neuron processor, synapse processor) and other control elements for ensuring massively parallel and deeply pipelined implementation of spike-based computing.

All cores inside the FPGAs communicate spike events between each using their own address-event-routing (AER) router interface connected to the network-on-chip (NoC) grids consisting of multicast high-performance buses (mAHBs). These mAHBs govern very low-latency spike transmission towards the post-synaptic destinations among the neighboring cores. The peripheral logic in mAHBs handle the shared bus access mechanisms between the cores along with handshaking between them to ensure timed arrival of spikes and preventing overflow of outgoing events. We currently have demonstrated spike throughput of 420Mevents/sec per 128k-neuron core over this NoC architecture.



Understanding Microwave Impedance Microscopy Images of Quantum Anomalous Hall Insulators

Presenter: ***Taige Wang***, Graduate student, Physics

Researcher: ***Chen Wu***, Graduate student, Physics

Advisor: ***Monica Allen***, Assistant Professor, Physics

Microwave impedance microscopy (MIM) has been widely used to probe local electromagnetic properties of the material to high spatial resolution. In quantum Hall (QH) and quantum anomalous Hall (QAH) insulators, enhanced MIM signal has been observed close to the edge of the sample. In this work, we show that the MIM signal can be understood as a convoluted static response function. In QAH insulators, the dominating contribution of the MIM signal comes from the edge plasmon (EMP) modes. We use a minimal model that captures the density profile of the EMP modes to numerically simulate the MIM readout across the QAH transition, which agrees exceptionally well with experiment data at various frequencies. We also propose a new method to probe the Chern number of the system using MIM.

Powerful Error Correction Codes for QLC/PLC/HLC NAND Flash Memory

Presenter: ***Dongmin Shin***, Visiting Researcher, Samsung Electronics

Researcher: ***Dongmin Shin***, Visiting Researcher, Samsung Electronics

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

Over the past decade, triple-level cell (TLC) has been adopted in common flash memory devices beyond multi-level cell (MLC) to dramatically reduce costs by implementing different levels of storage density. However, the reliability still remains as a critical issue in the devices. In addition, the top flash memory manufacturers have been developing the quadra-level cell (QLC), penta-level cell (PLC) and hexa-level cell (HLC). It is expected in their next generation that the reliability of flash memory will be degraded further.

Among a variety of solutions for reliability of flash memory devices, a powerful error-correction code (ECC) is generally adopted as a core solution due to their strong error-correctability. In particular, low-density parity-check (LDPC) codes[1] have been already used for TLC SSD. Although binary LDPC code is known to approach Shannon limit (theoretical maximum correction capability limit), it is not easy to make it in practice. This is because the cost (decoding power or hardware size) of ECC is consumed close to infinity in order to obtain a correctability close to the theoretical limit.

In this reason, for QLC and beyond QLC, it is necessary to find an ECC that is more competitive than current LDPC. It is preferable that the power and size of ECC hardware are smaller as well as the correctability is better. To this end, the competitiveness of various ECC is compared and analyzed, and the ECCs mainly reviewed are as follows:

1. Generalized LDPC Code

2. Polar Code [2]

3. Generalized Concatenated Code with Polar subcode and LDPC subcode

4. Spatially Coupled Code

5. Non-binary LDPC or Polar Code

[1] R. G. Gallager, "Low Density Parity Check Code. Cambridge, MA:MIT Press, 1963

[2] E. Arikan, "Channel polarization: A method for constructing capacity-achieving codes for symmetric binary-input memoryless channels," IEEE Trans. Inf. Theory, vol. 55, no. 7, pp. 3051-3073, Jul. 2009.

Polar Shaping Codes for Costly Noiseless and Noisy Channels

Presenter: ***Karthik Nagarjuna***, Graduate Student, ECE

Researcher: ***Karthik Nagarjuna***, Graduate Student, ECE

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

In the Fall research review, we present a shaping code based on polar codes. For a costly noiseless channel, we show that the total cost of the polar shaping code approaches the optimal total cost as block length grows. We also consider shaping for costly noisy discrete memoryless channels (DMCs). We first give an upper bound on the rate that can be achieved with a specified symbol occurrence probability distribution over a DMC. Then we formulate an optimization problem whose solution gives a lower bound on the optimal total cost for a costly noisy DMC. We compute the lower bound for the costly M-ary erasure channel. Finally, we propose polar shaping codes for costly noisy channels that achieve the lower bound by adapting polar codes for asymmetric channels proposed by Honda and Yamamoto.

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Decoding for Optimal Expected Normalized Distance over the t-Deletion Channel

Presenter: ***Omer Sabary***, Ph. D. Student, ECE, UCSD

Researchers: ***Omer Sabary***, Ph. D. Student, ECE, UCSD

Daniella Bar-Lev, Ph.D. Student, CS, Technion

Yotam Gershon, M.Sc. Student, ECE, Technion

Eitan Yaakobi, Professor, CS, Technion

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

This work studies optimal decoding for a special case of the deletion channel, referred by the t-deletion channel, which deletes exactly t symbols of the transmitted word uniformly at random. The goal of the paper is to understand how such an optimal decoder operates in order to minimize the expected normalized distance. A full characterization of a decoder for this setup is given for a channel that deletes one or two symbols. For t = 1 it is shown that when the code is the entire space, the decoder is the lazy decoder which simply returns the channel output. Similarly, for t = 2 it is shown that the decoder acts as the lazy decoder in almost all cases and when the longest run is significantly long, it prolongs the longest run by one symbol.

Modeling Flash Memory Channels Using Conditional Generative Nets

Presenter: ***Simeng Zheng***, Graduate Student, ECE

Researcher: ***Simeng Zheng***, Graduate Student, ECE

Collaborator: ***Chih-Hui Ho***, Graduate Student, ECE

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

Realistic models for digital communication and storage channels are essential tools in the design and optimization of signal processing, detection, and coding algorithms that achieve peak performance. Understanding the NAND flash memory channel has become more and more challenging due to the continually increasing density and the complex distortions arising from the write and read mechanisms.

In this work, we propose a data-driven generative modeling method to characterize the flash memory channel. The learned model can reconstruct the read voltage from an individual memory cell based on the program levels of the cell and its surrounding array of cells. Experimental results show that the statistical distribution of the reconstructed read voltages accurately reflect the measured distribution on a commercial flash memory chip, both qualitatively and as quantified by the total variation distance. Moreover, we observe that the learned model can capture precise inter-cell interference (ICI) effects, as verified by comparison of the hard error rates associated with specific configurations of program levels in wordlines and bitlines.

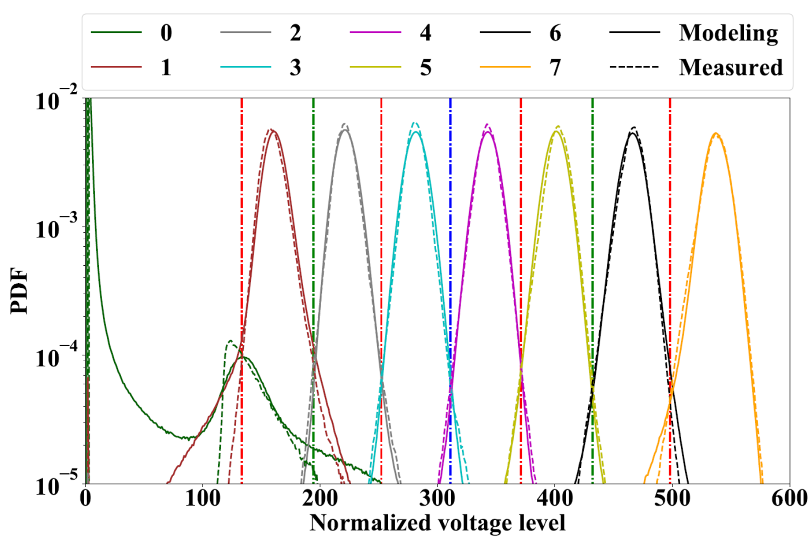

Fig. The estimated probability density functions of measured data (dotted curves) and generative modeling data (solid curves) at 4000 program/erase cycles. The vertical dash-dotted lines are hard read thresholds.

Electrical transport in chemically ordered $CrPt_3$ and $FePt_3$ epitaxial thin films

Presenter: ***Yuxuan Xiao***, Graduate researcher, CMRR

Advisor: ***Eric E. Fullerton***, Professor, CMRR Director, Electrical and Computer Engineering, NanoEngineering

The nature of XPt_3 intermetallic alloys attract significant interest due to their distinctive varieties of magnetic properties when X is 3d transition metals (V, Cr, Mn, Fe, Co) [1]. Previous investigations revealed rich physics such as large Kerr rotation in $CrPt_3$ [2] and second order phase transition in $FePt_3$ [3]. Recently, theoretical work suggested that XPt_3 alloys display topological Weyl semimetal properties which lead to intriguing and tunable electrical transport properties such as large intrinsic anomalous Hall conductivity and negative longitudinal magnetoresistance [4][5]. Here, we report the epitaxial growth of chemically ordered $CrPt_3$ and $FePt_3$ thin films. By performing electrical transport measurements, we obtained strong anomalous Hall conductivity of 2000 S/cm in $CrPt_3$ thin film, which is much larger than some of well-known ferromagnetic materials such as Ni and Co. Further exchange bias measurements on $FePt_3$/Fe bilayer gives insight to the tunable Néel vector orientation and might shine a light antiferromagnetic spintronics and memory applications.

This work is supported by US Department of Energy under Grant No. DE-SC0019273.

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[5] A. A. Burkov, et al., *Phys. Rev. Lett.* **113**, 247203 (2014).

Interplay of the half-skyrmion topology and spin-orbit torque on the growth of magnetic stripe domains

Presenter: ***Jeff Brock***, Graduate Student, CMRR

Researcher: ***Daan Swinkels***, Visiting Student, CMRR

Advisor: ***Eric Fullerton***, Director, CMRR

In recent years, the spin-orbit torque (SOT) generated when a charge current is passed through a heavy metal with sizeable spin-orbit coupling [1] has attracted significant research interest, given that it gives rise to the efficient movement of novel magnetic textures, such as chiral domain walls and skyrmions. Here, we discuss an experimental study of the SOT-induced motion of magnetic stripe domains in several heavy metal/ferromagnet thin-film heterostructures that possess an interfacial Dzyaloshinskii-Moriya interaction that favors the formation of chiral Neel-type domain walls [2]. In agreement with previous reports, we find that the domains exhibit a significant transverse velocity relative to driving force of the SOT. In these past works, this behavior was attributed to the Magnus force-like skyrmion Hall effect exhibited by the stripe domain topology (equivalent to that of a half-skyrmion) [3-5]. However, magnetometry and ferromagnetic resonance spectroscopy measurements suggest that the theoretically predicted transverse motion of stripe domains in our samples is too large to be explained by the skyrmion Hall effect alone. Analytically modeling the steady-state dynamical reconfiguration of the half-skyrmion profile induced by SOT, we demonstrate how motion with similar directionality and symmetry as the skyrmion Hall effect can originate – further highlighting the sensitivity of SOT to the local orientation of the domain wall magnetization profile.

This work is supported by the National Science Foundation, Division of Materials Research (Award #: 2105400).

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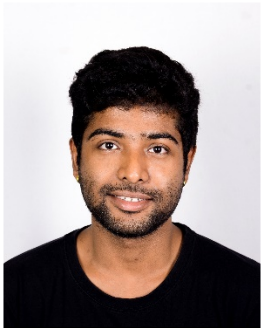

Efficient charge to spin conversion in 5d transition metal oxide

Presenters: ***Biswajit Sahoo***, Graduate Student, Physics

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

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

With charge-based electronics reaching their limitations, more attention is being focused on developing systems utilizing spin currents. Recent focus has been on developing materials with a large spin Hall angle (SHA), the ratio of the charge to spin current density. Transition metal oxides (TMOs) such as iridium oxide IrO_2 are attractive candidates that have large conductivity and high SOC. Further, IrO_2 is a Weyl semimetal and possesses Dirac nodal lines (DNLs) in its band structure which is gapped by its strong SOC [1]. In this work, we have fabricated bilayers of $IrO_2/Co_{40}Fe_{40}B_{20}$ samples to investigate the SHA in IrO_2 with different thicknesses and crystal structures. X-ray reflectivity (XRR), X-ray diffraction (XRD) and atomic force microscopy (AFM) have been used to verify the smoothness and crystallinity of IrO_2. We perform ST-FMR measurements on this system for different thicknesses of IrO_2 yielding SHA to be 40% in IrO_2 which is comparable to Pt. The resistivity of IrO_2 thin film is found to be 142 μΩ-cm, putting it in the metallic regime and close to that of CoFeB (120 μΩ-cm). Large SHA and high conductivity makes IrO_2 a robust candidate for further applications such as spin Hall nano-oscillators and magnetization switching.

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Tracking spatiotemporal magnetic domain correlations through a morphological phase transformation

Presenter: ***Ruben Saatjian***, Undergraduate Student, CMRR

Researcher: ***Jeff Brock***, Graduate Student, CMRR

Advisor: ***Eric Fullerton***, Director, CMRR

In recent years, the winding-like quantized topology of the magnetic quasi-particles known as skyrmions has attracted significant research attention from fundamental and applied perspectives.[1.2] As such, the design of materials capable of hosting such exotic spin textures remains an active area of interest. In thin-film ferromagnet/heavy metal multilayers, it has recently been shown that a dramatic evolution in domain morphology can be induced by small changes in sample temperature or thickness in the limit of low exchange stiffness.[3] In the midst of this morphological transformation, skyrmion phases can be stabilized by applying small perpendicular magnetic fields. While the observed transformation draws strong parallels with the well-studied spin reorientation transition known to occur in the limit of low PMA in similar materials systems [4], the significant PMA of our samples may preclude an understanding by similar means.

To better understand the nature of the morphological transformation in our samples, we have experimentally tracked the spatial and temporal correlations of the domain state as a function of temperature while traversing the morphological transformation using polar magneto-optic Kerr effect (MOKE) microscopy. We find that the domain periodicity rapidly decreases as the sample is heated through the transformation, such that we lose the ability to optically resolve domains using polar MOKE. Simultaneous to this change in domain periodicity, we find that the characteristic time required for the domain pattern to decorrelate (*i.e.*, randomize) decreases dramatically. Combined with temperature-dependent measurements of the DC magnetic susceptibility, these results permit a glimpse at the dynamics of the underlying phase transition that governs the transformation in domain morphology.

This work is supported by the National Science Foundation, Division of Materials Research (Award #: 2105400).

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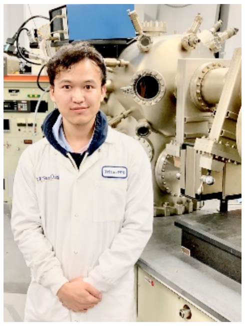
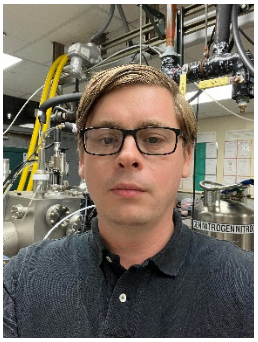


Unusual phenomena on capacitively coupled stochastic spiking oscillators

Presenter: ***Ben Erbin QIU***, Ph. D student, ECE

Advisor: ***Ivan Schuller***, Professor, Physics

We take advantage of the stochastic threshold resistive switching phenomenon and self-oscillation behavior of Mott insulator VO_2, implementing the stochastic spiking oscillators, which perfectly resemble the jittering behavior of biological neurons. Interestingly, we observe that the intrinsic spiking stochasticity have a strong impact on the capacitive coupled oscillators. The deterministic anti-phase synchronization can be achieved when two oscillators are coupled with small capacitor. However, as the capacitive coupling strength increases, the deterministic alternating spiking train gives way to stochastic spiking patterns where an oscillator may have the stochastic disruptive events, which is extremely counterintuitive. The stochastic disruptions of the alternating sequence of the coupled spiking oscillators leads to a multimodal ISI distribution that also resembles the multimodal spiking behavior in biological sensory neurons, which may have a potential application in SNN and neuromorphic computing. Based on the stochastic disruptive events of the coupled spiking oscillators, we are providing a new impetus to demonstrate the true random number generator which is of great significance to many cryptographic applications.



Magnetoresistance anomaly in a resistive switching system

Presenter: ***Pavel Salev***, Department of Physics

Researcher: ***Pavel Lapa,*** Department of Physics

Collaborators: ***Iana Volvach, Vitaliy Lomakin,*** University of California, San Diego, ***Dayne Sasaki, Yayoi Takamura,*** University of California, Davis

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

Application of a strong electric stimulus, voltage or current, to the ferromagnetic oxide (La,Sr)MnO_3 (LSMO) triggers the intrinsic metal-insulator transition producing a volatile switching from a low- to high-resistance state. This resistive switching occurs in a characteristic spatial pattern, the formation of a paramagnetic insulating barrier perpendicular to the current flow, in contrast to the conventional filamentary percolation parallel to the current. We explored the evolution of anisotropic and colossal magnetoresistance in LSMO devices as they undergo resistive switching. We found that the magnetoresistance magnitude can be increased severalfold by initiating the switching and inducing the formation of a paramagnetic barrier inside the device. Moreover, by driving the LSMO device through the resistive switching the sign of magnetoresistance can be flipped from positive to negative and vice versa. Our results demonstrate the potential use of resistive switching in magnetic materials for novel spintronic applications.

This work was supported by the U.S. Department of Energy (DOE), Office of Science, Basic Energy Sciences (BES), Materials Sciences and Engineering Division under Award # DE-FG02-87ER-45332.

Photo-assisted non-volatile and volatile resistive switching in hybrid CdS/Mott heterostructures

Presenter: ***Henry Navarro***, postdoc, Physics department, UCSD

Researchers: ***Sarmistha Das***, postdoc, ***Erbin Qiu***, graduate student, ***Rourav Basak***, graduate student, ***Fernando Ajejas***, postdoc, ***Coline Adda***, postdoc, ***Alex Frano***, Professor, UCSD.

Collaborators: ***Victor Rouco*** postdoc, ***Alberto R. Calzada***, Professor, ***Jacobo Santamaria***, Professor, Universidad Complutense de Madrid. Spain.

Marcelo Rozenberg, Researcher, Université Paris Saclay, France.
Javier del Valle, Postdoc, University of Geneva, Switzerland.
Yoav Kalcheim, Professor, Technion-Israel Institute of Technology, Israel.
Nicolas M. Vargas, Scientist, General Atomics, USA.
Minhan Lee, Scientist, Applied Materials, Inc, USA.

Advisor: ***Ivan K. Schuller***, Professor, Physics department, UCSD

The manipulation of the insulating to metal transition (IMT) of strongly correlated oxides is of major interest due to its potential applications in optoelectronics and neuromorphic computing. We have recently showed that the IMT of VO_2, V_2O_3 and V_3O_5 can be manipulated by the incorporation into heterostructures and use of photodoping. We discovered recently large effects in heterostructures which incorporate a photoconducting material (CdS) and a strongly correlated Mott oxide [1]. In this work, we have extended it to heterostructures containing manganites, e.g., $La_{0.3}Sr_{0.7}MnO_3$ (LSMO) that exhibit volatile behavior in the insulating state, and to nickelates like $PrNiO_3$ (PNO). We studied PNO thin films grown on $NdGaO_3$ substrate with two different orthorhombic crystal plane orientation, *i.e.*, PNO(101) and PNO(110), respectively. The optical functionalities of these films are manipulated by incorporation into CdS/PNO heterostructures. Depending on the growth symmetry CdS/PNO(101) and CdS/PNO(110) films exhibit two very different low temperature photoinduced non-volatile and volatile changes in the resistivity, respectively. We will discuss the possible physical origin of this interesting phenomena.

This collaborative work was supported as part of the "Quantum Materials for Energy Efficient Neuromorphic Computing" (Q-MEEN-C), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences under the Award No. DE-SC0019273. The magnetism work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division under Award # DE-FG02-87ER-45332.

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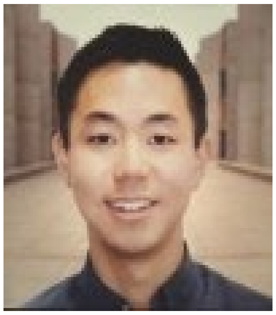

High Thermal Conductivity Aluminum Nitride Thin Films

Presenter: ***Scott T. Ueda***, GSR, Materials Science and Engineering

Researcher: ***Aaron McLeod***, GSR, Chemistry and Biochemistry

Collaborators: ***Chris Perez***, GSR, Mechanical Engineering, Stanford

Michelle Chen, GSR, DMSE, Stanford

Eric Pop, Professor, ECE, Stanford

Advisor: ***Andy C. Kummel***, Distinguished Professor, Chemistry, UCSD

Although microelectronic scaling is typically thought of in terms of a simple shrink in transistor size, an often-overlooked consequence is the increasing need for removing the heat generated in these complex, 3-dimensional microelectronic circuits. Aluminum nitride (AlN) has the benefit of both high thermal conductivity and large bandgap, which makes it ideal for integration as a heat spreader material for both CMOS and RF devices. Although the bulk thermal conductivity of AlN is similar to that of gold (~ 300 W/m-K), the effective thermal conductivity is highly dependent on defect density and so in order for successful integration, a method of depositing high-quality crystalline AlN at T < 400 °C must be realized. This work details progress on the use of reactive sputtering to deposit thin (< 2 um) AlN films with thermal conductivity > 120 W/m-K. An additional technique known as atomic layer annealing (ALA) will also be discussed where inert gas ions are used to induce crystallinity in each atomic layer deposition cycle. This technique was used to deposit template layers for sputtered film growth and has shown initial promise to increase the grain size and thermal conductivity of the AlN thin films.

MemComputing Quantum State Tomography

Presenter: ***Yuanhang Zhang***, Graduate Student Researcher, Department of Physics

Researcher: ***Yuanhang Zhang***, Graduate Student Researcher, Department of Physics

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

Quantum state tomography is the process by which a quantum state is reconstructed using measurements on an ensemble of identical quantum states. This is a difficult task, as traditional methods suffer from the exponential growth of the Hilbert space, and recent machine learning-based methods are hindered by sampling problems and instabilities during training. In this talk I will show that, by combining MemComputing [1] with machine learning, we can improve the quality of quantum state tomography significantly, while reducing the number of required measurements. We employ a novel training method called ``mode-assisted training'', [2] which samples the mode of the distribution of a neural network with MemComputing to construct an off-gradient training step and stabilize the training process. Work supported in part by CMRR and DOE.

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