Revisiting The Labeled Coupon Collector Problem

Presenter: ***Andrew Tan,*** PhD Student, ECE

Researcher: ***Andrew Tan,*** PhD Student, ECE

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

Previously, we introduced an interesting combinatorial problem dubbed the "Labeled Coupon Collector Problem", which can be stated as follows:

> Suppose there are n different types of coupons, where each is assigned a distinct and unknown label from 1 to n, and you would like to identify the label of each coupon. You can draw k different coupons uniformly at random, where you are then given the labels of the drawn coupons in a random order. What is the minimum as well as the expected number of draws required to identify the labels of all n coupons?

This problem has potential applications in watermarking in DNA data storage, and when $k = 1$, this problem becomes nearly identical to the well-known Coupon Collector Problem [1].

We also proposed a method to solve the problem through constructing a Markov chain [2] from a graph-based formulation of the problem and computing the absorption times of each state.

In this talk, we provide an improved understanding of the Labeled Coupon Collector Problem. Through the simulation algorithm mentioned in the previous talk, we construct a new Markov chain whose states can be expressed as a k-tuple that obeys a certain Diophantine inequality. Although the method of computing the expected number of draws through absorption times [3] of states is the same as before, the Markov chains discussed in this talk are better-structured and can be more easily generalized with respect to the parameter k. We once again pay closer attention to the case of $k = 2$, where a few interesting observations can be made.

[1] Wikipedia contributors. (2024, February 9). Coupon collector's problem. In Wikipedia, The Free Encyclopedia. Retrieved 18:18, May 30, 2024, from https://en.wikipedia.org/w/index.php?title=Coupon_collector%27s_problem&oldid=1205223195

[2]J.R. Norris, *Markov Chains*. Cambridge: Cambridge University Press, 1997.

[3] Wikipedia contributors. (2024, May 25). Absorbing Markov chain. In Wikipedia, The Free Encyclopedia. Retrieved 18:29, May 30, 2024, from https://en.wikipedia.org/w/index.php?title=Absorbing_Markov_chain&oldid=1225622508

Generalizing Functional Error Correction for Vision-Language Models

Presenter: ***Wenyu Peng***, Graduate Student, ECE

Researcher: ***Wenyu Peng***, Graduate Student, ECE

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

Collaborator: Simeng Zheng, Graduate Student, ECE

The goal of functional error correction is to preserve neural network performance when stored network weights are corrupted by noise [1]. To achieve this goal, a selective protection (SP) scheme was proposed to optimally protect the functionally important bits in binary weight representations in a layer-dependent manner. Although it showed its effectiveness in image classification tasks on some relatively simple networks such as ResNet-18 and VGG-16, it becomes inadequate for emerging complex machine learning tasks generated from natural language processing and vision-language association domains. To solve this problem, we extend the SP scheme in three directions: task complexity, model complexity, and storage complexity. Extensions to complex vision-language tasks include "zero-shot" textual classification of images. Extensions to more complex models with attention-based large language models consist of Contrastive Language-Image Pre-Training (CLIP) networks [2]. Extensions to more complex storage configurations focus on distributed storage architectures to support model parallelism. Experimental results show that the optimized SP scheme preserves network performance in all these settings. The results also provide insights into redundancy-performance trade-offs, generalizability of SP across datasets and tasks, and robustness of partitioned network architectures.

[1] K. Huang, P.H. Siegel, and A. Jiang, "Functional error correction for robust neural networks," *IEEE Journal on Selected Areas in Information Theory*, vol. 1, no. 1, pp. 267-276, May 2020.

[2] A. Radford, J.W. Kim, C. Hallacy, et al., "Learning transferable visual models from natural language supervision," *International Conference on Machine Learning*. PMLR, 2021: 8748-8763.

Stopping Set Analysis for Concatenated Polar Code Architectures

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

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

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

We investigate properties of concatenated polar codes and their potential applications. We start with reviewing previous work on stopping set analysis for conventional polar codes [1], which we extend to concatenated architectures. Specifically, we present a stopping set analysis for the factor graph of concatenated polar codes, deriving an upper bound on the size of the minimum stopping set. To achieve this bound, we propose new bounds on the size of the minimum stopping set for conventional polar code factor graphs. The tightness of these proposed bounds is investigated empirically and analytically. We show that, in some special cases, the exact value of the minimum stopping set can be determined with a time complexity of O(N). The stopping set analysis motivates a novel construction method for concatenated polar codes. This method is used to design outer polar codes for two previously proposed concatenated polar code architectures: augmented polar codes [2] and local-global polar codes [3]. Simulation results demonstrate the advantage of the proposed codes over previously proposed constructions based on density evolution.

[1] A. Eslami and H. Pishro-Nik, “On finite-length performance of polar codes: Stopping sets, error floor, and concatenated design,” *IEEE Transactions on Communications*, vol. 61, no. 3, pp. 919-929, March 2013.

[2] A. Elkelesh, M. Ebada, S. Cammerer and S. t. Brink, “Flexible length polar codes through graph based augmentation,” SCC 2017; *Proc. 11th International ITG Conference on Systems, Communications and Coding*, 2017, pp. 1-6.

[3] Z. Zhu, W. Wu and P. H. Siegel, “Polar codes with local-global decoding,” *Proc. 56th Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, USA, 2022, pp. 392-396.

Presenter: Yun Chen
Professor Yang's group.

Title: **First-Principles Descriptor for Predicting Chiral Helimagnetism**

Chiral helimagnets have attracted considerable research interest for their potential applications in spintronics. However, studies on chiral helimagnetism have largely focused on experimental methods, with theoretical calculations remaining a significant challenge. In this work, we explored chiral helimagnetism in Cr-intercalated transition metal dichalcogenides (TMDs), specifically $Cr_{1/3}MX_2$ (where M = Nb, Ta and X = S, Se), using first-principles calculations based on density functional theory (DFT). Our findings show excellent agreement with existing experimental data, providing a computational framework that could accelerate future studies and the exploration of helimagnetic systems.

Presenter's name: Tianxing D. Wang

Lab: Ivan K. Schuller

Title: Anomalous exchange bias in hematite/permalloy heterostructures

Abstract: Exchange bias (EB) is an interfacial effect that plays a crucial role in magnetic recordings. It arises from the exchange interaction between an antiferromagnet (AFM) and a ferromagnet (FM). Hematite (α-Fe_2O_3) is an AFM that shows spin-flop (Morin) transition at $T_M \approx 260$ K. This extra degree of freedom makes hematite an interesting case when studying exchange interactions in a heterostructure. We fabricated epitaxial hematite thin films and coupled them with a soft magnet permalloy. Surprisingly, we observed sizable EB after field cooling these samples across T_M which sat far below the hematite's Néel temperature (~950 K). This EB also shows unexpected temperature dependence compared to that of a typical EB system. It reaches a maximum value of ~40 Oe near T_M but drops off to zero when temperature is away from T_M. Notably, the polarity of the EB can be reversed by applying a large magnetic field without cycling temperature across T_M. Moreover, surface treatment using plasma cleaning on hematite before depositing permalloy dramatically changes the EB temperature dependence. A significantly larger EB ~600 Oe is observed at 5 K following such procedure. We propose a mechanism that involves the competition of magnetic anisotropies in hematite to explain this effect. This study provides insights into the AFM spin structure of hematite, and it also shows the potential of using spin-flop AFM in spintronics for additional functionalities.

Presenter's name: Juan Andres Hofer

Lab: Ivan K. Schuller

Title: Importance of substrate's thermal and mechanical properties on VO_2 neuromorphic devices

Abstract: Materials that undergo metal-to-insulator transition (MIT) are prime candidates for making neuromorphic devices, among which vanadium dioxide (VO_2) is an archetypical compound. Applying an external electric field can trigger the MIT in VO_2, which is called resistive switching (RS). The RS is the base for many neuromorphic devices, such as spiking oscillators that mimic the functionalities of a biological neuron. Hence, understanding the RS from a thermo-electric perspective is critical for its applications in energy-efficient neuromorphic computing. However, the deposition of VO_2 on substrates with different properties can be challenging, since thin films characteristics depend strongly on the growth conditions. In this work, we report an effective method to deposit VO_2 on various substrates with distinct thermal and mechanical properties. By measuring *in operando* infrared emissions, we assess the thermal behaviors of the micro devices fabricated using these samples when they undergo RS. Our results demonstrate that the energy-efficiency and scalability of VO_2 based devices can be significantly enhanced by selecting substrates with low thermal conductivity. Meanwhile, substrates with distinct mechanical properties allow us to explore the role of defects on RS of VO_2 based devices.

Title: Design and Material Characterization of Silicone-composite Elastomers and Multi-chamber Dilator for Biomedical Devices

Brian Li, Po-Han Chen, and Shreyaa Ramakrishnan

Our project aims to analyze the structure and behavior of complex geometries in composite materials to replicate the mechanical properties of vaginal tissue and to provide an accurate vaginal model to test single and multi-chamber dilator designs. Previously, a thermoplastic polyurethane (TPU) gyroid scaffold encased in a soft silicone matrix was used to mimic the J-shape stress-strain response of soft tissue due to the re-arrangement and stretching of collagen fibers. However, the stress-strain curve of the gyroid scaffold indicated that its strain-stiffening behavior was substantially different from that found for vaginal tissue, and further investigations were needed to modify the properties of the composites.

1D sinusoidal patterns and 2D kirigami patterns were manufactured and incorporated into the TPU scaffold to reduce the bending-dominated elongation and to investigate the effect of non-linearity in uniaxial tensile tests. Finite element analysis (FEA) of a 1D sinusoidal pattern in tension was performed to study the influence of material properties and design parameters on the desired J-shape stress-strain response. Additional simulations were performed by incorporating the 1D sinusoidal pattern into a vaginal phantom to study its response when inflated by a single-chamber vaginal dilator. Varying degrees of vaginal stenosis can be simulated through changes in the dimensions of the vaginal phantom. Pressure and deformation analysis can be used to infer the vaginal stenosis conditions.

In order to enable targeted dilation, we are currently developing a multi-chamber dilator with region-specific inflation. This design provides a simplified control mechanism and enables precise, localized therapy.

Presenter: Steven Hui

Group: Frank Talke

Title: Assessment of an Integrated Computer Vision and AR Approach for Improved Minimally Invasive Spinal Procedures

Abstract:
Surgical navigation has revolutionized the healthcare industry, playing a key role in enhancing the precision, safety, and efficiency of various medical procedures. In this paper, we present a novel 3D computer navigation approach that uses augmented reality and computer vision to assist in spinal pain management procedures such as radiofrequency ablation or epidural steroid injections. We evaluate the accuracy of augmented reality overlay of MRI scans or CAD models on the patient through simulated spinal injection experiments and assess the accuracy of computer vision algorithms via optical tracking experiments. Our results show that augmented reality and computer vision offer a cost-efficient and radiation-free alternative to traditional fluoroscopy.

Presenter: Biswajit Sahoo
Group: Eric Fullerton

Title: Oxide based spintronics

Complex oxides are emerging as a versatile platform for spintronic applications due to their rich interplay of charge, spin, lattice, and orbital degrees of freedom. These materials, characterized by strong electron correlations and tunable functionalities, exhibit a range of phenomena, including ferromagnetism, antiferromagnetism, multiferroicity, and spin-orbit coupling. The ability to engineer interfaces and heterostructures in oxide systems enables precise control over spin transport and magnetoresistance effects, paving the way for low-power and high-speed spintronic devices. Furthermore, the integration of oxides with traditional semiconductors offers opportunities for hybrid devices that leverage the unique spin-related properties of oxides. In this talk some results relating to the interesting temperature dependent magnetization dynamics of oxide ferromagnet La0.67S0.33MnO3 on its own and in conjunction with thin films of Pt, a paramagnetic metal-antiferromagnetic insulator transition perovskite NdNiO3 and paramagnetic insulator-anti-ferromagnetic insulator transition material La0.3Sr0.7FeO3 will be discussed.

Presenter: Aleksandar Jeremic
Group: Eric Fullerton

Title: Modelling and Measurements of Magnetic Tunnel Junctions (MTJ)

The Magnetic Tunnel Junction (MTJ) is a stacked pillar composed of two ferromagnetic layers a Reference Layer (RL), and a Free Layer (FL), separated by a tunnel barrier. The Tunnel MagnetoResistance (TMR) is low when the ferromagnetic layers have aligned magnetization, and high when the magnetizations is antiparallel. Using Spin Transfer Torque (STT) it is possible to create non volatile, low power bit arrays which do not require magnetic fields for writing commands. My talk will introduce the MTJ, STT, findings and future uses of MTJs for low-power on-chip machine learning. Using special manufacturing techniques MTJs can have increased TMR without a large effect on the anisotropy. The thermal stability of MTJ can be controlled during manufacturing process. High thermal stability can be used to create long term memory, and low thermal stability can be used to create stochastic bits. In this work a code in Python was developed to extract MTJs parameters during the measurements, such as the thermal stability, anisotropy and critical switching current.

Presenter: Sheena Patel
Group: Eric Fullerton

Title: Magnetic Phase Diagram and Antiferromagnetic Spin Canting in FeRh

FeRh is a material that has been of increasing interest, primarily because it exhibits strong coupling of spins, charges, and lattice and a first-order hysteretic phase transition near room temperature between a low-temperature high-resistance antiferromagnetic state and a higher-temperature low-resistance ferromagnetic state, along with a 1-2 % isotropic change in unit cell volume. The application of an external magnetic field is known to shift the transition to lower temperatures by around 8-9 K/T [1], however the phase transition has not previously been studied above the 9 T commonly reachable in laboratory measurements. In addition, there is no previously reported experimental work studying the nature of the antiferromagnetic phase and the canting of the spins under application of a field. In this work [2], we conduct high-field and low-temperature resistance measurements of the phase transition in an FeRh wire to map out the field-temperature phase diagram and perform x-ray magnetic circular dichroism (XMCD) of an FeRh film in order to study the antiferromagnetic phase and measure the spin canting. These measurements contribute to mean-field modeling of the phase diagram.

A. G. Buzdakov,[1] I. A. Dolgikh,[2,3] K. A. Zvezdin,[4] A. K. Zvezdin,[5,6] K. Rubi,[2,3] U. Zeitler,[2,3] P. C. M. Christianen ,[2,3] Th. Rasing,[2] S. K. K. Patel,[7] R. Medapalli,[7] E. E. Fullerton ,[7] E. T. Dilmieva,[3] and A. V. Kimel[2]

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[1] S. Maat, *et al.*, “Temperature and field hysteresis of the antiferromagnetic-to-ferromagnetic phase transition in epitaxial FeRh films,” *Phys. Rev. B*, **72**, 214432 (2005).

[2] Buzdakov, *et al.* “Phase diagrams for magnetic field and temperature induced ferromagnetism in antiferromagnetic FeRh.” *Phys. Rev. B* **108**, 184420 (2023).

Resistive Switching Behavior Of Lithium Titanium Oxide During Spinel To Rock Salt Conversion For Neuromorphic Application

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ABSTRACT

Lithium based synaptic device research has been a growing new field in the last few years for enabling robust neuromorphic hardware systems. It can realize parallel analogue computation which is beyond the conventional von Neumann computing architecture which is slow, energy inefficient and expensive to execute complex tasks. In this study, we showcase the remarkable potential of Lithium Titanium Oxide ($Li_4Ti_5O_{12}$) spinel, both computationally through Density of States (DoS) analysis using Density Functional Theory (DFT), and experimentally via direct current (DC) polarization investigation of electrochemically lithiated $Li_4Ti_5O_{12}$ thin film, examining diverse states of discharge (SoD) in out-of-plane configurations. The observed conductivity jumps spans up to six orders of magnitude, transitioning from the $Li_4Ti_5O_{12}$ spinel phase to the fully lithiated $Li_7Ti_5O_{12}$ rock salt phase. Raman Spectroscopy validates the transformation from the $Li_4Ti_5O_{12}$ spinel phase to the $Li_7Ti_5O_{12}$ rock salt phase. Moreover, the onset of an increase in conductivity during this transformation is corroborated by changes in the oxidation state of Titanium (Ti), as explained with the help of X-ray Photoelectron Spectroscopy. To actualize these findings, we engineered a three-terminal artificial synaptic device integrating Lithium Phosphorous Oxynitride (LiPON) solid-state electrolyte as the lithium-ion source and conductor, while employing Lithium Titanium Oxide (Li4Ti5O12) spinel as the channel material. For transfer characteristics of the device, we maintained a source-drain voltage (V_{SD}) of 500 mV, while sweeping the gate voltage (V_G) from -3 V to 3 V at a rate of 90 mV/s, resulting in switching spanning up to 4 orders of magnitude, consistently replicable across 90 cycles. The transfer characteristics were also done on the device by varying V_{SD} and keeping V_G constant (90 mV/s) and also varying V_G sweep rate and keeping V_{SD} constant (500 mV). The transfer characteristics test was also done on the widened gate voltage window from ±3 V to ±7V. A retention test was done to track the retention of the High Conductance State (HCS) and Low

Conductance State (LCS) and it showed a switch ratio of 2.10 after 50 s. The LTP and LTD test was further done to check the neuromorphic response in the device. A control device replacing LiPON with Si_3N_4 was fabricated to show that the hysteresis in the device was due to the Lithium insertion and de-insertion. These compelling results portray a promising trajectory for the development of a robust synaptic device architecture reliant on lithium-based all solid-state materials, catalyzing the evolution of high-precision analogue neuromorphic computing systems.

Abstract for CMRR review

Student: Jiawei Duan

Professor: Vitaliy Lomakin

Soft magnetic materials play a critical role in high-frequency applications, such as transformers, inductors, and electromagnetic shielding. Their low coercivity and high permeability make them ideal for efficient magnetic flux control. I want to present some progress on the modeling of soft magnetic materials, particularly by incorporating the effects of eddy currents. Our approach enables the modeling of grain sizes up to micrometers, allowing for detailed analysis of various magnetic behaviors.

We examine the BH loop, hysteresis loss, and dynamic responses of these materials under different conditions. Specifically, we investigate the losses under a DC magnetic field, as well as in demagnetized and remanent states. Additionally, our models consider the effects of different interface exchange couplings on the material's behavior.

Also, our methods leverage advanced finite element modeling techniques, integrating electromagnetic solvers with micromagnetic solvers to accurately simulate the combined magnetization and eddy current dynamics. This integration allows for a comprehensive understanding of the material's performance in real-world applications, providing insights into optimizing material design and improving device efficiency.

The outcomes of this research enhance our ability to predict the behavior of soft magnetic materials, paving the way for more efficient and effective magnetic devices.

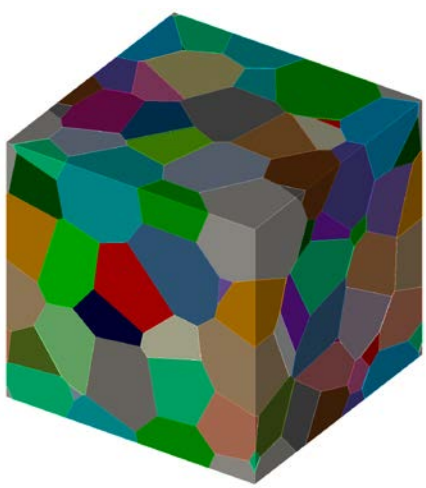

Fig. 1. Modeling of a block of soft material has 60 grains of size 2 um.

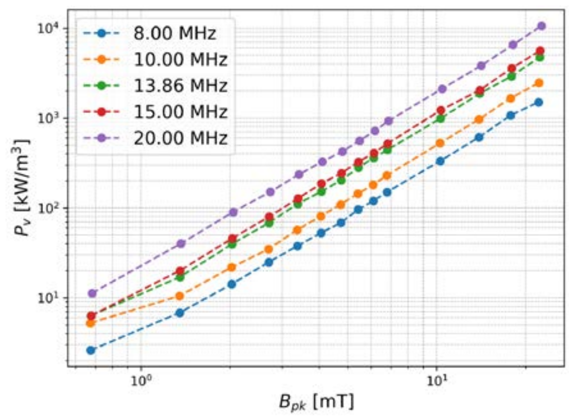

Fig.2 Core loss at different frequencies and applied field