Center for Magnetic Recording Research

University of California – San Diego

La Jolla, California 92093-0401

Research Review and Advisory Council Meeting

April 30 – May 1, 2015

Website: http://cmrr.ucsd.edu

Center for Magnetic Recording Research

Research Review Schedule

Thursday, April 30, 2015		
8:30 AM - Continental Breakfast at CMRR		
8:55 AM - Welcome and Introduction		
9:00 AM - Tribology and Mechanics ***Professor Frank Talke***		
1	Effect of Head-Disk Interface Biasing on Head Wear of Thermal Flying Height Control Sliders	*Liane Matthes*
2	Investigation of Hydrocarbon and Lubricant Transfer at the Head-Disk Interface	*Young Woo Seo*
3	Investigation of HAMR Interfaces Using Tip Enhanced Raman Spectroscopy	*Ben Suen*
4	Thermal Response of a Thermal Asperity Sensor to Disk Asperities	*Youyi Fu*
5	Simulation of Collocated Dual Stage Suspensions	*Karcher Morris and Yangfan Wang*
10:20 AM - 10 Minute Break		
6	Flying Height Control of Recording Heads at Sub-Nanometer Spacing	*Liane Matthes*
7	Investigation of the Effect of Diamond-like Carbon Overcoat on the Tribological Performance of the Dimple/Gimbal Interface in Hard Disk Drives	*Youyi Fu*
8	Development of an Optical Based Pressure Sensor for Continuous Glaucoma Monitoring	*Alex Phan*
9	Future Research on Tribochemistry and Nano Wear of the Head Disk Interface	*Tan Trinh*
11:30 AM - Ultrafast and Nanoscale Optics ***Professor Shaya Fainman***		
10	Nanophotonics Technology and Applications	*Shaya Fainman*

12:30 PM - Lunch		
1:30 PM - Special Session: Experimental Condensed Matter ***Professor Kai Liu***		
11	Magnetometry-Based Order Parameter to Probe the A1 to $L1_0$ Transformation in FeCuPt	*Kai Liu*
2:10 PM - Design & Fabrication of NanoMagnetic Materials ***Professor Sungho Jin***		
12	Magnetic Composites with Advanced Functionality	*Sungho Jin*
2:30 PM - 10 Minute Break		
2:40 PM - Micromagnetic Modeling and Recording Physics ***Professor Vitaliy Lomakin***		
13	Micromagnetics and Recording Physics at CMRR	*Vitaliy Lomakin*
13	Fast Block Inverse Preconditioner for Implicit Time Integration in Finite Element Micromagnetic Solvers	*Sidi Fu*
14	Accelerate Object Oriented Micromagnetic Framework (OOMMF) on GPU	*Sidi Fu*
14	Simulation of Granular Media in HAMR	*Marco Menarini*
15	Model to Simulate Optical Effects in Ferromagnetic Materials	*Marco Menarini*
15	High-Performance Nudged Elastic Band Method for Computing Energy Barriers in Complex Nanomagnetic Systems	*Vitaliy Lomakin*
16	Micromagnetic Modeling of Nano-Granular Materials	*Simon Couture*
16	High Frequency Measurement of Complex Permeability	*Simon Couture*
4:30 PM - Poster Session		
5:00 PM - Advisory Council Meeting		

Friday, May 1, 2015		
8:00 AM - Continental Breakfast at CMRR		
8:40 AM - Welcome and Introduction		
8:45 AM - Signal Processing & Coding ***Professor Paul H. Siegel***		
17	Generalized Multihead Multitrack Detection with Reduced State Sequence Estimation (prerecorded presentation)	*Bing Fan*
18	Linear Locally Repairable Codes with Availability (prerecorded presentation)	*Pengfei Huang*
19	Error Analysis and Inter-Cell Interference Mitigation in Multi-Level Cell Flash Memories	*Veeresh Taranalli*
20	Row-by-Row Coding for ICI Mitigation in Flash Memories (prerecorded presentation)	*Sarit Buzaglo*
10:10 AM - 10 Minute Break		
10:20 AM - Non-Volatile, Solid State Memory ***Associate Professor Steven Swanson & Professor Paul H. Siegel***		
21	Endurance Code Design and Evaluation for Flash Memories	*Dustin Hudson*
22	Mojim: A Reliable and Highly-Available Non-Volatile Memory System	*Jian Yang*
11:00 AM - Magnetic Films and Nanostructures ***Professor Eric Fullerton***		
23	All-Optical Control of Magnetization in Ferromagnetic Thin Films	*Rajsekhar Medapalli*
24	Tuning Surface Plasmon Resonances of the Layered Ferromagnetic Nanostructures using Magnetic Field, Structure, and Optical Radiation	*Conrad Rizal*
25	Enhanced Kerr Microscopy Systems at the Center for Magnetic Recording Research	*Robert Tolley*
26	Resonant Properties of a Skyrmionic RE-TM Ferrimagnet with Perpendicular Magnetic Anisotropy	*Sergio Montoya*
12:00 PM - Thermal Energy Transport ***Asst. Professor Renkun Chen***		
27	Nanoscale Thermal Energy Transport	*Renkun Chen*
12:30 PM - Lunch		

Effect of Head-Disk Interface Biasing on Head Wear of Thermal Flying Height Control Sliders

Presenter: ***Liane M. Matthes***, PhD Candidate, MAE
Researchers: ***Liane M. Matthes***, PhD Candidate, MAE
Frederick E. Spada, Associated Researcher, CMRR
Collaborator: ***Bernhard E. Knigge***, Manager, Western Digital
Advisor: ***Frank E. Talke***, Professor, MAE

As the physical spacing between the recording head and the magnetic disk decreases, wear of the recording head becomes an increasing concern. It has been reported that the wear rate of the slider can be reduced by biasing the head-disk interface (HDI) with a proper voltage [1-2]. The authors of these patents state that wear occurs primarily on the disk surface rather than the slider when a negative voltage is applied to the slider with respect to the disk. This result is interesting because it is unclear why a negative slider bias should result in diminished head wear. If head wear is enhanced by increased slider-disk attraction arising from electrostatic forces, wear should be independent of the polarity applied to a particular surface and depend only on the potential difference across the HDI. Potential differences at the head-disk interface can also have detrimental effects such as lubricant degradation [3-4] and changes in flying height [5-6].

In this investigation, we study head wear as a function of a dc bias voltage applied across the head-disk interface (HDI). Head-wear is determined by measuring the change in the heater touch-down power before and after 10 minute wear tests. It is found that applying a positive bias to the disk with respect to the slider results in reduced head wear.

[1] B. E. Knigge and B. Marchon, "Negative biasing a slider with respect to a disk to reduce slider wear and provide burnish rate control," US 0157739A1, 2011.
[2] J. Contreras, L. Franca-Neto, and B. E. Knigge, "Integrated slider bias control," US 8,049,984 B2, 2011.
[3] S. Matsunuma, "The initial step of tribochemical reactions of perfluo-ropolyether on amorphous carbon," *Wear*, vol. 213, pp. 112–116, 1997.
[4] F. E. Spada and D. Basov, "Fourier transform infrared investigation of thin perfluoropolyether films exposed to electric fields," *Tribology Letters*, vol. 8, pp. 179–186, 2000.
[5] M. Suk, R. Kroeker, and D. Gills, "Investigation of slider dynamics under electro-static force," *Microsystem Technologies*, vol. 9, pp. 256– 265, 2003.
[6] B. E. Knigge, C. M. Mate, O. Ruiz, and P. M. Baumgart, "Influence of contact potential on slider-disk spacing: Simulation and experiment," *IEEE Transactions on Magnetics*, vol. 40, no. 4, Jul. 2004, pp. 3165– 3167.

Investigation of Hydrocarbon and Lubricant Transfer at the Head-Disk Interface

Presenter: ***Young Woo Seo***, Graduate Student, CMRR, MAE
Researcher: ***Young Woo Seo***, Graduate Student, CMRR, MAE
Collaborators: ***Andrey Ovcharenko***, Sr. Staff Engineer, Western Digital
Min Yang, Director, Western Digital Corporation
Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Due to the small head-disk spacing, on the order of 1 nm, the head-disk interface has become increasingly more susceptible to contaminants such as hydrocarbon oil molecules. Hydrocarbon contamination can cause flying instability, stiction, and read/write errors due to head-disk contacts, ultimately leading to hard disk drive failures. In this study, we have investigated the transfer mechanism of hydrocarbon and lubricant molecules at the head-disk interface both experimentally and numerically. We hypothesized that the transfer mechanism involves "two-steps." First, hydrocarbon molecules condense onto the disk surface. Then, as the slider flies in close proximity to the disk surface, hydrocarbon and lubricant molecules are transferred to the slider surface even in the absence of actual head-disk contacts. Fig. 1 shows the contaminated air bearing surface, in which hydrocarbon oil droplets are formed and clearly visible. Scanning electron microscope (SEM) and Time-of-Flight Secondary Ion Mass Spectroscopy (ToF-SIMS) results showed that hydrocarbon and lubricant molecules transferred from the disk to the slider surface in the absence of actual head-disk contacts. In Fig. 2, we show a molecular dynamics simulation model of hydrocarbon and lubricant transfer at the head-disk interface. We studied the transfer mechanism as a function of temperature and minimum flying height.

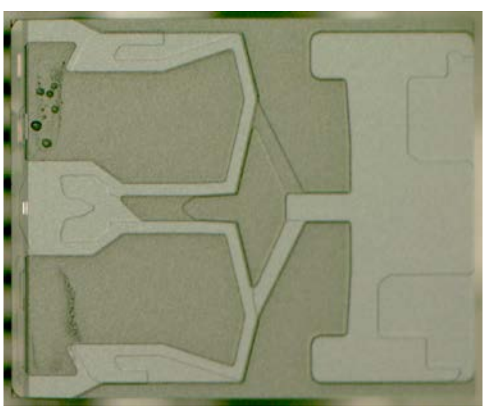


Fig. 1. Formation of hydrocarbon oil droplets on the air bearing surface

Investigation of HAMR Interfaces

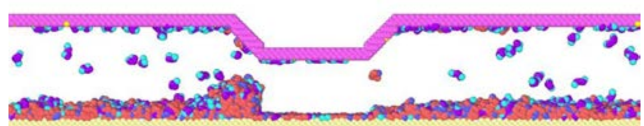


Fig. 2. Molecular dynamics simulation model of hydrocarbon and lubricant transfer at the head-disk interface

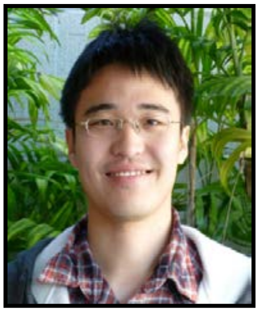
Investigation of HAMR Interfaces Using Tip Enhanced Raman Spectroscopy

Presenter: ***Benjamin Suen***, Graduate Student, CMRR, MAE
Researcher: ***Benjamin Suen***, Graduate Student, CMRR, MAE
Collaborator: ***Longqiu Li***, Vising Professor, CMRR, MAE
Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Heat assisted magnetic recording (HAMR) can overcome the super-paramagnetic limit and increase areal density beyond 1 Tb/in^2 in hard disk drives [1]. In HAMR, a pulsed laser beam is first used to heat the magnetic medium beyond its Curie temperature, and then data is magnetically recorded during the cool-down process while the coercivity of the medium is still low. High temperatures at the head disk interface are caused by the laser heating process, which leads to lubricant depletion, magnetic degradation, and carbon overcoat damage of the head/disk interface [2]. The carbon overcoat can also be graphitized or oxidized which leads to poor corrosion protection and inferior tribological performance [2]. The heated spot size achieved by the pulsed laser is very small, approximately 25nm in diameter. In addition, the duration of a typical laser heating cycle, including the cooling process, is very short, on the order of one ns. The measurement of the temperatures in the heated laser spot is of great interest for HAMR technology since reliability is strongly affected by the temperature rise in the heated laser spot. It is very difficult, if not impossible, to measure the temperature rise in the laser heated spot using conventional methods such as thermocouple measurements. To simulate and investigate the near field effects in heat assisted magnetic recording, tip enhanced Raman spectroscopy can be used (Fig. 1). Tip Enhanced Raman Spectroscopy (TERS) combines an atomic force microscope (AFM) and a Raman spectrometer to investigate the near field effects between the tip of an AFM and the adjacent surface. In TERS, a laser is focused on the tip of a metallized AFM tip, which is mounted in a scanning probing microscope. The laser illumination causes localized heating of the probe tip and the disk surface. Plasmon interactions at the interface between the probe tip and the surface enhance Raman scattering from the laser illumination. The scattered light is measured with a spectrometer and then analyzed in order to quantify the temperature rise in the disk due to the near-field heating by the AFM tip.

[1] M. H. Kyder, and R. W. Gustafson, “High-density perpendicular recording—advances, issues, and extensibility”, *J. Magn. Magn. Mater.*, 287, 449-458, (2005).

[2] B. K. Pathem, X.-C. Guo, F. Rose, N. Wang, K. Komvopoulos, E. Schreck, and B. Marchon, “Carbon overcoat oxidation in heat-assisted magnetic recording”, *IEEE Trans. Magn.*, 49(7) 3721-3724, (2013).



Thermal Response of a Thermal Asperity Sensor to Disk Asperities

Presenter: ***Youyi Fu***, Graduate Student, CMRR, MAE
Researcher: ***Chuanwei Zhang***, Graduate Student, Harbin Institute of Tech.
Collaborators: ***Andrey Ovcharenko***, Sr. Staff Engineer, Western Digital
Min Yang, Director, Western Digital Corporation
Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Disk asperities, which contact the magnetic head in hard disk drives, are generally called "thermal asperities". Contact between a magnetic head and a disk asperity can cause plastic deformation and high temperatures at the head disk interface. To prevent failure of the head disk interface, it is necessary to accurately detect the position of thermal asperities on a magnetic disk. In recent years, thermal asperity sensors have been developed and implemented in hard disk drives to detect thermal asperities on a disk. During contact between the sensor and disk asperities, frictional heating occurs, changing the temperature and, consequently, the resistance of the sensor. Thus, a change in the output signal from the sensor indicates that contact between the magnetic head and the thermal asperity has occurred.

In this study, a finite element model is used to study the transient thermo-elastic-plastic contact between a thermal asperity sensor and a thermal asperity. The temperature change of the thermal asperity sensor is determined during contact with an asperity. The results show that sensor temperature is a function of the operational temperature of the sensor and the friction coefficient between the sensor and the asperity.

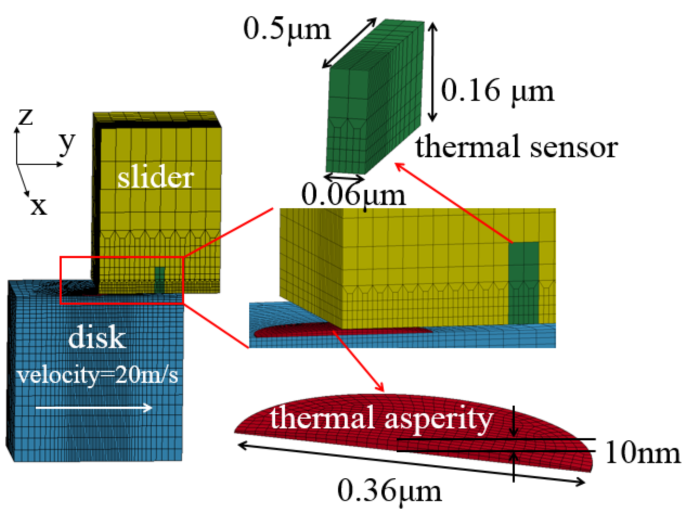


Fig. 1 Finite element model for simulating contact between the thermal asperity sensor and the thermal asperity

Simulation of Collocated Dual Stage Suspensions

Presenter: ***Karcher Morris***, Graduate Student, CMRR, MAE
Presenter: ***Karcher Morris***, Graduate Student, CMRR, MAE
Yangfan Wang, Student Volunteer, CMRR
Collaborator: ***John Hogan***, NHK International
Advisor: ***Frank E. Talke***, Professor, MAE

Hard disk drive (HDD) suspensions have been advancing to meet the demands of increasing areal density on magnetic recording disks. Improved suspension performance has been achieved through a second actuator to promote lateral deflection of the read / write element. These designs are called dual stage actuated (DSA) suspensions. As shown in Fig. 1, suspension-based designs are a type of DSA that have been implemented in higher performing HDDs. Suspension-based designs utilize two piezoelectric actuators (PZTs) toward the base of the suspension. They are aligned to extend and contract, leveraging the moment arm to induce a lateral deflection of the read / write element.

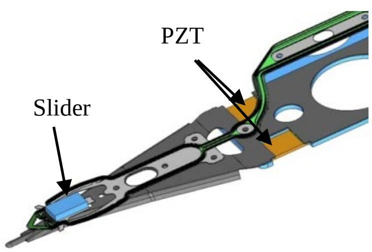


Fig. 1 Suspension-based

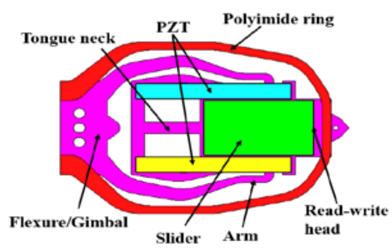


Fig. 2 Collocated Design

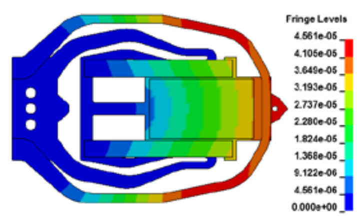


Fig. 3 Collocated Design

The collocated design makes even further advances using similar techniques seen in Fig. 2. As compared with the suspension-based design, the collocated design addresses the need for better accuracy and responsiveness counteracting undesirable lateral motion in the higher frequency ranges. The main drawback of this design has been the low lateral deflection per voltage input to the piezoelectric actuators. In this research project, we have attended to this issue designing a new type of collocated suspension using SolidWorks and HyperMesh. The effect of design parameters on the lateral deflection is analyzed using LSDYNA, a commercially available finite element software. There are still man challenges to overcome with the implantation of collocated designs, particularly ones involving the piezoelectric actuators including their bonding to the suspension as well as their brittle characteristics exemplified during high shock loads. Away from those concerns, these piezoelectric actuators may also act as sensors to reveal valuable information about the head dynamics.

Flying Height Control of Recording Heads at Sub-Nanometer Spacing

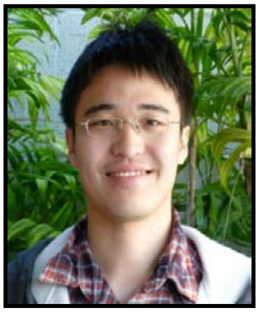
Presenter: ***Liane M. Matthes***, PhD Candidate, MAE
Researcher: ***Liane M. Matthes***, PhD Candidate, MAE
Collaborator: ***Bernhard E. Knigge***, Manager, Western Digital
Co-Advisor: ***Raymond A. de Callafon***, Professor, MAE
Advisor: ***Frank E. Talke***, Professor, MAE

By 2020, the amount of data that is created annually is estimated to reach 44 zettabytes (or 44 trillion gigabytes), 40 percent of which will be stored in the cloud [1]. This tremendous growth in data generation calls for cheap, fast and reliable storage solutions. There has been the perception that hard disk drives (HDDs) will eventually be replaced by the much faster, and more reliable, solid state drives (SSDs). However, the cost per bit of HDDs is significantly lower compared to that of SSDs, which makes HDDs the preferred solution for servers and data centers. To maintain the cost advantage of HDDs over SSDs, larger capacities need to be provided at lower cost.

Higher recording densities can be achieved by reducing the clearance between the magnetic disks, on which data is stored, and the recording head, which is used for reading and writing data, and by minimizing flying height variations around the circumference of the disk. Variations in flying height are caused by disk run-out, air-flow induced vibration, and surface features on the magnetic disk.

In this study, we propose feed-forward and feed-back control schemes to minimize flying height variations of the recording head with respect to the magnetic disk at sub-nanometer spacing.

[1] V. Turner et al. "The Digital Universe of Opportunities: Rich Data and Increasing Value of the Internet of Things", IDC, 2014



Investigation of the Effect of Diamond-like Carbon Overcoat on the Tribological Performance of the Dimple/Gimbal Interface in Hard Disk Drives

Presenter: ***Youyi Fu***, Graduate Student, CMRR, MAE
Collaborator: ***Vlado A. Lubarda***, Professor, CMRR, MAE
Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

We performed fretting wear tests of stainless steel dimples contacting gimbals coated with diamond-like carbon (DLC) of different thicknesses. Using a scanning electron microscope (SEM), we observed the formation of wear particles and cracks on the dimple. In this study, a finite element analysis model of the dimple/gimbal interface was developed and numerical simulation was performed to calculate the stress distribution in the dimple during contact with the gimbal. We investigated the effect of thickness and elastic modulus of the DLC overcoat on the maximum principal stress in the dimple. From the simulation results, we find that both the thickness and the elastic modulus of the DLC overcoat affect the magnitude of maximum principal stress in the dimple. Comparing the experimental results and the simulation results, we observed that more wear particles and larger cracks will be generated on the dimple if the dimple experiences larger maximum principal stress during a fretting wear test.

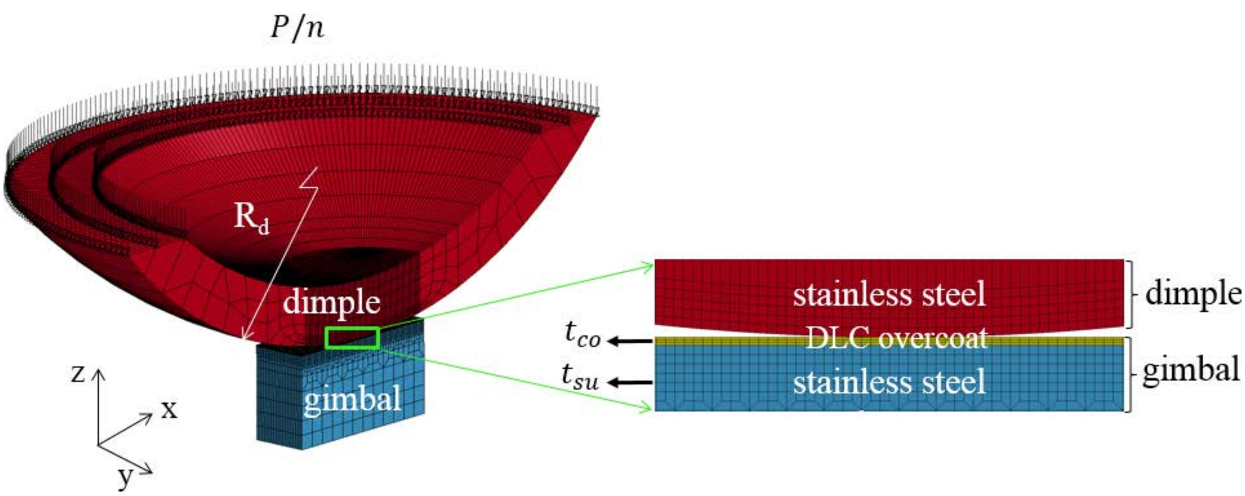


Fig. 1 Finite element model for simulating the contact between the dimple and the gimbal. The radius of the dimple R_d is 200 µm. P is the normal load; n is the number of nodes on the top of the dimple. The thickness of the stainless steel substrate of the gimbal t_{su} is 40 µm. The thickness of the DLC overcoat t_{co} was chosen to be 15 nm, 70 nm, 250 nm, and 690 nm, respectively.

Development of an Optical Based Pressure Sensor for Continuous Glaucoma Monitoring

Presenter: ***Alex Phan***, Graduate Student, CMRR, MAE
Researchers: ***Alex Phan***, Graduate Student, CMRR, MAE
Phuong Truong, Undergraduate Student, SE
Advisor*:* ***Frank E. Talke***, Professor, MAE

Glaucoma is a condition in which elevated intraocular pressure (IOP) causes damage to optic nerve and leads to permanent loss of vision. The objective of this research is to develop a pressure sensor that enables long term and continuous IOP monitoring in order to better understand glaucoma and improve quality of patient care. With the idea of developing a passive micro-fabricated pressure sensor, the following wireless optical based sensing concept was proposed: a high resolution camera is used to capture changes in appearance/light reflectance of an elastomer due to pressure variation. Images are then analyzed to compute pressure profile. Sensor is designed to be implanted on the surface of the iris or to be incorporated on the intraocular lens as shown in Fig.1. This can be done through cataract surgery or as a stand along procedure. Prototypes were built and used to demonstrate proof of concept. A sensitivity as high as 1mmHg has been measured. Finite element models were built using ANSYS to simulate responses of prototype under applied pressures. Results were used to optimize sensor designed parameters. Fabrication processes for miniaturized prototypes are being developed using micromachining and photo lithography. The sensor is envisioned to be implanted in the eye and capable of measuring direct IOP continuously to aid glaucoma study and treatment.

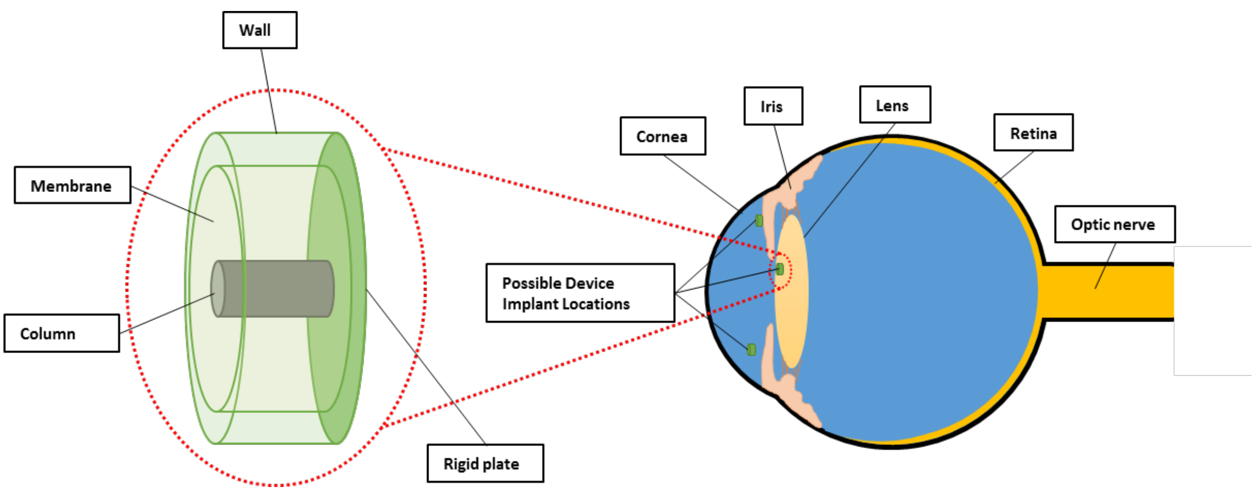


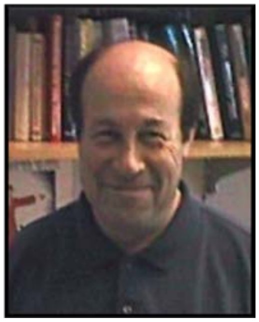
Fig. 1 Schematic for intraocular pressure sensor

Future Research on Tribochemistry and Nano-Wear of the Head Disk Interface

Presenter: ***Tan D Trinh***, PhD Candidate, MAE, CMRR
Researcher: ***Tan D Trinh***, PhD Candidate, MAE, CMRR
Advisor: ***Frank E. Talke***, Professor, MAE, CMRR

In high density recording, very small head-disk spacing is required in order to maintain a sufficient signal to noise ratio. However, at very small spacing, intermittent contacts are likely to occur, which cause wear and degradation of the head disk interface. In recent disk drives, helium has been used to reduce the effect of turbulence and air borne vibrations and eliminate the reactivity of an oxygen environment.

In the research proposed in this study, we will investigate the effect of helium on the tribochemistry of the head disk interface. We will study the effect of head biasing on the tribochemistry and nano-wear of thermal flying-height control (TFC) sliders in helium environments and compare these results with measurements in normal air environment. The effect of lubricant type, humidity and head design on the tribology of thermal flying height control sliders will also be investigated.



Nanophotonics Technology and Applications

Presenter: ***Y. Fainman***, Professor, ECE
Researcher: ***Y. Fainman***, Professor, ECE

Various future system applications, that involve photonic technology, rely on our ability to integrate it on a chip to augment and/or interact with other signals (e.g., electrical, chemical, biomedical, etc.). For example, future computing and communication systems will need integration of photonic circuits with electronics and thus require miniaturization of photonic materials, devices and subsystems. Another example involves the integration of microfluidics with nanophotonics - the former is used for particle manipulation, preparation and delivery, and the latter in a large size array form parallel detection of numerous biomedical reactions useful for healthcare applications. To advance the nanophotonics technology, we established design, fabrication and testing tools. The design tools need to incorporate not only the electromagnetic equations, but also the material and quantum physics equations to include near field interactions. These designs are integrated with device fabrication and characterization to validate the device concepts and optimize their performance. Our research work emphasizes the construction of passive (e.g., engineered composite metamaterials, filters, etc.) and active (e.g., nanolasers) components on-chip with the same lithographic tools as electronics. In this talk, we discuss some of the passive metamaterials and devices that have recently been demonstrated in our lab. These include our most recent results on monolithically-integrated, short pulse compressor utilized with SOI material platform and design, fabrication and the testing of nanolasers constructed using metal-dielectric-semiconductor resonators confined in all three dimensions.

Y. Fainman received the PhD from Technion in 1983. He is a Cymer Professor of Advanced Optical Technologies and Distinguished Professor of ECE at the University of California, San Diego (UCSD). His current research involves near field optical science and technology, nanophotonics, nanolasers, nanoiplasmonics and ultrafast optics. He is a Fellow of OSA, IEEE, and SPIE. He Chaired, co-Chaired and served on numerous program committees for various conferences for OSA, IEEE/LEOS, and SPIE. He is a recipient of the Miriam and Aharon Gutvirt Prize, Technion, Haifa, Israel (1982), Lady Davis Fellowship (2006), Brown award (2006), Gabor Award (2012) and E. Leith Medal (2015). He was a General Chair for Inaugural OSA Topical Meeting on Nanophotonics for Information Systems in 2005 and served as a topical editor and board member for various journals. He contributed over 250 manuscripts in peer review journals and over 450 conference presentations and conference proceedings.

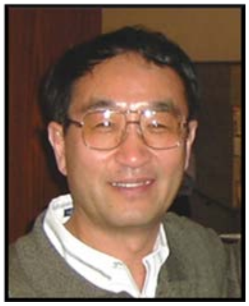
Magnetometry-Based Order Parameter to Probe the A1 to $L1_0$ Transformation in FeCuPt

Presenter: ***Kai Liu***, Professor, UC Davis
Researcher: ***Kai Liu***, Professor, UC Davis

Nanostructures with perpendicular magnetic anisotropy (PMA) are a class of technologically important materials. For example, $L1_0$ FePt is the material of choice for the emerging heat-assisted magnetic recording technology. A key limiting factor has been the high annealing temperature necessary to transform the as-deposited disordered cubic $A1$ phase into the ordered tetragonal $L1_0$ phase. We have achieved (001) oriented $L1_0$ FeCuPt thin films, using atomic-scale multilayer sputtering and rapid thermal annealing (RTA) at 400 °C for 10 seconds [1], which is substantially more benign compared to earlier studies. Due to non-ideal crystallinity of the $A1$ phase, traditional x-ray diffraction is not always applicable in generating a true order parameter. Using the first-order reversal curve (FORC) method [2], the $A1$ and $L1_0$ phases are de-convoluted into two distinct features in the FORC distribution whose relative intensities change with the RTA temperature [3]. The $L1_0$ ordering takes place via a nucleation-and-growth mode. A magnetization-based phase fraction is extracted, providing a quantitative measure of the $L1_0$ phase homogeneity. This approach is applicable to studies of other $L1_0$ materials, as well as magnetic phase separation in general.

This work has been supported by the NSF (DMR-1008791 & ECCS-1232275).

[1]. D. A. Gilbert, L. W. Wang, T. J. Klemmer, J. U. Thiele, C. H. Lai, and Kai Liu, *Appl. Phys. Lett.*, **102**, 132406, (2013).
[2]. D. A. Gilbert, G. T. Zimanyi, R. K. Dumas, M. Winklhofer, A. Gomez, N. Eibagi, J. L. Vicent, and Kai Liu, *Sci. Rep*, **4**, 4204 (2014).
[3]. D. A. Gilbert, J. W. Liao, L. W. Wang, J. W. Lau, T. J. Klemmer, J. U. Thiele, C. H. Lai, and Kai Liu, *APL Mater*, **2**, 086106 (2014).



Magnetic Composites with Advanced Functionality

Presenter: ***Sungho Jin***, Professor, CMRR, MAE
Collaborators: ***Renkun Chen,*** Professor, CMRR, MAE
Leon Chen, Research Scientist, CMRR, MAE
Edward Chulmin Choi, Postdoctoral Researcher, CMRR, MAE
Chad Dongwon Chun, Graduate Student, CMRR, MAE
Isaac Chin-Hung Liu, Graduate Student, CMRR, MAE

Magnetic materials are useful as a class functional material for a variety of applications including information storage, sensors/actuators, energy generation, and energy release. As the manufacturing science/technology is becoming one of the prioritized R&D fields in US these days, robotics design, assembly, control and operations are also becoming important areas of greater interest.

Robotic sensing, such as a tactile shear sensing, is an important detection mechanism for touch-sensitive actuators, like robot skin/finger sensors or computer controllers, that are finger-tip operated. A new composite magnetic material with vertically aligned magnetic metal microparticles can be prepared by using unidirectional magnetic field alignment of magnetic particles in an elastomer matrix before curing. An anisotropically conductive composite elastomer in the configuration of a thin sheet layer is prepared by placing the precursor liquid on circuit pad arrays and *in situ* curing, in the presence of a *z*-direction applied magnetic field of several hundred oersteds, to form a new type of compliant tactile shear sensor. A small metallic cursor embedded in an overlaid elastomeric skin slides over the *z*-direction conductive polymer upon shear motion, and its change in position is detected by the occurrence of simple circuit connections between neighboring contact pads. This shear sensor has the advantages of being compliant, transparent, able to accommodate pad height variations, and capable of high-resolution sensing.

Another example of useful magnetic composites can be a magnetocaloric effect (MCE) material in which repeated magnetization and demagnetization causes the MCE material to gradually cool, thus accomplishing refrigeration or cooling by purely magnetic means. Because of the limitation of the currently available MCE alloys requiring a not-so-practical, tesla-level magnetic fields, it will be highly desirable to incorporate soft magnetic materials within the MCE alloy for composite structuring so as to provide locally amplified magnetic field for a given, relatively low applied field.

Micromagnetics and Recording Physics at CMRR

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

An overview of the last half-year progress of research conducted at CMRR on Micromagnetics and Recording Physics is provided. The code development component includes a new version of FastMag with new features, an updated granular media code, particle code, and energy barrier code. The use of these codes for physics study as well as device and material design includes granular media modeling, HAMR modeling, all-optical switching study, and modeling of soft particulate materials.

Fast Block Inverse Preconditioner for Implicit Time Integration in Finite Element MicroMagnetic Solvers

Presenter: ***Sidi Fu***, PhD Candidate, CMRR, ECE
Researcher: ***Sidi Fu***, PhD Candidate, CMRR, ECE
Ruinan Chang, PhD Candidate, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

A block-inverse preconditioner is proposed to accelerate solving implicit time integration in the context of Newton-Krylov approach used in micromagnetic simulations. A coefficient matrix is generated and stored for the linear system of Newton method. The novel preconditioner is formulated by subdividing the coefficient matrix into small matrices and directly inverse them. The cost of preconditioning is low because inverting small matrices is fast. The cost of preconditioning can be further minimized by easy implementation of parallel computing on multi-core CPUs or GPUs. The effectiveness of block-inverse preconditioner has been demonstrated by numerical simulation experiments. Comparisons to incomplete LU decomposition method have also been addressed to conclude the practicability of the new approach.

Accelerate Object Oriented MicroMagnetic Framework (OOMMF) on GPU

Presenter: ***Sidi Fu***, PhD Candidate, CMRR, ECE
Researcher: ***Sidi Fu***, PhD Candidate, CMRR, ECE
Weilong Cui, Visiting Scholar, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

The integration of OOMMF solver on Graphics Processing Units (GPU) is presented. OOMMF is one of the most prevalently used Finite Difference Method based micromagnetic solver in the scientific world. In this work, we extend its availability to the massively parallel computing system GPU, which gives up to 25x GPU-CPU speed-up with single precision and 8x with double precision. The good acceleration results are guaranteed by the fact that we offload all the computational work of OOMMF onto GPU to avoid the GPU-CPU memory transfer. The implementation details such as the code structure, speed-profiling, and speed-scaling will be provided.

Simulation of Granular Media in HAMR

Presenter: ***Marco Menarini***, Graduate Student, CMRR, ECE
Researcher: ***Marco Menarini***, Graduate Student, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

Heat assisted magnetic recording (HAMR) is a promising technology for the recording media industry. In this presentation, we summarize our in the code development for simulating realistic recording media using our Voronoi Code and the Landau-Lifshitz-Bloch formulation for single and multilayer granular structures. In particular, we discuss a two time-step method to improve the speed of our simulations combined to the moving window approach previously developed.

Model to Simulate Optical Effects in Ferromagnetic Materials

Presenter: ***Marco Menarini***, Graduate Student, CMRR, ECE
Researcher: ***Marco Menarini***, Graduate Student, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

Ultrafast magnetization is one of the most challenging quests in recording media technology. A recent observation of the phenomena in ferromagnetic materials, using circularly polarized sub-picosecond laser pulse, has been challenging to simulate with existing physical models, such as the Landau-Lifshitz-Bloch equation (LLB). We consider a new physical model for describing the magnetization dynamics and photon-spin interactions.

High-Performance Nudged Elastic Band Method for Computing Energy Barriers in Complex Nanomagnetic Systems

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

The ability to compute thermal stability in nanomagnetic structures is an important component of understanding many magnetic materials and devices. Here, we present our work on creating a high-performance Nudged Elastic Band (NEB) method for micromagnetics. In the NEB method an energy path is defined as a set of magnetization states, referred to as images. A minimization algorithm is then used to find the minimal energy path along the direction tangential to the image change. In our NEB method implementation, we have an analytical Jacobian accounting for the image tangents and springs. The spring strength can be chosen fully automatically. The tangents are implemented to account for the magnetization direction exactly. In addition, a climbing image approach is implemented, which allows significantly reducing the number of images, e.g. if only a single energy barrier is present, then only a single image is required to find the energy barrier.

Micromagnetic Modeling of Nano-Granular Materials

Presenter: ***Simon Couture***, Graduate Student, CMRR, ECE
Collaborators: ***Sergio Montoya***, Graduate Student, CMRR
Eric Fullerton, Professor, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

Nano-granular ferromagnetic materials have been shown to have excellent soft-magnetic properties such as high permeability, high linearity and low losses. With the aim of better understanding the properties of this class of materials, the micromagnetic solver FastMag is used to perform parametric studies numerically. From these studies, relations are established between material parameters, such as inter-grain exchange coupling, grain shape and spatial arrangement, saturation magnetization and random distribution of the grains' anisotropy directions, and magnetic properties, such as permeability, coercivity and switching dynamics. The micromagnetic model for nano-granular ferromagnetic materials will be described, and the relations between material parameters and magnetic properties will be used to suggest guidelines for the design of soft magnetic materials.

High Frequency Measurement of Complex Permeability

Presenter: ***Simon Couture***, Graduate Student, CMRR, ECE
Collaborators: ***Sergio Montoya***, Graduate Student, CMRR
Eric Fullerton, Professor, CMRR, ECE
Advisor: ***Vitaliy Lomakin***, Professor, CMRR, ECE

Ferromagnetic films with soft properties are used extensively in electronic and power electronic components such as inductors and transformers. One of the key properties of these films is the complex permeability over a given frequency band which depends on the application. Because of this, when developing recipes to grow high quality magnetic films, it is important to be able to measure the complex permeability of magnetic films within a broad range of frequencies. For this purpose, a customized version of a commercially available apparatus that measures permeability is developed and built at the CMRR. The working principle, design process, measurement procedure and expected performance of the measurement system will be presented.

Generalized Multihead Multitrack Detection with Reduced State Sequence Estimation

Presenter: ***Bing Fan***, PhD Candidate, ECE
Researcher: ***Bing Fan***, PhD Candidate, ECE
Collaborator: ***Hemant K. Thapar***, Visiting Researcher, CMRR
Advisor: ***Paul H. Siegel***, Professor, ECE

In shingled magnetic recording (SMR), tracks are squeezed much more heavily to achieve higher areal density, which also leads to severe intertrack interference (ITI). The multihead multitrack (MHMT) detector can better combat the effect of ITI, but also incurs challenging implementation problems. In the past two CMRR research reviews (held in May 2014 and October 2014), we considered a two-head two-track (2H2T) system and introduced two novel approaches to reduced-complexity detection. In the first, we use weighted sum-subtract joint detection (WSSJD) on transformed channel outputs and deploy gain loops to estimate the ITI level. In the second, we show that the reduced state sequence estimation (RSSE) algorithm can significantly reduce the number of trellis states in WSSJD while retaining near optimal performance. Full treatments of these topics will soon appear [1], [2].

In this presentation we will show that the proposed techniques in [1] and [2] can also be applied to a generalized multihead multitrack system, in which *n* heads ($n>2$) are evenly spread over *n* tracks. The channel is modeled as

$$R(D) = A_n X(D) h(D) + \Omega(D)$$

where $h(D)$ denotes the channel response, A_n is an $n \times n$ matrix which models the ITI level, and $X(D)$, $R(D)$, and $\Omega(D)$ are length-*n* vectors representing the inputs recorded on the *n* tracks, the received sequences from the *n* heads, and the additional electronic noise sensed by the *n* heads, respectively. We assume that the ITI only comes from adjacent tracks; for example, a 3×3 ITI matrix has the form

$$A_3 = \begin{bmatrix} 1 & \epsilon & 0 \\ \epsilon & 1 & \epsilon \\ 0 & \epsilon & 1 \end{bmatrix}.$$

We show that this system can be decomposed into *n* parallel channels, and that the value of ϵ can be estimated by using multiple gain loops. New simulation results about the RSSE algorithm will be presented, and error event analysis will be used to predict the performance of RSSE on a specific subset trellis configuration. Finally, we show that it is possible to use RSSE on a generalized MHMT system.

[1] B. Fan, H. K. Thapar, and P. H. Siegel, “Multihead multitrack detection in shingled magnetic recording with ITI estimation,” in *Proc. IEEE Int. Conf. Commun*.(ICC), London, UK, June 2015, to appear.

[2] B. Fan, H. K. Thapar, and P. H. Siegel, “Multihead multitrack detection with reduced-state sequence estimation in shingled magnetic recording,” in *Proc. IEEE Intermag*, Beijing, China, May 2015, to appear.

Linear Locally Repairable Codes with Availability

Presenter: ***Pengfei Huang***, PhD Candidate, ECE
Researcher: ***Pengfei Huang***, PhD Candidate, ECE
Collaborators: ***Dr. Eitan Yaakobi,*** Assistant Professor, Technion
Dr. Hironori Uchikawa, Visiting Scholar, Toshiba
Advisor: ***Paul H. Siegel***, Professor, ECE

Locally repairable codes (LRCs) are a class of codes designed for the local correction of erasures. They have received considerable attention in recent years due to their applications in distributed storage. In addition to their symbol locality, another important property of LRCs is their symbol availability, meaning the number of disjoint sets of symbols that can be used to recover a given symbol. High availability is a particularly attractive property for so-called *hot data* in a distributed storage network [1].

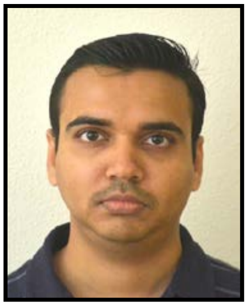
Most existing results on LRCs do not explicitly take into consideration the field size q, i.e., the size of the code alphabet. In particular, for the binary case, only a few specific results are known [2]. Recently, however, an upper bound on the dimension k of LRC was presented in [3]. The bound takes into account the length n, minimum distance d, locality r, and field size q, and it is applicable to both non-linear and linear codes.

In this work, we first present a new upper bound on the minimum distance d of linear LRCs with information locality and availability. The bound takes into account the code length n, dimension k, locality r, availability t, and field size q. Then, we use tensor product codes to construct several families of LRCs with information locality. Some of these codes are shown to be optimal with respect to their minimum distance, achieving the new bound. Finally, we study the all-symbol locality and availability properties of several classes of one-step majority-logic decodable codes, including cyclic simplex codes, cyclic difference-set codes, and 4-cycle free regular low-density parity-check (LDPC) codes. We also investigate their optimality using the new bound.

[1] A. Wang and Z. Zhang, "Repair locality with multiple erasure tolerance," IEEE Trans. Inf. Theory, vol. 60, no. 11, pp. 6979-6987, Nov 2014.

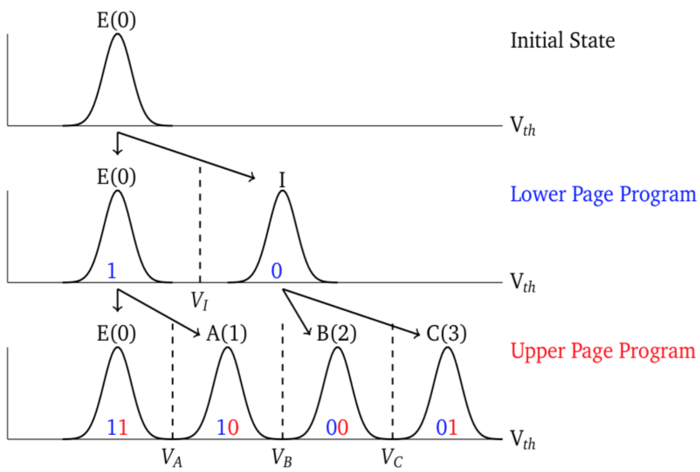
[2] S. Goparaju and R. Calderbank, "Binary cyclic codes that are locally repairable," in Proc. IEEE ISIT, pp. 676-680, June 2014.

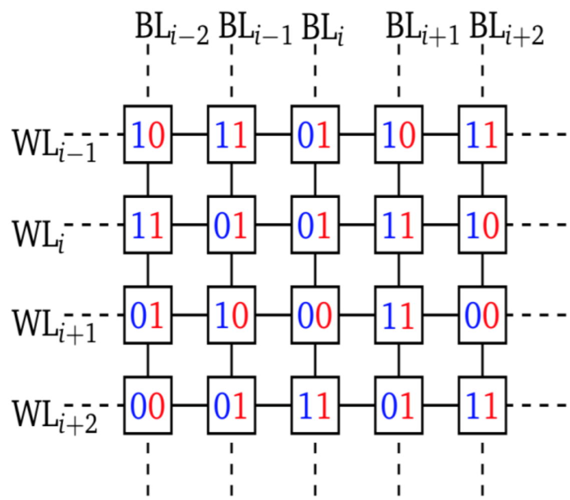
[3] V. Cadambe and A. Mazumdar, "An upper bound on the size of locally recoverable codes," in Proc. IEEE International Symposium on Network Coding (NetCod), pp. 1-5, 2013.



Error Analysis and Inter-Cell Interference Mitigation in Multi-Level Cell Flash Memories

Presenter: ***Veeresh Taranalli***, PhD Candidate, ECE
Researcher: ***Veeresh Taranalli***, PhD Candidate, ECE
Collaborator: ***Dr. Hironori Uchikawa***, Toshiba Corporation
Advisor: ***Paul H. Siegel***, Professor, ECE





NAND Flash memory has become a widely used non-volatile data storage technology and its application areas are only expected to grow in the future. This has led to aggressive scaling down of the NAND flash memory cell sizes and the increased adoption of multi-level cell (MLC) and three-level cell (TLC) technologies. The scaling down of the flash memory cell sizes has caused an increase in the parasitic capacitance coupling between the neighboring floating gate transistors (cells) in a flash memory block. Thus floating gate interference or inter-cell interference (ICI) has become a leading cause of errors in flash memories, thus affecting their reliability. In this work, we study and present results on the characterization and mitigation of errors observed due to the ICI effect in 1x-nm MLC flash memories.

With an aim to characterize, model and understand the types of errors caused by the inter-cell interference (ICI) effect in flash memories, we perform a series of program/erase (P/E) cycling experiments designed to quantify the effects of ICI. We create a database of errors at various levels of granularity such as bit, cell, page, block and record the neighborhood data patterns of cells in error to provide a quantitative understanding of the underlying channel model in multi-level cell (MLC) flash memories. We then utilize this empirical data to model and study the flash memory channel as a time-varying 4-ary discrete memoryless channel (DMC). We also present results from experiments to quantify the error rate performance gain obtained by the use of constrained codes, which prevent some ICI-susceptible data patterns from being written to the flash memory.

Row-by-Row Coding for ICI Mitigation in Flash Memories

Presenter: ***Sarit Buzaglo***, Postdoctoral Researcher, CMRR
Researcher: ***Sarit Buzaglo***, Postdoctoral Researcher, CMRR
Collaborators: ***Paul H. Siegel***, Professor, CMRR
Eitan Yaakobi, Professor, Technion
Advisor: ***Paul H. Siegel***, Professor, CMRR

Inter-cell interference (ICI) is a significant cause of errors in flash memories. In the simplest model of ICI, parasitic capacitance can cause an undesirable increase in the voltage level of a *victim* cell when high voltages are applied to some of its neighboring cells [2].

In a recent work [4], experimental results showed the data dependent nature of ICI in multi-level cell (MLC) flash by studying the correlation of cell errors and their neighborhood data patterns, both in the horizontal (wordline) and vertical (bitline) directions. For the case of single-level cell (SLC) flash (binary-cell case), if a group of three consecutive cells are programmed with the pattern 101, then the level of the middle cell may be increased due to the effect of ICI [1]. To combat the ICI effect, the use of a constrained code that prevents the appearance of the ICI-prone symbol pattern 101 has been proposed [1]. These solutions can easily mitigate the horizontal ICI since data is written in pages on the wordlines. However, additional bitline ICI, caused by the same patterns due to the vertical parasitic capacitance, is even more severe [4].

In this talk we present ICI-mitigating coding techniques that respect the standard page-oriented sequential programming and reading of horizontal wordlines. This is done by allowing the encoding and decoding algorithms to read the previous two wordlines when writing or reading a particular wordline. We first present a coding scheme, which eliminates all ICI-inducing 101 patterns along bitlines, while asymptotically achieving the capacity of this constraint ($\approx$0.8114). This solution is an embodiment of the row-by-row coding method proposed in [3]. To increase capacity, we present an alternative approach that allows the occasional appearance of this pattern and uses an error-correcting code to correct the resulting ICI-induced errors. Our methods can be generalized to mitigate ICI errors in both wordlines and bitlines for MLC flash memory and in all three directions for 3D triple-level cell (TLC) flash memory.

[1] A. Berman and Y. Birk, ``Constrained flash memory programming," Proc. *IEEE Symp. Inf. Theory*, pp. 2128--2132, St. Petersburg, Russia, July--August, 2011.
[2] J.-D. Lee, S.-H. Hur, and J.-D. Choi,``Effects of floating-gate interference on NAND flash memory cell operation," *IEEE Electron Dev. Lett.*, pp. 264--266, vol. 23, 2002.
[3] I. Tal, T. Etzion, and R. Roth, ``On row-by-row coding for 2-D constraints," *IEEE Trans. on Information Theory*, vol. 55, pp. 3565--3576, 2009.
[4] V. Taranalli, H. Uchikawa, and P.H. Siegel, ``Error analysis and inter-cell interference mitigation in multi-level cell flash memories," to appear in Proc. *IEEE Int'l Conf. Communications*, June 2015.

Endurance Code Design and Evaluation for Flash Memories

Presenter: ***Dustin Hudson***, Undergraduate Student, CMRR, ECE
Researcher: ***Dustin Hudson***, Undergraduate Student, CMRR, ECE
Collaborator: ***Dr. Hemant K. Thapar***, Visiting Researcher, CMRR
Advisor: ***Paul H. Siegel***, Professor, CMRR, ECE

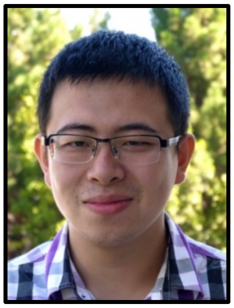
Endurance coding for flash memory is motivated by the desire to limit the wear from writing to the device. Roughly speaking, the goal is to limit the frequency of writing to the most wear-inducing levels while incurring the minimum rate penalty.

When designing endurance codes, we must first assume a cost model associated with device wear. We assume a linear total cost model as proposed in [1]. We consider possible measures of cell-level cost, and then determine probability distributions for codes that give the minimum average cost associated with a particular rate.

We present several different approaches to endurance code design and evaluate the performance of each construction method. The methods evaluated include the reverse compression code technique, a shell mapping approach, and a "data shaping" algorithm recently introduced by SanDisk [2].

[1] A. Jagmohan, M. Franceschini, L.A. Lastras-Montano, J. Karidis, "Adaptive endurance coding for NAND Flash," in *Proc. GLOBECOM Workshops*, Miami, FL, Dec. 6-10, 2010, pp.1841-1845.

[2] Sharon, E. (2015, March 2). Data Shaping for Improving Endurance and Reliability in Sub-20nm NAND. *Non-Volatile Memories Workshop*. Lecture conducted from San Diego, CA.



Mojim: A Reliable and Highly-Available Non-Volatile Memory System

Presenter: ***Jian Yang***, Graduate Student, CMRR, CSE
Researcher: ***Yiying Zhang***, Postdoctoral Researcher, CMRR
Collaborators: ***Jian Yang***, Graduate Student, CMRR, CSE;
Amir Saman Memaripour, Graduate Student, CMRR, CSE
Advisor: ***Steven Swanson,*** Professor, CMRR, CSE

Next-generation non-volatile memories (NVMs) promise DRAM-like performance, persistence, and high density. They can attach directly to processors to form non-volatile main memory (NVMM) and offer the opportunity to build very low-latency storage systems. These high-performance storage systems would be especially useful in large-scale data center environments where reliability and availability are critical. However, providing reliability and availability to NVMM is challenging, since the latency of data replication can overwhelm the low latency that NVMM should provide.

We propose Mojim - a system that provides the reliability and availability that large-scale storage systems require, while preserving the performance of NVMM. Mojim achieves these goals by using a two-tier architecture in which the primary tier contains a mirrored pair of nodes and the secondary tier contains one or more secondary backup nodes with weakly consistent copies of data. Mojim uses highlyoptimized replication protocols, software, and networking stacks to minimize replication costs and expose as much of NVMM's performance as possible. We evaluate Mojim using raw DRAM as a proxy for NVMM and using an industrial NVMM emulation system. We find that Mojim provides replicated NVMM with similar or even better performance than un-replicated NVMM (reducing latency by 27% to 63% and delivering between 0.4 to 2.7× the throughput). We demonstrate that replacing MongoDB's built-in replication system with Mojim improves MongoDB's performance by 3.4 to 4×.

All-Optical Control of Magnetization in Ferromagnetic Thin Films

Presenter: ***Rajasekhar Medapalli***, Postdoctoral Researcher, CMRR
Researcher: ***Rajasekhar Medapalli***, Postdoctoral Researcher, CMRR
Yassine Quessab, Graduate Student, CMRR
Yukiko Takahasi, Visiting Researcher, CMRR
Advisors: ***Y. Shaya Fainman***, Professor, ECE
Eric Fullerton, Professor, CMRR

Until recently, the only class of material that demonstrated all-optical switching (AOS) is a narrow range of rare-earth (RE) and transition-metal (TM) alloy compositions. However, very recent experimental investigations have broadened the choice of materials for AOS and showed that optical control of magnetization is a much more general phenomenon. These materials include wide variety of ferrimagnetic RE-TM alloys, RE-free Co-Ir based synthetic ferrimagnets and, moreover, ferromagnetic thin films, multi-layers and even their granular films. By employing a magnetization sensitive microscopy technique we investigated the AOS in various ferromagnetic materials like Co/Pt multi-layers as a function of material composition, structure, laser pulse fluence, and size of patterned thin films and multi-layer thickness and also in FePt granular thin films, as a function of grain sizes. Our results show the optimal material conditions in ferromagnets and highlight pathways for reducing possible energy consumption for the AOS in these materials. Moreover, our time-resolved pump-probe measurements on CoPt thin films and their multi-layers reveal the ultrafast magnetization response to the 100 fs laser pulses and its role in AOS.

Tuning Surface Plasmon Resonances of the Layered Ferromagnetic Nanostructures using Magnetic Field, Structure, and Optical Radiation.

Presenter: ***Conrad Rizal***, Postdoctoral Researcher, CMRR, ECE
Researcher: ***Conrad Rizal***, Postdoctoral Researcher, CMRR, ECE
Advisors: ***Eric Fullerton***, Professor, CMRR
Zhaowei Liu, Professor, ECE

When magnetoplasmonic oscillations in the ferromagnetic/dielectric nanostructures are excited by an incident optical radiation and tuned with the magnetic field, the magnetoplasmonic oscillations propagate at the interface of the metal/dielectric media, and generate highly confined evanescent fields at the interface. The excitation condition strongly depends on the orientation of the magnetic spin, structure, layer thicknesses, and material properties, especially the refractive indices and permeabilities of the layers involved. While this phenomenon is the basis of quantifying bio-molecular interactions in liquids, especially using conventional Au or Ag based surface plasmon resonance (SPR) sensing principles, there are two major challenges with this scheme. One is that the angular shift introduced by the SPR phenomena is minimal. The other is that the signal-to-noise ratio (SNR) of the device is poor. As a result, detecting dielectric samples with extremely small molecular concentration has been a great challenge, as low cost and ultra-sensitive sensing schemes are required for that.

In this work, I will explain how incorporating one of the ferromagnetic components in the nanostructure, and tuning the SPR resonance in the presence of magnetic field, would maximize the magnetic-plasmonic coupling at the metal/dielectric interface and introduce interesting optical and magneto-optical phenomena in these nanostructures. In addition, I will briefly show how the sensitivity and the SNR of the new structure, at the visible optical regime, to the small changes in refractive indices of the dielectric materials of interest, would dramatically improve the performance of the device over the conventional surface plasmon resonance sensing schemes. Both the increased sensitivity and the signal-to-noise ratio of the ferromagnetic nanostructure are closely linked to the amplified magneto-optic signal at the metal-dielectric interface that are further enhanced by the applied magnetic field and transverse-magnetic polarized optical radiation.

Enhanced Kerr Microscopy Systems at the Center for Magnetic Recording Research

Presenter: ***Robert Tolley***, PhD Candidate, ECE
Researcher: ***Robert Tolley***, PhD Candidate, ECE
Collaborator: ***Fred Spada***, Associate Researcher, CMRR
Advisor: ***Eric Fullerton***, Department Chair, CMRR

Kerr microscopy provides a unique insight into the formation and propagation of magnetic domains within thin films. By utilizing the Kerr effect rotation, a change in polarization of light due to reflection from a magnetic surface, it is possible to image magnetic domains at the sub-micrometer level. The technique offers significant advantages in speed over magnetic force microscopy, and can include multiple active probing techniques including applied field, electrical and spin transport, and sample heating. The CMRR Enhanced Kerr Microscope offers both in and out of plane magnetic fields with 3 different configurable magnets. This can be combined with a transport stage to enable measurement of electrical transport or to apply thermal gradients by applied joule heating current. A separate vacuum heating stage allows for sample measurements up to 600C. With both high resolution and inspection capabilities, this system represents a next step for magnetic material characterization at UCSD. This presentation displays some of the capabilities of the microscope system and outlines future plans for research.

Resonant Properties of a Skyrmionic RE-TM Ferrimagnet with Perpendicular Magnetic Anisotropy

Presenter**:** ***Sergio Montoya***, Graduate Student, ECE
Collaborators: ***Simon Couture***, Graduate Student, ECE
Peter Fischer, Beam Line Scientist, ALS, LBNL
Advisor: ***Eric Fullerton***, Professor, ECE

Magnetic skyrmions are promising candidates for high-density non-volatile memory since they are topologically protected spin structures with bit size in the sub 100-nm scale [1,2]. Depending on the mechanism that stabilizes the skyrmion and drives the system from a stripe domain configuration to a bubble hexagonal lattice, one could ultimately achieve size features relative to the crystal lattice spacing (<1nm) - thus, potentially enabling the ultimate memory density. To realize the development of novel spintronic devices utilizing skyrmions, we must design materials that enable the skyrmionic phase to coexist in a wide window of magnetic fields and temperatures around room temperature. Furthermore, manipulation of skyrmions will require a good understanding of the resonant modes.

Last year, we presented evidence of the existence of a skyrmionic crystal lattice in a RE-TM ferrimagnet, with perpendicular magnetic anisotropy (PMA) at room temperature, which was verified by means of real and reciprocal space measurements, including: Lorentz Transmission Electron Microscopy (LTEM), Xray Magnetic Circular Dichroism (XMCD), Xray Microscopy, and Magnetic Force Microscopy (MFM). Here, we will present the resonant properties of these skyrmions, and demonstrate that the microwave properties of skyrmions are independent of the mechanism that stabilizes a skyrmion. Further extending the recent results of T. Schawarze, et al. [3], who demonstrated that different classes of materials that show skyrmions by means of Dzyaloshinskii–Moriya interaction (DMI) have the same resonance spectrum. Using a broad-band coplanar waveguide technique, we study the resonant modes of an Fe\Gd system exhibiting a skyrmion phase at RT and below 200K. By comparing the topological features observed via X-ray microscopy/LTEM as a function of field with the resonant field at which resonance modes appear, we are able to correlate the mode spectrum to specific spin textures. In addition, we investigate the frequency and thickness effect on the resonance mode spectrum.

[1] A. Fert, et. al. *Nature Nanotechnology* 8 , 152-156 (2003)

[2] N. Nagaoasa, et. al. *Nature Nanotechnology* 8, 899-911 (2013)

[3] T. Schawarze, et. al. *Nature Materials*, 1476-4660 (2015).

Nanoscale Thermal Energy Transport

Presenter: ***Renkun Chen,*** Assistant Professor, CMRR, MAE

Thermal transport plays a significant role in modern technologies, such as energy conversion, energy efficiency, and thermal management of electronic and memory devices. The fundamental length scales associated with the basic heat carriers, such as phonons and electrons, generally fall in the range of 1-1000 nm. Therefore, exploring and exploiting basic nanoscale thermal transport and conversion phenomena holds the key for developing high performance materials and devices for thermal energy conversion and management. In this presentation, I will discuss our recent work on using rationally designed nanostructures and new thermal instrumentations to study thermal transport and conversion phenomena in nanoscale structures, including inorganic and organic nanowires, and multilayers. Depending on the material systems, we showed that nanostructures exhibit either diminished thermal conductivity in electrically conductive materials, which is appealing for thermoelectric applications, or enhanced thermal conductivity in electrically insulating and soft materials, such as polymers, which is relevant for thermal interface applications. Finally, the role of nanoscale thermal transport in emerging data storage devices will be discussed.