Center for Magnetic Recording Research

University of California – San Diego

La Jolla, California 92093-0401

Research Review
and
Advisory Council Meeting

October 23 & 24, 2014

Website: http://cmrr.ucsd.edu

CMRR
Center for Magnetic Recording Research

Research Review Schedule – Thursday, October 23, 2014		
8:30 AM - Continental Breakfast at CMRR		
8:55 AM - Welcome and Introduction		
9:00 AM – Tribology and Mechanics ***Professor Frank Talke***		
1	Investigation of Tribo-Voltages at the Head-Disk Interface	*Liane Matthes*
2	Experimental Investigation of Hydrocarbon Oil Transfer at the Head-Disk Interface	*Young Woo Seo*
3	Theoretical Analysis of Crack Generation at the Dimple/Gimbal Contact Interface	*Youyi Fu*
4	Numerical Simulation and Experimental Measurement of the Heat Transfer at the Head/Disk Interface in Heat Assisted Magnetic Recording	*Longqiu Li*
10:00 AM - 10 Minute Break		
5	Raman Spectroscopy Investigation of the Effects of Heating of Diamond-like Carbon Overcoat Used in Hard Disk Drives	*Benjamin Suen*
6	Design and Optimization of Collocated Dual Stage Suspensions	*Yangfan Wang*
7	Cooling Effect of the Air Bearing on Thermal Contact Sensors in Thermal Flying-height Control Sliders	*Alex Phan*
8	Dynamic Behavior of Air Bearing Slider in Air-Helium Gas Mixtures	*Frank E. Talke*
11:00 AM – Dynamic Modeling and Servo Technology ***Professor Raymond De Callafon***		
8	PZT Charge Driver for Reducing Hysteresis in DSA	*Xin Zhao*
9	Adaptive Regulation for Vibration Control in Tape Drives	*Raymond de Callafon*
11:30 AM – Shpyrko Research Group ***Associate Professor Oleg Shpyrko***		
10	Study of Magnetic and Structural Dynamics by Coherent X-ray Diffraction	*Andrej Singer*
12:00 PM – Lunch at CMRR		

1:00 PM – Special Session ***Jan Ulrich Thiele, Seagate Technology***		
11	Heat Assisted Magnetic Recording – magnetism, plasmonics and heat transfer at the nano-scale for next-generation data storage	*Jan-Ulrich Thiele*
2:00 PM – Magnetic Materials and Devices ***Research Professor Ami Berkowitz***		
12	Improvement of Magnetization in Bulk MnBi Ingots by Vacuum Annealing Process	*Phi Khan Nguyen*
2:20 PM – 10 Minute Break		
2:30 PM – Micromagnetic Modeling and Recording Physics ***Professor Vitaliy Lomakin***		
13	Micromagnetics and Recording Physics at CMRR	*Vitaliy Lomakin*
13	Micromagnetics on High-performance Workstation and Mobile Computational Platforms	*Sidi Fu*
14	Micromagnetic Modeling of Nano-Granular Materials	*Simon Couture*
14	Domain Wall Motion in Antiferromagnetically Coupled Nanowires	*Majd Kuteifan*
	3:30 PM – 10 Minute Break	
15	Numerical Model to Simulate All Optical Switching Effect	*Marco Menarini*
	Micromagnetic Modeling of Coupled Spin Transfer Torque Oscillators	*Iana Volvach*
	Simulating X-Ray Scattering Images from Magnetic Domains	*Attieh Shahvarpour*
4:30 PM - Poster Session		
5:00 PM - Advisory Council Meeting		

Research Review Schedule --Friday, May 23, 2014		
8:30 AM - Continental Breakfast at CMRR		
8:55 AM - Welcome and Introduction		
9:00 AM – Signal & Coding ***Professor Paul H. Siegel***		
16	Multihead Multitrack Detection with Reduced-State Sequence Estimation	*Bing Fan*
17	Linear Cyclic Binary Locally Repairable Codes	*Pengfei Huang*
18	Algebraic and Geometric Problems for Non-Volatile Memory	*Sarit Buzaglo*
10:10 AM - 10 Minute Break		
10:20 AM – Non-Volatile, Solid State Memory ***Associate Professor Steven Swanson***		
19	Reliable and Highly-Available Persistent Memory System	*Yiying Zhang*
10:40 AM – Magnetic Films and Nanostructures ***Professor Eric Fullerton***		
20	High Annealing Stability in Perpendicular MTJ Pinned Layer Utilizing a Composite Spacer	*Dokyun Kim*
21	Generation and Manipulation of Domain Walls Using a Thermal Gradient in a Near-Compensation Ferrimagnetic CoTb Wire	*Robert Tolley*
21	Hexagonal Lattice in Fe\Gd Thin Film Multilayer	*Sergio Montoya*
22	All-Optical Control of Magnetization in Thin-films and Nanostructures	*Rajasekhar Medapalli*
11:40 PM – Design & Fabrication of Nano Magnetic Materials ***Professor Sungho Jin***		
22	Fabrication of Nano-Sized MTJ Array for MRAM Devices	*Edward Choi*
23	Adding Another Dimension to Communications/Entertainments Techonologies	*Calvin Gardner*
12:10 PM – Lunch		
2:30 PM Adjournment - Thank you!		

Investigation of Tribo-Voltages at the Head-Disk Interface

Presenter: ***Liane Matthes***, PhD student, CMRR, MAE

Researchers: ***Liane Matthes***, PhD student, CMRR, MAE;

Fred Spada, Associate Researcher, CMRR

Collaborators: ***Bernhard Knigge***, Western Digital Corporation

Advisor: ***Frank Talke***, Professor, MAE department, CMRR

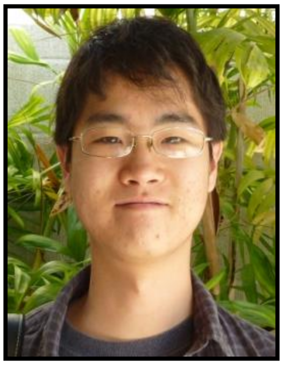
In hard disk drives, there exists a potential difference between the recording head and the magnetic disk due to the use of dissimilar materials. This potential difference varies over time as material is being transferred at the head-disk interface or due to changes in the environment (i.e., temperature and humidity). Material transfer takes place as lubricant or contaminants are picked up by the recording head from the disk or during intermittent head-disk contacts. As a result of the potential difference at the interface, there exists an electrostatic force between the recording head and the disk which can negatively affect the performance of hard-disk drives. For example, it is known that degradation of the lubricant occurs in the presence of electric fields [1] and under electron bombardment [2], both being a consequence of the presence of electric charges at the interface. It it has been shown that head wear and lubricant interactions can possibly be reduced by controlling the voltage at the interface [3].

In this study, we investigate the potential difference at the head-disk interface and investigate the effect of lubricant type, radial position, disk velocity and head-disk contacts.

[1] F. E. Spada and D. Basov, “Fourier transform infrared investigation of thin perfluoropolyether films exposed to electric fields,” vol. 8, pp. 179–186, 2000.

[2] S. Matsunuma, “The initial step of tribochemical reactions of perfluoropolyether on amorphous carbon,” vol. 213, pp. 112–116, 1997.

[3] B. Knigge and B. Marchon, “Negative biasing a slider with respect to a disk to reduce slider wear and provide burnish rate control,” US2011/0157739 A12011.



Experimental Investigation of Hydrocarbon Oil Transfer at the Head-Disk Interface

Presenter: ***Young Woo Seo***, PhD Student, CMRR, MAE

Researcher: ***Young Woo Seo***, PhD Student, CMRR, MAE

Collaborators: ***Andrey Ovcharenko***, Engineer, Western Digital Corporation;
Min Yang, Director, Western Digital Corporation

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

In current hard disk drives, the spacing between the slider and the disk is on the order of 1 nm. At such a small spacing, even a minute amount of contamination can be detrimental to the tribological performance of hard disk drives and can lead to hard disk drive failures. In this study, we have investigated the transfer mechanism of hydrocarbon oil molecules at the head-disk interface. We studied a "two-step" transfer mechanism as shown in Fig. 1. First, airborne hydrocarbon molecules condense onto the disk surface. Since the slider flies only a few nanometers above the disk surface, hydrocarbon molecules transfer from the disk surface to the slider surface. This process is observed to take place after long-term usage of hard disk drives. In order to accelerate the process, we deposited hydrocarbon molecules (C24, C28, C32, and C36) onto the disk surface by outgassing in a thermal chamber. Then, a Vena tester was used to fly the slider on the disk surface for a desired duration of time (4, 8, 12, and 16 hours) at a temperature of 60C. An optical microscope, an AFM, and an SEM were used to characterize the hydrocarbon molecules on the disk and slider surfaces. Fig. 2 shows a hydrocarbon droplet formed on the air bearing surface.

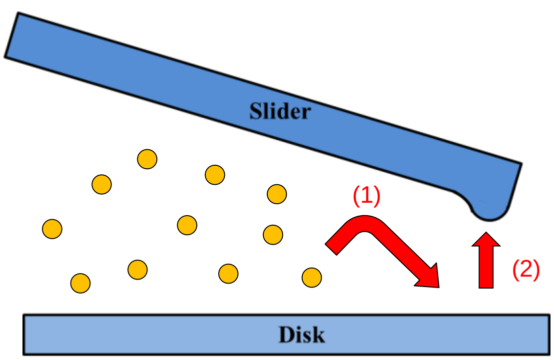


Fig. 1. A schematic of two-step transfer mechanism of hydrocarbon molecules at the

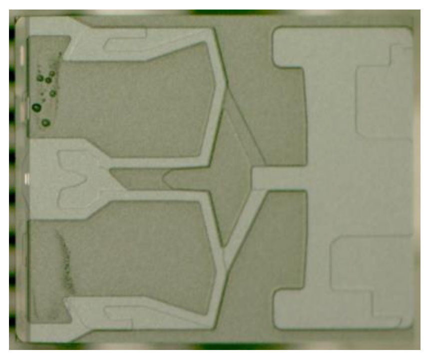


Fig. 2. Formation of hydrocarbon oil droplet on the air bearing surface

Theoretical Analysis of Crack Generation at the Dimple/Gimbal Contact Interface

Presenter: ***Youyi Fu***, PhD Student, CMRR, MAE

Researcher: ***Vlado A. Lubarda***, Professor, CMRR, MAE

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Fretting wear tests of stainless steel dimples contacting gimbals coated with Diamond-like carbon (DLC) of different thickness were performed. Using a scanning electron microscope (SEM), we observed the formation of cracks on dimples after 3.456×10^6 wear cycles. In this study, a contact model of the dimple/gimbal interface was developed and numerical simulation was performed to calculate the shear stress distribution in dimples during contact with gimbals of different thickness DLC overcoats. Comparing the experimental results and the simulation results, we observed that the crack size on the dimple increases with an increase of the shear stress in the dimple.

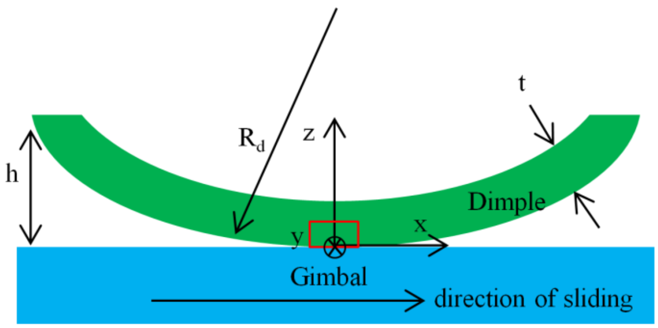


Fig. 1 Contact model of dimple and gimbal interface

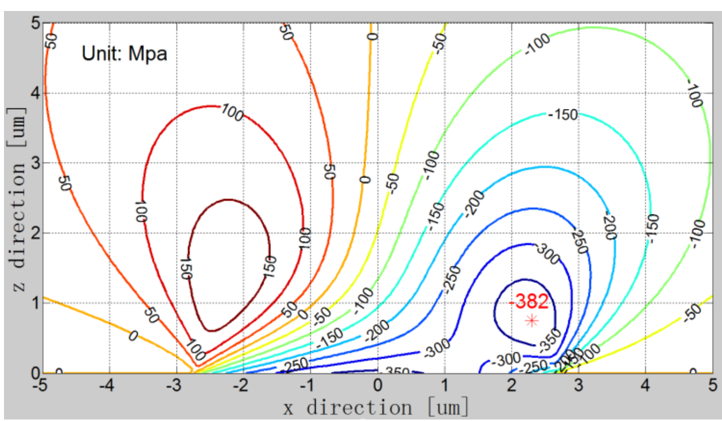


Fig. 2 Shear stress distribution on x-z plane of dimple when it slides on gimbal coated with 10nm DLC overcoat

Numerical Simulation and Experimental Measurement of the Heat Transfer at the Head/Disk Interface in Heat Assisted Magnetic Recording

Presenter: ***Longqiu Li***, Visiting Scholar, CMRR

Researcher: ***Longqiu Li***, Visiting Scholar, CMRR

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Heat assisted magnetic recording (HAMR) is currently being investigated as a means to overcome the super-paramagnetic limit in magnetic recording. In HAMR, a laser beam is used to first heat the magnetic medium beyond its Courier temperature and then information is recorded magnetically during the cool-down process when the coercivity of the medium is still low. In HAMR, the typical head disk spacing is on the order of 1 nm, i.e., HAMR is a phenomenon related to near field optics effects. In order to understand heat assisted magnetic recording, the heat transfer between the head and the disk must be determined. Traditional heat transfer studies of HAMR have considered heat conduction and heat convection occurring in the air bearing between slider and disk. However, in most of the investigations of HAMR, the effect of radiation has been neglected. It is apparent, however, that radiation at the head disk interface plays an important role in the operation of the head disk interface for HAMR.

In this research project, we address both the numerical and experimental aspects of heat transfer at the head disk interface in HAMR. In the numerical part, we investigate the heat transfer of a thermal flying height control slider by considering nano-scale thermal tunneling in addition to the effects of conduction and convection.

In the experimental investigation of HAMR, we study near field heat transfer of the HAMR interface by using tip enhanced Raman spectroscopy. To accomplish this, we have built a new test apparatus that combines a Raman spectrometer and an Atomic Force Microscopy (AFM). We use the laser beam of the Raman spectrometer and couple this beam into the tip of an AFM, thereby allowing the study of near field effects between the tip of the AFM and the disk. The reflected radiation is returned to the Raman spectrometer, allowing the observation of frequency shift as a function of the interface temperature. Calibration of the temperature will be performed in an off-line experiment.

The method provides a new way to measure the temperature distribution and surface profiles changes of the head/disk interface in HAMR. Experimental results will be compared with the numerical modeling results.

Raman Spectroscopy Investigation of the Effects of Heating of Diamond-like Carbon Overcoat Used in Hard Disk Drives

Presenter: ***Benjamin Suen***, Graduate Student, CMRR, MAE

Researcher: ***Benjamin Suen***, Graduate Student, CMRR, MAE

Collaborator: ***Longqiu Li***, Vising Scholar, CMRR, MAE

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Heat assisted magnetic recording technology presents many engineering challenges due to the high temperatures required to heat the recording media past the Curie temperature. To simulate near field effects in heat assisted magnetic recording, tip enhanced Raman spectroscopy can be used. Tip Enhanced Raman Spectroscopy (TERS) combines an atomic force microscope (AFM) and a Raman spectrometer. In TERS, a laser is focused on the tip of a metallized AFM tip, 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 signal is measured with a spectrometer and then analyzed in order to quantify changes in thermal and chemical properties.

In this study, temperature will be measured by correlating the peak positions of the Stokes Raman signal to a known temperature. The heating of the test sample is achieved by constructing a low-cost and simple microscope heating stage. The heating stage is composed of an insulated ceramic heating chamber and a cooling sleeve. The sample is heated to a known temperature, as measured by a thermocouple, in the heating chamber. The cooling sleeve uses cold air around the chamber to prevent the experimental setup from overheating. The Raman scatting of the heated sample is measured with a confocal Raman spectrometer aimed at the heated sample through a heat resistant fused quartz window in the heating stage.

A single crystal diamond sample formed by chemical vapor deposition will be used to correlate the temperature to the Raman peak position. The sample will be heated to various increasing temperatures and the corresponding Raman shifts will be recorded. Future work may include studying the accuracy of the aforementioned calibration curve when applied to the thin-film diamond-like carbon coatings found in hard disk drives and to Tip Enhanced Raman Spectroscopy measurements of the thin diamond-like carbon films.

Design and Optimization of Collocated Dual Stage Suspensions

Presenter: ***Yangfan Wang***, Graduate Student, CMRR

Researcher: ***Yangfan Wang***, Graduate Student, CMRR

Collaborators: ***Longqiu Li***, Visiting Scholar, CMRR; ***Karcher Morris***, Graduate Student, CMRR; ***John Hogan***, NHK International

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Higher performance suspensions are necessary to increase the areal density of hard disk drives (HDDs). Currently suspension-based dual stage actuated (DSA) designs utilize two piezoelectric actuators placed at the base of the suspension, allowing for a secondary input that can respond to undesirable off-track motion. Collocated designs are a probable DSA alternative. Placing the actuators "collocated" with the head allows higher frequency response and better track registration. In this research project, we design a new type of collocated suspension using SolidWorks and HyperMesh. The effect of design parameters on the lateral deflection is optimized using LS-DYNA, a finite element software. A comparison of the proposed dual stage head-based actuator is made with other suspension-based designs and the collocated design proposed by Lengert et al. (2012). Guidelines for optimization of the designs are presented and discussed.

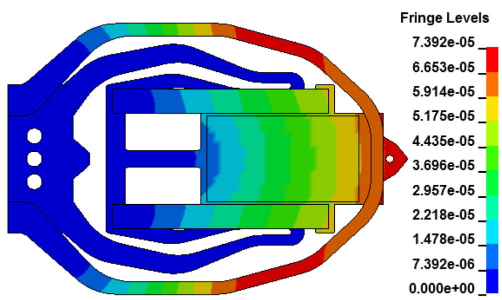


Figure 1 FEA contour plots of trailing edge deformation

Cooling Effect of the Air Bearing on Thermal Contact Sensors in Thermal Flying-height Control Sliders

Presenter: ***Alex Phan***, PhD Student, CMRR, MAE

Researchers: ***Chuanwei Zhang***, Visiting Graduate Student, CMRR, MAE; ***Alex Phan***, PhD Student, CMRR, MAE; ***Young Woo Seo***, PhD Student, CMRR, MAE

Collaborator: ***Andrey Ovcharenko***, Engineer, Western Digital Corp.

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

The flying height of typical thermal flying height control (TFC) sliders is on the order of 1 nm. At this small spacing, controlling the flying height is an important task for the reliability of the head disk interface. In the last few years, thermal contact sensors with high sensitivity to temperature changes have been used for slider/disk contact detection and defect mapping. For the detection of slider/disk contacts, the thermal contact sensor has similar sensitivity to that of conventional acoustic emission sensors. In addition, the air bearing has a great cooling effect on the thermal response of thermal contact sensors and should be considered in the process of detecting the slider/disk contact.

In our previous study, we built a thermo-elastic-plastic contact finite element model between a disk asperity and a thermal contact sensor in a TFC slider, and investigated the sensitivity of a thermal contact sensor for the detection of asperity contacts. In this study, we investigate the cooling effect of the air bearing on the thermal contact sensor. Fig. 1 shows the schematic of heat transfer at the head disk interface. In order to study the effect of air bearing, the Reynolds equation and the energy equation are solved to obtain the pressure distribution and heat transfer in the air bearing, respectively. The temperature of the thermal contact sensor as a function of the flying height, disk velocity, and environment temperature is obtained.

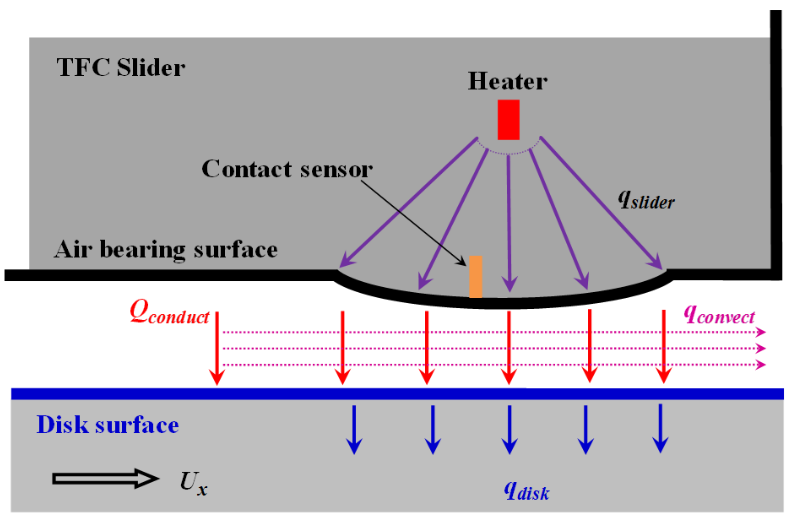
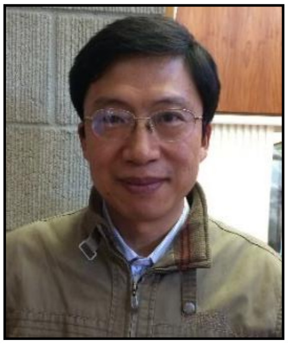


Fig.1 Schematic of heat transfer at the head disk interface



Dynamic Behavior of Air Bearing Slider in Air-Helium Gas Mixtures

Presenter: ***Bao-Jun Shi***, Visiting Scholar, CMRR *presented by Frank E. Talke*

Researcher: ***Bao-Jun Shi***, Visiting Scholar, CMRR

Collaborator: ***Zhengqianq Tang***

Advisor: ***Frank E. Talke***, Professor, CMRR, MAE

Dynamic behavior of a pico-type air bearing slider in air-helium gas mixtures is investigated numerically. A slider/disk contact model including van der Waals and friction forces is used to determine the contact characteristics in the slider/disk interface in magnetic recording disk drives. A finite element-based dynamic air bearing simulator is coupled with the contact model to obtain the flying characteristics of the slider. The dynamic minimum flying height and the air bearing force are investigated as a function of helium percentage, disk velocity and/or the tracking position on the disk. Power spectrum analysis is also conducted to investigate the dynamic performance of the head disk interface in the frequency domain.

Keywords: Air-helium, Slider/disk contact, Dynamic behavior, Air bearing

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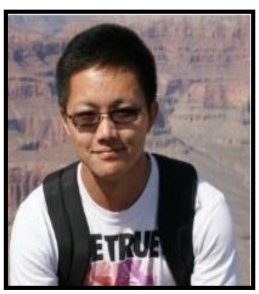


PZT Charge Driver for Reducing Hysteresis in DSA

Presenter: ***Xin Zhao***, PhD Student, CMRR, MAE

Researcher: ***Xin Zhao***, PhD Student, CMRR, MAE

Advisors: ***Guoxiao Guo and Jianguo Zhou***, Western Digital Corp

This presentation shows a survey on piezoelectric (PZT) charge driver technology. PZT actuator is widely applied in Dual-Stage Actuator (DSA) of high-density hard disk drivers. There exists a nonlinearity issue while driving PZT with a voltage driver. Such issue can be solved by applying a PZT charge driver, which is studied during the presenter’s summer internship in WDC.

Adaptive Regulation for Vibration Control in Tape Drives

Presenter: ***Raymond A. de Callafon***, Professor, CMRR, MAE

Fig.1: Vibration setup with LTO drive on shaker table.

The motion control of a magnetic tape storage system is subjected to periodic disturbances with multiple harmonic components that are time varying. However, knowledge of the dynamics of the servo actuator in the tape storage can be used to estimate the disturbances present in a digital servo system that is controlling the servo actuator. It is show how the actuator dynamics can be used to parametrize perturbations on the control algorithm to minimize the effects of periodic disturbance via adaptive regulation. The approach relies on a fractional representation of the actuator dynamic model and a parametrization of the servo controller that preserves convexity during the minimization of the effects of the disturbances. Vibration experiments of a servo actuator in a Linear Tape Open drive operating under feedback (see Fig. 1) with noisy and periodic components in the Position Error Signal (PES) measurements will be used to illustrate the effectiveness of the adaptive regulation of the controller. The results show the possibility to implement a motion control system with adaptive regulation that cancels periodic disturbances with multiple harmonic components, as indicated in Fig. 2.

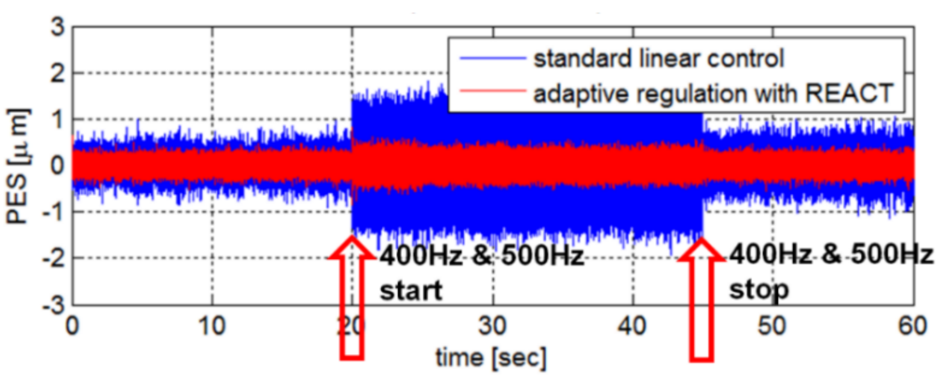


Fig. 2: Comparison of performance of a standard linear control algorithm compared with an adaptive control algorithm when the tape drive is subjected to multiple harmonic disturbances. The plot shows how the Position Error Signal (PES) during track following remains at a small level.

Study of Magnetic and Structural Dynamics by Coherent X-ray Diffraction

Presenter: ***Dr. Andrej Singer***, Postdoc, Department of Physics,

Advisor: ***Prof. Oleg Shpyrko***, Department of Physics, CMRR

Understanding and controlling the coupling and decoupling between various degrees of freedom (spin, charge, lattice) in strongly correlated materials rank among the most important problems in today's condensed matter physics. Coherent x-ray diffraction proves to be an exemplary tool to probe nanoscale magnetic properties directly [1] or through lattice imperfections, such as strain waves due to antiferromagnetic ordering [2]. We used x-ray diffraction to study re-condensation dynamics of strain waves in chromium using synchrotron radiation after excitation by infrared pulses. Our study indicates a presence of the strain wave despite substantial excitation of the electronic subsystem. We also used coherent x-ray diffraction to map inhomogeneous strain distribution and structural phase transitions in lithium ion batteries during charging and discharging. Our in situ measurements reveal a hysteretic behavior of the structure upon cycling and we directly observe the interplay between different transformation mechanisms: solid solution and two-phase reactions at the single nanoparticle level [3]. Finally coherent x-ray diffractive imaging was used to image topological defects in single nanoparticles. The mobility of single defects was investigated and the displacement fields around individual defects were used as local nanoprobes of elastic properties of the material [4].

[1] A. Tripathi *et al*., PNAS **33**, 13393-8 (2011)

[2] A. Singer *et al*., in preparation (2014)

[3] A. Singer *et al*., Nano Letters 14, 5295 (2014)

[4] A. Ulvestad *et al*., submitted (2014)

Special Session Speaker

Heat Assisted Magnetic Recording – Magnetism, Plasmonics and Heat Transfer at the Nano-Scale for Next-Generation Data Storage

Presenter: ***Jan-Ulrich Thiele, Ph.D.*** Seagate Technology

Researcher: ***Jan-Ulrich Thiele, Ph.D.*** Seagate Technology

The ongoing shift of consumers from personal computers to mobile devices have led to increased use of solid state drives (SSD), resulting in media reports predicting the impending end of the venerable hard disk drive (HDD) for mainstream data storage applications. In this presentation we will take a look at some of the underlying economic and technological trends and make the case for continuing strong demand for HDDs. The next big technology transition in HDDs, heat assisted magnetic recording (HAMR), will bring profound changes to the components and architecture of the HDD, incorporating laser diodes, and plasmonic light delivery into the recording heads, and novel nano-magnetic materials and layer architectures in the recording media. We will give an overview of the working principles of HAMR, the current status and remaining challenges for the envisioned introduction of this recording technology at areal densities of 1 Tit/in^2 or above within the next few years.

About the presenter: Jan-Ulrich Thiele holds a PhD in Physics from the University of Basel in Switzerland. After 12 years at IBM and Hitachi GST working on many aspects of magnetic recording technology, he joined Seagate Technologies in Spring 2008 as a Technologist and Senior Director for Media R&D. He currently leads the team of Scientists and Engineers that developed the media for the first 1 Tbit/in^2 HAMR demonstration in 2012.

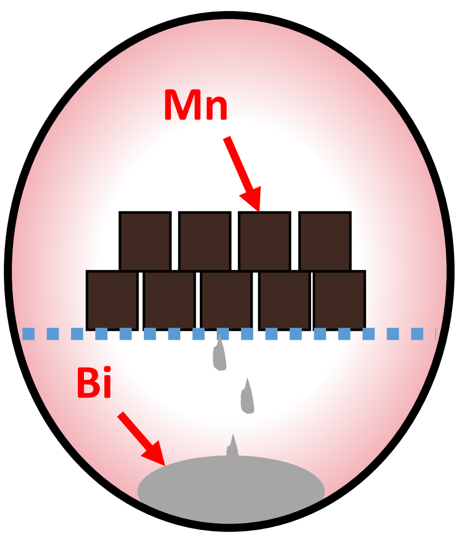
Improvement of Magnetization in Bulk MnBi Ingots by Vacuum Annealing Process

Presenter: ***Phi-Khanh Nguyen,*** PhD Student, CMRR, MS&E

Researchers: ***Phi-Khanh Nguyen,*** Graduate Student, CMRR, MS&E
Vaibhav Jayaraman, Intern, Del Norte High School, Poway, CA
Ami E. Berkowitz, Professor Emeritus, CMRR, Physics Dept.

Advisors: ***Ami E. Berkowitz,*** Professor Emeritus, CMRR, Physics Dept.
Sungho Jin, Professor, CMRR, MAE

Rare-earth-free permanent magnets (REFPM) are in high demand, particularly for use in wind turbines and electric vehicles that use motors with permanent magnets. The low-temperature-phase of MnBi (LTP-MnBi) has attracted much interest as a potential REFPM because of its high uniaxial magnetocrystalline anisotropy at room temperature, $K \approx 10^7$ emu/cc, and the unusual increase of anisotropy with increasing temperature, that produces a high coercive force (H_C) at the appropriate operating temperature for motors (180°C). However, due to the complex Mn-Bi phase diagram and the slow interdiffusion of Mn and Bi below the 350°C phase change temperature, bulk samples of LTP-MnBi with high saturation magnetization (M_S) have been difficult to achieve. When cast by conventional means, bulk MnBi ingots exhibit significant regions of unreacted Bi, a heavy metal that reduces the fraction of desired LTP-MnBi, thereby reducing the overall M_S. We report a process for increasing the overall M_S by annealing the ingots in high vacuum. The vacuum serves a dual purpose: it protects the ingot from oxidation, and it creates a pressure differential between the interior and exterior of the ingot. The ingots are placed on a mesh screen so that when heated above the Bi melting point (271°C), molten Bi is extracted from the ingot, leaving behind mostly LTP-MnBi. The overall ingot then exhibits M_S of up to 90% of pure LTP-MnBi.



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 in-house high-performance ODE solver, an updated granular media code, a CPU version of FastMag, and a version of FastMag for mobile computing systems. 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.

Micromagnetics on High-performance Workstation and Mobile Computational Platforms

Presenter: ***Sidi Fu***, PhD. Student, CMRR, ECE

Researcher(s): ***Sidi Fu***, PhD. Student, CMRR, ECE; ***Simon Couture***, PhD. Student, CMRR, ECE; ***Marco Menarini***, PhD. Student, CMRR, ECE; ***Majd Kuteifan***, PhD. Student, CMRR, ECE

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

The feasibility of using high-performance desktop and embedded mobile computational platforms for micromagnetic simulations is presented, including Intel Xeon CPU, Nvidia desktop GPUs, and Nvidia Jetson TK1 Platform. FastMag FEM-based micromagnetic simulator is used as a testbed, showing high efficiency on all the platforms. A detailed performance comparison for micromagnetic simulations on all the platforms will be discussed. The high performance, low cost, low power consumption, and rapid performance increase of the embedded mobile systems make them a promising candidate for micromagnetic simulations. Such architectures can be used as standalone systems or can be built as low-power computing clusters.

Micromagnetic Modeling of Nano-Granular Materials

Presenter: ***Simon Couture***, PhD Student, CMRR, ECE

Collaborators: ***Sidi Fu***, Graduate Student, CMRR, ECE; ***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, that is 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.

Domain Wall Motion in Antiferromagnetically Coupled Nanowires

Presenter: ***Majd Kuteifan***, PhD Student, CMRR

Collaborators: ***Marko Lubarda***, Visiting Scholar, CMRR; ***Ruinan Chang***, Ph.D. Graduate, CMRR; ***Sidi Fu***, Graduate Student, CMRR, ECE; ***Eric Fullerton***, Professor, CMRR, ECE; ***Vitaliy Lomakin***, Professor, CMRR, ECE

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

Magnetic nanowires supporting field- and current-driven domain wall motion are considered as candidates for enabling new methods of information storage and processing. The domain wall motion phenomena are described by the Landau-Lifshitz-Gilbert equation and they can be reproduced by numerical simulations and analytical models. A major issue limiting the domain wall velocity in a nanowire is an effect called "Walker breakdown", which manifests itself through the precession, backward motion, and overall slow down of the domain wall propagation when the applied field or current is too strong. We study domain wall motion in antiferromagnetically coupled magnetic nanowires and show that Walker breakdown can be reduced or completely eliminated in such structures. For field-driven domain wall motion the maximally achieved domain wall speed and corresponding applied field can be much higher than those of single-phase nanowires. The speed increases as the difference between the saturation magnetization of the two coupled phases decreases. However, the domain wall cannot move for fully compensated phases. For the case of current-driven domain walls, the Walker breakdown is completely eliminated for the fully compensated case and the domain wall speed is only limited by additional mechanisms, such as heating and defects. The study includes two analytical models and numerical simulations, which match each other very well.

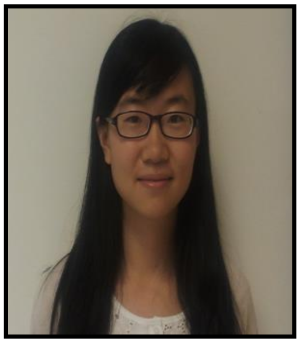
Numerical Model to Simulate All Optical Switching Effect

Presenter: ***Marco Menarini***, PhD Student, CMRR, ECE

Advisor(s): ***Vitaliy Lomakin***, Professor, CMRR, ECE; ***Lu J Sham,*** Professor Emeritus, Physics, CMRR

We present a model to simulate the effect of all optical switching in ferromagnetic material in granular media using a Stochastic Landau Lifshitz Bloch model approach. We assume the film to be composed of FePt L10 single domain grains. The effect of the optical pulse is a combination of ultrafast thermal demagnetization and a direct optical effect. The direct optical effect is modeled as a pseudo magnetic field generated by the interaction between the polarized light and the electrons.

The physical mechanisms involve the initial fast demagnetization and switching followed with longer time-scale demagnetization while the media cooling down. The presented model and simulation agree with experimental data of AOS on granular FePt media candidate for heat assisted magnetic recording



Multihead Multitrack Detection with Reduced-State Sequence Estimation

Presenter: ***Bing Fan***, Ph.D. Student, CMRR, ECE

Researcher: ***Bing Fan***, Ph.D. Student, CMRR, ECE

Collaborator: ***Dr. Hemant K. Thapar***, Visiting Scholar, CMRR

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

In shingled magnetic recording (SMR), the multihead multitrack (MHMT) detector can better combat the effect of intertrack interference (ITI) than the single-head single-track (SHST) detector [1], but it also has significantly higher complexity, which might preclude its use in practice. In this presentation we will show that the use of reduced-state sequence estimation (RSSE) algorithm can significantly reduce the complexity of MHMT detector while achieving near maximum-likelihood (ML) performance. A symmetric two-head two-track (2H2T) channel model, characterized by the ISI channel polynomial h(D) and the ITI level ε, is considered in this work. The joint inputs of the 2H2T channel are represented by a 4-symbol constellation. Considering effective symbol-pair distances, a reduced-state trellis can be constructed by applying set partitioning principles [2], with states formed using signal sets chosen from different partition levels, illustrated in Fig. 1. The underlying idea is to drop less likely paths at each step of the Viterbi algorithm while retaining a prescribed structure for the reduced-state trellis. Different trellis configurations can be obtained based on the desired performance/complexity tradeoff. Fig.2 shows the simulation results of RSSE with a varying number of states on the EPR4 channel. As shown, the RSSE algorithm can nearly achieve the ML performance even with 50% fewer states.

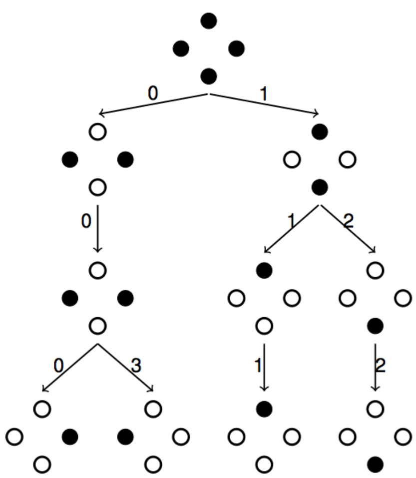


Fig. 1. Set partitioning of the input constellation

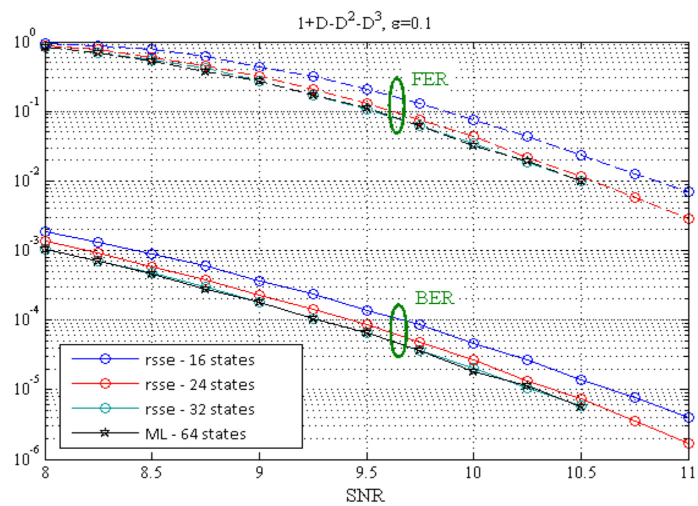
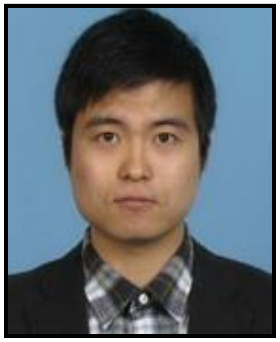


Fig. 2. Performance of RSSE with different configurations on 2H2T system with EPR4 channel polynomial assumed

[1] E. Soljanin, C. Georghiades, "Multihead detection for multitrack recording channels," *IEEE Trans. Inform. Theory*, vol. 44, no. 7, pp. 2988-2997, Nov. 1998.
[2] M. V. Eyuboglu and S. U. Qureshi, "Reduced-state sequence estimation with set partitioning and decision feedback," *IEEE Trans. Commun.* vol. 36, no.1, pp. 13-20, Jan. 1988.



Linear Cyclic Binary Locally Repairable Codes

Presenter: ***Pengfei Huang***, Ph.D. Student, CMRR, ECE

Researcher: ***Pengfei Huang***, Ph.D. Student, CMRR, ECE

Collaborators: ***Dr. Eitan Yaakobi,*** Assistant Professor, Technion

Dr. Hironori Uchikawa, Visiting Scholar, Toshiba

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

Locally repairable codes (LRC) 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. Most existing results on LRC 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 [1]. Recently, however, an upper bound on the dimension k of LRC was presented in [2]. 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 develop an improved version of the bound mentioned above for linear codes. We then focus on cyclic linear binary codes. By leveraging the cyclic structure, we show that the locality of such a code is determined by the minimum distance of its dual code. Using this result, we investigate the locality of a variety of well known linear cyclic binary codes, e.g., Hamming codes and Simplex codes, and also prove their optimality with respect to our improved bound for linear codes. We also discuss the locality of codes which are obtained by applying the operations of Extend, Expurgate, Augment, Lengthen, and Shorten to linear cyclic binary codes. Several families of such modified codes are considered and their optimality with respect to the new bound is addressed. Finally, we investigate the locality of Reed-Muller codes. Even though they are not cyclic, it is shown that some of the locality results for cyclic codes still apply.

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

[2] 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.

Algebraic and Geometric Problems for Non-Volatile Memory

Presenter: ***Sarit Buzaglo***, Postdoctoral Scholar, CMRR

Researcher: ***Sarit Buzaglo***, Postdoctoral Scholar, CMRR

Co-authors: ***Prof. Tuvi Etzion***, Technion; ***Prof. Eitan Yaakobi***, Technion;b ***Prof. Jehoshua (Shuki) Bruck***, Caltech

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

Flash memory is the most important type of non-volatile memory (NVM) in use today. Flash devices are employed widely in mobile, embedded, and mass-storage applications, and the growth in this sector continues at a staggering pace. The high interest and many applications of such memories increase the importance of this research and lead to a wide range of stimulating problems. Flash memory cells are electrically programable to one of q discrete states and therefore, can store $\log_2 q$ bits. Reducing a cell state into a lower state requires the erasure of the whole block to which the cell belongs. In order to lower the probability of over-shooting errors, charge is injected into a cell over several iterations, which results in a slow programming. Two coding frameworks for flash memory were studied in the last four years, *the asymmetric limited magnitude error model* [6] and the *rank modulation scheme* [7,8]. The asymmetric limited magnitude error model addresses inherit asymmetric behavior of common error types in flash memory, under the reasonable assumption that errors are not likely to exceed a certain limit. Rank modulation is a coding scheme that was designed to improve the efficiency of programming a flash memory cell. Under this setup, data is encoded into permutations which are derived by the relative charge levels of the cells, rather than by their absolute levels.

In this talk I will present some results from my PhD thesis [1]. For the asymmetric limited magnitude error model we study perfect linear codes [2]. Using two concepts which are equivalent to perfect linear codes, namely, lattice tiling and group splitting, we present constructions of perfect linear codes of length n that can correct up to $n-1$ asymmetric errors with limited magnitude ℓ for every n and ℓ. We also prove the nonexistence of perfect linear codes for other parameters. For the rank modulation scheme we present results that are related to three fundamental concepts in coding theory; perfect codes [3], systematic codes [5], and constrained codes [4].

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[3] S. Buzaglo and T. Etzion, ``Perfect permutation codes with the Kendall's τ-metric," submitted to *IEEE Trans. on Inform. Theory*.

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Reliable and Highly-Available Persistent Memory System

Presenter: ***Yiyang Zhang***, Postdoctoral Researcher, CMRR

Researcher: ***Yiyang Zhang***, Postdoctoral Researcher, CMRR

Advisor: ***Steve Swanson***, Professor, CMRR, CSE

The next-generation non-volatile memory (NVMpromises performance close to DRAM, persistence, and high density. However, providing the level of reliability and availability that large-scale storage system demands is challenging. We propose Mojim, a system that preserves the performance of NVMs while providing the reliability and availability that modern storage systems require. Mojim achieves good performance by decoupling reliabilityavailability, redundancy, and consistency, and prioritizing reliability and availability over consistency. Mojim efficiently replicates NVM content to a high-availability backup machine through efficient memory managemenand a simple networking stack. It checkpoints data to one or more backup machines through low-speed network foreliability. Mojim uses a new atomic group commit API to ensure metadata consistency. Our evaluation results with micro- and macro-benchmarks show that Mojim can provided replicated NVM with 66% of the bandwidth and only 1.5x the average latency of local, non-replicated NVM. We have also also ported MongoDB to use Mojim in place of its native replication mechanism. The resulting system is 2 to 3.5x faster than unmodified MongoDB.

High Annealing Stability in Perpendicular MTJ Pinned Layer utilizing a Composite Spacer

Presenter: ***Dokyun Kim,*** Postdoctoral Researcher, CMRR

Collaborator(s): ***Kangho Lee*** & ***Jimmy Kan***

Advisor: ***Eric E. Fullerton,*** Professor, CMRR, ECE

In order to productize Spin-Transfer-Torque MRAM (STT-MRAM) for embedded applications, the high temperature annealing stability of magnetic tunnel junctions (MTJs) is a crucial parameter for consideration. The thermal cycles that a CMOS wafer undergoes during back-end-of-line processing can reach temperatures up to 400°C. These required thermal cycles can negatively impact the magnetic properties of MTJs via interdiffusion and structural transformations. Here, we present an alternative perpendicular MTJ pinned layer spacer material designed to address the problem of high temperature annealing stability in MTJs. In this study, we investigated the high temperature annealing stability of various perpendicular MTJ reference layer schemes such as single-pinned, ferromagnetically coupled, and antiferromagnetically coupled. It was found that Co/Pt multilayers can maintain high perpendicular magnetic anisotropy (PMA) after 400°C annealing for 30 minutes. However, this Co/Pt system coupled to Ta/CoFeB/MgO shows a sharp loss of PMA for the same annealing condition. This degradation is attributed to film roughness and atomic interdiffusion between Co/Pt and Ta/CoFeB. In order to resolve these issues, the seed layer thickness was optimized to decrease crystalline grain size and surface roughness, and an ultrathin Co/Ta/Ru-type spacer was introduced in place of Ta. In this structure, Co/Ta/Ru plays the role of an interdiffusion barrier between CoFeB[1] and Co/Pt while simultaneously enhancing the strength of the exchange coupling[2]. With this new spacer, the thermal budget of this PMTJ pinned layer structure was greatly enhanced.

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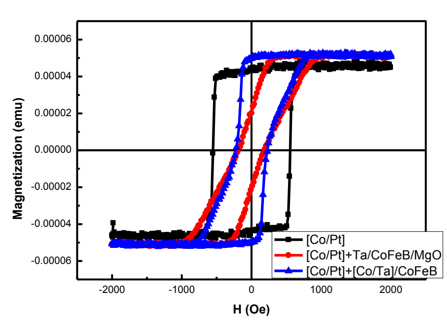
[2] Matthias Gottwald, Jimmy J. Kan, Kangho Lee, Seung H. Kang, and Eric E. Fullerton, APL Mater. 1, 022102 (2013)

Fig.1 Comparison of M-H loops of single pinned layer structure after 400°C annealing process.



Generation and Manipulation of Domain Walls Using a Thermal Gradient in a Near-Compensation Ferrimagnetic CoTb Wire

Presenter: ***Robert Tolley***, PhD Student, CMRR, ECE

Researcher: ***Robert Tolley***, PhD Student, CMRR, ECE

Advisors: ***Eric Fullerton***, Professor, CMRR, ECE; ***Stephane Mangin***, Professor, Institut Jean Lamour – Universite de Lorraine

We demonstrate the ability to create and control the propagation and annihilation of domain walls in 25-nm thick $Tb_{22}Co_{78}$ ferrimagnetic alloy wires using a temperature gradient and applied field. The temperature gradient is generated by passing a Joule heating current through the wire and the domain wall properties are imaged using Kerr microscopy. The manipulation of the domain wall is made possible by creating a temperature gradient such that the temperature at one end of the wire is above the compensation temperature for the Tb-Co alloy while the other end remains below the compensation temperature. By tuning the intensity of the applied magnetic field and the current flowing inside the wire it is possible to carefully control the domain wall position such that it can then be stabilized under zero applied field and current.

Hexagonal Lattice in Fe\Gd Thin Film Multilayer

Presenter: ***Sergio Montoya***, PhD Student, CMRR, ECE

Collaborators: ***James Lee***, Postdoctoral Fellow, ALS, LBNL; ***Xiaowen Shi***, Postdoctoral Fellow, ALS, LBNL; ***Shawan Mishra***, Postdoctoral Fellow, ALS, LBNL; ***Sujoy Roy***, Beam line Scientist, ALS, LBNL; ***Peter Fischer***, Beam line Scientist, ALS, LBNL

Advisor: ***Eric Fullerton***, Professor, CMRR, ECE

Magnetic skyrmions are promising candidates for high-density non-volatile memory since they are topologically protected spin structure 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. The highest stable skyrmion observed has been in epitaxial FeGe (111) at 250K [3,4], which is in the neighborhood of the lower operating limit of a CMOS device.

We present evidence of the first metallic system which presents a skyrmionic-bubble phase that coexists in a wide window of temperatures and magnetic fields. The metallic structure consists of alternating sputter deposited Fe\Gd ultra-thin films, were coexisting and competing long range dipolar magnetic fields and Dzyaloshinskii-Moriya (DM) interactions balance energetically to allow the formation of skyrmionic-bubbles in a hexagonal lattice. Futhermore, by varying the composition of the Fe\Gd we can move the transition of the hexagonal lattice to different temperature windows. Most recent measurements have shown the existence of the hexagonal lattice at room tepmertaure with bubble feature size of 64.15 ± 0.3nm. Initial measurements using Lorentz Transmission Electron Microscopy (LTEM) has provided evidence that these bubbles are helicity dependent, which is an indication that the Fe\Gd system is in fact skyrmionic.

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

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[4] Huang, S. et. al. Phys. Rev. Lett. 106, 227201 (2012)

All-Optical Control of Magnetization in Thin-films and Nanostructures

Presenter: ***Rajasekhar Medapalli***, PhD, CMRR
Researcher: ***S. Mangin***, CMRR
Advisors: ***Y. Shaya Fainman***, Prof., ECE and ***Eric Fullerton***, Prof., CMRR

The possibility of manipulating magnetic systems without applied magnetic fields has attracted growing attention over the past fifteen years. The low-power manipulation of the magnetization, preferably at ultrashort timescales, has become a fundamental challenge with implications for future magnetic information memory and storage technologies. Here we explore the optical manipulation of the magnetization in engineered magnetic materials. We demonstrate that all-optical helicity dependent switching (AO-HDS) can be observed not only in selected rare earth–transition metal (RE–TM) alloy films but also in a much broader variety of materials, including RE–TM alloys, multilayers and heterostructures. We also show that RE-free Co–Ir-based synthetic ferrimagnetic heterostructures designed to mimic the magnetic properties of RE–TM alloys also exhibit AO-HDS. Further, for the first time, optical control of ferromagnetic materials ranging from magnetic thin films to multi-layers and even granular films being explored for ultra-high-density magnetic recording are presented. Finally, we discuss the ultrafast magnetization dynamics, observed in $Gd_{19}FeCo$ thin-film, using time-resolved pump-probe technique. These promising measurements pave a way to study the laser in magnetization dynamics in newly developed magnetic systems.

Fabrication of Nano-Sized MTJ Array for MRAM Devices

Researcher: ***Edward Choi,*** Postdoctoral Researcher, CMRR, MAE

Collaborators: ***Youngjin Kim,*** Graduate Student, CMRR, MAE; ***Leon Chen***, Research Scientist, CMRR, MAE; ***Dokyun Kim***, Postdoctoral Researcher, CMRR; ***Eric Fullerton***, Professor, CMRR, ECE

Advisor: ***Sungho Jin***, Professor, CMRR, MAE

Spin-torque controlled, MgO-based magnetic tunnel junctions (MTJs) with a large TMR are promising candidates for non-volatile random access memory. Such MTJs can provide high MR ratio, high-speed operation scalability and many read/write cycle endurance. To integrate high-density spin transfer torque magnetic random access memory (STT-MRAM), a stable process for patterning metallic multilayer MTJs to sub-20 nm dimensions is highly desired. However, dry etching such as ion milling using Cl_2, may cause the thin films to corrode and induce an undesirable re-deposition of the ion-etch removed metallic particles on the side of the MTJs. Such re-deposition can cause unwanted electrical shorts across the tunnel barrier reducing the TMR ratios. Therefore, a new approach of nano array patterning techniques can be utilized for sub-20 nm MTJ fabrication, without using ion milling.

Isolated Si nanopillar arrays are first fabricated by lithography or self-assembly such as by e-beam or nano imprinting lithography. The nano-patterned islands can be in the range of 20 – 100 nm size. In order to ensure a good signal-to-noise ratio and reduced inter-island device interference, the magnetic material deposition is restricted only onto the top surface of the patterned islands, using a convenient, and reliable trench-filling planarization and magnetic material isolation process, which is applied between each successive layer deposition steps. On planarized surface, a uniform and undistorted magnetic layers, barrier layers or texture-inducing surface layers are deposited. By subsequent lift-off processing, the magnetic material outside the protruding island top surface area is removed together with the resist in the valley region, thus leaving isolated devices array. Using such planarization processes, perpendicular patterned, vertically protruding magnetic devices such as MTJ and MRAM can be fabricated without using dry etching, thus avoiding ion milling process that tends to deteriorate the MTJ performance in high density device array structures.

Adding Another Dimension to Communications/Entertainments Technologies

Researcher: ***Calvin Gardner***, PhD Student, CMRR, MAE

Presenter: ***Calvin Gardner,*** PhD Student, CMRR, MAE

Collaborators: ***Isaac Liu,*** Graduate Student, CMRR, MAE ; ***Youngjin Kim,*** Graduate Student, CMRR, MAE ; ***Edward Choi***, Postdoctoral Researcher, CMRR, MAE ; ***Leon Chen***, Research Scientist, CMRR, MAE

Advisor: ***Sungho Jin***, Professor, CMRR, MAE

In recent decades, much research has been dedicated to the development of virtual reality for entertainment, engineering, and medical application. Virtual reality can be made more realistic with an artificial three-dimensional visual or other sensory environment using the experience of moving seats, odors of explosives or flowers, sprinkling water, laser lights and wind blowing. Odor releasing devices that allow repeatable, remote, and reliable switching of odor flux, in particular, could have a significant impact on the effectiveness of virtual reality. However, although various devices for the added sensual experience have been developed recently, very few odor generating devices with practical and useful control of induced sense of smell have been reported. Some of the known technologies for odor release are coarse and crude in nature, and it is hard to apply them to delicate home electronics or personal devices due to the bulkiness, their lack of reproducible release over multiple cycles, their slow response times to stimuli, as well as their inability to dynamically adjust the amount/intensity of odor according to the recipient's needs. Therefore, the development of versatile and multi-channel switchable odor releasing systems is highly desirable for advancement of modern electronic device virtual reality.

In the present work, we designed and demonstrated X-Y matrix controllable odor release systems, in which only those odor chambers at the cross-point (e.g., X3-Y5) is allowed to activate the chamber and release the odor. This system thus requires only 100+100 line controls to selectively activate 10,000 odor chambers. Some example odor releases using perfumes, pizza and coffee odors have been demonstrated. Technical approaches for further improvement of the thermally actuated odor release systems and possible magnetic-switch-controlled odor release devices will also be discussed.