CMRR REPORT

Center for Magnetic Recording Research

Spring 2015 : Issue 43

Sixth Annual Non-Volatile Memories Workshop

More than 200 researchers from industry and academia recently gathered in La Jolla to share their latest ideas about the future of computer memory technology and data storage systems, as UCSD hosted its 6th Annual Non-Volatile Memories Workshop (NVMW) on March 1–3, 2015.

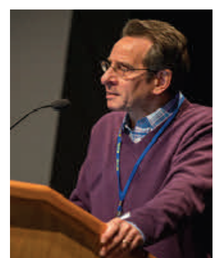
Like its predecessors, NVMW 2015 provided researchers and practitioners the opportunity to gain a broader understanding of what is needed to accelerate the development and adoption of new non-volatile storage paradigms, and to establish professional relationships that will provide the basis for further technological advances. The technical program again represented a “vertical” cross-section of the storage system stack, offering a selection of the hottest developments in device technologies, data encoding techniques, hardware and software architectures, and innovative storage applications.

Responding to the largest number of submitted papers in the history of the NVMW, the Program Committee, whose membership included 26 experts from university, corporate, and government labs, expanded the program to include 42 papers, divided into two parallel tracks, to accompany the three invited keynote talks.

The workshop began with a well-attended, half-day tutorial by Prof. John Ousterhout, of Stanford University, who described the latest progress in his exciting and revolutionary computer architecture known as “The RAMCloud Storage System.” The 42 contributed presentations were organized into 10 sessions. Topics in advanced coding included rewriting and replications codes, data compression and shaping codes, error reduction techniques, and error correcting codes. In the area of system architectures, the sessions addressed important problems relating to solid-state drive design, memory hierarchies, persistence, and a potpourri of other system aspects. Wide-ranging sessions on devices and applications rounded out the oral presentation program. A lunch-time poster session featured an additional 20-plus interesting papers that broadened the scope and depth of the workshop’s technical content.

The keynote addresses provided a forum for three technology leaders to share their perspectives on future directions in non-volatile storage systems. Bob Brennan, Samsung Senior Vice President and head of Samsung's Memory Solution Lab, presented his view on “How NAND-based Technology is Transforming the Data Center.” Phil Brace, Executive Vice President, Electronic Solutions at Seagate Technology, spoke about ways to tackle the complex problem of integrating emerging storage technologies into next-generation storage systems in a talk entitled “Storage – Moving Towards Tailored Solutions.” Finally, Dr. Andy Rudoff, Principal Engineer in NVM Software at Intel Corporation, looked down the road at the vast implications for software design when, with the steady progress in non-volatile memories, we find ourselves “In a World … with Persistent Memory.”

In This Issue



Paul Siegel

Steven Swanson

Sixth Annual Non-Volatile Memories Workshop Dinner

Photos by Alex Matthews

FACULTY PROFILE

RENKUN CHEN

Assistant Professor, MAE

Assistant Professor Renkun Chen is a professor of UC San Diego's Mechanical Engineering Department. He will be joining CMRR as a new CMRR Affiliate Professor starting Spring 2015. Prof. Chen joined the UCSD faculty in November 2009. Chen received his Ph.D. in Mechanical Engineering at the UC, Berkeley, where his research in Prof. Arun Majumdar group (now at Stanford) was focused on nanoscale thermal energy conversion. Subsequently, Chen continued working as a post-doctoral fellow in Prof. Majumdar's group, where he investigated nanoscale phonon transport physics using advanced nanofabrication tools.

Professor Chen and his group are interested in thermal energy transport, conversion, storage, and management across different length scales. Their group is particularly working on developing nanostructured materials and devices for thermal to electrical energy conversion and studying fundamental transport physics of charge and heat carriers (electrons, phonons and photons) at micro and nano scale. Professor Chen and his group are also developing materials and systems for applications in solar-thermal energy conversion, thermal energy storage, and thermal management.

CMRR's NEW FUND MANAGER

Jonathan Chae joined the team in the Fall as the new Fund Manager for CMRR. Jonathan is a UCSD Alumnus and graduated with a Bachelor's degree in Economics with a minor in Accounting. He is excited to be a part of the team and grateful to everyone for welcoming him to the department.

Sixth Annual Non-Volatile Memories Workshop Welcome Session

The workshop attendance represented a roughly even mix between industry and academia, including more than 50 graduate students and post-doctoral researchers whose participation was supported by generous grants from the National Science Foundation and a number of corporate sponsors. The social program included a welcome reception at the Sheraton La Jolla Hotel and a banquet at Bertrand at Mister A's featuring spectacular views of downtown San Diego and performances by The Tritones, UCSD's very talented a cappella group.

The NVMW was co-organized by Prof. Paul H. Siegel of the Center for Magnetic Recording Research (CMRR) and Prof. Steven Swanson of the Non-Volatile Systems Laboratory (NVSL) in Computer Science and Engineering at UCSD, in collaboration with Prof. Eitan Yaakobi of the Computer Science Department at Technion - Israel Institute of Technology. This year's corporate sponsors included HGST, HP, Huawei, Marvell, Micron, NetApp, PMC, and Samsung, as well as CNEX Labs, Intel, SanDisk, Seagate, Toshiba, and Western Digital.

An archival website at http://nvmw.ucsd.edu provides a lasting record of all of the NVMW workshop proceedings and a resource for the scientific community and general public.

Letter from the Director

Eric Fullerton
Director, CMRR

This newsletter comes at a time of continued growth of activities and changes at CMRR that is reflected in increased corporate memberships and federal grants, and the presentations at the Spring 2015 review. This is the first research review that will be hosted in the recently renamed auditorium, which is now the Jack Keil Wolf Auditorium at CMRR, in honor of Jack Wolf, one of the founding CMRR faculty. This is in recognition for Jack's extensive contributions to research and education at CMRR, UCSD, and the broader engineering community. The naming ceremony had speakers from the ECE department, the Dean's office, office of Research Affairs and a number of Jack's former students. The first lecture of the new auditorium was by Professor Shivendra Panwar of NYU Polytechnic School of Engineering who was a former student of Jack. The new sign for the auditorium was unveiled by Jack's wife Toby Wolf.

Another dramatic change to CMRR is the retirement of Chaired Professor Sungho Jin effective this summer. Sungho is a giant in the field of magnetic materials and their application in a broad range of technologies.

He has been an important contributor to CMRR's growth over the last decade. Although retired, he will still remain an active part of CMRR while some of his research activities will be taken over by the new CMRR affiliated faculty, Assistant Professor Renkun Chen, who is highlighted in the newsletter. I personally would like to thank Sungho for his many contributions to CMRR and for his support and advice during my time as Director.

We are pleased with the strong interaction between our students and our industrial partners as a part of CMRR's mission is to train students for the information technologies industries. We will have 14 CMRR students receiving their Ph.D. this year, with many may-be joining our corporate sponsors after graduation. We will also have students participating as summer interns. I would encourage companies interested in CMRR students for summer interns to contact me, or other CMRR faculty, sooner than later. I hope we can keep this strong participation of our students with our corporate sponsors to grow in the coming years. We continue to expand our educational and outreach efforts by organizing various conferences and workshops such as the Non-Volatile Memories Workshop (NVMW) organized by Paul Siegel and Steve Swanson. As described in the newsletter, the workshop provides a unique showcase for outstanding research on solid state, non-volatile memories. We look forward to NVMW 2016 and are planning additional workshops in the coming years.

CMRR has a long history of hosting visiting professors, researchers, and students from international research institutions. To expand these efforts , we recently successfully submitted a proposal to The *Centre National de la Recherche Scientifique* (National Center for Scientific Research), which established an International associated laboratories (LIA) between CMRR, the University of Lorraine, University of Paris Sud and Thales, in France. The *Centre National de la Recherche Scientifique* is the main research funding organization in France under the responsibility of the French Ministry of Higher Education and Research. The focus of the new laboratory will be "Nano-electronics: from fundamental phenomena to next generation technologies" and the kickoff meeting and workshop will be in September of this year. The LIA is a "laboratory without walls" that formulizes a collaborative research agreement between CMRR and our French partners. I'm excited about this new research direction and opportunities for CMRR.

Research Highlight

(continued on p.4 & 5)

Magnetic Vortices: Controlled Dynamic Switching of the Curl Made Fast and Energy-Efficient

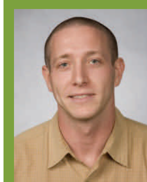
By Vojtěch Uhlíř[1]*, Michal Urbánek[2], Peter Fischer[3], Tomáš Šikola[2] and Eric E. Fullerton[1]

The circulating topology of vortices is a physical phenomenon, which is found across a large range of length scales, from galaxies, hurricanes down to the nanoscale, e.g. in superconducting materials under an applied magnetic field. Magnetic vortex structures also form in thin disk shaped ferromagnetic elements where the magnetic moments, i.e. the spins in the plane of the disk try to follow the disk shape's boundary. In the center of a magnetic vortex, there is a vortex core where the magnetization points perpendicular to the plane. These in-plane and out-of-plane spin configurations of a magnetic vortex define its two independent binary parameters—the polarity and circulation. Controlling those entities on a sub-nanosecond timescale is currently a hot topic both for fundamental and applied reasons.

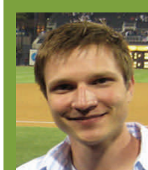
When excited by a fast-rising magnetic field or spin-polarized current, vortices exhibit a rich variety of fundamental dynamic behaviors that are inherent to chiral structures [1–4]. Generally, the magnetization distribution of a vortex is an example of a magnetic topological soliton [5] and features low-frequency precessional modes [2] associated with the translational motion of the core. The precessional mode has been the subject of considerable interest, with applications in oscillators [3,4] and resonant amplification of gyrotropic precession for low-field [6] or low-current [7] excitations. Because of their multiple stable ground states, vortices have also been studied as potential multibit memory cells [8]. This application requires independent control of both the circulation and the polarity. The polarity can be reversed by applying a static out-of-plane magnetic field, although its magnitude needs to be quite large, on the order of 0.5–1.0 T [9]. However, fast stimuli can lead to much more efficient core polarity switching. Using a magnetic field [6], or current [7], the vortex core can be driven into gyrotropic precession and the core polarity reversed as soon as the core reaches a critical velocity [10]. The switching process typically occurs in less than 0.1 ns.

CMRR Ph.D. Graduates

Phi-Khanh Nguyen
Department: MAE
Ph.D.: Winter 2015
Advisor: Ami Berkowitz
Thesis: Development of Thermoelectric and Permanent Magnet Nanoparticles for Clean Energy Applications
Future Plans: Touring Asia for the next few months. Will be returning to the U.S. to find a position in his preferred field.



Jacob Stanley
Department: Physics
Ph.D.: 2015
Advisor: Oleg Shpyrko
Future Plans: Working as a postdoctoral researcher at University of Colorado Boulder.



Sebastian Dietze
Department: Physics
Ph.D.: 2015
Advisor: Oleg Shpyrko
Future Plans: Currently looking for a positon.

Jong Woo Kim
Department: Physics
Ph.D.: 2015
Advisor: Oleg Shpyrko
Future Plans: Working as a postdoctoral researcher at Argonne National Lab.

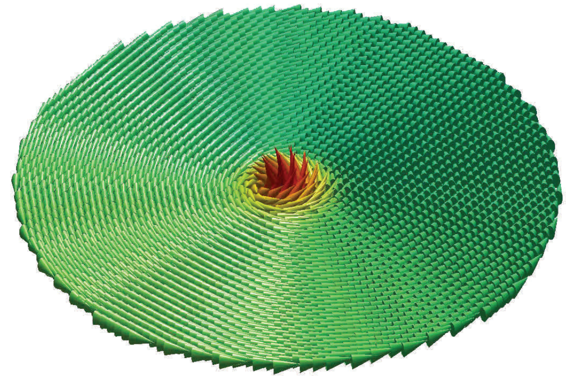
Dylan Lu
Department: ECE
Ph.D.: Fall 2014
Advisor: Zhowei Liu
Thesis: Plasmonic Metamaterials for Active and Passive Light Control
Future Plans: Academia

Paul Duyoung Choi
Department: MAE
Ph.D.: Winter 2015
Advisor: Sungho Jin
Thesis: Design and Fabrication of Nano-Bio Materials for Sensor and Device Applcations
Future Plans: Currently looking for a position.

 (Continued from p. 3)

Magnetic Vortices: Controlled Dynamic Switching of the Curl Made Fast and Energy-Efficient

The subnanosecond character of vortex polarity switching raises the question of controlling the spin circulation on similar timescales (Fig. 1), thus opening a path to selective and independent control of the polarity and circulation. Unlike switching core polarity, controlled switching of spin circulation with magnetic fields requires displacing the vortex core out of the disk and then reforming the vortex with the opposite spin circulation. The core expulsion can be performed by using an in-plane static magnetic field that moves the core to the side of the disk and finally annihilates the vortex when $B_{an\text{-}stat}$ is reached [12]. The sense of magnetization circulation that forms as the field is removed can be controlled either by exploiting an asymmetry in the structure shape [13] or in the spatial distribution of the applied magnetic field [14].



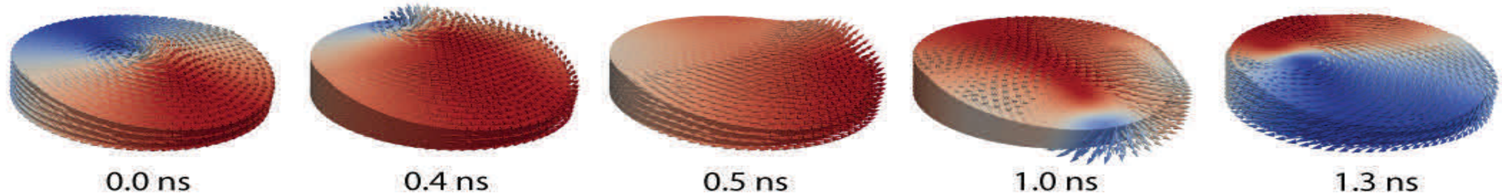


Fig. 1 Temporal evolution of the magnetization circulation switching in a 100-nm-wide nanodisk by a 0.5-ns-long magnetic field pulse applied in the disk plane (micromagnetic simulation in the finite-element FastMag code [11]). Snapshots show the instantaneous magnetization configuration at indicated time delays.

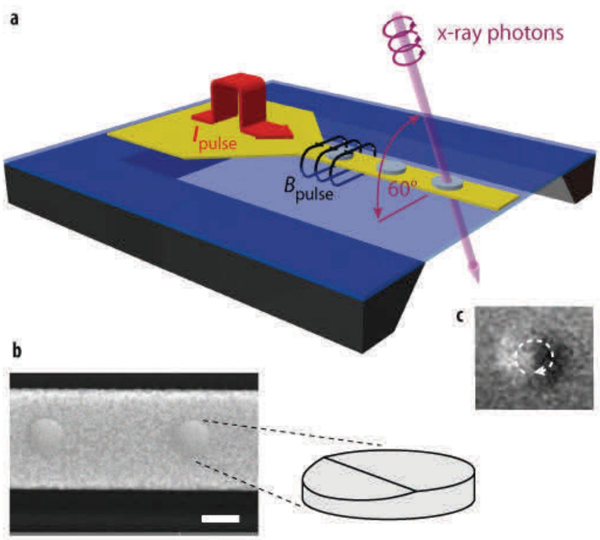


*Fig. 2 Schematic of the sample: **a** nanodisk chain fabricated on top of a 50-nm-thick gold waveguide. An applied positive current I_{pulse} produces an in-plane field B_{pulse} transverse to the stripline. The stripline is fabricated on a 200-nm-thick Si_3N_4 membrane window, which is transparent to the incoming soft X-rays, allowing magnetic imaging in transmission geometry. **b**, A scanning electron microscopy (SEM) image showing the detail of a 500-nm-wide and 20-nm-thick disk. The thickness asymmetry at the bottom-left part of the disks is highlighted by the schematic close-up. Scale bar, 500 nm. **c**, Magnetic contrast in the image of a 1,000-nm-wide nanodisk after dividing it with a reference image containing a vortex with the opposite spin circulation. The curl of the magnetization is indicated. The black and white domains represent parallel and antiparallel orientation of the magnetization projected on the incident soft X-ray beam.*

Magnetic imaging of the dynamic spin circulation switching

In our initial study [15], we showed that far-from-equilibrium gyrotropic precession enables dynamic switching of spin circulation and substantially decreases the dynamic annihilation field $B_{an\text{-}dyn}$ compared to static conditions. This annihilation field reduction is analogous to the reduction of switching fields in Stoner–Wohlfarth particles by precessional reversal using fast-rising magnetic field pulses [16]. We further showed that the lower bound of the time required for spin circulation switching is set by the gyrotropic eigenfrequency of the vortex core motion, which is defined by the disk geometry [2].

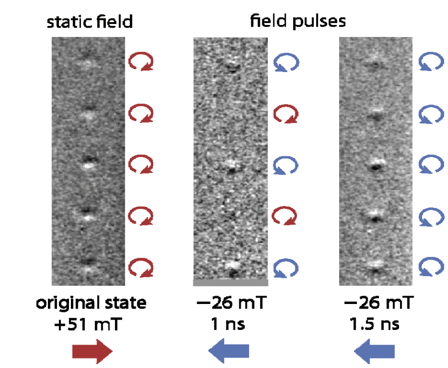


Fig. 3 The MTXM images of vortices in 250-nm-wide and 20-nm-thick disks were taken after application of in-plane magnetic fields. The arrows on the right of each image indicate spin circulation. Arrows and labels below the images show the polarity and magnitude of the applied field, as well as pulse duration where applicable.

In particular, we studied permalloy ($Ni_{80}Fe_{20}$) disks of different diameters (250–1100 nm) and thicknesses (20 and 30 nm) that are excited by externally applied static magnetic fields or by applying in-plane magnetic field pulses created by current pulses in a waveguide (details of the sample and waveguide are shown in Fig. 2). Magnetization states were imaged with full-field magnetic soft X-ray transmission microscopy (MTXM) at the Advanced Light Source (ALS), BL 6.1.2 [17].

After applying both the static and pulsed magnetic fields, the final circulation is the same in all the disks and depends solely on the sign of the applied magnetic field. This is a result of a controlled symmetry-breaking in the disks arising from a wedge-like variation in the disk thickness at the disk boundary (Fig. 2b). Figure 3 shows the remanent magnetic state in 250/20 disks in response to pulsed magnetic fields. From the left: the initial state set by a static field, followed by magnetic states after applying 1 ns and 1.5 ns pulsed fields, respectively, to initiate dynamic switching. Although we see a significant reduction in the switching field with pulsed current, there is a lower limit to the pulse duration where switching is not observed or could only be achieved at higher applied fields. In 250/20 disks, the onset of switching was observed for pulses of 1 ns or longer.

The results are supported by both analytical models and micromagnetic simulations, showing that both the time and field switching scales strongly depend on the disk geometry. Importantly, scaling down the disks accelerates circulation switching. The analytical model and micromagnetic simulations predict that switching times shorter than 0.5 ns are possible for 100/20 disks. The limit is set by the transition of the vortex state to a monodomain state for permalloy disks smaller than 100 nm [18]. In our experiments we observed nucleation of a random core polarity upon circulation reversal, preventing full control of vortex chirality by in-plane field pulses. However, currently we are testing ways how the core polarity could potentially be controlled by an additional out-of-plane bias field and temporal shape of the in-plane field pulse. Alternatively, the core polarity can be subsequently adjusted by an additional pulse with parameters leading to toggle-switching or selective polarity switching [19].

Exploring the limitations and efficiency of circulation switching

Can we switch the vortex circulation for a given disk geometry even faster than in the threshold-field limit? Although this might be less energetically favorable, by increasing the field amplitude the core follows a shorter trajectory, so the time it needs to reach the disk boundary is lower. On top of that, increasing the field also increases the velocity of the core. However, this eventually leads to reaching the critical core velocity for polarity switching. This substantially complicates the situation – for instance when the amplitude of the pulse is only slightly above the threshold, the polarity switching might prevent the core from reaching the disk boundary, even if the field strength should initially be enough to expel the core. This aspect becomes an issue for disks thicker than approximately 20 nm, where the eigenfrequency of the core gyrotropic motion leads to velocities reaching the polarity switching threshold.

However, in our experiments, the circulation is switched by threshold-amplitude pulses in disks up to 30 nm thick and 1100 nm in diameter. This is not expected based on the analytical model or simulations and can be explained by the positive effect of finite pulse rise time. If the rise time is comparable to the period of the core eigen-oscillation, the core moves together with the equilibrium point (set by the instantaneous value of the magnetic field during the pulse). The core follows a cycloidal trajectory, and the instantaneous distance between the core and the equilibrium point is decreased, maintaining the core velocity below the critical velocity for core polarity switching. Consequently, the amplitude of the pulse has to be increased above $B_{an\text{-}stat}/2$ to expel the core, but the polarity is not flipped.

The experimentally determined pulse rise time–pulse amplitude phase diagram showing the regions of successful circulation switching was reproduced with an analytical model based on Thiele's equation [20] describing vortex core motion in a parabolic potential. We found that the analytical model is in good agreement with experimental data for a wide range of disk geometries. From both the analytical model and the experimental findings, we have determined the geometrical condition for dynamic vortex core annihilation and the pulse parameters giving the most efficient and fastest circulation switching [21]. We have also determined the maximum thickness (37 nm) of the disk above which the model does not predict a possibility of dynamic annihilation of the core with a pulse amplitude lower than $B_{an-stat}$. Pulses with an amplitude approaching, or exceeding, $B_{an-stat}$ and a sufficient duration will annihilate the vortex no matter what the exact dynamic behavior is, with no benefit for the energy cost associated with the circulation switching.

These studies set an important milestone towards fast and energy-efficient control of magnetic vortex structures in novel magnetic devices.

This work has been a collaborative effort between CMRR and the Central European Institute of Technology at Brno University of Technology, Czech Republic, and the Advanced Light Source at Lawrence Berkeley National Laboratory. It is partially supported by a DOE grant DE-SC0003678.

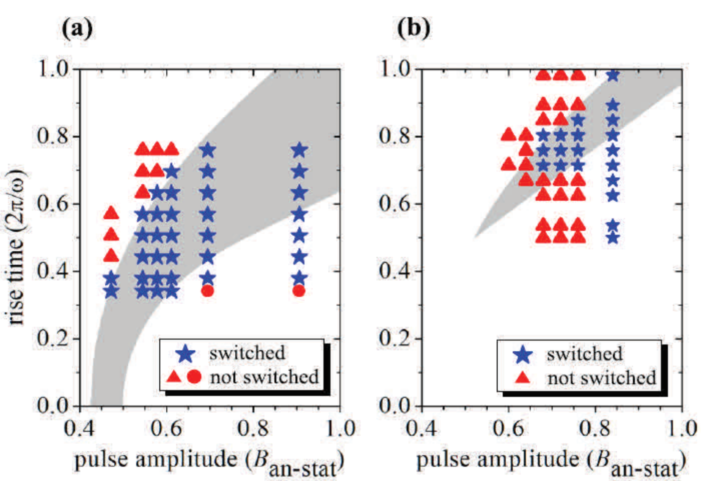


Fig. 4 (a) Pulse rise time–pulse amplitude phase diagram experimentally determined for a 1600-nm-wide, 20-nm-thick permalloy disk with an estimated eigenperiod 2π/ω = 7.9 ns and experimentally determined static annihilation field $B_{an-stat}$=19 mT. The pulse rise times and pulse amplitudes are given in units of the gyrotropic oscillation period (2π/ω) and vortex static annihilation field ($B_{an-stat}$), respectively. Red triangles represent a case of unsuccessful switching. Blue stars represent a case where successful core annihilation led to a circulation switching. Red dots represent a case where the circulation switching was not achieved in spite of using shorter rise time and larger pulse amplitudes (limit of the core polarity switching). (b) Phase diagram for a 1600-nm-wide, 30-nm-thick permalloy disk. The region of successful circulation switching moved towards top right of the normalized phase diagram. The gray areas in the phase diagrams define boundary of the region of successful circulation switching predicted by the analytical model.

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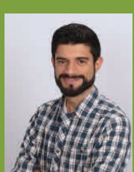
Ph.D. Students Near Completion

Leandra Boucheron
Department: Physics
Ph.D.: Fall 2015
Advisor: Oleg Shpyrko

Andrew Ulvestad
Department: Physics
Ph.D.: Spring 2015
Advisor: Oleg Shpyrko

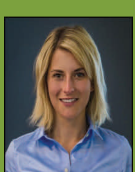
Calvin Gardner
Department: MAE
Ph.D.: Spring 2015
Advisor: Sungho Jin

Chin-Hung Liu
Department: MAE
Ph.D.: Spring 2015
Advisor: Sungho Jin



Cyrus Rustomji
Department: MAE
Ph.D.: Spring 2015
Advisor: Sungho Jin

Justin Taekyoung Kim
Department: MAE
Ph.D.: Spring 2015
Advisor: Sungho Jin



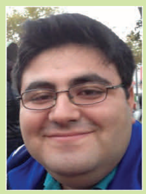
Liane Matthes
Department: MAE
Ph.D.: Spring 2015
Advisor: Frank Talke

Youyi Fu
Department: MAE
Ph.D.: 2015/2016
Advisor: Frank Talke

NEW CMRR RESEARCHERS & VISITORS

Lihua Yang is a visiting scholar from China who is working at CMRR under the supervision of Professor Franke Talke. Dr. Yang is a professor at Xi'an Jiaotong University of China, majoring in Mechanical Engineering. Her research focuses on lubrication, and dynamics of the bearing-rotor system.

Vitaly F. Rodríguez-Esquerre is a visiting scholar from Peru who is working at CMRR under the supervision of Professor Zhaowei Liu. Dr. Esquerre has been an Adjunct Professor at the Department of Electrical Engineering (DEE) at the Federal University of Bahia, UFBA, Salvador, since 2009. His current research interests include numerical methods based on finite difference methods, integrated optics, optical fibers, and free space propagation. Dr. Esquerre also conducts research on evolutionary computing for microwave and optical devices design, as well as computer assisted learning and education.



Sebastián Castillo is a visiting PhD student from Chile who is working at CMRR under the supervision of Professor Vitaliy Lomakin. Mr. Castillo is a Physics major at the Universidad de Santiago de Chile, Chile. Sebastian's research focuses on magnetic domain walls in nanostructures.

Hao Shen has been a Post-doctoral scholar-employee at CMRR working under the supervision of Professor Zhaowei Liu. Dr. Hao obtained his Ph.D. in condensed matter physics at Institute of Physics Chinese Academy of Sciences, China. His scientific research includes fundamental plasmonics, metamaterial, fluorescent lifetime, ultra-fast optics as well as nanofabrication and nano-device development.

Naveen Pouse is a 3rd year graduate student working on his PhD in Physics at UCSD. He works for Professor M. Brian Maple on strongly correlated electron systems, and is mentored by CMRR professor Ami Berkowitz. His work includes synthesizing materials containing rare earth elements and measuring their properties down to temperatures as low as 50 mK to observe phenomena such as superconductivity, heavy fermion behavior, or magnetic ordering, among many other low temperature phenomena.

Julian Trumpp is a fifth year graduate student studying mechanical engineering at the Karlsruhe Institute of Technology, Germany. He is at the University of California, San Diego to write his master's thesis with the CMRR department. With his work, he is assisting PhD student Alex Phan, who is working in Professor Frank Talke's lab on developing a new MEMS-device for measuring intraocular eye pressure. In the future, Julian plans to complete his graduate studies and continue working in the United States.

Yassine Quessab is a visiting graduate student who is working at CMRR under the supervision of Professor Eric Fullerton. Quessab is a master's student majoring in Material Science at the University of Lorraine, France. He is currently doing research in Professor Fullerton's lab on all-optical helicity-dependent magnetic switching (AO-HDS). In the future, Yassine plans to pursue his studies with a PhD in Material Sciences related to nanomagnetism.

Alexandre Bezerra is a fourth-year undergraduate student studying Electrical Engineering at the University of California, San Diego. He is currently working in Professor Ami Berkowitz's lab on achieving GMR in room temperature through coated nanoparticles. In the future, Alex plans to pursue graduate studies in Electronic Circuits Systems and Electronic Devices and Materials.

SELECTED PAPERS & TALKS

Professor Eric E. Fullerton

Alex Safsten, Karine Chesnel, and **Eric Fullerton**, "Mapping Magnetic Memory in [Co/Pd] IrMn Thin Films Under Field Cooling Conditions," *Bulletin of the American Physical Society,* Vol. 59, October 18, 2014.

JW Kim, S Manna, SH Dietze, A Ulvestad, R Harder, E Fohtung, OG Shpyrko, and **Eric Fullerton**, "Curvature-Induced and Thermal Strain in Polyhedral Gold Nanocrystals," *Applied Physics Letters,* Vol. 105, 173108, October 27, 2014.

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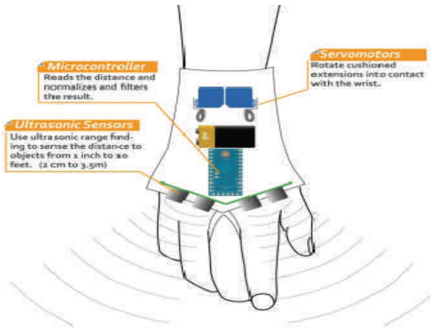
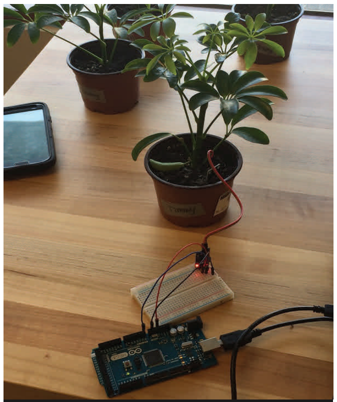
CMRR Hosts Divergent Engineering Pitch Day!

Divergent Engineering is an interdisciplinary engineering team that is committed to promoting diversity, ingenuity, and interdisciplinary collaboration among students through team projects. Started in summer of 2014, the team has since fostered the culture of allowing students to pitch their own ideas and cultivate projects that ultimately interest them. On April 8th, the team held a quarterly event at CMRR where students were able to present new projects and give demos and poster presentations of the progress they've made in their projects. It was a successful event that allowed the students to enhance their communication skills and increase team morale. Divergent Engineering hopes to continue to grow and further develop in the future with the help of UCSD and its abundant resources.

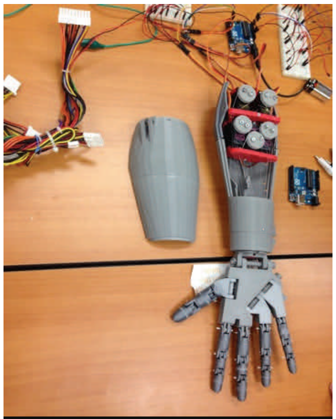
Divergent Engineering Projects



Tacit Project
A device to help blind people navigate into complex environments.



Automated Irrigation System
Instead of watering plants manually, use a micro-controller to determine if your plant needs any moisture.



Kai (Human Robot)
Based on the open source humanoid robot “Inmoov”, the project objective is to build and animate a human-sized robot.

More information: DIVEIN.UCSD.EDU