

CMRR REPORT

Center for Memory and Recording Research

Spring 2017 : Issue 47



NVMW 2017

Brain Inspired Memory “At the Center of the Universe”

By Tiffany Fox

San Diego, Calif., May 15, 2017 -- It's been decades in the making -- with hundreds of academic papers and new technologies to show for it -- but non-volatile memory (NVM) has now become firmly established as the memory of choice for long-term persistent data storage. It was no doubt a refreshing change of pace, then, for attendees at this year's annual Non-Volatile Memories Workshop to spend time discussing not if NVM will succeed, but instead how to make NVM even more powerful (or even how to make it, in one presenter's bold vision, the center of the computing universe).

NVM, in its most basic sense, is what makes it possible for you to turn off your computer (or unplug your flash drive, a form of NVM) and have it still 'remember' the last draft of the book you're working on. It's also relatively low-power, boasts fast random-access speed and is known for being rugged since it doesn't require a spinning disk or other moving mechanical parts.

The latest Non-Volatile Memories Workshop was held March 12-14 at the University of California San Diego and brought together both academic researchers and industry representatives from Intel, Facebook, IBM, Microsoft and other major corporations to discuss, for the eighth year running, how to best store increasingly large amounts of data in smaller spaces. Ideally, this would also be done at faster data transfer speeds and at lower cost to the consumer. While those three aspects will likely always be at the forefront of NVM development, how NVM will evolve -- and how computing itself will change as the result of advances in NVM -- is anyone's guess.

Stanford Electrical Engineering Professor H.S.-Philip Wong has a hunch, however, and he and others at NVMW think the answer can be found in one of the most powerful and complicated computational tools in the known universe: The human brain.

In its 2015 grand challenge to develop transformational computing capabilities using nanotechnologies, the White House called the human brain “a remarkable, fault-tolerant system that consumes less power than an incandescent light bulb.” Could the IT industry, which has long struggled to make computers more energy-efficient, rise to the occasion and create a scalable, fast and ‘green’ computation platform that could rival the gray matter inside our skulls?

Wong and his colleagues (including UC San Diego Bioengineering Professor Gert Cauwenberghs) were up to the challenge, but they knew that for brain-inspired computing to succeed, the energy-demand of memory and accesses would have to be addressed. In his keynote presentation at NVMW, Wong described the development of his team's end-product: “The Nano-Engineered Computing Systems, or N3XT Technology for Brain-Inspired Computing,” a new type of silicon-compatible 3D chip that provides massive storage and improves efficiency by reducing “computational sprawl.”

Building ‘Up’ Instead of ‘Out’

Take a look inside a modern computer processor and it's not too difficult to imagine it as a suburban neighborhood filled with single-story ranch-style homes, where wires connect chips much the way roads connect structures.



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But suburban neighborhoods are also notorious for “sprawl” and all the problems that go along with it: wasted space, long commutes and traffic jams. Similarly, inefficiently designed chips lead to data bottlenecks and longer processing times -- something that won't pass muster among consumers increasingly accustomed to ultra-fast computing for gaming, video-streaming and other high-demand applications.

Just as city planners have long called for building “up” instead of “out,” Wong and his team architected the N3XT (pronounced ‘next’) microchips in the same way, building super-dense skyscraper-style chips that integrate processors with memories and increase efficiency by a factor of a thousand.

“In two-dimensional systems, energy is spent on memory access and being idle,” explained Wong at the workshop. “But with 3D memory-on-chip and high bandwidth, you are only limited by compute computation, and that’s what we want.”

Wong further explained that this type of “hyperdimensional computing” could ultimately combine biologically-inspired algorithms and machine-learning algorithms with neuromorphic hardware and conventional hardware (CPUs, GPUs, supercomputers, etc) to create neuromorphic chips -- chips that can simulate synaptic function in the brain to perform “one-shot learning” that wouldn't require training over time.

“N3XT takes to the next level the concept of low-power, volume-efficient, ‘3D’ circuitry that is already revolutionizing NVM design,” said Paul Siegel, professor at UCSD's Center for Memory and Recording Research and NVMW co-organizer. “By tightly integrating memory and logic, it paves the way for future applications of machine learning and artificial intelligence, technologies that have transformed the fields of natural language processing, e-commerce, self-driving vehicles, and personalized health.”

Added Siegel: “As a platform for the next generation of brain-inspired computing, N3XT opens the door to a flood of novel real-time computing applications that will profoundly affect how we reason about and interact with the world. These advances will impact the ways that we - and a new generation of intelligent robots - communicate, make things, travel, and even express ourselves artistically.”

Memory-centric Computing: “Music to Our Ears”

It's one thing to rethink chip architecture -- it's another thing altogether to suggest a complete overhaul of how computers are built, from top to bottom. But that's essentially what Western Digital Chief Technology Officer Martin Fink proposed in his keynote talk, delivered on the second day of NVMW before technical sessions on database and file systems, coding for structured data and other specializations. (The previous day's technical sessions included talks on operating systems and runtimes for NVM, error modeling and error-mitigation codes as well as architecture and management policies).

Fink began by discussing one of the stark realities of computing: Networks are increasingly unable to handle the high rate of data growth and are simultaneously becoming more expensive to operate. Storage, meanwhile, continues to diminish in cost while increasing in density, which suggests the next logical step is to move toward memory-centric computing.

To achieve this, Fink -- the former director of HP Labs -- proposed that engineers must rethink the entire computing stack “from the ground up” by architecting chips to be completely memory-centric, where computer memory rather than the CPU “is at the center of the universe” (something Siegel remarked “should be music to our ears”). Petabyte-scale memory, in other words, would be its own independent system (likely a type of memory known as resistance RAM or ReRAM), with CPUs attached to the memory as needed. Instead of moving the data to the CPUS, in other words, the CPUs would move to the data.

Fink admitted that “rethinking how we've done things since 1945 is really, really hard. Rather than the CPU being the center of the universe,” he continued, “we need to flip the model to minimize the travel of data through the storage memory hierarchy and instead distribute the CPUs and have ‘near’ and ‘far’ data with memory storage at the center.”

Fink likened this change in paradigm to the disruption that arose when scientists believed that the universe revolved around the Earth “and then Copernicus came in and turned that on its head.”

“There is a lot of work across the ecosystem that needs to happen, a lot of invention required,” Fink added, encouraging those in attendance at NVMW to write systems and applications software that rethinks the current hierarchy.

“Martin has the right idea -- the changes that NVMS require are dramatic and we have found that once you start unraveling them, they reach almost every aspect of computer system design,” said Steve Swanson, director of UCSD's Non-volatile Systems Laboratory and co-organizer of the workshop.

Fink acknowledged that modern computing is built on mathematician John Von Neumann's concept that a computer's program and the data it processes can be stored in the computer's memory, but he also noted that Von Neumann proposed this approach in 1945 when computer memory was a scarce resource. Added Fink: “If you had access to all of the existing compute technology, but were building the world's first computer, would you build it the same way? I think the answer is no. It's time to let go of all the conventional thinking.”



NVMW 2017

DIRECTOR'S LETTER



Eric E. Fullerton

As you can see in both the presentations and discussions with students and faculty, the Center for Memory and Recording Research continues to expand its research into non-volatile memories, which complements our strong history in magnetic recording research. The research on non-volatile memory is also highlighted by the 8th annual Non-Volatile Memories Workshop (NVMW), which was held on March 12-14, 2017 and was organized by Paul H. Siegel, Steve Swanson, Eitan Yaakobi, and Hung-wei Tseng (NSU). This workshop provides a unique showcase for outstanding research on solid state, non-volatile memories, and the planning for the next workshop has begun. We also continue to build our partnership between CMRR, NYU, the University of Lorraine, the University of Paris-Sud, and the Thales Laboratory in France. The collaboration is part of the new International Associated Laboratories (LIA), which is a "laboratory without walls", focused on Nanoelectronics and sponsored by the Centre National de la Recherche Scientifique (CNRS) in France. This association will enhance the exchange of faculty, post-docs, and students between labs, and provide new opportunities for collaborative research.

However, I have to close on a sad note, both for myself and the CMRR community. Professor Sheldon "Shelly" Schultz, one of the founding members of the physics faculty at UC San Diego, who received world-wide acclaim for his contributions to the discovery of "metamaterials," passed away on January 31 in his La Jolla home at the age of 84. Professor Schultz was integral in the founding of CMRR and was the Director of CMRR for ten years, where his efforts led to the successful development of CMRR into a world-class research organization. The "Sheldon Schultz Prize for Excellence in Graduate Student Research" was established in part to honor his contributions to CMRR. There will also be a Schultz Symposium on Sept. 18, 2017 at the Jack Keil Wolf auditorium located in CMRR to honor the scientific accomplishments of Shelly Schultz, where the speakers will include a number of Shelly's former students and collaborators.

RESEARCH HIGHLIGHT

Skyrmion Formation in Magnetic Thin Films and Heterostructures

Sergio Montoya, Simon Couture, Vitaliy Lomakin and Eric E. Fullerton, UC San Diego
UC San Diego, CMRR

Magnetic skyrmions are small magnetic domains that are topologically non-trivial as shown schematically in Fig. 1. They are characterized by a twist of the magnetization that forms a continuous winding of the magnetization across the domain. The topology is described by a quantized and conserved winding number. The term skyrmion arises from the original work of Skyrme some fifty years ago that described baryons as topological defects of continuous fields. These defects could be considered "protected" because they were characterized by a topological integer that cannot be changed through any continuous deformation of the field. Since then "skyrmion" states have been found in condensed matter systems such as liquid crystals, quantum Hall systems, ferroelectrics, and magnetic materials. The interest in magnetic skyrmions is driven by novel physics and potential applications. The spin texture topology "protects" skyrmions from scattering by structural defects, allowing them to be moved with $\sim 10^5$ times lower current density than a conventional magnetic domain. These features make magnetic skyrmions appealing for low power memory and information processing applications based on spin torque transfer and the topological spin Hall effect. We have ongoing research into the discovery of new magnetic materials hosting skyrmions, the observation of novel properties of skyrmions and the integration into skyrmion-based devices [1-5].

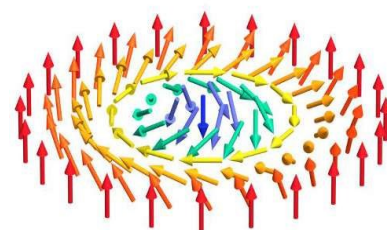


Figure 1: Schematic spin structure of a magnetic skyrmion showing a continuous winding of the magnetization.

Skyrmion Formation in Magnetic Thin Films and Heterostructures

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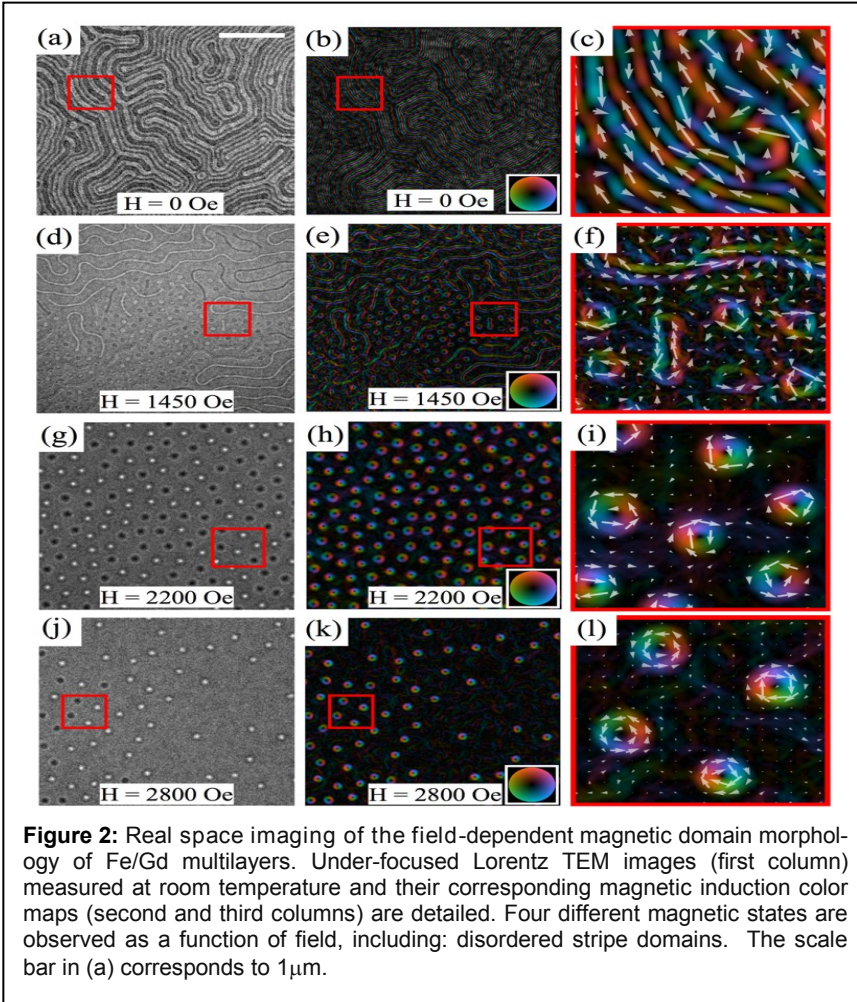


Figure 2: Real space imaging of the field-dependent magnetic domain morphology of Fe/Gd multilayers. Under-focused Lorentz TEM images (first column) measured at room temperature and their corresponding magnetic induction color maps (second and third columns) are detailed. Four different magnetic states are observed as a function of field, including: disordered stripe domains. The scale bar in (a) corresponds to 1 μm .

There are increasing number of magnetic materials where skyrmions have been observed from bulk magnets to thin films and have been shown to be stable under several physical mechanisms. The most heavily studied mechanism to stabilize skyrmions is the Dzyaloshinskii-Moriya interaction arising in non-centrosymmetric magnetic materials or thin films. However, topologically similar spin structures can be stabilized by the competition of long-range dipolar energy in a thin film geometry and domain wall energy, a mechanism by which magnetic stripes and bubbles form. Commonly a chiral magnetic bubble is termed a dipole stabilized skyrmion given the resemblance to a Bloch-type Dzyaloshinskii-Moriya interaction skyrmion shown in Fig. 1 where the domain wall is a Bloch wall. These chiral bubbles or dipole-stabilized skyrmions present a test-bed to explore how the balance of ferromagnetic exchange, anisotropy and dipolar energy results in domains that are topologically non-trivial and to explore their properties.

Shown in Fig. 2 are imaging results for an Fe/Gd multilayers film where we have used the unique features of the ferrimagnetic Fe/Gd system to tune the magnetization, anisotropy, and exchange [1-3]. This has allowed us to stabilize isolated or closed-packed lattices of bound skyrmion molecules [1] or dipole skyrmions [2] under the application of a magnetic field, which are sub-100-nm in size [2]. Unlike in Dzyaloshinskii-Moriya interaction materials, the dipole skyrmion phase consists of an equal population of chiral domains with two possible helicities. Since the Bloch-line continuously wraps around the magnetic texture, we define it as a dipole skyrmion that possesses a winding number $S = 1$. If the Bloch-line wraps itself around in a clockwise direction it has helicity $\gamma = -\pi/2$; conversely, a Bloch-line wall that wraps counter-clockwise has helicity $\gamma = +\pi/2$. Skyrmion molecules (or bi-skyrmions) are when two skyrmions of opposite chirality are bound together [1]. To probe the physics of these skyrmions we have probed them with neutron reflectivity, resonant soft x-ray scattering, resonant soft x-ray imaging, Lorentz TEM (Fig. 2), ferromagnetic resonance, magneto-transport and modeling [1-4].

To understand the detailed three-dimensional magnetic structure of the skyrmion we compared our experimental results to micro-magnetic simulations performed using the FASTMag framework developed at UCSD. Examples are shown in Fig. 3 where we are able to reproduce many of the experimental features in Figs. 2 including both the transition from stripe to skyrmions phases with increasing applied magnetic field using the average properties of the sample. The modeling (Fig. 3) also shows a complex 3-D structure (that is not reflected in the 2-D images in Fig. 2 that are averaged over the thickness of the film) with relatively broad domains walls that have both Néel and Bloch character and closure domains that form towards the surfaces as shown in Fig. 3. We have further been able to probe the resonant properties in modeling and compare the results to ferromagnetic resonant measurements [3].

The Lorentz-TEM images (Fig. 2) and numerical simulations (Fig. 3) suggests the stabilization of these skyrmions is purely driven by competing dipolar and exchange energies and that no Dzyaloshinskii-Moriya interaction is present in these films. The Lorentz-TEM images show two helicity textures with an equal population distribution in the skyrmion phase. If some Dzyaloshinskii-Moriya interaction were present, then the system would likely favor the formation of a one chiral domain compared to the other, as well as one Néel cap orientation over the other which is not the case here. The fact that we numerically observe the stabilization of the same 2-helicity skyrmions in simulations with no Dzyaloshinskii-Moriya interaction supports this observation. Given the nature of these skyrmions we can observe skyrmion molecules and these films could potentially also be designed to host anti-skyrmions as recently theoretically predicted. Unlike bubble domains which typically observed in materials with perpendicular magnetic anisotropy, our chiral domains appear in a material parameter space where the anisotropy is relatively low and the formation of perpendicular domains results from a thickness driven domain morphology rearrangement.

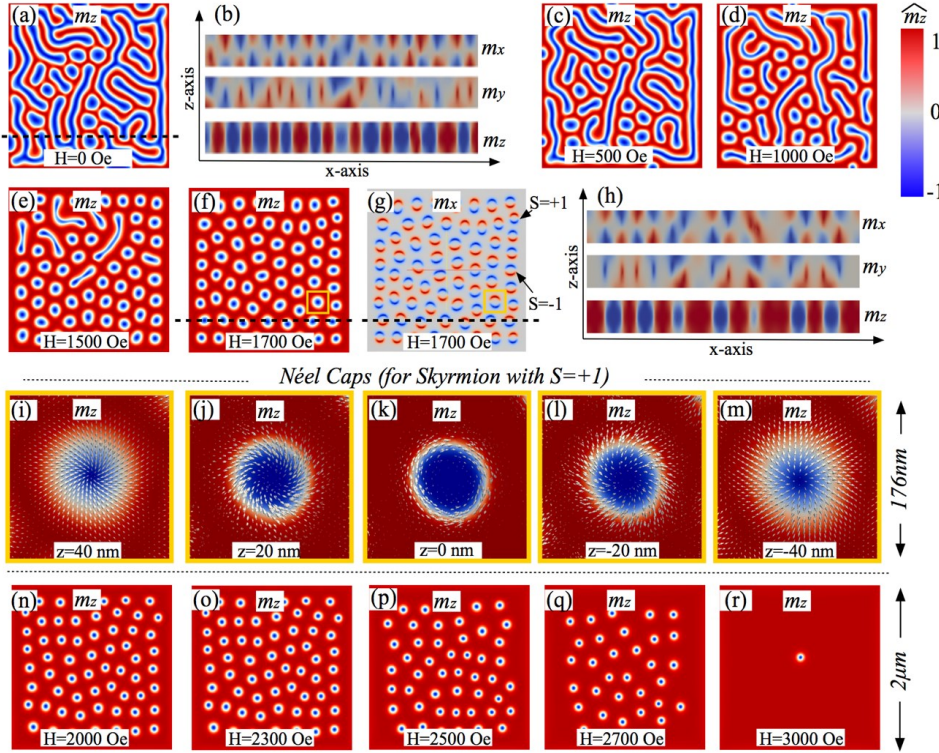
RESEARCH HIGHLIGHT

(Continued from P. 4)

Skyrmion Formation in Magnetic Thin Films and Heterostructures

Sergio Montoya, Simon Couture, Vitaliy Lomakin and Eric E. Fullerton, UC San Diego, CMRR

UC San Diego, CMRR



We have shown that by tuning the magnetic properties and film thickness we can control the stabilization of skyrmion phases in temperature and applied magnetic fields. The simplicity of the magnetic material and the easily tunable properties makes it of interest for studying physics of skyrmions, as well as, for potential memory technologies. We are currently studying the magneto-transport properties and the potential for current-induced control of the skyrmion and skyrmion lattice. Furthermore, the universality of our numerical model presents a roadmap to design new classes of materials that can exhibit dipolar field driven skyrmions. This work was the focus of the Ph.D. thesis of Sergio Montoya [5] and was done in collaboration with S. A. Montoya, S. Couture, J. J. Chess, J. C. T Lee, N. Kent, D. Henze, M.-Y. Im, S.D. Kevan, P. Fischer, B. J. McMorran, V. Lomakin, S. Roy, and S. K. Sinha.

Figure 3: Micromagnetic modeling of domain morphology. (a-r). These images primarily depict the top side view of the magnetization along the z-axis (m_z) at the top surface of the slab ($z=40\text{nm}$). The magnetization (m_z) is represented by regions in red ($+m_z$) and blue ($-m_z$); whereas the in-plane magnetization (m_x , m_y) is represented by white regions surrounding the blue features. (b, h) Illustrates the lateral magnetization components (m_x , m_y , m_z) across the film thickness for the disordered stripe domains in (a) and the skyrmion phase in (f, g) along the dashed line. Inspection along the lateral magnetization reveals a Bloch-like wall configuration with closure domains in both states. The chirality of the skyrmions is depicted in (g) along top side-view of m_x across the center of the slab. (i-m) Detail the magnetization distribution at different depths ($z=40, 20, 0, -20, -40\text{nm}$) for a skyrmion with chirality $S = +1$, $\gamma = -\pi/2$ that is enclosed in a box in (f, g). At each depth, the perpendicular magnetization is represented by blue ($-m_z$) and red ($+m_z$) regions and the in-plane magnetization distribution (m_x and m_y) is depicted by white arrows. The white arrows illustrate how the magnetization of the closure domains and Bloch-line arrange at different depths of the slab. (n-r) Detail the field evolution from an ordered skyrmions to disordered Néel skyrmions.

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- [2]. S. A. Montoya, S. Couture, J. J. Chess, J. C. T Lee, N. Kent, D. Henze, M.-Y. Im, S.D. Kevan, P. Fischer, B. J. McMorran, V. Lomakin, S. Roy, and E.E. Fullerton, "Tailoring magnetic energies to form skyrmions and skyrmion lattices", *Physical Review B* **95**, 024415 (2017).
- [3]. S. A. Montoya, S. Couture, J. J. Chess, J. C. T Lee, N. Kent, M.-Y. Im, S.D. Kevan, P. Fischer, B. J. McMorran, S. Roy, V. Lomakin, and E.E. Fullerton, "Resonant properties of dipole skyrmions in amorphous Fe/Gd multilayers", *Physical Review B*, accepted and in press (2017).
- [4]. J. J. Chess, S. A. Montoya, T. R. Harvey, C. Ophus, S. Couture, V. Lomakin, E. E. Fullerton, and B. J. McMorran, "A streamlined approach to mapping the magnetic induction of skyrmionic materials", *Ultramicroscopy* **177**, 78-83 (2017).
- [5]. S. A. Montoya, "Dipole Stabilized Magnetic Bubbles, Skyrmions and Skyrmion Lattices in Amorphous Fe/Gd Multilayers", Ph.D. Thesis, UCSD (2017).

NEW CMRR RESEARCHERS

POSTDOCTORAL RESEARCHERS



Andreas Rosenkranz is a new postdoctoral researcher in Professor Talke's group. He received his PhD in Material Science and Engineering from Saarland University in 2015. He came to UC San Diego with a Feodor Lynen Research fellowship granted by the Alexander von Humboldt Foundation. His research activities involve characterizing chemical, structural and microstructural changes in carbon overcoat and lubricant layer induced by HAMR using modern characterization techniques with a resolution in the nm-range, such as atomic force microscopy, X-ray photoelectron spectroscopy, Tip-enhanced Raman Spectrometry, and other techniques, and to link these changes to the tribological characteristics of the head disk interface. As a result, the project is intended to provide fundamentally and urgently needed insight into these complicated inter-disciplinary phenomena. The research project can provide a significant contribution to the further development of HDD technology based upon HAMR and will be an important contribution to the development of this technology.

Mohammed El Hadri received his PhD in Physics, Magnetism from the University of Lorraine in 2016. He came to CMRR as a visiting graduate student in 2013 and 2016, and is now a postdoc in Fullerton's group. His research at CMRR involves thin films growth and characterization of materials for optical and magnetic applications. The focus is on the development of ultrathin multilayer growth and structural characterization at sub-5 nm scale with various types of material combinations and its optimization.



Yonglong Li is a new postdoctoral researcher in Professor Paul Siegel's group. He received his PhD in Information Theory from the University of Hong Kong in 2016. His research activities at CMRR involve information-theoretic analysis of channel models for non-volatile memories such as multilevel flash memory, phase change memory, and 3D-memories.

GRADUATE STUDENTS

Yi Liu is a 3rd-year PhD student in the Electrical and Computer Engineering (ECE) department here at UC San Diego working under the supervision of Professor Paul Siegel. He received his B.E. degree in Physics from Peking University, Beijing, China, in 2014. His current research focuses on shaping codes and flash memory characterization.



Anay Pandit is a Masters of Science Student at UC San Diego in the Mechanical Engineering Department. He completed his Bachelor of Engineering in Mechanical Engineering from the University of Mumbai in 2015. He is currently involved in research for developing a disposable medical device for contamination purposes. His previous projects include design and optimization of a Formula One car chassis for Formula Student India competition, and designing a brake fail detection assembly for motorbikes to reduce the accident rate in India. Anay has done internships in reputed companies such as Cymer, USA and Larsen and Toubro, India .

Haowen Ren is a graduate student majoring in Materials Science and Engineering in the Electrical and Computer Engineering (ECE) department at UC San Diego. Haowen started as a student volunteer in Professor Fullerton's group. Currently, his research mainly focuses on fabrication and characterization of magnetic nano-materials and their interplay with superconducting materials. He also studies thin film solid oxide fuel cell in the CER department.



Venkata Tunuguntula is a 2nd-year PhD student in the Electrical and Computer Engineering (ECE) department here at UC San Diego working under the supervision of Professor Paul Siegel. He is currently working on polar codes.

Wei Wu is a 2nd-year PhD student in the Electrical and Computer Engineering (ECE) department here at UC San Diego working under the supervision of Professor Paul Siegel. He received a B.E. degree in Information Engineering from Shanghai Jiao Tong University, Shanghai, China, in 2013 and a M.S. degree in Electrical Engineering from NYU Tandon School of Engineering, New York, NY, in 2015. His research interests are communication network, information theory and coding theory. His current research focuses on polar codes and polarization theory.



Xueyang Wang is a first-year graduate student in the Electrical Computer Engineering (ECE) department at UC San Diego. He obtained his bachelor degree in Tsinghua University in Beijing, China. He is currently working on developing GPU accelerated algorithms in the lab of Professor Vitaliy Lomakin.

NEW CMRR RESEARCHERS

VISITING SCHOLARS



Lingjun Kong is an associate professor at Najing University of Posts & Communications. His visit to Professor Paul Siegel's group at CMRR is sponsored by the China Scholarship Council. His research involves signal processing and coding for non-volatile memories and high density magnetic recording.

Dr. **Longqiu Li** is a Professor at Harbin Institute of Technology (HIT), China. He received his PhD from HIT in 2010 and became an assistant professor. During his PhD studies, he spent two years as a visiting graduate student at CMRR between 2008-2010, then as a visiting research scientist in 2014. His research interests are involved in the mechanics and multiple modeling (MD, FEA), as well as experimental study on mechanical, electrical and physical properties of surfaces and interfaces of micro/nano structures, thin films, photonic crystals, MEMS/NEMS. Dr. Longqiu Li joined Prof. Talke's group again this year as a visiting scholar working on in situ investigation of head/disk interface of Heat Assisted Magnetic Recording (HAMR).



Yiting Wu is a visiting graduate student from the Nanjing University of Science and Technology in China, and was awarded a scholarship by NUST to come to UCSD. His main research interests include time-domain integral solvers and their application in electromagnetic compatibility problems. Yiting is a PhD candidate working under the supervision of Professor Vitaliy Lomakin on investigation of fast algorithms for integral solvers like Multi-Level Non-uniform grid Time-Domain.

VISITING GRADUATE STUDENTS

Alexander Kief is a visiting graduate student in Professor Talke's group. He is currently a PhD candidate at the Technical University of Munich. At CMRR he worked with Alex Phan and Phuong Truong on the intra-ocular pressure sensor project (IOP). He concentrated on the design and hardware implementation of a hand-held interface fringe read-out, and on improving the manufacturability and reliability of our sensor. He completed the fringe read-out device and obtained very promising results. Alex completed his Master's thesis before returning to Germany, and defended the thesis on April 27, 2017, in Munich. Alex's visit to CMRR was partially supported by a BaCal grant. He is starting his permanent job at Mercedes Benz in Germany in May of this year.



Lars Ringel is a visiting graduate student in Prof. Talke's group. He studied mechanical engineering with focus on development and design at RWTH Aachen University in Germany. He is interested in the field of medical devices and joined CMRR in February. Currently, he is working on a 3-D printable, disposable endoscope.

Mark Van Ommeren is a visiting graduate student in Professor Fullerton's group. He is working on his Master's degree in applied physics at the University of Technology in Eindhoven, in the Netherlands. Part of his program includes a three month long project in another country. Therefore, he is currently working under the supervision of Prof. Eric Fullerton and PhD Rajasekhar Medapalli at UC San Diego. His research includes the asymmetric displacement of skyrmions (which are a specific kind of magnetic domain walls) under the effect of short current pulses. He is a PhD candidate at the Eindhoven University of Technology.



AWARDS



Professor Eric E. Fullerton received a J. William Fulbright Foreign Scholarship Award to France. Professor Fullerton's hard work and dedication has earned him this award. Fulbright alumni have become heads of state, judges, ambassadors, cabinet ministers, CEOs, and university presidents, as well as leading journalists, artists, scientists, and teachers. They include 58 Nobel Laureates, 82 Pulitzer Prize winners, 31 MacArthur Fellows, 16 Presidential Medal of Freedom recipients, and thousands of leaders across the private, public, and non-profit sectors. Congratulations, Professor Fullerton!

Nelson Hua, a PhD student in Professor Oleg Shpyrko's physics lab, has been awarded the 2016 Chateaubriand STEM Fellowship.

The Chateaubriand Fellowship in Science, Technology, Engineering, Mathematics & Health for doctoral students aims to initiate or reinforce collaborations, partnerships or joint projects between French and American research teams. The Chateaubriand Fellowship supports PhD students registered in an American university who wish to conduct part of their doctoral research in a French laboratory. This fellowship is offered by the Office for Science & Technology (OST) of the Embassy of France in Washington in partnership with American universities and French research organizations such as CNRS, Inria and Inserm. It is a partner of the National Science Foundation's GROW program.



FAREWELL & WELCOME



Congratulations on graduation, Gabby!

Gabby started working at CMRR during her freshman year at UCSD. As a member of the CMRR team, she exhibited enormous enthusiasm in her job. She has shown to be very creative, as displayed when she was in charge of NVMW giveaways, flyers for special events, and various holiday parties. She is a great coordinator and has excellent customer support. Congratulations Gabby and thank you for giving us four years of dedication. Job well done.



Welcome, Sally!

Sally is a third-year undergraduate student majoring in Economics and double-minoring in Business and Literatures of the World. She currently holds an executive position for Cornerstone Community Consultants, and used to work for The Guardian newspaper as a Senior Staff Writer. She is very excited to bring her past experiences and learned skills to CMRR as the new Administrative Coordinator. She will also be involved in the process of restructuring the CMRR website.

Selected Papers

Professor Eric Fullerton

P. W. Granitzka, E. Jal, L. Le Guyader, M. Savoini, D. J. Higley, T. Liu, Z. Chen, T. Chase, H. Ohldag, G. L. Dakovski, W. Schlotter, S. Carron, M. Hoffman, P. Shafer, E. Arenholz, O. Hellwig, V. Mehta, Y. K. Takahashi, S. L. Johnson, **E. E. Fullerton**, J. Stöhr, A. H. Reid and H. A. Dürr, "Magnetic switching in granular FePt layers promoted by near-field laser enhancement", *Nano Letters*, Vol. 17, No. 04 (Apr. 2017) pp 2426-2432.

H.-H. Lin, M.-H. Yang, R. Sharma, M. W. Puckett, S. Montoya, C. D. Wurm, F. Vallini, **E. E. Fullerton**, and Y. Fainman, "Synthesis of second-order nonlinearities in dielectric-semiconductor-dielectric metamaterials", *Applied Physics Letters*, Vol. 110, No. 11 (Mar. 2017) pp 113103/1-4.

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J. S. T. Smalley, F. Valini, S. Montoya, L. Ferrari, S. Shahin, C. T. Riley, B. Kanté, **E. E. Fullerton**, Z. Liu, and Y. Fainman, "Luminescent Hyperbolic Metasurfaces", *Nature Communications*, Vol. 8, (Jan. 2017) pp 13793/1-8.

Y.K. Takahashi, R. Medapalli, S. Kasai, J. Wang, K. Ishioka, S.H. Wee, O. Hellwig, K. Hono, and **E.E. Fullerton**, "Accumulative Magnetic Switching of Ultra-High-Density Recording Media by Circularly Polarized Light", *Physical Review Applied*, Vol. 6, No. 5 (Nov. 2016) pp 174110/1-5

Professor Frank Talke

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