Professor Raymond de Callafon


Professor Eric F. Fullerton


T. Zhang and E. Talke. “Microfluidic Switches with all-optical control on a small random access memories.” Their work was then a postdoctoral fellow in the Physics and Nanotechnology Department at UCSC on low-temperature physics as related to quantum information processing. Dr. Bandaru then joined UC San Diego as an assistant professor.

Bandaru and his research group are mainly interested in analytical and experimental materials science, physics and chemistry, broadley looking at the electrical, thermal, electro-chemical, magnetic, photonic and magnetic properties of materials at the mesoscopic and microscopic levels. Bandaru Professor Vitaliy Lomakin


Professor Steve Swanson


Professor Frank Talke


P. K. Nguyen, S. Jin and A. E. Berkowitz. “Multi particles with high energy density made by spark erosion,” Published Aug. 21 in the journal Science Express, focused on materials currently being developed for high-density storag applications. Ferromagnetism’s most familiar form is the humble refrigerator magnet, but it is also a core component in many electrical devices, including magnetic storage used in commercial computing applications. In traditional magnetic storage devices magnetic bits are switched using magnetic fields, a slow process that consumes considerable energy and is reaching its density limits. For example, storing a single bit of data requires the direction of magnetization to be opposite orientation. “There is also a lot of work to understand the underlying mechanisms for optical switching of ferromagnets,” said Fullerton. “We showed it works and how to optimize it for applications still need to be addressed.”

The research team includes first author Charles-Henri Lambert a Ph.D. student at the University of Lorraine in France who participated in the research as a visiting student at UC San Diego and second author Stephane Magin, also of the University of Lorraine, who was on sabbatical at UC San Diego at the time.

The paper is “All-optical control of ferromagnetic thin films and nanostructures.” In addition to Magin and Lambert, the international research partners included scientists from the National Institute for Materials Science in Japan and University of Lorraine in France. The research was funded in part by an Office of Naval Research Multidisciplinary University Research Award.

"Our results showing that it is possible to switch magnetic bits using only the polarization of light could significantly simplify the design and improve the speed of the storage recording," said CMRR director and electrical and computer engineering professor Eric Fullerton. "Magnetic storage is emerging in the memory market due to demands for high-density, fast, and low power non-volatile memory. As industry trends toward silicon nanophotonics, miniaturization, and photonics-electronics integration the ability to couple photonic, electronic, and magnetic materials could enable completely new applications."

Fullerton is also a professor of nanengineering at UC San Diego Jacobs School of Engineering.

Hard Drives: Faster, Simpler and Higher Density

Researchers in the Center for Magnetic Recording Research (CMRR) at the Jacobs School of Engineering have discovered that a wide range of ferromagnetic materials, including magnetic thin films, multilayers and granular films. Previously, scientists have only been able to use all-optical control on a small set of ferromagnetic materials that did not lend themselves for data storage applications.

The next step is to scale the technology to be able to write data on the nanoscale (vs. the micrometers as the team demonstrated) and time scales required for data storage applications.

"Also there is a lot of work to understand the underlying mechanisms for optical switching of ferromagnets,” said Fullerton. “We showed it works and how to optimize it for applications still need to be addressed.”

The research team includes first author Charles-Henri Lambert a Ph.D. student at the University of Lorraine in France who participated in the research as a visiting student at UC San Diego and second author Stephane Magin, also of the University of Lorraine, who was on sabbatical at UC San Diego at the time.

The paper is “All-optical control of ferromagnetic thin films and nanostructures.” In addition to Magin and Lambert, the international research partners included scientists from the National Institute for Materials Science in Japan and University of Lorraine in France. The research was funded in part by an Office of Naval Research Multidisciplinary University Research Award.
This newsletter comes at a time with many new activities as well as new and returning faces to CMRR. The center was re- reviewed as an organized research unit (ORU) after a one-year review by the UCSD Office of Research Affairs. The conclusions were very positive and commented on the breadth of research and strong funding from our corporate members as well as state and federal sponsors. In the review process, it was recommended that a name change may be needed to reflect the current research portfolio. To address this issue, we are considering a name change to Center for Memory and Recording Research to maintain the CMRR acronym but reflect the research in non-volatile memory.

We welcome our visiting scholars: Dr. Yukiko Takahashi from the National Institute for Materials Science in Tsukuba, Japan; Dr. Yuan Zhu from Sun Yat-sen University in China; Dr. Jun Huyn Han from Chungnam National University, and Dr. Jin-Kyu Byun from Soongsil University, in Daejon and Seoul, Korea, respectively. We also welcome three new visiting graduate students; six Ph.D. students, three new post-doctoral researchers and several undergraduates who are volunteers. Welcome to all of you.

Over the summer, we had eight CMRR graduate students participating in summer internships with a range of employers, including Western Digital, Intel, HGST, Northrop Grumman, Sandia National Lab, and SPAWAR. Their summer projects covered much of the current research at CMRR. This strong interaction of our students with our industry partners is a cornerstone of the CMRR mission, i.e., to train students for the information technology industries. We hope you will continue to keep this strong participation of our students with our corporate sponsors in the coming years.

We continue to expand our educational and outreach efforts by organizing various conferences and workshops. In particular, I would like to highlight the upcoming 6th annual Non-Volatile Memories Workshop (NVMW 2015), part of a conference series that provides a unique showcase for outstanding research on solid-state, non-volatile memories. It will feature a vertically-integrated program that includes presentations on devices, data encoding, systems architecture, and applications related to these exciting new data storage technologies. NVMW 2014 included 32 speakers from top universities, industry research labs, and device manufacturers, and the workshop attracted over 230 attendees. For more information, visit http://nvmw.ucsd.edu/. We plan to host more such workshops going forward and as part of future research reviews. We would appreciate input on potential topics.

Finally I would like to highlight that we are changing the name of the CMRR auditorium to the Jack Keil Wolf Auditorium at CMRR in honor of the late Jack Wolf, one of the founding members of the CMRR, for his many contributions to the center. The name change will be Oct. 28 at 2-4pm in the Jack Keil Wolf Auditorium. The event will include a technical presentation by Prof. Shivendra S. Panwar on the topic, “Streamloading: Low-Cost, High-Quality Video Streaming,” (see page 4), as well as brief testimonials by some of Jack’s former students and remarks from campus administrators. I hope you may be able to join us.

The authors of this article are Massimiliano Di Ventra from the Department of Physics at UC San Diego, Fabio Traversa from the Department of Physics at UC San Diego and the Department of Electronics and Telecommunication at the Politecnico di Torino in Turin, Italy, and Yuriy V. Pershin from the Department of Physics and Astronomy at the University of South Carolina in Columbia, SC.

The corresponding author of this article is Massimiliano Di Ventra. He can be contacted at diventa@physics.ucsd.edu.

This work is a collaborative effort between CMRR and the Physics Departments at UC San Diego and the University of South Carolina. It is partially supported by NSF grant ECCS-1102383.

Ph.D. Graduates

MINHAI QIN
Department: ECE
Ph.D.: September 2014
Advisor: Paul H. Siegel
Thesis: Signal Processing and Coding for Non-Volatile Memories
Storage Architecture Engineer
Now at HGST Research

AMAN BHATIA
Department: ECE
Ph.D.: August 2014
Advisor: Paul H. Siegel
Thesis: Improved Coding Techniques for Digital Recording Systems
Job: NAND Management
Now at SK Hynix Memory Solutions

RUINAN CHANG
Department: ECE
Ph.D.: September 2014
Advisor: Vitaly Lomakin
Thesis: Finite Element and Integral Equation Methods for High-Performance Micromagnetic and Electromagnetic Solvers
Now at Oracle

Letter from the Director

Eric Fullerton
Director, CMRR

We welcome our visiting scholars: Dr. Yukiko Takahashi from the National Institute for Materials Science in Tsukuba, Japan; Dr. Yuan Zhu from Sun Yat-sen University in China; Dr. Jun Huyn Han from Chungnam National University, and Dr. Jin-Kyu Byun from Soongsil University, in Daejon and Seoul, Korea, respectively. We also welcome three new visiting graduate students; six Ph.D. students, three new post-doctoral researchers and several undergraduates who are volunteers. Welcome to all of you.

Over the summer, we had eight CMRR graduate students participating in summer internships with a range of employers, including Western Digital, Intel, HGST, Northrop Grumman, Sandia National Lab, and SPAWAR. Their summer projects covered much of the current research at CMRR. This strong interaction of our students with our industry partners is a cornerstone of the CMRR mission, i.e., to train students for the information technology industries. We hope you continue to keep this strong participation of our students with our corporate sponsors in the coming years.

We continue to expand our educational and outreach efforts by organizing various conferences and workshops. In particular, I would like to highlight the upcoming 6th annual Non-Volatile Memories Workshop (NVMW 2015), part of a conference series that provides a unique showcase for outstanding research on solid-state, non-volatile memories. It will feature a vertically-integrated program that includes presentations on devices, data encoding, systems architecture, and applications related to these exciting new data storage technologies. NVMW 2014 included 32 speakers from top universities, industry research labs, and device manufacturers, and the workshop attracted over 230 attendees. For more information, visit http://nvmw.ucsd.edu/. We plan to host more such workshops going forward and as part of future research reviews. We would appreciate input on potential topics.

Finally I would like to highlight that we are changing the name of the CMRR auditorium to the Jack Keil Wolf Auditorium at CMRR in honor of the late Jack Wolf, one of the founding members of the CMRR, for his many contributions to the center. The name change will be Oct. 28 at 2-4pm in the Jack Keil Wolf Auditorium. The event will include a technical presentation by Prof. Shivendra S. Panwar on the topic, “Streamloading: Low-Cost, High-Quality Video Streaming,” (see page 4), as well as brief testimonials by some of Jack’s former students and remarks from campus administrators. I hope you may be able to join us.

The authors of this article are Massimiliano Di Ventra from the Department of Physics at UC San Diego, Fabio Traversa from the Department of Physics at UC San Diego and the Department of Electronics and Telecommunication at the Politecnico di Torino in Turin, Italy, and Yuriy V. Pershin from the Department of Physics and Astronomy at the University of South Carolina in Columbia, SC.

The corresponding author of this article is Massimiliano Di Ventra. He can be contacted at diventa@physics.ucsd.edu.

This work is a collaborative effort between CMRR and the Physics Departments at UC San Diego and the University of South Carolina. It is partially supported by NSF grant ECCS-1102383.

Ph.D. Graduates

MINHAI QIN
Department: ECE
Ph.D.: September 2014
Advisor: Paul H. Siegel
Thesis: Signal Processing and Coding for Non-Volatile Memories
Storage Architecture Engineer
Now at HGST Research

AMAN BHATIA
Department: ECE
Ph.D.: August 2014
Advisor: Paul H. Siegel
Thesis: Improved Coding Techniques for Digital Recording Systems
Job: NAND Management
Now at SK Hynix Memory Solutions

RUINAN CHANG
Department: ECE
Ph.D.: September 2014
Advisor: Vitaly Lomakin
Thesis: Finite Element and Integral Equation Methods for High-Performance Micromagnetic and Electromagnetic Solvers
Now at Oracle

Letter from the Director

Eric Fullerton
Director, CMRR
be made using CMOS-compatible structures and devices, thus offer- ing unprecedented opportunities in electronics. In particular, these stan- dard and non-standard systems and devices allow precisely the paradigm we are looking for. We named this paradigm memcomputing i.e., comput- ing within memory [4], [5], namely, the ability to process information directly in the memory (see Figure 1, right panel for a schematic of a memcomputing architecture). This computing paradigm rests on the solid mathematical foundation of uni- versal memcomputing machines [5]. We have indeed recently shown that these machines have the same com- putational power of non-determinis- tic Turing machines, thus allowing the solution of complex problems in polynomial time with polynomial resources.

Practical realizations

We have recently proposed a simple and practical realization of mem- computing [6] that utilizes easy-to- build memcapacitive systems [15]. We have named this architecture dynamic computing random access memory (DCRAM) (see Fig. 2). We have shown that DCRAM provides massively parallel and polymorphic digital logic; namely, it allows for different logic operations within the same architecture by varying only the control signals. In addition, by taking into account realistic param- eters, its energy expenditures can be as low as a few fJ per operation. DCRAM is also fully compatible with CMOS technology, can be realized with current fabrication facilities and therefore can serve as an alternative to the present computing technology.

Conclusions

In conclusion, we have introduced the concept of computing with and in memory: memcomputing. This new computing para- digm employs the Turing machine concept [2], [3], and involves a significant amount of information transfer between a central pro- cessing unit (CPU) and memory, with concomitant limitations in the actual execution speed and large amounts of energy used to move data. Therefore, there is currently a surge of interest in unconventional computing approaches [4]-[11] that can outperform the present Von Neumann approach [4], [5]. It is clear that such alternatives have to fundamentally depart from the existing one in both their compu- tational complexity as well as in the way they handle information. For at least a couple of decades, quantum computing [12] has been considered a promising alternative in view of its intrinsic massive paral- lelism afforded by the superposition principle of quantum mechanics. However, the practical realization of quantum computers seems still too far away from the practical and yet near-future, technologies. In order to overcome the above mentioned limitations, we need to look for another paradigm. The sol- id-state simulation of our own brain may provide the solution.

RESEARCH HIGHLIGHT

Memcomputing: Computing With and In Memory

The Need for a New Computing Paradigm

Current electronic systems used for computing (CPU, workstations, and clusters) are based on the von Neumann architecture (see Figure 1, left panel) [11]. This computing par- adigm employs the Turing machine concept [2], [3], and involves a significant amount of information transfer between a central pro- cessing unit (CPU) and memory, with concomitant limitations in the actual execution speed and large amounts of energy used to move data. Therefore, there is currently a surge of interest in unconventional computing approaches [4]-[11] that can outperform the present Von Neumann approach [4], [5]. It is clear that such alternatives have to fundamentally depart from the existing one in both their computational complexity as well as in the way they handle information. For at least a couple of decades, quantum computing [12] has been considered a promising alternative in view of its intrinsic massive parallelism afforded by the superposition principle of quantum mechanics. However, the practical realization of quantum computers seems still too far away from the practical and yet near-future, technologies.

In order to overcome the above mentioned limitations, we need to look for another paradigm. The solid-state simulation of our own brain may provide the solution.

It is estimated that our brain uses only 10 to 25 Watts per day to perform about 1016 operations per second [13]. A supercomputer would require more than 107 times that power to do the same amount of operations. And a computer does not even come close to performing such complicated tasks as pattern recognition, optimization problems, decision making, etc., we do in the noisy and unpredictable environment we live in, and in a massively-parallel way.

How is it then pos- sible that our brain is such a powerful computing machine and yet uses so lit- tle energy to oper- ate? The answer definitely cannot come only from the number of computing elements (about 1011 neurons). Rather, it has to ultimately boil down to the fundamentally different way in which computation and information storage are accomplished in our brain. In fact, unlike our present (super) computers, calcula- tions in the brain are not performed in a CPU that is physically sepa- rated from the memory: our brain computes and stores information in the same physical location. This way of computing avoids the large amount of information transfer to the CPU and the memory, sav- ing both energy and time.

Memcomputing

Can we realize this paradigm in the solid state? The answer is yes, with the availability of CMOS technology, as well as materials or two-terminal systems that can hold information even in the absence of an external power source. These systems are resistors, capacitors and inductors with memory (memristors, memcapacitors, and meminductors, respectively) [14]. They can also be made using CMOS-compatible structures and devices, thus offering unprece- dented opportunities in electronics. In particular, these standard and non-standard systems and devices allow precisely the paradigm we are looking for. We named this paradigm memcomputing i.e., computing within memory (see Figure 1, right panel for a schematic of a memcomputing architecture). This computing paradigm rests on the solid mathematical foundation of universal memcomputing machines [5]. We have indeed recently shown that these machines have the same computational power of non-deterministic Turing machines, thus allowing the solution of complex problems in polynomial time with polynomial resources.

“Can we realize this paradigm in the solid state? The answer is yes.”

References

James Anagnost is a fourth-year undergraduate student studying Electrical Engineering at the UC San Diego. He is currently working in the lab of Dr. Fred Spada for Safe Erasure of Magnetic Data. In future, Anagnost plans to pursue graduate studies in Signal Processing, Materials Science, or Photonics.

Sarit Buzaglo is a post-doctoral employee at CMRR under the supervision of Prof. Paul H. Siegel. She has recently received her Ph.D. from the Department of Computer Science at Technion-Israel Institute of Technology, where she has worked under the supervision of Prof. Tuvi Etzion and Prof. Alfan Yaakobi. Dr. Buzaglo’s research interests include error-correcting coding for storage devices and fault-tolerant coding for distributed storage networks.

Jin-Kyu Byun is an associate professor at Soongsil University in Seoul, Korea. He received his Ph.D. from Seoul National University in 2001, and worked as a post-doctoral researcher at the University of Illinois at Urbana-Champaign from 2003-2005. Prof. Byun’s research interests include optimization of electromagnetic devices, simulation of magnetic field-induced current in the human body and simulation of wireless power-transfer systems. Dr. Byun joined Prof. Vitaly Lomakin’s research group as a visiting scholar in January 2014. His current research focus involves the optimal design of spin torque oscillators (STOs) using FastMag, a micromagnetic simulator.

Matthew Ellis is a Ph.D. student from the University of York in the UK, where he is studying under the supervision of Prof. Roy Chantrell. For his Ph.D., Ellis has worked on computational models of magnetization dynamics and magnetic recording media at an atomistic scale. In particular, he has investigated the properties of FePt for heat-assisted magnetic recording. He is joining CMRR to work with Prof. Fullerton in modeling all-optical switching in FePt.

Jun Hyun Han is currently a visiting scholar in Prof. Sungho Jin’s research group. Since 2011, he has been an associate professor in the Department of Nano Materials Engineering at Chungnam National University in Daejeon, South Korea. Han obtained his Ph.D. in 2004 in Materials Science and Engineering from Seoul National University. Prof. Han’s current research interests at UC San Diego include fatigue lifetime improvement of the magnetic shape memory alloy thin films, which can be applicable to micro-actuators and control test of magnetic thin films.

Tyler Hennen is an incoming graduate student joining the group of Prof. Eric Fullerton. He previously worked at HGST San Jose Research Center doing magnetic characterization of advanced recording media. Hennen received a dual Bachelor’s degree in Physics and Mathematics from the University of Minnesota.

Chih-Cheng Huang is a second-year Ph.D. student in the Materials Science and Engineering Program at UC San Diego. He received his B.S. degree in Materials Science and Engineering from National Taiwan University in 2010 and M.S. degree in Nanoengineering from National Tsing Hua University in 2012. He is currently working with Prof. Drew Hall to develop a novel, magnetoresistive biosensing platform based on magnetorelaxometry (in collaboration with Prof. Eric Fullerton).

Pengfei Huang is a new graduate student in Prof. Paul Siegel’s group. He earned his M.S. degree in Information and Communication Engineering in 2013 from Shanghai Jiao Tong University, after which he enrolled in UC San Diego to do his doctoral in Communication Theory and Systems (which he hopes to complete in 2017). Huang received his B.S. degree from Zhejiang University in Information and Communication Engineering in 2010.

Gunwoo Kim is a second-year Ph.D. student in Materials Science and Engineering at UC San Diego. He obtained his M.S. from the Department of Science at the University of Tokyo. He is working under the supervision of Prof. Sungho Jin, whose research interest is in superparamagnetic nanoparticles and their applications.

Roojali Kukreja is a post-doctoral researcher at CMRR who will be working under the supervision of Prof. Eric Fullerton, effective Oct. 15, 2014. She obtained her Ph.D. from Stanford University in Materials Science and Engineering. During her Ph.D., Dr. Kukreja worked on imaging of ultrafast phase separation in magnetic and spin-injection and nanomagnetism across a Co/Cu interface. She will fault-tolerant coding for distributed storage networks. Sheena Patel is an incoming first-year graduate student in the Physics Department at UC San Diego. She received her B.S. in Physics from Harvey Mudd College in 2014, where she studied magnetotransport properties of ferromagnetic CoNi multilayers and ferromagnetic Co/Cu multilayers. She joined Prof. Fullerton’s group in August 2014.

Conrad Rizal has been a Postdoctoral Scholar-Employee at CMRR since June 9, 2014. He is working under the supervision of Professors Fullerton and Zhaowei Liu, and his scientific activities include optimizing magnetic microstructure, and magneto-optical properties of ferromagnetic multilayers, as well as developing novel magnetoplasmonic materials and devices. Dr. Rizal obtained his Ph.D. in Electrical Engineering at the University of British Columbia, Canada, and M.Sc. in electronics at the Muranor Institute of Technology in Japan.

Yukiko Takahashi is a visiting scholar from the National Institute for Materials Science, Japan, where she works on the magnetic properties for HDD and spintronic devices. Takahashi is working in the lab of Prof. Eric Fullerton, where she will investigate magnetic properties of non-magnetic materials with magnetic and micromagnetic simulation.

Iana Volvach is an incoming Ph.D. student in the Materials Science and Engineering program at UC San Diego. She obtained her M.S. degree in the Department of Radio Physics at Kharkiv National University in Ukraine. Volvach is working under the supervision of Prof. Vitaliy Lomakin, and her research interest involves physics of nanomagnetic materials and micromagnetic modeling and simulation.

Sicong Yan is a second-year graduate student at CMRR working under the supervision of Prof. Lomakin. He received his B.S. degree in July 2013 and is currently a second-year graduate student from Tongji University in Shanghai, where he is working on a Master’s degree in electromagnetic and microwave technology. At CMRR, he is working in the lab of Prof. Lomakin on computational electromagnetics.

Sarah (Ying) Zhong is a third-year Ph.D. student from State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin, China. She came to UC San Diego in September 2013 as a visiting student for a two-year program supervised by Prof. Sungho Jin. Her main research interest is in materials and their application and reliability in electronic packaging. Zhong is working on nano-sensors for electronic devices.

Yuan Zhu is a visiting scholar in Prof. Zhaowei Liu’s group. Dr. Zhu received her BE and Ph.D. degrees in Materials Science from Tsinghua University in China. Her research interests center on heat transfer materials/ measurement, semiconductor materials and optoelectronics. At CMRR, Dr. Zhu is working on heat transport measurement in metamaterials.