Straintronics: Switching nanomagnets with strain for extremely energy-efficient Boolean and non-Boolean computing

Presented by

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Wednesday, November 16, 2016
4:00 PM
F.W. Olin Hall Room 105
2190 E. Iliff Avenue
Refreshments at 3:45PM in the Olin Rotunda

Many of today’s computing challenges (protein folding, decoding the human genome, weather forecasting, predicting stock market behavior) require massive computational resources and cognitive computing capability that call for major advances in computing machinery. Two looming roadblocks in the way of such advances are: (1) the excessive energy dissipation that occurs in performing a computation, and (2) the inability of the same device to perform a computation and then store the result in-situ, thereby doubling as both logic and memory.

We have developed the field of “straintronic computing” which is an extremely energy-efficient hardware platform where nanotransistors that act as the basic digital switch are replaced with multiferroic nanomagnets. The nanomagnets switch between two stable magnetization states which encode the binary bits 0 and 1. The switching is accomplished by mechanically straining the multiferroic nanomagnets with a tiny voltage (few mV) which results in a miniscule energy dissipation of few aJ (1-2 orders of magnitude less than in state-of-the-art nanotransistors). We have experimentally demonstrated Boolean logic operation, Bennett clocking and non-volatile rewritable non-toggle memory with Co and FeGa nanomagnets fabricated on a piezoelectric PMN-PT substrate. The energy dissipation per bit operation extrapolated from the experimental results is 3-4 aJ for scaled devices.

Straintronic logic is non-volatile, i.e. the Boolean gate remembers the output bits after powering off. This feature can be exploited to build powerful computing architectures such as Bayesian inference engines which can compute in the presence of uncertainty (stock market, disease progression). The device characteristics can be engineered to have unusual features (e.g. a sharp notch in the transfer characteristic) which can be exploited to build ternary content addressable memory with high device density and low standby power dissipation. This talk will provide a broad overview of straintronic computing and discuss recent progress.

1 In collaboration with Prof. Jayasimha Atulasimha of Virginia Commonwealth University, Prof. Jianping Wang of Univ. of Minnesota, Prof. Csaba Andras Moritz of Univ. of Massachusetts at Amherst and Prof. Amit Ranjan Trivedi of University of Illinois at Chicago. This work has been supported by the US National Science Foundation under grants ECCS-1124714 and CCF-1216614, as well as by the Semiconductor Research Corporation and the State of Virginia through the Center for Innovative Technology.
Supriyo Bandyopadhyay is Commonwealth Professor of Electrical and Computer Engineering at Virginia Commonwealth University where he directs the Quantum Device Laboratory. Research in the laboratory has been frequently featured in national and international media (newspapers, internet blogs, magazines such as Business Week and EE Times, CBS, NPR, journal highlights such as Nature highlights, and internet news portals). Inventions made in this laboratory have been featured in the US Army Nanoscience Poster prepared for the Pentagon and have resulted in multiple patents (one licensed). Its educational activities were highlighted in a pilot study conducted by the ASME at Pennsylvania State University to assess nanotechnology pipeline challenges. The laboratory has graduated many outstanding Ph.D.s who have become internationally recognized faculty members and won numerous national and international awards, including the Nano Pioneer Award (highest honor from the IEEE Nanotechnology Council), the TRLabs Innovation Award in Canada and the Materials Research Society Medal.

Prof. Bandyopadhyay has authored and co-authored nearly 400 research publications and presented some 150 invited talks and colloquia across four continents. He has also authored/co-authored two classic textbooks that have taught the field of spintronics and quantum device theory to hundreds of thousands of students across the world. He is currently a member of the editorial board of nine international journals and served in the editorial boards of three other journals in the past. He is the current Chair of the Institute of Electrical and Electronics Engineers (IEEE) Technical Committee on Spintronics (Nanotechnology Council), and past-chair of the Technical Committee on Compound Semiconductor Devices and Circuits (Electron Device Society). He was an IEEE Electron Device Society Distinguished Lecturer (2002-2012), and is currently an IEEE Nanotechnology Council Distinguished Lecturer. He is also a past Vice President of the IEEE Nanotechnology Council and had served in many administrative committees of that Council.

Prof. Bandyopadhyay received the College of Engineering Research Award (1998), the College of Engineering Service Award (2000) and the Interdisciplinary Research Award (2001) given jointly by the College of Engineering, the College of Science and the Institute of Agricultural and Natural Resources at University of Nebraska-Lincoln. At Virginia Commonwealth University, he was given the Lifetime Achievement Award by his department for sustained contributions to scholarship, education and service (one of two given by the department in its history). He was also honored by Virginia Commonwealth University with the Distinguished Scholarship Award (2012) given annually to one faculty member in the University spanning all disciplines of science, technology, business, arts, humanities, life sciences and medicine. It is the highest award given by the University for scholarship. In 2016, he was named Virginia’s Outstanding Scientist by Governor Terence R. McAuliffe. His alma mater, the Indian Institute of Technology, Kharagpur, India named him a distinguished alumnus in 2016.

Prof. Bandyopadhyay is a Fellow of the Institute of Electrical and Electronics Engineers, the Institute of Physics, American Physical Society, the Electrochemical Society and the American Association for the Advancement of Science.