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Spins, Bits, and Flips: Essentials for High-Density Magnetic Random-Access Memory

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Abstract:

The magnetic tunnel junction (MTJ), a device comprised of two ferromagnetic electrodes with a thin (about 1 nm) insulating tunnel barrier in between, was first proposed in a Ph.D. thesis by Michel Jullière in 1975 [1], [2] and reached widespread commercialization nearly 30 years later as the read sensor in hard disk drives. MTJs became essential for data storage in consumer laptop and desktop computers, early-generation iPods, and now in data centers that store the information in “the Cloud.” The application of MTJs has expanded even further, becoming the storage element in non-volatile memory, first in toggle magnetic random access memory (MRAM) used in automotive applications and outer space, and now in the production of spin-transfer torque MRAM as a replacement for embedded flash memory. As computing capabilities advance and drive demand for high-performance memory, innovation in MTJ continues in order to deliver faster, high-density MRAM that can support last-level cache, in-memory computing, and artificial intelligence.

In this talk, I will describe the seminal discoveries [3] that enabled MTJs for pervasive use in hard disk drives, MRAM, and magnetic sensors, such as the discovery of tunnel magnetoresistance (TMR) at room temperature, the invention of spin-transfer torque as the means to flip magnetization without a magnetic field, and the prediction and realization of high TMR using MgO tunnel barriers. As the demand for faster and higher density memory persists, still more breakthroughs are needed for MTJs contained in device pillars (or bits) just tens of nanometers in diameter. These advances require tuning of material properties at the atomic scale as well as across arrays of millions of bits in a memory chip. I will describe the magnetic properties of MTJs that are essential for high-performance MRAM, including perpendicular magnetic anisotropy, damping parameter, exchange constant, thermal stability factor, and TMR, and how to engineer these properties to deliver high spin-transfer torque efficiency and high data retention in spin-transfer torque MRAM devices [4], [5].

[1] M. Jullière, Ph.D. thesis, Rennes University, No. B368/217, Rennes, France, 1975; M. Jullière, “Tunneling between ferromagnetic films,” Phys. Lett. A, vol. 54, pp. 225-226, September 1975.
[2] J. S. Moodera, G.-X. Miao, and T. S. Santos, “Frontiers in spin-polarized tunneling,” Physics Today, vol. 63, pp. 46-

51, April 2010.
[3] T. S. Santos, G. Mihajlović, N. Smith, J.-L. Li, M. Carey, J. A. Katine, and B. D. Terris, "Ultrathin perpendicular free layers for lowering the switching current in STT-MRAM," J. Appl. Phys. vol. 128, 113904, September 2020.
[4] G. Mihajlović, N. Smith, T. Santos, J. Li, B. D. Terris, and J. A. Katine, "Thermal stability for domain wall mediated magnetization reversal in perpendicular STT MRAM cells with W insertion layers," Appl. Phys. Lett., vol. 117, 242404, December 2020.

Short Bio:
Tiffany S. Santos (Member, IEEE) received the S.B. and Ph.D. degrees in materials science and engineering from the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA, in 2002 and 2007, respectively. Her Ph.D. thesis was on thin-film magnetism and spin-polarized tunneling in magnetic tunnel junctions under the supervision of Jagadeesh Moodera from the Francis Bitter Magnet Laboratory, MIT.

She is the Director of Non-Volatile Memory Materials Research at the Research Division, Western Digital Corporation, San Jose, CA, USA, where she leads a team working on materials for magnetic random access memory technology and other exploratory projects. She first joined the company in 2011, when it was previously known as Hitachi Global Storage Technologies, to work on research on granular FePt media for heat-assisted magnetic recording. She became a Distinguished Post-Doctoral Fellow, and later an Assistant Scientist, at the Center for Nanoscale Materials, Argonne National Laboratory, Lemont, IL, USA, where she studied emergent phenomena at the interfaces of complex oxide heterostuctures.

Dr. Santos has played an active role in professional societies in the magnetism community, serving as a Secretary/Treasurer for the Topical Group on Magnetism and Its Applications (GMAG) of the American Physical Society, on the program committees of several magnetism and magnetic materials (MMMs) and international magnetics (INTERMAG) conferences, the Program Co-Chair of INTERMAG 2020, the Exhibits Chair of several MMMs and the International Conference on Magnetism, multiple terms on the MMM Conference Advisory Committee, and the Publicity Chair of the Magnetic Recording Conference. In 2009, she was awarded the L'Oréal USA Fellowship for Women in Science.

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