

Eby Friedman, University of Rochester Compact Models of Magnetic Tunnel Junction



Electrical control of magnetic tunnel junctions (MTJs) provides opportunities to introduce two and three terminal MTJs into high performance applications requiring low power consumption. The magnetic state of an MTJ can be electrically controlled through: 1) the spin transfer torque (STT) effect; 2) the voltage controlled magnetic anisotropy (VCMA) effect; and 3) the fusion of STT and VCMA. A model of a two terminal MTJ comprising a free layer, an analysis layer, and a spin polarizing layer will be described. The adaptive compact MTJ model includes the effects of asymmetry on the MTJ behavior, and models a device controlled through the STT, VCMA, or a combined STT–VCMA mechanism. This model also includes the dynamics of the junction temperature. This model can be adapted to configurations including in-plane MTJ (IMTJ), IMTJ with a perpendicular-to-the-plane polarizer, perpendicular-to-the-plane MTJ (PMTJ), and PMTJ with an additional easy axis. Spin–orbit torques (SOTs) support a high speed and energy efficient three terminal MTJ with PMTJ magnetization. The read path is separated from the write path, enhancing the reliability of the device. SOTs exhibit two coexisting contributions: 1) a damping-like torque and 2) a field-like torque. A physics-based compact model for a three terminal PMTJ will be presented which accurately models the magnetic, electrical, and thermal behaviors of a PMTJ controlled through SOTs. The ability to integrate this compact model with CMOS will also be described.

Bio:

Eby G. Friedman received the B.S. degree from Lafayette College in 1979, and the M.S. and Ph.D. degrees from the University of California, Irvine, in 1981 and 1989, respectively, all in electrical engineering.

From 1979 to 1991, he was with Hughes Aircraft Company, rising to the position of manager of the Signal Processing Design and Test Department, responsible for the design and test of high performance digital and analog integrated circuits. He has been with the Department of Electrical and Computer Engineering at the University of Rochester since 1991, where he is a Distinguished Professor, and the Director of the High Performance VLSI/IC Design and Analysis Laboratory. He is also a Visiting Professor at the Technion - Israel Institute of Technology. His current research and teaching interests are in high performance synchronous digital and mixed-signal microelectronic design and analysis with application to high speed portable processors, low power wireless communications, and power efficient server farms.

He is the author of more than 500 papers and book chapters, 13 patents, and the author or editor of 18 books in the fields of high speed and low power CMOS design techniques, 3-D integration, high speed interconnect, and the theory and application of synchronous clock and power delivery and management. Dr. Friedman is the Editor-in-Chief of the

Comments:

Microelectronics Journal, a Member of the editorial board of the *Journal of Low Power Electronics* and *Journal of Low Power Electronics and Applications*, and a Member of the technical program committee of numerous conferences. He previously was the Editor-in-Chief and Chair of the Steering Committee of the *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, the Regional Editor of the *Journal of Circuits, Systems and Computers*, a Member of the editorial board of the *Proceedings of the IEEE*, *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, *Analog Integrated Circuits and Signal Processing*, and *Journal of Signal Processing Systems*, a Member of the Circuits and Systems (CAS) Society Board of Governors, Program and Technical chair of several IEEE conferences, and a recipient of the IEEE Circuits and Systems 2013 Charles A. Desoer Technical Achievement Award, a University of Rochester Graduate Teaching Award, and a College of Engineering Teaching Excellence Award. Dr. Friedman is an inaugural member of the University of California, Irvine Engineering Hall of Fame, a Senior Fulbright Fellow, and an IEEE Fellow.

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