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Modeling Approach to Ultra-Scaled MRAM Cells

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Abstract

Emerging spin-transfer torque (STT) magnetoresistive random access memory (MRAM) is one of the most promising candidates for future memory capable of supporting the growing computing memory demands from data centers to wearables, artificial intelligence, and the Internet-of-Things. for embedded applications. for embedded applications. STT-MRAM has been increasingly adopted as a reliable, persistent nonvolatile memory for embedded applications. To replace the ubiquitous DRAM, scaling STT-MRAM cells down to achieve higher densities is a key task, as well as improving the endurance and write speed. STT-MRAM shows promise as universal memory, with the attributes of SRAM, DRAM, and small to medium capacity storage memory.

The design of advanced single-digit nanometer footprint MRAM cells requires precise knowledge of spin currents and torques in magnetic tunnel junctions (MTJs) with elongated free and reference layers. Interface induced effects, like the perpendicular magnetic anisotropy, must be carefully included. The spin-transfer torque must be carefully evaluated in the free layers. The task is nontrivial as the free layers are typically composed of several ferromagnetic parts separated by MgO tunnel barriers to boost the perpendicular magnetic anisotropy. Recently, structures with an additional reference layer separated by a non-magnetic metallic spacer were proposed aiming at a reduction of the switching current and the cell size.

Modeling STTs in magnetic cells comprising of several magnetic layers separated by tunnel barriers and non-magnetic spacers requires a solution of the Landau-Lifshitz-Gilbert (LLG) equation which describes the magnetization dynamics in presence of magnetic fields and currents. The effective magnetic field includes the contribution of external field, exchange interaction, anisotropy field, and demagnetizing field. The contribution of the demagnetizing field is evaluated only on the disconnected magnetic domain by using a hybrid approach combining the boundary element method and the finite element method. To evaluate the magnetization dynamics, we must also evaluate the torques acting of the magnetization when the electric current is run through a memory cell. To do so, we compute the nonequilibrium spin accumulation by solving the coupled system of the spin and charge transport equations.

As the spin and charge currents depend on the magnetization orientation, the LLG and the transport equations must be solved simultaneously.

To accurately describe the spin and charge transport in presence of tunnel barriers, we augmented the semi-classical spin and charge transport approach used to compute the STT in nanovalves to model the transport in ultra-scaled magnetic tunnel junctions. To properly describe the dependence of the torque on the tunneling process across a magnetic tunnel junction, appropriate boundary condition for the spin and charge currents are applied at both interfaces of the tunnel barrier. By using our approach we were able to analyze the magnetization dynamics and switching in ultra-scaled MRAM cells of small diameters with composite free layers containing several tunnel barriers, with a single or double reference layers. Results of our simulations agree well with the recent experimental demonstrations of switching of ultra-scaled MRAM cells.

Keywords

Spin Transfer Torques; Magnetoresistive Memory; Modeling; Finite Element Method

Biography

Viktor Sverdlov received his Master of Science and PhD degrees in physics from the State University of St.Petersburg, Russia, in 1985 and 1989, respectively. From 1989 to 1999, he worked as a staff research scientist at the V.A.Fock Institute of Physics, St.Petersburg State University. During this time, he visited ICTP (Italy, 1993), the University of Geneva (Switzerland, 1993-1994), the University of Oulu (Finland, 1995), the Helsinki University of Technology (Finland, 1996, 1998), the Free University of Berlin (Germany, 1997), and NORDITA (Denmark, 1998). In 1999, he became a staff research scientist at the State University of New York at Stony Brook. He joined the Institute for Microelectronics, Technische Universität Wien, in 2004 and he is currently on a tenure-track position. His scientific interests include device simulations, computational physics, solid-state physics, and nanoelectronics.