Magnetic field-free fast reliable switching by spin-orbit torque in advanced MRAM

Viktor Sverdlov

Christian Doppler Laboratory for Nonvolatile Magnetoresistive Memory and Logic

Institute for Microelectronics, TU Wien, Austria

(joint work with Alexander Makarov and Siegfried Selberherr)

The continuous increase in performance of modern integrated circuits supported by device miniaturization is compromised by a rapid growth of dynamic and stand-by power. A promising way to overcome this trend is to introduce non-volatility in circuits. The development of an electrically addressable embedded fast and reliable non-volatile memory is paramount to achieve these goals. Modern magnetoresistive random access memory (MRAM) is competitive with embedded flash as it possesses an almost infinite endurance and is cheaper to produce. MRAM operated by spin-transfer torque is sufficiently fast for contesting as a replacement the main volatile computer memory and last level processor caches. In order to further reduce the energy consumption, it is essential to replace high-level static RAM with a non-volatile memory technology. Spin-orbit torque MRAM (SOT-MRAM) combines non-volatility, high speed, and high endurance and is thus suitable for applications in caches. However, its development is still hindered by relatively high switching currents and the need of an external magnetic field for deterministic switching of perpendicular free layers. By means of extensive micromagnetic simulations we show that switching by employing two consecutive current pulses applied through orthogonal wires is suitable for fast and reliable switching of both in-plane and perpendicularly magnetized free magnetic layers of rectangular shape by means of spin-orbit torques. For perpendicular structures, the spin-orbit torque due to the first current pulse tilts the magnetization of the free layer in-plane perpendicular to the pulse direction. The spin-orbit torque of the second consecutive current pulse leads to a precession of the magnetization in the part of the free layer under it, which is propagated to the remaining part of the free layer through the exchange interaction. Depending on the direction of the second pulse, the magnetization tilts up or down with respect to its in-plane orientation due to the precession, which results in deterministic switching without any need of an external field. Results of micromagnetic calculations for several pulse durations demonstrate that sub-300ps, reliable, and magnetic field-free switching is achieved, when the overlap between the rectangular free layer and the wire delivering the second pulse is about one-third of the free layer width.