Status and Future of Solid-State Non-Volatile Memory

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Solid-state non-volatile memory was invented about forty years ago under the name electrically erasable programmable read-only memory (EEPROM). Since then a breathtaking development took place, which lead to the at present mostly utilized NAND-type flash memory, which revolutionized digital storage capabilities in form of USB memory sticks, memory cards, and solid-state drives. The worldwide market is about 16 billion US dollars this year and will more than double in the next three years. Scaling of semiconductor devices has been the main driving force ensuring the outstanding complexity and performance increase of any modern integrated circuits.

However, as the device scaling is showing signs of saturation, an introduction of new disruptive technological solutions for energy efficient storage and also computation becomes paramount. Various types of new concepts for future non-volatile memory structures are therefore intensely researched.

As the electron charge is fully employed in microelectronic circuits, another intrinsic electron's property – the electron spin – attracts particularly much attention. The electron spin is characterized by the two well-defined projections on an axis and is therefore perfectly suited for digital applications. Similarly, the magnetization of the free recording layer can be parallel or anti-parallel to the magnetization of the fixed magnetic layer in a magnetic tunnel junction. The two relative magnetization configurations can be used to store binary data. As the two configurations feature different resistances, the stored data can be accessed electrically enabling spin-based non-volatile magnetoresistive memories. The relative magnetization configuration is manipulated by means of a spin-transfer or spin-orbit torque acting on the free layer. The torques are generated electrically by passing the current through the structure or through a heavy metal line under it. Purely electrically addressable spin-transfer torque and spin-orbit torque magnetoresistive memories are superior in many aspects compared to conventional flash memories. Magnetoresistive memory possesses a simple structure, long retention time, high endurance, and fast operation speed. It can be fabricated with a CMOS-friendly process and can thus also compete with DRAM and SRAM.

In addition, a combination of non-volatile elements with CMOS devices brings data processing close to the storage alleviating the data transfer bottleneck. Shifting data processing capabilities into the nonvolatile segment paves the way for a new low power and high-performance computing paradigm based on logic-in-memory and in-memory computing architectures, where the same nonvolatile elements are used to store and to process information.