Magnetic Tunnel Junctions for Magnetoresistive Random Access Memory

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Magnetoresistive random access memory (MRAM) employs a magnetoresistive device integrated with standard silicon-based microelectronics, resulting in a combination of speed, nonvolatility, and endurance not found in other memory technologies. Optimized MTJ material and a new toggle-writing method are used in Freescale's 4Mb MRAM circuit, currently being sampled to select customers. Fundamentals of MRAM based on Magnetic Tunnel Junction (MTJ) devices will be reviewed. The properties of our unique toggle-switching MRAM bit, as well as specific magnetic and electrical properties required for our MRAM architecture, will be discussed.

Reading bits in an array

Materials that enable higher MR are very desirable for MRAM technology because the larger signal will improve read speed. However, the higher MR must not be at the cost of other material qualities, particularly resistance uniformity. For our MRAM architecture we use a reference generator circuit that produces a signal at the midpoint between the high and low state of the bits. The state of an individual bit is read by comparison to the reference. To have working Mb memories, the circuit must be able to correctly read the state of bits in the tails of the resistance distributions. Statistically, if bits 5σ from the mean are unreadable there will be approximately one bad bit in 2Mb. Allowing for some finite signal beyond the distributions, a reasonable criterion for feasibility would be 6σ separation from the midpoint, or 12σ separation between the high and low resistance states. A number of factors can contribute to the resistance distribution width, but we have found that the quality of the MTJ material itself plays a major role in determining the resistance distributions. Very small variations in the tunnel barrier thickness, with certain spatial characteristics, cause significant variations in the bit-to-bit resistance. Thus MTJ material for MRAM must be optimized for a uniform tunnel barrier. Opportunities for research in this area include: high-polarization materials, alternate tunnel barrier dielectrics, and fundamental studies of specific electrode/dielectric combinations.

Writing bits in an array

Our bit cell uses a balanced synthetic-antiferromagnetic free layer and a phased write pulse sequence to provide robust switching performance with immunity from half-select disturbs. The moment-balanced SAF free-layer responds to an applied magnetic field differently than the single ferromagnetic layer of conventional MRAM. For moderate fields, the SAF free-layer flops perpendicular to the field and can be rotated between the two stable states only with properly phased pulses. Opportunities for research in this area include magnetic imaging with deep sub-micron spatial resolution and sub-nanosecond time-resolved measurements of magnetic switching.