Challenges toward voltage-torque MRAM

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A magnetic tunnel junction (MTJ) consisting of a thin insulating layer (a tunnel barrier) sandwiched between two ferromagnetic electrodes exhibits the tunnel magnetoresistance (TMR) effect due to spin-dependent electron tunneling. Since the discovery of room-temperature TMR,[1,2] MTJs with an amorphous aluminum oxide (Al–O) tunnel barrier, which exhibit magnetoresistance (MR) ratios of several tens percent, have been studied extensively. In 2004, MR ratios of about 200% were obtained for fully epitaxial MTJs with single-crystal MgO(001) tunnel barrier [3] and textured MTJs with (001)-oriented MgO tunnel barrier[4]. MTJs with a CoFeB/MgO/CoFeB structure were also developed for practical application.[5] In the CoFeB/MgO/CoFeB MTJ, a highly textured MgO(001) barrier layer is grown on an amorphous CoFeB bottom electrode layer. By post-annealing the MTJs, the amorphous CoFeB layers are crystallized in bcc(001) structure due to the solid-phase epitaxial growth from the MgO interfaces[6]. Then, the (001)-textured CoFeB/MgO/CoFeB MTJ exhibit giant MR ratios as well as other practical properties such as low resistance-area (RA) product [7,8] and/or interfacial perpendicular magnetic anisotropy (PMA).[9] Because of the high manufacturability and practical magneto-transport properties, the CoFeB/MgO/CoFeB MTJs are widely used as the read heads of hard disk drives (HDDs), memory cell of non-volatile memory (STT-MRAM) especially with perpendicular magnetization, spin-torque oscillator (STO), and physical random number generator (Spin Dice).[10,11]

Although the textured CoFeB/MgO/CoFeB MTJs have been very successful, the properties are not sufficient for future device applications. Novel voltage-driven MRAM or voltage-torque MRAM based on voltage-induced dynamic switching [11] requires not only very high MR ratio (>>300%) but also very large voltage-control of magnetic anisotropy (VCMA) effect and PMA at the same time.[12] For satisfying these requirements, we need to develop novel MTJs with new materials for barrier and magnetic layers by using epitaxial growth on Si substrate as well as the wafer bonding and three-dimensional integration technologies to integrate the epitaxial MTJs in practical LSI. This paper summarizes challenges toward the voltage-torque MRAM.

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