Advanced magnetic tunnel junctions for voltage-controlled MRAM

Shinji Yuasa[1], Takayuki Nozaki[1], Tatsuya Yamamoto[1], Tomohiro Nozaki[1], Hiroyasu Nakayama[1], Tomohiro Ichinose[1], Junyeon Kim[1], Sumito Tsunegi[1], Shingo Tamaru[1], Kay Yakushiji[1], Hitoshi Kubota[1]

[1]National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, 305-8568, Japan, yuasa-s@aist.go.jp

Voltage-controlled (VC) – MRAM based on the voltage-controlled magnetic anisotropy (VCMA) effect and dynamic switching is expected to be an ultimate writing technology with ultra-low power consumption. Magnetic tunnel junctions (MTJs) for VC-MRAM need to have high magnetoresistance (MR) ratio, large perpendicular magnetic anisotropy (PMA) and high VCMA ecoefficiency. To develop such MTJs, we developed a novel sputtering deposition process at cryogenic temperatures. By means of the cryogenic temperature deposition, we fabricated high-quality free layers with ultrathin CoFeB and boron-free ferromagnetic materials on MgO or Fe-doped MgO tunnel barrier.

***Index Terms*— Magnetic tunnel junction, Tunneling magnetoresistance, Perpendicular magnetic anisotropy**

I. INTRODUCTION

GIANT tunnel magnetoresistance (TMR) effect in MgO-based magnetic tunnel junctions (MTJs) is the key technology in magnetoresistive random-access memory (MRAM). Among several types of magnetoresistive random-access memory (MRAM), spin-transfer-torque (STT) – MRAM has been extensively studied and already commercialized as embedded non-volatile memory for system LSI. For MRAM to replace high-speed memory such as SRAM, however, MRAM needs to have higher speed and lower energy consumption for writing. One of the candidates for such advanced MRAM is voltage-controlled (VC) – MRAM based on voltage-induced dynamic switching, which is expected to be an ultimate writing technology with ultra-low power consumption [1]. For practical VC-MRAM, magnetic tunnel junctions (MTJs) need to have high magnetoresistance (MR) ratio, large perpendicular magnetic anisotropy (PMA) and high voltage control of magnetic anisotropy (VCMA) coefficient. We also need to suppress write errors of the dynamic switching. High-density VC-MRAM requires MTJs to have PMA > 0.5 mJ/m^2 and VCMA coefficient > 300 fJ/Vm.

II. NEW MATERIALS AND PROCESSES FOR VC-MRAM

To establish basic technologies for VC-MRAM, we developed advanced MTJs with new materials. By using new free-layer materials such as Ir-doped Fe(-Co) and hybrid tunnel barrier, we have achieved VCMA > 300 fJ/Vm and PMA > 0.5–1 mJ/m^2 [2-4], which almost satisfy the requirements for VC-MRAM.

It is also important to fabricate high-quality ultrathin free layer on MgO(001) tunnel barrier. However, an ultrathin free layer grown on MgO(001) tends to be low quality due to the poor wettability of ferromagnetic layer on MgO surface. To overcome this difficulty, we developed a novel sputtering deposition process at cryogenic temperature [5-6]. CoFeB/MgO/CoFeB MTJ films were deposited on 300 mm Si wafers by using an advanced sputtering system shown in Fig. 1. The top CoFeB free layers were deposited at 100 K. The cryogenic temperature deposition improves the quality of CoFeB/MgO interface, resulting in a thinner dead layer, higher MR ratio, larger PMA and VCMA, and lower damping constant. Moreover, Fe-doping into MgO tunnel barrier was found to be effective for further improving the quality of free layer and thus the voltage-induced switching properties [7-8]. These properties are favorable not only for VC-MRAM but also for STT-MRAM.

Fig. 1. Manufacturing-type sputtering deposition system (left) and schematic illustration of sputtering deposition chamber with wafer cooling stage (right).

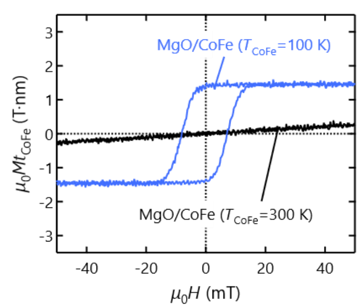

Fig. 2. Magnetization curves of an ultrathin Co-Fe layer deposited on MgO at 300 or 100 K.

By using the cryogenic temperature deposition technique, we have also prepared high-quality free layers without boron [9-10]. It should be noted that the sputtering deposition of ultrathin Co-Fe layer on oxide tunnel barrier is more difficult than the deposition on CoFeB because the wettability of Co-Fe on MgO is poorer than that of CoFeB. By means of the cryogenic temperature deposition process, we fabricated uniform ultrathin Co-Fe top free layer with sharp interfaces, resulting in better perpendicular magnetic anisotropy compared with the case of room temperature deposition (Fig. 2). The cryogenic temperature deposition of Co-Fe on the Fe-doped MgO tunnel barrier further improved the MTJ properties, providing a high potential of boron-free ferromagnetic materials [10]. In the talk, we will also discuss write errors of voltage-induced dynamic switching.

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