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Recent Progress on MgO-based Magnetic Tunnel Junctions

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First-principle theories predicted that a coherent tunneling of electrons in fully epitaxial magnetic tunnel junction (MTJ) with a crystalline MgO(001) barrier yields huge magnetoresistance (MR) ratio above 1000% [1,2]. We have experimentally achieved giant MR ratios of up to 410% at room temperature in fully epitaxial MTJs such as Fe/MgO/Fe and Co/MgO/Co [3-4]. The theory also predicted an oscillation of tunneling conductance with respect to MgO barrier thickness (t_{MgO})as a result of an interference of tunneling states [1]. In our previous study, we experimentally observed an oscillation of MR ratio as a function of t_{MgO} with a period of 0.3 nm [3]. However, it is still unclear whether the observed TMR oscillation can be explained bythe conductance oscillation theory although this is an essential issue in understanding the physics of coherent tunneling. The most fundamental question is whether the TMR oscillation originates from parallel (P) magnetization alignment or antiparallel (AP) one. In our previous study, it was experimentally difficult to observe the oscillation in tunneling resistance because of larger experimental variations in the tunneling resistance compared with that in the MR ratio. In this study, we performed high-precision measurements of the tunneling resistance as a function of t_{MgO} using fully epitaxial MTJ films with a wedge-shaped MgO layer. We successfully observed that the TMR oscillation originates from the tunneling resistance in parallel alignment (RP). The tunneling resistance in antiparallel alignment (RAP) also exhibited a specific structure, which is clearly different from that of RP.The results contain an important clue in clarifying the detailed mechanism of coherent spin-dependent tunneling. This study was supported by New Energy and Industrial Technology Development Organization (NEDO).

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BA02

Spin-transfer Torque Switching in nano-sized MTJ

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With its non-volatility and infinite endurance, MRAM has the large potential as one of the leading candidates for non-volatile memory device to replace DRAM, SRAM and FLASH memory. In particular, a new concept MRAM utilizing a new writing scheme known as the spin-transfer torque effect (hereafter, STT-MRAM), which is induced by the direct injection of spin-polarized current into the magnetic tunnel junction (MTJ) to reverse magnetization direction of its free layer, has been recently proposed and demonstrated by several research groups [1,2]. STT-MRAM has an advantage in avoiding half-selected problem and writing disturbance between adjacent cells when compared with conventional MRAM, because its switching operation is governed by the amount of spin polarized current instead of induced magnetic field. However, there still exist some issues we should overcome to achieve high density STT-MRAM. Firstly, J_c should be reduced below 10^6 A/cm^2 for reliable operation without breakdown oftunnel oxide and for low power operation. Secondly, thermal instability due to the reduction of MTJ size should be improved, especially for sub-50 nm MTJ. Finally, the reliability of tunnel oxide needs to endure 10^{15} cycling test for working memory application.

In this paper, these key issues are taken into account to estimate the feasibility of STT-MRAM. One of the reasons that STT-MRAM has a great improvement is due to the development of MgO barrier with high MR [3,4]. However, the reliability issue still exists in MgO barrier. The quality of MgO barrier sensitively depended on the chamber atmosphere, especially, in case of rf-sputtered MgO barrier. In this paper, we will introduce the characteristics of rf-sputtered MgO barrier deposited under various conditions comparing with radical oxidized MgO barrier. In order to investigate STT, nano-sized MTJs were patterned by conventional lithography and etching process. Cell widths and aspect ratios (AR) of MTJs were 30 ~ 100 nm and 2 ~ 3, respectively. Thethickness of MgO was carefully controlled less than 1 nm to keep resistance area product (RA) below 30 Ω-m^2. Low switching current density (Jc) of 1.63 × 10^6 A/cm^2 with 10ns pulse was achieved by optimizing magnetic materials and MTJ structure. As cell width decreased from 65 nm to 30 nm, switching current decreased from 133μA to 25μA. This indicates that STT-MRAM has an excellent scalability as well as the feasibility of low power and high density. In viewpoint of switching current and MRAM cell size, STT-MRAM has a good scalability. However, thermal stability issue is a bottleneck to scale down beyond 30 nm. Thermal stability factor (SF, K_uV/k_BT) of MTJ can be obtained measuring the time dependence of I_{sw}. In this paper, we will present the thermal stability of sub-50 nm MTJ in detail.

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