Perpendicular magnetic tunnel junctions with Hf/Pt composite capping layers

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Perpendicular magnetic tunnel junctions (p-MTJs) are the key building blocks of promising non-volatile magnetic memories because of its high thermal stability and low critical current in comparison with those of in-plane MTJs [1]. A nonmagnetic layer/ CoFeB/ MgO structure has attracted a large amount of attention as a free layer of p-MTJs. It have been demonstrated that a Ta/ CoFeB/ MgO structure exhibits a considerably high PMA[2], and the PMA can be further enhanced by replacing Ta with other nonmagnetic materials such as Hf [3]. In this study, we investigated the PMA and thermal robustness of MgO/ CoFeB/ capping layers consisting of various nonmagnetic materials. We found that the Hf capping layer has an inferior thermal robustness than the Ta layer, and the robustness can be improved by using composite capping layers. It has been demonstrated that the p-MTJs with Hf/Pt composite capping layers have decent robustness and reasonably high tunnel magnetoresistance (TMR).

We fabricated the MTJs consisting of synthetic antiferromagnetic (SAF) pinned layer/ MgO/ $Co_4Fe_4B_2$(1.2)/ [Hf(5)/ Ta(5)], [Pt(0.2)/ Hf(2.5)/ Ta(2.5)], or [Pt(0.2)/ Hf(2.5)/ Pt(2.5)] / Ru(5). The numbers in parenthesis are the thickness in nanometer. The samples were deposited on thermally oxidized Si (100) substrates by using both DC and RF magnetron sputtering in ultrahigh vacuum condition. Magnetic characterizations using a vibrating sample magnetometer (VSM) confirmed the PMA of constituting layers and a balanced SAF structure. For TMR measurement, 8μm×8μm square junctions were patterned by the photo-lithography and Ar ion milling processes, and, subsequently, annealed at 250 ~ 330℃ for 30 min in 1×10^{-5}Torr. The TMR was measured at room temperature using a four probe method.

We found that the diffusion of boron as well as the nonmagnetic materials mainly contributes to the effective magnetic thickness, saturation magnetization, and interfacial PMA of MgO/ CoFeB/ nonmagnetic layer structures. By selecting a proper combination of nonmagnetic materials, it is possible to obtain a high interfacial PMA with annealing at a relatively high-temperature. In the p-MTJ with a Pt/ Hf/ Ta/ Ru capping structure, the TMR is increased to approximately 46% with increasing annealing temperature up to 270℃. In case of Pt/ Hf/ Pt/ Ru, the TMR reaches approximately 80% at 320℃. The increase of TMR can be understood in terms of the boron diffusion from CoFeB to the capping layers, which is followed by the improvement of grain-to-grain epitaxy at the CoFeB/ MgO interface. The TMR has been reduced after further annealing at higher temperatures. The degradation of TMR is interpreted as a signature of diffusion of nonmagnetic materials into the CoFeB layer.

Our experimental results suggest that the magnetic properties of MgO/ CoFeB/ nonmagnetic capping layer structure are affected by the diffusion of boron as well as the nonmagnetic materials through annealing process. A proper combination of nonmagnetic materials opens a possibility to obtain a high TMR and good robustness after annealing.

References

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