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The intrinsic temperature dependence and the origin of the crossover of the coercivity in perpendicular MgO/CoFeB/Ta structures

Meng-Chiau Tsai,[1] Chih-Wei Cheng,[1] C. C. Tsai,[2,a)] and G. Chern[1,a)]
[1]*Department of Physics, National Chung Cheng University, Chia Yi 62102, Taiwan*
[2]*Department of Engineering and Management of Advanced Technology, Chang Jung Christian University, Tainan 71101, Taiwan*

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A collapse of tunnel magneto resistance (TMR) in the perpendicular magnetic configuration of CoFeB/MgO/CoFeB tunnel junction at high annealing temperatures has been reported recently [Ikeda *et al.*, Nature Mater. **9**, 721 (2010)]. This observation indicates that not only the temperature-dependent magnetic characterization is important in a pseudo-spin valve type devices but also implies an asymmetrical dependence on the magnetic behavior between the top and bottom CoFeB layers. In this report, we have measured a series of MgO/CoFeB/Ta with different thicknesses of CoFeB (1.0−1.7 nm) and Ta cap layer (1–5 nm) and found a intrinsic dependence of magnetic coercivity of $Hc = Hc_o[1-(T/T_B)^{1/2}]$, where Hc_o is Hc at 0 K and T_B is the blocking temperature, for all films. A systematic study shows that Hc_o varies in the range of 2500 Oe−250 Oe with a rough inverse linear dependence on CoFeB layer thickness. The T_B for all films except the thinnest one (1.0 nm) is in a smaller range of 280–300 K, but drops to 150 K for the thinnest film. The corresponded particle sizes are estimated ∼30 nm. The origin of the microstructure of the present films is probably related to the defect at the interface and formed during the post annealing process. A control of the collapse of the TMR through the cap Ta layer thickness will be discussed. © *2013 American Institute of Physics*. [http://dx.doi.org/10.1063/1.4799518]

I. INTRODUCTION

MgO-based magnetic tunnel junctions (MTJs) have attracted much research interest since the theoretical prediction of extremely high tunneling magnetoresistive (TMR) ratios in these MTJs.[1,2] Experiments[3–6] then followed and high TMR ratios were demonstrated in the CoFeB/MgO-based MTJs with in-plane magnetic anisotropy using simply a conventional sputtering deposition technique. Recently, Ikeda *et al.*[5] reported observation of a perpendicular magnetic anisotropy (PMA) in the CoFeB/MgO interface with reduced ferromagnetic layer thickness. Their CoFeB/MgO-based perpendicular MTJ (p-MTJ) stacks, after a post-annealing treatment at temperature T_a of 300 °C, showed a high TMR ratio of 120%. These CoFeB-MgO p-MTJs, which offer reduced critical switching currents as well as a high enough thermal stability factor, are of great interest because of their potential applications in the next-generation high-density spin-transfer torque magnetoresistive random access memory (STT-MRAM).

On studying the annealing temperature dependence of TMR ratios in the structure of CoFeB/MgO/CoFeB, Gan *et al.*[7] observed a reduction of the TMR ratio at room temperature to a value close to zero%, which is known as the TMR collapse of a MTJ, in the samples with annealing temperature of 400 °C. This might be problematic in the perspective of practical industrial applications since the temperature in a standard backend Complementary metal–oxide–semiconductor (*CMOS*) integrated process, for example, is in the range of 350-400 °C. They also studied the temperature dependence of magnetoresistance for samples with different annealing temperatures. The results depicted a drastic decrease of TMR ratio at temperatures above 260 K for the sample of $T_a = 400$ °C, which was suggested related to the T-dependent coercivities of the two FM layers. This observation indicates that not only the temperature-dependent magnetization is important in the pseudo-valve type devices but also implies an asymmetrical dependence on the magnetic behavior between the top and bottom CoFeB layers.

In this report, a series of MgO/CoFeB/Ta and a series of CoFeB/MgO/Ta with different thicknesses of CoFeB and Ta cap layer were fabricated. Here, we systematically studied the magnetic response to the field at various temperatures for all the samples after annealed at 300 °C and the nature of a TMR collapse was investigated. Although no films are annealed at higher temperature (∼400 °C), we believe that the origin of collapse may be better understood from the respective temperature dependent $H_c(T)$ measurements in films of the two structures. Alternatively, a control of the collapse of the TMR through the cap Ta layer thickness will be discussed.

II. EXPERIMENTAL

Stacks of Ta(5)/MgO(1)/$Co_{20}Fe_{60}B_{20}$(x = 1.0-1.6)/Ta(1) and $Co_{20}Fe_{60}B_{20}$(y = 0.8-1.6)/MgO(1)/Ta(5) (unit in nm) were grown by conventional sputtering deposition technique. Another stacks of Ta(5)/MgO(1)/$Co_{20}Fe_{60}B_{20}$(1.2)/Ta(x = 1–5) were also fabricated for study of the effect of Ta cap layer thickness in the system. All the samples were vacuum annealed at 300 °C for 1 h without further application of external fields. The magnetization curve at room temperature was measured using a vibrating sample magnetometer (VSM). A physical properties measurement system (PPMS) from Quantum Design was used for measurements at low temperatures.

a)Authors to whom correspondence should be addressed. Electronic addresses:gchern@ccu.edu.tw and quantumtsai@hotmail.com.

