B-1

Bias voltage dependence of magnetic tunnel junctions comprising amorphous ferromagnetic CoFeSiB layer with double barriers

이선영[1]*, 임혜인[1], 이장로[1], 황재연[2], 전병선[3], 김영근[3], 김태완[4], 이상석[5], 황도근[5], 유성초[6], 이희복[7]
[1]숙명여대 물리학과
[2]원자연
[3]고려대 신소재공학과
[4]세종대 신소재공학과
[5]상지대 물리학과
[6]충북대 물리학과
[7]공주대 물리교육과

Ⅰ. Introduction

Magnetic tunnel junctions (MTJs) have shown promise in high-density, read head and non-volatile, magnetic random access memory (MRAM) applications due to their large tunneling magnetoresistance (TMR) ratios [1, 2]. However, when the applied voltage is increased the TMR ratio became decreased. This phenomenon known as bias voltage dependence of the TMR ratio[3, 4]. One reason of bias voltage dependence of the TMR ratio resulted from the increase in conductance with the ferromagnet/tunnel barrier interface [5]. Because, in the MTJs, an insulating layer acts as a tunnel barrier of spin polarized tunneling electrons between two ferromagnetic electrodesand the conductance is increased through the electrically weak point in the ferromagnet/tunnel barrier interface. In light of the suppression of bias voltage dependence in MTJs, a nanometer-thick tunneling barrier continuous is indispensable.

To get achieve ultra-smooth interface, we introduced an amorphous ferromagnetic $Co_{70.5}Fe_{4.5}Si_{15}B_{10}$ layer into the MTJs as the free layer. Because amorphous materials in the absence of grain boundaries, in principle, it could offer better surface smoothness resulted from retarding of irregular growth such as columnar growth. By using this material, the dependence of the TMR ratio on the bias voltage could be reduced.

Ⅱ. Experimental Procedure

The MTJs consisting of Si/SiO_2/Ta 45/Ru 9.5/IrMn 10/CoFe 7/AlO_x 1.5/free layer 10/AlO_x 1.5/CoFe 7/IrMn 10/Ru 60 (in nm) wereprepared using a six-target *dc* magnetron sputtering system under the typical base pressure of less than 510^{-8}Torr. A magnetic field of 100 Oe was applied during deposition to induce uniaxial magnetic anisotropy in the ferromagnetic layers. Tunnel barriers were formed by oxidizing 1.0 nm thick Al layers under an *rf* plasma environment in a load-locked chamber. A photolithographic patterning procedure, including ion beam etching, was used to fabricate the 10 x 10 μm^2 of MTJs. Annealing was carried out *in situ* at 200°C in a

5×10^{-4} Torr vacuum under an applied field of 300 Oe for 2 hr. Magnetic hysteresis of various free-layer structures was characterized by a vibrating sample magnetometer (VSM) and a probe station capable of generating external magnetic field was used to measure the transport properties of the MTJs.

Ⅲ. Results and Discussion

In order to investigate the magneto-transport properties, various free layered double MTJs (DMTJs) were prepared. The junctions consisted of Si/SiO_2/Ta 45/Ru 9.5/IrMn 10/CoFe 7/AlO_x 1.5/CoFeSiB 10, CoFeSiB 5/CoFe 5, or CoFe 10/AlO_x 1.5/CoFe 7/IrMn 10/Ru 60 (in nm). The CoFeSiB-used MTJs showed a lower in both H_{sw} (magnetization switching field) and H_i (interlayer coupling field) compared to those of the CoFe-used MTJ. The H_{sw} and H_i values of (a) CoFeSiB 10, (b) CoFeSiB 5/CoFe 5, and (c) CoFe 10 (nm) free layered structures were 11 and 27 Oe, 35 and 30 Oe, and 55 and 47 Oe, respectively. Because the CoFeSiB has low saturation magnetization (M_s), the H_{sw} of the (a) was much lower than that of the (c).[1] By using the CoFeSiB layer, the H_i decreased presumably due to the free layer/tunnel barrier interface of the (a) was smoother than that of the (c). Because the H_i is relevant to the ferromagnetic interaction across the tunnel barrier [6], a junction with smooth barrier interfaces could offer a lower H_i.

In the figure shown the normalized TMR ratios as a function of the applied voltage, the TMR ratio became decreased with increased in the applied voltage. The bias voltage dependence of the TMR ratio has not been well understood, but it seems to be due to an increase in conductance with bias, magnetic impurity, and excitations of magnon at the ferromagnet/tunnel barrier interface. By using the DMTJ, the reduction of the TMR ratio at a given bias is smaller than that in the single barrier MTJ [7]. Becauseof the applied voltage is divided between two tunnel barriers.

The normalized TMR ratios of (a) CoFeSiB 10, (b) CoFeSiB 5/CoFe 5, and (c) CoFe 10 (nm) free layered structures samples at the applied voltage of +0.4 V were 0.83, 0.74, and 0.71, and those values at −0.4 V were 0.88, 0.84, and 0.83, respectively.

The normalized TMR ratio of the DMTJs with an amorphous layer in the free layerwas higher than without an amorphous layer for the whole range of the applied voltage measured. This result can be attributed to the fact that the CoFeSiB/AlO_x interface was more uniform and less defective than that of the CoFe/AlO_x interface due to the amorphous layer insertion. Because the metallic polycrystalline free layer over the bottom tunnel barrier, in the DMTJ, is difficult to grow uniformly due to the presence of grain boundary, and consequently, the top barrier interface became rough.

We measured the surface roughness of the top tunnel barrier by AFM. The CoFeSiB-used DMTJs in comparison with the CoFe-used one offered smoother root-mean-square (rms) surface roughness. The rms surface roughness of the CoFe and CoFeSiB free layered DMTJ were 0.40 and 0.21 nm, respectively. The absence of grain boundary in NiFeSiB appeared to retard the columnar

The junction resistance, V_h (voltage where the TMR ratio becomes half of its nonbiased value), and V_{bd} (breakdown voltage) properties of the DMTJs depending on the free layer structure are summarized in Table I. By using the CoFeSiB as the free layer into the MTJs, the V_h, V_{bd}, and resistance values increased. The junction resistance and H_i are relevant to the tunnel barrier/ferromagnetic free-layer interface, the junction with smooth barrier interfaces induces a higher resistance and a lower H_i. And moreover, due to the smooth interface in the CoFeSiB-used DMTJs, the V_h and V_{bd} is increased.

Table 1. Magnetotransport properties of the CoFeSiB 10, CoFe 5/CoFeSiB 5, and CoFeSiB 10 (nm) free layered DMTJs.

Structure (nm)	R (Ω	V_h (V)	V_{bd} (V)	H_i (Oe)
CoFeSiB 10	524	1.1	1.7	27
CoFeSiB 5/CoFe 5	432	1.0	1.5	30
CoFe 10	252	0.8	1.4	47

Ⅳ. Conclusions

We have employed amorphous ferromagnetic CoFeSiB layer as the free layer of the DMTJ to improve the interface roughness of the tunnel barrier with a suppression of the bias voltage dependence. Smooth interface reduced the interlayer coupling field and bias voltage dependence of the MTJ. The presence of the amorphous layer, it offers better surface smoothness. Hence, the H_i and bias voltage dependence was decreased.

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