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Crystallization behavior of CoFeB electrode layers in annealed MTJs

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1. Introduction

The MR ratio of MTJs depends on not only materials but the structure and characteristics of the interface between FM electrode and insulating layer. The previous authors reported that a large MR appears in spin-valve structures with the amorphous FM electrode.[1-4] In the MTJs, there have been reported high MR ratios with the amorphous electrode.[6,7] In this work, the crystallization behavior of CoFeB amorphous FM electrode was investigated by annealing MTJs. For this purpose, three different pinned layers were studied; CoFeB monolithic layer (PL1), CoFe/CoFeB/CoFe composite layer (PL2) and CoFe monolithic layer (PL3). We have studied crystallization behavior of CoFeB amorphous layers and their effects on MR behavior and resistance change.

2. Experiment

CoFeB tunnel junctions were prepared in a DC magnetron sputtering system with a base pressure of 3×10^{-8} Torr and deposition pressure of 1 mTorr. The structure of MTJs was Ta(50nm)/NiFe(8nm)/IrMn(10nm)/PL(4nm)/AlOx(Al 1.1nm)/CoFeB(3nm)/NiFe(15nm). In these junctions the following three different PLs were used CoFeB 4nm (PL1), CoFe 1nm/CoFeB 2nm/CoFe 1nm (PL2) and CoFe 4nm (PL3). The junctions were made by a photolithographic method to measure the MR ratio. The samples were annealed from 200°C to 380°C for 50min with a magnetic field in a vacuum atmosphere with a pressure of 3×10^{-6} Torr. The structural analysis was carried out by XRD. Cross-sectional images of the samples were taken by TEM.

3. Results and discussion

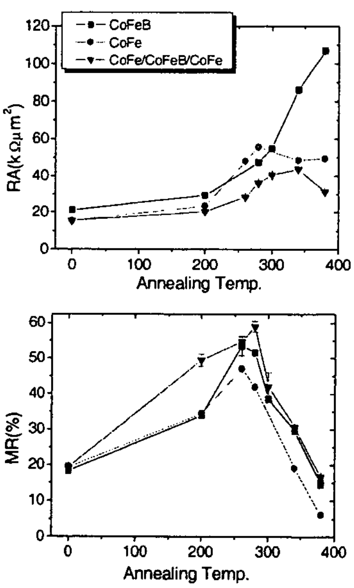
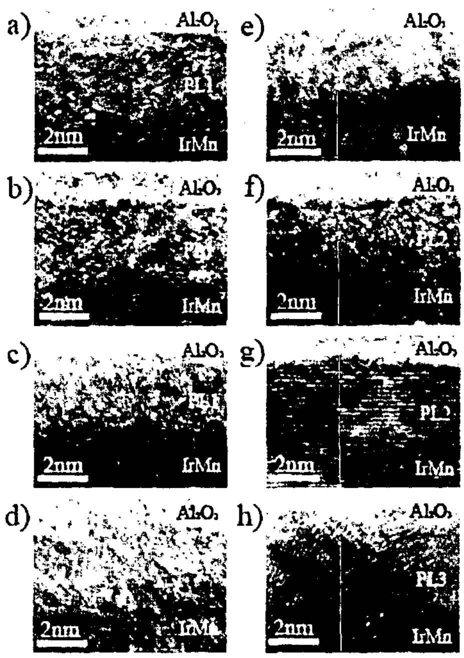


Fig. 1 Change of MR ratio and RA product with increasing annealing temperature were measured for Ta/NiFe/IrMn/PL/AlO/CoFeB/NiFe/Ru ; PL1 (CoFeB), PL2 (CoFe/CoFeB/CoFe) and PL3 (CoFe).

Fig. 1 shows change of MR ratio and RA products with annealing temperature. The MR peak appeared upon 260°C to 280°C annealing in the all specimens. The maximum MR ratio of 60% was observed in PL1 after 280°C annealing and 55% in PL2 at 260°C. The MR ratio of PL3 case was lower than those in whole temperature range. The RA products increased up to a 280°C to 300°C annealing and decreased over these temperature in the tunnel junctions with PL2 and PL3. In PL1 junctions, the RA products increased with increasing annealing temperature up to 380°C annealing. In order to study crystallization behavior of CoFeB layer cross-sectional TEM images were investigated for the three kinds of specimens in as-deposited states and after annealed states. The crystallization behavior of the CoFeB layer in the pinned layer was analyzed by imaging lattice fringe of the CoFeB layer by high resolution TEM method. These results are appeared in Fig. 2. In the case of PL 1, where 4nm CoFeB was used as a pinned layer, crystallization partially appeared in 340°C annealing at the interface between IrMn and CoFeB layer. However, the PL2 already had complete crystal structure after 340°C annealing. This is consistent with the above mentioned phenomenon where the CoFeB on crystalline structure crystallize at the lower temperature when CoFeB is deposited on CoFe. Once CoFeB crystallizes, B has no solubility in Co and Fe. B will form cobalt boride or iron boride and some will diffuse into AlOx layer. As the high chemical affinity to oxygen, B diffusion into AlOx layer is very possible.



The rapid increase of RA value with further annealing in Fig. 1 for the PL1 may be associated with B diffusion into AlOx layer. For this reason the PL1 showed high RA measure with annealing. To confirm the low temperature crystallization behavior of the CoFeB layer on different underlayers, Ta/NiFe/IrMn/CoFeB and Ta/NiFe/IrMn/CoFe/CoFeB were annealing at various temperatures. The XRD showed CoFeB crystallization at 380°C on CoFe layer and beyond 380°C on IrMn layer. This shows crystallization temperature of CoFeB depends on the structure and lattice parameters of the nearest neighbor layer.

Fig. 2 In as-deposited films, the enlarged cross-sectional TEM images were taken for IrMn/PL/Al_2O_3; a) as-deposited state, b) 260°C, c) 340°C d) 380°C annealed state for PL1 (CoFeB), e) as-deposited state, f) 260°C, g) 340°C annealed state for PL2 (CoFe/CoFeB/CoFe) and h) as-deposited state for PL3 (CoFe).

4. Conclusions

The crystallization behavior of CoFeB amorphous FM electrode was investigated in annealed MTJs with the three different pinned layer structures. The monolithic CoFeB PL1 started crystallization at 340°C, but the crystallization of CoFeB had completed at the lower temperature than 340°C when the CoFe initial layer existed. This indicates crystallization temperature of the CoFeB layer is different depending on the structure and lattice parameters of the connecting layer.

The maximum MR ratio was observed around 260°C to 280°C annealing. At this temperature range, the amorphous CoFeB layer in PL1 and the crystalline CoFe layer in PL2 were contact with AlOx layer but the maximum MR ratio were comparable. This indicates the surface flatness may affect the higher MR ratio in the CoFeB electrode of the previous reports. As B has the high chemical affinity to oxygen and has no solubility in crystalline structure of CoFe, B diffusion into AlOx layer is very possible. The rapid increase of RA value in MTJs with CoFeB PL may be associated with B diffusion into AlOx layer.

5. References

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