Interlayer Coupling of Co/NM/FM(NiFe and Co) Nano-Sandwich Films

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Abstract: Cu/Co, Cu/NiFe, Ta/NiFe bilayers and Co/Cu/Co, Co/Cu/NiFe, Co/Ta/NiFe sandwich films were deposited by a magnetron sputtering method. Magnetic properties were evaluated by VSM and spin valve magnetoresistance was investigated by a four-probe method to study the interlayer coupling of the two magnetic layers. It has been found that the interlayer coupling depended not only on the layer thickness of the nonmagnetic spacer but also on the nature of the spacer. The interlayer coupling was reduced as the spacer layer thickness increased. The result was consistent with those from observations of the magnetic domain for the trilayers by means of Lorentz Electron Microscope. The trilayers with Cu spacer layer have shown a stronger coupling than those with Ta spacer layer.

Key words: bilayer; trilayer; interlayer coupling; nonmagnetic spacer; domain observation

Co/NM/FM(NiFe and Co)纳米多层膜的层间耦合效应. 马晓艳, 毕晓昉, 宫声凯, 徐惠彬. 中国航空学报(英文版), 2003, 16(4): 253- 256.

摘 要: 巨磁电阻自旋阀多层膜作为磁敏传感器材料与磁随机存储器(MRAM)材料,具有高的可靠性与灵敏度,在航空航天等高科技领域有着极大的应用前景。研究多层膜各层间的耦合效应与各层厚度、磁学性能之间的内在关系,对提高自旋阀的巨磁电阻效应、磁灵敏性等具有重要的作用。本研究采用磁控溅射沉积制备了(Cu/Co、Cu/NiFe, Ta/NiFe 双层膜与 Co/Cu/Co、Co/Cu/NiFe、Co/Ta/NiFe) 三明治结构薄膜。采用振动样品磁强计对薄膜磁性、四探针法对薄膜磁阻性能进行了测试研究,采用洛仑兹电子显微镜法观察了薄膜的磁畴结构。研究结果表明,层间耦合效应不仅与非磁性中间层的厚度相关,而且与中间层材料的特性相关。磁阻与磁畴观察均表明层间耦合效应随中间层厚度的增加而减小,而 Cu 作为中间层的多层膜的层间耦合大于 Ta 作为中间层的层间耦合。

关键词: 双层膜; 三层膜; 层间耦合; 非磁性中间层; 磁畴观察

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Giant magnetoresistive (GMR) spin valve multilayers have attracted considerable attention for application in magnetic random access memory (MRAM), read-out heads and various sensors[1-4]. Because of their high reliability and sensitivity, they are becoming the most promising candidates for the next generation of the recording media and magnetoresistive sensor with high sensitivity in the field of aeronautics and astronautics.

On the basic principle of the spin valve, the giant magnetoresistive effect and the field sensitivity are dependent largely on the effect of interlayer coupling of the adjacent magnetic layers, which is a function of the magnetic properties of the magnetic layers and, in particular, the nonmagnetic spacer layer thickness used for separating the magnetic layers. Therefore, it is very important to investigate the influence of the layer thickness on the interlayer coupling of the two magnetic layers to increase the giant magnetoresistive effect and field

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sensitivity. In this work, Cu/Co, Cu/NiFe, Ta/NiFe bilayers and Co/Cu/Co, Co/Cu/NiFe, Co/Ta/NiFe sandwich films were deposited by a magnetron sputtering method, their magnetic properties were evaluated by VSM, and the spin valve magnetoresistance was investigated by a four-probe method to study the dependence of interlayer coupling of the adjacent magnetic layers on the thickness and nature of the spacer layer.

1 Experimental Methods

Samples were prepared by DC magnetron sputtering at an argon pressure of 1Pa. The layer structure of the bilayer was Cu(20)/Co(t), Cu(20)/NiFe(t) and Ta(20)/NiFe(t), while that of the trilayer was Co(10)/Cu(t)/Co(2), Co(10)/Cu(t)/NiFe(10) and Co(10)/Ta(t)/NiFe(10), respectively. All the layer thickness was in nm. Deposition rate was 1~2Å/s. The two configurations were deposited successively in the following order: in the bilayer structure the nonmagnetic layers and magnetic layers and in the trilayer structure, Co magnetic layer, nonmagnetic spacer and Co or NiFe magnetic layer. Composition of NiFe film was Ni80Fe20, which was confirmed by EDX analysis. AES depth analysis was utilized to evaluate the trilayer structure. Coercivity was obtained from the magnetization loop measured by Vibrating Samples Magnetometer(VSM). Magnetic domain structure was observed by means of Lorentz Electron Microscope. Magnetoresistance was measured at room temperature by the four-probe method.

2 Results and Discussion

Fig. 1 is dependence of coercivity on the magnetic layer thickness in the bilayer structure with nonmagnetic layer thickness 20nm. No obvious change in coercivity was observed with the change of the magnetic layer thickness, implying that no change in structure and microstructure took place within the thickness range in this work. It can be seen that Cu(20nm)/Co showed a larger coercivity than Cu(20nm)/NiFe and Ta(20nm)/NiFe bilayers. Furthermore, the coercivity of NiFe can be reduced with Ta buffer layer compared to that with Cu buffer layer. This means that the spin valve magnetoresistance can be improved by the nonmagnetic layer through adjusting the coercivity of the magnetic layers.

Fig. 2 is a typical AES depth profile for the Cu(20nm)/Co(8nm)/Cu(3nm)/Co(2nm) trilayer film. It can be seen that the sample has a nanomultilayer configuration. The thickness for each layer estimated from the profile is consistent with the corresponding nominal thickness.

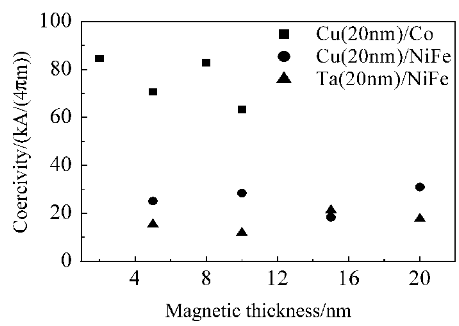


Fig. 1 Dependence of coercivity on magnetic layer thickness and nonmagnetic layer in the bilayer

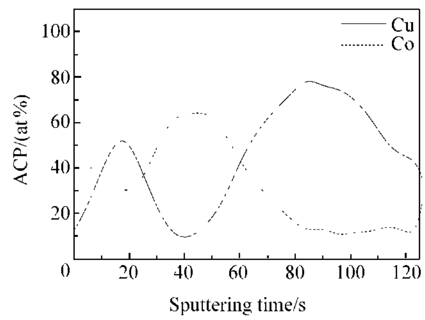
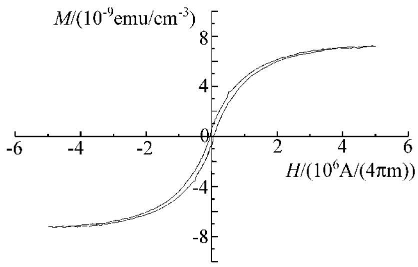
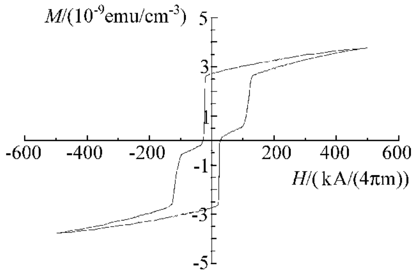


Fig. 2 An AES depth profile of Co(8nm)/Cu(3nm)/Co(2nm) nanotrilayer film

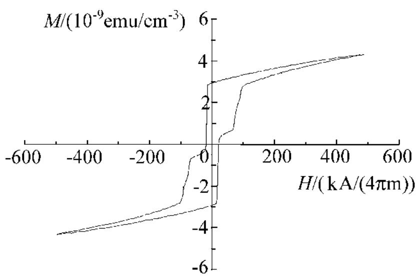
Fig. 3 is a series of magnetization loops of the sandwich films with Cu and Ta spacers. For the Co/NM/NiFe sandwiches, the magnetization loops are characterized by a difference in the switching fields between the two magnetic layers, while for Co/NM/Co the loop shows only a normal shape. The result indicates that an antiparallel alignment of the magnetization can be realized between the two magnetic layers in Co/NM/NiFe. It is the antiparallel configuration that gives rise to the spin valve effect. Furthermore, the trilayers with Ta spacer are expected to have a larger spin valve effect than those with Cu pacer, because the former shows a smaller coercivity than the latter. When the spacer layer thickness increases, the coercivity was reduced, as shown in Fig. 4. The results suggested that the interlayer coupling became weaker



(a) Co(8nm)/Cu(3nm)/Co(2nm)



(b) Co(10nm)/Cu(3nm)/NiFe(10nm)



(c) Co(10nm)/Ta(3nm)/NiFe(10nm)

Fig. 3 Magnetization curves of sandwich films

between the two magnetic layers as the spacer thickness increased. The observation of the magnetic domain supported this argument. It is also observed that, as shown in Fig. 4, the coercivity of Co/Ta/NiFe decreased quickly with increasing spacer thickness, compared to that of Co/Cu/NiFe. It is probably because of the polarization of electrons in Cu layer[5], which enhanced the interlayer coupling between the two adjacent magnetic layers.

Fig. 5 shows magnetic domain images for Co (8nm)/Cu/Co(2nm) trilayer films with Cu layer thickness of 2 and 4nm observed by Lorentz electron microscopy. It can be seen that when the thickness of Cu layer is 2nm, a bubble domain image was observed, which means that the easy magnetization direction is perpendicular to the film sur-

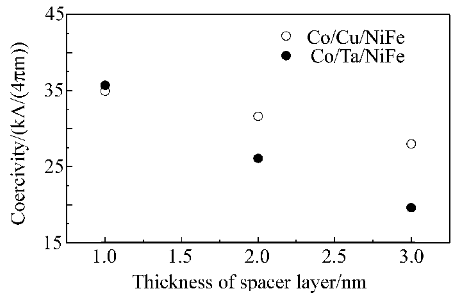
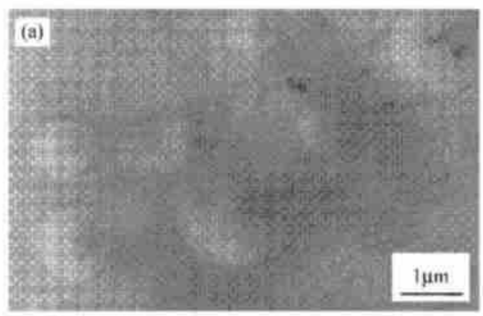
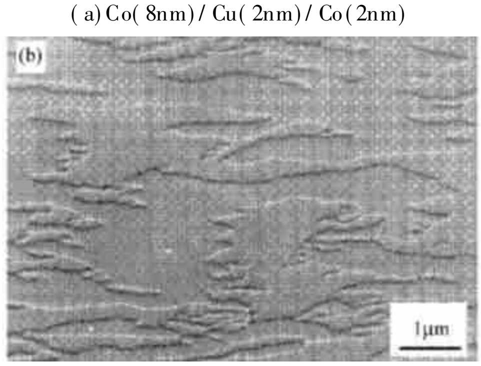


Fig. 4 Dependence of coercivity on the thickness of spacer layer in Co/Cu/NiFe and Co/Ta/NiFe sandwiches



(a) Co(8nm)/Cu(2nm)/Co(2nm)



(b) Co(8nm)/Cu(4nm)/Co(2nm)

Fig. 5 Domain images for Co(8nm)/Cu/Co(2nm) trilayer films

face. However, when the Cu layer thickness is 4nm, the bubble domain image disappeared and in-plane domain structure was observed, implying that the easy direction is parallel to the film surface. Generally, the easy magnetization direction should be parallel to the film when the film thickness is very thin. The existence of the perpendicular easy direction indicated that the interlayer magnetic coupling took place when Cu layer thickness is 2nm. As Cu thickness increased to 4nm, the bubble domains disappeared due to the fact that the interlayer coupling was weakened. On the basic principle of the spin valve, the giant magnetoresistive effect should be enhanced in such a case, because antiparallel magnetic alignment can occur between the two magnetic layers.

Fig. 6 exhibits the effect of the spacer layer thickness on magnetoresistance for the trilayer films. MR ratio increases with increasing Ta spacer thickness due to weakening the interlayer coupling between Co and NiFe layers. For the Co/Cu/NiFe trilayers, however, MR ratio shows a slight decrease with increasing the Cu spacer thickness. The result can be explained by the increased current shunting effect with increasing Cu spacer thickness. The result that Co/Ta/NiFe showed a larger MR ratio than Co/Cu/NiFe supports the explanation.

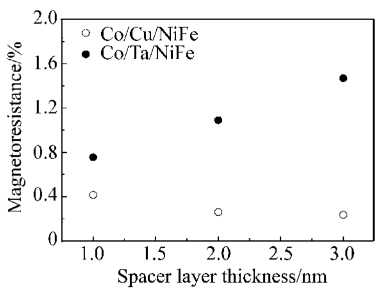


Fig. 6 Magnetoresistance for Co/Cu/NiFe and Co/Ta/NiFe trilayers with different Cu and Ta spacer layer thickness

3 Conclusions

Cu/Co, Cu/NiFe, Ta/NiFe bilayers and Co/Cu/Co, Co/Cu/NiFe, Co/Ta/NiFe sandwich films were deposited by a magnetron sputtering method. It has been found that the interlayer coupling depended not only on the layer thickness of the nonmagnetic spacer but also on the nature of the spacer. Magnetization loops and magnetic domain structure showed that the interlayer coupling was reduced as the spacer layer thickness increased. The trilayers with Cu spacer layer have shown a stronger coupling than those with Ta spacer layer. MR ratio increases with increasing Ta spacer thickness due to weakening the interlayer coupling between Co and NiFe layers. And also, Co/Ta/NiFe showed a larger MR ratio than Co/Cu/NiFe trilayers.

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