Effects of substrate temperature and buffer layer on the anisotropic magnetoresistance of $Ni_{81}Fe_{19}$ ultra-thin films

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A series of Ta(5nm)/$Ni_{81}Fe_{19}$(20nm)/Ta(3nm)and $(Ni_{81}Fe_{19})_{1-x}Cr_x$(5nm)/$Ni_{81}Fe_{19}$(20nm)/Ta(3nm) $Ni_{81}Fe_{19}$ magnetic ultra-thin films were prepared by magnetron sputtering method under different temperature. Effects of substrate temperature and buffer layer on the anisotropic magnetoresistance (AMR) of $Ni_{81}Fe_{19}$ thin films had been investigated. The grain size and grain orientation were analyzed by X-ray diffraction. AMR value of $Ni_{81}Fe_{19}$ ultra-thin films were measured by Four-point probe technology. The buffer layer of Cr atoms in the percentage content was determined by EDS. Surface morphology of the samples was measured by AFM. The results showed that Substrate temperature and buffer layer have significant effects on anisotropic magnetoresistance. With the rise of substrate temperature, AMR value increases. The $Ni_{81}Fe_{19}$ films were prepared at the substrate temperature of 400℃ shows the highest AMR value. When the substrate temperatures are higher than 400℃, as the substrate temperature gets up, the values become stable. With the buffer layer thickness increased, AMR values go up. It has a topped peak 3.67% when the thickness reaches 4nm. Once the thickness is greater than 4nm, AMR values decrease. The AMR value of $Ni_{81}Fe_{19}$ Ultra-thin Films with NiFeCr as the buffer layer was significantly greater than the samples with Ta as the buffer layer; When the thickness of $Ni_{81}Fe_{19}$Cr buffer layer is about 4nm and the buffer layer of Cr atoms in the percentage content is 32%, the maximum anisotropic magnetoresistance (AMR) value reaches 3.67% and the maximum grain size is 23.1nm.

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1. Introduction

Anisotropy magnetoresistance(AMR) was discovered by Thomoson in 1857 in the ferromagnetic polycrystal, with the scientific level and technical conditions of development, the effect has been widely used in magnetic sensors, magnetic recording and other areas [1]. AMR has the small saturated field as well as high magnetic field sensitivity [2], even if after Giant Magneto Resistive (GMR) effect discovery, the computer Reading-Writing heads and sensors were made by the traditional Anisotropy magnetoresistance(AMR) of permalloy films in the market still accounted for the very great proportion now. Currently the major foreign companies continue to mine the potential of AMR reading head [3]. Based on the needs of practical application, the permalloy thin film for AMR reading head must be very thin and the coercivity must be very small, while the AMR value, saturation magnetization Ms is as large as possible [4]. However, with the thickness of $Ni_{81}Fe_{19}$ films decreasing, the anisotropy magnetoresistance value will decline sharply, thus limiting the application of $Ni_{81}Fe_{19}$ films is needed [5]. How to prepare as thin as possible and increase the greatest possible value of AMR permalloy films is an important research topic at home and abroad.

Studies have shown that the substrate temperature [6] and the buffer layer have greater impacts on the permalloy thin film micro-structure, also on AMR and other performances .Since 1980 Ta buffer layer due to a number of advantages is widely recognized [7]. In 2000, Lee et al found NiFeCr buffer layer was superior to Ta in enhancing AMR of permalloy films but the reason is not very clear [8]. For Commercial interests and other reasons, the process of its preparation and structure analysis, there are no substantial research progress reports. In these studies, the base pressure was 5.0×10^{-4} Pa but in many other studies the base pressure was less than 5.0×10^{-6}. In the process of preparation, though the base pressure was not very well, the AMR value was higher. $Ni_{81}Fe_{19}$Cr as the buffer layer, a series of excellent $Ni_{81}Fe_{19}$ Ultra-thin Films were prepared under different temperature and the highest anisotropic magnetoresistance (AMR) value up to 3.67%. The preparation process of ultra-thin $Ni_{81}Fe_{19}$ films was studied as well as the reasons of NiFeCr buffer layer superior to Ta. The results of this study have great significances for the application of $Ni_{81}Fe_{19}$ films in magnetic recording and magnetic sensors.

2. Experiment

Permalloy $Ni_{81}Fe_{19}$ films were deposited on corning glass substrates by a DC magnetron sputtering system (JGP-450).$Ni_{81}Fe_{19}Cr$ buffer layer in the bottom, and then permalloy layer was sputtered. Finally a protective layer was sputtered on the permalloy layer. The work gas was Ar with a purity of 99.99%. The base pressure was less than 5.0×10^{-4} Pa and the Ar pressure was 0.3Pa. A permanent magnet which produced a magnetic field of 2.56×10^{4}A/m along the substrate surface was presented during the deposition process. The field produced an easy axis in $Ni_{81}Fe_{19}$ films. During the deposition process, the glass substrates had been rotating at 18r/min. Ta sputtering deposition rate is 0.0258nm/s and $Ni_{81}Fe_{19}$ sputtering deposition rate is 0.197nm/s. A series of $(Ni_{81}Fe_{19})_{68}Cr_{32}(t)/Ni_{81}Fe_{19}(z)$/Ta (3 nm) $Ni_{81}Fe_{19}$ magnetic ultra-thin films were prepared. The *t* is representative of the buffer layer thickness and the *z* is representative of the thickness of the films. The grain size and grain orientation were analyzed by X-ray diffraction. AMR value of $Ni_{810}Fe_{19}$ ultra-thin films were measured by Four-point probe technology. The percentage content of Cr atoms in the buffer layer was determined by EDS. Surface morphology of the samples was measured by AFM.

3. Results and discussion

3.1 Effects of Cr content of $Ni_{81}Fe_{19}Cr$ buffer layer on anisotropic magnetoresistance of $Ni_{81}Fe_{19}$ films

Cr content of Buffer layer was controlled by the Cr target sputtering current. Fig. 1 shows the AMR of films $(Ni_{81}Fe_{19})_{1-x}Cr_x$(4nm)/$Ni_{81}Fe_{19}$(20nm)/Ta(3nm)dependence on *x*, which *x*=20%,25%,32%,38%,44% respectively. In Fig. 1, it can be seen that as a function of *x*, AMR has a topped peak when *x*=32% and it fall off quickly near the peak. In order to reveal the reasons that the content of Cr of a buffer layer have influence on AMR. A series of $(Ni_{81}Fe_{19})_{1-x}Cr_x$(4nm)/$Ni_{81}Fe_{19}$(100nm)/Ta(3nm) films which *x*=20%,25%,32%,38%,44% respectively were prepared. Fig. 2 is X-ray diffraction patterns of the films. Fig. 2 shows that with Cr content of the buffer layer increases, the film (111) diffraction peak increased first and then decreased and the crystallinity of the films also undergo the same process. When the *x* is 32%, the diffraction peak intensity reaches the strongest, and when the *x* is 20% it becomes the weakest. With the Scherrer formula we can calculate the grain size of the films.

$$D=\frac{K\lambda}{\Delta_{2\theta}\cos\theta} \quad (1)$$

In the formula (1), *D* is particle average diameter. K is shape parameter (k=0.9). λis Cu radiant wavelength K_α (λ=0.1541nm). $\Delta_{2\theta}$ is half peak width. By analyzing with X-ray diffraction spectrum, we can come to conclusion that when *x* are 20%, 25%, 32%, 38%, 44% respectively, the grain sizes are 10.68 nm, 13.87 nm, 23.1 nm, 15.4 nm, 13.31 nm respectively. It is obvious that the Cr content of the Buffer layer has significant influences on the film grain size. When the Cr content of the buffer layer is 32%, the films have the biggest grain size and the best crystallinity and the particle distribution is even. When the grain size of the films becomes bigger, on the contrary, the grain boundary area gets smaller so that reduce the electronic scattering. Thus it causes AMR value of the film to increase.

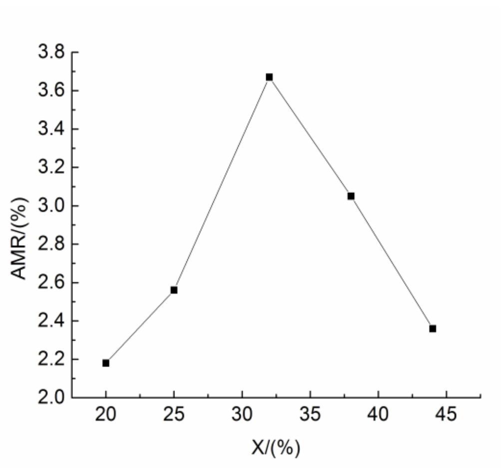

Fig. 1. AMR of films dependence on x.

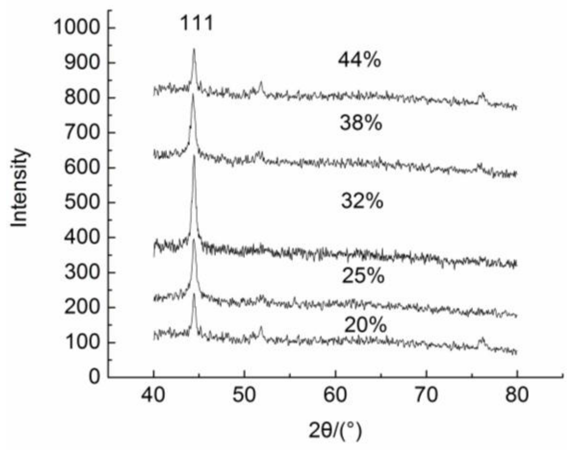

Fig. 2. X-ray diffraction patterns of the $Ni_{81}Fe_{19}$(100nm) films.

3.2 Effects of substrate temperature on $Ni_{81}Fe_{19}$ anisotropic magnetoresistance films

A series of $(Ni_{81}Fe_{19})_{68}Cr_{32}$(4nm)/$Ni_{81}Fe_{19}$(20 nm)/Ta(3 nm) $Ni_{81}Fe_{19}$ magnetic ultra-thin films were prepared at ambient temperature,200℃, 250℃, 300℃,350℃, 400℃, 450℃, respectively. Fig. 3 shows AMR curves of the group of samples. It can be seen from the figure, as the substrate temperature rise, the AMR values increase, when the substrate temperature is 400 ℃, the AMR value reaches the maximum. After that, as the substrate temperature gets up, the values are stable. In the following experiments, the substrate temperature was fixed at 400℃. In order to reveal the reasons of the films AMR values which increase with the rise of temperature, Surface morphology of the samples were measured by AFM. Fig. 4 shows surface morphology of the samples was prepared under different temperatures. By the analysis of the Fig. 4, we can come to the conclusion that the substrate temperature has significant effect on grain size of the films. With the rise of substrate temperature, grain size increased. When the substrate temperature is room temperature, 250℃, 300℃, 350 ℃, 400℃, 450℃, respectively, the grain size of the films is 5.6nm, 10.3nm, 14.2nm, 17.3nm, 23.1nm, 21.2nm, respectively. When substrate temperature is lower, the films are not easily to crystallize but it is easy to form the films without finalized structure. The Fig. 4 (a) shows that the film was prepared at room temperature is basically not crystallized and the particle is not obvious. The grain size is just 5.6 nm. The Fig. 4 (e) shows that the grain size of the film which was prepared at 400℃ reach the maximum (23.1nm) and the particle distribution is even. When the grain size of the films become bigger, on the contrary, the grain boundary area gets smaller so that reduce the electronic scattering. Thus it causes AMR value of the film to increase.

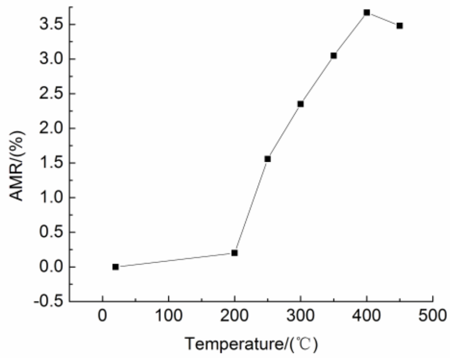

Fig. 3. AMR of films dependence on substrate temperature.

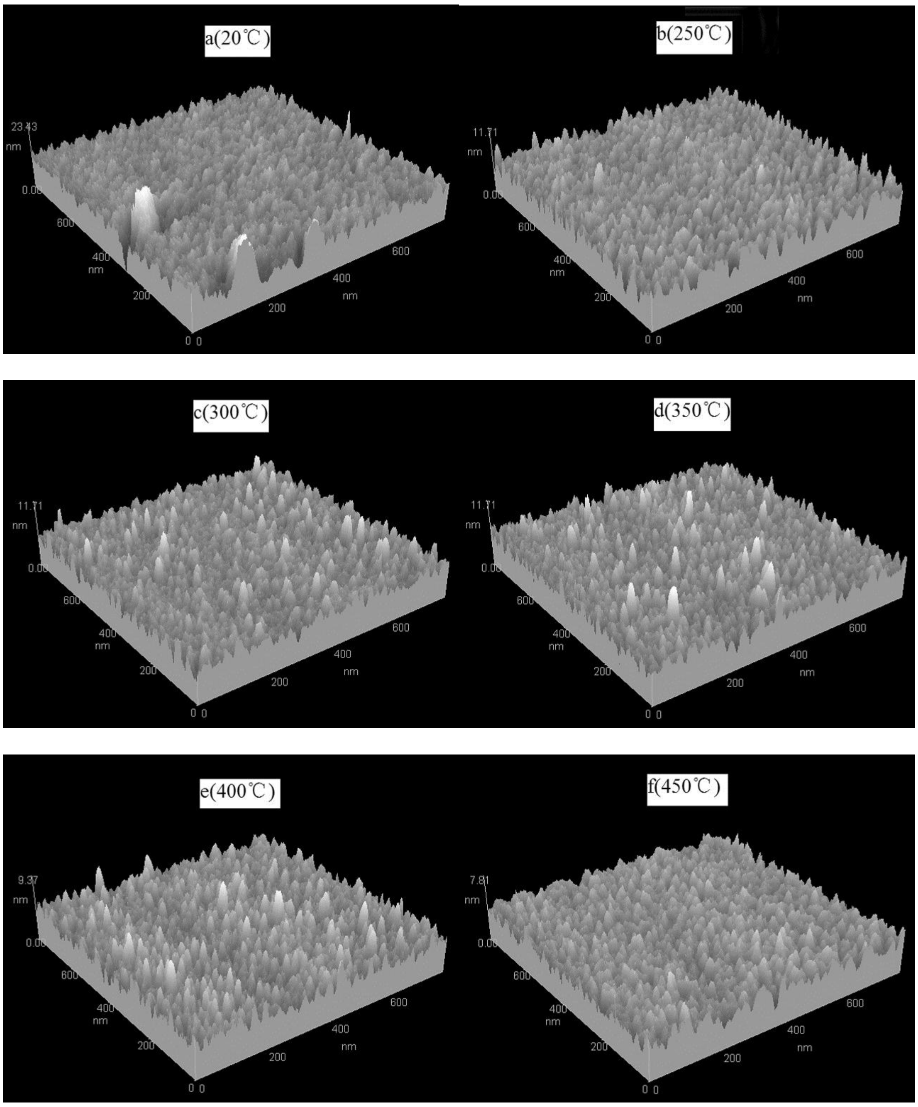

Fig. 4. AFM images of the films were prepared under different temperatures.

3.3 Effects of Buffer layer thickness on $Ni_{81}Fe_{19}$ anisotropic magnetoresistance films

A series of $(Ni_{81}Fe_{19})_{68}Cr_{32}(t)/Ni_{81}Fe_{19}$(20nm)/Ta(3nm) $Ni_{81}Fe_{19}$ magnetic ultra-thin films were prepared when the substrate temperature was fixed at 400℃. *t* is representative of the buffer layer thickness and its value is 0,1,2,3,4,5,6 nm respectively. In figure5 it can be seen that with the buffer layer thickness increased, AMR values go up. It has a topped peak 3.67% when *x*=4nm. After that, with the buffer layer thickness increases, AMR values decrease. This is consistent with the previous experimental results [8]. So in the study the thickness of the buffer layer was fixed at 4nm.

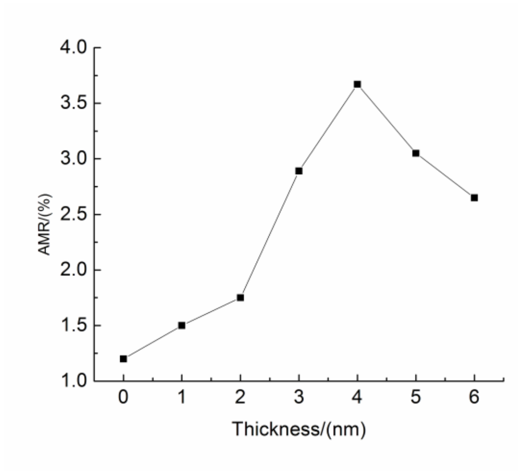

Fig. 5. AMR of films dependence on the buffer layer thickness.

3.4 Effects of Buffer layer type on $Ni_{81}Fe_{19}$ anisotropic magnetoresistance films

A series of $(Ni_{81}Fe_{19})_{68}Cr_{32}$(4 nm)/$Ni_{81}Fe_{19}$(*x* nm)/Ta(3 nm) and Ta(5nm)/$Ni_{81}Fe_{19}$(*x* nm)/Ta(3 nm) $Ni_{81}Fe_{19}$ films were prepared. In figure6, Curve 1 indicates the AMR of the films with NiFeCr buffer layer and Curve2 indicates the AMR of the films with Ta. From Fig. 6, it can be seen that in enhancing the AMR, NiFeCr buffer layer is superior to Ta. The maximum value of $(Ni_{81}Fe_{19})_{68}Cr_{32}$(4nm)/$Ni_{81}Fe_{19}$(20nm)/Ta(3nm)films reach 3.67%.Why is the NiFeCr buffer layer superior to Ta? Studies have shown that with Ta buffer layer, Ta film and NiFe film will react (2Ta + Ni = $NiTa_2$) then the reaction produce a "dead layer" between the films and so these lead to reduction of the effective thickness and the magnetic moment[9]. But for $Ni_{81}Fe_{19}$ films with NiFeCr buffer layer, it is contrary to Ta.

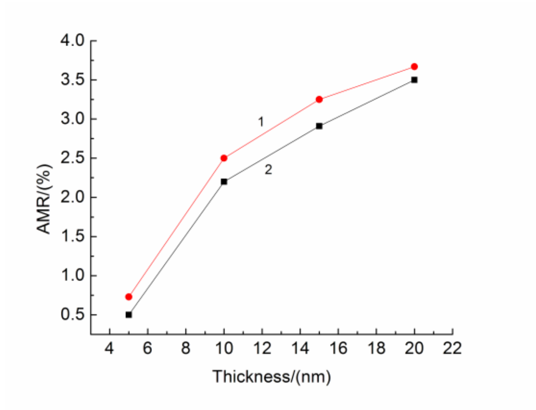

Fig. 6. AMR of $Ni_{81}Fe_{19}$ films with different buffer layers.

4. Conclusions

In summary, substrate temperature and buffer layer type and buffer layer thickness have significant effects on the anisotropic magnetoresistance of $Ni_{81}Fe_{19}$ films. The increase of grain size is the main reason for the increase of AMR value of the films. With NiFeCr buffer layer when Cr atomic percentage of the buffer layer is 32% and the substrate temperature is 400℃, and the thickness of buffer layer is 4nm, anisotropic magneticresistance and grain size of $Ni_{81}Fe_{19}$ (20nm) films reach the maximum. The largest AMR value is 3.67 % and the maximum grain size reaches 23.1nm. The NiFeCr buffer layer compared with Ta can greatly increase the anisotropic magnetoresistance value of $Ni_{81}Fe_{19}$ films. When the permalloy layer thickness within 20nm, the AMR value of $Ni_{81}Fe_{19}$ film with NiFeCr buffer layer higher than that of film with Ta buffer layer by about 12%.

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