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Periodic structure and MR characteristic of Co/Au multilayered films

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We studied the structure and magnetoresistance characteristic of Co/Au multilayered films. The multilayered films were fabricated by the dual-source RF magnetron sputtering method. Co/Au films were annealed in a vacuum (1×10^{-4}Pa). The temperature ranged from 373K to 573K and the time was 0.5h. The magnetoresistance measurement was carried out by a DC two-point method at room temperature in magnetic fields applied parallel to the DC current. We analyzed the structure of multilayered films by X-ray diffraction (XRD). Magnetoresistance ratios (MR ratios) after 373 K and 573 K annealing were big and they were small before annealing and after 473 K annealing.

Key words: magnetoresistance, Co/Au multilayered films

1. INTRODUCTION

The electrical resistance depends on the direction of the magnetization for the ferromagnetic material, and the resistance is the largest when the electric current direction is parallel to the magnetization direction, and is the smallest when the current is perpendicular to the magnetization. This phenomenon is anisotropy magnetoresistance effect (AMR). In magnetic metals / nonmagnetic metals multilayered films, when the magnetization directions of the magnetic metal layers are anti-parallel ordered state, the multilayered type giant magneto resistance(GMR) effect appears [1]. When magnetic metal micro size clusters disperse in nonmagnetic metal matrix, the granular type GMR appears [2][3]. The magnetic signals from the medium become smaller with making a magnetic recording high density and a magnetic encoder small size and high resolution. As a result, the material which has a big MR ratio becomes need to get big signals. GMR is very promising in the purposes.

2. EXPERIMENTAL

Co/Au metal multilayered films were fabricated by a dual-source RF magnetron sputtering on the rotating glass substrates at ambient temperature. Ar gas was used for the sputtering gas; the gas pressure was 0.4 Pa.

We search the formation rate of Co and Au for the fabrication of multilayered film as a preliminary experiment. The film thickness in respectively sputtering for 10 minutes was measured by α step-traceable film thickness meter in 5 points. The mean value except for maximum and minimum values was divided by the sputtering time, and the formation rate was obtained. The measurement accuracy was about several Å.

Fig.1 shows the structure of Co/Au multilayered films. It respectively changed Co and Au, the sample was made to produce 20 stages. These films were shown in Table.1

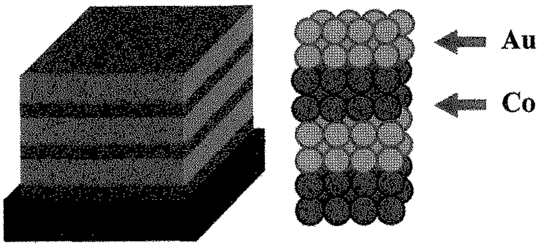


Fig.1 The structure of Co/Au multilayered films

Table.1 Layered structure of Co/Au films

Sample	{Co(7.7Å)/Au(XÅ)}$_{20}$
1	{Co(7.7Å)/Au(13Å)}$_{20}$
2	{Co (7.7Å)/Au(26Å)}$_{20}$
3	{Co (7.7Å)/Au(39Å)}$_{20}$
4	{Co (7.7Å)/Au(52Å)}$_{20}$
5	{Co (7.7Å)/Au(65Å)}$_{20}$
6	{Co (7.7Å)/Au(78Å)}$_{20}$

These films were annealed in vacuum (1×10^{-4}Pa) at temperature range from 373K to 573K for 0.5h. The structure analyses were carried out by XRD. Using the Cu target, XRD was measured between the scanning angle 2θ of 1.3～15 deg (low angle region) and 30～50 deg (high angle region). The MR ratio was measured by DC two-point method at a room temperature, in magnetic field up to 1.03 MA/m applied parallel to the measuring current. The MR ratio was defined by $\Delta\rho=(\rho_0-\rho_S)/\rho_S\times100$, where ρ_0 and ρ_S are the electrical resistance without a field and with the maximum field, respectively.

3. RESULTS AND DISCUSSIONS

3.1 Structure of Co/Au multilayered films

The X-ray diffraction pattern of Co/Au multilayered film is shown in Fig.2. The sharp peak in all patterns of the low-angle region has appeared. The Bragg peak in the low-angle region originates from the periodic composition modulation in the sample.

With the increase of the Au layer thickness, it is proven that the peak interval becomes narrow. This reason is clear from that artificial period Λ of the multilayer film increases with the increase of the Au layer thickness and Bragg equation $2\Lambda\sin\theta = n\lambda$.

Fig.3 shows the X-ray diffraction patterns of Co/Au (Au: 52Å) multilayered films. In as-sputtered, 373K annealed, and 473K annealed specimens the XRD peaks based on their periodic thickness are observed in the low angle region.

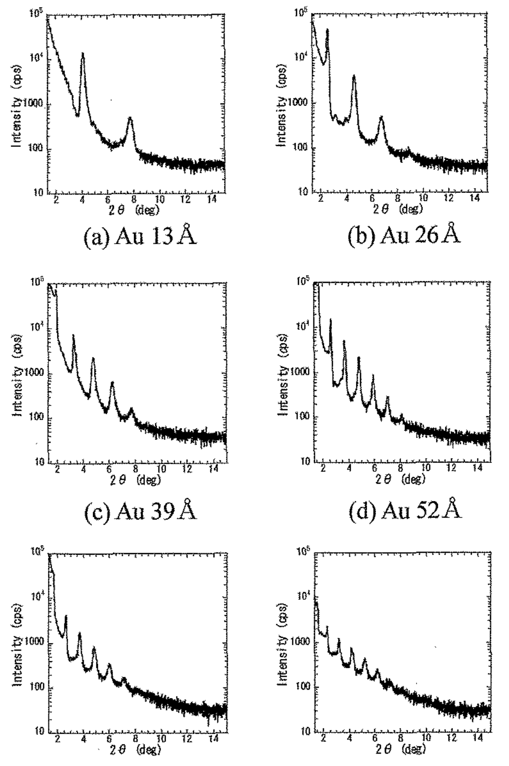


Fig.2 XRD patterns of Co/Au film

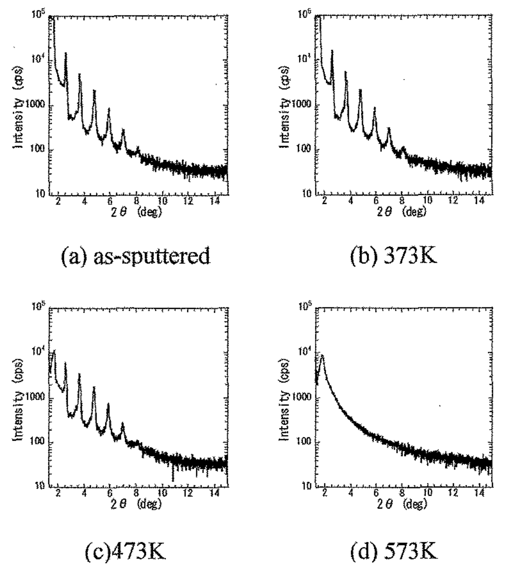


Fig.3 XRD patterns of annealed Co/Au films

Furthermore, the peaks of low angle region disappear with annealing at 573K because high temperature annealing breaks down the layered structure.

3.2 Effect with Au thickness

Fig.4 shows relations between the nonmagnetic Au layer thickness and the MR ratio. As-sputtered, 373K, and 473K annealed samples are shown together. The MR ratios show some peaks with the Au layer thickness.

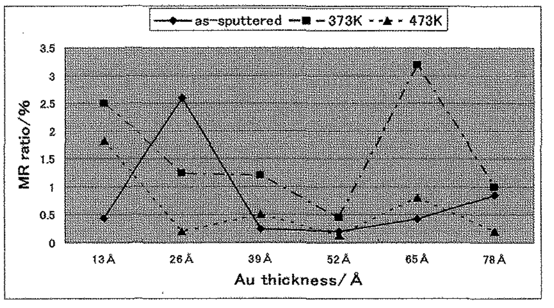


Fig.4 Relations between the Au layer thickness and the MR ratio

Fig.5 shows the MR ratio of the Co/Cu multilayered films [4]. The MR ratios show some peaks depending on the nonmagnetic Cu layer thickness. The direction of the magnetization of the ferromagnetism layer must line up in the condition of the magnetic field zero in the anti-parallel so that the GMR effect may happen. The electric resistance decreases with the process which gathers by the impression of magnetic field in the unidirection, and the scattering which depends on the spin of conduction electron decreasing. The following are proposed as the theory which explains the oscillatory phenomenon of exchange combination of the ferromagnetism intercalation in multilayered film: Theories based on the RKKY interaction [5] or spin polarize quantum well potential theory [6], etc.

In Co/Cu multilayered films, the magnetization of Co layers are parallel ordered state or anti-parallel ordered state and they depends on the thickness of the Cu layer. Large MR ratios by GMR are obtained when the magnetization of Co layers are anti-parallel ordered state, and MR ratios are small when the magnetization of Co layers are parallel ordered state, so the oscillatory changes in the MR ratios appear. The peaks seen with the Co/Au multilayered films can be though to be the same reason as the explanation with the Co/Cu multilayered films, too.

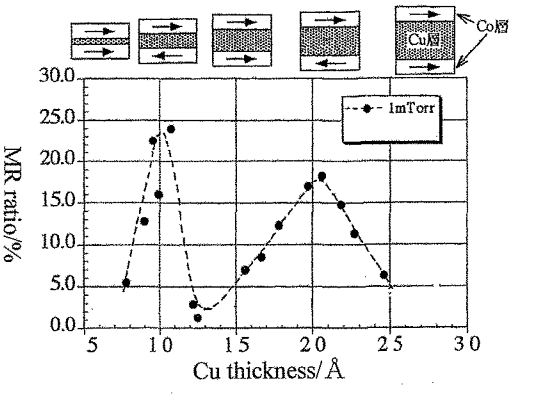


Fig.5 MR ratio of Co/Cu multilayered films

3.3 Annealing effects in the MR ratio

Fig.6 shows the changes in the MR ratios with the annealing. In 373K and 573K annealed specimens the MR ratios are large, but in as-sputtered and 473K annealed specimens the MR ratios are small.

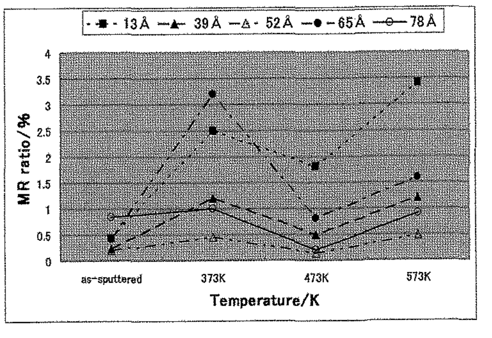
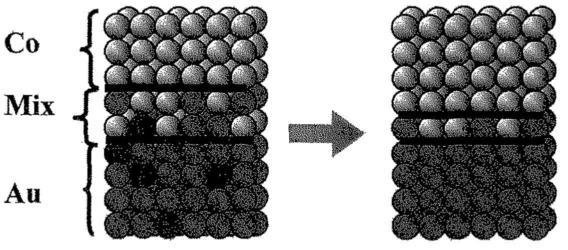


Fig.6 Changes in the MR ratios with the annealing

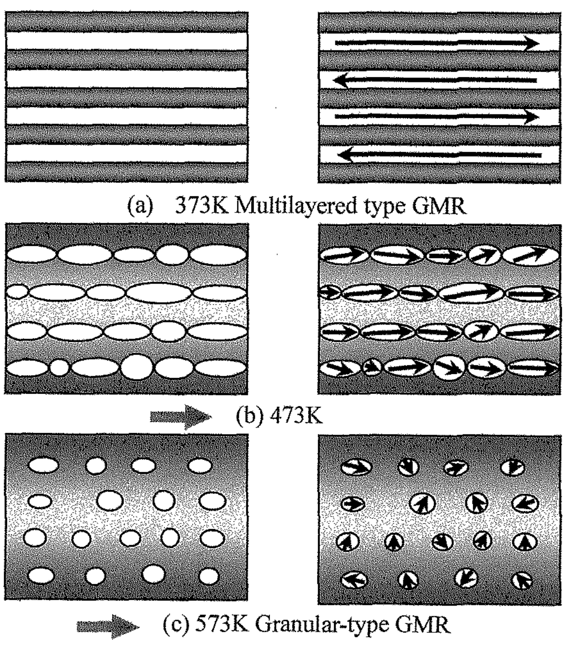
The change in the MR ratio can be ascribed to the change in the microstructure of the Co/Au multilayered films as shown in Fig.7. With the 373K annealing, it thinks that Co atoms move to the Co layer side and that Au atoms move to the Au layer side in the mixed layers because Co and Au are a eutectic system. As a result, that the phase boundary becomes sharper by the annealing [7]. In other words, it is possible to say that the MR ratios increased because the disorder of the phase boundary was eased with the annealing. As the whole layered structure and the multi-layer construction which is ideal more than the condition of as-sputtered was gotten by the low temperature annealing. So, the antiferromagnetic combination between Co layers is intensified (Fig.8 a).



(a) as-sputtered (b) 372K

Fig.7 Low temperature annealing

Furthermore, when annealed at high temperature, it thinks that it had changed into the condition as the separation of Co and Au progresses more, the layered structure collapses at last and Co micro clusters are separating in the Au matrix. Therefore, it thinks that the layered structure changed from the multilayer type GMR to the granular type GMR [8]. Fig.8 shows the change of layered structure.



(a) 373K Multilayered type GMR

(b) 473K

(c) 573K Granular-type GMR

Fig.8 High temperature annealing

4. CONCLUSIONS

MR ratios show some peaks with the nonmagnetic Au layer thickness. In Co/Au multilayered films, the magnetization of Co layers are parallel ordered state or anti-parallel ordered state and they depends on the thickness of the Au layer. Big MR ratios are obtained when the magnetization of Co layers are anti-parallel ordered state.

Mixed layers were at the boundary of the Co layers and Au layers in as-sputtered specimens. With the 373K annealing, the phase boundary becomes sharper and the multi-layer construction which is ideal more than the condition of as-sputtered was gotten by the low temperature annealing.

Furthermore, when annealed at high temperature, it thinks that it had changed into the condition as the separation of Co and Au progresses more, the layered structure collapses at last and Co micro clusters are separating in the Au matrix. Therefore, it thinks that the layered structure changed from the multilayer type GMR to the granular type GMR.

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