

Structural Analysis of Multiple-structure Multilayered Co/Au Films

Rimika Koiwai, Yukako Kozuka, Yoshinori Maeno*, and Masanobu Kobayashi

Dept. of Material Science, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino-shi, Chiba 275-0016, Japan
 FAX: +81-047-478-0329, e-mail: g0072501@cc.it-chiba.ac.jp

*Advanced Device Laboratory, Oki Electric Industry Co. Ltd., 550-5 Higashiasakawa, Hachioji-shi, Tokyo 193-8550, Japan
 FAX: +81-0426-62-6581, e-mail: macno352@oki.co.jp

Multiple-structure multilayered Co/Au films (MSM Co/Au) consist of periodic piles of multilayered Co/Au film layers and Au thin film layers. These films are expected to show more interesting characters than former Co/Au films. Therefore we analyzed their magnetic properties and annealing effects with VSM, XRD, and extended 3-step model profile fitting. The MSM Co/Au films showed a perpendicular magnetization the same as Co/Au films. Compared to Co/Au films, the XRD peaks of MSM Co/Au films were complicated, since multiple-structure has two types of periodic thickness. The MSM Co/Au films kept their structure at 200°C. The perpendicular magnetic anisotropy reached the highest value at this temperature. Consequently, these films were annealed at 200°C, changing an annealing time from 0.5h to 12h. The energy of perpendicular magnetic anisotropy showed the highest value after 1h-annealing, keeping the multiple-structure. As a result of extended 3-step model profile fitting, the mixed layers between Co and Au layers decreased from 2 to 1 atomic planes after 1h-annealing. Since Co and Au is a eutectic system, the interfaces became sharper with annealing.

Keywords: multiple-structure multilayered Co/Au film, extended 3-step model, profile fitting, perpendicular magnetization

1. INTRODUCTION

We have studied the structural analysis of Co/Au films. Co/noble metal films such as Co/Au films are known for perpendicular magnetization films. These films are expected to be a future material, particularly in a high-density recording media. [1] Multiple-structure multilayered Co/Au films (MSM Co/Au films) consist of more complicated structure than Co/Au films, so that new functions will be found. For MSM Co/Pd films, the multistage shape magnetization curve was confirmed from our studies. [2] This peculiar magnetization character is caused by a difference in coercivity of each multilayered Co/Pd film layer of its multiple structure. It is possible that MSM Co/Au films show the same magnetization curve as MSM Co/Pd films. In this paper, we report magnetic properties and annealing effects on MSM Co/Au films. Structural analyses and magnetic properties were measured by x-ray diffraction (XRD) and vibrating sample magnetometer (VSM). To analyze a structural change of interface in detail, a profile fitting method with the extended 3-step model was used.

2. EXPERIMENTAL

The MSM Co/Au films and the Co/Au films were fabricated by dual-source RF magnetron sputtering system, using Ar as a sputtering gas. Structure of MSM Co/Au films are as follows: $[(\text{Co/Au})_n / \text{Au}]_m = [(7.6\text{\AA}/54.0\text{\AA})_3 / 9.5\text{\AA}]_{20}$. Structure of Co/Au films are as follows: $(\text{Co/Au})_n = (8.1\text{\AA}/54.2\text{\AA})_{30}$. They were annealed in vacuum (1×10^{-4} Pa), changing an annealing temperature and an annealing time. Magnetic

properties were measured by VSM under 5kOe. Structural analyses were performed by XRD, using Cu target (40kV, 200mA) Scanning area is 1.3-15deg (low angle region) and 30-50 deg (high angle region). The extended 3-step model [3] was made use of profile fittings to analyze structural changes at interfaces. The periodic thickness was determined by optical thin film model profile fitting. [4]

3. RESULTS AND DISCUSSION

3.1 Structure of MSM Co/Au films

MSM Co/Au films have more complicated structure than Co/Au films. Fig.1 shows the periodic thickness of Co/Au

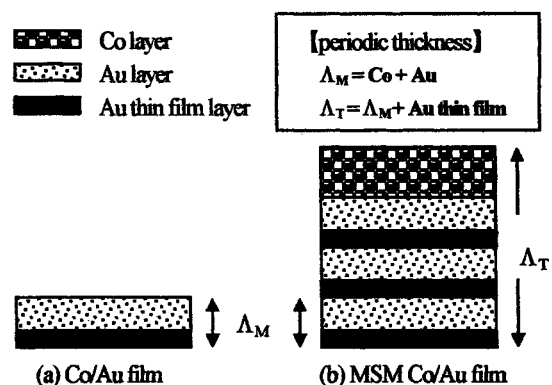


Fig.1 Comparison of periodic thickness

films and MSM Co/Au films. For Co/Au films, the periodic thickness Λ_M consists of Co layer and Au layer. MSM Co/Au films have two sorts of periodic thickness. One is Λ_M and the other is Λ_T . The periodic thickness Λ_T consists of Λ_M piled few times and Au thin-film layer. If the periodic thickness is piled N times, the total film thickness is expressed $N\Lambda_M$ in Co/Au films and is expressed $N\Lambda_T$ in MSM Co/Au films. Fig.2 shows the magnetization curve of Co/Au films and MSM Co/Au films. The MSM Co/Au films showed the same perpendicular magnetization as Co/Au films.

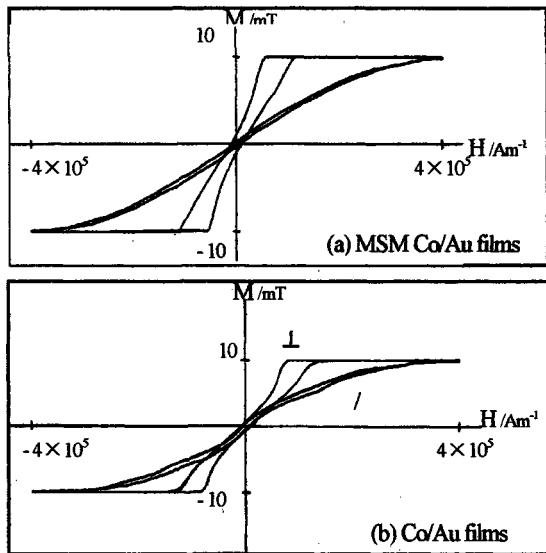


Fig.2 Magnetization curve of Co/Au films and MSM Co/Au films

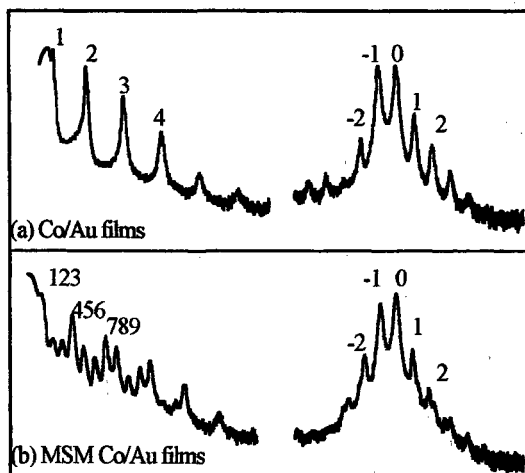


Fig.3 XRD patterns of Co/Au films and MSM Co/Au films
The XRD pattern in the low angle region (1.3-15deg) is left, and in the high angle region (30-50deg) is right.

However, the same multistage shape magnetization curve as MSM Co/Pd films could not be observed. Fig.3 shows the XRD patterns of Co/Au films and MSM Co/Au films. For both films, the XRD peaks based on their periodic thickness were observed in the low angle region. In the high angle region, main peaks (0 order) and satellite peaks ($\pm 1, \pm 2, \dots$) were observed. Here, the main peaks are complex peaks of Co and Au, and the satellite peaks are based on the periodic thickness. Fig.4 shows the relation of XRD peaks to periodic thickness. The MSM films contain two periodic thicknesses, so that their XRD patterns are more complicated than that of Co/Au films.

3.2 Effect with changes of annealing temperature

The MSM Co/Au films were annealed at 100 to 400°C, keeping 0.5h respectively. Fig.5 shows the relation between perpendicular magnetic anisotropy and annealing temperature. The perpendicular magnetic anisotropy increased slightly, and then it reached the highest value at 200°C. When these films were annealed at 300°C, the perpendicular magnetic anisotropy decreased remarkably. The XRD pattern of MSM Co/Au films still remained after annealing at 200°C, so that their multiple-structure was kept at this temperature. Therefore, 200°C is the best temperature to improve their stacking structure.

3.3 Effect with changes of annealing time

In the above discussion, it was found that the best temperature for the MSM Co/Au films was 200°C. Thus, these films were annealed at 200°C, changing an annealing time from 0.5 to 12h. Fig.6 shows the relation between perpendicular

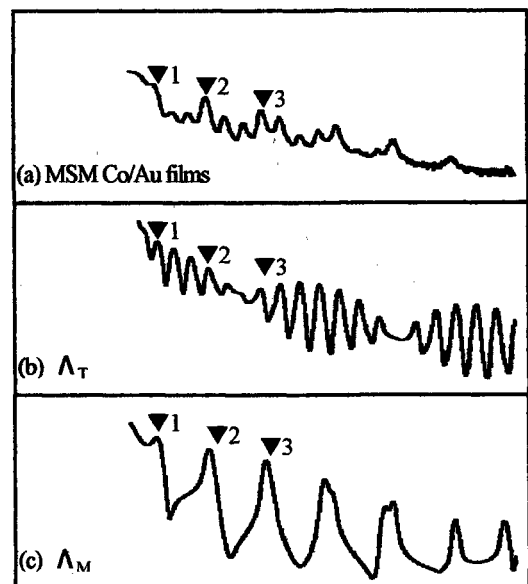


Fig.4 Relation between XRD peaks and periodic thickness
(Low angle region)

The peaks of Λ_M and Λ_T were calculated peaks with the extended 3-step model.

magnetic anisotropy and annealing time. The perpendicular magnetic anisotropy is reached the highest value after 1h-annealing. Fig.7 shows the changes of XRD patterns with annealing. The multiple-structure of MSM Co/Au films still remained after 1h-annealing, and Au (111) peak appeared in the high angle region after 1.5h-annealing. After 12h-annealing, the MSM Co/Au films was keeping their multiple-structure, since the low angle XRD peaks and the satellite peaks could be observed, while Au (111) and Au (200) peaks appeared.

Consequently, the best annealing condition for MSM Co/Au films were found that these films show a large perpendicular magnetic anisotropy, keeping their multiple-structure, i.e., 1h-annealing at 200°C.

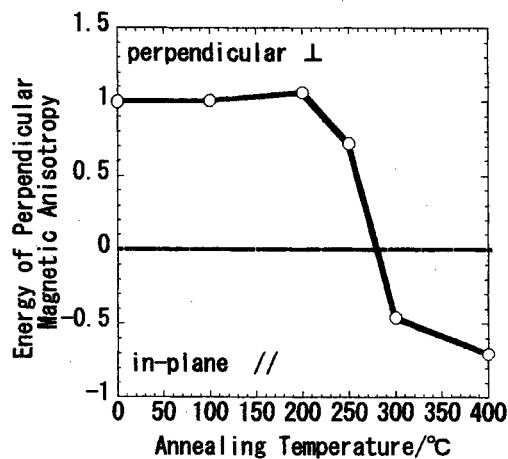


Fig.5 Relation between perpendicular magnetic anisotropy and annealing temperature
The MSM Co/Au films were annealed for 0.5h.

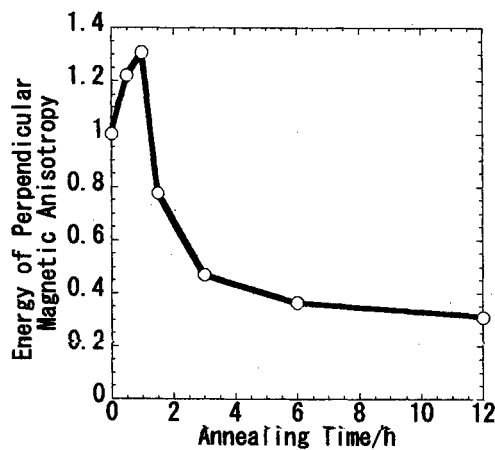


Fig.6 Relation between perpendicular magnetic anisotropy and annealing time
The MSM Co/Au films were annealed at 200°C.

3.4 Annealing effect on interface

As stated above, the best annealing condition was confirmed. Therefore, the MSM Co/Au films were annealed for 1h at 200°C in order to analyze an annealing effect on the interfaces between Co layers and Au layers in detail. Profile fittings with the extended 3-step model are very useful method for structural analyses of interfaces. Fig.8 shows the schematic view of extended 3-step model. This model was improved in consideration of two fluctuations that were included in periodic thickness and mixed layer thickness.

First of all the periodic thickness must be determined to perform the extended 3-step model profile fittings. The periodic thickness was determined by low angle profile, using the optical thin film model that was based upon the dynamical theory. Fig.9 shows the profile fitting in the low angle region. The periodic thickness of MSM Co/Au films was 27 atomic planes, and the mixed layers of interfaces were 2 atomic planes. The high angle profile fittings were shown in Fig.10. The mixed layers decreased from 2 atomic planes to 1 atomic plane with annealing. This decrease corresponds in that Co and Au is a eutectic system.

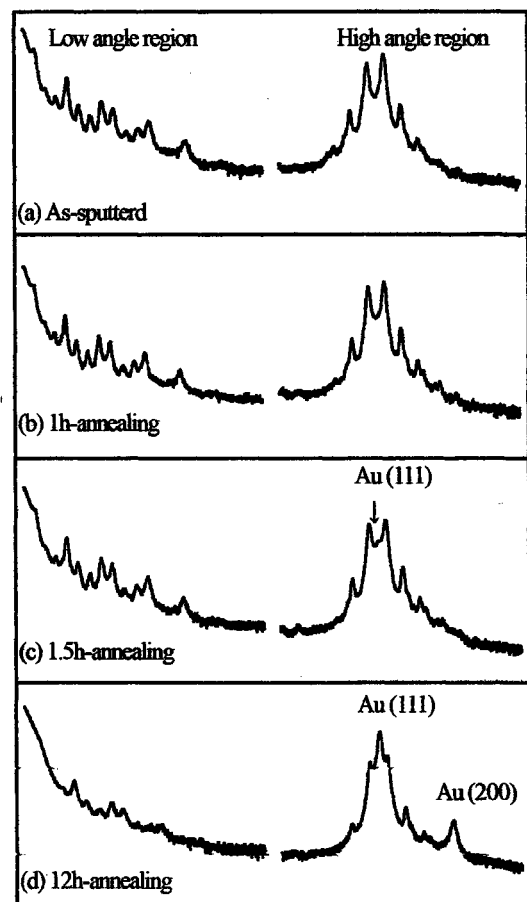


Fig.7 Changes of XRD patterns with annealing

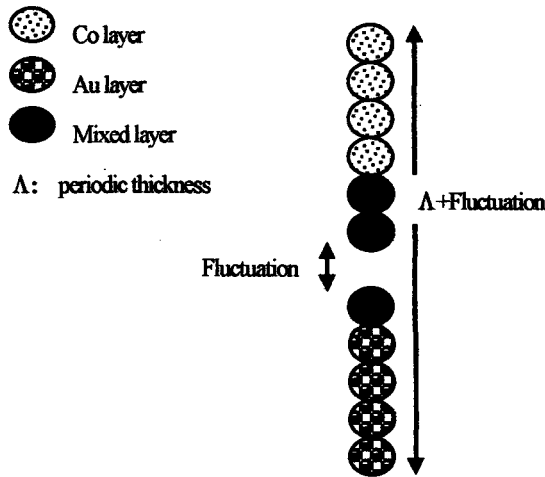


Fig.8 Schematic view of extended 3-step model

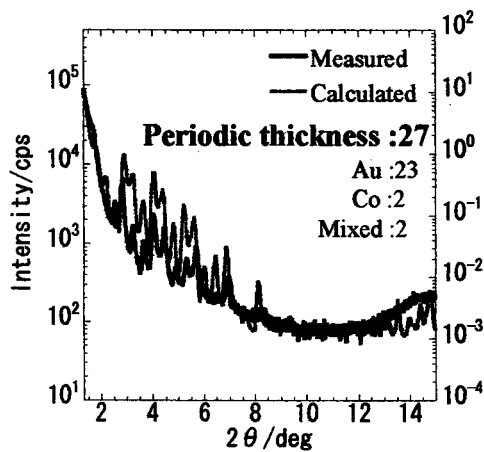
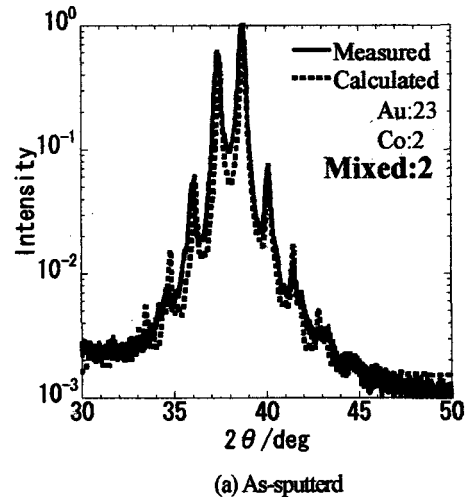
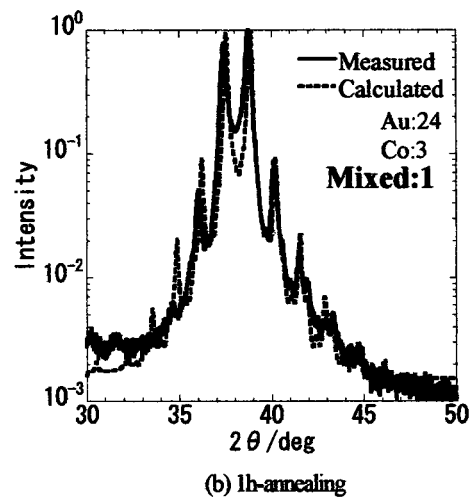


Fig.9 Profile fitting in the low angle region



(a) As-sputtered



(b) 1h-annealing

Fig.10 Profile fitting in the high angle

4. CONCLUSION

The MSM Co/Au films showed the same perpendicular magnetization as Co/Au films. However, the same multistage shape magnetization curve as MSM Co/Pd films could not be observed. The XRD peaks of these films were more complicated than Co/Au films because there are two periodic thicknesses, Λ_M and Λ_T . The MSM Co/Au films were annealed for 1h at 200°C in order to analyze an annealing effect on the interfaces between Co layers and Au layers in detail. When the MSM Co/Au films were annealed under these conditions the perpendicular magnetic anisotropy reached the highest value, keeping their multiple-structure. For the low angle profile fitting, the periodic thickness of MSM Co/Au films was 27 atomic planes. For the high angle region profile fitting using the extended 3-step model, the mixed layers of interfaces between Co layers and Au layers decreased a one

atomic plane with annealing. Consequently, it was found that the mixed layers of interfaces decreased with annealing, since Co and Au is a eutectic system.

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