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Effect of annealing on the characteristics of Au layers grown on the high-temperature deposited $Ni_{50}Fe_{50}$ layers

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Abstract

80 nm-thick $Ni_{50}Fe_{50}$ layers were sputter-deposited on glass substrates at 400 °C and then Au layers were sputter-deposited on the $Ni_{50}Fe_{50}$ layers. The Au/$Ni_{50}Fe_{50}$ bilayer films were annealed in a vacuum of 5×10^{-4} Pa from 250 to 450 °C for 30 min or 90 min. The characteristics of the Au layers were studied by Auger electron spectroscopy, field emission scanning electron microscopy, X-ray diffraction and a four-point probe technique. When the annealing temperature reaches 450 °C, Fe and Ni atoms diffuse markedly into the Au layer and the Fe content is more than the Ni content. When the annealing temperature is lower than 450 °C, the grain size of the Au layers does not change markedly with annealing temperature. However, as the annealing temperature reaches 450 °C, the annealing promotes the grain growth of the Au layer. As the annealing temperature exceeds 300 °C, the resistivity of the bilayer films increases with increasing annealing temperature. The diffusion of Fe and Ni atoms into the Au layer results in an increase in the resistivity of the annealed bilayer film. Large numbers of Fe and Ni atoms diffusing into the Au layer of the annealed Au/$Ni_{50}Fe_{50}$ bilayer film lead to a significant decrease in the lattice constant of the Au layer.

Keywords: Au/$Ni_{50}Fe_{50}$; Bilayer film; Annealing; Diffusion; Characteristic

1. Introduction

The thermal stability of bilayer and multilayer films formed by Ni–Fe alloys and non-magnetic metals have been actively investigated. Hecker et al. [1] reported that for the $Ni_{81}Fe_{19}$/Cu multilayers annealed at over 250 °C Ni atoms diffused preferentially into the Cu layer, resulting in a degradation of the giant magnetoresistance of the multilayers. Kitada et al. [2] found that for Ta/$Ni_{82}Fe_{18}$ bilayer films annealed at over 300 °C Ni atoms diffused preferentially into the Ta layer, resulting in an increase in the coercivity of the NiFe layer. Stavroyiannis [3] sputter-deposited $Ni_{81}Fe_{19}$/Ag multilayers on Si(1 0 0) substrates. After annealing the as-deposited multilayers at 400 °C, granular films of $Ni_{81}Fe_{19}$ nanoparticles embedded in the Ag matrix were obtained as a result of the diffusion between $Ni_{81}Fe_{19}$ and Ag layers. Recently, Huang et al. [4] prepared Au/$Ni_{80}Fe_{20}$ and Au/$Ni_{30}Fe_{70}$ bilayer films on glass substrates and then annealed them in vacuum from 100 to 350 °C for 15 and 30 min. As the annealing temperature and time increased, the Ni atoms in the $Ni_{80}Fe_{20}$ layer diffused preferentially into the Au layer whereas a significant diffusion of the Fe atoms in the $Ni_{30}Fe_{70}$ layer into the Au layer was observed, although a few Ni atoms also diffused into the Au layer. It is an interesting topic which atom is the significant atom diffusing into the Au layer for the Au/$Ni_{50}Fe_{50}$ bilayer film. In the present work, 80-nm-thick $Ni_{50}Fe_{50}$ layers were sputter-deposited on glass substrates at 400 °C and then Au layers were sputter-deposited on the $Ni_{50}Fe_{50}$ layers. The compositional, structural and electrical properties of the Au/$Ni_{50}Fe_{50}$ bilayer films are studied by using Auger electron spectroscopy (AES), field emission scanning electron microscopy (FE-SEM), X-ray diffraction (XRD) and a four-point probe technique as a function of

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annealing temperature and time. The effect of annealing on the characteristics of the bilayer films will be briefly discussed.

2. Experimental procedure

$Ni_{50}Fe_{50}$ layers with a thickness of about 80 nm were deposited on glass substrates at 400 °C by DC magnetron sputtering. The target was 50 mm in diameter and 4 mm in thickness. The substrate was a grounded anode. The background pressure was 3×10^{-4} Pa and the Ar gas pressure was 1.0 Pa during sputtering. The deposition rate of the $Ni_{50}Fe_{50}$ layers was about 10 nm/min. Composition of the $Ni_{50}Fe_{50}$ layer was confirmed using energy-dispersive X-ray spectroscopy. The glass substrates were ultrasonically rinsed in acetone, distilled water and ethanol, successively. Au layers with a thickness of about 80 nm were deposited on the substrates coated with the $Ni_{50}Fe_{50}$ layers by using a SBC-12-type DC sputtering system [KYKY] [4,5]. Prior to deposition, the chamber was evacuated to a pressure of 2 Pa using a rotary pump for 1 min. The sputtering was started at an Ar gas pressure of 4 Pa. The sputtering power was $1000\,V\times10\,mA$. The substrate was also a grounded anode. The distance between the target and the substrate was 25 mm. The substrate temperature gradually raised from room temperature to about 150 °C during sputtering because of both the bombardment of energetic particles and the thermal radiation of target. The deposition time of the Au layer was 4 min and the deposition rate was 20 nm/min. Before depositing Au layers, the substrates coated with the $Ni_{50}Fe_{50}$ layers were exposed to air. Thicknesses of the $Ni_{50}Fe_{50}$ and Au layers were measured by using multiple beam interferometry. The $Au/Ni_{50}Fe_{50}$ bilayer films were annealed in a vacuum of 5×10^{-4} Pa from 250 to 450 °C for 30 or 90 min. The annealing temperature was controlled with a deviation of ±1 °C using SR73-type temperature controller [Shimaden].

For the $Au/Ni_{50}Fe_{50}$ bilayer film annealed at 450 °C for 90 min, composition inside the Au layer was analyzed using AES [Perkin Elmer] with a background pressure of 1×10^{-8} Pa at an Ar sputtering voltage of 3 kV. AES measurements were carried out after sputtering off the surface of the Au layer for 0.6, 1.2 and 1.8 min. An average composition inside the Au layer can be obtained by calculating the average value of relevant elements for the three-time measurements. The sputter etching rate was about 0.6 nm/s. The FE-SEM of XL30S-FEG type [Philips] was used to observe the structure of the Au layers. XRD [Rigaku] was used to investigate the crystalline structure and the lattice constant of the bilayer films. The XRD experiments were performed in a standard θ—2θ scan using a CuKα radiation filtered by a crystal monochromator (wavelength $\lambda = 0.15417$ nm). 2θ scanned from 30° to 80°. X-ray source was operated at power of $40\,kV\times100\,mA$. A scan speed was 0.1°/s and a scan step was 0.02°. The measuring accuracy of diffraction angle is ±0.01°. After and before annealing, sheet resistances of the bilayer films were measured at room temperature using the four-point probe technique.

3. Results

3.1. Composition

Fig. 1 shows a typical Auger electron spectrum inside the Au layer of the $Au/Ni_{50}Fe_{50}$ bilayer film annealed at 450 °C for 90 min after sputtering off the surface of the Au layer for 1.2 min. As can be seen from Fig. 1, no impurities such as carbon, nitrogen and oxygen can be detected inside the Au layer. Fe and Ni atoms are detected in the Au layer. The Fe and Ni contents inside the Au layer is about 20 and 10 at%, respectively. Therefore, it can be concluded that both Fe and Ni atoms diffuse markedly into the Au layer and the Fe content is more than the Ni content when the $Au/Ni_{50}Fe_{50}$ bilayer film is annealed at 450 °C for 90 min. Chang [6] reported that, for the electron-beam-evaporated Au/Ni bilayer film, the diffusion of Ni atoms into the Au layer occurs at an annealing temperature of 300 °C in oxygen and 400 °C in nitrogen. Sakamoto et al. [7] found that, for the electron-beam-evaporated Au/Fe multilayer film the Fe atoms diffuse into the Au layer at an annealing temperature of 200 °C. It seems that the Fe atoms could diffuse easily into the Au layer compared to the Ni atoms. On the other hand, the structure of the Au layer could significantly affect the diffusion of Ni or Fe atoms into the Au layer. As is well known, a film structure is strongly influenced by the deposition conditions and different deposition conditions could lead to the different structures of the Au layers [6,7]. In the present work, the Fe content is more than the Ni content in the Au layer of the annealed $Au/Ni_{50}Fe_{50}$ bilayer film. Therefore, it could be said that the Fe atoms could diffuse easily into the Au layer compared with the Ni atoms.

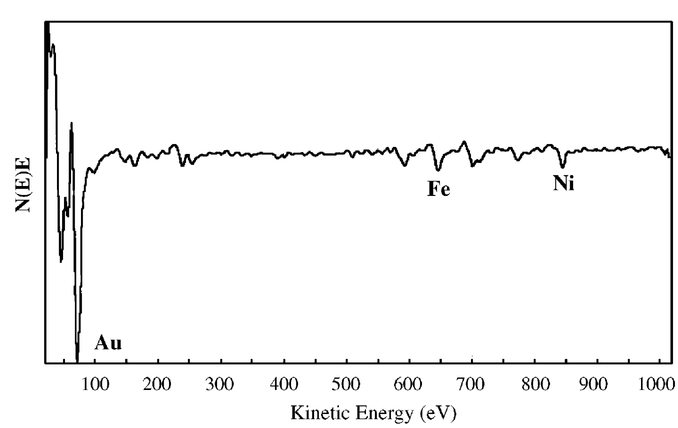

Fig. 1. A typical Auger electron spectrum inside the Au layer of the $Au/Ni_{50}Fe_{50}$ bilayer film annealed at 450 °C for 90 min after sputtering the surface of the Au layer for 1.2 min.