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IN SITU STRESS MEASUREMENT WITH MONOATOMIC LAYER SENSITIVITY

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1. Introduction

Stress in thin films inevitably introduced into thin films during fabrication is known as a prime limitation to the growth of very thick films, and causes problems such as film fracture, which result from excess of tensile stress, and film buckling, which result from excess of compressive stress. Also, the introduction of stress into active regions of thin films can seriously affect their physical properties. For instance, film stresses can induce band gap shifts in semiconductor, transition temperature changes in superconductor, and magnetic anisotropy in magnetic films via inverse magnetostriction mechanism. So, accurate measurement of stress in thin films are very important for understanding a deformation mechanism and futhermore improving a reliability of thin film as devices.

Various methods have been suggested for stress measurements [1], but the cantilever beam technique pioneered by Klockholm [2] is widely used, where one side of the substrate is fixed by a substrate holder and the other side of the substrate is free to move. Stress of a film is determined by detecting the deflection of a thin substrate as the film is deposited on it. Several methods have been developed for the measurement of deflection. The cantilever capacitance method, where a change of capacitance between substrate and electrode is monitored, has been popularly adopted for in situ measurement of deflection. However, this method can not applied to a sputtering system, since the capacitance is largely influenced by plasma existed during sputtering process. Therefore, we have adopted an optical method, where a change of the reflectivity with deflection of a substrate was monitored.

In this paper, we describe an in situ stress-measurement apparatus using an optical displacement detector and report in situ stress measurements of several multilayer films prepared by dc magnetron sputtering.

2. Experiment and Results

Stress of Ni/Pt and Co/Pt multilayers was measured *in situ* during the deposition using a homemade optical displacement detector[3]. The displacement sensing probe, detecting a deflection of the substrate, was composed of 40 multimode fibers of 50 μm core diameter. They were divided into 20 'sending fibers' where the light was transmitted to the substrate and 20 'receiving fibers' where the reflected light was guided to a photodetector. For a cantilever geometry where the back side of the substrate was coated by 1000-Å-thick Al , the probe was located behind the free end of the substrate. The substrate was 4-cm-long, 1.1-cm-wide, and 130-μm-thick. A change in the gap distance between the probe and the substrate, caused by the stress of a film, was measured by linearly responsed change in the intensity of the reflecting light. The sensitivity of the displacement probe was 132 mV/μm, and minimum detectable displacement was 7.6 Å using a voltmeter of 100-μV resolution : the probe turned out to be sensitive enough to detect displacement caused by a monoatomic layer deposition. The output intensity was measured every 0.051 sec using GPIB interface to a computer.

The stress of a multilayer was determined from the change of the gap distance ⊿d using a well-known Stoney's formula as follows:

$$\sigma = \frac{E_s t_s^2}{3l^2(1 - \nu_s)} \frac{\Delta d}{\Delta h} \qquad (1)$$

where E_s, n_s, t_s ,and l are Young's modulus, Poisson's ratio, thickness, length of the substrate, respectively, and ⊿h is the change of the film thickness. So, using E_s= 1.51 × 10^{12} dyne/cm^2 , n_s= 0.3, t_s=130 μm, l=4 cm for glass substrate and assuming a monoatomic layer deposition of ⊿h = 2 Å, a minimum detectable stress of the probe was estimated to be 2.9 × 10^7 dyne/cm^2.

Fig. 1 shows a plot of the gap distance vs. deposition time for (4- Å Co/ 9- Å Pt)$_{30}$. Tensile stress in Co sublayers and compressive stress in Pt sublayer is obtained. Fig. 2 shows a plot of the gap distance vs. deposition time for (7- Å Ni/ 3- Å Pt)$_{30}$. A distinct change in the stress can be seen around Ni/Pt interfaces, which is believed to be related with a structural change from a coherent to incoherent interfacial matching between Ni and Pt sublayers. The critical thickness for a coherency-incoherency transition observed in our samples is agreed with a theoretical value of ~ 1 Å estimated by den Broeder *et al*[4]. In conclusion, we could successfully measure the stress with a high sensitivity enough to observe interfacial stress in the multilayers.

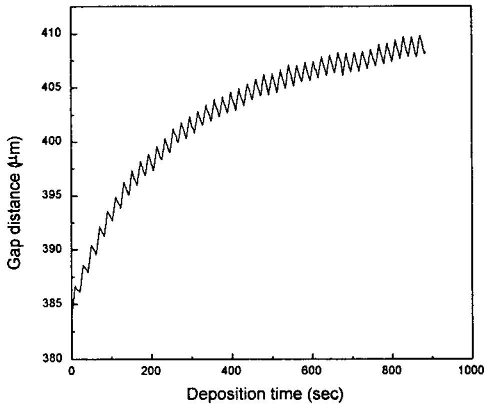

Fig. 1. A plot of the Gap distance vs. deposition time for (4- Å Co/ 9-Å Pt)$_{30}$.

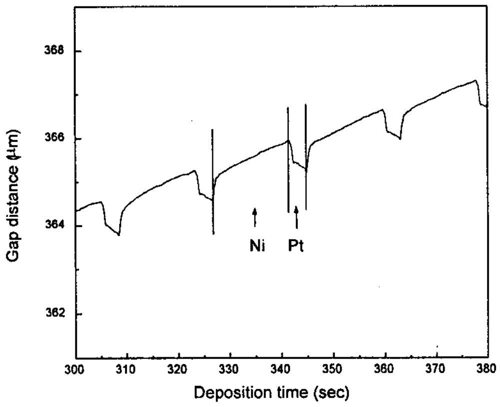

Fig. 2. A plot of the Gap distance vs. deposition time for (7- Å Ni/ 3-Å Pt)$_{30}$.

3. References

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