Observation of Magnetic Dead Layer in Ni/Pt Multilayers

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Abstract—Magnetically dead layer in Ni/Pt multilayer was found for the samples of constant 3 Pt and less than 9 Ni sublayer thicknesses, prepared by sequential dc magnetron sputter deposition at an Ar sputtering pressure of 7 mTorr. Low angle x-ray diffraction peaks and cross-sectional TEM images revealed that this dead layer was due to the interfacial effects rather than the interface diffusion or mixing.

Index Terms—Magnetization, Ni/Pt multilayers, interface, dead layer.

I. INTRODUCTION

The surface magnetization of Ni has attracted considerable interest in surface and thin film magnetism, since Liebermann et al.[1] discussed the possibility of a nonmagnetic 'dead layer' in the topmost Ni layer. Several experimental observations of this dead layer were reported for single Ni films[2-6]. However, some theoretical calculations showed that this phenomenon was an experimental artifact resulted from the incorporation of H atoms into Ni layers[7]. Furthermore, these theoretical results expected an enhancement of magnetic moment at the first layer of Ni[8]. However, recent studies on Ni-based multilayers revealed that the magnetization of Ni was strongly dependent on the adjacent circumstance of Ni layer. For instance, it was reported that the magnetization was enhanced in Ni/Pd multilayers[9], whereas the magnetization was reduced in Ni/Mo multilayers[11,12].

In this paper, we have investigated the magnetization of Ni/Pt multilayers with varying the Ni-sublayer thickness, and compared its variation together with the case for Ni/Pd multilayers.

II. EXPERIMENT

Ni/Pt multilayers were prepared by sequential dc magnetron sputtering onto glass substrates under a base vacuum of 8×10⁻⁷ Torr and Ar sputtering pressure of 7 mTorr. The power applied to Ni and Pt targets was 30 W each. The thickness of platinum sublayer was fixed to 3 Å, while thickness of Ni sublayer was varied from 7 Å to 30 Å. The sublayer thickness was engineered by manipulating the dwelling time of the substrate over the targets using a microprocessor controlled stepping motor. The number of multilayer repeats was fixed at 30. To see the dependence of Ar pressure effect on the dead layer, the other set of samples was made at an Ar pressure of 2 mTorr with the same platinum sublayer thickness of 3 Å. The low-angle x-ray diffraction patterns of all Ni/Pt multilayers in this study showed peaks characteristic of the multilayer structure, and the actual thickness was found to be within a variation of ± 5% from the nominal thickness. The samples will be designated by (tNi Ni/30-A Pt), where tNi is the thickness of nickel sublayer, t is the thickness of platinum sublayer, and n is the number of multilayer repeats.

The saturation magnetization was measured for each sample using a vibrating sample magnetometer(VSM) with an external field up to 10 kOe. To analyze its variation, we have examined the microstructure of Ni/Pt multilayers using cross-sectional transmission electron microscope(TEM). Cross-sectional TEM specimens were prepared via mechanical polishing followed by ion milling, using a specimen stage cooled by liquid nitrogen. TEM specimens were examined in a JEOL JEM 2000EX electron microscope with a point-to-point resolution of 0.21 nm, operated at 200 kV.

III. RESULTS AND DISCUSSION

In Fig. 1 we plot the saturation magnetization $M_s$ of Ni/Pt multilayers as a function of the Ni sublayer thickness $t_{Ni}$, together with the results of ($t_{Ni}$ Ni/5.7-Å Pd) $\gamma_{0}$ fabricated under the same Ar pressure of 7 mTorr[9,10]. The saturation magnetization was found to be decreased with decreasing the Ni sublayer thickness and it became nearly zero when the Ni sublayer thickness was 7 Å. For the analysis of dead layer, the magnetization in a multilayer might be expressed by a simple phenomenological relationship of $M = M_0 (1-2 \delta/t_{Ni})$, where $M$ is the Ni magnetization of a multilayer, $M_0$ is the magnetization of thick Ni, and $\delta$ is the thickness of magnetically dead layer. Using this relationship we obtained the well-fitted values of $M_0 = 349 \pm 17$ emu/cm³ and $\delta = 2.7 \pm 0.3$ Å. This means that at least one atomic Ni layer near the interfaces in Ni/Pt...
The saturation magnetization of Ni/Pt and Ni/Pd multilayer films varies from 5 Å to 45 Å with an interval of 5 Å. Prior to measuring the saturation magnetization of the samples, we have examined the interface with low angle x-ray diffraction.

Figure 2 shows two x-ray diffraction curve for the sample A of (25-Å Ni/3-Å Pt)10 fabricated at 2-mTorr Ar pressure and the sample B of (18-Å Ni/3-Å Pt)10 fabricated at 7-mTorr Ar pressure. Considering the fact that an FWHM of the low-angle x-ray diffraction peak of the multilayer is related to a degree of interfacial sharpness, a smaller FWHM of sample A of $\Delta \theta_{\text{FWHM}}=0.45$ compared to that of sample B of $\Delta \theta_{\text{FWHM}}=0.53$ suggests a possibility that the sample made at 2 mTorr Ar pressure has sharper interfaces and less interface mixing compared to the sample made at 7-mTorr Ar pressure. Another hint of sharper interface at 2-mTorr Ar pressure was obtained for the sample of (24-Å Ni/27.6-Å Pt)30 via a cross-sectional TEM. Figure 3 shows TEM image of this sample, which again confirms the sharp interface at this Ar pressure.

If the interface mixing is the origin of dead layer in Ni/Pt multilayers, smaller thickness of dead layer or larger magnetization is expected for 2-mTorr samples compared to 7-mTorr samples due to the sharper interface. To check this scenario, we measured the saturation magnetization of the samples made at 2-mTorr Ar pressure. Fig. 4 shows the linear fitting of the saturation magnetization of these samples using the phenomenological relation. From this linear fitting, we obtained that the dead layer thickness is about 4.8 Å for 2-mTorr samples and it is about 2.2 Å for 7-mTorr samples. The larger dead layer thickness of 2-mTorr samples than that of the 7-mTorr samples implies that interface mixing is not a major origin for the magnetic dead layer. This suggests that the surrounding atom...
We have measured the magnetization of Ni/Pt multilayers with varying the Ni-sublayer thickness, and compared its variation together with the case of Ni/Pd multilayers. The sharper interface for the samples made at 2-mTorr Ar pressure does not yield larger magnetization of the samples compared to the samples made at 7-mTorr Ar pressure. Thus, it could be concluded that the interface mixing is not responsible for the existence of magnetic dead layer in Ni/Pt multilayers.

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**REFERENCES**