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Magnetic and structural properties of ultrathin magnetic films : Ni/Pt(111)

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Abstract

We have studied magnetic and structural properties of ultrathin Ni films grown on Pt(111) surface using in situ surface magneto-optic Kerr effect and X-ray photoelectron spectroscopy. Perpendicular magnetic anisotropy was absent, and longitudinal Kerr signal was only detectable for Ni films thicker than 6 monolayers. Enhancement in longitudinal Kerr signal by 30% was achieved by post-annealing at temperatures below 800K, but upon annealing at 820K, surface alloy was formed. By using core-level binding-energy shifts, the composition was determined to be Ni 70 at.%.

Keywords : surface magneto-optic Kerr effect (SMOKE); X-ray photoelectron spectroscopy (XPS), interdiffusion, Nickel, Platinum, magnetic films

1. Introduction

The research on magnetic properties of ultrathin films and multilayers has received much attention mainly due to their technological application as data storage devices. Ni/Pt(111) multilayers have been investigated intensively both experimentally and theoretically. The observation of perpendicular magnetic anisotropy (PMA) at room temperature (RT) was reported [1,2], and efforts have been made to understand the origin of the perpendicular magnetic anisotropy [3-5]. There have been some inconsistent experimental results based on X-ray magnetic circular dichroism and superconducting quantum interference measurements about the existence of the magnetically dead layers [6,7], and a recent calculation employing various interface conditions tried to explain this inconsistency by assuming different structural configurations [8,9]. Therefore, it is important to study intermixing and initial growth mode of ultrathin layers in order to understand those properties of multilayers.

However, Ni ultrathin films on Pt(111) have been relatively less studied. A photoelectron diffraction study reported that the first Ni monolayer grows strained in-plane to match the substrate pseudomorphically, and that the multilayer maintains the horizontal strain and consequently shows a vertical spacing contraction [10]. Low-energy diffraction (LEED) study on this system showed a complex behavior, and it was concluded that thin film growth follows the Stranski-Krastanov mode [11].

In this report, surface magneto-optic Kerr effect (SMOKE) and X-ray photoelectron spectroscopy (XPS) were used to study the magnetic property of Ni ultrathin films on Pt(111) surface. Since it was suggested that the origin of room-temperature PMA observed in multilayers be the magnetoelastic anisotropy induced by tensile stress [7], it is probable that ultrathin Ni/Pt(111) also has PMA, but we could observe no RT PMA. The

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change of magneto-optic behavior and the interdiffusion upon heating were also investigated. In the previous study, the Kerr signal from Fe/Pd(111) was increased by more than 200% when annealed at 600K [12], but such strong enhancement was not observed in Ni/Pt (111).

2. Experiment

The SMOKE and XPS measurements were performed in a home-made ultrahigh vacuum chamber. The base pressure of the chamber was 1×10^{-10} torr and all the measurements were done at room temperature except for the SMOKE measurements for determining T_c. The Pt(111) substrate was a disk-type sample with 10 mm diameter and 1mm thickness. The surface was cleaned by several cycles of Ar^+ sputtering at 1 keV and annealing at 870K in the UHV chamber until the crystal surface showed a well-defined LEED pattern with no contamination detected in XPS spectrum. The light source for SMOKE measurement was 10mW He-Ne laser with λ=623.8 nm. The XPS spectra shown here were obtained with unmonochromatized Mg K_α lines with $h\nu$=1253.6 eV. The overall resolution was 0.9 eV.

Ni film was deposited on the Pt substrate at RT by e-beam heating method. Film thickness was calibrated using quartz thickness monitor, and the deposition rate of Ni films was about 1 ML per 900s. The thickest film we studied was 10.3 ML. In this work, Ni film thickness was represented in the unit of monolayers and set 1 ML as 1.30×10^{15} Ni atoms cm^{-2}, assuming a pseudomorphic growth of Ni film on Pt(111) surface.

3. Results and Discussion

Figure 1 shows the change of the longitudinal Kerr signal as a function of Ni-layer thickness. The Kerr signal was detected only when the thickness was more than 6 ML, and no polar Kerr signal was observed within experimental error. From the figure, extrapolation

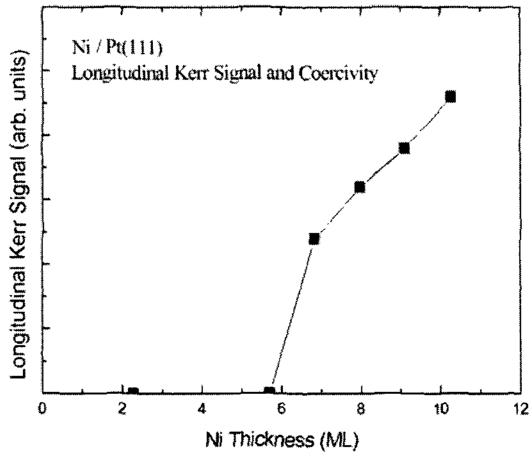

Fig. 1. Longitudinal Kerr signal (filled rectangles) and coercivity (open rectangles) as a function of Ni-adlayer thickness.

may lead to the conclusion that the critical thickness is about 3 ML. However, the calculation on magnetic properties of Ni/Pt(111) system considering various intermixed cases predicted that magnetically dead layers can be present only when there is intermixing between Ni and Pt atoms [8,9], and it seems that T_c of thin Ni layers is simply lower than RT.

In order to investigate intermixing and morphological change upon heating, we compared the intensities of photoelectron spectra of Ni 2p and Pt 4f levels. Figure 2 shows the intensity changes of both core levels when

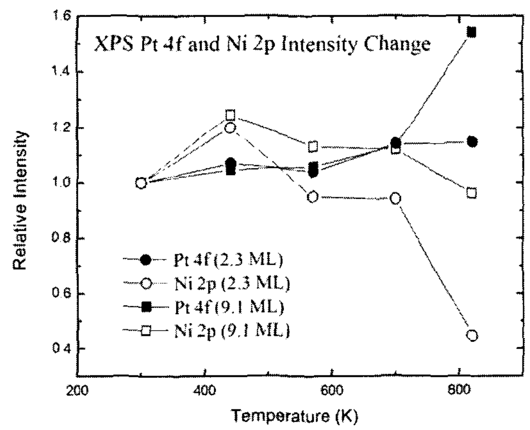

Fig. 2. Intensity changes of Ni 2p and Pt 4f core levels upon heating when Ni thickness is 2.3 and 9.1ML.

Ni adlayer thickness was 2.3 and 9.1 ML. The duration time of annealing was 5 min. Upon heating at 440K, both intensities of Ni 2p and Pt 4f levels increased, which is expected when adatom islands are flattened. However, upon heating at 570K and 700K, the intensity of Ni 2p level was decreased.

Upon further heating at 820K, rapid decrease of Ni 2p level intensity as well as increase of Pt 4f level intensity were observed. These imply that intermixing between Ni adlayer and Pt substrate already occurs by annealing at 570 and 700K, and that strong mixing at 820K leads to Ni-Pt alloy formation. This behavior is slightly different from the report using Auger electron spectroscopy (AES) [11], which did not show much change in the intensity of Ni MVV 102eV Auger peak below 750K for the Ni films thicker than 6 ML. Since the deposition rate of the AES study in Ref. [11] was 1 ML per 400 s, it might be that there was some difference in the morphology of the as-deposited films.

The Ni-Pt alloy formation induced by heating was confirmed by the analysis of the XPS spectra. Since the binding energies of core levels are affected by the chemical environment of the atom, we can determine the composition of alloy by measuring the binding-energy shifts of Pt 4f and Ni 2p levels. For all the Ni films annealed at 820K, the binding energy shifts were 0.21 ~0.24 eV and -0.04 eV for Pt 4f and Ni 2p levels, respectively. Using the previous XPS study on Ni-Pt alloys [13], we can conclude that the composition of surface alloy formed by 820K anneal is about Ni 70 at.%. Although Ni-Pt alloy system has two ordered phases NiPt and Ni_3Pt [14], there was no additional spots in LEED patterns. Hence it can be concluded that the complete intermixing leads to compositionally disordered $Ni_{70}Pt_{30}$ alloys.

It was found that the 5.7 ML Ni film the Kerr signal of which was not observed at RT show hysteresis curve upon heating at 570K. This ferromagnetic behavior disappeared upon further heating at 820K. For thicker films, Kerr signals were enhanced upon annealing at 570 or 700K by at most 30%. This is different from the Fe/Pd(111) case where we had observed more than 200% enhancement [12]. The appearance of ferromagnetism in 5.7 ML Ni film must be a result of morphological change as observed in 2.0 ML Fe film on Pd(111) surface [12], but slight enhancement of Kerr signal in thicker films upon heating seems to be largely related to the change in reflectance resulted from the intermixing at the interface as in Fe/Pd(111) and Co/Pt(111) [15]. The disappearance of Kerr signal in 5.7 ML film and reduction of Kerr signal for thicker films upon annealing at high temperature can be understood from the magnetic phase diagram of Ni-Pt alloys [16]. While Fe-Pd and Fe-Pt alloys are ferromagnetic at RT when Fe is diluted to about 30 at.%, Ni-Pt alloy becomes paramagnetic at RT when Ni content is still 65 at.%. Hence, for the films thin enough to be completely mixed with the substrate upon heating for 5min, the surface alloy can be almost or completely paramagnetic. For thicker films, we can expect that T_c is higher than that of thinner films but lower than that of bulk Ni, and only reduction of Kerr signal is observed.

Kerr signals from various post-annealed 9.1 ML Ni films are shown in Fig. 3, in which the signals are normalized to have the same value at RT. The values of T_c are less than 440, 495, and 390K for the films annealed at 440, 570, and 820K, respectively. The

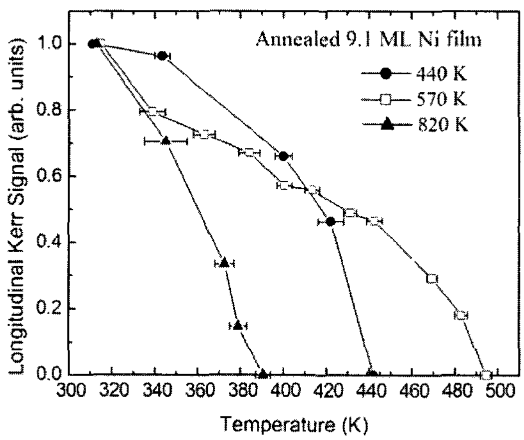

Fig. 3. Longitudinal Kerr signal of 9.1~ML Ni film on Pt(111) post-annealed at 440, 570, and 820K.

highest T_c was observed for the 570K post-annealed film, for which Kerr signal was also enhanced. Apparently, flattening of the surface and slight intermixing at the interface enhances magneto-optic behavior.

4. Conclusions

To summarize, we studied magnetic and structural properties of ultrathin Ni films grown on Pt(111) substrate using SMOKE and XPS. PMA was not observed either in as-deposited nor in post-annealed films. Longitudinal Kerr signal was only detectable for Ni films thicker than 6 ML, but 5.7 ML Ni film showed ferromagnetic behavior when annealed at 570-700K. Enhancement in longitudinal Kerr signal by 30% was achieved by post-annealing at temperatures below 800K, but upon annealing at 820K, surface alloy was formed. By using core-level binding-energy shifts, the composition was determined to be Ni 70 at%.

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