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THE EFFECT OF SUBSTRATE TEMPERATURE ON GRAIN STRUCTURES AND MAGNETIC PROPERTIES OF Pd/(Pt/Co/Pt) MODULATED MULTILAYERS

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Abstract—Pd/(Pt/Co/Pt) modulated multilayer films have been deposited on various substrates with Pd/Pt buffer layers. Films grown at different temperatures have very distinct magnetic properties and surface microstructures. Atomic force (AFM) and scanning tunneling (STM) microscopies studies of these films reveal that films deposited at room temperature have small grain structures with an average grain size of about 140 Å. However, much larger grains of about 1200 Å in size are observed in the films grown on buffer layers which were deposited at 500°C. These large grains are found to actually consist of smaller grains of about 170 Å in diameter. SQUID magnetic and Kerr hysteresis loop measurements indicate that multilayer films with large grains exhibit high magnetic coercivities of around 5 kOe. A subgrain growth model is proposed to understand the observed grain structures in the multilayers.

I. INTRODUCTION

It is well known that the microstructures strongly affect the properties of the magnetic films. Columnar grain structures may cause the reduction of demagnetizing factor of the films thus resulting in an increase of the perpendicular magnetic anisotropies, and hence magnetic coercivities. In addition, the grain size of the magnetic films is often found to be one of important factors affecting the magnitude of coercivity. Large grains are usually favorable for high coercivity. However, for magnetic or magneto-optical (MO) recording media small grain structures are desirable to minimize media noise level. Among many thin film growth parameters, substrate temperature is the most important factor which governs the grain size and structure of evaporated metal films. In a recent study [1], it is proposed that grain structures depend on the ratio of substrate temperature T_s to the material melting point T_M, and columnar grains appear when $T_s/T_M > 0.37$.

In this paper, we present our recent studies of the grain structure of e-beam evaporated Pd/(Pt/Co/Pt) modulated multilayers as a function of substrate temperature. A subgrain growth model along with experimental results are presented based on a Zone Model [1] for evaporated metal films. Magnetic and magneto-optical properties of multilayer films grown at different substrate temperatures are also discussed.

II. FILM GROWTH MODELS

A. Zone Model for Evaporated Metal Films

It is well known that condensation from the vapor involves incident atoms becoming bonded adatoms, which then diffuse over the film surface until they desorb or, more commonly, are trapped at low-energy lattice sites. Finally, incorporated atoms reach their equilibrium positions in the lattice by bulk diffusive motion. This atomic odyssey involves four basic processes: shadowing, surface diffusion, bulk diffusion, and desorption. The last three are quantified by the characteristic diffusion and sublimation activation energies whose magnitudes scale directly with the melting point T_M of the condensate. Shadowing is a phenomenon arising from the geometric constraint imposed by the roughness of the growing film and the line-of-sight impingement of arriving atoms. The dominance of one or more of these four processes as a function of substrate temperature T_s is manifested by different structural morphologies. This is the basis of the zone structure models [2] that have been developed to characterize film and coating grain structures.

In a recent study, a zone model for thin evaporated metal films of 1000 Å thick has been developed [1]. For $T_s/T_M < 0.2$, the grains are equiaxed with a diameter of less than 200 Å. Within the range $0.2 < T_s/T_M < 0.3$, some grains larger than 500 Å appear surrounded by smaller grains. Columnar grains make their appearance at $T_s/T_M > 0.37$, and still higher temperature promote lateral growth with grain sizes larger than the film thickness.

B. Subgrain Growth Model for Evaporated Metal Films

As already outlined in the introduction, MO media with large grain structures suffer high media noise although large grains may result in a high coercivity. In order to get low media noise and high coercivity at the same time, a new growth method—two-stage growth should be employed. First, an appropriate metallic buffer layer will be deposited prior to a film deposition in the temperature range for promoting columnar growth ($T_s/T_M > 0.37$). Then, the metal film will be grown on the top of the buffer layer at a relatively low temperature ($T_s/T_M < 0.2$) to obtain a small grain (~ 100 Å) structure. Due to grain to grain epitaxial growth, the metal film will have a large grain structure stemming from the grain structure of the buffer layer. On the other hand, a small grain structure should also exist in the metal film due to its low deposition temperature. Therefore, the large grains in the metal film will actually consist of smaller grains. This growth model is defined as *subgrain growth model.*

III. EXPERIMENTAL

The Pd/(Pt/Co/Pt) modulated multilayer films were sequentially deposited by e-beam evaporation in a Leybold L560 Universal Deposition System with one electron gun and four crucibles. Substrate temperatures were in a range of room temperature to 300°C. Pd-30Å/Pt-60Å buffer layers were deposited either at 500°C or at room temperature. The deposition rates were kept below 0.5 Å/s for all elements at a background pressure of 1.5×10^{-6} Torr. Glass, Si, surface oxidized Si, MgO, and sapphire were used as substrates. Two sets of films were deposited simultaneously: one set of films was deposited on the substrate at room temperature, while the other set was deposited on substrate at predetermined temperature T_s. The thickness as well as deposition rate of each metal layer was measured and controlled by a computer with a previously calibrated quartz thickness monitor. The thicknesses of the Co, Pt, and Pd layers were 3 Å, 2 Å, and 6 Å, respectively. In all cases, the final film consisted of 30 periodic layers.

The magneto-optical polar Kerr rotations of the multilayer films were measured at room temperature using a Kerr loop tracer, over the wavelength range 350 to 900 nm with magnetic fields up to 13.5 kOe. Because of almost perfect square magnetic loops, the Kerr measurements would be in the remnant saturation magnetic state. The magnetic hysteresis loops of the multilayers were measured in a temperature range from 5 to 300 K using a SQUID magnetometer. Low angle and high angle x-ray diffraction (XRD) measurements were carried out to verify the superlattice structures and determine the textures of the multilayered films. Surface microstructures of the films were characterized by means of scanning tunneling microscopy (STM) and atomic force microscopy (AFM) with a Burleigh Personal SPM.

IV. RESULTS AND DISCUSSIONS

STM and AFM characterizations of Pd/(Pt/Co/Pt) multilayer films indicate that films deposited at room temperature have smooth surface morphologies and no feature can be detected in a 3 μm×3 μm scan area. However, in a much smaller scan area, STM images reveal that these films consist of uniformly distributed grains about 140 Å in size sitting side by side over the entire substrates, as shown in Fig. 1.

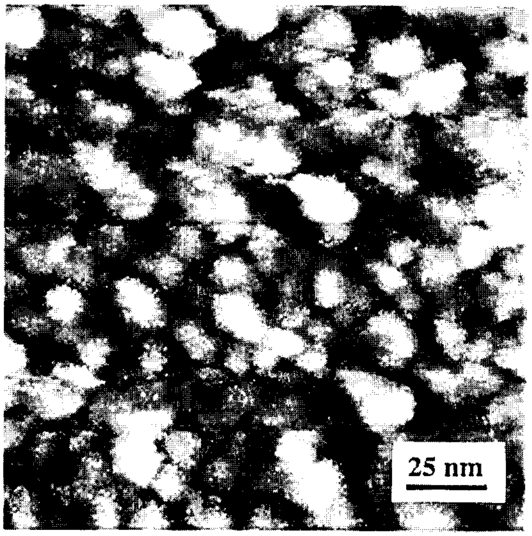

Figure 1. STM image of a Pd/(Pt/Co/Pt) multilayer film grown on oxidized Si at room temperature.

Multilayer films produced at elevated temperatures by the two-stage growth method have interesting grain structures. Figure 2 shows an AFM image of a Pd-30Å/Pt-60Å buffer layer deposited on sapphire at 500°C. Large grains of about 340 nm are found in this buffer layer. AFM-imaging of a Pd/(Pt/Co/Pt) multilayer film deposited at 250°C on such a buffer layer indicates that it consists of an average size of 1200 Å grains (see Fig. 3a). Higher resolution STM images of the same film reveal that those grains actually consist of much smaller grains about 170 Å in size, as shown in Fig. 3b. These observations are in agreement with the Subgrain Growth Model.

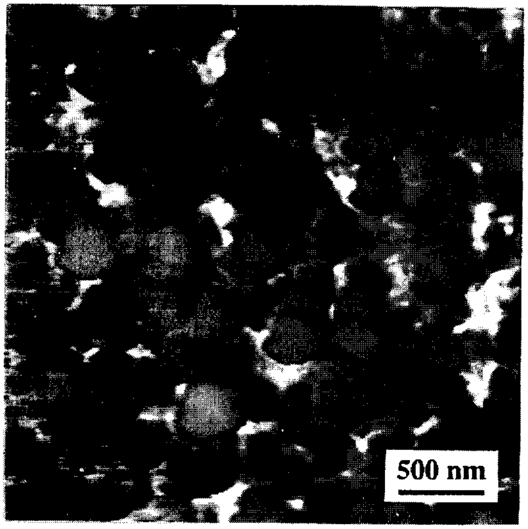

Figure 2. AFM image of a Pd-30Å/Pt-60Å buffer layer deposited on sapphire at 500°C.

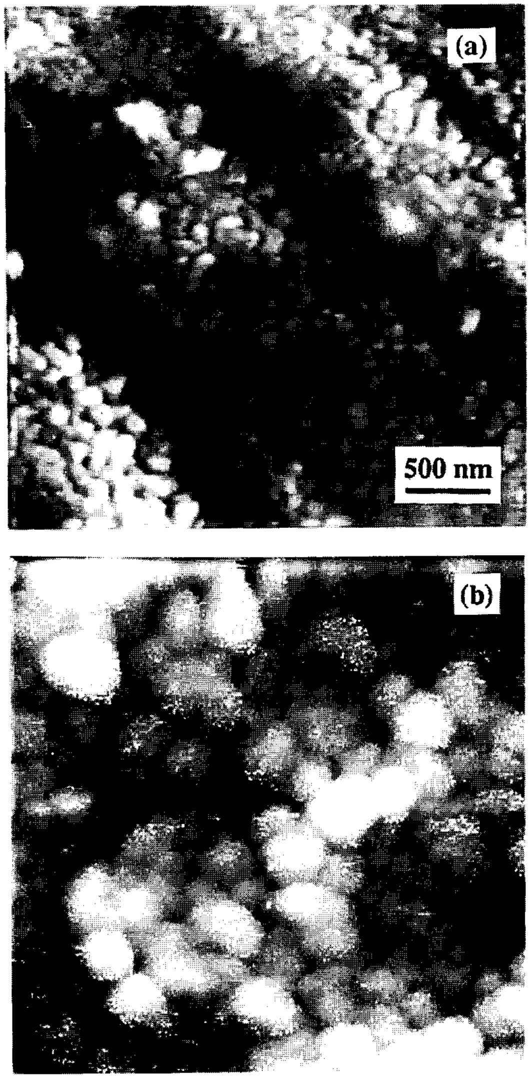

Figure 3. (a) AFM and (b) STM images of a Pd/(Pt/Co/Pt) multilayer film deposited at 250°C on a Pd-30Å/Pt-60Å buffer layer (grown at 500°C on sapphire).

High angle XRD measurements reveal that Pd/(Pt/Co/Pt) multilayer films grown at various substrate temperatures have a dominant overall fcc (111) texture along the film normal. However, as evidenced in the small angle XRD spectra, films deposited at room temperature have smoother surface morphologies than those of films grown at elevated temperatures. The modulation wavelength of the multilayers calculated from the superlattice reflections as well as high angle satellite peaks is very close to the designed value of 13 Å (±5%).

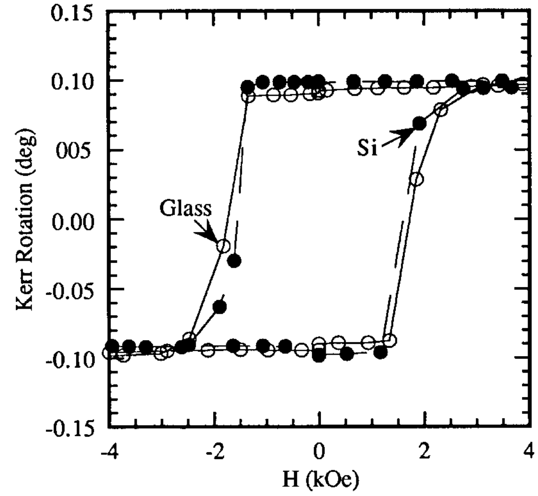

Figure 4. Kerr hysteresis loops at 630 nm for Pd/(Pt/Co/Pt) multilayers deposited at room temperature on oxidized Si and glass.

Kerr hysteresis loop measurement results reveal that all Pd/(Pt/Co/Pt) multilayers grown on all types of substrates used in this work exhibit perpendicular magnetic anisotropy. Multilayer films grown at room temperature on different substrates with Pd-30Å/Pt-60Å buffer layers (deposited at room temperature) are found to have almost identical Kerr hysteresis loops with good squarenesses. The Kerr rotations and magnetic coercivities of these films are around 0.1° at 630 nm and 2 kOe respectively. Figure 4 shows two Kerr hysteresis loops for Pd/(Pt/Co/Pt) multilayers deposited at room temperature on oxidized Si and glass.

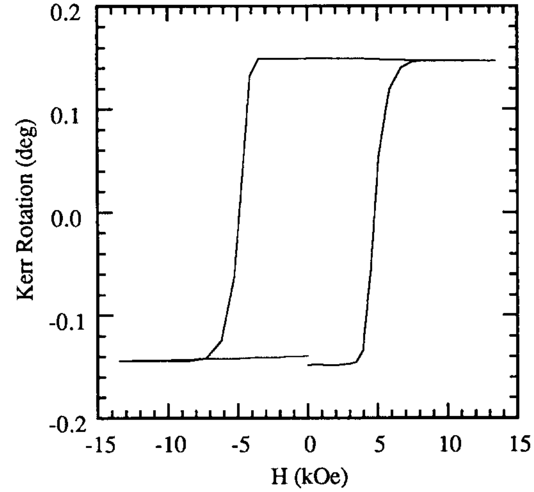

Figure 5. A typical Kerr hysteresis loop at 630 nm for Pd/(Pt/Co/Pt) multilayers deposited at 250°C on sapphire.

Pd/(Pt/Co/Pt) multilayer films deposited at elevated temperatures on Pd-30Å/Pt-60Å buffer layers (grown at 500 °C) present better MO properties than those of films made at room temperature in terms of larger Kerr rotations (~ 0.15° at 630 nm and 0.3° at 400 nm) and higher magnetic coercivities (~ 5 kOe). A typical Kerr hysteresis loop for Pd/(Pt/Co/Pt) multilayers deposited at 250°C is shown in Fig. 5. In contrast to that observed in the films grown at room temperature, MO properties of Pd/(Pt/Co/Pt) multilayer films fabricated at elevated temperatures on different substrates are quite different, especially in terms of the magnetic coercivities and squarenesses of Kerr hysteresis loops. Generally, films grown on sapphire, MgO, and oxidized Si substrates have higher coercivities and better squarenesses of Kerr hysteresis loops than those of films deposited on Si and glass substrates. STM and AFM studies at each stage of the multilayer film growth reveal that buffer layers of Pd-30Å/Pt-60 Å grown at 500°C on different substrates have remarkably different surface microstructures. A detailed study of the relationship between the surface microstructures and magnetic properties of the Pd/(Pt/Co/Pt) multilayers will be presented elsewhere.

SQUID magnetic measurements evidence a rather high induced magnetic moment in these multilayer films. At 5 K, the magnetization is determined to be about 3050 emu/cm^3 more than twice the value expected for Co at 0 K (~ 1446 emu/cm^3). The high Kerr rotation near 400 nm in the multilayers is most likely a result of the polarization effect of Co at Pt/Co sites, and possibly at Pt/Pd sites as well.

V. SUMMARY

STM and AFM analyses of Pd/(Pt/Co/Pt) multilayer films grown at two substrate temperature stages reveal that these films consist of a large grain structure of 1200 Å in diameter which in turn is composed of smaller grains of 170 Å in size. SQUID magnetic and Kerr hysteresis loop measurements indicate that these multilayer films exhibit high magnetic coercivities of around 5 kOe and large polar Kerr rotation of 0.3° at 400 nm. A growth model is proposed to interpret the observed subgrain structure. This model provides a useful two-temperature-stage growth processing method to tailor MO media for low media noise and reasonably high coercivities.

ACKNOWLEDGMENT

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