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Elastic Property of Fe/Pt Superlattice Studied by Picosecond Ultrasounds

ピコ秒超音波法による Fe/Pt 磁性超格子の弾性特性評価

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1. Introduction

$L1_0$-ordered FePt alloy film attracts great attentions as a candidate for ultra-high density magnetic-recording media, because it possesses a large uniaxial magnetocrystalline anisotropy energy, K_u=7.0×10^6 J/m^3, where the easy magnetization direction is parallel to c axis.[1] $L1_0$-ordered FePt alloy film is usually fabricated by depositing Fe and Pt simultaneously on substrates followed by the annealing at temperatures of excess of 500 °C.[2] However, it is reported that the annealing temperature is decreased by annealing Fe/Pt multilayer film.[3] Lowering of the annealing temperature is one of the important tasks for industrial use, and for understanding the mechanism of the structure change from the multilayered structure into the alloy structure, relationship among the annealing condition, microstructure, and the magnetic properties has been studied.[4), 5)]

In this study, we pay attention to the relationship between the microstructure and elastic constant. It is well known that elastic constant is sensitive to the microstructure, and measurement of the elastic constants enables us to evaluate the microstructure inversely, which give us valuable knowledge about the structure change originating from the annealing. Measurement of the thin-film elastic constants is never straightforward, and annealing effect on elastic constant of Fe/Pt superlattice has not been studied. We solve the difficulty using the picosecond ultrasounds, and evaluate the annealing effects on the out-of-plane longitudinal elastic constant, $C_\perp$.

2. Specimens

Fe/Pt superlattice was fabricated by depositing Fe and Pt alternately on glass substrates by RF-magnetron sputtering. Thickness of each layer was 2 nm, and the total film thickness was 60 nm, [Fe(2nm)/Pt(2nm)]$_{15}$. Background pressure was less than 9.0×10^{-6} Pa and Ar pressure during deposition was 1.3 Pa. The deposition rate of Fe and Pt layer was 0.1 and 2.1 Å/s, respectively. After the deposition, films were annealed at 300, 400, and 500 °C for 60 min. Periodicity and film thickness was confirmed by the x-ray measurements. **Figure 1** shows the x-ray reflectivity spectra and x-ray diffraction spectra at high-angle regions. In x-ray reflectivity spectra, two kinds of peaks appeared: small peaks and a broad peak. The former originates from the interference between x-ray reflected at the film surface and that reflected at the interface with the substrate. The latter appeared around 2θ=2.5°, and originates from the interference of x-rays reflected at the interfaces between Fe and Pt layers. Film thickness was determined by fitting the theoretical function to the small peaks.[6] In x-ray diffraction spectra of as-deposited superlattice and that annealed at 300 °C, fundamental peak appeared between the diffraction peak angle of Pt(111) and that of Fe(110), which indicates that Pt and Fe layers show

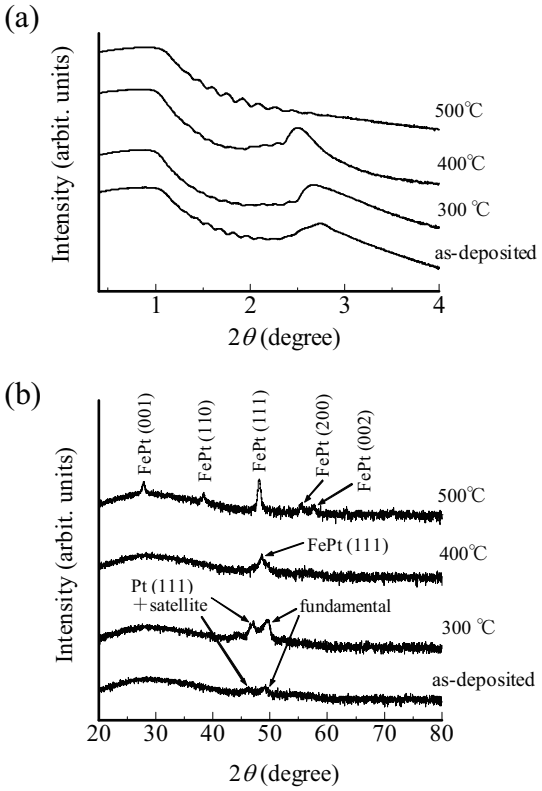

Fig. 1 (a) X-ray reflectivity spectra and (b) x-ray diffraction spectra of [Fe(2nm)/Pt(2nm)]$_{15}$/glass specimens at different annealing temperatures (CoK_α). The vertical axis is scaled logarithmically.

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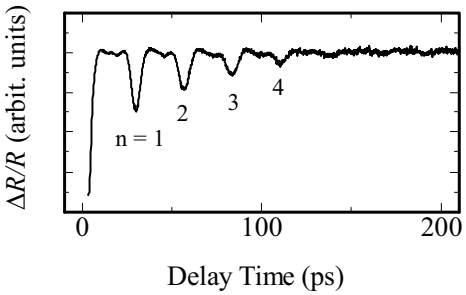

Fig. 2 Time-resolved reflectivity change of the as-deposited Fe/Pt superlattice on glass substrate obtained by picosecond ultrasound method.

<111> and <110> orientation in the film thickness direction, respectively.

3. Measurements

$C_\perp$ was determined by measuring the velocity of a longitudinal acoustic phonon propagating in the film-thickness direction using the picosecond ultrasound technique.[7] Irradiation of a film surface with a femtosecond pulse laser excites a coherent longitudinal-wave phonon pulse. The coherent phonon propagates in the thickness direction, and reflects at the interface between the film and substrate. By measuring the round trip time Δt, $C_\perp$ is determined by $C_\perp = \rho(2d/\Delta t)^2$, where d is the film thickness and ρ the mass density. The coherent phonon is detected by measuring the reflectivity change of the probing light pulse reflected at the film surface, because the reflectivity changes when the film surface is strained by the acoustic phonon. Detail of our measurement setup is described elsewhere.[8] **Figure 2** shows the typical time-resolved reflectivity change. The reflectivity change shows a train of echo signals (n=1, 2, …).

4. Results and discussions

Figure 3 shows the relationship between $C_\perp$ and annealing temperature. As the annealing temperature increased, $C_\perp$ increased, and by the annealing at 500 °C, $C_\perp$ became smaller than that at 400 °C. This trend is explained by the structure change observed by the x-ray diffraction measurements. When the annealing temperature was less than 400 °C, a broad peak appeared in x-ray reflectivity spectra. The peak originates from interference of x-rays reflected at the interface between Fe and Pt layers, and the appearance indicates that the Fe/Pt superlattice shows good periodicity. At 400 °C, a diffraction peak of FePt(111) plane was observed in Fig. 1(b), which indicates that FePt alloy is formed locally at the interface between Fe and Pt layers. Considering this structure change, increment of $C_\perp$ is consistently explained as follows. In superlattice, interfacial dislocations and nano-scale defects exist at the

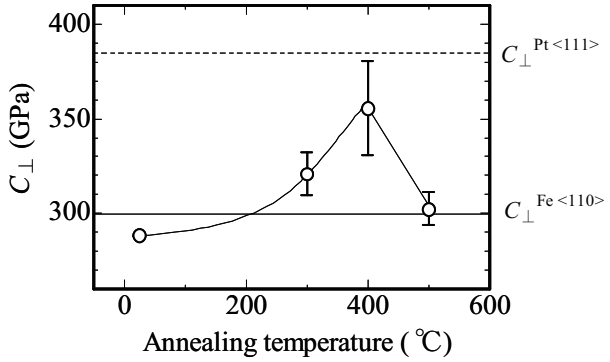

Fig. 3 The relationship between the annealing temperature and $C_\perp$. Open circles denote the $C_\perp$ of Fe/Pt superlattice. Dashed line and solid line denote the longitudinal modulus in <111> direction of bulk Pt and that in <110> direction of bulk Fe, respectively.

interfaces because of lattice misfit between Fe and Pt, and the interfacial defects could soften the superlattice. We consider that annealing improved the bonds at the interface and the macroscopic elastic constant was increased. Actually, $C_\perp$ of the as-deposited film is smaller than both $C_\perp^{Pt<111>}$ and $C_\perp^{Fe<110>}$, which implies the presence of the interfacial defects.

At 500 °C, the broad peak disappeared, and diffraction peaks of $L1_0$-ordered FePt alloy was observed in Fig. 1(a), which indicates that Fe/Pt superlattice was completely transformed into a $L1_0$-ordered FePt alloy film. Considering that locally formed FePt alloy increased $C_\perp$ at 400 °C, transformation to alloy structure at 500 °C should have increased $C_\perp$. However, by the annealing at 500 °C, crystallographic orientation was changed into the random orientation, as shown in Fig. 1, and $C_\perp$ was decreased. Thus, we observed annealing-temperature dependence of $C_\perp$ in Fe/Pt superlattice, and it was consistently related with the structure change.

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