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Elastic Stiffness of Magnetic Thin Film at High Temperatures Monitored by Picosecond Ultrasound
ピコ秒超音波を用いた磁性薄膜の高温弾性モニタリング

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1. Introduction

Thin films are used in various devices in many fields, including electronics as well for biological applications. Physical properties of thin films are often different from those of their corresponding bulk materials, and anomolous properties have contributed to the designing of state-of-the-art devices. Temperature dependence of the properties is one of the important research topics, since these devices are often exposed to temperature variation during operation. Elastic stiffness is one of the physical properties that show difference between thin films and bulk materials, and its variation during use could directly affect performance of acoustic devices such as film-bulk acoustic resonator used in communication devices. Although elasticity of nano-scale structures had been difficult to investigate, measurements of elastic stiffness have been performed for various thin films[1,2] by employing picosecond ultrasound developed by Thomsen *et al.*[3].

Magnetic thin films are key materials for recording media, and are versatile in many fields of application. In those films, relationship between magnetic properties and elasticity has been observed by experiments, for example, perpendicular magnetic anisotropy and elastic stiffness in Co/Pt superlattice[4]. The finding indicates that understanding the elastic property possesses potential to provide an insight to mechanism of unusual magnetic properties, contributing to development of new functional magnetic thin films. At high temperatures, magnetic materials often show magnetic phase transitions, and around the temperatures, it is expected that unusual elastic behavior that cannot appear in bulk materials occurs.

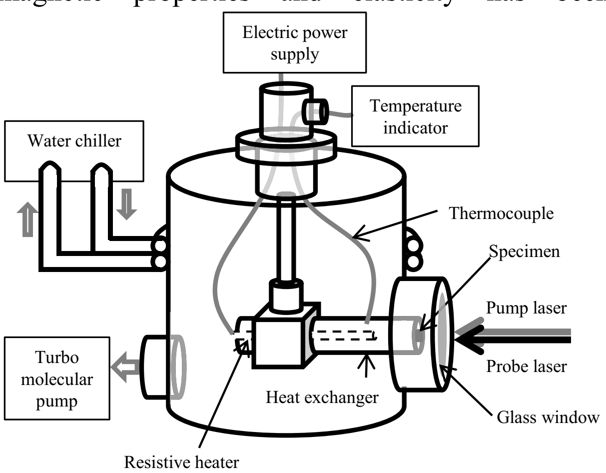

Fig. 1 Vacuum chamber for picosecond ultrasonic measurements at high temperatures. Specimen held at the top of the heat exchanger is irradiated with pump and probe laser through a glass window.

In this paper, we monitored the temperature dependence of elastic stiffness of Co thin films using a measurement system developed based on PU. Elastic stiffness is measured up to 500°C, and the temperature dependence is discussed.

2. Measurement Setup and Specimen

Irradiation of a thin film with a femto-second laser pulse excites acoustic phonon near the film surface, and it propagates in the thickness direction. It reflects back at the interface between the film and substrate, and multiple reflections occur in the film. By detecting the multiple reflections using another laser pulse, one can determine the round-trip time. This method is known as PU. From the round-trip time and the film thickness, longitudinal sound velocity in the direction perpendicular to the film surface is determined, and elastic stiffness is then deduced. This method is capable of generating and detecting ultrafast acoustic pulses, and suitable for evaluations of elastic property of nano-scale thin films.

Figure 1 shows the vacuum chamber used for high temperature measurements. The specimen held at the top of the heat exchanger is heated by resistance heater in vacuum. This chamber is capable of heating the specimen up to 500°C. Pressure inside the chamber is maintained to be of the order of 10^{-4} Pa before heating using a turbo molecular pump, and it increases up to the order of 10^{-2} Pa at 500°C. Pump and probe laser beams irradiate the specimen through a glass window, and

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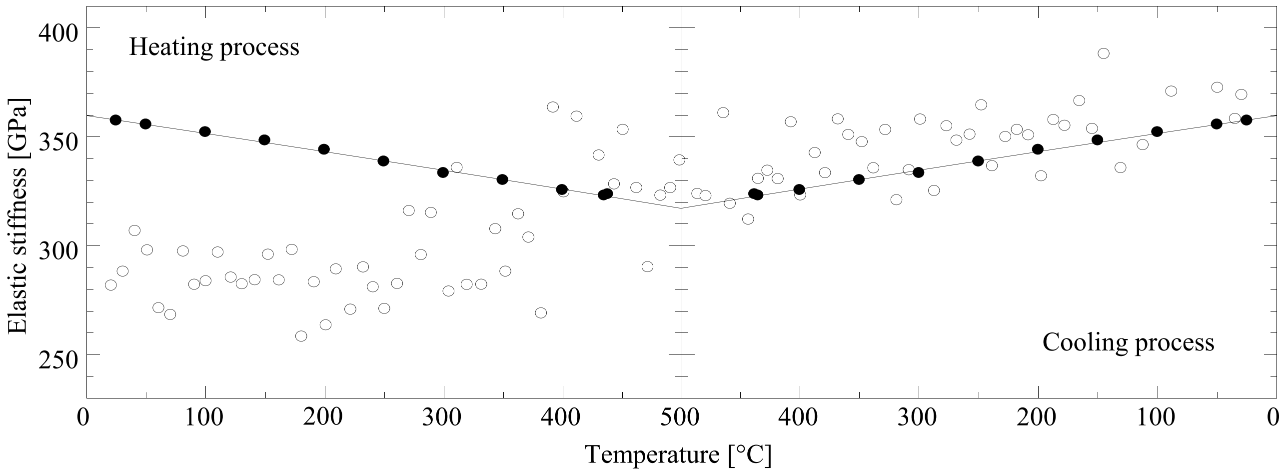

Fig. 3 Elastic stiffness of Co thin film of thickness 62.1 nm monitored for both heating and cooling processes. White circles represent experimental data, and black circles denote values for bulk material from Ref. [5]. Black solid lines represent fitted curve of the bulk value determined by least square method.

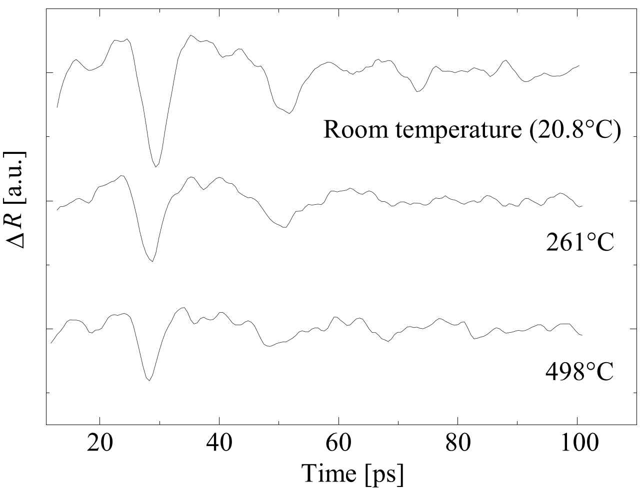

Fig. 2 Pulse-echo signals obtained for three different temperatures.

the effect of this window on the measurement is negligible.

Co thin films were sputtered on Si substrates by RF magnetron sputtering. Film thickness was determined by x-ray reflection measurements, and x-ray diffraction measurements confirmed (0001) orientation in the film-thickness direction.

3. Results and Discussion

Figure 2 shows pulse-echo signals obtained at three different temperatures in the heating process. **Figure 3** shows the elastic stiffness calculated from the time of flight (TOF) Δt, mass density ρ, and film thickness d as follows.

$$C_{\perp} = \rho(2d/\Delta t)^2. \quad (1)$$

Since ρ and d change due to thermal expansion, these contributions are taken into account. In Fig. 2, two or three acoustic pulses can be observed, and the TOF becomes smaller as the temperature rises. 2nd and 3rd echoes become indistinct from the background noise at high temperatures, thus making the measurement of TOF difficult. This should be the reason why elastic stiffness widely varies at high temperatures in Fig. 3. Elastic stiffness of Co thin film is almost unchanged near room temperature, starts to increase at around 300°C, and closely follows the temperature dependence of bulk material in the cooling process. We can say that the elastic stiffness of Co thin film recovers to the bulk value with heating up to 500°C. Another feature is the stiffening from 300°C in the heating process. In the temperature range, spin reorientation transition of Co occurs [6]. The increment in elastic stiffness might be correlated with magnetic phase transition, thus suggesting a possibility of a relationship between magnetic properties and elasticity.

4. Conclusion

In this study, we succeeded in monitoring the elastic stiffness of Co thin film up to 500°C, and observed the recovery of elastic stiffness to the bulk value. Also, relationship between magnetism and elasticity can be suggested since increase in elastic stiffness occurs in the magnetic phase transition temperature range. Further research is needed to clarify this relationship.

Reference

1. H. Ogi, M. Fujii, N. Nakamura, T. Shagawa, M. Hirao: Appl. Phys. Lett. **90** (2007) 191906.
2. N. Nakamura, H. Ogi, T. Shagawa, M. Hirao: Appl. Phys. Lett. **92** (2008) 141901.
3. C. Thomsen, H.T. Grahn, H.J. Maris, J. Tauc: Phys. Rev. B **34** (1986) 4129.
4. N. Nakamura, H. Ogi, T. Yasui, M. Fujii, M. Hirao: Phys. Rev. Lett. **99** (2007) 035502.
5. E.S. Fisher, D. Dever: Trans. Metal. Soc. AIME **239** (1967) 48.
6. J.E. Bidaux, B. Cao: J. Phys. Condens. Matter **3** (1991) 2263.