Perpendicular Magnetization of 1-nm-Thick Epitaxial FePt Films Probed by Soft X-ray Magnetic Circular Dichroism

Perpendicular magnetization makes it possible to magnetize a much smaller area of a magnetic film than in-plane magnetization. This is why perpendicular magnetization has become an essential technology for hard disks, storage capacity of which is growing rapidly. It might also be applicable to spintronic devices, which are a new technology of data processing using the spin of electrons. Epitaxial FePt film with the $L1_0$ crystal structure, which is characterized by alternately stacked of Fe and Pt monatomic-layer sheets, shows stable perpendicular magnetization. Epitaxial FePt film is therefore attracting much attention from the viewpoint of its applications. For such applications, it is crucial to determine how thin the magnetic layer can be made while maintaining perpendicular magnetization at room temperature. Since ferromagnetism is a collective phenomenon, it could be weakened when the thickness is reduced, leading to lower Curie temperatures and possibly to the disappearance of perpendicular magnetization even in the ferromagnetic phase. The verification of such hypotheses is important from the viewpoints of both applications and fundamental research.

In order to determine the thinnest limit for epitaxial FePt films to have perpendicular magnetization, ultrathin films of FePt sandwiched by Pt, as shown in Fig. 1, were fabricated by the alternate monatomic layer (ML) deposition of Fe and Pt [1]. When the thickness of the magnetic layer is a few ML, it is extremely difficult to measure magnetization precisely by conventional techniques such as SQUID because of a large magnetic background due to the substrate. Therefore, we utilized the soft X-ray magnetic circular dichroism [2] of Fe 2*p*→3*d* photoabsorption (Fe 2*p*→3*d* XMCD), which can yield an accurate Fe 3*d* magnetic moment even for Fe coverage of below 1 ML.

Fe 2*p*→3*d* XMCD was measured at beamline **BL25SU** by the total electron yield method in the Faraday configuration, in which the soft X-ray is incident parallel to the magnetic field applied to the sample. The magnetic field was applied perpendicularly to the sample films. The XMCD spectrum was measured by switching the photon spin of the incident light between +1 and –1. The magnetic moments due to spin and orbital angular momenta, μ_{spin} and $\mu_{orbital}$ were estimated by applying the XMCD sum rules to the observed XMCD spectrum.

In Fig. 2 is shown the temperature and thickness dependence of the perpendicular Fe 3*d* magnetic moment [3] in Pt/(Fe 1ML/Pt 1ML)$_n$/Pt(100) under a magnetic field of 1.4 T (a) and under remanent magnetization (b). In the latter, samples were first subjected to a magnetic field of 1.4 T and were then measured without a magnetic field. The drastic decrease from n = 2 to 1 of the moment at room temperature (RT) under 1.4 T (see Fig. 2(a)) might suggest that the Curie temperature T_C is above RT for n ≥ 2 and below RT for n=1. On the other hand, the perpendicular remanent magnetization at RT reaches zero when n = 2. Let us define the temperature at which the perpendicular remanent magnetization drastically increases as T_{rem}. T_{rem} is between 250 K and 300 K for n=2 and T_{rem} ~ 160 K for n=1. These results, characterized by the decrease in both T_C and T_{rem} with the reduction of thickness n, agrees well with the expectation that ferromagnetism should be weakened as the thickness is reduced.

A possible mechanism for the absence of remanent magnetization between T_{rem} and T_C is the formation of stripe domains characteristic of perpendicular magnetization. However, one cannot exclude other possibilities such as the spin reorientation transition to in-plane magnetization. In order to clarify the actual mechanism, it will be

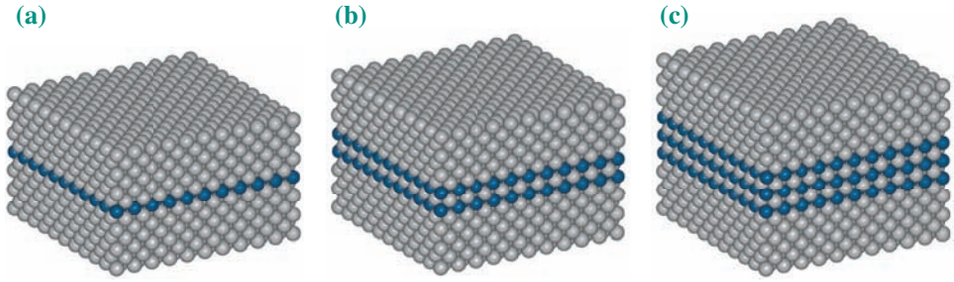

Fig. 1. Schematic view of ultrathin FePt films sandwiched by Pt, where gray and blue spheres represent Pt and Fe atoms, respectively, for Pt/(Fe 1ML/Pt 1ML)$_n$/Pt(100) with n=1 **(a)**, n=2 **(b)**, and n=3 **(c)**.

necessary to investigate magnetic domain structures by methods such as XMCD microscopy.

The magnetic hysteresis loop of Pt/Fe 1ML/Pt (001), i.e. only one atomic layer of Fe sandwiched by Pt, was successfully observed with satisfactory precision, as shown in Fig. 3. This demonstrates the usefulness of XMCD for the study of potentially applicable magnetic ultrathin films. It was observed that the perpendicular remanent magnetization is as large as about 80% of the saturated value and that the coercivity is about 0.1 T at 25 K.

In summary, Pt/(Fe 1ML/Pt 1ML)$_3$ /Pt (001) was found to exhibit perpendicular remanent magnetization at room temperature, which is expected to enable the development of applications in the field of magnetic storage and spintronics. Samples with a thinner FePt layer exhibited perpendicular remanent magnetization at lower temperatures. The thickness dependence of perpendicular magnetization can be attributed to the decreasing in T_C with reduced thickness because ferromagnetism is thought to be weakened due to the crossover from three dimensions to two dimensions.

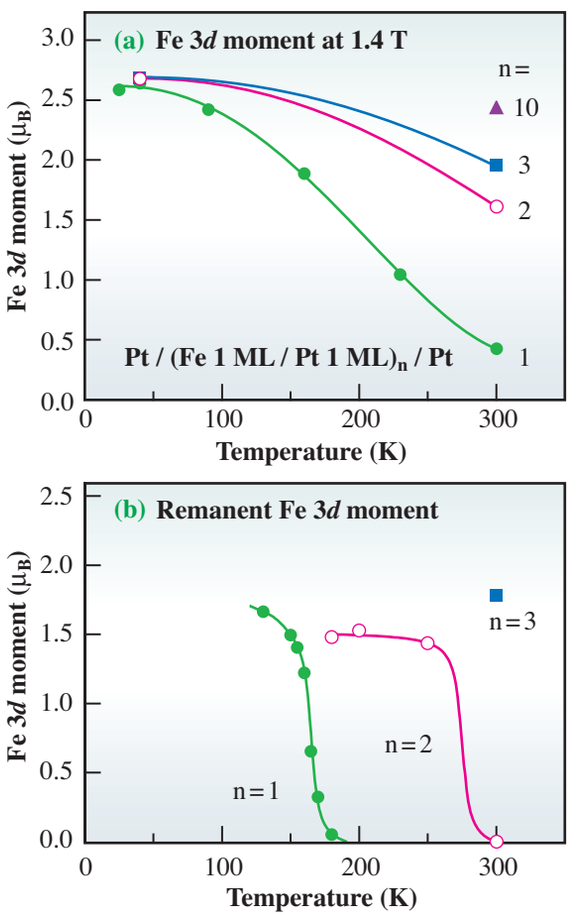

Fig. 2. Temperature and thickness dependence of the perpendicular Fe 3*d* magnetic moment per atom in Pt/(Fe 1ML/Pt 1ML)$_n$ /Pt(100) under a magnetic field of 1.4 T **(a)** and under remanent magnetization **(b)**. The markers represent measured values and the solid lines are guides for the eyes.

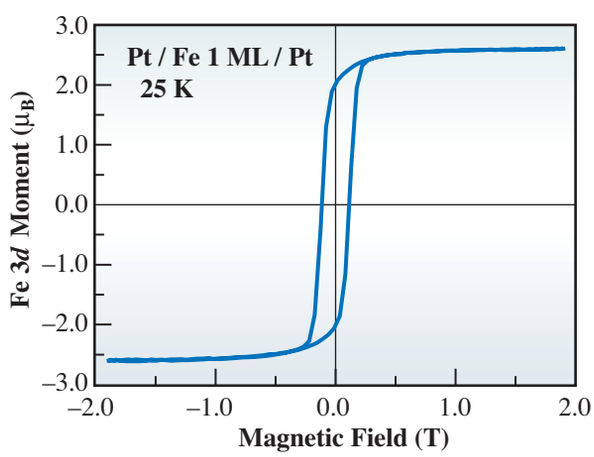

Fig. 3. Magnetization hysteresis loop of Pt/Fe 1 ML/Pt(001) at 25 K obtained by magnetic field dependence of the XMCD intensity.

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