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Aspect ratio dependence of hysteresis property of high density Co wire array buried in porous alumina template

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Abstract

Co wire array with 50 nm intervals was formed by electrodeposition in porous alumina template that was formed on Si substrate. Coercive field of Co wire array under perpendicular magnetic field significantly increased when aspect ratio increased from 1.5 to 2.5. This behavior was well explained by the micromagnetic simulation when magnetic anisotropy axis was assumed to be parallel to the substrate.

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Keywords: Magnetic recording; Feromagnetic nanostructure

There is a strong demand for realizing ultra high-density magnetic recording beyond 400 G bit/in^2. Perpendicular magnetic anisotropy is required for the ultra high-density magnetic recording, although it is not easy to attain it by granular films or self-assembled magnetic nanoparticle films [1]. Magnetic nanowire array buried in a self-organized porous alumina nanohole array is one of the promising materials for realizing perpendicular magnetic anisotropy [2–4]. Porous alumina is known to have densely packed ordered nanohole array with a nanohole interval ranging from a few tens of nm to several hundred nanometers depending on the anodic voltage [5,6].

We fabricated Co wire array with 50 nm intervals by electrodeposition in porous alumina template that was formed on Si substrate. At first pure aluminum (Al) film was sputtered on Si, and two-step anodic oxidation of Al [7] was carried out at anode voltage of 20 V with 0.15 M sulfuric acid, at 3°C. Finally Co wires of 30 nm in diameter with various heights from 20 to 500 nm were electrodeposited with AC voltage of 1 kHz, 15 V.

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The one example of cross-sectional TEM micrograph of Co wire array is shown in Fig. 1, where wire average height is 120 nm. We evaluated aspect ratio (AR: a ratio of height to diameter) dependence of $M-H$ hysteresis property by polar Kerr effect magnetometer. $M-H$ loops under perpendicular magnetic field to substrate measured for Co wire arrays with different AR are shown in Fig. 2. It is clear that the Co wire array with higher AR has a larger coercive field. Coercive field of the Co wires with AR of 3.3 is 1.7 kOe, while that with AR of 1.8 is 0.3 kOe. The AR dependence of the coercive field (H_c) is shown in Fig. 3. The H_c is negligibly small when AR is smaller than 1.5. It rapidly increases to 1.7 k Oe from AR = 1.5–2.5, and almost saturates beyond AR = 3.0. Annealing around 500°C was effective for improving crystalline structure of Co, however, there was not significant change in the AR dependence of H_c. X-ray diffraction analysis revealed that Co wires are polycrystals with hexagonal crystalline structure. The Co (0 0 0 1) axis having a large crystalline anisotropy was mostly not perpendicular to the substrate, and Co (1 0 1 2) axis were rather perpendicular. We carried out micromagnetic simulation based on Landau–Lifshitz–Gilbert equation for $M-H$ properties of a solitary single crystalline Co wire with various AR. Comparison

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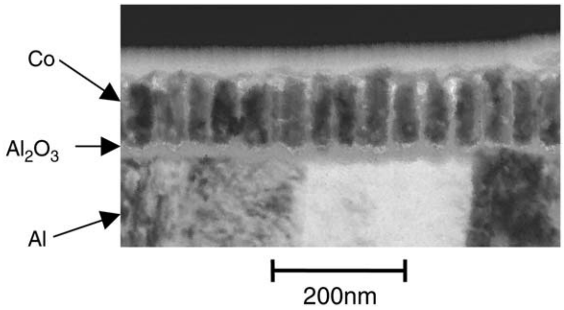

Fig. 1. Cross-sectional TEM micrograph of Co wire array deposited by AC electroplating of 1 kHz.

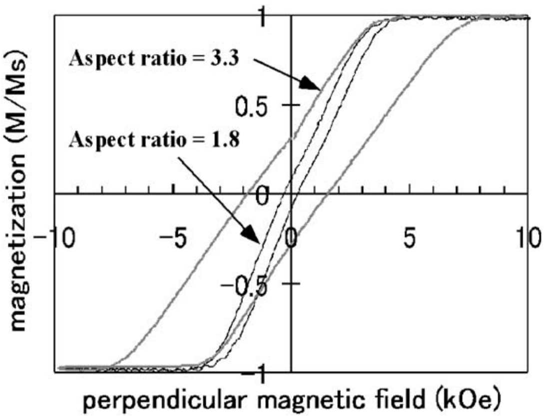

Fig. 2. $M-H$ loop of Co wire arrays with different AR measured by Polar Kerr effect magnetometer.

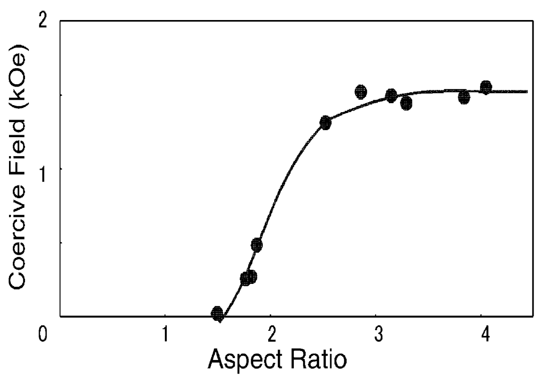

Fig. 3. Coercive field as a function of the AR of Co wire array under perpendicular magnetic field.

of the AR dependence of coercive field between the two cases of crystalline anisotropy; ⟨0001⟩ axis (anisotropy axis) parallel to the substrate and ⟨0001⟩ axis perpendicular to the substrate, are compared in Fig. 4. When the anisotropy axis is parallel to the substrate, clear AR dependence appears, and the coercive field rises critically at the AR of 1.5. When the anisotropy axis is perpendicular to the substrate, a large coercive field is obtained and there is no clear AR dependence. Our experimental results resemble the case of anisotropy axis parallel to the substrate, and the amount of coercive field is almost the same value. The reason of the gradual increasing behavior in the AR range between 1.5 and 2.5 would be ascribed to the polycrystalline crystal structure of the experimentally obtained Co wires.

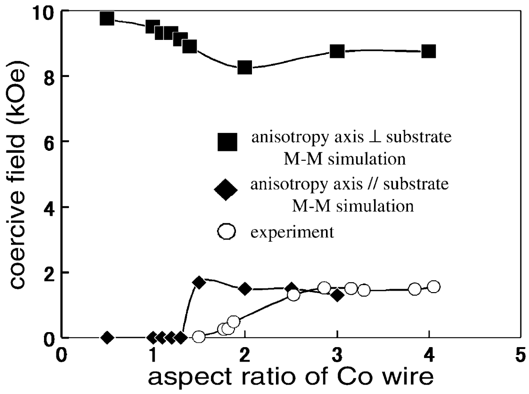

Fig. 4. Comparison of the AR dependence of coercive field between the two cases of crystalline anisotropy and the experimental result.

The results strongly suggest that the coercive field is determined mainly by the AR of Co wires when crystalline anisotropy axis is parallel to substrate. Ferromagnetic nano wire arrays based on porous alumina template have a high controllability in diameter as well as AR of wires, and are suitable for high-density magnetic recording. However, further improvement in crystalline structure would be needed.

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