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Fabrication and magnetic properties of $Fe_{14}Ni_{86}$ alloy nanowire array

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Abstract

Ordered $Fe_{14}Ni_{86}$ alloy nanowire arrays embedded in an anodic alumite template (AAT) have been fabricated by electrodepositing the corresponding materials into the pores of the AAT. The length and the diameter of the nanowires are about 50 μm and 25/43 nm respectively. Their aspect ratios (ratio of length to diameter) are more than 1000, which results in the distinctive magnetic anisotropy. The easy magnetization axis of this system is perpendicular to the membrane. Enhanced coercivity as high as 962 Oe and remnant magnetization up to 70% of the saturation magnetization have been observed. It is suitable to use as rewritable vertical magnetic recording media, and the ideal storage density is about 200 Gbit inch^{-2}.

1. Introduction

Most magnetic devices used today are based on the magnetic thin film. That is changing drastically, however, due to the advent of nano-fabrication technology. Nano-fabrication offers unprecedented capabilities in patterning materials with a size smaller than a magnetic domain wall, and in manipulating the size, shape and orientation of the structure [1]. It also gives us a better understanding of micro-magnetism [12]. Many methods have been developed to fabricate these kinds of structured material [2–4], but deposition of metals inside the nanometric pores of a template is the most inexpensive technique to produce the patterned structure [5–6, 10]. In this paper, we fabricate the $Fe_{14}Ni_{86}$ alloy nanowire array, which has an enhanced coercivity (about 962 Oe, when magnetic field is applied parallel to the wires) and a high square ratio (about 0.7). The coercivities are comparable to that of a 1.44 Mb, 3.5 inch floppy disk (about 800 Oe). If a bit of information can be stored in every wire, the ideal storage density would be about 170 Gbit inch^{-2}, which is about 200 000 times than that of a 1.44 Mbyte floppy disk.

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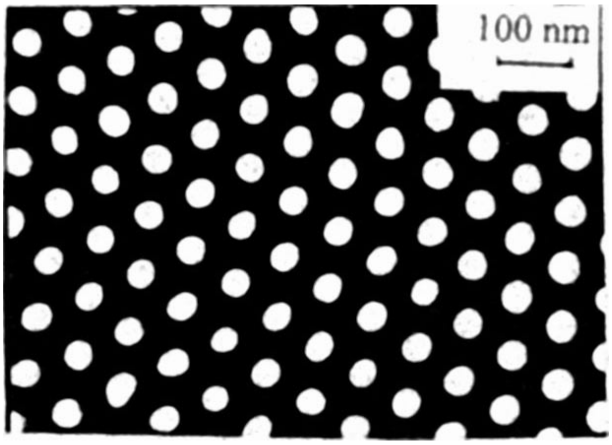

Figure 1. TEM top image of AAT (fabricated with potential 25 V and widened for 20 minutes at 30 °C).

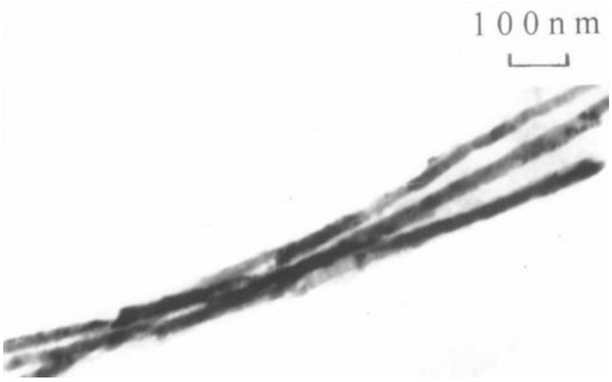

Figure 2. Micrograph of the nanowires.

2. Experiment and discussion

The AAT templates were prepared as described previously [7, 11]. Aluminium sheets (purity 99.999%), approximately 0.5 mm in thickness, were used as starting materials. The anodizations were conducted under 25 V potential at 0 °C in 0.4 M H_2SO_4 solution. The distance between the neighbouring pore centres is about 60 nm and the pore diameters can be manipulated from 20 nm to 50 nm by being widened for different times in 5 wt% H_3PO_4 solution at 30 °C. Figure 1 is a transmission electron microscopy (TEM) top view of the fabricated AAT. The pores are 25 nm in diameter and the pore distance is about 60 nm. The pores are about 50 μm in depth and distributed in perfect hexagonal order in defect free distance. The mechanism is explained by the volume expansion of the aluminium during the oxidization resulting in repulsive forces between neighbouring pores, which lead to self-organization formation of hexagonal pore arrays [8].

For fabricating nanowire arrays, the remaining aluminium works as a cathode instead of being removed. The alloy is electrodeposited from the electrolyte containing $FeSO_4 \cdot 7H_2O$ 6 g l^{-1}, $NiSO_4 \cdot 7H_2O$ 218 g l^{-1}, H_3BO_3 25 g l^{-1} and NaCl 10 g l^{-1}. A graphite rod works

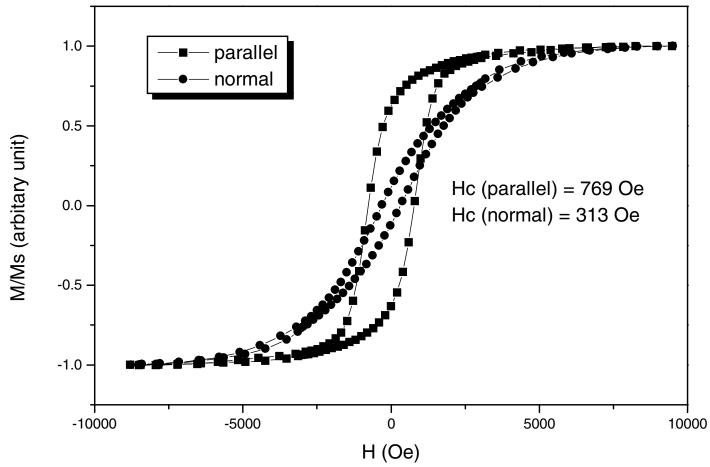

Figure 3. Hysteresis loops of nanowire arrays. The wire diameter is about 43 nm, squares mean field is applied parallel to wires, circles mean field is applied normal to wires.

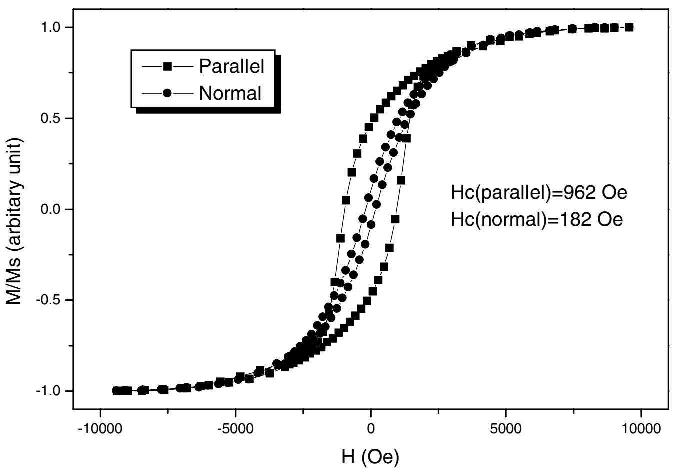

Figure 4. Hysteresis loops of nanowire arrays. The wire diameter is about 25 nm, squares mean field is applied parallel to wires, circles mean field is applied normal to wires.

as anode. The composition changes during the electrodeposition can be ignored because the number of ions consumed is very small relative to that in the bath. Figure 2 is the TEM image of the nanowires after removing the templates in 10 wt% NaOH solution. The diameter of the nanowire is about 25 nm.

The composition of the alloy (Fe 14 at.% and Ni 86 at.%) was investigated by the energy dispersive spectrum (EDS). With this concentration, the alloy should be a soft magnetic material and the coercivity of bulk material is less than 10 Oe [9].

The magnetic properties of the alloy nanowire arrays were investigated with a vibrating sample magnetometer (VSM, Lakeshore model 7300 series). Hysteresis loops of nanowire arrays (with wire diameter 43 nm and 25 nm) are shown in figure 3 and figure 4. Because the pores of AAT with larger diameter are more perfect in shape, the same thing will occur for the magnetic wires. This is maybe the reason for the difference between figure 3 and

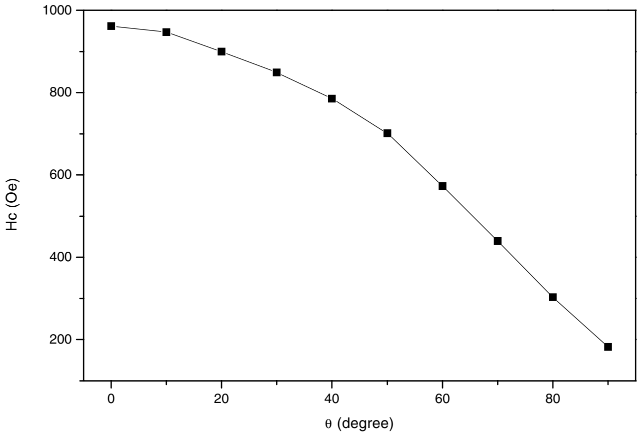

Figure 5. Angular dependent coercivities of nanowire arrays with wire diameter 25 nm: θ is the angle between the applied field and the axis of wire parallel to wires; squares mean field is applied normal to wires.

figure 4. When magnetic field is applied along the wires, their enhanced coercivity (about 769 Oe/962 Oe) is much more than that of the bulk materials (less than 10 Oe). It is obvious that the easy magnetization axis is along the wire, or say perpendicular to the membrane. The coercivity of a magnetic nanowire array is comparable to that of a floppy disk (1.44 Mb, 3.5 in), and it has potential application as rewritable vertical magnetic recording media.

Coercivity of a material can be influenced by many factors, such as shape anisotropy, magneto-crystalline anisotropy, stress anisotropy and magneto-static interaction. Because the aspect ratio of the nanowire is more than 1000 and other anisotropies are minor, the shape anisotropy dominates in this case [2]. The angular dependent coercivities of nanowire (with diameter 25 nm) arrays are shown in figure 5. As we can see, the coercivity is decreasing with the decreasing angle between applied field and membrane plane.

3. Conclusion

In conclusion, highly ordered $Fe_{14}Ni_{86}$ alloy nanowire (with diameter 25 nn/43 nm, distance between the neighbouring pore centres 60 nm) arrays are fabricated in AAT. Enhanced coercivity (about 962 Oe) and remnant magnetization up to 70% have been observed. The coercivity is comparable to that of a 1.44 Mb, 3.5 inch floppy disk (about 800 Oe). The easy magnetization axis of the magnetic nanowire arrays is perpendicular to the membrane. It has potential application to be used as rewritable ultra-high density vertical magnetic storage media. Its storage density would be more than 200 000 times than that of 3.5 inch floppy disk.

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