8 Fabrication, Characterization and Physical Properties of Nanostructured Metal Replicated Membranes

Yong Lei*, Weiping Cai and Lide Zhang
Institute of Solid State Physics, Chinese Academy of Sciences, Hefei 230031, People's Republic of China

1 INTRODUCTION

As a well-known host, highly ordered anodic alumina membranes (AAMs) have been playing an important role in the fabrication of many kinds of nanowires (Lei *et al.*, 2001) and nanotubes (Hulteen and Martin, 1998). However, the AAMs have some disadvantages in actual use such as the insufficient chemical and thermal stability, together with the low mechanical strength. Moreover, the AAM itself is an insulator. Therefore, it is worth studying how to fabricate highly ordered metal (Masuda and Fukuda, 1995) or semiconductor membranes (Hoyer *et al.*, 1995) with attractive chemical and physical properties.

Recently, highly ordered metal (Co and Ni) replicated membranes (MRM) were fabricated by a novel replicating method in our lab (Lei *et al.*, 2001). We used some new techniques to replicate the MRMs from the AAMs, such as the immersion of the AAM in methyl methacrylate (MMA) monomer, pre-polymerization of MMA, and four-directional evaporation of Pd catalyst. These new techniques lead to a full replication of the AAM and result in an almost ideally arranged nanohole array of the replicated MRM with the following features: high aspect ratio of more than 320, highly ordered pore arrays, narrow size distributions of pore diameters. Moreover, the overall fabrication process of MRMs was greatly simplified.

After the magnetic measurement to the MRMs, we found out that they have some novel magnetic properties due to their special nanostructures. The most desirable is their unusual preferred magnetization direction. Different from many usual magnetic films, the preferred magnetization direction of the metal membranes (both in Co and Ni membranes) is perpendicular to the membrane plane, which is valuable to be used in perpendicular magnetic recording systems.

* Corresponding author, now is a Visiting Scholar in National University of Singapore. Email address: yuanzhilei@yahoo.com, smaleiy@nus.edu.sg.

2 FABRICATION AND MAGNETIC PROPERTIES

Fig. 1 summarizes our preparation procedure in a schematic manner. After the preparation of the through-hole AAM [(a)-(d)], a very thin Pd catalyst layer was deposited on the surface of it by using a four-directional evaporation method to improve the distribution regularity of the catalyst on the surface [(e)]. The AAM was then immersed into the MMA monomer followed by the pre-polymerization and polymerization of MMA [(f)-(g)], that resulted in a PMMA cylindrical array with Pd catalyst located at the root of the PMMA cylinders [(h)]. Finally, the electroless deposition was carried out at the catalyst site [(h)-(i)], forming double-sided and single-sided MRMs by changing the deposition times. The MRMs have a very good regularity of the pore arrangement [Figs. 2(a) and (b)] and is almost identical to that of the original mother membranes – AAMs, but most important is that the pore arrays of the MRMs have a very high aspect ratio of about 320, which is a great improvement in this field.

It is well know that all the ferromagnetic materials, such as Co and Ni, have anisotropic magnetic properties. For a ferromagnetic thin film, because the demagnetizing factors are about 0 and 4π for fields parallel and perpendicular to the film plane, the shape anisotropy tends to force the magnetization M to be in the film plane, resulting in a preferred magnetization direction parallel to the film plane. However, it is highly desirable, particularly in perpendicular magnetic recording systems, to have M perpendicular to the film. Many attempts have been done to overcome the difficulty; the most successful is the metallic nanowire arrays prepared by Whitney *et al.* (1993). But this kind of magnetic film is actually not a continuous film and should have some confinement in application.

We carried out the measurement of the magnetic hysteresis loop to both the Co and Ni MEMs [Fig. 3]. The Ni MEM has a preferred magnetization direction perpendicular to the film plane both in 5 K and 300 K [Figs. 3(a) and (b)]. Also, we fabricated a normal compact Co film by using the same electroless deposition process as that of the Co MEM. It can be seen that this Co film has a preferred direction parallel to the film [Fig. 3(c)] while the Co MEM has a perpendicular preferred direction [Fig. 3(d)].

This unusual preferred magnetization direction of the MEMs should originate from their unique nanoporous structure, in some ways like that of the magnetic metallic arrays. The pore walls of the MEM are composed of very small nanoparticles with diameters of about 10 nm; also they have configuration with a high aspect ratio along the pore axis, forming a highly anisotropic structure in nanometer scale. In the magnetization process, this anisotropic structure should force the domain wall to move along the perpendicular direction of the pore wall, thus cause the domain to extend along the same direction. All these will result in a preferred magnetization direction along the pore axis, which is the same direction as that perpendicular to the MEM film plane.

The new features and the novel magnetic properties of the MRMs should lead to a potential technological and scientific application in many fields, including magnetic recording system, electrodes and sensor devices.

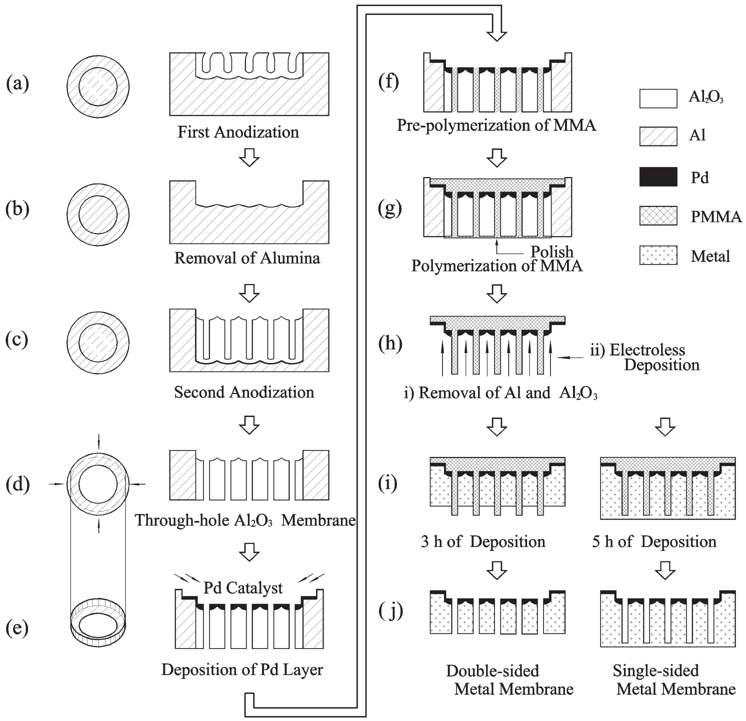

Figure 1 Schematic Diagram of the fabrication of highly ordered nanoporous metal membranes.

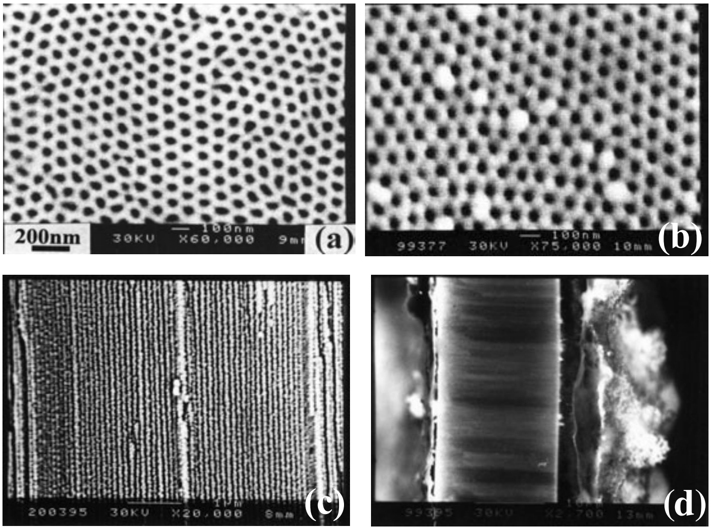

Figure 2 SEM images of the highly ordered metal membranes: top view of the Ni membrane (a) and the Co membrane (b), partial (c) and entire (d) cross section view of the Co membrane.

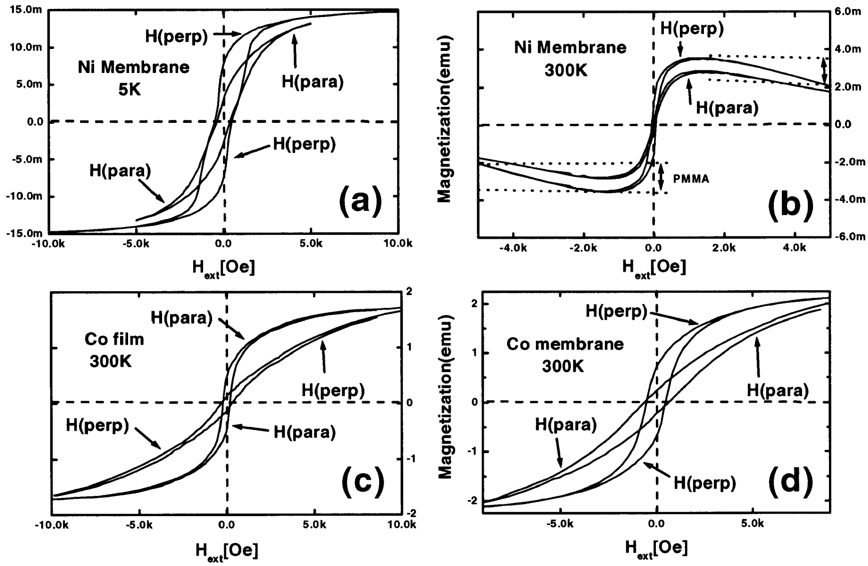

Figure 3 The magnetization hysteresis loops with the magnetic field applied parallel and perpendicular to the membrane (or film) planes: Ni nanoporous membranes measured at 5 K (a) and 300 K (b); a normal compact Co film prepared by the same electroless deposition as that of the Co nanoporous membrane (c), measured at 300 K; Co nanoporous membranes measured at 300 K (d).

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