# 1P012　Anomalous magnetic properties of Ni nanowire arrays in an anodic porous alumina template

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Ferromagnetic (FM) nanowires (NWs) have attracted much attention in recent years because the FM NWs exhibit a high remanence to saturation magnetization ratio ($\mathbf{M}_r/\mathbf{M}_s$) due to the shape anisotropy. The high $\mathbf{M}_r/\mathbf{M}_s$ ratio is suitable for the high-density perpendicular magnetic recording. The FM NW arrays can be simply fabricated by electrochemical deposition of metallic ions onto anodic alumina template with self-assembled nanoholes. The most of 3-*d* FM NWs (Fe, Co, and Ni) embedded in an alumina template have shown the excellent magnetic properties compared to the correspondings in bulk. Only for Ni NWs, however, they occasionally show the poor magnetic properties with decreasing temperature. This has been explained by magnetoelastic effects in the Ni NWs caused by a large mismatch of the thermally induced contraction between the Ni NWs and the alumina template in the cooling process. This implies that the magnetically recorded information may be erased at low temperatures, but studies for this anomalousness have been very few. In this study, we focused on the electrochemically prepared Ni NWs, and obtained a direct evidence for a magnetic phase transition in the Ni NWs embedded in the alumina for the first time.

Alumina template with self-assembled nanoholes was prepared by two-step anodizing processes for a high purity aluminum substrate (99.999 %) in 0.3 M oxalic acid. The constant voltage of DC 40 V, and a platinum counter electrode were used. With the Watts bath consisting of 300 g/L $NiSO_4 \cdot 6H_2O$, 45 g/L $NiCl_2 \cdot 6H_2O$, and 45 g/L $H_3BO_4$, the Ni NW array was fabricated by the electrochemical deposition of Ni ions onto the nanohole array by applying constant voltage of AC 10-15 V. Their morphologies and magnetic properties were characterized with a field emission scanning electron microscope (FE-SEM) and superconducting quantum interference device (SQUID), respectively.

Figures 1(a) and (b) show the SEM images for the top view of alumina template with self assembled nanohole arrays, and the section view of Ni NW arrays embedded in the alumina template, respectively. The diameter and length of the Ni NWs are 70-80 nm and ~2 μm, respectively. Figs. 2(a) and (b) show the magnetic hysteresis loops for the parallel (//) and perpendicular direction (⊥) to the long axis of the Ni NWs, clearly indicating that the coercivity of $\mathbf{H}_{c//}$ becomes smaller at 2 K than at 300 K, while that of $\mathbf{H}_{c\perp}$ becomes larger. The plot of $\mathbf{H}_{c//}$ and $\mathbf{H}_{c\perp}$ as a function of temperature (Fig. 2(d)) shows this anomalous behavior more clearly: The plot of the $\mathbf{H}_{c//}$ has a minimal value at 20~80 K, implying the magnetic phase transition (insert of Fig. 2(d)). The behaviors for $\mathbf{M}_{r//}$ and $\mathbf{M}_{r\perp}$ consistently exhibit similar tendency. We also obtained a direct evidence for the magnetic phase transition with the zero-field-cooling/field cooling (ZFC/FC) measurement. As provided in Fig. 2(c), there are two peaks at ~210 K for the ZFC/FC$_{//}$ and ~80 K for the ZFC/FC$_{\perp}$ measurements, which may be caused by magnetoeleastic effects of the Ni NWs embedded in an alumina template. The magnetic phase transition will be discussed in details in the presentation with plots of $\mathbf{M}_r$ and $\mathbf{M}_s$, and various field-dependent ZFC/FC.

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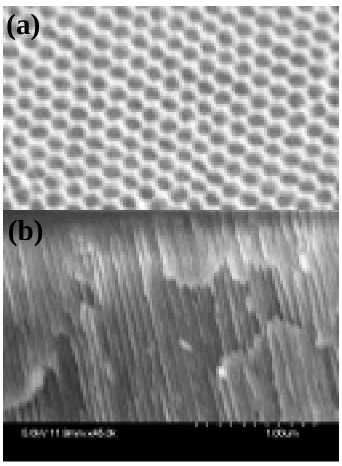


Fig. 1. SEM images of alumina template with self-assembed nanohole arrays ((a)), and the section view of the Ni NWs embeded in alumina template ((b)).

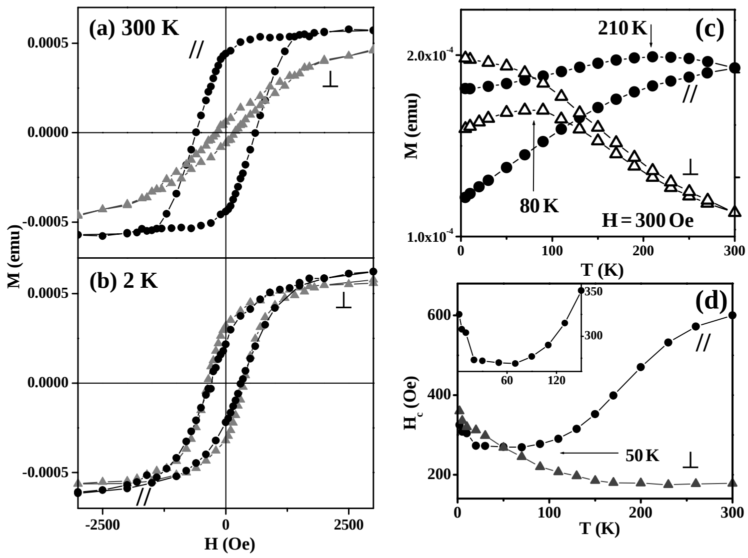


Fig. 2. Hystersis loops for the parallel (●) and perpendicular direction (▲) to the Ni NWs at 300 K ((a)) and 2 K ((b)), ZFC/FC curves ((c)), and plot of $\mathbf{H}_{//}$ and $\mathbf{H}_{\perp}$ as a function of $\mathbf{T}$ ((d)).