Microstructure in MgB$_2$/Ni Alternately-Layered Superconducting Film

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The critical current density, $J_c$, in MgB$_2$ superconductor depends strongly on microstructures such as crystalline grain boundaries, impurity phases, etc. The authors reported that MgB$_2$ films with an artificial MgB$_2$/Ni alternately-layered structure show a notable superconducting property: $J_c$ is significantly enhanced when a magnetic field is applied in parallel to the MgB$_2$/Ni multilayer [1-3]. In the present study, the MgB$_2$/Ni alternately-layered structure has been observed in detail by electron microscopy.

MgB$_2$ and Ni layers were alternately deposited on a Si(001) substrate with a thin B buffer layer using an electron beam evaporation technique [1-3]. During the deposition, the substrate was kept at 533 K. Thicknesses of MgB$_2$ and Ni layers, evaluated from the deposition rates of Mg, B and Ni, were 15-35 nm and 0.2 nm respectively, and the total film thickness were 300 nm. Cross-sectional specimens of the MgB$_2$/Ni multilayered film were prepared by a focused ion beam (FIB) microsampling technique. Microstructural observations were carried out using an FEI Tecnai-F20 transmission electron microscope (TEM) operating at an accelerating voltage of 200 kV.

Figure 1 shows a result of cross-sectional TEM observation. The bright-field (BF) image (a) confirms the alternate deposition of MgB$_2$ and Ni layers. The diffraction pattern taken from the MgB$_2$/Ni multilayer (b) exhibits clear diffraction from only MgB$_2$ phase. The dark-field (DF) images taken with different diffracted beams (c, d, e and f) indicate several features. MgB$_2$ crystals smaller than 100 nm show columnar arrangements perpendicular to the substrate, and $c$-axes of the MgB$_2$ crystals show preferred orientations along the columns (c). Ni layers in the DF images (d, e and f) are observed as bright bands. This DF image contrast cannot be explained by an assumption of a face-centered cubic (FCC) Ni phase formed in the Ni layers. Figure 2 shows a high-resolution (HR) TEM image together with a corresponding diffraction pattern and Fourier power spectra acquired from square regions denoted with broken lines. Both the MgB$_2$ and Ni layers exhibit two-dimensional lattice fringes. However, intensity maxima in the Fourier power spectra do not exhibit net-patterns corresponding to crystalline phases other than MgB$_2$, such as fcc-Ni. From the results, there is a possibility that thin ($\text{Mg}_{1-x}\text{Ni}_x$)B$_2$ layers are formed in the film and they act as strong flux-pinning centers.

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References
FIG. 1. (a) TEM BF image, (b) electron diffraction pattern, and (c, d, e and f) TEM DF images taken with different diffracted beams from MgB$_2$ crystals denoted in the figures.

FIG. 2. HRTEM image together with a corresponding diffraction pattern and Fourier power spectra taken from Ni layers indicated with open broken squares.