Flux pinning characteristics in NbTi/Nb superconductor/superconductor multilayers

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Abstract

Flux pinning characteristics have been investigated for superconductor(S)/superconductor(S') NbTi/Nb multilayers. The maximum of the perpendicular pinning force ($F_{p,\perp}$) as a function of the structure modulation length $\Lambda$ has a peak in the quasi-two-dimensional superconductivity region. The large perpendicular pinning force observed in the S/S' multilayer is caused by Nb layers, which act as the repulsive pinning centers. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Multilayers; Niobium–titanium; Pinning strength

In superconductor(S)/normal metal(N) multilayers, the perpendicular pinning force $F_{p,\perp}$ acting in the perpendicular direction to the layer plane is usually much enhanced compared to the parallel pinning force $F_{p,\parallel}$. In S/N multilayers, the N layer works as an attractive pin center for vortices. Recently, Matsushita et al. \cite{1,2} suggested that in S/S' structures ($\zeta_{s} < \zeta_{c}$), the large enhancement is possible in $F_{p,\parallel}$, where the boundary works as a repulsive pinning center. We investigate $F_{p,\perp}$ in NbTi/Nb (S/S) multilayers in this note. We discuss about the size of $F_{p,\perp}$ with respect to the GL coherence length $\xi_{c}$ of NbTi layer.

Three series of NbTi/Nb (Nb\textsubscript{50}Ti\textsubscript{35}/Nb(N1), Nb\textsubscript{28}Ti\textsubscript{72}/Nb(N2) and Nb\textsubscript{50}Ti\textsubscript{50}/Nb(N4)) multilayers have been fabricated by an RF dual sputtering onto quartz substrates. Samples have equal sublayer thicknesses, $d_{NbTi} = d_{Nb} = (1/2)A$, where $d_{NbTi}$ and $d_{Nb}$ denote the thickness of NbTi and Nb layer, respectively, and $A$ is the modulation wavelength. The critical current density $J_{c}$ was determined resistively at 1.5 K for the three series of N1, N2 and N4. $F_{p,\perp}$ and $F_{p,\parallel}$ were estimated from $J_{c}$ as $F_{p,\perp} = J_{c} \times H_{\perp}$ and $F_{p,\parallel} = J_{c} \times H_{\parallel}$, where $H_{\perp}$ and $H_{\parallel}$ are applied fields parallel and perpendicular to the layer. The current $J_{c}$ is always applied along the layer.

Our recent experimental study \cite{3} revealed that in S/S' multilayers, the maximum pinning force $F_{p,\max}$ is comparable to that of S/N multilayer NbTi/Ti. These results indicate that in NbTi/Nb, Nb layers actually act as equally strong repulsive pinning centers as Ti layers in NbTi/Ti which act as attractive pinning centers. We define $F_{p,\perp,\max}$ as the maximum value of the $J_{c} \times H_{\perp}$ curve and $F_{p,\parallel,\max}$ as a function of $\Lambda$ is shown in Fig. 1. All $F_{p,\perp,\max}$ versus $\Lambda$ curves have a broad peak at around $\Lambda = 200$–300 Å. The peak value of $F_{p,\perp,\max}$ is the largest for Nb\textsubscript{28}Ti\textsubscript{72}/Nb. The difference in the peak values should originate from the difference in the coherence length $\xi_{c}$ of each NbTi layer. According to the $H_{\perp}$ measurement \cite{4}, $\xi_{c}(0)$ of each material at 0 K is estimated as 100.0, 63.4, 58.9 and 42.4 Å for Nb, Nb\textsubscript{50}Ti\textsubscript{35}, Nb\textsubscript{50}Ti\textsubscript{50} and Nb\textsubscript{28}Ti\textsubscript{72}, respectively.

The energy of a single vortex line per unit length is made up of contributions from inside and outside of the core. In a parallel flux configuration to the layer, the contribution from outside of the core is averaged over several S and S' layers and may roughly be independent of the vortex core size. The superconducting condensation energy is almost the same for Nb and NbTi sub-layers. Then the main difference in the vortex core energy of S and S' layers comes from the kinetic energy term.
$h^2(V/\Psi r)^2/2m^*$, in the GL free energy density, which is approximately equal to $\pi B_{c2}^2 / \mu_0$. Dividing the energy difference by $2\zeta_s$, the elementary pinning force $f_{p,\perp}$ by this term is estimated to be

$$f_{p,\perp} \approx 0.5\pi \frac{B_{c2}^2 (\zeta_s^2 - \zeta_s^2)}{\zeta_s^2},$$

(1)

where $B_{c2}$ is the thermodynamic critical field and $\mu_0$ is the permeability of vacuum. Thus, $f_{p,\perp}$ and, as a result, the maximum macroscopic pinning force $F_{p,\perp,\max}$ is expected to depend linearly on $g(\zeta_s)$, where $g(\zeta_s) = (\zeta_s^2 - \zeta_s^2)/\zeta_s^2$. We can see from the plot that $F_{p,\perp,\max}$ as a function of $g(\zeta_s)$ follows a linear relation.

In summary, the $S/S'$ multilayer, NbTi/Nb, has a large $F_{p,\perp,\max}$ which is comparable to that of NbTi/Ti [3]. Three series of NbTi/Nb having different Ti compositions show a broad peak in their $F_{p,\perp,\max}$ versus $A$ curve in the quasi-2D superconductivity region. The peak value of $F_{p,\perp,\max}$ as a function of $g(\zeta_s)$ has nearly a linear relation. This should originate from the Nb sublayers which act as repulsive pinning centers in the parallel flux configuration.

References