LT 21 Proceedings of the 21st International Conference on Low Temperature Physics
Prague, August 8-14, 1996
Part S2 - Superconductivity 1: LTS - Tunnelling phenomena, etc.

Flux Pinning and Dimensionality of Superconductivity in Multilayers

Manabu Ikebe[a], Yoshihisa Obi[b], Hiroyuki Fujishiro[a] and Hiroyasu Fujimori[b]

[a] Faculty of Engineering, Iwate University, 4-3-5, Ueda, Morioka 020, Japan
[b] Institute for Materials Research, Tohoku University, Aoba-ku, Sendai 980, Japan

Flux pinning mechanisms were studied for superconductor/normal metal (S/N), superconductor/superconductor (S/S') and superconductor/insulator (S/I) multilayers. For the superconducting sublayer Nb and NbTi alloy, for the metal sublayer Ti and for the insulator sublayer Al_2O_3 were adopted, respectively. Under the parallel magnetic field, the pinning force was enhanced in quasi-two-dimensional (quasi-2D) and 2D regions of superconductivity and in this enhanced region the peak of the pinning function $F_p(h_{//})/F_{pmax}$ shifted toward a high reduced field $h_{//}$. These characteristics were found to be common in all types (S/N, S/S' and S/I) of the multilayers.

1. INTRODUCTION

The vortex pinning in a superlattice superconductor is an interesting problem because the layer structure itself is expected to enhance the pinning force F_p. In many materials such as high T_c oxide superconductors [1] and α-Ti in worked NbTi alloys [2], plane-like structures are actually at work as pinning centers. In almost all circumstances, the surface or boundary of defect structures are important for the flux pinning. Thus the layer structure is of the most fundamental importance from the viewpoint of the flux pinning.

2. EXPERIMENTAL

Superconductor/normal metal (S/N, NbTi/Ti and Nb/Ti), superconductor/superconductor (S/S', NbTi/Nb) and superconductor/insulator (S/I, Nb/Al_2O_3) multilayers were fabricated by an rf sputtering method. The thickness of each sublayer was designed to be equal except for Nb/Al_2O_3. For Nb/Al_2O_3, the thicknesses of Al_2O_3 were changed for a fixed Nb thickness (=100Å). The measurement of J_c was performed by a 4-terminal resistance method mainly at 1.5K in a 9T superconducting magnet. The magnetic field was applied either parallel ($H_{//}$) or perpendicular ($H_\perp$) to the layer plane and the magnetic field was always perpendicular to the electric current.

3. RESULTS AND DISCUSSION

We define the pinning force density perpendicular ($F_{p\perp}$) and parallel ($F_{p//}$) to the layer by the following relations.

$$F_{p\perp}=(1/C)\, J \times H_{//} \quad (1)$$

$$F_{p//}=(1/C)\, J \times H_{\perp} \quad (2)$$

Fig. 1 shows the maximum value ($F_{p\perp max}$) of $F_{p\perp}$ vs. structural modulation wavelength λ for NbTi/Ti, Nb/Ti and NbTi/Nb. With increasing λ, the dimensionality of the superconductivity changes from three-dimension (3D) to quasi-2D and from quasi-2D to 2D. Commonly for all kinds of superlattices in Fig. 1, $F_{p\perp max}$ is enhanced in the quasi-2D and small λ value 2D ("shallow 2D") regions. This enhancement of $F_{p\perp}$ in the quasi-2D and in the "shallow 2D" region also occurs in Nb/Al_2O_3 (S/I) multilayers as shown in Fig. 2. In Fig. 1 we notice that the magnitude of $F_{p\perp}$ is almost independent of S layer materials (*i.e.*, NbTi or Ni). This fact suggests that the layer structure really makes a main contribution to $F_{p\perp}$. Comparing Fig. 1 and Fig. 2, we notice that $F_{p\perp}$ of Nb/Al_2O_3 is almost twice as large as that of other S/N multilayers. This comes probably from the fact that the pinning force is given by the

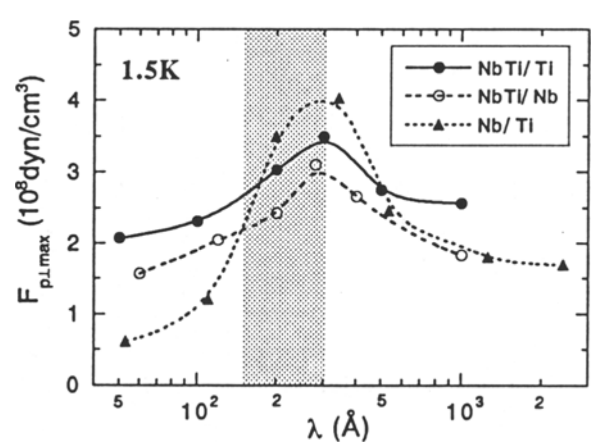

Fig. 1. $F_{p\perp max}$ vs. λ for NbTi/Ti, Nb/Ti and NbTi/Nb. The shaded region roughly corresponds to quasi-2D region.

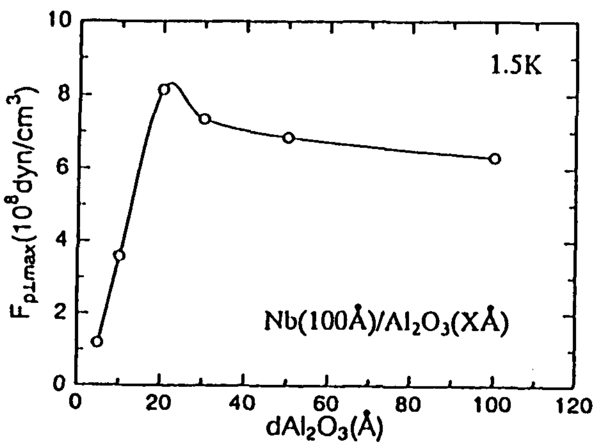

Fig. 2. $F_{p\perp max}$ vs. $d_{Al_2O_3}$ (=Al_2O_3 sublayer thickness) for Nb/Al_2O_3. The superconductivity is 3D for $d_{Al_2O_3}$=5Å, quasi-2D for =10Å and 2D for $d_{Al_2O_3}\geq$20Å.

spatial derivative of that condensation energy U ($F_p \propto \partial U/\partial x$). Because of the absence of the proximity effect, the order parameter should change spatially more steeply in S/I system than S/N system at the boundaries.

Fig. 3 and Fig. 4 show the pinning function $f_{p\perp}$ (=$F_{p\perp}/F_{p\perp max}$) vs. reduced parallel field $h_{//}$ (=$H_{//}/H_{c2//}$) for NbTi/Ti and NbTi/Nb. In Fig. 3, the peak of $F_{p\perp}$ shifts toward higher h in quasi-2D (λ=200Å) and 2D (λ=300Å and 500Å). The similar shift of the peak position related to the dimensionality was also noticed for Nb/Ti [3]. We have firstly noticed this type of the transition of the pinning function for Nb/Al_2O_3 [4,5]. In contrast, we can not clearly recognize the corresponding transition for NbTi/Nb (S/S') multilayers. Takahashi-Tachiki [6] and Koorevaar et al. [7] suggested a complicated phase diagram of S/S' multilayers under $H_{//}$; the center position of vortices is expected to jump between the two kind

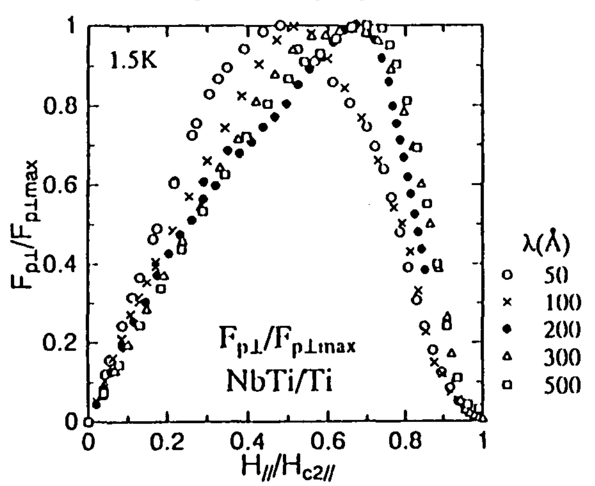

Fig. 3. $f_{p\perp max}$ vs. $h_{//}$ for NbTi/Ti multilayers.

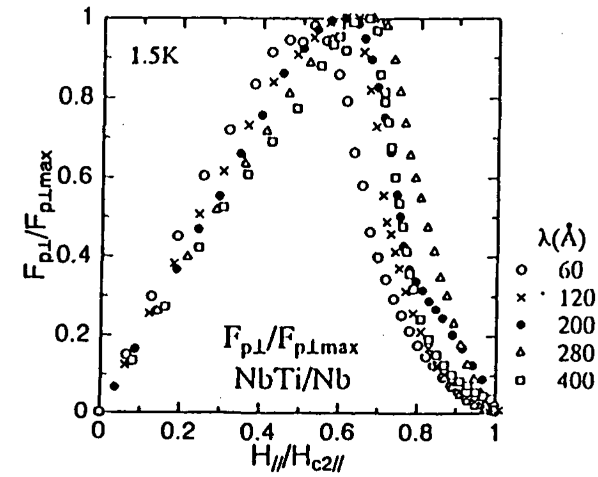

Fig. 4. $f_{p\perp max}$ vs. $h_{//}$ for NbTi/Nb multilayers.

superconducting sublayers in a complex manner. This complexity of the vortex site may masked out the simple transition of the pinning function peak pervasively observed in superconductor/non-superconductor multilayers. The pinning force enhancement and the shift of the pinning function peak in the quasi-2D and the "shallow 2D" regions were not observed in $H_\perp$ configuration ($F_{p//}$). This result also suggests that the observed anomalies in the vortex pinning really originate from the layer structure.

4. CONCLUSION

1) The pinning force $F_{p\perp}$ perpendicular to the layer (in parallel magnetic field) is enhanced in the quasi-2D and 2D regions of superconductivity. This enhancement is commonly observed in superconductor/normal metal, superconductor/insulator and also superconductor /superconductor multilayers.

2) In case of the enhanced $F_{p\perp}$ in quasi-2D and small λ 2D regions, the peak of the pinning function shows a characteristic shift toward a high field. In superconductor/superconductor multilayers, however, the corresponding shift of the peak cannot be confirmed, presumably because of complex motion of the vortex center site in the S/S' system under parallel fields.

REFERENCES

[1] M. Tachiki and S. Takahashi: Solid State Com. 70 (1991) 291.
[2] R.G. Hamphire and M.T. Taylor: J. Phys. F2 (1972) 89.
[3] Y. Obi, M. Ikebe, Y. Muto and H. Fujimori: Supplement to Trans. JIM 29 (1988) 313.
[4] Y. Obi, M. Ikebe and H. Fujimori: Jpn. J. Appl. Phys. 31 (1992) 1334.
[5] M. Ikebe, Y. Obi, H. Fujishiro and H. Fujimori: Jpn. J. Appl. Phys. 32 (1993) 55.
[6] M. Tachiki and S. Takahashi: Solid State Com. 72 (1989) 1083.
[7] P. Koorevaar, W. Maj, P.H. Kes and J. Aarts: Phys. Rev. B47 (1993) 934.