NONEQUILIBRIUM STATES OF HIGH Tc YBCO SUPERCONDUCTORS UNDER TUNNEL INJECTION OF QUASIPARTICLES

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The nonequilibrium states of high Tc superconductors are investigated by means of tunnel injection of quasiparticles using Pb(or Au)/MgO/YBCO tunnel junctions. The effective critical-current reduction due to tunnel injection is observed, whose behavior is different from simple heating. The observed results suggest that the resultant nonequilibrium states may also differ from those described by conventional nonequilibrium models.

The nonequilibrium states of low T_c metal superconductors under high quasiparticle injection attracted considerable attention. They can be created by injecting photons or quasiparticles into a superconducting film. Under strong injection of quasiparticles, various interesting phenomena such as the gap reduction, the spatial instability, the multiple gap states have been observed [1-5] . On the other hand, there have been very few reports on the nonequilibrium states of high T_c superconductors. By means of optical excitation technique, both bolometric and nonbolometric reponses to pulsed laser excitations have been observed [6-8] . For tunnel injection of quasiparticles, we have recently reported the strong critical-current suppression under tunnel injection current [9,10] . Here we report these observed results on tunnel injection of quasiparticles into a superconducting YBCO film and the further extended works.

The samples were prepared by fabricating a tunnel junction onto a YBCO stripline by in situ deposition technique. First, a YBCO film was epitaxially grown onto a MgO(100) single crystal. The film was patterned out either by in situ metal mask technique or by photolithography technique. The film width was 0.2mm for the former case and 15-60 μm for the latter case. The film thickness was 40-100nm. The junction was formed by depositing MgO barrier of 1-4nm thick and subsequently a Pb or an Au counterelectrode.

The measurements for Pb(or Au)/MgO/YBCO junctions were performed by feeding two currents in a YBCO film, one across the junction(injector current: *Iinj*), the other through a YBCO film only (transport current *I*). The Pb/MgO/YBCO injector junctions showed a reasonable gaplike structure at $V=\Delta/e\sim20$mV and a sharp Pb gap structure [11,12] .

It was found that the film critical current *Ic* decreased as *Iinj* was increased. Figure 1 shows an example for the *I-V* characteristics under different injector current Iinj for an Au/MgO/YBCO junction. The junction resistance was about 30 Ω. The positive current axis corresponds to the case that *I* flows in the same direction as *Iinj* in a YBCO film. *Ic* (=20mA) was suppressed to zero at *Iinj*=14mA, suggesting the effective gap reduction due to quasiparticle injection. The second bend in the *I-V* curve may correspond to the critical current in the unperturbed film part. The current gain defined by *Ic*(*Iinj*=0)/*Iinj*(*Ic*=0) was about 1.45. Figure 2 depicts the plot of *Ic* as a function of *Iinj* at 4.2K for the other sample. The solid line corresponds to the case that only the current summation effect is involved. The calculation for simple heating model (dashed line) yielded the curve with downward

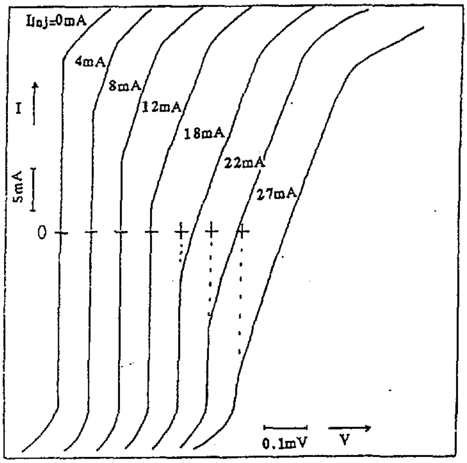

Fig.1 Current-voltage characteristics of a YBCO film under different injection current *Iinj*

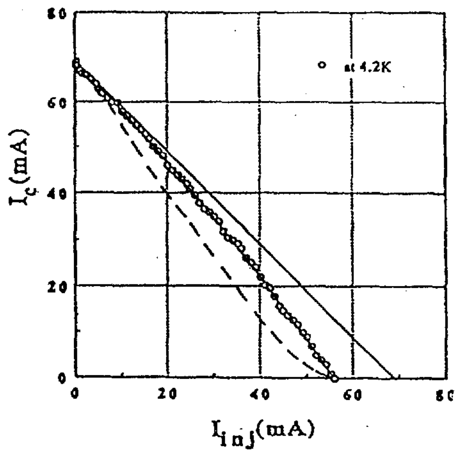

Fig.2 YBCO film critical current *Ic* as a function of injection current *Iinj*

curvature, in qualitative disagreement with the experimental data. When I flowed opposite to I_{inj} (negative axis in Fig.1), the value of I_c was almost unchanged or slightly dereasing. This is a rather obvious fact since the film critical current is the smallest in the unperturbed part of a film.

For Pb/MgO/YBCO tunnel junctions, more interesting phenomena were observed. Figure 3 shows the change in the critical current I_c with an increase of I_{inj}. When I flowed in the same direction as I_{inj} in a YBCO film, I_c decreased monotonically with I_{inj}. The injection current I_{inj}=56mA yielded a complete suppression of I_c (=70mA), again demonstrating the effective involvement of quasiparticle injection effect. The dashed line shows the simple current summation effect. On the other hand, when I flowed in opposite direction to I_{inj}, the apparent enhancement behavior in I_c was observed. For example, at 4.2K, I_c took a maximum value around I_{inj}=20mA and decreased for I_{inj} >20mA. This behavior cannot be interpreted by the conventional nonequilibrium enhancement model since the

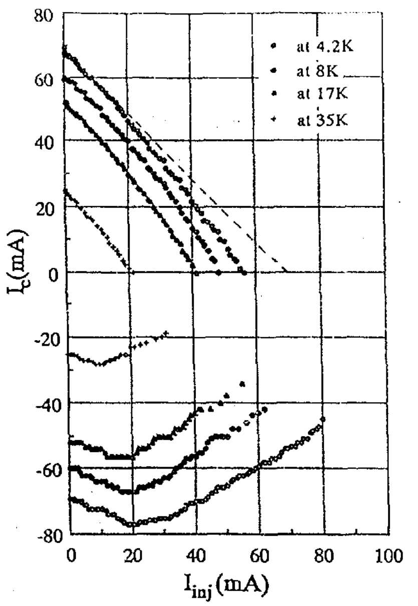

Fig.3 YBCO thin film curent I_c as a function of injection current I_{inj} at different temperatures.

bias voltage for the injector junction is much greater than Δ. The enhancement of I_c in the experimental situation may be interpreted by assuming that I_c of a YBCO film underneath a junction part is smaller than that outside a junction part due to possible damage by multilayer deposition process. It should be emphasized that the enhancement can be observable only for a certain range of junction resistance ($75\,\Omega - 300\,\Omega$) The mechanism of enhancement of I_c is, however, still unclear. We conjecture that it may arise from either the inelastic scattering effect (hence creating preferable nonequilibrium enhancement condition) due to injection of very high energy quasiparticles ($\sim$0.5eV) or the local current distribution in a junction part.

In conclusion, the tunnel injection of quasiparticles into a YBCO film yielded a variety of interesting phenomena, which may be different from those observed for low T_c superconductors. Further study is necessary to clarify the nonequilibrium states of high T_c superconductors.

1. D. N. Langenberg, in *Proceedings of the 14th International Conference on Low Temperature Physics*, edited by M. Krusius and M. Vuorio (North-Holland, Amsterdam, 1975) Vol. V, p.223.
2. A.-M. S. Trembley, in *Nonequilibrium Superconductivity, Phonons and Kapitza Boundaries*, edited by K. Gray (Plenum, New York, 1981), p.309.
3. I. Iguchi, Phys. Rev. B16, 1954 (1977).
4. G. A. Sai-Halasz, C. C. Chi, A. Denenstein and D. N. Langenberg, Phys. Rev. Lett. 33, 215 (1974).
5. I. Iguchi and D. N. Langenberg, Phys. Rev. Lett. 44, 486 (1980).
6. S. G. Han, Z. V. Vardeny, K. S. Wong and O. G. Symko, Phys. Rev. Lett. 65, 2708 (1990).
7. A. Frenkel et al., Appl. Phys. Lett. 54, 1594 (1989).
8. M. Johnson, Appl. Phys. Lett. 59, 1371 (1991).
9. I. Iguchi, K. Nukui and K. Lee, Phys. Rev. B50, 457 (1994).
10. Q. Wang and I. Iguchi, Physica C228, 393 (1994).
11. I. Iguchi et al., Jpn. J. Appl. Phys. 29, L614 (1990).
12. I. Iguchi and Z. Wen, IEEE Trans. Mag. MAG-27, 3102 (1991).