LOW TEMPERATURE PHYSICS VOLUME 25, NUMBER 5 MAY 1999

Microwave transmittance of a high-T_c superconductor film in a magnetic field

V. V. Eremenko, V. A. Novosad, and V. V. Pishko*

B. I. Verkin Institute for Low Temperature Physics and Engineering, National Academy of Sciences of Ukraine, 47, Lenin Ave., 310164, Kharkov, Ukraine

C. Falco

University of Arizona, PO Box 210077, Tucson, Arizona, USA

V. M. Rashkovan

State Aerospace University, 310070, 17 Chkalova St., Kharkov, Ukraine

(Submitted December 30, 1998; revised January 28, 1999)
Fiz. Nizk. Temp. **25**, 519–520 (May 1999)

The results of microwave transmittance measurements of crystalline high-T_c YBaCuO film under the influence of an external magnetic field are presented. Generally, in high-T_c superconductors dissipation mechanisms different from those in conventional superconductors may take place as well as transport current. Josephson-junction and anisotropy resistance-connected processes. Measurements of transmittance induced by the magnetic field demonstrate the dominance of flux flow dissipation mechanism and nonlinear transmittance dependence when approaching T_c. This makes possible to detect and characterize all the mechanisms mentioned above. © *1999 American Institute of Physics.* [S1063-777X(99)01505-4]

Our measurements were carried out in the 2-mm wave range. Under these conditions the transmittance is sensitive to the presence of ''normal'' electrons, whereas infrared measurements sense the superconducting energy gap. The backward-wave tube was used as a microwave generator, with the radiation channeled through a measurement cell that consists of two (in and out) symmetrical quasioptical waveguides inside the pulse solenoid. The sample was placed between the waveguides in the region of the maximum, homogeneous magnetic field. Finally, the radiation was detected after the measurement cell which was placed in a cryostat with special windows to transmit the microwaves. To obtain the best sensitivity a liquid helium cooled n-InSb detector was used.[1] Such a technique produces ultrahigh frequency (130–150 GHz) current densities in the sample which are much smaller in magnitude than the critical current, and thus avoids test current inside the sample that is a consequence of direct current investigations.

The sample under study was made using magnetron sputtering procedure. The 1000 Å YBaCuO (123) film, which was deposited on the surface of a 0.5 mm-thick $SrTiO_3$ substrate, exhibited a micro-twinned crystalline structure with its C-axis perpendicular to the surface. Preliminary testing determined a superconducting transition at 87.8 K with 1 K width.

The experimental dependences of the magnetic field-induced transmittance at different temperatures are shown in Fig. 1. As can be seen, the transmittance value rises monotonically when the temperature rises from 4.2 K to T_c. At low temperatures a linear behavior of the transmittance versus the external field with a slope of 1%. T^{-1} was exhibited, which is consistent with results reported in Refs. 3 and 4 where the bolometric and reflectance measurements were performed. This linear dependence of microwave transmittance on magnetic field may be explained in terms of flux flow dissipation. In contrast, the slope value at temperatures approaching the T_c rised to $3\%\cdot T^{-1}$ and the behavior was strongly nonlinear. Evidently, this region is dominated by the influence of the magnetic field on the superconducting phase transition.

Normal electron transmittance includes dissipation resulting from the Lorentzain-like force motion due to the transport current normal to applied magnetic field H. For the HTSC the microwave frequency range is higher than the depinning frequency. Consequently, electromagnetic interaction is much stronger than the pinning force, and the major source of the dissipation is due to the free-moving vortices.

In the London electrodynamics approach it is possible to represent the current density J as

$$J=-\frac{1}{i\omega\mu\lambda^2}(E-f\nu B), \tag{1}$$

where λ is the London penetration depth; E is the microwave electric field; f is the fraction free vortices.[2] Writing the vortex velocity as $\nu=Jf/n$, the expression for the flow resistivity may be obtained as

$$\rho=\varphi_0\frac{fB}{\eta}-i\overline{\omega}\mu\lambda^2, \tag{2}$$

which is true for H smaller than critical field and temperatures that are not too high. Taking into account that a typical HTSC critical field is of order 100 T, the limit representation for surface resistance R_s demonstrates a linear dependence on H:

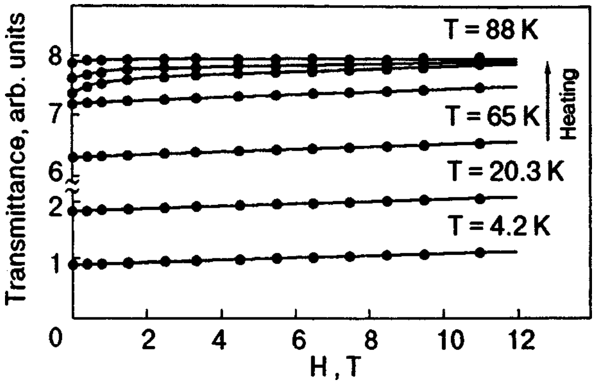

FIG. 1. Magnetic field effect on transmittance of the HTSC thin film at different temperatures.

$$R_s = \varphi_0 \frac{fB}{2\lambda\eta}. \tag{3}$$

This approximation is based on the pure flow regime and neglects the normal electron contribution, so the model is not valid in the region very close to T_c. A more detailed consideration of high frequency magneto-absorption was developed based on the equation of motion for a flux line in a sinusoidal pinning well under an alternating field and a random driving force due to thermal fluctuations.[5]

The granularity and various inhomogenities of the sample can produce a weak-like structure or, if there is an intrinsic Josephson junction inside, either effect may dominate in the microwave response. We assume the observed behavior of microwave properties near T_c may be due to the domination of dissipation effects from losses related to the Josephson junctions. To clarify this problem a set of additional measurements on other HTSC thin films are expected to be carried out. Attention will be given to the hysteresis phenomena due to the thermal and magnetic history of samples with different crystalline properties.

This work was supported by CRDF of USA and Government of Ukraine through the research project UP2-301 and by ONR N00014-92-J-1159.

*E-mail: pishko@ilt.kharkov.ua

---

[1] V. V. Eremenko, S. A. Zvyagin, V. V. Pishko, Yu. A. Pashkevich, and V. V. Shakhov, Fiz. Nizk. Temp. **18**, 255 (1992) [Sov. J. Low Temp. Phys. **18**, 175 (1992)].

[2] A. M. Portis, K. W. Blazey, and K. A. Muller, Europhys. Lett. **5**, 467 (1988).

[3] Y. Masuda, N. P. Ong, Y. F. Yan, J. M. Harris, and J. B. Peterson, Phys. Rev. B **49**, 4380 (1994).

[4] P. B. Tharane, G. Dumas, C. Schlenker, and R. Buder, Physica C **127**, 147 (1997).

[5] M. W. Coffey and J. R. Clem, Phys. Rev. Lett. **58**, 1143 (1991).

This article published in English in the original Russian journal.