Photoresponse of Epitaxial $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ Ultrathin Films

A.P. Zhuravel', A.G. Sivakov*, O.G. Turutanov*, I.M. Dmitrenko*, K. Joosse**, G.J. Gerritsma**, and H. Rogalla**

*B.I. Verkin Institute for Low Temperature Physics & Engineering, 47 Lenin Ave., 310164 Kharkov, Ukraine

**University of Twente, Department of Applied Physics, Low Temperature Division, P.O. Box 217, 7500 AE Enschede, The Netherlands

The voltage photoresponse of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}/\text{SrTiO}_3$ 10 nm-thick films on laser irradiation is studied using the low temperature scanning laser microscopy (LTSLM) technique. The irradiation wavelength is 633 nm. The spatial response dependencies via temperature (4-100 K), beam intensity modulation frequency (0-150 kHz) and bias current are examined. The bolometric and non-bolometric components are separated. The amplitude of the non-bolometric component at 4.2 K is about 10 times higher than that of bolometric one measured near the midpoint of the superconducting transition. The non-bolometric component is presumably associated with weak links in the film due to interdiffusion of SrTiO_3 into YBCO layer. The spatial irregularity in superconducting parameters is not resolved by the LTSLM method since the spacing between weak links is appeared to be less than 1 μm .

INTRODUCTION

The interaction between high T_c superconducting (HTS) epitaxial thin films with optical irradiation is under intensive study over the last few years. The current interest to these films is associated with their possible application as a high-sensitive liquid nitrogen-cooled broadband radiation detector. The responsibility and the response rate of HTS dc current biased sensor depends on the particular mechanism of optical film-absorbed power conversion into the electrical signal. At least, two response mechanisms are known, namely, bolometric (thermal) and non-bolometric (nonequilibrium, or non-thermal).

The highly epitaxial HTS films are known to exhibit mainly bolometric photoresponse (PR) due to the large value of dR/dT within the superconducting transition temperature range. The existence of the nonequilibrium component δV_n is under discussion at present. In this work the ultrathin epitaxial films are demonstrated to generate the photoresponse of both bolometric and non-bolometric origin. To evaluate the contributions δV_n and δV_b we exploit the difference in their dependencies on the optical irradiation intensity modulation

frequency f . In the frequency range of 0-150 kHz available in our experiments the thermal component δV_b considerably decreases while rising the modulation frequency due to high thermal capacity of the HTS film-substrate system. The non-bolometric component δV_n originated from only optical but not thermal disturbance of the film keeps practically constant in the specified frequency range.

EXPERIMENTAL PROCEDURE

Samples

The samples were the 10 nm *ab*-oriented epitaxial YBCO films deposited by RF magnetron sputtering onto the SrTiO₃ substrate (size 10 mm x 5 mm x 0.9 mm, orientation (100)) using the 10 nm PBCO buffer layer. To protect the ultrathin films against the oxygen loss and environment attack they were *in situ* covered by 100 nm epitaxial SrTiO₃ film. All the details are described in [1]. The films were patterned by a laser cutting or photolithographically into bridges with potential leads to perform standard four-terminal dc and ac measurements. The zero-resistance critical temperatures $T_{c0} = 32 - 40$ K, the transition width $\Delta T_c = 40 - 48$ K, and the critical current density $j_c(4.2 \text{ K}) = (1.3 - 5) \cdot 10^6 \text{ A/cm}^2$ (criterion was the voltage onset of 10^{-7} V). The samples resistivity $\rho(100 \text{ K}) = 1.2 \text{ m}\Omega \text{ cm}$.

Experimental setup

The photoresponse studies were carried out by means of the low temperature scanning laser microscope (LTSLM) described in details elsewhere [2]. With this instrument the distribution of voltage response signal $\delta V(x,y)$ as a function of light spot (probe) position x,y in the sample plane was build at temperatures ranged from 4.2 to 100 K (within 5 mK stability). The scanning was performed by a He-Ne laser ($\lambda = 633 \text{ nm}$, 2 mW) beam focused in a $1.5 \mu\text{m}$ diameter spot (probe). The raster covered the $100 \mu\text{m} \times 100 \mu\text{m}$ area. The beam intensity was sinusoidally modulated at a frequency $f = 0 - 150 \text{ kHz}$ and the amplitude of ac response voltage across the sample was recorded at the same frequency

RESULTS AND DISCUSSION

From the two dimensional LTSLM response maps $\delta V(x,y)$ it was derived that the response was almost constant within the instrument resolution (several micrometers) over the sample area at any T , I and f which is evidence for the uniform distribution of the superconducting properties. Fig. 1 illustrates one of the LTSLM images of the sample obtained at frequency $f = 20 \text{ kHz}$ (the sample thermal relaxation time was measured to be $1/\tau = 1.2 \text{ kHz}$) and the spatial resolution in this image is limited not only by the laser probe size but also by the substrate thermal diffusion length which results in the background signal outside the sample area. The half-tone presentation of this image implies that the black and white correspond to the maximum and minimum of signal amplitudes $\delta V(x,y)$, respectively. The distinct white strips are the sample parts of the film removed from the substrate by the laser cutting and therefore transparent for the laser irradiation.

Since the voltage response distribution for all the samples was spatially uniform we restricted ourselves to the measurements of the response signal in the sample midpoint.

Fig 2 Voltage response and resistivity vs. temperature plots at $I=0.078 \text{ mA}$ (a) and $I=1 \text{ mA}$ (b)

Fig 3 Normalized response vs. modulation frequency at $I=1 \text{ mA}$ and several temperatures

Fig. 2 shows the experimental curves of the superconducting transition $\rho(T)$ and the voltage response $\delta V(T)$ at 0.078 mA (a) and 1 mA (b) recorded in the temperature range $T=4.2$ -100 K. Down to the midpoint of the superconductive transition ($T=56$ K) all the experimental curves $\delta V(T)$ fit the bolometric dependence $\delta V(T)=I(dR/dT)\delta T$ with $\delta T=0.03$ K as the adjustment parameter. Below this temperature the response $\delta V(T)$ at low current (Fig. 2,a) still follows the bolometric formula while at higher currents the curves considerably diverge due to the non-bolometric component contribution. It should be noted that the experimental response at $I=1$ mA and $T=4.2$ K exceeds the maximum value of the bolometric one in the midpoint of superconducting transition by an order of magnitude.

Fig. 3 demonstrates the response vs. frequency plots obtained in the sample center at $I=1$ mA and various T . All the curves are normalized to maximum response amplitude. Down to the midpoint of superconducting transition all the curves are described by the only dependence which is the bolometric decay of δV with increasing frequency. As temperature goes down, the frequency-independent part of signal δV arises and becomes dominant at $T<T_c$. This part is associated with the non-bolometric component δV_n whose nature could lie in a non-equilibrium of the resistive state in the current-carrying HTS film at $T<T_c$. This nonequilibrium state may appear at boundaries of individual grains, magnetic flux creep areas, Josephson weak links, the interface between a normal metal and a superconductor, etc. The latter two mechanisms are most reasonable in our case. This is confirmed by wide superconducting transition and the critical current via temperature dependence composed of two linear parts (crossover) which is characteristic of 2-D random array of weak links.

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Fig 1 LTSLM voltage response image of the bridge. $T=18$ K, $I=1$ mA, $f=20$ kHz