International Journal of Infrared and Millimeter Waves, Vol. 21, No. 3, 2000

NEAR-FIELD INDUCED FIR JOSEPHSON-DETECTION BY c-AXIS-ORIENTED $YBa_2Cu_3O_{7-\delta}$-FILMS

E. Zepezauer,[1] A. Kalbeck,[1] S. D. Ganichev,[1,2] W. Korzenietz,[1] and W. Prettl[1]

[1]*Institut für Experimentelle und Angewandte Physik*
Universität Regensburg
93040 Regensburg, Germany
[2]*A. F. Ioffe Physicotechnical Institute of the RAS*
St. Petersburg 194021, Russia

Received December 16, 1999

Abstract

A novel approach to intrinsic Josephson-detection of far infrared radiation is reported utilizing near-zone field effects at electric contacts on c-axis oriented $YBa_2Cu_3O_{7-\delta}$ films. While only a bolometric signal was observed focusing the radiation far off the contacts on c-axis normal films, irradiating the edge of contacts yielded an almost wavelength independent fast signal showing the characteristic intensity dependence of Josephson-detection. The signal is attributed to a c-axis parallel component of the electric radiation field being generated in the near-zone field of diffraction at the metallic contact structures.

Key words: near field, far infrared, Josephson effect, $YBa_2Cu_3O_{7-\delta}$.

1 Introduction

Thin granular superconducting films of high-T_c superconductors, biased close to their critical currents, have been shown to be fast and sensitive detectors for the far infrared (FIR) and millimeter wave regime [1–5]. These films consist of stoichiometric crystallites, each of which is coupled to its neighbors by weak links. The films are thus comprised of a random array of Josephson junctions, the critical currents of which are depressed by below gap radiation. Measured responsivities are unsurprisingly found to vary considerably between samples, due to the reliance of the detectivity on the properties of the random array. Inherent Josephson junctions have also been found in small single crystals of Bi- and Tl-based high-T_c superconducting materials [6]. In this case, in contrast to granular films, a regular microscopic array of junctions is formed along the c-axis by the quasi two-dimensionality of the material. However, for efficient FIR radiation detection with these small crystallites, a component of the electric field of the radiation must be applied along the c-axis of the superconductor. This is only realizable by using delicate antennas to contact a small crystal with μm dimensions. A considerable improvement in FIR Josephson detection including difference frequency mixing has been achieved by using thin film structures grown with a controllable misalignment between the c-axis and the substrate surface normal [7,8]. The coherent growth of such films on appropriately oriented substrates has been established by the observation of a tilt angle dependent lateral thermoelectric effect in the normal state [9]. In such films normal incidence irradiation applies an electric field along the c-axis.

Here we report on a new approach to FIR-Josephson detection using c-axis oriented epitaxial grown $YBa_2Cu_3O_{7-\delta}$ films which are of much better quality than those prepared with a tilt angle to the c-axis. The necessary component of the electric field of the FIR radiation normal to the film surface is achieved by making use of the optical near-zone field effect of diffraction on suitable electrode structures on the sample surface. Similar diffraction generated near-zone field enhancement of electron tunneling has been previously observed applying high-power FIR radiation on n-GaAs tunnel Schottky diodes [10] and between metallic contacts and δ-doped 2DEG in n-GaAs 20 nm below the surface [11].

2 Experimental

Epitaxial $YBa_2Cu_3O_{7-\delta}$-layers have been prepared by UV-laser evaporation on (100)$LaAlO_3$-substrates. The thickness of the films was 300 nm. The samples were oxygen depleted by thermally forced oxygen diffusion in Ar atmosphere at 600 K for several hours.

In Fig. 1 a plot of resistance as a function of temperature is shown for the samples used here with T_c around T = 80 K. Due to oxygen deficiency the samples show semiconductor-like behavior below and above T_c, the slope of the resistance versus temperature is negative away from T_c. This allows to distinguish easily between Josephson- and bolometric signal as they differ in polarity.

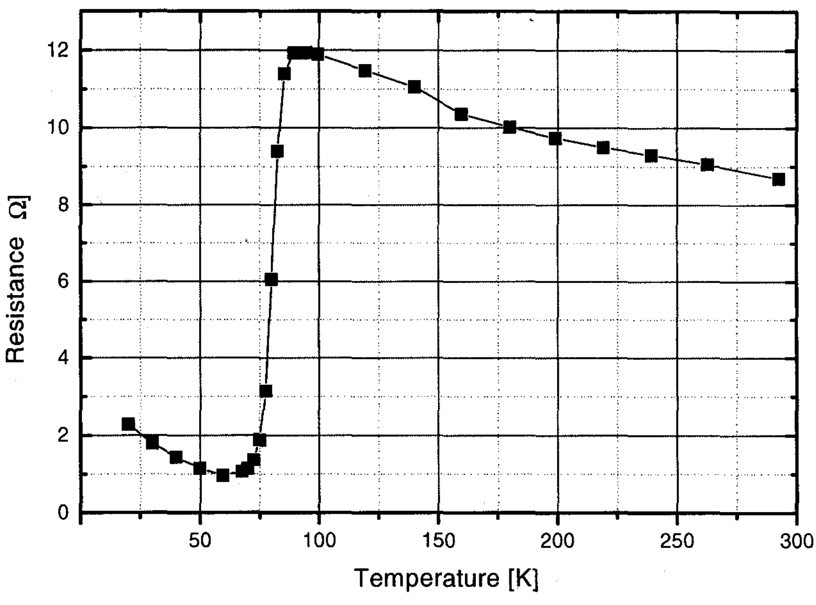

Figure 1: *Sample resistance as function of temperature showing semiconductor like behavior below* T_c.

On top of the films diffracting electrode structures were deposited by sputtering large non-transparent parallel Au stripe contacts with various spacing widths around 100 μm in the range of the employed FIR-wavelengths. In addition stripe contact pairs with a large distance of 3 mm were also used allowing irradiation of one contact only.

To allow polarization independent diffraction measurements at contact edges, silver paint dots of 1 mm diameter were applied on the edge of one metal contact of the 3 mm slit sample covering partly the plain superconductor surface (see Fig. 4). The rough boundary of the silver paint spot yields diffraction for all polarizations of the radiation field.

Measurements of the photoresponse were carried out using a TEA-CO_2 laser pumped molecular FIR laser with NH_3 as active gas yielding laser lines of $\lambda = 76$, 90, 148 and 280 μm with a peak intensity up to 2 MW/cm^2 in 100 ns pulses. The intensity of the laser pulses was controlled by calibrated attenuators and monitored using a fast photon drag p-Ge detector [1].

The superconducting samples were biased by a fast constant current source with bias current up to 100 mA and the voltage across the sample in response to FIR laser pulses was recorded with a digital storage oscilloscope. The measurements were carried out in a temperature controllable cryostat with optical access in the range 25 to 60 K.

3 Results and Discussion

Fig. 2 shows the sample response to 76 μm laser pulses (lower traces) in comparison to reference detector signals (upper traces). The upper plate exhibits a signal trace when the laser was focused on the edge of the the silver paint contact whereas in the lower plate the signal is plotted which was observed when the laser was focused on the superconductor away from the contacts. In the first case we see a fast positive signal ($\tau < 10$ ns) being synchronous to the leading edge of the reference detector signal and a slower negative signal ($\tau \approx$ 100 ns). When, on the other hand, solely the superconductor was irradiated the slow negative signal was found only. Thus, the slow negative signal can be identified with a bolometric effect whereas the fast positive signal can be attributed to the Josephson effect. In the signal trace bottom left the Josephson signal is truncated by the bolometric signal of the opposite sign.

Fig. 3 shows the intensity dependence of the signal voltage for different wavelengths demonstrating the typical behavior of Josephson response following power laws [4]. The upper and lower plates show the response irradiating one contact edge of a 3 mm slit sample and a 100 μm slit, respectively. In both cases at low intensities an almost wavelength independent power law is observed which proceeds at high intensities into signal $\propto I^{\frac{1}{2}}$ where I is the intensity. The crossover occurs at practically the same intensity for all wavelengths

[1] ARTAS GmbH, model PD5F

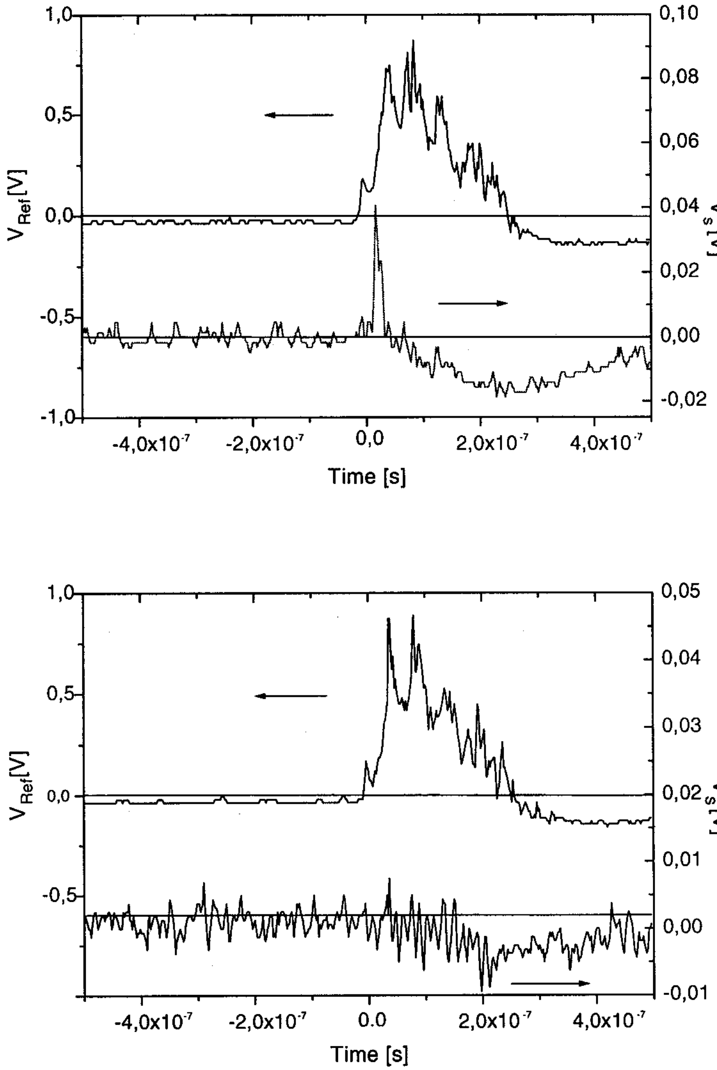

Figure 2: *Typical signal pulse shapes (lower traces) compared to reference photodetector signals (upper traces) showing fast Josephson plus bolometric signal at a contact edge (upper plate) and only bolometric response from the plain surface (lower plate).*

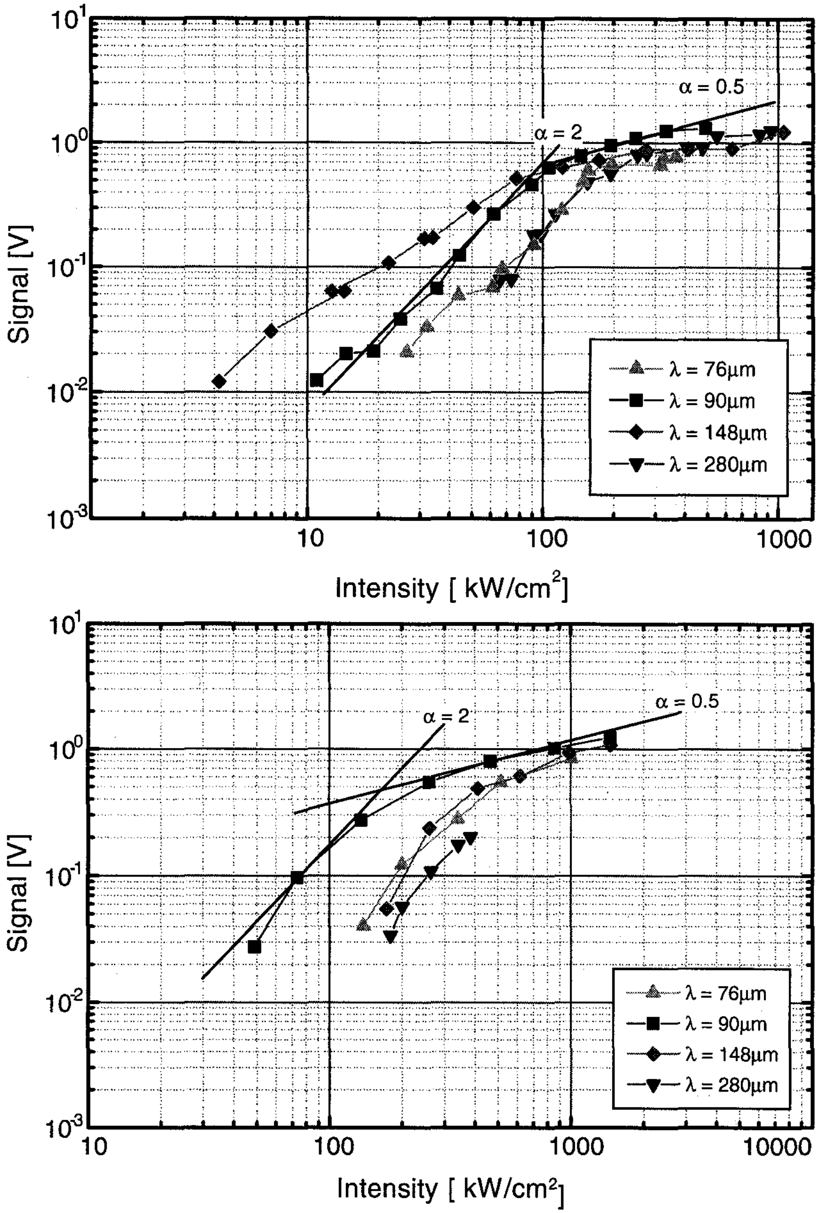

Figure 3: *FIR-intensity dependence of the Josephson signal at a temperature of 40 K on the 3 mm slit edge (upper plate) and on the 100 μm-slit (lower plate).*

except for the 100 μm slit sample and $\lambda = 90.5\,\mu$m wavelength which is almost equal to the contact distance.

In Fig. 4 the signal voltage is shown as a function of the spatial location of the laser focus scanned across the sample surface perpendicular to the silver paint contact. The peak signal is plotted as a function of the center of the focal spot with respect to the contact geometry. The spatial signal distribution corresponds to the intensity profiles of the laser focus as obtained by a high resolution pyroelectric camera[2]. A signal is observed only in the case of incidence onto the silver paint contact edge and vanishes if only the plain $YBa_2Cu_3O_{7-\delta}$ surface is irradiated. This observation gives evidence that the signal must be due to a component of the electric field of the radiation which is normal to the c-axis oriented sample modulating the critical current of the intrinsic Josephson effect. Such a longitudinal electric field component may be caused in the near-zone field of diffraction at the silver paint contact.

The formation of effective intrinsic Josephson junctions in the c-axis of $YBa_2Cu_3O_{7-\delta}$-layers is dependent on the oxygen deficiency δ. A particular δ can be achieved by thermally forced oxygen diffusion in and out of the sample along the ab-crystal planes. Due to our sample geometry with large contact surfaces and its c-axis orientation this diffusion is locally inhibited, leading to an inhomogeneous oxygen distribution and therefore inhomogeneous superconducting characteristics across the sample like different critical temperatures and currents, as a semiconductor-like residual resistance in the superconducting state. Electrical measurements also indicate an inhomogeneous current distribution between the contacts, showing several distinguished current paths.

4 Conclusions

In c-axis oriented thin oxygen depleted $YBa_2Cu_3O_{7-\delta}$-films a fast response to far infrared laser radiation has been observed only if diffracting metallic structures on top of the film have been irradiated. Therefore it is concluded that the signal is due to suppression of the critical current of the intrinsic Josephson coupling between adjacent superconducting layers. This suppression is caused by an electric field component of the high frequency radiation which is normal to the plane of the superconducting film and is generated in the near-zone field of diffraction. As the effect depends on the struc-

[2]Spiricon, Pyrocam I

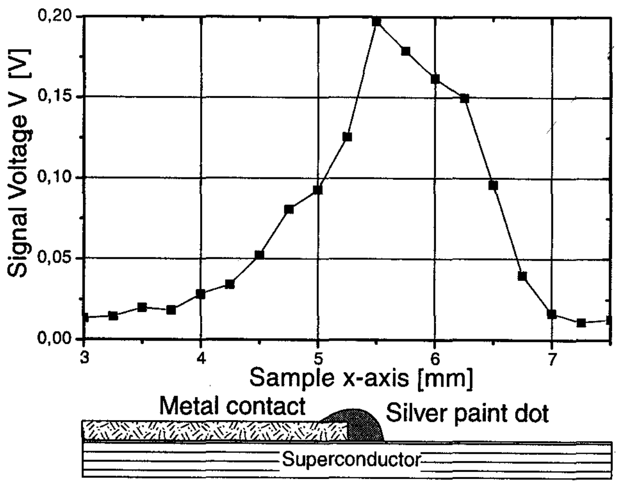

Figure 4: *Signal height at scans of the laser focus across the 3 mm slit.*

ture of metal electrodes, the prepararation of suitable grating or dot structures may both enhance detectivity and yield a wavelength as well as a polarization selective detector.

5 Acknowledgments

Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged. We thank H. Lengfellner for advice in sample preparation and A. Ya. Shulman, IRE Moscow, for helpful discussions.

References

[1] M. Leung, P. R. Broussard, J. H. Claassen, M. Osofsky, S. A. Wolf, and U. Strom, Appl. Phys. Lett **51**, 2046 (1987).

[2] P. G. Huggard, Gi. Schneider, T. O'Brien, P. Lemoine, W. Blau, and W. Prettl, Appl. Phys. Lett **58**, 2549 (1991).

[3] Gi. Schneider, P. G. Huggard, T. O'Brien, P. Lemoine, W. Blau, and W. Prettl, Appl. Phys. Lett. **60**, 648 (1992).

[4] P. G. Huggard, Gi. Schneider, C. Richter, R. Rickler, and W. Prettl, Phys. Rev. B **49**, 9949 (1994).

[5] W. M. Huber, B. Arendt, P. G. Huggard, and W. Prettl, Supercond. Sci. and Tech. **8**, 769 (1995).

[6] R. Kleiner, F. Steinmeyer, G. Kunkel, and P. Müller, Phys. Rev. Lett. **68**, 2394 (1992).

[7] W.M. Huber, M. Berr, A. Kalbeck, W. Prettl, and P.G. Huggard, Appl. Phys. Lett. **68**, 3338 (1996).

[8] W.M. Huber, A. Kalbeck, M. Berr, R. Titz, R. Nitsche, and W. Prettl, Int. J. Infrared and Millimeter Waves **18**, 991 (1997).

[9] S. Zeuner, W. Prettl, and H. Lengfellner, Appl. Phys. Lett. **66**, 1833 (1995).

[10] S. D. Ganichev, A. Ya. Shul'man, N. A. Mordovets, I. N. Kotel'nikov, and W. Prettl, Int. J. Infrared and Millimeter Waves **17** (1996)

[11] I. N. Kotel'nikov, A. Ya. Shul'man, S. D. Ganichev, N. A. Varvanin, B. Mayerhofer and W. Prettl, Sol. St. Comm. **97** (1996)