

THz imaging of supercurrent distribution in Meisner state of LPE-BSCCO film

Murakami H., Kiwa T.^a, Tonouchi M.^b, Yasuda T.^c,

^a Research Center for Superconductor Photonics, Osaka Univ., Suita, Osaka 565-0871, Japan

^b Research Center for Superconductor Photonics, Osaka Univ. and CREST-JST, Suita, Osaka 565-0871, Japan

^c Dept. Computer Science and Electronics, Kyushu Inst. Tech., Iizuka, Fukuoka 820-8502, Japan

Abstract

In order to apply the terahertz (THz) imaging technique to high- T_C superconductor thick film, the THz imaging system was improved to observe the back-scattered THz radiation pulse. Using the improved system we succeeded in the observation of supercurrent distribution in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ thick film in Meisner state.

Key words: terahertz; femtosecond laser; $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$; liquid phase epitaxy; supercurrent distribution

1. Introduction

Progress in femtosecond laser technology has brought various remarkable developments in research fields. One of potential applications is an optical source for terahertz (THz) wave radiation. It is known that a current biased high- T_C superconductor (HTS) thin films, $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$, $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ (BSCCO) and $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_{8+\delta}$, radiate THz pulse into free space by femtosecond laser pulse (FLP) illumination. [1-3] The phenomenon is well explained by ultrafast supercurrent modulation induced by FLP. The optical pulse produces a large number of excitation carriers by avalanche effect, and THz pulse is emitted according to the classical formula of electrodynamics $\mathbf{E} \sim d\mathbf{J}/dt$, where \mathbf{E} is a radiated electric field in the far-field approximation and \mathbf{J} is current density. The intensity in the amplitude of the radiated THz pulse almost linearly increases with the magnitude of the local supercurrent density. Using this phenomenon supercurrent imaging system was developed, which enabled us to observe the supercurrent distribution in optically transparent HTS thin films (with thick-

ness less than about 100 nm) without any contacts and damages, by detecting the THz wave transmitted through the thin film.

In the present study, we developed the THz imaging system to be applicable to bulk- or thick-superconductors. The experimental technique and the results obtained on a liquid phase epitaxy grown (LPE-)BSCCO thick film are presented.

2. Experiments and results

For the measurement, *c*-axis oriented single-crystalline BSCCO film (LPE-BSCCO) was prepared in between two pieces of MgO (100) substrates by liquid phase epitaxy method. After the growth, surfaces were exposed by cleavage. X-ray diffraction pattern and atomic force microscopy observation showed well-defined crystal properties for these films. The resistive measurement showed the critical temperature of about 75 K. The details of sample preparation have been reported elsewhere. [4]

Fig. 1 shows the optical system of improved THz imaging. The optical pulses were generated by a mode-locked Ti:sapphire laser with a central wavelength of

¹ Corresponding author. E-mail: murakami@rcsuper.osaka-u.ac.jp

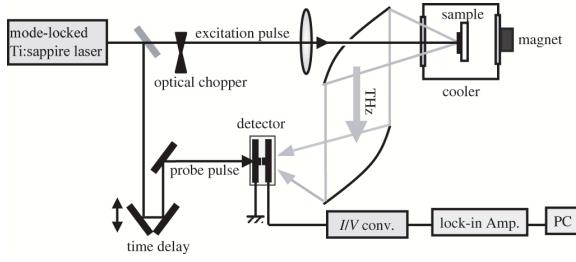


Fig. 1. Schematic illustration of improved optical system for THz imaging.

790 nm and a repetition rate of 82 MHz. The excitation-laser beam was chopped at 2 kHz, and focused onto the sample surface through a hole of one of the paraboloidal mirrors at a focal spot size of about 30 μm in diameter. Using a pair of off-axis paraboloidal mirrors the back-scattered THz pulses radiated into free space were collimated on a low temperature grown GaAs bow-tie antenna detector through a Si hemispherical lens, and the photocurrent induced in the detector was lock-in detected. After adjusting the time delay between the excitation- and probe-pulse to the peak position of the THz waveform, supercurrent distribution image was observed by scanning the focused FLP beam over the sample surface with use of the movable $x - y$ stage. For the imaging, the power of laser was set at about 20 mW.

Figures 2(a) shows an optical microscope image of the LPE-BSCCO thick film. Since the film surface was exposed by the cleavage between two pieces of MgO substrates, distribution in the thickness from 0 to several μm with several defects and cracks (corresponding to the lower region of the image) was observed for the present film.

On the other hand, Fig. 2(b) shows typical supercurrent distribution image observed in Meisner state under a magnetic field of about 100 Oe parallel to the crystal c -axis. The magnetic field was applied to the film from the opposite side of the cooler using a permanent magnet after cooling the sample at about 10 K. Here, white region corresponds to the positive current in the x -direction, and black region to the negative current. It can be seen that the Meisner current concentrates on the edge regions as observed in optically transparent HTS films before. We observed clear current signal at the upper edge region and weak one at the bottom edge region probably due to the inhomogeneous film configuration. The weak positive current seen near the bottom edge region shows the possibility for existence of trapped fluxes in the narrow defect region which is seen in the right bottom region in Fig. 2(a). It is considered that the magnetic fluxes penetrated into the defect regions through the weak links corresponding to the cracks. These defects and cracks existing in the half bottom regions may make the su-

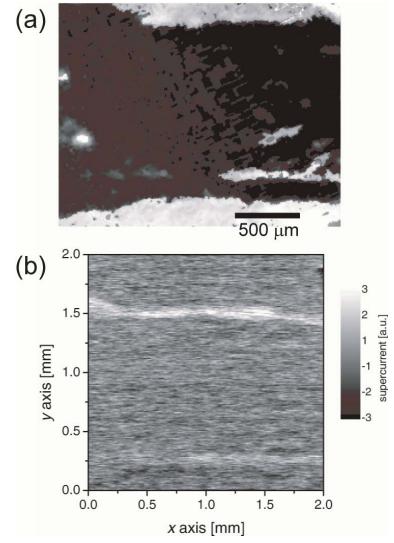


Fig. 2. (a) optical microscope image of LPE-BSCCO sample, and (b) supercurrent distribution image of sample in Meisner state under a magnetic field of about 100 Oe parallel to the crystal c -axis. Here, the white and black regions correspond to positive and negative current in x -direction.

percurrent spread and weaken the intensity of the THz radiation signal.

3. Summary

We developed the new type of imaging system to be applicable to bulk- and thick HTS materials. Using this system, the supercurrent distribution in Meisner state of LPE-BSCCO thick film was successfully obtained. These obtained results show a possible application of this system to check superconducting electronics devices.

Acknowledgements

This work was supported in part by a Grant-in-Aid for Scientific Research (B) No.12450146 and No.13555107 from the Japan Society for the Promotion of Science. One of the authors (H.M.) acknowledges the support of the Murata Science Foundation.

References

- [1] M. Tonouchi *et al.*, Jpn. J. Appl. Phys. **35** (1996) 2624.
- [2] H. Murakami *et al.*, Jpn. J. appl. Phys. **41** (2002) 1992.
- [3] Y. Tominari *et al.*, Appl. Phys. Lett. **80** (2002) 3147.
- [4] T. Yasuda *et al.*, Extend. Abs. of 8th ISEC, (2001) 255.