Ultrafast optical response of TBCCO(2212) thin films

Murakami H., Tominari Y. [a], Tonouchi M. [b], Yasuda T. [c], Wald H., Seidel P. [d], Schneidewind H. [e]

[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*
[d] *Friedrich-Schiller Univ., Helmholtzweg 5, D-07743 Jena, Germany*
[e] *Institute for Physical High Technology, P. O. Box 100239, D-07702 Jena, Germany*

Abstract

Ultrafast optical response of carriers in $Tl_2Ba_2CaCu_2O_{8+\delta}$ thin films was, for the first time, investigated by means of time-resolved pump and probe reflectivity measurement using femtosecond optical pulse (FOP). The reflective data showed a relaxation time of optically excited quasi-particles as long as 3.6ps at 4.6K. This value is intermediate between those for $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$, and well explains the difference in the terahertz radiation properties for these high-T_C superconducting materials.

Key words: terahertz; femtosecond laser; $TlBa_2CaCu_2O_{8+\delta}$; relaxation time

1. Introduction

It is known that current biased high-T_C superconductors (HTSs), such as $YBa_2Cu_3O_{7-\delta}$ (YBCO) and $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO), radiate THz-wave pulse into free space by femtosecond optical pulse (FOP) illumination. [1,2] The phenomenon has been well explained by ultrafast supercurrent modulation induced by FOP illumination. The optical pulse produces a large number of excited carriers by avalanche effect, and THz-wave pulse is emitted with the deceleration of supercarrier followed by the relaxation of the optically excited quasi-particle in the non-equilibrium state of superconductivity. Therefore, the detailed properties of the radiated THz-wave pulse strongly depend on the ultrafast dynamics of supercarrier or optically excited quasi-particles. Previous our experiments showed that the effective cut-off frequency, f_C, of the Fourier spectrum of the THz-wave pulse for YBCO is about 2 THz, and it is one order of magnitude higher than $f_C \sim 200$ GHz for BSCCO. Recently, we have also observed the THz radiation property from c-axis oriented $Tl_2Ba_2CaCu_2O_{8+\delta}$ (TBCCO) thin films [3]. In a current biased state the observed THz-wave radiation property was well explained by the ultrafast supercurrent modulation model, and the Fourier spectrum showed an intermediate cut-off frequency $f_C \sim 600$ GHz between those for YBCO and BSCCO.

It may be useful to observe the relaxation phenomena of photo-excited carriers to investigate the origin of the difference in the THz-wave radiation properties among these HTSs. In this paper, we report, for the first time, the relaxation properties of photo-excited carriers in TBCCO by means of time-resolved pump and probe reflectivity (TRP) measurements.

2. Experimental

The TBCCO thin film of about 220 nm-thick was prepared on an $(1\underline{1}02)$ sapphire substrate by a two-step magnetron sputtering method with the intermediating

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

CeO_2 buffer layer of about 55 nm-thick [4]. The thin film showed a critical temperature T_c of 99 K, and a critical current density J_c of about 2 MA/cm^2 at 77 K.

In the TRP measurements the optical pulse emitted from a mode-locked Ti:sapphire laser was split by a beam splitter to pump and probe pulse. The mode-locked laser produces optical pulses with width of about 0.1 ps and a wavelength of 800 nm at a repetition rate of 82 MHz. Since photo-excited carriers by pump pulse immediately relax to the excitation state of the superconducting gap within ~0.1 ps by electron-electron and electron-phonon scatterings [5], we can investigate the following relaxation processes taken place at the superconducting gap as the transient change in the reflectivity of probe pulse. In the experiments, the polarizations for pump and probe pulse were set to be perpendicular each other with use of polarization filters, and the pump and probe pulses were illuminated to the same spot on the sample surface with time-difference. The focal spot sizes of pump and probe pulse were about 80 μm and 50 μm in diameter, and the averaged powers were about 0.42 and 0.14 nJ/pulse, respectively. To detect the change in the reflectivity, the intensity of the reflected probe pulse, $\mathcal{R}(t)$, and the reference pulse, $\mathcal{R}_{ref}$, were detected by silicon PIN photo-diodes, and the difference, $\Delta\mathcal{R}(t)=\mathcal{R}(t)-\mathcal{R}_{ref}$, was lock-in detected. Here, $\mathcal{R}_{ref}$ was adjusted to the value of $\mathcal{R}(t)$ just before pump pulse excitation.

3. Results and discussion

Figure 1 shows a typical time-resolved pump and probe refrectivity data, $\Delta\mathcal{R}(t)/\mathcal{R}_{ref}$ for TBCCO at 4.6 K. It also shows the data observed for liquid phase epitaxy BSCCO film for comparison. The sign of $\Delta\mathcal{R}(t)$ was positive for these HTSs. It shows a sudden increase in the reflectivity at 0 ps corresponding to the pump pulse illumination, and followed by gradual decrease over several ps. To estimate the relaxation time, fitting was applied using the exponential decay function, $\Delta\mathcal{R}(t)/\mathcal{R}_{ref}=A(T)\exp(-\tau/t)$, where $A(T)$ is a temperature dependent amplitude closely related both to the magnitude of the superconducting gap and to the number of the photo-excited carriers, and τ is the relaxation time. The fitting curves using the exponential decay function are also displayed in Fig.1. In this measurement the amplitude $A(T)$ closed to zero near T_C. Therefore, it is considered that the observed transient changes in the reflectivity were caused by the photo-excitation carriers at the low energy superconducting gap. On the other hand, the relaxation time of 3.6±0.1 ps was estimated for TBCCO film from the fitting. The value is shorter than that for BSCCO of the same crystal structure, and longer than 1.7 ps for YBCO [6]. The intermediate τ value for TBCCO qualitatively explains the difference in the cut-off frequency of THz-wave radiation properties among these HTSs.

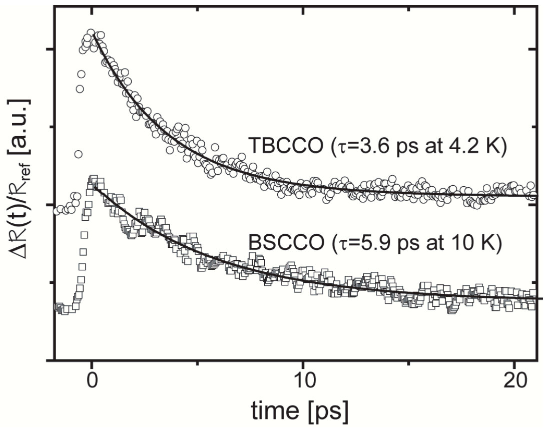

Fig. 1. Typical time-resolved pump and probe reflectivity data of TBCCO film at 4.6 K. For comparison, the data obtained on liquid phase epitaxy BSCCO film is also displayed. The solid lines show the fitting curves using the exponential decay function of $\Delta\mathcal{R}(t)/\mathcal{R}_{ref}=A(T)\exp(-\tau/t)$. The relaxation times obtained from the fitting process are also displayed.

4. Summary

TRP measurements on TBCCO thin film showed the relaxation time, $\tau = 3.6\pm0.1$ ps, for the optically excited carriers at 4.6K. This is an intermediate value between those for $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_{8+\delta}$, and qualitatively explains the difference in the THz-wave radiation phenomena for these HTSs.

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