Photoexcited Carrier Relaxation in a-axis Oriented $YBa_2Cu_3O_{7-\delta}$ Thin Films Measured by Femtosecond Time-Resolved Spectroscopy

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Abstract

The photoexcited carrier relaxation dynamics in a-axis oriented $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films has been investigated by femtosecond time-resolved spectroscopy. Distinct responses along b-axis (CuO_3 chain) and c-axis of YBCO have been separated by the polarization-dependent femtosecond pump-probe measurements. It is found that the transient reflectivity (ΔR/R) curves for the electric field E of the polarized light parallels to b- or c-axes of the a-axis YBCO film (E//b or E//c) are significantly different. The opening of superconducting gap in CuO_3 chain was obviously observed from the measurements of the ΔR/R curves for E//b at temperatures below T_c. However, the ΔR/R curves for E//c did not exhibit the similar characteristics.

Key words: photoexcited carrier relaxation; a-axis oriented $YBa_2Cu_3O_{7-\delta}$; femtosecond time-resolved spectroscopy; transient reflectivity

1. Introduction

Some fundamental properties of superconductors, such as the strength of carrier- phonon coupling, the relaxation behavior of hot carriers, the position of Fermi level, and the nonequilibrium superconducting dynamics, have been investigated using ultrafast optical techniques [1]-[4]. Recently, the femtosecond time-resolved optical spectroscopy has been used to study the energy gap evolution in the high-T_c superconductors $Ca_xY_{1-x}Ba_2Cu_3O_{7-\delta}$ over a wide range of doping [5],[6]. Much valuable information about the formations of superconducting gap and pseudogap has been obtained from these studies. However, it is also interesting to use the polarization-dependent femtosecond pump-probe measurements to study the optical responses along different axes. P. Gay et al. have measured the anisotropic responses along the a- and b-axes (CuO_3 chain) in detwinned single-crystal of YBCO [7]. In this paper, we shall report that the transient reflectivity (ΔR/R) along the b-axis and c-axis can be measured separately by using the highly in-plane aligned a-axis $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films.

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2. Experiment

Highly in-plane aligned a-axis oriented YBCO thin films have been prepared on (100) $LaSrGaO_4$ (LSGO) substrates by pulsed laser deposition. A 230 nm-thick $PrBa_2Cu_3O_{7-\delta}$ (PBCO) thin film was used as a buffer layer between YBCO and LSGO. The crystallinity of the films was analyzed by measuring the X-ray diffraction (XRD) pattern, the full-width at half maximum (FWHM) of the rocking curve of the (200) peak. The percentage of in-plane alignment, larger than 95%, was obtained by the X-ray ϕ scanning. The transition temperature, 88.7 K, was measured by a standard four-probe method. A passively mode-locked Ti-sapphire laser system, which produces an 75 MHz

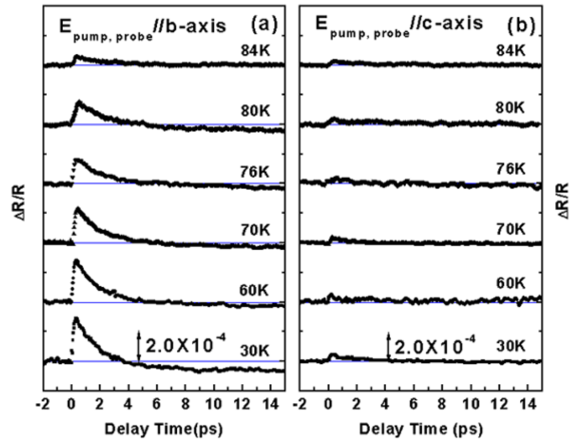

Fig. 1. The transient reflectivity (ΔR/R) curves of a-axis oriented YBCO thin films for $E_{pump,probe}$//b- (a) and //c-axes (b) were measured at various temperatures.

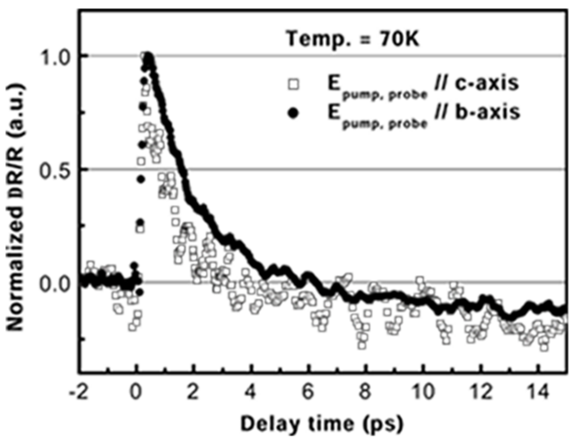

Fig. 2. Comparison of the normalized transient reflectivity (ΔR/R) curves of a-axis oriented YBCO thin films in b- and c-axes at 70 K.

train of 30 fs pulses with photon energy ∼1.53 eV, was used for the polarization-dependent pump-probe measurements. The detail experimental arrangement will be reported elsewhere.

3. Results and discussion

The electric field E of the polarized light (both pump beam and probe beam) can be rotated to parallel the b- or c-axes of the a-axis YBCO film (E//b or E//c). The typical ΔR/R curves for E//b and E//c at various temperatures are shown in Fig. 1. Once the temperature of sample is below the transition temperature (88.7 K), the amplitude of positive ΔR/R increases with the decreasing of temperature for E//b (see Fig.1 (a)). However, as shown in Fig.1 (b), the magnitude of ΔR/R for E//c is much smaller than that for E//b. It is noted that the changes of ΔR/R for E//c are independent of the temperature of sample. The extremely different responses for E//b and E//c indicate the anisotropic superconducting properties in YBCO. For T= 30 K case, the ΔR/R rises to a maximum immediately after exciting by the pump beam, then relaxes through ΔR/R = 0 at a delay time ∼4 ps to negative level which is lower than starting point (at delay time = -2 ps). This implies that there are two kinds of carrier relaxation processes in CuO_3 chain at superconducting state. One, positive and fast (∼2 ps) component, relates to the formation of superconducting gap. The other, negative and long-lived (>15 ps) component, relates to the localized carriers [8]. Additionally, the relaxation time of carriers at T = 70 K in b-axis direction is 2.08ps that is longer than that, 1.57 ps, in c-axis direction, as shown in Fig. 2. Hence, the anisotropy of YBCO is also exhibited in the relaxation behavior of carriers.

4. Summary

In summary, we have separated the ultrafast responses for E//b from E//c by using the polarization-dependent femtosecond pump-probe measurements on the highly in-plane aligned a-axis YBCO thin films. The ΔR/R for E//c reveals that the ultrafast response correlates to the opening of superconducting gap is very weak in c-axis direction. On the contrary, the opening of superconducting gap in CuO_3 chain can be probed easily by measuring the ΔR/R for E//b.

Acknowledgements

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