Physica C 470 (2010) S176–S177

Contents lists available at ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

Observation of vortex-like excitations in Pr-doped YBCO thin films from femtosecond spectroscopy

C.W. Luo

Department of Electrophysics, National Chiao Tung University, Hsinchu, Taiwan, ROC

ARTICLE INFO

Article history:
Accepted 2 November 2009
Available online 4 November 2009

Keywords:
Ultrafast dynamics
Pr-doped YBCO
Nernst signal

ABSTRACT

The ultrafast dynamics of photoinduced quasiparticles in the (001) Pr-doped YBCO ($Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}, x = 0.1$ and 0.2) thin films is revealed by using the femtosecond spectroscopy. Above the zero resistance transition temperature (T_c), the anomalous rise in the amplitude of the transient reflectivity curves ($\Delta R/R$) were clearly observed. The temperature (T_N) corresponded to the negative peak in temperature-dependent $\Delta R/R$ is well associated with the onset temperature of the anomalous Nernst signal. These ultrafast responses are attributed to vortex-like excitations in the phase incoherent condensate existing above T_c.

1. Introduction

Recently, a large Nernst signal well above the zero-field T_c has been observed in many hole-doped cuprates [1,2]. The results have been interpreted as evidence for vortices existing above T_c and the phase-disordering scenario associated with the appearance of thermally created vortices [3,4]. Due to the Nernst region which extended above T_c overlaps with the area where a pseudogap in underdoped regime of the phase diagram, it suggests that the anomalous Nernst effect may be related to the pseudogap phenomenon [5,6]. Here, we report the vortex-like excitations in the Nernst region of high-T_c superconductors (HTSC) by femtosecond time-resolved spectroscopy.

2. Experiments

The well characterized (001)-oriented $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ with $x = 0.1$ and 0.2 thin films were used in this study. All 300-nm thick samples were prepared on (001) $LaAlO_3$ substrates by pulsed laser deposition using a 248-nm KrF excimer laser with the energy density and the repetition rate of 3 J/cm^2 and 5 Hz, respectively. During deposition, the oxygen partial pressure was maintained at 280 mTorr and the substrate temperature was kept at 790 °C. The crystallinity of the c-axis-oriented $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ films was analyzed by measuring the X-ray diffraction pattern. The transition temperature as shown in Fig. 1 was determined by a standard four-probe method. The zero resistance transition temperatures (T_c) are 80.5 K and 66.5 K for various Pr-doped YBCO films with $x = 0.1$ and 0.2, respectively.

Samples were mounted on the cold finger of a Janis flow-through cryostat and the temperature was monitored by the thermometer buried in the finger below samples. The femtosecond time-resolved spectroscopy was carried out by the standard pump-probe scheme. The pump-probe measurements utilized a mirror-dispersion-controlled mode-locked Ti:sapphire laser which produced a 75 MHz train of 30 fs pulses with a central wavelength of 800 nm. The laser beam was divided into an intensive pump beam and a weak probe beam by a continuous variable beam-splitter. The average pump power was kept at 40 mW while the probe power was kept at 1 mW. The probe pulses were delayed with respect to the pump pulses by computer-controlled delay stage with a step size resolution of 0.1 µm. The pump beam and probe beam, which were cross polarized, were focused on the surface of a sample with spot diameters of 125 µm and 80 µm, respectively. The small reflecting signals were detected by a lock-in amplifier referenced at the 97 kHz chopping frequency.

3. Results and discussion

Fig. 2 shows the transient reflectivity curves ($\Delta R/R$) of the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films with $x = 0.1$ and 0.2, respectively, at various temperatures. For both, the significant distinction between the normal and superconducting states could be easily interpreted by the following picture which is generally accepted. Namely, the pump pulse excites the electron-hole pairs that relax to the states in the vicinity of the Fermi energy (E_F) by scattering mechanisms (e.g., electron–electron or electron–phonon scattering). This process occurs in the normal state ($T > T_c$) within a sub picosecond time scale [7,8]. The presence of a gap near Fermi surface (E_F) leads to the carrier accumulation in the quasiparticle (QP)

E-mail address: cwluo@mail.nctu.edu.tw

0921-4534/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.physc.2009.11.026

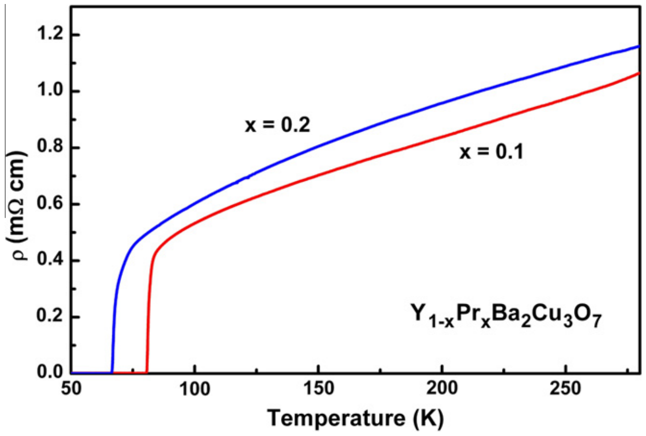

Fig. 1. Electrical resistivity as a function of temperature for the $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ films with $x = 0.1$ and 0.2.

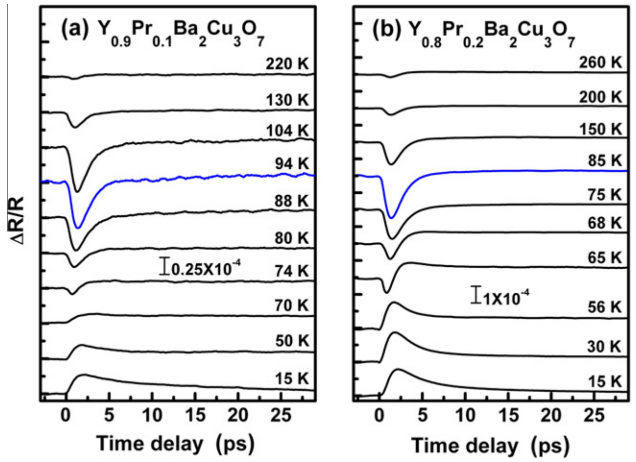

Fig. 2. The temperature dependence of $\Delta R/R$. (a) Measured in a (001) $Y_{0.9}Pr_{0.1}Ba_2Cu_3O_{7-\delta}$ film with $T_c = 80.5$ K. (b) Measured in a (001) $Y_{0.8}Pr_{0.2}Ba_2Cu_3O_{7-\delta}$ film with $T_c = 66.5$ K.

states above the gap at $T < T_c$. This, in turn, gives rise to the $\Delta R/R$ which was detected by a second laser (probe) pulse as a function of the delay time (t) between a pump pulse and a probe pulse. The amplitude and characteristic relaxation time of the measured $\Delta R/R$ thus give important information about the number of the accumulated QPs and the amplitude of the gap [7,9–12]. For the case of $x = 0.1$ (Fig. 2a), the amplitude of positive component in $\Delta R/R$ dramatically rise near T_c which is suggestive of the opening of superconducting gap [7,8,13]. Additionally, it is worth emphasizing that the significant change of the rather large and negative component appears well above T_c. As decreasing temperatures, the negative component gradually rises and then reach maximum at $T_N \approx 94$ K (the blue line in Fig. 2a).[1] Similar characteristics are also observed in $x = 0.2$ (Fig. 2b) except the negative component reaches maximum at lower temperature $T_N \approx 85$ K (the blue line in Fig. 2b).

The change of $\Delta R/R$ sign around T_c can be interpreted as the temperature dependence of E_F shift and the opening of superconducting gap [14]. In femtosecond time-resolved spectroscopy, a large number of QP will be generated inside the illuminated area of a sample by excitation of the intense pump pulses. Besides, the motion of vortex and antivortex bundle pairs caused by the pump pulses [15] in Nernst regime could generate additional QPs. It is the variation of the QP number induced by these cascade processes that leads to the modulation of the smearing effect in vicinity of the E_F and causes the $\Delta R/R$ changes [11,12] probed near the Nernst regime.

Consequently, the T_N is gradually reducing as increasing the content of Pr in YBCO, which consists with the results reported by Li et al. [2]. They measured the Nernst effect in the same $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ films and observed the rapid rise for Nernst signal at a certain temperature which depends on the Pr concentration. Recently, the Nernst effect has been identified as a sensitive indicator of the presence of superconducting fluctuations by the thermoelectric experiments [3], and the onset of a substantial Nernst signal significantly above T_c in the underdoped copper oxides has been interpreted as strong evidence for the existence of superconducting fluctuations and vortex-like excitations in the pseudogap phase [1,3]. These imply that the further dynamic studies by ultrafast spectroscopy could provide more information for understanding the correlation between the anomalous Nernst effect and the pseudogap phenomenon.

4. Summary

In summary, the transient reflectivity change $\Delta R/R$ in $Y_{1-x}Pr_xBa_2Cu_3O_{7-\delta}$ thin films with $x = 0.1$ and 0.2 have been systematically measured by the femtosecond time-resolved spectroscopy. The doping-dependent T_N well above T_c, which is relative to the Nernst effect, is also clearly observed in ultrafast responses.

Acknowledgements

This work was supported by the NSC of Taiwan, ROC under Grant: NSC95-2112-M-009-011-MY3, NSC98-2112-M-009-008-MY3, and by the Grant MOE ATU Program at NCTU.

References

[1] Yayu Wang, Lu Li, N.P. Ong, Phys. Rev. B 73 (2006) 024510.
[2] Pengcheng Li, Soumen Mandal, R.C. Budhani, R.L. Greene, Phys. Rev. B 75 (2007) 184509.
[3] Z.A. Xu, N.P. Ong, Y. Wang, T. Kakeshita, S. Uchita, Nature 406 (2000) 486.
[4] Yayu Wang, S. Ono, Y. Onose, G. Gu, Y. Ando, Y. Tokura, S. Uchita, N.P. Ong, Science 299 (2003) 86.
[5] Iddo Ussishkin, S.L. Sondhi, David A. Huse, Phys. Rev. Lett. 89 (2002) 287001.
[6] A.S. Alexandrov, V.N. Zavaritsky, Phys. Rev. Lett. 93 (2004) 217002.
[7] V.V. Kabanov, J. Demsar, B. Podobnik, D. Mihailovic, Phys. Rev. B 59 (1999) 1497.
[8] J. Demsar, B. Podobnik, V.V. Kabanov, Th. Wolf, D. Mihailovic, Phys. Rev. Lett. 82 (1999) 4918.
[9] C.W. Luo, M.H. Chen, S.P. Chen, K.H. Wu, J.Y. Juang, J.-Y. Lin, T.M. Uen, Y.S. Gou, Phys. Rev. B 68 (2003) 220508(R).
[10] C.W. Luo, P.T. Shih, Y.-J. Chen, M.H. Chen, K.H. Wu, J.Y. Juang, J.-Y. Lin, T.M. Uen, Y.S. Gou, Phys. Rev. B 72 (2005) 092506.
[11] S.G. Han, Z.V. Vardeny, K.S. Wong, O.G. Symko, G. Koren, Phys. Rev. Lett. 65 (1990) 2708.
[12] J.M. Chwalek, C. Uher, J.F. Whitaker, G.A. MourouJ, J. Agostinelli, M. Lelental, Appl. Phys. Lett. 57 (1990) 1696.
[13] C.W. Luo, C.C. Hsieh, Y.-J. Chen, P.T. Shih, M.H. Chen, K.H. Wu, J.Y. Juang, J.-Y. Lin, T.M. Uen, Y.S. Gou, Phys. Rev. B 74 (2006) 184525.
[14] K.H. Wu, C.W. Luo, J.Y. Juang, T.M. Uen, Y.S. Gou, Physica B 284–288 (2000) 939.
[15] M. Tonouchi, K. Shikita, Physica C 367 (2002) 37.

---

[1] For interpretation of color in Fig. 2, the reader is referred to the web version of this article.