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Nonequilibrium carrier dynamics studied in underdoped Bi2212 by polarized optical pump-probe spectroscopy

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We investigate nonequilibrium quasiparticle dynamics measured by ultrafast optical spectroscopy on underdoped Bi2212 crystals, which provide direct evidence that superconducting (SC) and pseudogap (PG) quasiparticles coexist below T_c. We verify that the ratio of signals from SC and PG quasiparticles depends on both excitation energy and polarization of the probe beam due to the anisotropy of the probe transition matrix elements and the inter-band transition probability. Based on this property, we successfully separate the SC or PG component and precisely evaluate the temperature dependence of them across T_c.

I. INTRODUCTION

Femtosecond laser spectroscopy allows one to study nonequilibrium carrier dynamics immediately after excitation by ultrafast laser pulse. Recently, comprehensive experimental studies of various correlated electron systems involving superconductors have established a successful theoretical model[1]. A pump-probe method is usually employed in this kind of experiments, where optical measurements are done with an appropriate energy of probe pulse immediately after an intense pump pulse with a delay time between the two pulses. The pump pulse is utilized to excite the electronic system to a nonequilibrium state while the probe detects changes of the system through optical properties, such as reflection and transmission. Among various parameters, optical polarization plays an essential role for the transition probability of the probe excitation. In this paper, we ingeniously separate the relaxation processes involving PG and SC quasiparticles (QPs) in underdoped Bi2212 from the sign changes of transient reflectivity by changing the probe polarization. The results clearly show the coexistence of the SC and PG QPs below T_c and reveal the relationship between them.

II. EXPERIMENTAL

The sample used in this work was underdoped Bi2212 single crystals with $T_c \approx 76$ K grown by the traveling solvent floating zone method. The time-resolved reflectivity change ΔR was measured using a two-color pump-probe with micro-optical setup described elsewhere[2]. It is important to note that the coaxial configuration achieved in this setup is advantageous for the polarization spectroscopy with regular reflection. The carrier excitations were carried out using a mode-locked 100 fs Ti-sapphire laser oscillator operating at a repetition rate of about 76 MHz, which synchronously pumped an optical parametric oscillator (OPO). The cross-correlation between the two pulses showed a temporal resolution of 200 fs.

III. RESULTS AND DISCUSSIONS

Fig. 1 (a) shows typical ΔR below and above T_c under various excitation conditions as in (b). Below T_c, each ΔR consists of two components; one component has a slow decay ($\sim$2.5 ps) and exists below T_c, reflecting SC QPs dynamics, and another component with a fast decay ($\sim$0.5 ps) remains across T_c. The latter component fades out at T^* ($\approx$ 208 K), and is thus ascribed to PG QPs[2]. A comparison between upper and lower sets of ΔR verifies that the ratio of signals from SC and PG components depends on the energy of the probe beam (E_{pr}); SC is dominant at E_{pr}=1.55 eV while the ratio becomes equal at E_{pr}=1.07 eV.

Another comparison between left and right figures reveals the effect of probe polarization ($\mathbf{E}_{pr}$) on ΔR. Below T_c, ΔR at E_{pr}=1.55 eV (*i.e.*, SC component) is independent of $\mathbf{E}_{pr}$, and two identical signals are obtained for $\mathbf{E}_{pr} \parallel a$ and $\mathbf{E}_{pr} \parallel b$. On the other hand, PG component exhibits polarization anisotropy. Note that the polarized PG component can remain below T_c, but makes little contribution to the total signal due to its relatively small signal. In contrast to the upper sets of ΔR, no polarization was observed for PG component at E_{pr}=1.07 eV, while SC component exhibits a polarization anisotropy. The polarized SC component is more clearly confirmed in the left hand of Fig. 2 (a), in which the detected signal consists of two components with opposite and identical signs for $\mathbf{E}_{pr} \parallel a$ and $\mathbf{E}_{pr} \parallel b$, respectively. For $\mathbf{E}_{pr} \parallel 45^\circ$, ΔR exhibits a single exponential decay whose outline is identical to that obtained above T_c (Fig. 2 (b)). This means that we can directly evaluate the PG QPs dynamics even below T_c. In addition, it is possible to obtain the polarized SC signal (right hand of Fig. 2 (a)) by subtracting ΔR of $\mathbf{E}_{pr} \parallel 45^\circ$. We note again

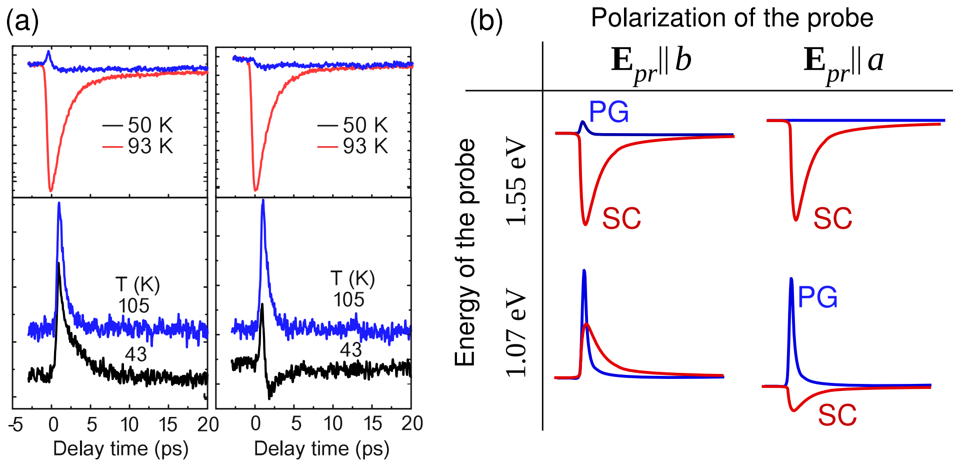

FIG. 1: (a) Typical transient reflectivity changes at various conditions as in (b). (b) Schematic views of the data.

that PG has no polarization for E_{pr}=1.07 eV (Fig. 2 (b)). By using the subtracting procedure, we obtain the temperature (T-) dependence of each component. The T-dependence of SC component qualitatively follows the theoretical curve using a BCS-like SC gap[1]. On the other hand, PG component exhibits a gradual T-dependence, which has a peak slightly above T_c, suggesting a precursor of SC gap formation. In addition, the results obtained at low-T show a similar dependence, which is consistent with the results obtained by ARPES[3].

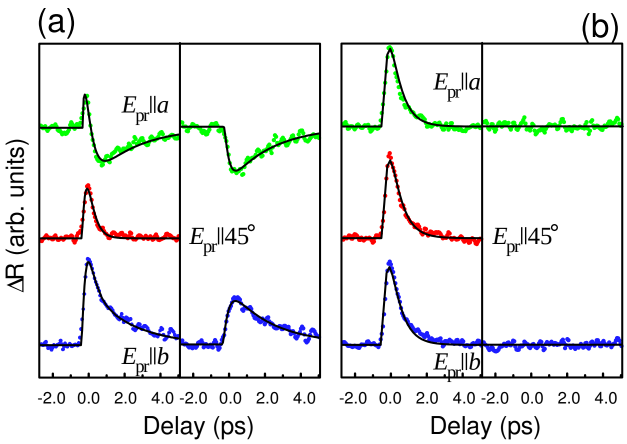

FIG. 2: (a)(left) ΔR measured at T=26 K with various probe polarizations. Probe energy is E_{pr}=1.07 eV. (right) ΔR subtracted by ΔR of $\mathbf{E}_{pr} \parallel 45°$ for polarized SC. (b) The same as (a) at T=86 K.

Finally, we note that the energy dependence of the PG polarization is in good agreement with the results of conventional reflectivity measurement on Bi2212 at room temperature, in which the crossing of polarization anisotropy exists around the plasmon minima (∼1.1 eV)[4]. In this sense, the energy dependence of the SC polarization should be anomalous, maybe due to the nodal SC gap. Although further investigation is needed, we stress the importance of the distinct polarization anisotropy which addresses the QPs dynamics associated with different electronic orders.

Acknowledgments

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[1] V.V. Kabanov, J. Demsar, B. Podobnik, and D. Mihailovic, *Phys. Rev. B*, **59**, 1497 (1999).
[2] Y.H. Liu, Y. Toda, K. Shimatake, N. Momono, M. Oda, M. Ido, *Phys. Rev. Lett.*, **101**, 137003 (2008).
[3] W.S. Lee, I.M. Vishik, K. Tanaka, D. H. Lu, T. Sasagawa, N. Nagaosa, T. P. Devereaux, Z. Hussain, and Z.-X. Shen, *Nature*, **450**, 81 (2007).
[4] M.A. Quijada, D.B. Tanner, R.J. Kelley, M. Onellion, H. Berger and G. Margaritondo, *Phys. Rev. B*, **60**, 14917 (1999).