Symmetry Crossover of the Superconducting Coherent Peak and the Quasiparticle Band in High T_c Superconductors

Shunji Sugai [a,1], Haruyuki Suzuki [a], Yasumasa Takayanagi [a] Toshihiko Hosokawa [a]
Naoki Hayamizu [a]

[a] *Department of Physics, Faculty of Science, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8602, Japan*

Abstract

The carrier density dependence of superconducting coherent peaks (pair-breaking peaks), two-phonon peaks, and two-magnon peaks was systematically investigated by Raman scattering on cleaved surfaces of $YBa_2Cu_3O_y$ (YBCO), $La_{2-x}Sr_xCuO_4$ (LSCO), $Bi_2Sr_2Ca_{1-x}Y_xCu_2O_{8+\delta}$ (Bi2212), and $Bi_{2-x}Pb_{x+y}Sr_{2-y-z}La_zCuO_{6+\delta}$ (Bi2201). The coherent peak is observed generally around $(\pi/2, \pi/2)$ at low carrier densities and $(\pi, 0)$ at high carrier densities. The clear crossovers are observed at $y = 6.63$ ($p = 0.1$) in YBCO and at $x = 0.15$ in LSCO. These crossovers are related to the change from $(\pi/2, \pi/2)$ to $(\pi, 0)$ of the low-energy density of states of the quasiparticle band. However, the rapid change in the coherent peak cannot be interpreted only by the smooth change of the low-energy density of states, but needs an additional anisotropic pair-breaking mechanism. We found that the momentum of the mode giving the strongest two-phonon peak changes from (π, π) to $(\pi, 0)$ with the increase of carrier density in good correlation with the coherent peak. It suggests that this electron-phonon interaction determines the superconducting region in the momentum space.

Key words: high T_c superconductor; coherent peak; electron-phonon interaction; Raman scattering

Raman scattering can separately detect electronic excitations around $(\pi/2, \pi/2)$ and $(\pi, 0)$ as B_{2g} and B_{1g} excitations, respectively. Experimental results that the energy of the B_{1g} coherent peak is larger than that of the B_{2g} coherent peak in optimally doped Bi2212 and LSCO were considered as the evidence of the $d(x^2-y^2)$ pairing [1,2]. However, at underdoping only the B_{2g} coherent peak was observed in YBCO, Bi2212, and LSCO [3–5]. In the optimum-overdoped region both the B_{1g} and the B_{2g} coherent peaks were observed in Bi2212 [6,7], but only the B_{1g} peak [8] or only the B_{2g} peak was observed in YBCO [5]. The symmetry of the coherent peak is still controversial. We supposed that the reason comes from the surface condition of crystals. Then we measured Raman spectra on fresh cleaved surfaces.

Single crystals of YBCO and the insulating antiferromagnetic phase of Bi2212 were synthesized by a flux method and others were by a floating zone method. Raman spectra were obtained in a quasi-back scattering configuration utilizing a 5145 Å Ar-ion laser light. The carrier density p per copper atom was estimated by $T_c/T_{c,\max} = 1 - 82.6(p - 0.16)^2$ for YBCO, Bi2212, and Bi2201. p of LSCO is equal to x.

Figure 1(a) shows the B_{1g} and B_{2g} coherent peak energies and the effective exchange interaction energies $J^* = \frac{1}{3}\hbar\omega_{two-magnon}$. Figure 1(b) shows the coherent peak height measured in the differential spectra between 5 K and just above T_c. In YBCO the B_{2g} coherent peak energy is much lower than J^* and the energy increases as carrier density increases from $y = 6.46$ to $y = 6.68$ in the 60 K phase. At $y = 6.63$ the B_{1g} coherent peak appears above J^* and the energy decreases as carrier density increases. In LSCO the B_{1g} and B_{2g}

[1] Corresponding author. E-mail: sugai@nucc.cc.nagoya-u.ac.jp

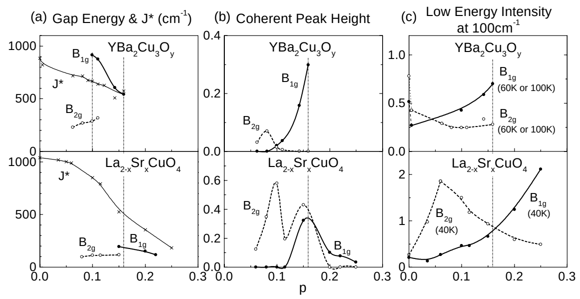

Fig. 1. (a) B_{1g} and B_{2g} coherent peak energies and the effective exchange interaction energies J^*, (b) B_{1g} and B_{2g} coherent peak heights, (c) B_{1g} $(\pi, 0)$ and B_{2g} $(\pi/2, \pi/2)$ low-energy electronic Raman scattering intensities at 100 cm^{-1} just above T_c (60 K for $y \leq 6.63$ and 100 K for $y \geq 6.68$ in YBCO and 40 K in LSCO).

coherent peak energies are smaller than J^*. The B_{2g} coherent peak is observed at $x \leq 0.15$ and the energy increases as carrier density increases. The dip in the peak height at $x = 0.115$ comes from the "1/8 problem". The B_{1g} coherent peak appears at $x \geq 0.15$. The energy is proportional to J^* and the intensity decreases with the increase of carrier density.

Figure 1(c) shows the scattering intensity at 100 cm^{-1} just above T_c. The typical carrier density dependence is observed in LSCO. The B_{2g} scattering intensity increases rapidly from AFI to the insulator-metal transition point and decreases gradually as carrier density increases, while the B_{1g} scattering intensity increases with the increase of carrier density. The crossover of the intensity occurs near the optimum doping. These carrier density dependences are qualitatively the same as the previous reports [9], but the monotonic changes across $x = 0.15$ suggest that the doped carriers form a quasiparticle band near $(\pi/2, \pi/2)$ at low carrier densities and move to $(\pi, 0)$ as carrier density increases. The same carrier density dependence is commonly observed in YBCO, Bi2212 and Bi2201.

It was pointed that the coherent peak height is larger in the symmetry in which the low-energy scattering intensity is larger [3,4]. However, the symmetry crossover of the coherent peak occurs in the narrow carrier density region in spite of the gradual shift for the low-energy scattering intensity. Therefore an anisotropic superconductivity suppression mechanism is necessary to interpret the change of the coherent peak symmetry. Shen et al. [10] calculated that the zone-boundary mode at $(\pi, 0)$ on the longitudinal optical (LO) branch helps spin-mediated superconductivity around $(\pi, 0)$, however destroys superconductivity around $(\pi/2, \pi/2)$.

Figure 2 shows the A_{1g} Raman spectra at 5 K. In the two-phonon spectra from 700 to 1500 cm^{-1} the strongest peak changes from the 1441 cm^{-1} ($x = 0.06$) branch to the 1146 cm^{-1} ($x = 0.15$) branch. The former branch is the two-phonon scattering of the (π, π) mode and the latter is that of the $(\pi, 0)$ mode [11]. The change of the momentum for the strongest electron-phonon interaction mode is correlated with that for the superconducting coherent peak.

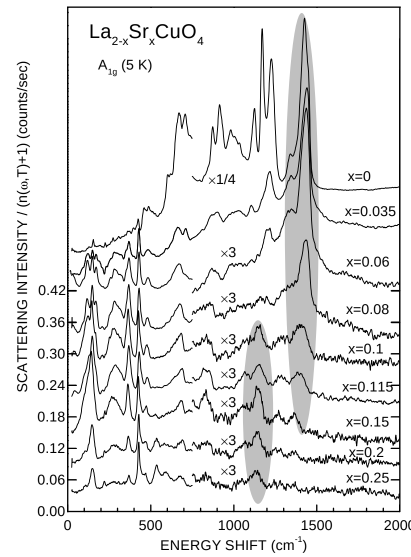

Fig. 2. A_{1g} Raman spectra obtained from the (x, x), (x, y), (a, a), and (a, b) spectra.

The same correlation is commonly observed in YBCO, Bi2212, and Bi2201. The energies of the $(\pi, 0)$ phonon modes, 1140 cm^{-1} in LSCO, 980 cm^{-1} in YBCO, 1060 cm^{-1} in Bi2212, and 1100 cm^{-1} in Bi2201 are close to twice the energy of the kink, ~ 70 meV (560 cm^{-1}), in the electronic dispersion curves observed in photoemission spectroscopy [10,12]. It suggests that the $(\pi, 0)$ phonon mode contributes deeply to the superconductivity mechanism.

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