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Far-infrared reflectivity study of vibrational structure in superconducting $Bi_2Sr_2CaCu_2O_{8+x}$

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Abstract. We report the anomalous temperature behaviour of phonons in the superconducting *a*-axis-oriented $Bi_2Sr_2CaCu_2O_{8+x}$ texture detected by far-infrared reflectivity spectroscopy.

1. Introduction

Since the discovery of YBCO superconductors, many Raman and infrared studies have been devoted to the analysis of the phonon properties of this compound below and above the superconducting transition [1–5]. Two types of anomalous temperature dependence of vibrational modes have been found around T_c. One is a softening of some modes which has been explained by a strong-coupling model [1, 2]. The other is caused by the Fano effect [5].

There are a few reports on phonon anomalies in the bismuth superconductors [6–8]. Infrared measurements are insufficient. In this paper we present the spectra of reflectivity and loss function of a $Bi_2Sr_2CaCu_2O_{8+x}$ texture in a frequency range 50–700 cm^{-1} at temperatures of 20, 80, 100 and 300 K. The new results show firstly a softening of the 153 cm^{-1} A_{2u} mode near T_c, secondly the splitting of the phonon structure below 120 cm^{-1} at a temperature in the vicinity of the superconducting transition and thirdly increases in the strength and the linewidth of the 280 cm^{-1} in-plane oxygen phonon (B_{2u}) at $T < T_c$ without detecting a frequency shift and the appearance of minima or an antiresonance feature in the loss-energy function near 280 cm^{-1} instead of maxima, indicating a strong Fano-type electron–phonon interaction.

2. Experiment and results

The measured sample of $Bi_2Sr_2CaCu_2O_{8+x}$ (2212) were obtained using the 'out-of-the-crucible' zone-melting technique [9]. The samples are characterized by a highly oriented grain structure which consists of bond-like and rod-like single crystals of dimensions 0.1 mm × (0.5–5) mm × 20 mm aligned parallel to the growth direction of the *a* axis. The 2212 material has the centrosymmetric space group D_{4h}^{17} with unit-cell parameters $a = b = 5.413(2)$ Å and $c = 30.75(2)$ Å. Textured samples have a marked anisotropic electrical resistivity at the value of $\rho(\rho_\perp/\rho_\parallel = 300\ K)$ [10]. The $\rho_\parallel(T)$ dependence shows a superconducting transition at $T_c = 83$ K with a width of 4 K.

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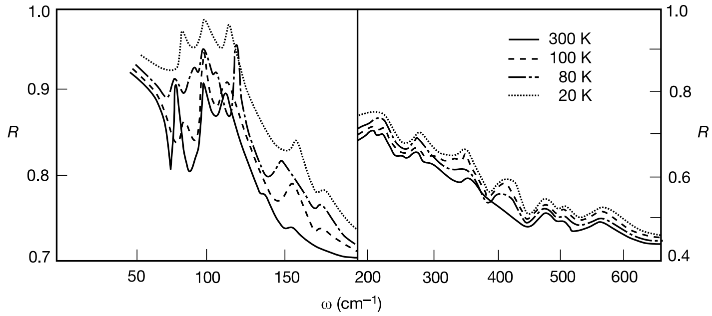

Figure 1. Infrared reflectivity spectra of $Bi_2Sr_2CaCu_2O_{8-x}$ at 20, 80, 100 and 300 K.

Table 1. The changes in the peak positions with temperature.

Frequency (cm^{-1})			
300 K	100 K	80 K	20 K
225	225	220	220
210	210		
153	158	150	155
120	120	110	120
		125	
100	100	100	100
80	85	80	85
		90	

Table 2. Frequencies ω, linewidths γ and oscillator strengths f of the phonons in the $Bi_2Sr_2CaCu_2O_{8-x}$ superconductor at 20 K $\leqslant T \leqslant$ 100 K.

300 K			100 K			80 K			20 K		
ω (cm^{-1})	γ (cm^{-1})	f	ω (cm^{-1})	γ (cm^{-1})	f	ω (cm^{-1})	γ (cm^{-1})	f	ω (cm^{-1})	γ (cm^{-1})	f
280	22	0.33	280	24	0.36	280	32	0.48	280	32	0.48
153	—	—	158	12	0.67	150	12	0.637	155	10	0.53

Reflectivity spectra in the frequency region 50–5000 cm^{-1} were obtained with a Bruker FTS 113v spectrometer in the temperature range 20–300 K. A SF-8 spectrophotometer was used in frequency region 5000–10 000 cm^{-1} at 300 K. Reflectivity spectra of the 2212 a-axis-oriented plate at 20, 80, 100 and 300 K are presented in figure 1. The phonon peaks visible at 300 K are 80, 100, 120, 153, 210, 225, 280, 350, 415, 475, 505 and 565 cm^{-1}. These frequencies are close to the data of previously published reports [11–13]. The main temperature changes are observed at low frequencies below 300 cm^{-1}. The phonon structure caused by Bi vibration at 85, 100 and 120 cm^{-1} in the 100 K spectrum appears to split into the 80, 90, 100, 110 and 125 cm^{-1} peaks at 80 K. The splitting vanishes at 20 K and its origin is still unclear. In contrast the doublet at 210 and 225 cm^{-1} in the 300 K spectrum is transformed into the singlet at 220 cm^{-1} upon cooling to 20 K. Perhaps these effects indicate local changes in the crystal composition of the oxygen-deficient 2212 superconductors near T_c. The frequency of phonons as a function of temperature is shown in table 1. Between 300 K and 100 K the 153 cm^{-1} mode displays the normal shift to higher

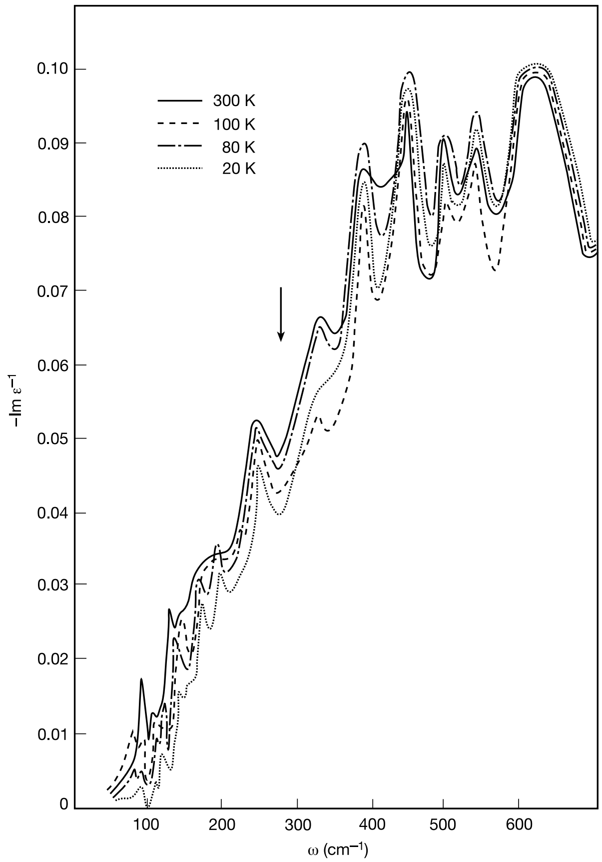

Figure 2. The imaginary part of the inverse dielectric function, $-\mathrm{Im}(-1/\epsilon)$, of $Bi_2Sr_2CaCu_2O_{8-x}$ at 20, 80, 100 and 300 K.

frequencies ($\Delta\omega = 5$ cm^{-1}); the phonon softens, its frequency falling 8 cm^{-1} by 80 K (see figure 1). Simultaneously, the 153 cm^{-1} phonon exhibits slight decreases in linewidth and oscillator strength below T_c. The phonon near 150 cm^{-1} has been assigned to the Sr(z) A_g mode or the Cu(2) vibration analogous to YBCO [8]. Phonon parameters were obtained by Kramers–Kronig transformation of the reflectivity, fitting the lm[$\epsilon(\omega)$] spectra to Lorentzian lineshapes, and are summarized in table 2. The temperature behaviour of the B_{2u} mode at 280 cm^{-1} (see figure 1) is also illustrated in table 2. In the superconducting state both the linewidth and the strength of the 280 cm^{-1} phonon show anomalous increases upon cooling to 20 K, while no frequency anomaly is detected. Such anomalous broadening of the B_{1g}-like phonon is known for $YBa_2Cu_3O_7$ below T_c [7]. The phonon at 280 cm^{-1} has been identified as the out-of-phase c-axis vibration of the O atoms in the CuO_2 planes, analogous to the 340 cm^{-1} mode in YBCO [1, 3]. In contrast, the linewidth of the corresponding B_{1g} mode at 285 cm^{-1} decreases in the $Bi_2Sr_2CaCu_2O_{8+x}$ crystal and is observed by Raman scattering below T_c [6]. The broadening and narrowing effects depend on the position of the phonon relative to the energy gap and are described by the theory of Zeyer and Zwicknagl [1]. The effect of gap formation on the frequency, linewidth and oscillator strength of the 153 and 280 cm^{-1} phonons is seen in table 2. The results of Drude–Lorentz fits to the reflectivity support these data. The low-frequency phonon at 153 cm^{-1} and in-plane oxygen mode at 280 cm^{-1} show controversial temperature behaviours. Anomalous broadening of the 280 cm^{-1} phonon is related to the Fano-type interaction. Figure 2 displays a loss function, $-\mathrm{Im}(-1/\epsilon)$, calculated by a Kramers–Kronig analysis at selected temperatures. The feature of this temperature dependence is the 'suppression' of the peak at 320 cm^{-1} and the appearance of minima near 280 cm^{-1} below T_c. This result indicates a strong Fano-type electron–phonon interaction and supports the fact that the *a*–*b* plane response affects the phonon structure in $Bi_2Sr_2CaCu_2O_{8+x}$ [5, 10].

3. Conclusions

In summary, we have presented anomalous temperature changes of some phonons below 300 cm^{-1} in the $Bi_2Sr_2CaCu_2O_{8+x}$ superconductor at temperatures between 300 K and 20 K. We have observed softening of the 153 cm^{-1} A_{2u} mode with a decrease in its linewidth below T_c and broadening of the B_{2u} 280 cm^{-1} phonon without detecting a frequency change upon cooling to 20 K. In principle the linewidth of phonons with an energy below the superconducting gap decreases in the superconducting state because the superconductivity reduces the number of possible electronic decay channels, while phonons above the gap broaden in the superconducting phase [1, 6]. Assuming the existence of a superconducting gap or pseudo-gap, we can estimate an energy gap value 2Δ as follows: 150 $cm^{-1} < 2\Delta <$ 280 cm^{-1}.

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References

[1] Zeyer R and Zwicknagl G 1990 *Z. Phys.* B **78** 175
[2] Thomsen C, Cardona M, Friedl B, Rodrigues C O, Mazin I I and Andersen O K 1990 *Solid State Commun.* **75** 219
[3] Friedl B, Thomsen C and Cardona M 1990 *Phys. Rev. Lett.* **65** 915
[4] Grinsberg D M (ed) 1989 *Physical Properties of High Temperatures Superconductor* vol 1 (Singapore: World Scientific)
[5] Cooper S L, Klein M V, Pazol B G, Rice J P and Grinsberg D M 1988 *Phys. Rev.* B **37** 5920
[6] Leach D H, Thomsen C, Cardona M, Mihaly L and Kendziyoga C 1993 *Solid State Commun.* **88** 457
[7] Boekholt G M, Erle A, Splitgerber-Hunneke P C and Guntherodt G 1990 *Solid State Commun.* **74** 1107
[8] Cardona M, Thomsen C, Liu R, von Schnering H G, Hartweg M, Yan Y F and Zhao Z X 1988 *Solid State Commun.* **66** 1225
[9] Bush A A, Goncharuk I N, Kitaev Yu E, Limonov M F, Markov Yu F and Evarestov R A *Prog. High Temp. Supercond.* **32** 732
[10] Bush A A 1990 *Sverkhprovodimost* **3** 2026
[11] Tajima S, Gu G D, Miyamoto S, Odagawa A and Koshizuka N 1993 *Phys. Rev.* B **48** 16 164
[12] Kamaras K, Herr S L, Porter C D, Tanner D B, Etemad S and Tarascon J-M 1991 *Phys. Rev.* B **43** 11 381
[13] Puro O E, Guido J A, Massa N E, Aumonio P J, Catellano E E Basso H C, Gallo J N H and Martin A A 1989 *Phys. Rev.* B **39** 7255