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Phonon Thermal Diffusivity and Conductivity of Oxygen Deficient $YBa_2Cu_3O_{7-X}$

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The thermal diffusivity $\alpha(T)$ and conductivity $\kappa(T)$ were measured between 10 and 200K quasi-simultaneously on 60K phase and non-superconductive $YBa_2Cu_3O_{7-X}$ (YBCO) sintered samples. The temperature dependence of the phonon mean free path l_{ph} and the phonon scattering time τ_{ph} was determined. Analyses based on the Tewordt-Wölkhausen theory gave the electron-phonon coupling parameter λ=0.65 for the 60K phase in contrast to the corresponding value λ=0.98 for the 90K phase.

1. INTRODUCTION

By measuring both the thermal diffusivity α and conductivity κ, the specific heat C can be estimated using the relation of $C=\kappa/\alpha$. By subtracting the electron contribution from the measured thermal diffusivity, the phonon thermal diffusivity α_{ph} ($=v^2\tau_{ph}/3=vl_{ph}/3$) can be estimated, where τ_{ph} is the total phonon scattering time, l_{ph} the phonon mean free path and v is the sound velocity, respectively. We have developed a quasi-simultaneous thermal diffusivity and conductivity measuring system using the GM refrigerator [1,2]. In this paper, we report the results on the oxygen deficient $YBa_2Cu_3O_{7-X}$ (YBCO) sintered samples. The amount of the oxygen deficiency was varied by quenching the YBCO samples into liquid nitrogen from various temperatures up to 900°C. The analyses of the thermal conductivity and diffusivity were performed based on the Tewordt and Wölkhausen (TW) theory [3].

2. EXPERIMENTAL

The starting YBCO sintered samples (#1 sample) with T_c=94K were fabricated by a solid state reaction method. The oxygen deficient sample (#2 sample) which was quenched from 600°C showed a sharp resistive transition at T_c=62K. The sample (#3 sample) which was quenched from 900°C showed a semiconductive electrical resistivity down to 10K. The resistivity values of the samples in the normal state increased with increasing quenching temperature. The conductivity measurement was performed by a steady state heat flow method. The diffusivity measurement was performed by recording the time variations of temperatures at two measuring points after applying the heat pulse and by comparing the measured temperature change with the calculated ones for various α values. One dimensional diffusion equation was numerically solved using the measured temperature change at the position nearer to the heater as the boundary condition.

3. RESULTS AND DISCUSSION

Figure 1 shows the temperature dependence of the thermal conductivity κ of the samples. The conductivity of the #1 and #2 samples showed the characteristic enhancement just below T_c. For the #3 semiconductive sample, the enhancement was completely wiped out. The electron contribution (κ_e) for κ, which was also shown in Fig.1, was estimated by the Wiedemann-Franz law above T_c and

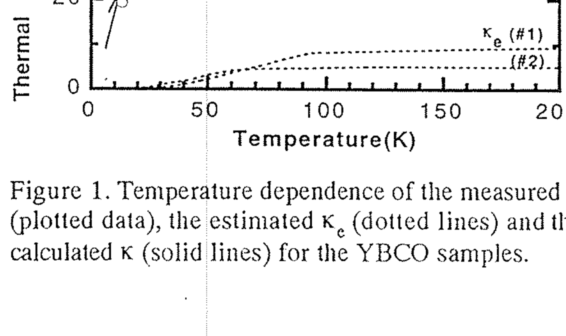

Figure 1. Temperature dependence of the measured κ (plotted data), the estimated κ_e (dotted lines) and the calculated κ (solid lines) for the YBCO samples.

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by numerically calculating Kadanoff's expression [4] below T_c. The phonon thermal conductivity κ_{ph} was obtained from the relation, $\kappa_{ph}=\kappa-\kappa_c$.

Figure 2 shows the temperature dependence of the thermal diffusivity α. In the normal state, α increases very gradually with decreasing temperatures. The values of $d\alpha/dT$ change around T_c and α increases more and more rapidly with decreasing temperature. The absolute value of α becomes smaller for the higher oxygen deficient #2 and #3 samples, especially in the temperature range between 30 and 100K. The separation of the phonon and the carrier contribution to the thermal diffusivity α can readily be achieved from the relation of $\alpha_{ph}=\alpha\kappa_{ph}/\kappa$. The Debye temperature Θ_D estimated from α and κ for these samples is shown in Table I, which was used in the present analysis of κ_{ph}.

κ_{ph} was analyzed using the TW formulation [3],

$$\kappa_{ph}=\frac{3dnRT^3v^2}{M\Theta_D^3}\int_0^{\Theta_D/T}\frac{x^4e^x}{(e^x-1)^2}\tau_{ph}\,dx, \qquad (1)$$

where d is the mass density, n the number of atoms per mole, M the molar weight of the sample, R the gas constant and x is the reduced phonon frequency, respectively. In Eq.(1), τ_{ph} is assumed to obey Matthiessen's rule,

$$\tau_{ph}^{-1}=\tau_b^{-1}+sT^2x^2+pT^4x^4+ETxg, \qquad (2)$$

where τ_b is the phonon scattering time due to grain boundaries and s, p and E refer to the phonon

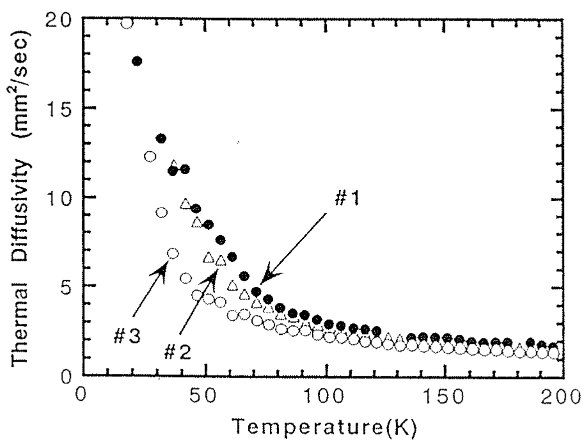

Figure 2. Temperature dependence of the thermal diffusivity α for the YBCO samples.

Table I
Characteristic parameters of the YBCO samples

parameters	#1 sample (no-quench)	#2 sample (600°C quench)	#3 sample (900°C quench)
d(g/cm^3)	5.7	5.8	5.9
M(g/mol)	666	658	650
τ_b^{-1}(sec^{-1})	4.5×10^8	6.2×10^8	5.4×10^8
p(K^{-4}sec^{-1})	9.3×10^2	7.1×10^2	1.2×10^4
s(K^{-2}sec^{-1})	9.2×10^6	9.7×10^6	6.7×10^6
E(K^{-1}sec^{-1})	2.4×10^9	2.0×10^9	≈ 0
λ	0.98	0.65	≈ 0
Θ_D(K)	300	380	320
v(m sec^{-1})	3110	3940	3320

scattering strength by sheet-like faults, point defects and the charge carriers, respectively. The function $g=\tau_{phn}/\tau_{phs}$ is the ratio of the phonon-electron scattering rate in the normal and superconducting state. Table I shows the values of these characteristic parameters used in this analysis. The value of v=3110m/sec is used for the #1 sample [5] and assumed to be proportional to estimated Θ_D values for other samples. The calculated total $\kappa=\kappa_c+\kappa_{ph}$ curves were also shown in Fig. 1, which reproduced the measured κ data satisfactorily. It was found that point defect scattering (p parameter) increased remarkably for the higher oxygen deficient sample (#3). The electron-phonon coupling constant λ estimated from the values of E [3] for #1, #2 and #3 sample was 0.98, 0.65 and 0, respectively. λ decreases with increasing oxygen deficiencies of the sample and electron-phonon interaction is more stronger in the higher T_c sample.

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