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SPECIFIC HEAT AND MAGNETORESISTANCE OF Y-, Tl- AND Bi-TYPE HIGH-TEMPERATURE SUPERCONDUCTORS

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Specific heat of polycrystalline $DyBa_2Cu_3O_7$ and $Tl_{0.58}Pb_{0.42}Sr_{1.6}Ba_{0.4}Ca_2Cu_3O_9$ samples, as well as the single crystal of $Bi_2Sr_2CaCu_2O_8$ have been measured within the temperature interval from 50 to 250 K. For Dy- and Tl-specimens the pronounced jump in specific heat and apparent contribution from Gaussian fluctuations of superconducting order parameter close to T_c have been observed. In contrary, for Bi-specimen only a rounded maximum within a broad interval around T_c has been detected. Magnetoresistance measurements as a function of temperature just below T_c have been carried out for Dy- and Tl-samples and the slopes of upper critical fields have been determined. The data have been analysed within a frame of Ginzburg–Landau–Abrikosov– Gorkov theory with additional Gaussian-like fluctuation term. The electronic specific heat coefficients γ, and the coherence length ξ have been obtained.

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The specific heat anomaly, especially the specific heat jump ΔC at the superconducting transition temperature T_c in high-temperature superconductors (HTSC) of yttrium, thalium and bismuth families have been thorougly investigated in view to look at the discrepancy between BCS-like and fluctuations-added-like behavior [1–3]. The classical BCS-Ginzburg–Landau (BCS–GL) approach [4] neglects any fluctuations because according to the so-called Ginzburg criterion [4, 5],

$$\frac{|T-T_c|}{T_c} < \left[\frac{kT_c}{H_c^2(0)\xi^3(0)}\right]^2 = 1.07\times 10^{-9}\frac{\kappa_{GL}^4 T_c^2}{H_{c2}(0)}, \qquad (1)$$

the temperature interval around T_c, in which this theory collapses, is extremally narrow for conventional superconductors. In Eq. (1) T_c, H_c, ξ have their usual meaning, $H_c(T) = H_{c2}(T)2^{-1/2}\kappa_{GL}^{-1}$, and the so-called G–L parameter κ_{GL} is the ratio of the penetration depth λ_{GL} to the coherence length ξ_{GL}. On the contrary, for the HTSC, the temperature interval is of the order of 0.1–1 K [5, 6], mainly due to a very short coherence length, and the fluctuations may play a predominant role in a wide temperature region close to T_c. The fluctuations are usually modelled as a Gaussian like contribution to the specific heat above and below T_c given by the following expression [4, 7]:

$$\Delta C_f = C_{\pm} t^{-(2-d/2)} \tag{2}$$

with $t = |T/T_c - 1|$, $C_+ = k_B[8\pi\xi^3_{GL}(0)]^{-1}$, and $C_+/C_- = n(2^{d/2})^{-1}$, where d is the dimensionality and n is the number of components of the order parameter.

In this paper we have focused attention on analysis of our heat capacity data of $DyBa_2Cu_3O_7$ [6] (DyBCO), $Tl_{0.58}Pb_{0.42}Sr_{1.6}Ba_{0.4}Ca_2Cu_3O_9$ (TlBCCO) and $Bi_2Sr_2CaCu_2O_8$ (BiSCO) specimens in the vicinity of T_c in order to calculate properly the electronic specific heat coefficients γ. Some other macroscopic normal- and superconducting-state quantities have been calculated taking into account our experimental data on the slopes of $\mathrm{d}H_{c2}/\mathrm{d}T|_{T_c}$.

Polycrystalline DyBCO and TlBCCO samples were prepared by the standard sintering procedure and sol-gel liquid-mix sintering technique, respectively [8]. A single crystal of BiSCO has been grown by travelling solvent floating zone method. Specific heat of all samples was measured by the adiabatic technique (and the continuous heating technique for DyBCO) within the temperature range from 50 to 250 K in the arrangement described elsewhere [9]. The results of the measurements are presented in Fig. 1a. Resistivity was measured as a function of applied magnetic field and temperature by the standard ac resistance method. The temperature dependence of H_{c2} has been calculated for the given magnetic field and the relevant zero-resistance temperature; this is shown in the inset of Fig. 1b for Dy-specimen, and in Fig. 2 for Tl-specimen.

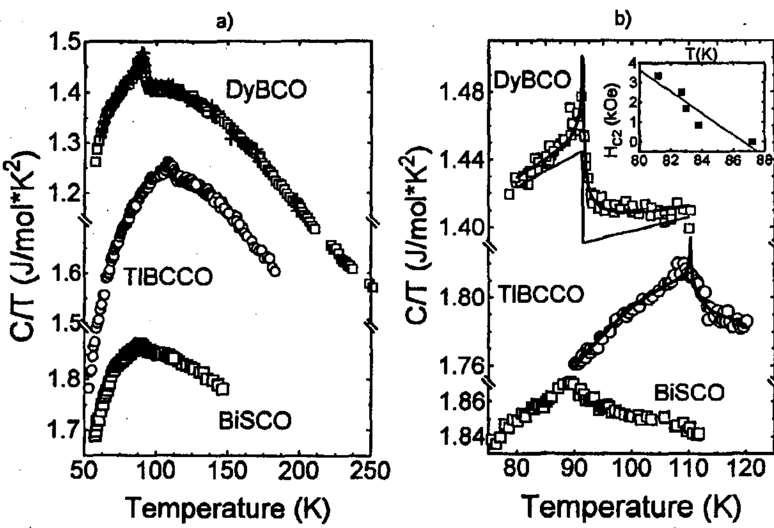

Fig. 1. C/T vs. T plots for investigated samples, where C is the measured specific heat; (a) full plots, (b) T-region close to T_c together with the fitting to the model (Eq. (3)), the inset: the upper critical field $H_{c2}(T)$ with its slope (solid line) for Dy-specimen.

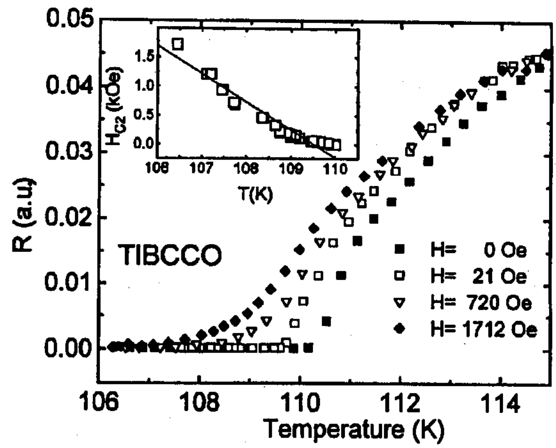

Fig. 2. Magnetoresistance data together with the temperature dependence of upper critical field H_{c2} and its slope (solid line) for Tl-specimen (inset).

Due to a possibly large fluctuation component to specific heat jump at T_c,we have tried to fit our data, close to T_c to the relation

$$\frac{C}{T} = a + bt + ct^2 + 1.43\gamma(1 + 1.83t) + \frac{\Delta C_f}{T}. \tag{3}$$

The term $a + bt + ct^2$ accounts for both lattice specific heat and any slowly varying specific heat component (e.g. magnetic contribution from either Dy^{+3} ions or antiferromagnetic correlations of Cu^{+2} sublattice) in a region close to the transition. The component $1.43\gamma(1 + 1.83t)$ describes BCS specific heat excess above the normal electronic component in the vicinity of T_c [10]. The last term describes Gaussian fluctuations [4, 10]. The results of fitting for Dy and Tl samples are shown in Fig. 1b, where also BCS contribution to the peak for Dy sample is shown. For DyBCO a satisfactory fit was obtained with a linear lattice component (i.e. $c = 0$), while Tl-sample required a full quadratic lattice form. For both samples the best results were obtained for $d = 3$. As is apparent from Fig. 1b the quality of fitting is better for DyBCO than for TlBCCO. This type of analysis fails completely for BiSCO, because only a rounded maximum within a broad temperature interval around T_c has been detected. The specific heat jumps at T_c, γ coefficients as calculated from fitting procedures described above, $\mathrm{d}H_{c2}/\mathrm{d}T|_{T_c}$ from magnetoresistance data of Fig. 1b and Fig. 2 and G–L coherence length ξ_{GL} as calculated from Eq. (2) for C_+, are collected in Table.

The coefficient γ can be also calculated from $\mathrm{d}H_{c2}/\mathrm{d}T|_{T_c}$ based on the GLAG formulae in the dirty limit of superconductivity, most likely valid also for HTSC,

$$\frac{\mathrm{d}H_{c2}}{\mathrm{d}T}\Big|_{T_c} = 4.48\gamma\rho, \tag{4}$$

where γ is in [erg/cm^3 K^2] and ρ is normal state resistivity just above T_c in [Ω cm].

TABLE

Experimental T_c, $\Delta C/T_c$, $\mathrm{d}H_{c2}/\mathrm{d}T|_{T_c}$ and calculated γ, ξ_{GL} values for investigated samples.

	T_c(K)	$\Delta C/T_c$ [mJ/(mol K)]	$\mathrm{d}H_{c2}/\mathrm{d}T\|_{T_c}$ [kOe/K]	γ [mJ/(mol K^2)]	ξ_{GL} [Å]
DyBCO	91.4 ± 0.1	53 ± 1	-0.55 ± 0.03	38.2 ± 0.5	6.5 ± 0.5
TlBCCO	110.0 ± 0.2	30 ± 2	-0.48 ± 0.03	25.9 ± 0.5	5.0 ± 0.5
BiSCO	87 ± 0.5	19 ± 4	–	–	–

The γ values calculated in such way are comparable to the respective values from Table, but are systematically smaller.

The main conclusion from the experimental and calculated superconducting parameters ΔC, $\mathrm{d}H_{c2}/\mathrm{d}T|_{T_c}$, ξ_{GL} and normal-state γ's is that these values systematically decrease in the sequence depicted in Table (from Dy- to Bi-specimens). If it is intrinsic property of the specimens (i.e. does not depend on the preparation procedure, e.g. oxygen content and microstructure) then it might support the theoretical suggestion that the specific heat jump at T_c decreases due to increasing anisotropy of the superconducting properties from YBCO to BiSCO type HTSC [11]. Further experimental data and more discussion on the subject will be published elsewhere.

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