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THERMAL CHARACTERIZATION OF HIGH T_c SUPERCONDUCTORS THROUGH THE PHOTODEFLECTION METHOD

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Abstract

The photothermal deflection method has been used for thermal diffusivity measurements on bulk YBCO and BISCCO high T_c superconductors. A cryostat set up is used to perform photothermal measurements from room temperature down to 77 K.

Keywords: photothermal method, superconductors

Description of photothermal method

The photothermal deflection (PD) technique, also called "mirage technique", is a well known method for the thermal diffusivity measurements amply described in the literature [1, 2]. This technique is based on the periodical heating produced by an intensity modulated pump beam. The heat diffusion produces a temporally varying gradient of the refractive index of the surrounding medium (usually air), which can be detected by a probe beam traveling parallel to the sample surface (transverse PD configuration). The deflection angle provides information about the thermal diffusivity of the sample in exam. The probe beam deflection is given by

$$\Phi = \frac{1}{n}\frac{\mathrm{d}n}{\mathrm{d}T}\int_s \nabla_t T(r, t)\mathrm{d}s$$

where n is the refractive index of the surrounding medium, T is the temperature s the probe beam path, and ∇_t the gradient perpendicular to the path s.

The deflection angle can be decomposed in a lateral component Φ_t (parallel to the sample surface) and in a vertical component Φ_n (orthogonal to the sample surface) (Fig. 1). In our case, we measure the lateral component as a function of the distance y between the probe and pump beam.

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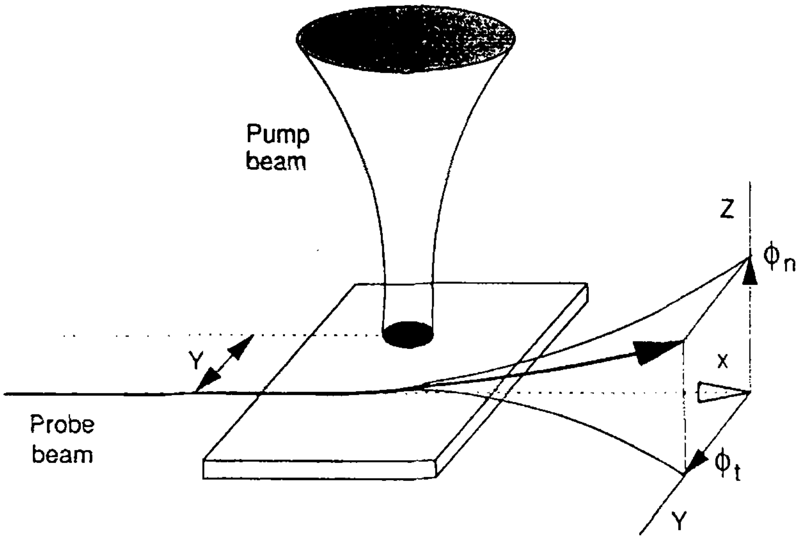

Fig. 1 Photodeflection scheme for the transverse configuration

Solving the heat diffusion equation, it has been found [2] for Φ_t an approximate expression given by

$$\Phi_t = |\Phi_t| \exp\left(+j\omega t - j\left(\frac{y}{l_{ch}} + \varphi\right)\right)$$

where l_{ch} is the characteristic length and φ is a slowly varying function depending on the pump beam spot size a, the chopper angular frequency $\omega = 2\pi f$, and the vertical distance z of the probe beam with respect to the sample surface.

The phase method [2], which permits to evaluate the thermal diffusivity, consists of the evaluation of the linear slope of the lateral phase deflection signal $\mathrm{Arg}[\Phi_t]$ against the offset y for large distance between pump and probe beam with respect to the pump beam spot size a ($y > a$). In this way, we can neglect the dependence of $\mathrm{Arg}[\Phi_t]$ on φ which depends on the particular experimental configuration adopted.

Using the relation

$$l_{ch} = -\frac{\Delta y}{\Delta \mathrm{Arg}[\Phi_t]}$$

we can obtain the characteristic length which is a function of ω and the thermal diffusivity given by

$$D = \pi\left[\frac{\Delta l_{ch}}{\Delta (f)^{-1/2}}\right]^2$$

Special care must be used in the case of samples characterized by a thermal diffusivity lower than that of the surrounding medium [2].

Thermal diffusivity measurements

For our measurements, a pump Ar^+ laser beam (γ=488 nm), intensity modulated by a mechanical chopper at a frequency varying from 2 Hz to 1000 Hz, was incident perpendicularly on the sample surface. A He–Ne laser

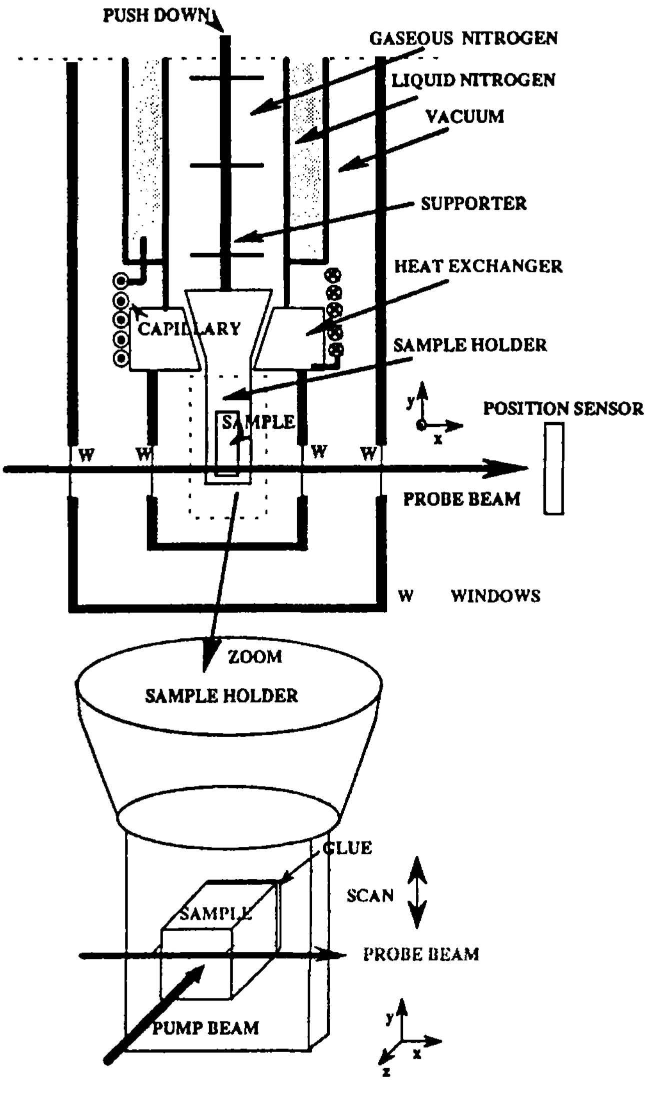

Fig. 2 Cryostat scheme

beam has been used as a probe beam that skimmed the sample surface at a given vertical offset z for different distances with respect to the pump beam axis. The photodeflection signal has been detected through a quadrant position sensor and a lock-in amplifier.

For low temperature measurements [3], the sample was put inside a properly designed cryostat (Fig. 2) which, fundamentally, consists of two chambers. One is filled of liquid nitrogen which supplies cryogen; through an exhaust valve, it is possible to obtain a temperature varying from room temperature to $T \approx 77$ K. The other chamber, containing the sample, is filled of gaseous nitrogen which provides the necessary medium for the probe beam deflection. The gaseous nitrogen is maintained at a pressure lower than $P=1$ Atm to prevent the nitrogen condensation in droplets.

The set up has been checked [3] through some preliminary measurements on a molybdenum sample whose thermal diffusivity ($D=0.53$ cm^2 s^{-1}) is well known. In particular, varying the gaseous nitrogen pressure, it has been found that the deflection modulus signal is linearly dependent on the pressure, while the deflection phase signal is not affected. In fact, in all the pressure range adopted, we have obtained the same slope of Arg[Φ_t] against the offset y, and as consequence, the same thermal diffusivity.

In this paper, we present some preliminary results obtained by using the photothermal deflection method to determine the thermal diffusivity of YBCO ($YBa_2Cu_3O_{7-x}$) and BISCCO ($Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+1}$) high T_c superconductors. Both superconductors have been prepared by hot-pressing sintering [4].

BISCCO samples

Results and discussion

The BISCCO samples have been characterized through X-ray diffraction (XRD), at room temperature, in order to reveal the main structural features of the sample [5]. Using the ratio of the intensities of the principal peaks falling in the same angular range, relative amounts of different phases belonging to BISCCO system (2201, 2212 and 2233) have been evaluated. The degree of

Table 1 Values of the thermal diffusivity derived for the examined BISCCO samples. The values reported for the sample No. 1, 2, 3 refer to room temperature measurements, while the value reported for the sample No. 4 has been obtained at T=77.3 K ($a//c$-axis; $b \perp a$)

Sample No.	Relative density/%	F/%	2223%	T_c/K	D/10^{-2} cm^2 s^{-1}
1	92	37	92	93	0.8
2	98.5	52	98	99	1.9$^{(a)}$ 0.7$^{(b)}$
3	98	–	(only 2212, 2201)	80	1.4
4	97.5	38	–	106	5.1

grain orientation in the axial direction, F, was determined by means of XRD analysis using for comparison signals coming from randomly oriented powders. The bulk density has been measured by Archimede's method. In Table 1 the relative density with respect to the theoretical expected density (6.3 g cm^{-3}) is given. The morphology of the sample has been analyzed through a scanning electron microscopy. Finally the value of the critical temperature T_c has been extracted from the electrical resistance *vs.* temperature data.

In Table 1 we report the main results on the BISCCO samples.

The experimental values of the thermal diffusivity D obtained with the phase method on different BISCCO samples are reported in the last column of Table 1 at room temperature. The data are in good agreement with those reported in literature (see for example Ref. [6]). These samples are characterized by a porous structure which affects the heat diffusion leading, in general, to a low thermal diffusivity coefficient [7]. The factor F expresses quantitatively the grain alignment which constitutes an important feature for the material transport properties. In fact, a best structural order facilitates the heat propagation, and looking at Table 1, we can see that the sample with a high orientation factor F has also a high thermal diffusivity (a). The other thermal diffusivity value (b), reported for the same sample, refers to a measurement performed on a different face orthogonal with respect to the first one. Probably, the different thermal diffusivity measured, is due to anisotropic thermal properties of BISCCO superconductor introduced by the Cu–O planes [8]. Finally, for the sample

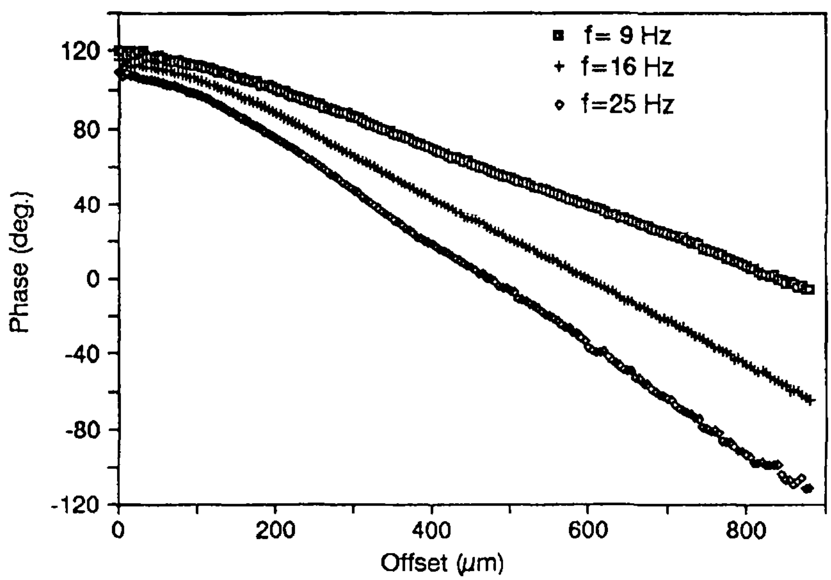

Fig. 3 Experimental photodeflection signal phase as a function of the probe and pump offset for a BISCCO (No. 4) sample: (□) f=9 Hz, (+) f=16 Hz, (◇) f=25 Hz

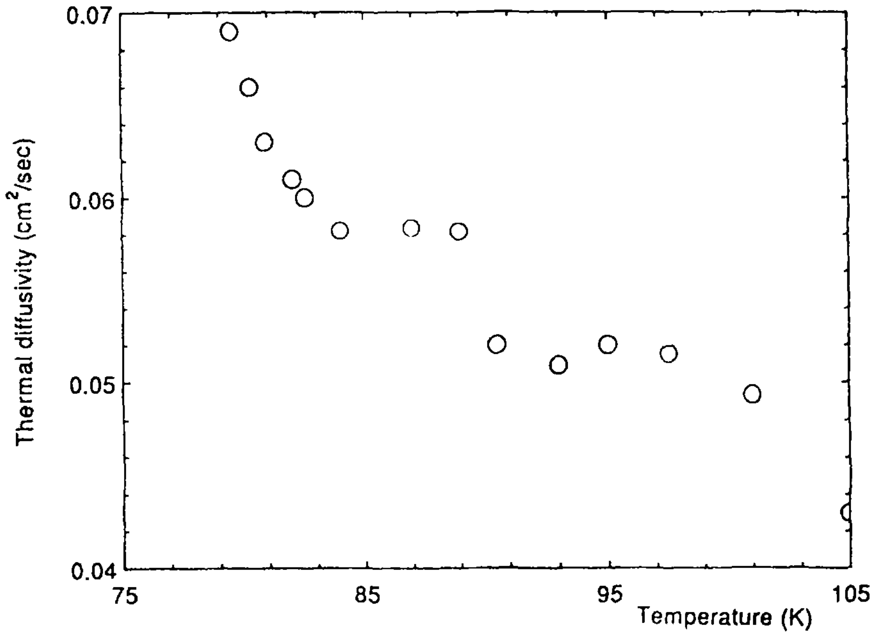

Fig. 4 Thermal diffusivity *vs.* temperature for the YBCO sample No. 1

No. 4, we have reported the measured thermal diffusivity keeping the sample at T= 77.3 K with the phase method (Fig. 3).

Results on YBCO sample and conclusion

In Figs 4 and 5 the experimental thermal diffusivity dependences on the temperature, in the range around the critical temperature, for two YBCO samples are shown. A discontinuity in the thermal diffusivity behaviour at T_c (T_c≈90 K) is evident. From the characteristic length dependence on $1/\sqrt{f}$, reported in Fig. 6, a thermal diffusivity D=2.5 10^{-2} cm^2 s^{-1}, at room temperature, for the YBCO sample No. 1 was determined.

It is well known that for $T<T_c$ the electrons condense in Cooper pairs that, regarding the heat propagation, have two fundamental properties: they do not carry heat and do not scatter phonons [9]. A competition, between the rapidly diminishing electronic contribution and the increasing phononic contribution, determines the overall heat transport properties in the superconducting state, which, fundamentally, depends on which of the two mechanism (electronic or phononic) was predominant in the normal state. This may explains why the sample of Fig. 4, as a function of decreasing temperature, has a sudden raise in thermal diffusivity near T_c, while the sample of Fig. 5 has a sudden drop.

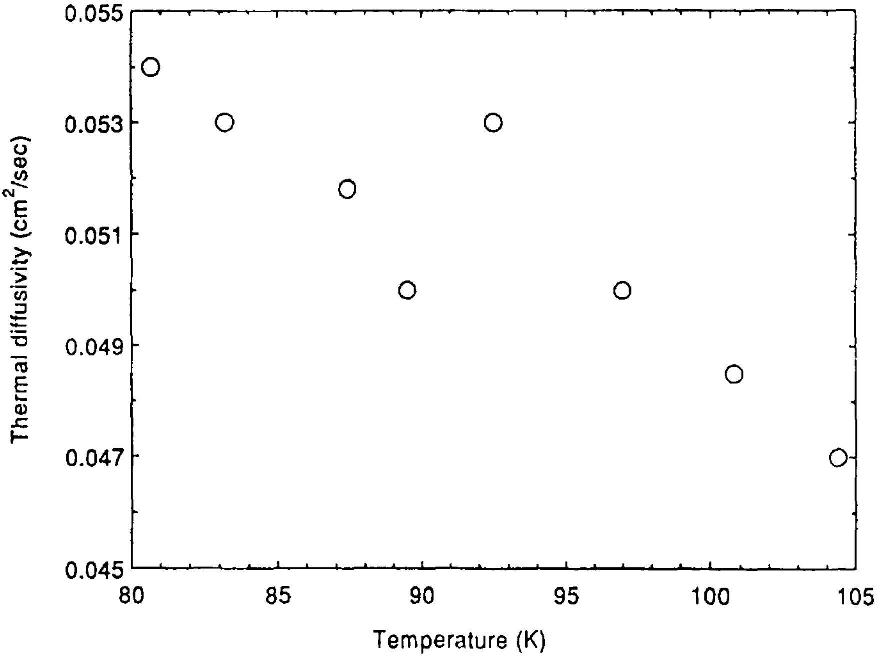

Fig. 5 The same of Fig. 4 for the YBCO sample No. 2

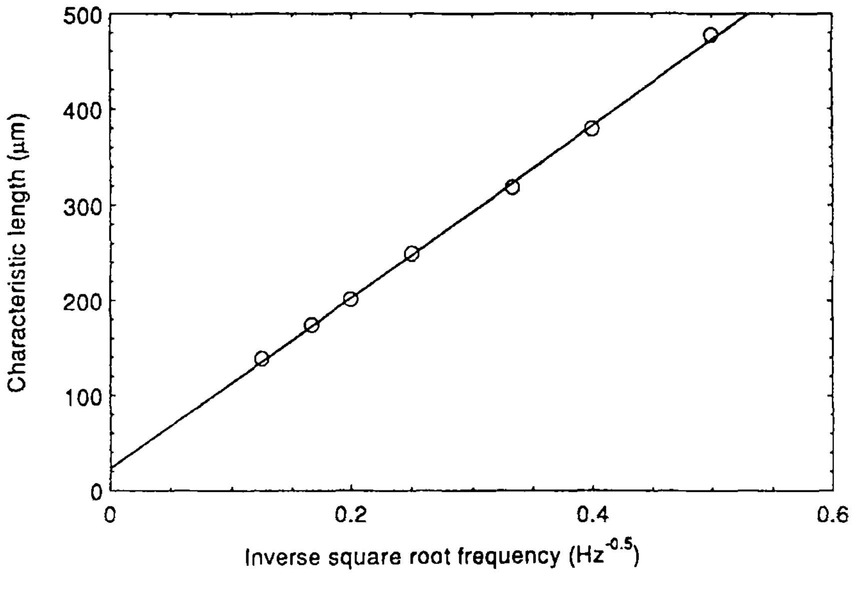

Fig. 6 Characteristic length l_{ch} *vs.* $1/\sqrt{f}$ for the YBCO sample No. 1: the circles represent the experimental data while the solid line is the theoretical fit

In conclusion, from these preliminary measurements on superconductor alloys, through the photothermal method, besides the value of the thermal diffusivity, we can obtain other information (critical temperature, structural order,..) which can constitute a help for a physical characterization of superconductor material.

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