Pertanika J. Sci. & Technol. **12(1)**: 129 - 135 (2004)
ISSN: 0128-7680

Thermal Diffusivity Measurement of BSCCO Superconductor (85 to 300 K) Using PVDF Transducer

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Received: 19 December 2002

ABSTRAK

Dilaporkan pengukuran peresapan terma untuk sampel seramik superkonduktor Bi-Pb-Sr-Ca-Cu-O. Dalam kerja ini 'camera flash' dan filem polyvinylidene difluoride (PVDF) adalah masing-masing digunakan sebagai sumber pemanas dan pengesan pyroelektrik. Pengiraan secara teori ke atas isyarat dilakukan dengan menggunakan penghampiran berdasarkan fungsi Dirac-g untuk profil tempohan cahaya kilat daripaa camera flash dalam menentukan pemalar peresapan terma. Pengukuran ini dijalankan dari suhu 85 K hingga suhu bilik. Lengkungan peresapan terma mempamerkan suatu gaung pada peralihan kerintangan pada suhu mula dan suatu puncak/bpnggol pada suhu akhir peralihan kerintangan sifar. Oleh itu, kami mendapati bahawa transducer PVDF adalah sangat berkesan dalam mengesan fenomena peralihan dari keadaan normal kepada keadaan superkonduktor dan juga dalam ukuran pemalar peresapan terma untuk bahan superkonduktor pada suhu rendah

ABSTRACT

Thermal diffusivity measurement of the Bi-Pb-Sr-Ca-Cu-O superconducting ceramic sample is reported. In this work camera flash and polyvinylidene difluoride (PVDF) film were respectively used as heating source and pyroelectric detector. The theoretical signal calculation based on Dirac- function approximation for camera flash temporal profile was used to deduce the thermal diffusivity. The measurement was done from 85 K to room temperature. The thermal diffusivity curve shows a dip at the resistive transition onset temperature and a cusp at the zero-resistance temperature. Thus, we found that the PVDF transducer is very effective in determining the normal-to-superconductor transition phenomena and also for the measurement of the thermal diffusivity of the superconducting samples at low temperatures.

Keywords: PVDF, thermal diffusivity, BSCCO, flash technique

INTRODUCTION

The thermal properties of high-T_c superconductor have been measured by various photoacoustic methods, such as the two-beam phase lag (Aravind *et al.* 1996), photothermal method (Bertolotti *et al.* 1995), thermocouple detection (Armstrong *et al.* 1991), photoacoustice technique (Yunus *et al.* 2002) and photopyroelectric method (Aravind and Fung 1999; Peralta *et al.* 1991). Photothermal technique, of which photopyroelectric detection forms a subset, has been widely applied in the measurement of thermal parameters as the thermal diffusivity for solids. Among the various photothermal detection schemes, however, photopyroelectric methods combine extreme sensitivity with high temporal resolution, as well as low cost. The photopyroelectirc method can be based on two different methods which depend on the sample heating source, i.e. modulated CW (Aravind and Fung 1999) and pulsed radiation (Peralta *et al.* 1991). In this paper we describe a method, based on photopyroelecric detection of the sample response to camera flash excitation, which allows measurement of the thermal diffusivity. For this work we chose polyvinylidene difluoride (PVDF) as the transducer, which demonstrates pyroelectrics properties, and camera flash was used as the heating source. The theoretical model is based on the Dirac- function heating source which was introduced before by Power and Mandelis (1987).

THEORY

For one-dimensional heating propagation in a system consisting of four layers: gas, sample, PVDF sensor and backing, assuming that the sample is optically opaque and the backing has similar thermal properties to the PVDF sensor (i.e. effusivity ratio = 1), the average temperature T_p, in the sensor has a simplified expression (Frandas 1995):

$$\langle T_p(x,t)\rangle = (-1)\frac{(\alpha_s\alpha_p)^{1/2}}{\alpha_s(b_{ps}+1)}\sum_{n=0}^{\infty}(-1)^n\gamma^n\left[erfc\left(\frac{(2n+1)\ell}{2\sqrt{a_s t}}+\frac{d}{2\sqrt{a_p t}}\right)-erfc\left(\frac{(2n+1)\ell}{2\sqrt{a_s t}}\right)\right] \quad (1)$$

where $\gamma = \frac{b_{ps}-1}{b_{ps}+1}$ the thermal reflectance, $b_{ps} = \frac{e_p}{e_s}$ the effusivity ratio pyroelectric material/sample, $e_p = \frac{k_p}{\sqrt{\alpha_p}}$, $e_s = \frac{k_s}{\sqrt{\alpha_s}}$, $k_{p,s}$ the thermal conductivity for the pyroelectric film and sample, α_p and α_s are the thermal diffusivity for the pyroelectric film and sample respectively, ℓ, d are the thickness of the sample and pyroelectric film, respectively. The current response $I(t)$ of the pyroelectric sensor is proportional to derivative of the average temperature profile i.e.

$$I(t) = \frac{pd}{\varepsilon}\frac{\partial\langle T_p(x,t)\rangle}{\partial t} \quad (2)$$

where p, ε are the pyroelectric coefficient and dielectric constant of the sensor, respectively.

The pyroelectric impulse response $I(t)$ can be extracted from Eq (1) and Eq (2) as

$$I(t)=\frac{KA}{t^{3/2}}\sum_{n=0}^{\infty}(-1)^{n}\gamma^{n}\left(\tau_{1n}^{1/2}e^{-\frac{\tau_{1n}}{4t}}-\tau_{2n}^{1/2}e^{-\frac{\tau_{2n}}{4t}}\right) \tag{3}$$

where $\tau_{1n}^{1/2}=\frac{(2n+1)\ell}{\sqrt{\alpha_s}}$, $\tau_{2n}^{1/2}=\frac{(2n+1)\ell}{\sqrt{\alpha_s}}+\frac{d}{\sqrt{\alpha_p}}$, $A=\frac{\sqrt{\alpha_s\alpha_p}}{\alpha_s\left(b_{ps}+1\right)}\frac{1}{\sqrt{\pi}}$ and K is a constant, which incorporates the electrical properties of the pyroelectric film. The factor A is a constant, which incorporates the static thermal properties of the sample/pyroelectric system. Because the absolute intensity of the recovered signal is a function of instrumental factors such as irradiation power, amplifier gain, and excitation geometry that has no bearing on the thermal diffusivity, the impulse response was conveniently normalized to give $I(t)$ at the peak of the time-delay response.

EXPERIMENT

The bulk sample used was BSCCO with nominal composition $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_\delta$, which was fabricated by coprecipitation technique (Hamadneh 2002). The metal acetates compounds of bismuth, strontium, lead, calcium and copper (purity ≥ 99.99 %), were weighed and dissolved with glacial acetic acid to form a clear blue solution. The oxalic acid solution was prepared and added to the blue solution and a uniform, stable blue suspension was obtained. The slurry was filtered and dried and subjected to the heat treatment which was carried out by heating the powders to 730 °C in air for 12 hours, calcined at 845 °C in air for 24 hours followed by cooling at 2 °C /minute. The powders were reground and pressed into pellets of 12.5 mm in diameter and 2 mm in thickness. The pellets were sintered at 850 °C for 24 hours and slowly cooled down to room temperature at 120 °C/ hour.

The experimental setup is schematically depicted in *Fig.1*. The sensor was a 52 μm thick, PVDF film where the thermal properties from low temperature to room temperature have been determined by Bonno *et al.* (2001). The excitation source was a flash camera (Minolta 5200i) with 5 *ms* pulse duration. The signal from the sensor was monitored by a digital oscilloscope (LeCroy 9310 A – 400 MHz) and fitting the theory to experimental data was done using Origin (Version 6). A vulcanized rubber was used as backing in four-layer setup and the sample thickness 0.875 mm was attached to the PVDF transducer with a thin layer of vacuum grease. The transducer was rigidly clamped to the glass holder inside the liquid nitrogen cryostat, which was equipped with a heater for temperature variation. The temperature was varied from 85 K up to room temperature and the value was measured by a calibrated platinum resistance thermometer with a resolution of 0.1 K.

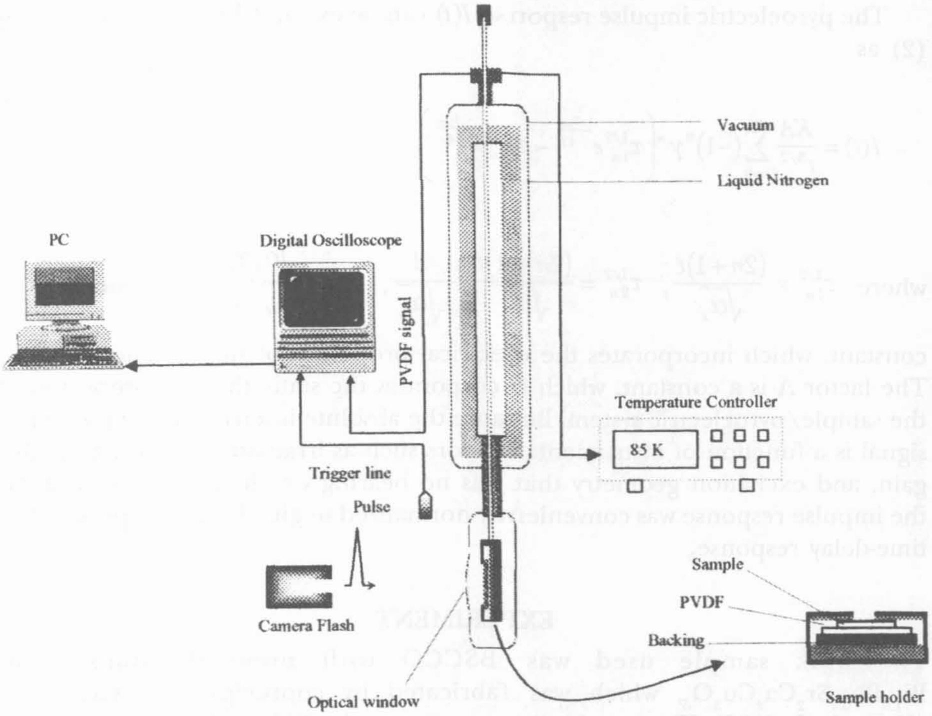

Fig. 1: The experimental setup

RESULTS AND DISCUSSION

Fig. 2 shows normalized impulse responses for the BSCCO sample at 85,102,110, 200 and 300 K.

It is observed that, the impulse response at low temperature is narrower than at higher temperature, which is due to the higher thermal diffusivity at low temperature. The initial normally present PVDF spike is negligible in our analysis, since the fastest thermal transit time through the sample is in the order of tens of milliseconds. The solid curves are the theoretical impulse response from Eq (3), using thermal diffusivity and thermal conductivity values for PVDF in different temperatures, from other works (Bonno *et al.* 2001). The fit of the theoretical expression to the experimentally obtained data is excellent, except the lingering tail that is almost of no effect on the fitted value of thermal diffusivity. This is a consequence of the fact that the signal response at earlier times is a strong function of the thermal diffusivity, while at long times at the tail is only very weakly dependent on the sample thermal diffusivity. The temperature dependence of the thermal diffusivity is shown in *Fig. 3.*

The curve exhibits that the minor dip at 110 K and a local CUSP at 102 K which correspond to resistive transition onset and resistive transition offset respectively. We believe that the minor dip in thermal diffusivity at the resistive transition onset temperature is a result of the abrupt increase in the electron

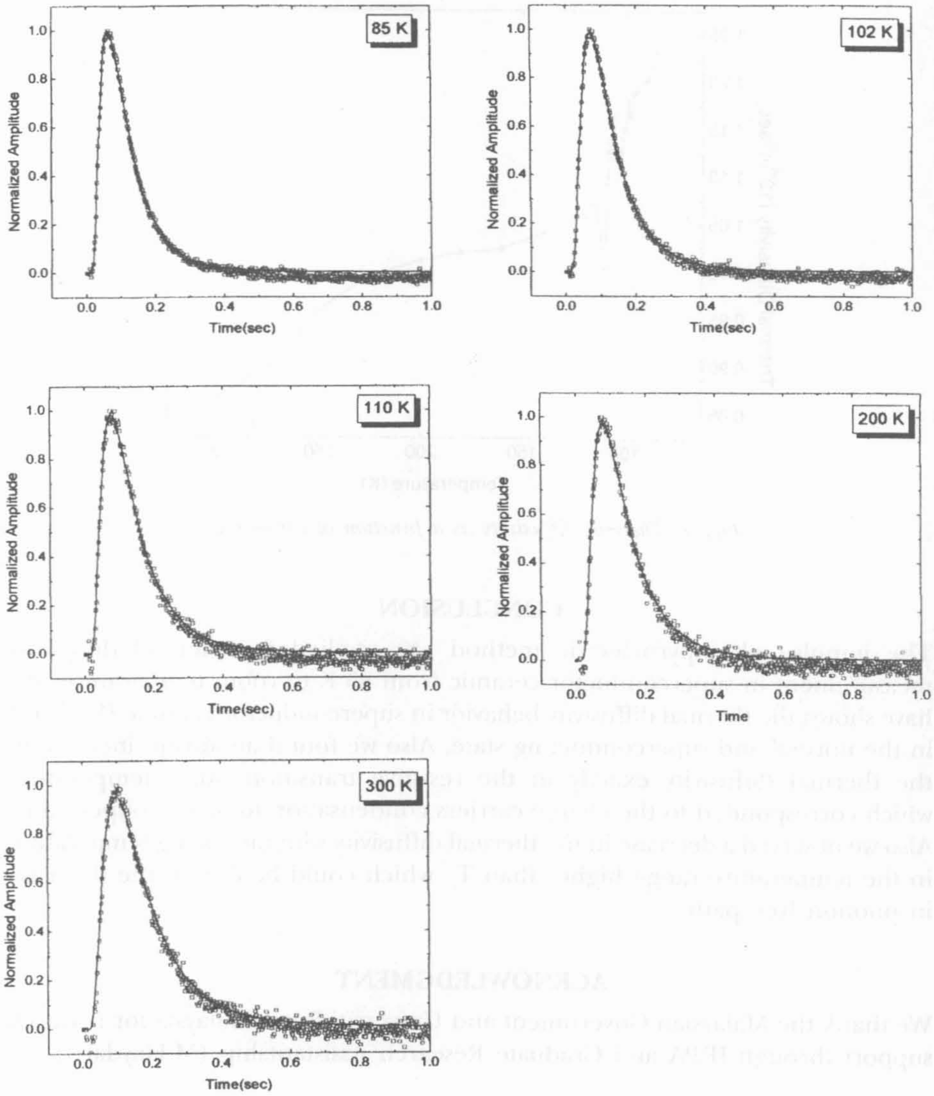

Fig. 2: Photophyroelectric response for $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_d$ (BSCCO) at 85, 102, 110, 200 and 300 K. Similar responses were observed at different temperatures. Solid curves correspond to the theoretical model

specific heat (Aravind and Fung 1999). Furthermore, the increase in the thermal diffusivity below T_c could be due to the increase in the mean free path of phonon. Below T_c the charge carriers condense to form Cooper pairs which do not scatter phonons and as a result the mean free path of phonon increases. Also we can see a decrease in the thermal diffusivity with increasing temperature in the temperatures higher than T_c which could be due to a decrease in phonon free path due to the lattice vibration.

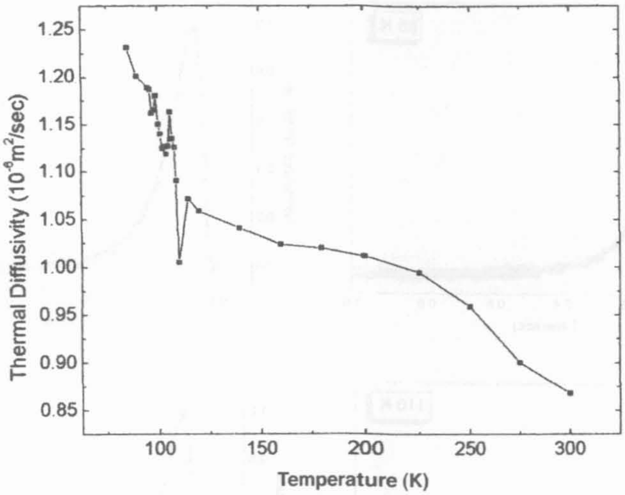

Fig. 3: Thermal diffusivity as a function of temperature

CONCLUSION

The impulse photopyroelectric method was applied for thermal diffusivity measurement in superconductor ceramic from 85 K to room temperature. We have shown the thermal diffusivity behavior in superconductor ceramic (BSCCO) in the normal and superconducting state. Also we found an abrupt increase in the thermal diffusivity exactly in the resistive transition onset temperature which corresponded to the charge carriers condensation to form Cooper pairs. Also we observed a decrease in the thermal diffusivity with increasing temperature in the temperature range higher than T_c which could be due to the decrease in phonon free path.

ACKNOWLEDGMENT

We thank the Malaysian Government and Universiti Putra Malaysia for research support through IRPA and Graduate Research Assistantship (M.Haydari).

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