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THERMAL DIFFUSIVITY OF $YBa_2Cu_3O_{7-x}$ SUPERCONDUCTOR USING OPEN-CELL PHOTOACOUSTIC

MARY ALVEAN B. NARRETO, HASAN ADLI ALWI

School of Applied Physics, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor

Abstract Thermal diffusivity of $YBa_2Cu_3O_{7-x}$ superconductor was measured using open-cell photoacoustic technique. The thermal diffusivity was obtained by analyzing the phase of photoacoustic signal of thermally thick sample. The value obtained was 0.019 $cm^2/s \pm 20\%$.

KEYWORDS: Thermal diffusivity, YBCO, photoacoustic

Introduction

Thermal diffusivity of $YBa_2Cu_3O_{7-x}$ has been measured by several authors using different kinds of techniques (Gomes *et al.*, 1988; Peralta *et al.*, 1991; Aravind and Fung, 1999). The thermal diffusivity of $YBa_2Cu_3O_{7-x}$ at room temperature from those measurements ranged from 0.013 to 0.025 cm^2/s. However, no measurement on YBCO using Open Photoacoustic Cell (OPC) has been reported. Although, OPC has been applied for some Bi-based superconductors, the analysis was on the photoacoustic (PA) amplitude (Isaac and Philip, 1992; Sarkar *et al.*, 1997; Yunus *et al.*, 2002). This method of analysis is not suitable for YBCO due to its very low value of thermal diffusivity, unless a very thin sample is used. In this paper, we avoid the difficulty of obtaining a very thin layer by analyzing the phase of the PA rather than the amplitude. Two methods of analyzing the PA phase, namely, Calderon's method and analysis of phase in thermally thick region are reported. These two analyses are suitable where the dominant mechanism contributing to the PA signal is due to thermal diffusion only. Both methods of phase analysis applied to superconductors have never been reported.

The method of determining thermal diffusivity from the analysis of phase at thermally thick region has been employed by Ravi *et al.*, (2003) for $CuGa_{1-x}Fe_xO_2$ ceramics, George *et al.*, (2003) for n-type InP and by Perondi and Miranda for Silicon (Perondi and Miranda, 1987; Ravi *et al.*, 2003; George *et al.*, 2003). The Calderon's method has been applied for thin aluminum, Si, GaAs, and InP semiconductor (Nikolic *et al.*, 2001; Calderon *et al.*, 2003).

Experimental Method

The $YBa_2Cu_3O_{7-x}$ pellets were prepared through the common solid state technique. Thermal diffusivities of different thicknesses of the sample (0.599-0.198 mm) were measured. Figure 1 shows the whole PA instrumentation for acquiring the PA signal.

The light source is a visible red laser diode (Sanyo 30mW) that is amplitude modulated by a laser diode driver (Newport Model 505) with an external voltage input from a function generator (Stanford Research (SR) Systems Model DS345). The detection section is composed of an OPC upon which the sample is directly mounted on the circular hole of Knowles electrets microphone. The front surface of the sample is illuminated by the modulated light. This causes a periodic heating of the sample that creates a pressure variation at its rear surface.

Correspondence: Mary Alvean B. Narreto, School of Applied Physics, Faculty Science and Technology, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia

This sound is then detected by the sensitive microphone and constitutes what is called PA signal. A low-noise preamplifier (SR560) is used to amplify this small signal. For data acquisition, a program written in C was developed to automatically acquire the PA signal from the lock-in amplifier (SR530). Analysis of PA phase signal was done using Microcal Origin 6.0.

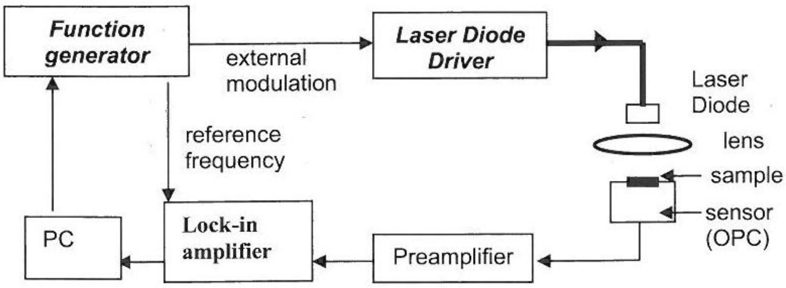

Figure 1. Schematic diagram of the Photoacoustic Instrumentation

Results and Discussion

At room temperature, superconductor behaves as semiconductor thus non-radiative recombination process also contributes to the PA signal (Nikolic *et al.*, 2001). This process is indicated by a sudden curve at higher frequency as shown in Fig. 2b. In the lower frequency range where the PA phase is linear, thermal diffusion is the only dominant mechanism contributing to the PA signal (George *et al.*, 2003). Thus, to obtain the thermal diffusivity, analysis were done at the low frequency range where recombination process is negligible.

In Calderon's method (Calderon *et al.*, 1998), the PA phase φ at low frequency f is reduced to a linear relationship given as

$$\varphi = -\frac{1}{\pi f_c} f - \frac{3\pi}{4} \quad \text{.............................(1)}$$

The characteristic frequency f_c is the frequency at which the sample changes from thermally thin to thermally thick. When PA phase φ is plotted against modulation frequency f, φ decreases linearly with a slope of $-1/\pi f_c$ in the interval $f/f_c \leq (\pi/2)^2$ as seen in Fig. 2a. By obtaining the f_c from the slope and with known sample thickness l_s, α_s was readily obtained by using the equation $\alpha_s = \pi f_c l_s^2$.

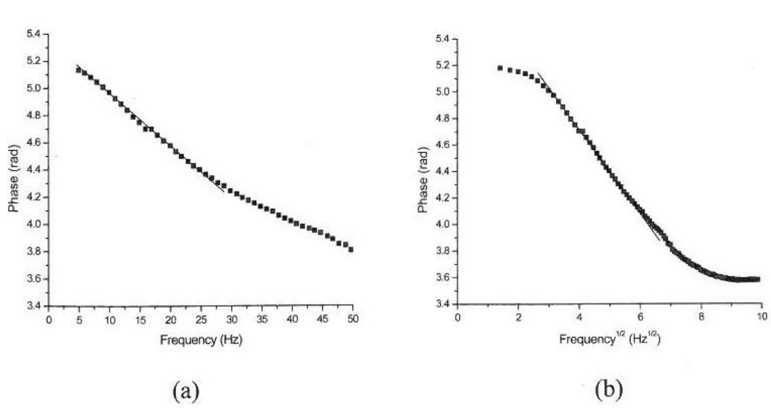

Figure 2. PA phase plots of 0.270 mm thick $YBa_2Cu_3O_{7-x}$ where the thermal diffusivity was determined using (a) Calderon's method and (b) phase analysis at thermally thick region

In the analysis of phase at thermally thick region (Ravi *et al.*, 2003), thermal diffusivity α_s was determined from the φ vs. $\sqrt{f}$ plot, Fig. 2b. Here, the phase also decreases linearly at low frequency, with a slope of a, where $a \equiv l_s \sqrt{\pi / \alpha_s}$. Thermal diffusivity α_s was then calculated with known sample thickness l_s.

Figure 3 shows the thermal diffusivities obtained using both methods at various thicknesses. From the graphs of eight different thicknesses, the average α_s measured from the Calderon's method is 0.018±10% cm²/s, whilst from the thermally thick analysis the average α_s is 0.02±20% cm²/s. These experimental results do well agree with the literature values of 0.013-0.020 cm²/s (Aravind and Fung, 1999). The values measured using Calderon's method are relatively lower because the approximation of equation 1 has an error of 1.2% (Nikolic *et al.*, 2001). It can be concluded that the average thermal diffusivity of YBCO is 0.019 cm²/s ±20%.

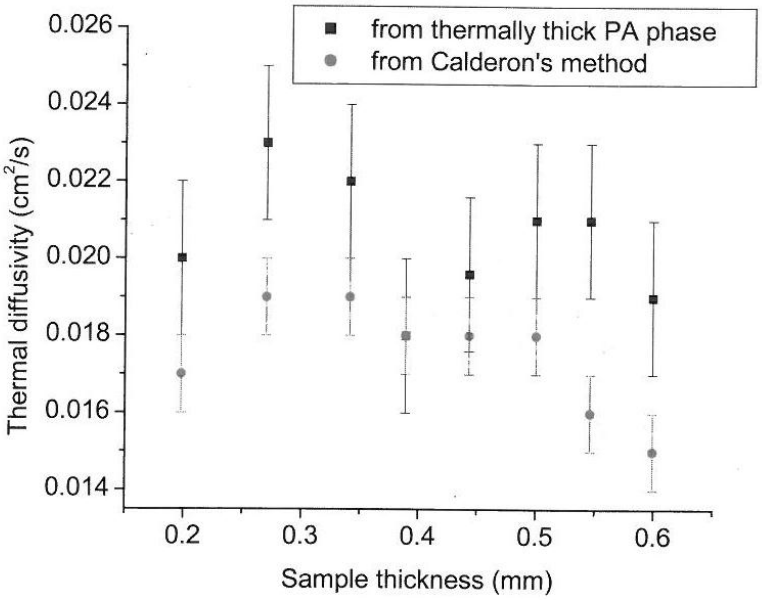

Figure 3. Thermal diffusivity of $YBa_2Cu_3O_{7-x}$ superconductor at different thicknesses determined from the PA phase

Conclusion

The thermal diffusivity of $YBa_2Cu_3O_{7-x}$ superconductor obtained was 0.019 cm²/s ±20%. The methods of analyzing the PA phase of OPC are suitable for materials with low value of thermal diffusivity because it is not necessary to obtain a very thin layer as required in the analysis of amplitude of PA signal. These methods are applicable where the dominant mechanism contributing to the PA signal is thermal diffusion only.

Acknowledgements

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