THERMAL DIFFUSIVITY MAPPING OF CARBONS USING PHOTO-THERMAL TECHNIQUE

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Introduction

Increasing interest in carbon-carbon composites for thermal management systems has resulted in several investigations into thermal conductivity [1]. The relationship between thermal conductivity and carbon structure is so strong that thermal conductivity measurement has been employed by several researchers to characterize the carbon material quality [2]. In this paper, we propose an alternative and direct method to measure thermal conductivity mapping of carbon materials using an automated photo-thermal technique.

Theory

Wide range of thermal diffusivities of materials might be measured using photo-thermal technique. The technique is based on the basic heat diffusion equation

$$\nabla^2 T = \frac{1}{\alpha}\frac{\partial T}{\partial t} \tag{1}$$

The physical model is based on the thermal behavior of a semi-infinite slab with a point on the surface acts as a sinusoidal point source of energy. The heat is liberated $\phi(t)c\rho$ in which the function $\phi(t)$ defines the sinusoidal behavior of the point source.

$$\phi(t) = \frac{q(1-\cos\omega t)}{2} \tag{2}$$

By integrating equation (1) using the heat source defined in equation (2), appropriate boundary and initial conditions, the temperature field was found as

$$T = \frac{q}{4\pi\alpha r}\left\{1 - \mathrm{erf}\left[\frac{r}{\sqrt{4\alpha t}}\right] - e^{-r\xi}\cos[\varpi t - r\xi]\right\} - \frac{q}{4\mu(\pi\alpha)^{3/2}}\int_0^{\mu/\sqrt{t}} \cos\left[\omega\left(t - \frac{r^2}{2\alpha\eta^2}\right)\right] e^{-\eta^2}\, d\eta + T_i \tag{3}$$

where $\xi = \left(\frac{\varpi}{2\alpha}\right)^{1/2}$, $\mu = \frac{r}{2\sqrt{\alpha}}$ and $\eta = \frac{r}{2\sqrt{\alpha(t-t')}}$

After the temperature field stabilizes, equation (3) can be reduced to

$$T = \frac{q}{4\pi\alpha r}\left[1 - e^{-r\xi}\cos(\varpi t - r\xi)\right] + T_i \tag{4}$$

Measurement Methods

Based on the reduced solution, two methods of measurements can be performed. The first method is based on the temperature changes at a fixed distance from the sinusoidal point source. The second method is based on phase changes to calculate the surface thermal diffusivities of a material. By rearranging the equation (4) and defining minimum to maximum temperature change ratio R, thermal diffusivity can be calculated as

$$\alpha = \pi f \left[\frac{r}{\ln\left[\frac{1+R}{1-R}\right]}\right]^2 \tag{5}$$

The second method is based on the observation of phase change in equation (4). The phase change is directly proportional the distance from the source. Thermal diffusivity can be calculated as

$$\alpha = \frac{180^2 f}{\pi k^2} \tag{6}$$

where k is the proportionality constant in degree/cm and f is the source frequency.

Experimental Setup

To map the thermal diffusivity topography of the material under examination, an automatic positioning stage is built. In order to simulate the sinusoidal behavior of the point source, a high intensity light is chopped at a constant frequency using mechanical chopper. Then, an optical microscope is used to focus the light source. To detect either the temperature or the signal phase, a micro-thermister is used and positioned on the surface of the material with few micrometers away from the source. The signals from the micro-thermister are then used to calculate the thermal diffusivity after amplification. Positioning of the micro-thermister on the sample is shown in Figure 1. Figure 2 shows the model of an automatic stage that has been designed and built for thermal mapping.

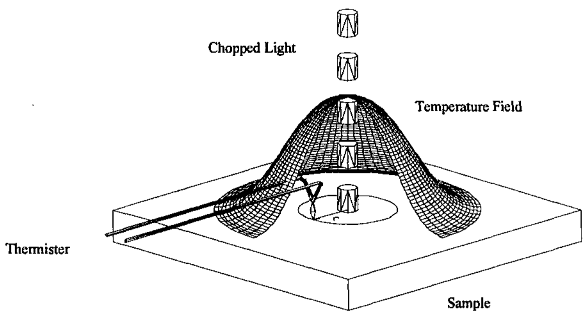

Figure 1: Measurement of the temperature and the phase of the temperature field using micro-thermister.

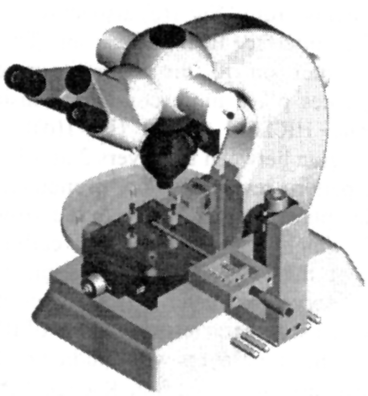

Figure 2: CAD model of the automatic stage with optical microscope.

Result

First of all, a homogenous carbon material (Poco graphite) has been chosen to test if photo-thermal measurement technique would provide an accurate data. In this regard, two techniques have been used: Laser Flash and Photo-Thermal methods. Figure 3 shows thermal diffusivity data using phase change method. The calculated value of thermal diffusivity using equation (6) is 0.97 cm^2/sec. By Laser Flash technique, thermal diffusivity of the same sample is found to be 1.07 cm^2/sec. Indeed, by using curve fitting (Figure 4) and interpolating the thermal diffusivity of Poco graphite at room temperature, the value of thermal diffusivity is 1 cm^2/sec.

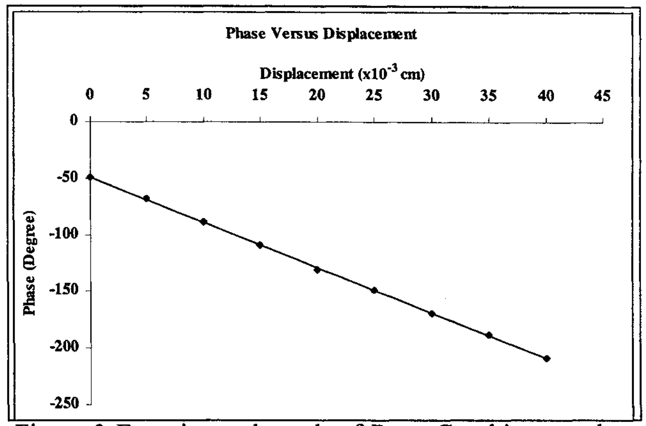

Figure 3 Experimental result of Poco Graphite sample using photo thermal measurement technique with a chopped beam source of a frequency of 15 Hz

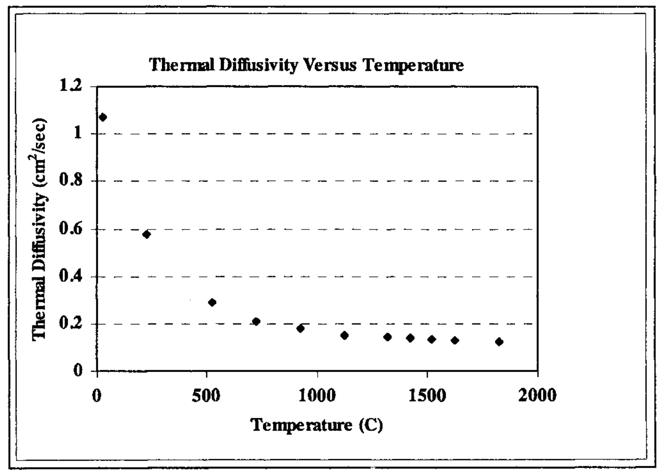

Figure 3 Thermal Diffusivity data of Poco Graphite sample using Laser Flash technique.

Conclusions

Photo-thermal Technique has been proven to be successful method for monitoring the change in the thermal diffusivity of carbon materials. Wide range of thermal diffusivity materials have been measured. The measurements might be performed at any direction of sample preparation.

References

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