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The evaluation of cross-plane/in-plane thermal diffusivity using laser flash apparatus

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A B S T R A C T

Generally, the laser flash method is only used to measure thermal conduction in the cross-plane direction. This study measured the thermal diffusivity of isotropic graphite (IG 110) in the cross-plane and in-plane directions. The cross-plane (or through-plane) direction is perpendicular to the substrate plane, and in-plane (or radial plane) direction is parallel to the substrate plane. In the laser flash method, thermal diffusivity shows a decreasing tendency as laser energy increases. Thermal diffusivity was taken as intrinsic thermal diffusivity for all specimens, as this method eliminates the influence of the laser's energy level as a factor. The cross-plane and in-plane thermal diffusivity of IG IG-110 were 10.13 × 10^{-5} m^2/s and 9.88 × 10^{-5} m^2/s, respectively.

1. Introduction

The laser flash method is often used in the measurement of the thermal diffusivity of solid materials. This measurement method involves the pulsed heating of the front of a solid specimen and the measuring of the temperature of the rear of the specimen using an infrared detector. The resulting temperature curve is used to measure thermal diffusivity [1,2]. Generally, the laser flash method is only used to measure thermal conduction in the cross-plane direction. However, it should be considered that thermal conduction takes place in 2 dimensions, in the cross-plane (through-plane) and in-plane directions. Donaldson measured in-plane thermal diffusivity by pulse heating the center of a specimen using a laser pulse, and measured the temperature rise at fixed intervals in the in-plane direction [3–5]. Schoderböck investigated the effect of specimen thickness in metals on the thermal diffusivity measured using a laser flash apparatus [6]. Results indicated that the thinner the specimen, the higher the deviation compared to thicker specimens, and the thermal diffusivity in 0.5 mm thick silver and copper were measured to be 55–60% less. Using this data, Schoderböck derived a formula for the relationship between the thickness and thermal diffusivity.

Graphite displays large differences in thermal conductivity depending on direction, and active research is being conducted to improve measurements for its in-plane thermal conductivity [7]. HOPG (highly oriented pyrolytic graphite) is highly anisotropic with an a-axis thermal conductivity of 1950 W/(mK), and c-axis thermal conductivity of 6.9 W/(mK) [8]. The thermal conductivity of materials along certain directions have to be accurately measured for them to be used in thin films. Heat dissipation is an important feature for thin films used in displays and electronics, and the difference in thermal conductivity according to direction is an important physical property for thermal design [9].

This study examined the usefulness of the laser flash apparatus as a device for measuring cross-plane and in-plane thermal diffusivity. Using isotropic graphite of varying thicknesses, the thermal diffusivity in both cross-plane and in-plane directions were measured to understand the limits of the laser flash apparatus. Isotropic materials maintain uniform structures regardless of direction, making them appropriate analysis of uncertainties in the measurement of cross-plane and in-plane thermal diffusivity. Isotropic graphite is also used as a standard material, and an international comparison material for the laser flash method, making it suitable for use in an evaluation of the laser flash apparatus [10,11]. Thin films these days are required to exhibit thermal conductivity in both in-plane and cross-plane directions.

2. Experimental procedure

2.1. Specimens

In this experiment, isotropic graphite (Toyo Tanso, IG-110) [12] plates (300 × 300 × 100 mm) were processed into rods of 25 mm and 10 mm in diameter. These rods were further sectioned into specimens with diameters of 10 mm and varying thicknesses of 0.5 mm to 4.0 mm for cross-plane thermal diffusivity measurement, and specimens of 25 mm diameter and varying thicknesses of 0.076 mm to 1.5 mm for in-plane thermal diffusivity measurement. As the properties of isotropic

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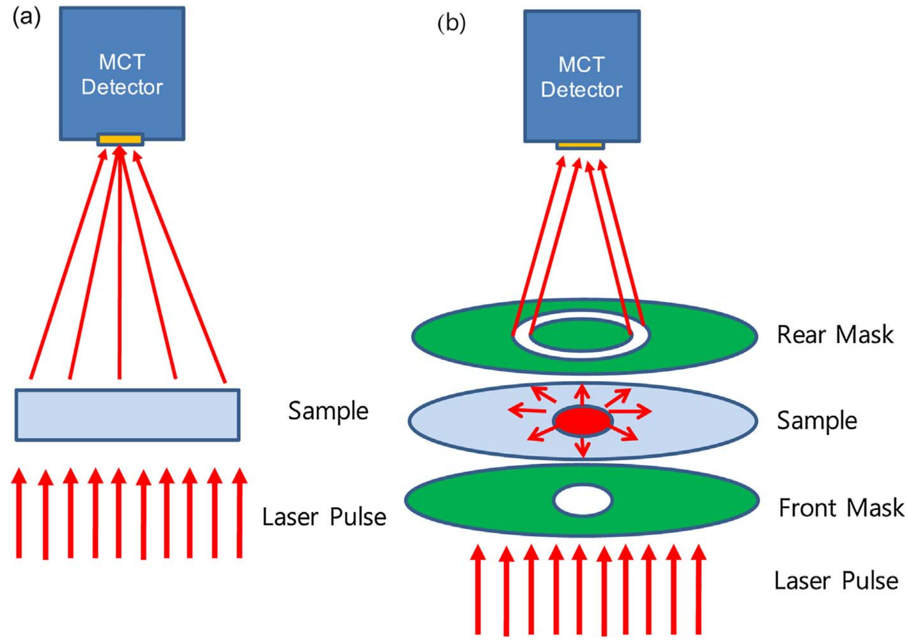

Fig. 1. (Color online) Schematic diagram of (a) cross-plane (b) in-plane thermal diffusivity measurement for laser flash apparatus.

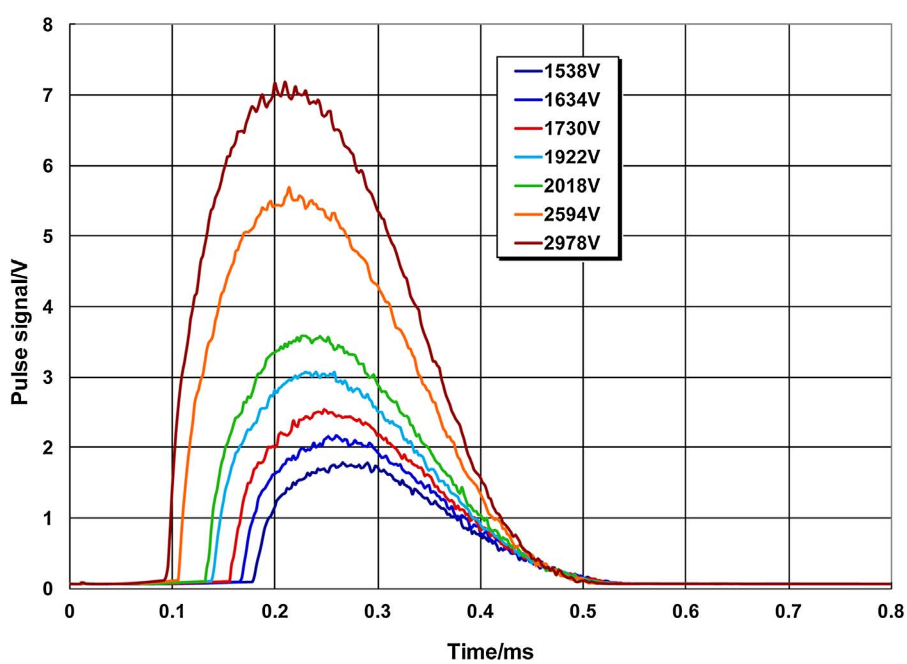

Fig. 2. (Color online) The laser pulse shape depending on laser power.

graphite remains uniform regardless of direction, it is an easy material to work with and apply to designs. Since the material is isotropic, the cross-plane and in-plane thermal diffusivities are identical by principle.

2.2. Laser flash apparatus

A laser flash apparatus (LF457A, NETZSCH, Germany) was used to measure thermal diffusivity. This device heats the front of the specimen with a pulse laser and measures the temperature on the rear using an infrared detector (MCT: Mercury Cadmium Telluride). For every measurement, the laser pulse was measured and the FWHM (full width at half maximum) was obtained using Azumi's method [13]. Azumi applied a time correction, taking the full width at half maximum point of the pulse as the start point of the laser. The cross-plane thermal diffusivity analysis was carried out using Cape-Lehman's method [2]. The analysis of the in-plane thermal diffusivity data was conducted through the in-plane mode of LF457A, and this method adheres to Donaldson's method [3,4].

Fig. 1 shows schematic diagrams of (a) cross-plane thermal diffusivity and (b) in-plane thermal diffusivity measurements using laser flash apparatus. In the cross-plane thermal diffusivity measurement, specimens of 10 mm diameter are heated in the front with a laser pulse and the temperature change at the back is measured using an infrared detector. The in-plane thermal diffusivity is measured using specimens of 25 mm heated in the front with a laser pulse of 5.03 mm diameter, which delivers the heat through the specimen in the in-plane direction. The temperature is measured at fixed intervals from the in-plane location on the rear of the specimen. The infrared temperature detector measures temperature change between the diameters of 9.56 mm and 12.11 mm. Thus, the average temperature change in the zone 2.28 mm