APPLICATION **NOTE**

Graphite Foils – Laser Flash Analysis

Laser Flash Analysis Makes Heat Transfer in Anisotropic Materials Measurable

Fabia Beckstein, Applications Laboratory, and Nico Dilsch, Software Department

Introduction

Graphite foils are used in many technical applications where efficient heat dissipation is required despite the material's thinness, such as in electronics, energy technology and mechanical engineering. In addition to their high thermal and chemical resistance, they are distinguished by their pronounced anisotropic thermal conducticity.

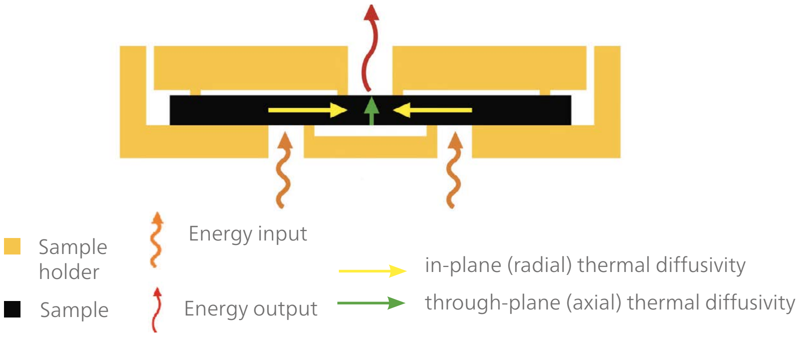
While their thermal conductivity perpendicular to the foil plane (*through-plane*) is comparatively low, they exhibit very high thermal conductivity in the plane (*in-plane*). These properties are largely production-related, e.g., due to rolling. The *in-plane* thermal conductivity enables rapid lateral heat distribution across the foil surface. This is particularly important for reducing local hotspots, as it allows localized heat sources to be efficiently dissipated. Thus, graphite foils act as heat spreaders, significantly contributing to the thermal stability and reliability of modern technical systems.

Through-Plane vs. *In-Plane*

Accurately determining the *through-plane* and *in-plane* thermal conductivity is of central importance for designing many technical applications. LFA (Laser Flash Analysis) can easily and user-friendly handle this task with suitable sample holders and models. *Through-plane* measurements are performed using the foil sample holder, which is optimized for measuring thin samples (see figure 1, left). *In-plane* measurements, however, are performed using the *in-plane* sample holder (heat flow inward); see figure 1, right.

Through-plane measurements are performed perpendicular to the sample surface. *In-plane* measurements use ring-shaped illumination of the sample, while the temperature rise is detected at the sample center. This makes the measurement signal characteristic of heat conduction in the plane. Figure 2 shows a sketch illustrating this.

1 Sample holder for *through-plane* (left) and *in-plane* measurements (right) on thin foils



2 Heat transfer during an *in-plane* measurement (heat flow inwards)

NGB · Application Note 431 · EN · 0426 · Technical specifications are subject to change.

Measurement Conditions

The measurement conditions are detailed in table 1.

Orthotropic Model

In order to account for the pronounced anisotropy of graphite foils during evaluation, the orthotropic model describes the thermal diffusivity as a quantity that depends on direction, with two independent components: one that is perpendicular to the sample plane ($\alpha\perp$), and one that is in the plane ($\alpha||$). This is reflected directly in the underlying heat conduction equation.

$$\frac{\partial T}{\partial t} = \frac{\alpha_{\parallel}}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \alpha_{\perp}\frac{\partial^2 T}{\partial z^2}$$

Here, z denotes the direction perpendicular to the sample surface (*through-plane*) und r the radial direction in the plane (*in-plane*). Rather than assuming uniform diffusivity in all directions, the model incorporates independent parameter values for $\alpha||$ and $\alpha\perp$, enabling it to account for the actual heat propagation in anisotropic materials. When evaluating an *in-plane* measurement, the *through-plane* diffusivity, $\alpha\perp$, which was previously determined in a separate measurement, is incorporated into the calculation as a known input parameter. This allows $\alpha||$ to be precisely determined.

Many commercial LFA systems exclusively use one-dimensional models to evaluate *in-plane* measurements. Since these models only describe the heat propagation along a single spatial direction, it is impossible to distinguish between the *in-plane* and *through-plane* diffusivity from the outset. For materials with pronounced anisotropy, such as graphite foils, this inevitably leads to underestimating the thermal diffusivity.

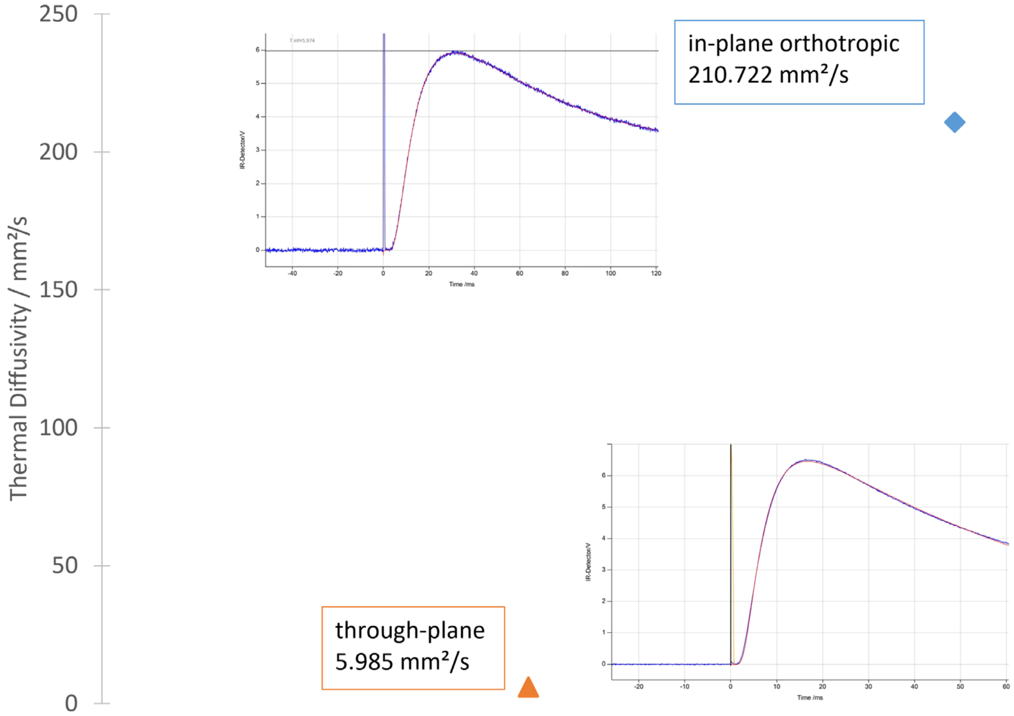
Table 1 Measurement conditions

LFA system	LFA 717 *HyperFlash*®
Sample	Grapite foil
Sample thickness	500 µm
Density	~ 1 g/cm³ from datasheet
Specific heat capacity	Literature values from POCO graphite [2]
Temperature program	25 to 500°C
Atmosphere	nitrogen
Measurement direction	*through-plane* and *in-plane*
Sample holder	*through-plane* → sample holder for foils *in-plane* → *in-plane* sample holder (heat flow inward)
Evaluation models	*through-plane* → standard model based on Cape Lehman *in-plane* → orthotropic model

Impact of the Chosen Model on the Measurement Result

Figure 3 shows the thermal diffusivity of the graphite foil at room temperature in the *through-plane* and *in-plane* directions. The thermal diffusivity perpendicular to the surface (*through-plane*) is evaluated with the standard model, based on Cape Lehman [1]. This is two orders of magnitude lower than the *in-plane* thermal diffusivity. The orthotropic model is therefore used to evaluate the *in-plane* measurement. Upon closer examination, the distinction between isotropic and anisotropic behavior in *in-plane* measurements is significant.

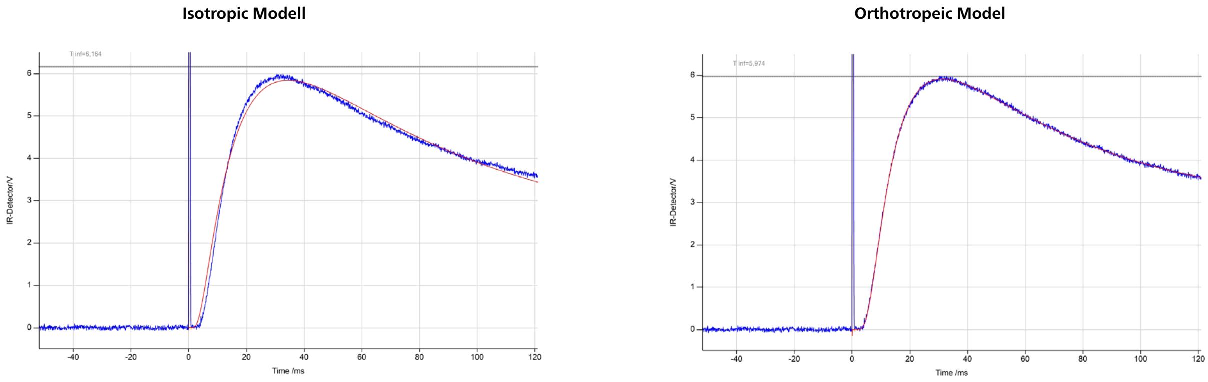
Figure 4 illustrates this clearly. Here, the measurement on the graphite foil evaluated using both the isotropic and orthotropic model. The isotropic evaluation yields significantly lower values (approx. -18%) and also shows a significantly poorer curve fit.



in-plane orthotropic
210.722 mm²/s

through-plane
5.985 mm²/s

3 Thermal diffusivity of the graphite foil at room temperature, *through-plane* and *in-plane*



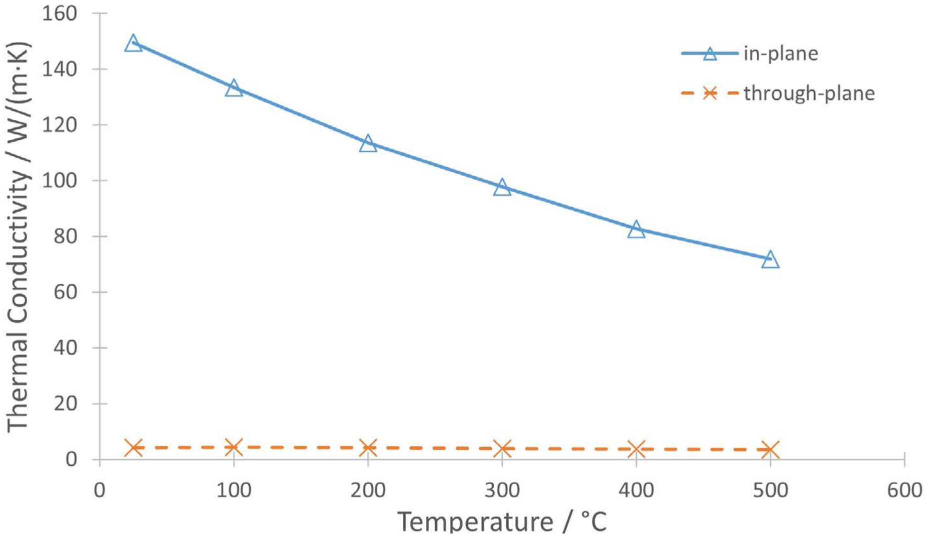
Isotropic Modell

α=173.875 mm²/s

Orthotropeic Model

α=210.722 mm²/s

4 Thermal diffusivity of the graphite foil at room temperature, evaluated with different models



5 Thermal conductivity of the graphite foil at room temperature *through-plane* and *in-plane*

Thermal Conductivity as a Funtion of Temperature and Measurement Direction

Figure 5 shows the thermal conductivity of the graphite foil in the *through-plane* and *in-plane* direction from room temperature to 500°C. The thermal conductivity was calculated using the specific heat capacity of POCO Graphite [2] and the density at room temperature. The thermal conductivity decreases with increasing temperature in both directions. The *in-plane* thermal conductivity is significantly higher than the *through-plane* thermal conductivity.

Summary

When combined with suitable sample holders, laser flash analysis enables the reliable determination of the highly anisotropic thermal conductivity of graphite foils in both the *through-plane* and *in-plane* direction. This reveals an *in-plane* thermal conductivity that is orders of magnitude higher, which is crucial for the efficient distribution of heat and reduction of hotspots. To ensure an accurate evaluation, it is essential to use a model that accounts for anisotropy, as isotropic approaches significantly underestimate the properties.

Literature

[1] J. A. Cape and G. W. Lehman: Temperature and finite pulse-time effects in the flash method for measuring thermal diffusivity; Journal of Applied Physics; 34(7):1909–1913; July 1963
[2] R.E. Taylor, H. Groot: Thermophysical properties of POCO Graphite; HTHP; 12(2): 147-160; 1980

NETZSCH-Gerätebau GmbH
Wittelsbacherstraße 42 · 95100 Selb · Germany
Phone: +49 9287/881-0 · Fax: +49 9287/881505
at@netzsch.com · www.netzsch.com