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A custom setup for thermal conductivity measurements

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Future detector systems have increasing demands on the performance of their mechanical support structures and cooling systems. Novel materials and cooling techniques are developed and continuously improved in order to fulfil these requirements. A custom thermal conductivity measurement setup is presented to measure these materials thermal conductivity.

The setup consists of two heat flux meter blocks between which the samples are clamped. The setup follows the American Society for Testing and Materials standard D5470-06[1] and consists of two brass blocks, which act as heat flow meters.

In order to minimize heat exchange between the heat flux blocks and the ambient via convection and radiation, the setup is covered with a radiation shield and measurements are carried out in a vacuum.

The contribution describes the setup in detail, motivates its design aspects and highlights the commissioning and calibration procedure. The analysis method and calibration procedure are presented.

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1. Introduction

Future detector systems have increasing demands on the performance of their mechanical support structures and cooling systems. Novel materials and cooling techniques are developed and continuously improved in order to meet these requirements. Various thermal interface materials are widely used in detector development, as they are important components of detector systems and are necessary for heat dissipation.

These materials have to undergo various tests and measurements to quantify their thermal and mechanical performance. To quantify the thermal conductivity of these materials, a custom trough-plane thermal conductivity measurement setup was developed.

2. Through-plane thermal conductivity measurement

The thermal conductivity measurement method is based on the ASTM D5470-06 standard [1]. The ASTM D5470-06 standard utilises the linear correlation between thermal resistance and thickness based on the measurement of at least three different thicknesses of the material to determine the thermal conductivity of the material.

The setup consists of two brass heat flux meter blocks between which the samples are clamped (see Fig. 1 (a)). A resistive load on top of the upper block acts as a heat source whereas the bottom block is thermally coupled to a cooling plate which acts as the heat sink. Each of the blocks has six temperature sensors embedded at equally spaced positions that allow to measure the heat flux as well as the temperature at the interface to the sample from which the temperature gradient across the sample can be determined.

Since the measurement method is based on the extraction of the slope of the linear dependency of the thermal resistance of the material vs. thickness, samples with at least three different thicknesses of the same material are measured.

The thermal conductivity k of the material is given by:

$$k = \frac{qt}{A\Delta T}, \tag{1}$$

where q is heat flux through the sample, t - thickness of the sample, A - sample area and ΔT - temperature gradient. The temperatures are extracted as a function of the position in the blocks (see Fig. 1 (b)), and the ΔT is obtained as a difference of the linear fits of the temperature readings from the top and bottom blocks extrapolated to the interfaces (see grey dashed line on Fig. 1 (b)) to the measured material.

$$\Delta T = T_{top} - T_{bottom} \tag{2}$$

The heat flux q through the sample is given by:

$$q = \frac{dT}{dl} k_{block} A_{block} \tag{3}$$

Where the temperature gradient $\frac{dT}{dl}$ is obtained from the temperature readings along the blocks, calculated as a mean value of $\frac{dT}{dl}_{top}$ and $\frac{dT}{dl}_{bottom}$ (see Fig. 1 (b)), k_{block} - thermal conductivity

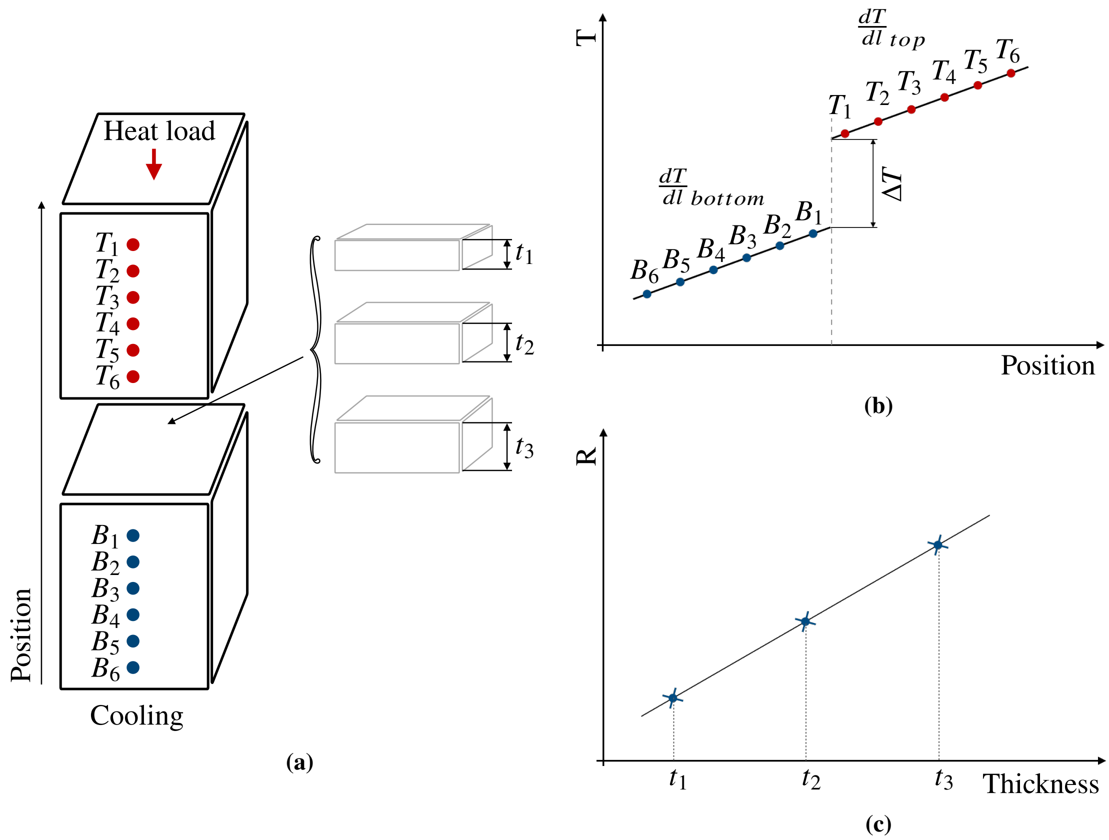

Figure 1: Schematics of the through-plane thermal conductivity measurement. a) Through-plane thermal conductivity measurement setup; b) Measured temperatures vs. position across the brass blocks; c) Measured thermal resistance vs. thickness of the material samples.

of the block and A_{block} - area of the block.

The thermal resistance R is calculated:

$$R = \frac{\Delta T}{q} A. \tag{4}$$

The thermal resistance includes the sample thermal resistance and contact resistance between the sample and the blocks. Hence, the thermal resistance is measured on samples with at least three different thicknesses, assuming the same contact thermal resistance over the measurements and the thermal conductivity is extracted from a linear fit R vs. t. The difference between the thermal resistance and the change in thickness is used to calculate the thermal conductivity (see Fig. 1 (c))

$$k = \frac{dt}{dR}. \tag{5}$$

To avoid dry thermal contact between the sample and the brass blocks, thermal grease is applied on the top and bottom of the sample. The setup can be used to measure different types of materials, including soft and paste-like materials. To ensure the same measurement conditions, samples are compressed with compression springs. Springs with various clamping forces can be applied. For most measurements performed using the setup, Febrotec 0X-RDF1611 clamping springs with a resulting clamping force of 70 N were used. The through-plane thermal conductivity measurement method is based on the conductive heat transport through the setup between the heat source and the cooling base. To decrease the uncertainty of the thermal conductivity measurement, the heat exchange with the ambient should be minimised. In order to decrease the effect of the radiative and convective heat exchange between the setup and the ambient, the setup is covered with a radiation shield and measurements are performed in a vacuum.

3. Calibration

The calibration of the setup is performed using Sapphire glass and Brass samples, the Brass samples are manufactured from the same material (CW614N) as the heat flux meter blocks. The thermal conductivity of Sapphire Glass is highly temperature-dependent [2], thus the nominal thermal conductivity value is used at the mean sample temperature. The calibration is performed on the Sapphire Glass as well as on the Brass samples to calibrate the setup in a broad range of values and to cross-check the accuracy of the calibration procedure. To perform the calibration the samples with 0.5 mm, 1 mm, 2 mm and 4 mm thickness of the Sapphire Glass and samples with 2 mm, 10 mm and 20 mm thickness of Brass CW614N were measured using the setup. The thermal conductivity is determined for Sapphire Glass and Brass samples in a combined fit. The calibration coefficient is the average of the calibration coefficients for Sapphire Glass and Brass samples. The thermal resistance offset is determined from a combined fit at position 0 mm thickness and corresponds to the thermal resistance of two layers of the thermal grease. In Fig. 2 combined constrained fit of the measured thermal resistance vs. thickness for brass (orange line) and Sapphire glass (blue line) is shown. Obtained thermal conductivity results in 37.84 $\frac{W}{mK}$ for the Sapphire glass (nominal value is 37.67 $\frac{W}{mK}$) and 112.52 $\frac{W}{mK}$ for the brass samples (nominal value is 113.00 $\frac{W}{mK}$ [3]).

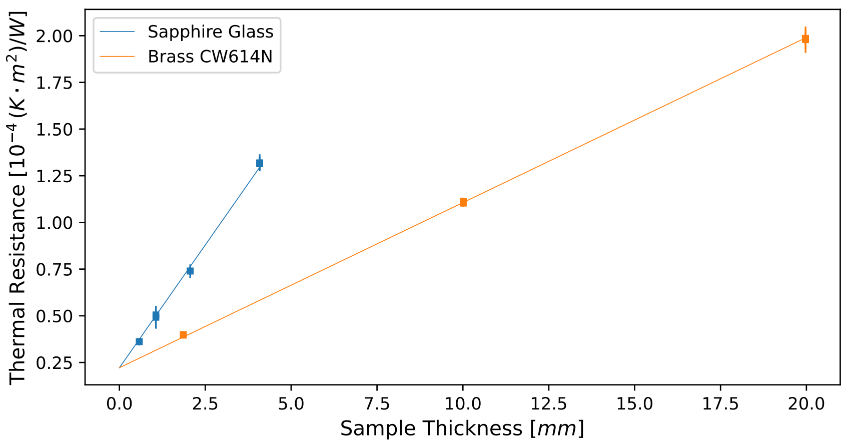

Figure 2: Thermal resistance vs. Sample thickness.

The temperature gradients in the blocks are multiplied by the obtained calibration coefficient (0.972) during the analysis. The calibration coefficient represents the uncertainty of the thermal conductivity measurement performed by setup against the nominal thermal conductivity values. Hence, the thermal flux through the blocks is calculated including the calibration coefficient.

4. Summary

This paper presents the design of a custom setup for measuring the through-plane thermal conductivity of materials. The setup is based on the ASTM D5470-06 standard and utilizes two heat flux meter brass blocks, with samples clamped between them. Temperature sensors embedded in both blocks allow for the measurement of heat flux trough and temperature gradient across the sample. To obtain the thermal conductivity, the thermal resistance of the samples with varying thicknesses are measured. The effectiveness of this setup is demonstrated by successfully calibrating it using brass and sapphire glass samples.

References

[1] ASTM D5470-06, Standard Test Method for Thermal Transmission Properties of Thin Thermally Conductive Solid Electrical Insulation Materials, ASTM International, 2006, DOI: 10.1520/D5470-06.

[2] David G. Cahill, S.-M. Lee, Torbjörn I. Selinder; Thermal conductivity of χ-Al2O3 and α-Al2O3 wear-resistant coatings. J. Appl. Phys. 1 June 1998; 83 (11): 5783–5786. https://doi.org/10.1063/1.367500

[3] Batz+Burgel GmbH. Brass alloy CW614N standard. batz-burgel.com

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