

# Characterization of the Thermal Conductivity of Silica Aerogels

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**Summary:** This study presents a simple and accurate method for quantifying the thermal conductivity of silica aerogels which are well-known for their low thermal conductivity ( $< 0.02 \text{ W m}^{-1} \text{ K}^{-1}$ ) and their highly porous structure [1]. In this setup, two aerogel blocks (diameter 2 cm, thickness 8 mm) are stacked with a small platin-based heating structure in-between and thermistors (diameter 7.5 mm) on the outside. This approach minimizes heating losses by ensuring the heat is transferred through the aerogel and measured by the sensors. The thermal conductivities found are in the range of  $0.015 - 0.024 \text{ m}^{-1} \text{ K}^{-1}$ , corresponding well to the values found in the current literature.

**Keywords:** High porosity, Silica Aerogel, Thermal conductivity, Thermal Insulation

## Introduction

The use of aerogels in microfluidic devices is very attractive due to their extremely high thermal insulation, which can be used in thermal micro-devices. Silica aerogels obtain their high insulation properties due to the high porosity (up to 99% [2]), and surface area. These properties and the fact that aerogels can be manufactured in all custom shapes make them ideal candidates for thermal insulation of microfluidic devices.

## Measurement principle and setup

The measurement principle to determine the thermal conductivity is based on the 'Absolute Method'. One side of the sample is placed on a heating structure with a set power, the other side is positioned on a temperature sensor (with heat sink). The thermal conductivity ( $\lambda$ ) can be determined from the temperature difference. The relation is shown in eq. (1) [3]. Here,  $\dot{Q}$  is the heat flow,  $s$  the height of the sample,  $A$  the cross-sectional area and  $\Delta T$  the temperature difference.

$$\lambda = \frac{\dot{Q} \cdot s}{A \cdot \Delta T} \quad (1)$$

The experimental setup is shown in Fig. 1. Sensors are glued with silver glue (Elecolit 414) to the aerogel samples and connected via  $150 \mu\text{m}$  wires to a digital multimeter (Keithley DMM6500). The heater is connected to a power supply, which is selected to give a total input power of 60, 220 and  $450 \text{ mW}$ .

## Sensor fabrication and characterization

The silica aerogels are manufactured based on the sol-gel process. First, Tetraethylorthosilicate (TEOS) is added to ethanol, DI water, and HCL to start the Hydrolyses reaction at  $45^\circ\text{C}$ . After 90

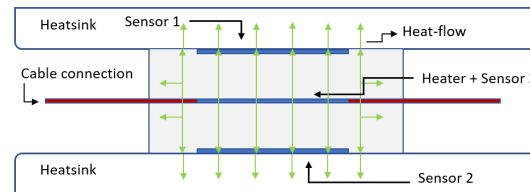


Fig. 1: Schematic side view of the setup. The green arrows indicate the flow-profile. Sensor 3 measures the temperature directly at the heater ( $T_{\text{Heater}}$ ).

minutes, the temperature is decreased to  $35^\circ\text{C}$ , and Ammonia is added to start the condensation reaction. After roughly 50 minutes, the gel is formed and the samples are placed in the mold (diameter 2 cm, height 8 mm). The samples are aged in a mixture of TEOS / ethanol and dried using  $\text{CO}_2$  critical drying (Leica CPD300). The complete process and molar ratios are shown in previous work [4].

The sensors are manufactured on silicon wafers and are based on a  $5 \mu\text{m}$  thick spin-coated polyimide layer (precursor U-varnish-S with 20% wt - polyamic acid content, UBE Europe GmbH) and 200 nm thick sputtered platin structures ( $100 \mu\text{m}$  linewidth) that serve as both a thermistor and a heater. The average resistances are  $320 \Omega$  and  $1650 \Omega$ , respectively. With a voltage applied, the aerogel structure heat up, changing the resistance of the thermistors. The relation between the actual temperature (in  $^\circ\text{C}$ ) and the resistance of the thermistors is give by eq. (2). These gave an average value for  $\alpha$  of  $0.0023 \text{ K}^{-1}$ .

$$R(T) = R(T_0)(1 + \alpha_{T_0} \cdot (T - T_0)) \quad (2)$$

## Results

An input power of 60, 220 and 450  $mW$  was applied to the heaters, and the resistance of the sensors (including the sensor directly next to the heater  $T_{Heater}$ ) was continuously monitored. The temperature is calculated from the resistance according to eq. (2), and the results are shown Fig. 2.

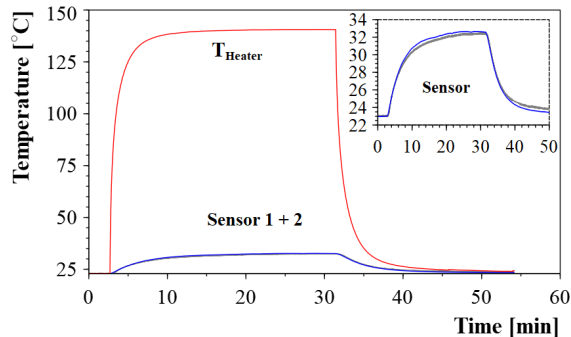


Fig. 2: Temperature response for 220  $mW$  applied to the heater.

The responses to a stepwise increase in the heating temperature is shown in Fig. 3, with a temperature of 70 to 230°C. Both sensors detect identical temperatures, confirming the robustness and reliability of the measurement setup.

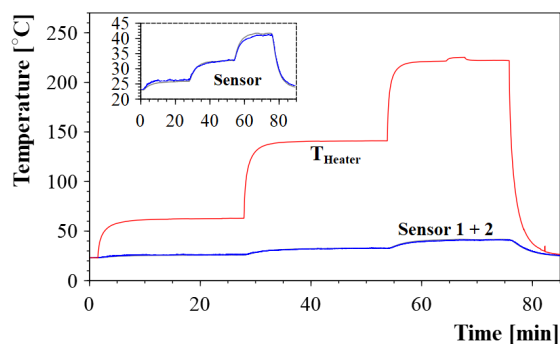


Fig. 3: Sensor response for step-wise increase of the heater power.

The calculated thermal conductivities ( $\lambda$ ) for the measurements are shown in Fig. 4. The values for  $\lambda$  changes slightly depending on the temperature of the aerogel, which is a known occurrence. The objects thermal properties are related by the objects temperature [5].

Every manufactured sensor consists of a heater and a thermistor. Therefore, it is possible to additionally measure the temperature with the heater structures on the outer sides of the aerogel blocks. This gives extra confirmation of the temperature, as shown in Fig. 4. The calculated values (with the heater structures) show identical values, validating the determined thermal conductivities.

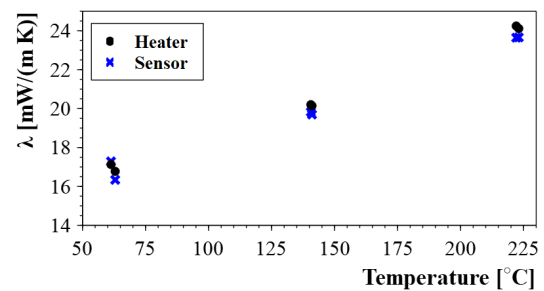


Fig. 4: Thermal conductivity of aerogel samples at different heating temperatures.

## Conclusions and Outlook

This abstract presents a reliable method for determining the thermal conductivity of samples with extremely low values. The thermal losses in the setup are minimized by placing the sensor between two small aerogel blocks. This inhibits heat flow around the samples and also ensures that all heat goes in the aerogel (evenly distributed in both samples). The measurement setup features a total of five temperature sensors, enabling for accurate temperature readings and calculated thermal conductivities. The thermal conductivities ( $0.015 - 0.024 m^{-1}K^{-1}$ ) found in this research can help further research to minimize heat losses in micro-chambers/reactors and/or other insulation in microfluidic devices. Future research will focus on integrating the aerogels with IC technology to improve the connections between the aerogel and the sensor.

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