Cold Under Control: Precise Thermal Conductivity Measurement on Silicone TIMs at Low Temperatures

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Introduction

Silicone-based gap pads are widely used as thermal interface materials (TIMs) in electronics, power modules and battery systems. Their main function is to bridge air gaps between heat-generating components and heat sinks while compensating for surface roughness and mechanical tolerances. Besides mechanical compliance, the thermal conductivity of the pad is one of the key parameters for evaluating its suitability in a specific thermal management design.

Method and Measurement Conditions

To obtain meaningful thermal conductivity values, especially at low temperatures, the LFA measurement is ideally complemented by DSC-based specific heat capacity determination. The powerful combination of LFA, DSC and density data provides an overall and dependable picture of the material's thermal performance.

Therefore, the thermal diffusivity was measured by Laser Flash Analysis using the NETZSCH LFA 717 *HyperFlash*®. The specific heat capacity (c_p) was determined separately by DSC using the NETZSCH DSC 204 ***F1*** *Phoenix*®. Together with the sample density, the thermal conductivity was calculated according to:

$$\lambda = \alpha \cdot c_p \cdot \rho$$

with
λ = thermal conductivity in W/(m·K)
α = thermal diffusivity in mm^2/s
c_p = specific heat capacity in J/(g·K)
ρ = density in g/cm^3

The measurements were carried out under a nitrogen atmosphere. The DSC measurement was used to determine the specific heat capacity and energetic transitions of the silicone pad. In total, two samples were tested and for calculation of thermal conductivity the averaged c_p values were taken.

The LFA measurement provided the temperature-dependent thermal diffusivity.

Table 1 shows the measurement conditions for DSC and LFA.

Table 1 Measurement conditions for DSC and LFA

Method	DSC	LFA
Instrument	DSC 204 ***F1*** *Phoenix*®	LFA 717 *HyperFlash*®
Atmosphere	Nitrogen	Nitrogen
Temperature program	-150°C to 310°C	-100°C to 300°C
Heating rate	10 K/min	10 K/min
Sample mass	Sample 1: 11.205 mg; Sample 2: 11.224 mg	-
Sample dimensions	Ø 4 mm, 1 mm thick	20 mm x 20 mm x 0.8 mm
Sensor/thermocouple	DSC 204 ***F1*** *t*-sensor, type E	MCT, type K

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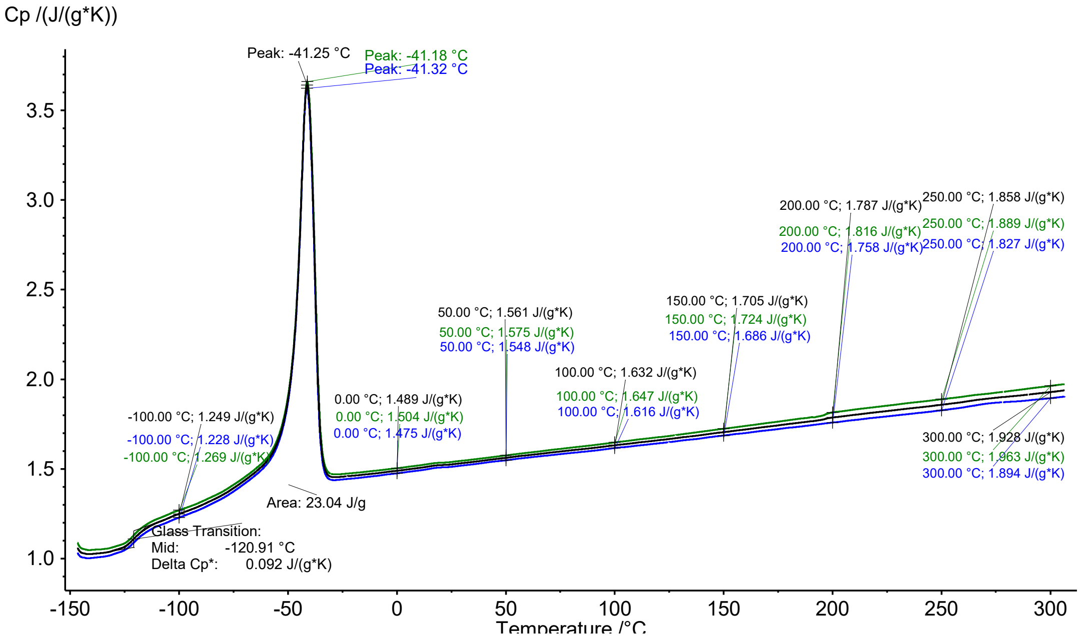
Results

The DSC measurement shows the temperature-dependent specific heat capacity of the silicone pad between -150°C and 310°C (Figure 1). At low temperatures, a glass transition is observed at approximately -121°C. The change in specific heat capacity at the glass transition is about 0.09 J/(g·K). A pronounced endothermic peak occurs at approximately -41°C, which is assigned to the melting transition of crystalline or ordered silicone-related domains. The measured melting enthalpy is approximately 23 J/g.

The results show a gradual increase in c_p with increasing temperature, as expected for polymeric materials. The endothermic effect around -41°C was not used directly for the thermal conductivity calculation. Instead, the c_p curve was interpolated across this transition region in order to avoid including latent heat contributions in the conductivity calculation.



1 Apparent specific heat capacity of the silicone pad.

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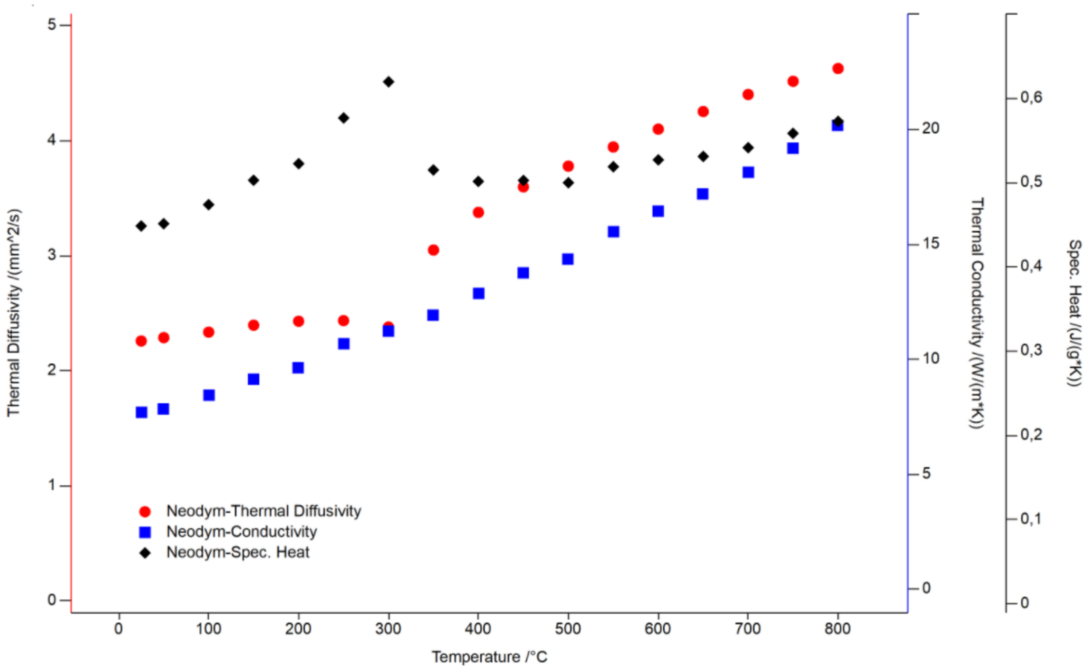

2 Thermophysical properties of the silicone pad.

The thermal diffusivity of the silicone pad decreases continuously with increasing temperature, see Figure 2. At low temperatures around -100°C, the diffusivity is approximately 0.18 mm^2/s. At room temperature, values around 0.14 mm^2/s are observed. At 300°C, the diffusivity decreases to approximately 0.08 mm^2/s.

This behaviour is typical for polymer-based materials. With increasing temperature, phonon transport becomes less efficient due to increasing molecular mobility and enhanced scattering processes. As a result, the thermal diffusivity decreases, even though the specific heat capacity increases.

The calculated thermal conductivity remains within a comparatively narrow range over the investigated temperature interval. At low temperatures, the conductivity is approximately 0.25 W/(m·K). With increasing temperature, the conductivity decreases and reaches values of approximately 0.17 W/(m·K) at 300°C.

Conclusion

This example shows that the LFA 717 *HyperFlash*® provides reliable thermal diffusivity data over a wide temperature range – including challenging cryogenic conditions – thanks to its high sensitivity and precise temperature control, even with slow-reacting silicone-based interface pads. Especially in the low-temperature range, the supplementary determination of the specific heat capacity using DSC is crucial, as only the combination of LFA data, c_p values and density allows for reliable calculation of the thermal conductivity. This ability to deliver reliable results even below room temperature is a clear advantage for the development of modern silicone TIMs.

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