APPLICATION **NOTE**

Liquid Metal – Laser Flash Analysis

Advanced LFA Solution: Analysis of Gallium-Based Liquids

Jinyan Li, Applications Laboratory Shanghai, and Dorothea Stobitzer, Applications Laboratory Selb

Introduction

Gallium (Ga)-based liquid metals are emerging as key materials in the field of high-power electronic cooling due to their exceptional electrical conductivity, thermal conductivity, and flow properties. In thermal management, Ga and Ga-indium (In) alloys can serve as thermal interface materials, filling the gaps between chips and heat sinks to efficiently dissipate heat generated by core components such as CPUs and GPUs. This significantly reduces operating temperatures and ensures stable device operation. Their thermal dissipation efficiency far exceeds that of thermal grease and thermal pads. Furthermore, Ga and Ga-based alloys possess an extremely wide liquid temperature range (from sub-zero temperatures to over 2000°C) and a thermal conductivity far superior to that of water, making them highly promising convective cooling media for high-power-density chips, aerospace applications, and other fields.

Accurate testing of the thermal conductivity of Ga and Ga-In alloys is essential to ensure their safe and efficient operation in critical thermal management applications. Laser/Light Flash Analysis (LFA) not only measures the thermal conductivity of conventional solid samples and – when using appropriate sample holders and selecting suitable calculation models – can also measure the thermal diffusivity of special samples such as liquids, pastes, and powders, and thereby calculate their thermal conductivity. This Application Note focuses on the method used by the NETZSCH LFA 717 *HyperFlash®* to determine the thermal conductivity of pure Ga and Ga-In alloy samples using a PEEK liquid sample holder.

Measurement Conditions

Table 1 Measurement conditions

Sample	Pure Ga GaIn (Ga_{75} In_{25}) GaInSn ($Ga_{68,5}$ $In_{21,5}Sn_{10}$)
Temperature	30°C, 60°C, 90°C, 120°C
Sample holder	PEEK sample holder for liquids
Specific heat capacity	DSC 300 *Caliris® Select*
Atmosphere	N_2
Model	3 layers + pulse correction

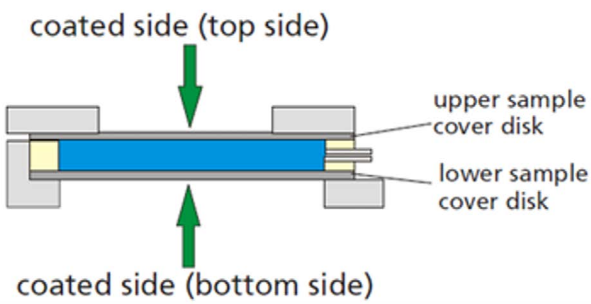
NGB · Application Note 462 · EN · 0726 · Technical specifications are subject to change.

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

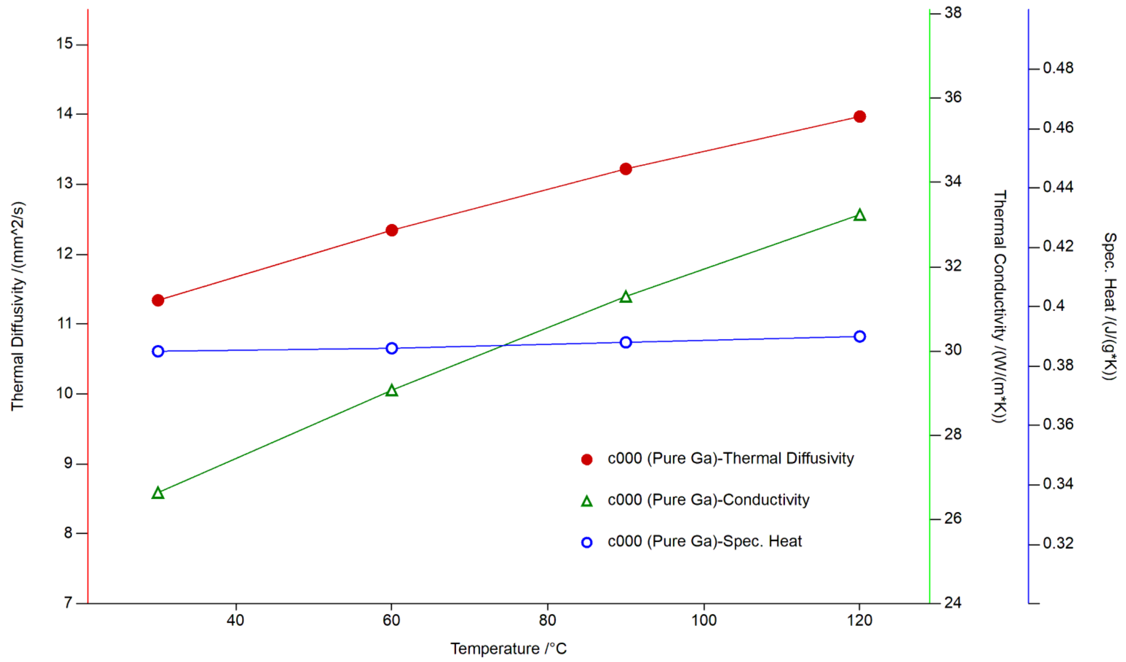
Measurement Results

Figure 1 shows the results for the thermal diffusivity, specific heat capacity (c_p), and thermal conductivity of a pure Ga sample, measured over a temperature range of 30°C to 120°C. At 30°C, the sample's thermal diffusivity and thermal conductivity amounted to 11.4 mm²/s and 26.6 W/(m·K), respectively, which is consistent with values reported in the literature [1]. Both the thermal diffusivity and thermal conductivity increase with rising temperature. The specific heat capacity (c_p) was measured using a NETZSCH DSC 300 *Caliris® Select*. It should be noted that, due to the aggressive reaction between Ga and aluminum (Al), a platinum (Pt) crucible lined with Al_2O_3 was used for the measurement.

The PEEK liquid sample holder is based on a three-layer model. After assembly, liquid samples can be loaded into the container – composed of upper and lower stainless-steel disks and a PEEK ring – via injection, droplet addition, or smearing (see Figure 2). This special sample holder can be used to test samples such as liquids, liquid metals, and pastes.



2 Photo (top) and schematic (bottom) of the PPEK liquid sample holder

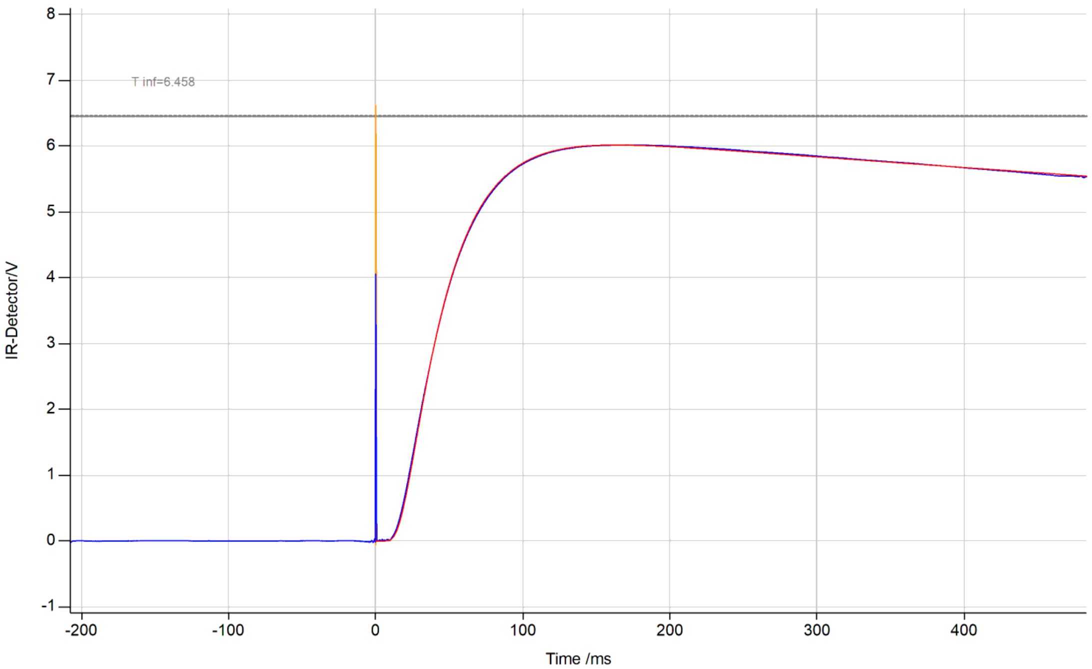


1 Thermophysical properties of pure gallium

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

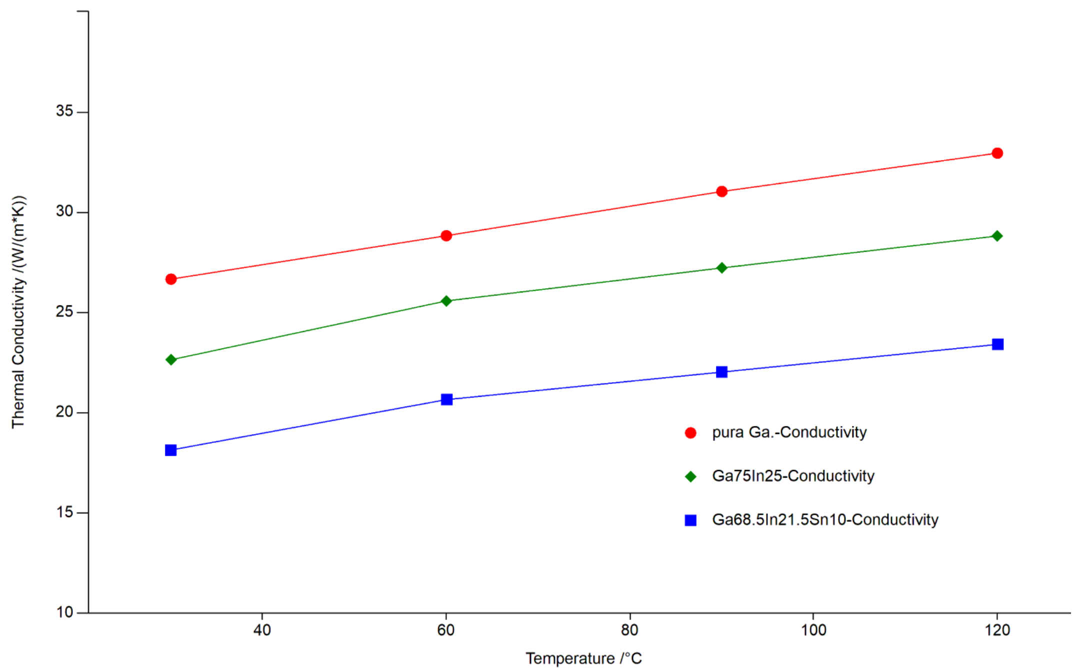
When using this holder, a three-layer model is employed to calculate the thermal diffusivity. Figure 3 shows the temperature rise curve of the pure Ga sample at 30°C. It can be seen that the measured curve (blue) matches the model-fitted curve (red) very well, further demonstrating the validity and accuracy of the test results obtained using the PEEK sample holder for liquids.

The melting point of pure Ga is approximately 29.8°C. It remains in a solid state under typical room temperature conditions and cannot be used directly as a liquid thermal interface material or a flowing working fluid. Adding elements such as In and tin (Sn) to Ga forms eutectic alloys that significantly lower the melting point. For example, the commercial Ga-In-Sn alloy Galinstan has a melting point as low as -19°C. This means it remains liquid under most natural environmental conditions, greatly expanding its range of applications.



3 Measured temperature rise curve (blue) and model-fitted curve (red) show excellent agreement. Sample: pure Ga. Temperature: 30°C.

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



4 Thermal conductivity of pure Ga, Ga-In alloy, and Ga-In-Sn alloy.

Figure 4 shows the thermal conductivity results for pure Ga and the GaIn (Ga_{75} In_{25}) and GaInSn ($Ga_{68.5}$ $In_{21.5}Sn_{10}$) alloys, tested using the PEEK liquid sample holder from 30°C to 120°C. It is evident that alloying Ga with In and Sn leads to a decrease in thermal conductivity. The addition of In and Sn introduces extra free-electron scattering centers in liquid Ga, shortening the electron's mean free path and lowering the thermal conductivity as heat transport in gallium liquid metals is dominated by free electrons [2]. An alloy composition (including In and Sn contents) significantly affects thermal conductivity, and accurate measurement of thermal conductivity provides a basis for the screening and formulation optimization of gallium-based liquid metals.

Summary

Liquid metals based on gallium can flow like water while possessing excellent thermal conductivity and stability, demonstrating extraordinary potential in the field of heat dissipation. The NETZSCH LFA 717 *HyperFlash*®, paired with the special PEEK sample holder for liquids and using a dedicated three-layer calculation model, can accurately measure the thermal conductivity of gallium-based liquid metals. This is very important for accurately evaluating the heat dissipation capability of liquid metals and further providing efficient and reliable thermal management solutions.

Literature

[1] Y. S. Touloukian et al. (1970). Thermophysical Properties of Matter: The TPRC Data Series. Thermal Conductivity: Metallic Elements and Alloys. (S. 107)
[2] Dickey, M. D. Gallium Liquid Metal: The Devil's Elixir. Annu. Rev. Mater. Sci. 2017, 47, 103–130.

NGB · Application Note 462 · EN · 0726 · Technical specifications are subject to change.

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