

Advanced Thermal Conductivity Measurement Techniques for Ultrathin Two – Dimensional Materials in 1 – 100 nm Regime

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Abstract

Thermal conductivity (κ) is an important physical parameter to know the electron and phonon behaviour across the dimensions of atomically thin materials. However, accurate measurement of κ in 2D materials when the film is within 1-100 nm is challenging due to experimental difficulties such as heat input precision, rise in temperature and stress induced uncertainties in addition to the sample variations. This work presents a focused assessment of experimentally validated thermal conductivity measurement techniques applicable to ultra-thin 2D materials in the thickness range from ~ 0.34 nm to ~ 100 nm, emphasizing their measurable κ ranges, thickness limits, and dominant uncertainties. Optothermal Raman thermometry, applicable to 2D materials up to 0.34–5 nm, enables non-contact in-plane κ measurement, typically resolving κ values between ~ 1000 and 4000 $\text{W m}^{-1} \text{K}^{-1}$, although uncertainties of ± 30 – 50% arise from laser absorption calibration and heat-spreading models. Suspended micro-bridge techniques, suitable for freestanding ultra-thin films up to ~ 50 nm, provide direct electrical heating and resistance thermometry, allowing absolute in-plane κ measurement over a broad range of ~ 1 to >3000 $\text{W m}^{-1} \text{K}^{-1}$ with reduced model dependence and typical uncertainties below $\pm 20\%$, at the expense of complex fabrication. For thin films ~ 20 – 100 nm, time-domain and frequency-domain thermoreflectance techniques enable cross-plane κ measurement in the range of ~ 0.1 – 100 $\text{W m}^{-1} \text{K}^{-1}$ and extraction of thermal boundary conductance values typically between 10 and 300 $\text{MW m}^{-2} \text{K}^{-1}$. However, sensitivity below ~ 20 nm becomes increasingly dominated by interface resistance and metal transducer properties. By clearly selecting each technique to its valid thickness and κ sensitivity range, this work provides practical guidance for selecting appropriate thermal measurement tools for selecting 2D materials in both fundamental studies and device-level applications.

References

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Figures

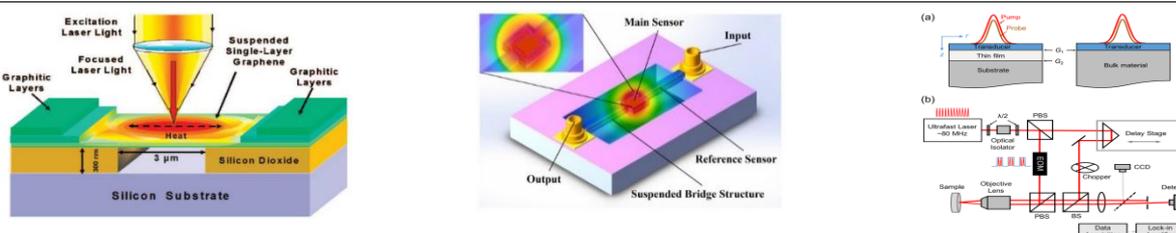


Figure 1. Schematic comparison of optothermal Raman thermometry, suspended micro-bridge, and thermoreflectance (TDTR/FDTR) techniques for thermal conductivity measurement in two-dimensional materials, highlighting their applicable thickness ranges, measurable conductivity regimes, and dominant uncertainty sources.