Raman Thermal Conductivity Measurements

Assessing Error & Uncertainty

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Purpose:

Raman thermometry increasingly utilized to measure thermal conductivity (κ).
Investigate sources of error & uncertainty within these measurements.

Problem:

Sources of error and uncertainty are convoluted in actual experiments.
It is difficult to systematically assess their presence and significance.

Premise:

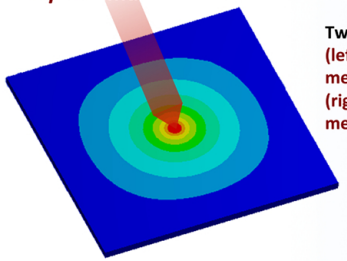
Perform a virtual experiment via numerical simulation.
Directly insert sources of error & uncertainty into simulation.
Assess induced alterations in "measured" thermal conductivity.

Advantages of Raman

Obtained Information	Material specific	In-plane conductivity	Sensitivity to 2D- materials
Experimental Set-up	Non-contact	<1μm spatial resolution	Minimal sample preparation

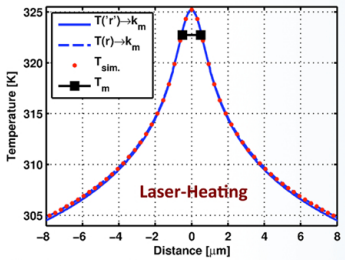
Virtual Raman Experiment

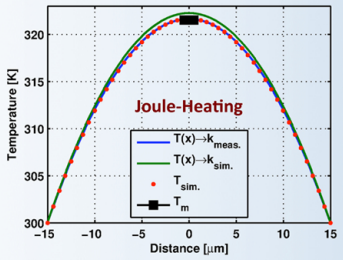
***Step 1:** Simulate Raman thermal conductivity measurement.*



Two experiments:
(left) Laser-heating used to measure 2D-materials.
(right) Joule-heating used to measure nanowires.

***Step 2:** Fit thermal conductivity within analytical model to match temperature measured using Raman.*

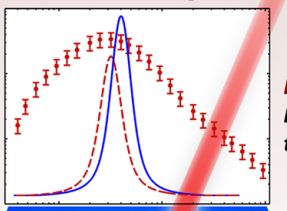


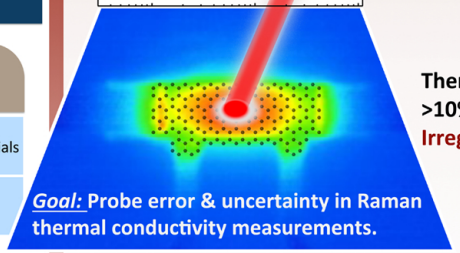


***Step 3:** Compare "measured" thermal conductivity to value used in simulation. Differences between values occur because of error and uncertainty.*

Quantifying Error & Uncertainty

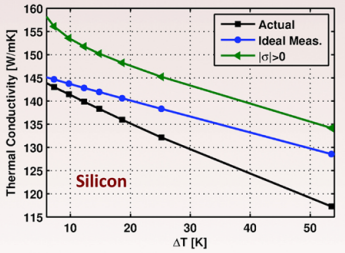
***Translator:** Thermal conductivity is not measured directly. Temperature is translated to κ using thermal model. Model is not perfect → Error*



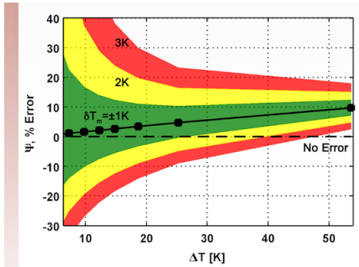


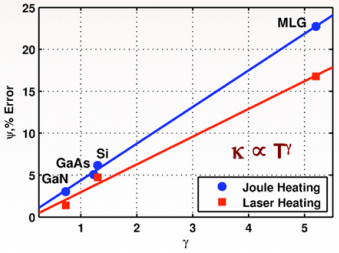
***Goal:** Probe error & uncertainty in Raman thermal conductivity measurements.*

Ideal is not enough:
Error exists even when thermometer is perfect.



Thermal models imperfectly describe experiment.
>10% error from: Interfaces, κ independent of T, Irregular geometries





***Uncertainty:** κ deduced from measurements of temperature & heat flux having uncertainty → ±κ*
Uncertainty comparable to other techniques if ΔT>20K

***Takeaway:** Errors of 10% coupled with uncertainties of ±10% achievable in typical experiments. But…technique ineffective for certain materials and ΔT.*

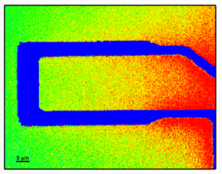
Error from Thermomechanical Stress

***Problem:** Evolution of stress causes error in Raman based temperature measurements → Error in κ*

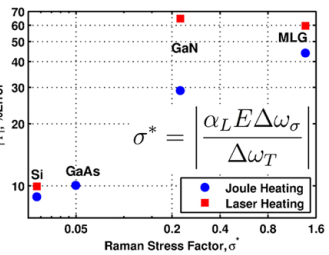
***Implication:** Error from stress can be >50%. Raman not effective if significant stress develops with heating.*

***Dependence:** Error scales with dimensionless parameter, σ*, termed the Raman stress factor.*

$$\sigma^* = \left| \frac{\alpha_L E \Delta\omega_\sigma}{\Delta\omega_T} \right|$$



σ* also provides sensitivity stress based errors for standard Raman thermometry measurements (right).



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