# A novel contactless technique for thermal field mapping and thermal conductivity determination: Two-Laser Raman Thermometry

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## Abstract

We present a novel contactless technique for thermal conductivity determination and thermal field mapping based on creating a thermal distribution of phonons using a heating laser, while a second laser probes the local temperature through the spectral position of a Raman active mode. The spatial resolution can be as small as 300 nm, whereas its temperature accuracy is ±2 K. We validate this technique investigating the thermal properties of three free-standing single crystalline Si membranes with thickness of 250, 1000, and 2000 nm. We show that for 2-dimensional materials such as free-standing membranes or thin films, and for small temperature gradients, the thermal field decays as $T(r) \propto \ln(r)$ in the diffusive limit. The case of large temperature gradients within the membranes leads to an exponential decay of the thermal field, $T \propto \exp[-A \cdot \ln(r)]$. The results demonstrate the full potential of this new contactless method for quantitative determination of thermal properties. The range of materials to which this method is applicable reaches far beyond the here demonstrated case of Si, as the only requirement is the presence of a Raman active mode.

In Fig. 1a we show schematically the two-laser Raman thermometry (2LRT) experimental arrangement. A heating laser with $\lambda_1$=405 nm is focused onto the lower surface of the Si membranes, whereas a probe laser with $\lambda_2$=488 nm is scanned over its upper surface to obtain the local temperature. We note that while relatively high powers were used for the heating laser ($\lambda_1$) in order to create a spatially dependent thermal field, low powers were employed for the probe laser ($\lambda_2$) to avoid an additional thermal perturbation. Figure 1b displays a 2-dimensional (2D) temperature map of a 250 nm thick Si membrane obtained using 2LRT. The maximum temperature at the center, i.e. with the heating and probe lasers at the same position of the membrane, is ≈800 K and a radially symmetric thermal decay is observed in a constant temperature projection plane. The radial symmetry observed in the 2D maps arises from the isotropic thermal behavior of Si at room temperature. However, for materials with a spatially-dependent thermal conductivity ($\kappa_{ij}$), an asymmetric thermal decay is expected.

In order to obtain the thermal conductivity of the membranes we measured a line scan of the thermal field in the (X, Y, 0) plane containing the coordinates origin as shown in Fig. 2a for three Si membranes with thicknesses of 250, 1000, and 2000 nm. The inset shows an optical image of the 250 nm thick membrane. All three membranes exhibit a qualitatively similar behavior, i.e. a similar decay length and half width of the thermal field profile. We note that the minimum temperature obtained in these maps is also above the thermal bath temperature, reaching ≈330 K at 150 μm in comparison to the ≈400 K obtained in the 2D thermal map of Fig. 1b, which arises from the smaller heating powers used for the line scans of Fig. 2. This is also reflected in the maximum temperature rise observed at the central position of the line scans. For this geometry, the thermal decay is linear in ln(r), thus, we show in Fig. 2b the data corresponding to Fig. 2a in logarithmic scale. Finally, we obtain $\kappa$ = 80 ± 3, 133 ± 6, 147 ± 8 W/mK for the 250, 1000, and 2000 nm membranes, respectively, which compare well with preciously published values. This technique should provide an extra step towards a deeper understanding of thermal management in n-dimensional materials since it gives the complete thermal response of a system, T (r), subjected to a thermal perturbation.

## Figures

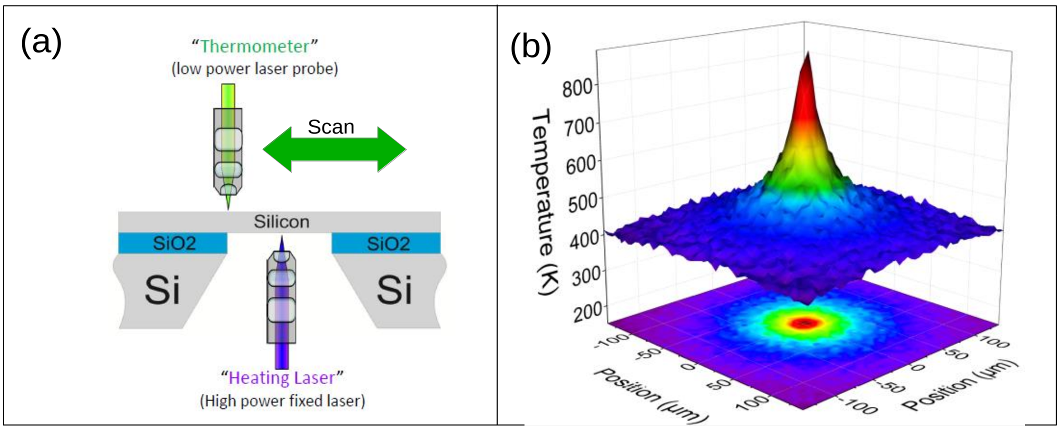

**Figure 1:** (a) Schematics of the Two-Laser Raman Thermometry experimental setup. To lower laser is used as heating source, whereas the upper laser probes the local temperature through the spectral shift of the longitudinal optical Raman mode of Si. (b) 2-dimensional thermal map of a 250 nm thick free standing Si membrane. A projection of the thermal field is also shown in a lower plane.

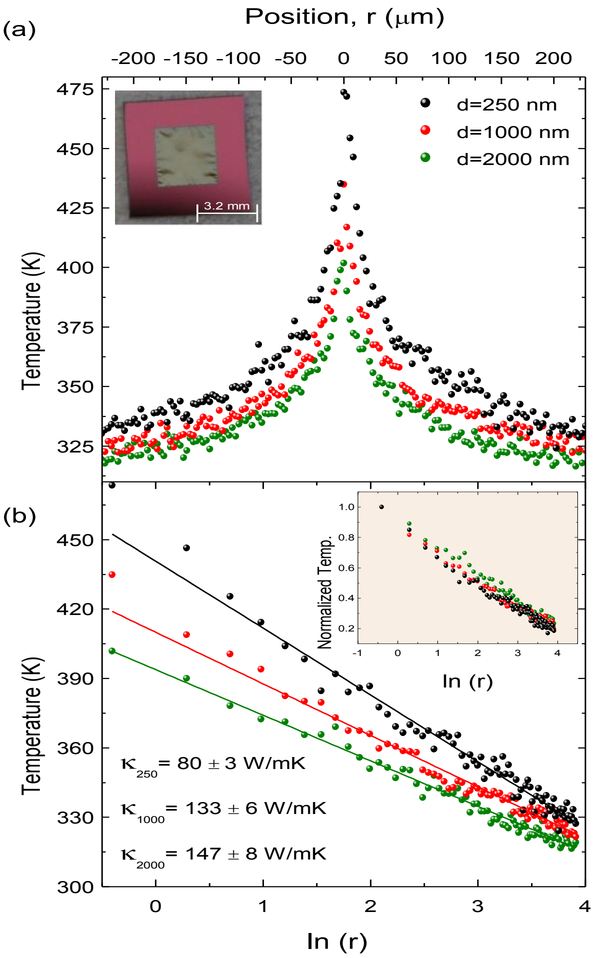

**Figure 2:** (a) Line scans of the thermal field as shown in Fig. 1b. The line scan was recorded using a lower heating power than for the 2D map in Fig. 1b to ensure that $\kappa \neq \kappa(T)$. The inset shows an optical image of the 250 nm thick membrane. (b) Same as (a) but in logarithmic scale to visualize the ln(r) dependence. The inset shows the normalized temperature rise, $T_{rise}$=T(r)−294K for the three membranes.