Influence of Flake Thickness and Environment on Heat Dissipation Capabilities of Suspended $MoSe_2$ Single Crystals

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Transition metal dichalcogenides (TMDs) are layered, two-dimensional (2D) semiconductors which hold promises in future (opto)electronic devices. Importantly, 2D materials can be thinned down to the monolayer, typically with sub-nanometer thickness. Recently, thermal transport properties of TMDs have gained considerable attention because of their anisotropic nature [1]. However, a deep understanding of heat flow in TMDs is missing even though such understanding is crucial to fully exploit them in device applications [2]. In this work [3], we use Raman thermometry to systematically study the effects of flake thickness (0.7–50 nm) and its environment (vacuum, air or N_2) on the thermal transport properties of single-crystalline $MoSe_2$ flakes suspended over large, circular apertures (177 µm^2). Our results suggest that, in vacuum, the in-plane heat flow has a similar thermal conductivity (κ) at 400 K in mono- and few-layer flakes (~20 W/m/K), as in their bulk counterparts (~30 W/m/K). This is due to the appearance of low frequency (~0.1 THz) heat-carrying phonon modes that compensate for the decreasing contribution of interlayer phonon modes (~1 THz) in the thinnest TMDs. Owing to the surface-to-volume ratio increase with decreasing thickness, efficient out-of-plane heat transfer to air or N_2 molecules results in an apparent thermal conductivity (κ_{app}) enhancement of up to one order of magnitude (~200 W/m/K for monolayer flakes) [3]. These findings may provide clear pathways to engineer heat flow in (sub-)nanometer TMDs that are significantly thinner than the smallest state-of-the-art Si structures.

References

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Figures

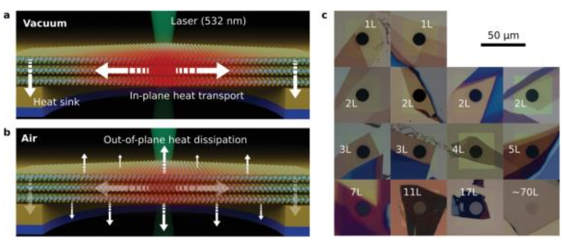

Figure 1: Raman thermometry experiment schematized in **(a)** vacuum and **(b)** air. A laser heats and monitors the temperature of a suspended flake to extract the thermal conductivity. A higher (lower) temperature corresponds to a less (more) efficient heat dissipation. **(c)** Optical images of the suspended few-layer $MoSe_2$ flakes studied in this work.