Observation of non-diffusive phonon heat transport in ultrathin layered semiconductors $MoSe_2$ and MoS_2

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Understanding and controlling heat flow is of great fundamental interest and of crucial importance for the design and operation of a host of semiconductor-based devices, components, and systems. The layered semiconductors of the transition metal dichalcogenide (TMD) family, such as $MoSe_2$, MoS_2, WSe_2 and WS_2, are projected to play an important role in several (opto)electronic applications. For example, there are roadmaps predicting TMDs serving as transistor channel material within a decade from now, and companies such as TSMC are actively researching TMD-based transistors [1]. It is therefore crucial to understand heat transport in these materials.

We have recently developed a novel experimental technique to follow heat diffusion in thin films directly in space and time and have applied this to the transition metal dichalcogenides $MoSe_2$, MoS_2, WSe_2 and WS_2 [2]. For flakes with a thickness around 15 nm, this spatiotemporal thermometry technique gives diffusivities that agree well with both experimentally obtained thermal conductivities in literature and our own ab-initio calculations of the thermal diffusivities of these materials [2]. We have also found that $MoSe_2$ starts outcompeting silicon for thicknesses below a few tens of nanometers in terms of in-plane thermal conductivity [3].

In most cases, heat transport follows Fourier's law of diffusion, where a photo-induced hot spot gradually spreads out spatially while cooling down. Deviations from diffusive Fourier heat transport can occur in the ballistic regime on short time- and length-scales, and in the hydrodynamic regime, where heat flow is "viscous". Hydrodynamic phonon heat transport has been predicted to occur for several layered materials [4,5], and manifestations of this regime have been observed in (multilayer) graphene below room temperature [6,7].

Using our spatiotemporal thermometry technique, we observe the occurrence of strongly non-diffusive heat transport for ultrathin suspended $MoSe_2$ and MoS_2 flakes at room temperature [8]. We attribute this observation to the combination of nonlocality and thermoelasticity, which constitutes a novel regime of non-diffusive transport. Our mesoscopic model of these combined effects indeed reproduces the experimental results.

The observation of non-diffusive heat transport at room temperature opens up interesting new pathways towards thermal management and thermoelectric energy generation based on ultrathin layered semiconductors.

References

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