Non-diffusive phonon heat transport in layered semiconductors

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For a host of applications it is crucial to understand and control heat dissipation. This is particularly true for transistors and interconnects, which are playing crucial roles in information and communication technologies. These are also applications where 2D materials will likely start playing an important role in the not-so-distant future. Therefore, it is 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 [1]. 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 [1,2]. For these flakes, heat transport follows Fourier's law of diffusion, where a photo-induced hot spot gradually spreads out 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 [3,4], and manifestations of this regime have been observed in (multilayer) graphene below room temperature [5,6].

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 [7]. This is not expected based on conventional ballistic or hydrodynamic heat transport. 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 identification 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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