Super-Planckian Electron Cooling in a van der Waals Stack

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Van der Waals heterostructures have emerged as promising building blocks that offer access to new physics, novel device functionalities, and superior electrical and optoelectronic properties. Applications such as thermal management, photodetection, light emission, data communication, high-speed electronics and light harvesting require a thorough understanding of (nanoscale) heat flow. In graphene, ultra-long cooling times due to the electron-phonon coupling, of the order of nanoseconds, have been theoretically predicted. [1,2] Unfortunately, the cooling dynamics in graphene samples deposited on SiO_2, is believed to be dominated by far more efficient disorder-assisted collisions between electrons and graphene acoustic phonons. [3]
On the contrary, graphene/hexagonal boron nitride (hBN) heterostructures exhibit nearly ideal transport characteristics, [4] but support low-loss standing phonon-polariton modes between the reflecting top and bottom interfaces. [5] Hot carriers in graphene can transfer their energy to the phonon-polaritons in hBN. We present a microscopic theory of radiative heat transfer (RHT) to hBN phonon-polaritons. RHT between macroscopic bodies at separations that are much smaller than the thermal wavelength is ruled by evanescent electromagnetic modes and can be orders of magnitude more efficient than its far-field counterpart, which is described by the Stefan-Boltzmann law. We demonstrate that RHT between hot carriers in graphene and hyperbolic phonon polaritons in hBN is in fact extremely efficient at room temperature, leading to picosecond time scales for the carrier cooling dynamics. [6] We find excellent agreement with time-resolved photocurrent measurements. [7]

Figures

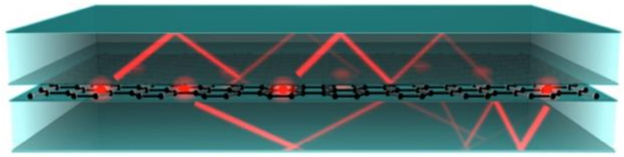

Figure 1: A schematic view of the physical system: hot carriers in graphene efficiently radiate energy into phonon-polariton modes in nearby hyperbolic crystal slabs. [6]

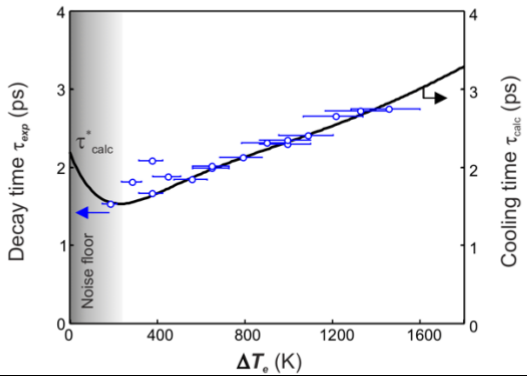

Figure 2: Comparison between measured decay time and calculated cooling time as a function of electron temperature. [7]

References

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