

Boron Nitride Encapsulated Structure as Efficient Heat Dissipation for Nano-Electronics

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Atomically thin two-dimensional materials, such as graphene, moly-disulfide (MoS₂), and hexagonal boron nitride (h-BN), attract increasing attention owing to their unique electrical, optical, and mechanical properties and applications. Among several 2D heterostructures, a fully h-BN encapsulated structure emerges as a novel platform with significant performance enhancement. Owing to strong, in-plane, ionic bonding of the planar hexagonal lattice structure, h-BN offers a flatter substrate which screens the dangling bonds and Coulomb scattering, in the electrical domain, photonics domain, etc. Though significant efforts have been achieved in h-BN encapsulated 2D devices, thermal properties, including both lateral and interfacial thermal transport, in encapsulated structures remain unexplored. In the present effort and process of achieving high-quality 2D field effect transistors (FET), low thermal conductance between 2D materials and the substrate is regarded as one of the major limitations. In this work, we investigate both lateral and interfacial thermal transport in fully h-BN encapsulated MoS₂ devices. We fabricate a suspended and supported h-BN/MoS₂/h-BN structure using the PDMS dry-transfer method. Utilizing the refined optothermal Raman technique, interfacial thermal conductance as well as lateral thermal conductivity in the BN/MoS₂/BN interface are studied. The top(bottom) h-BN exhibits lateral thermal conductivity around 131 ± 27 W/mK. Lateral thermal conductivity of MoS₂ in the encapsulated device is about 86 ± 31 W/mK, which is higher than MoS₂ on SiO₂. The interfacial thermal conductance in BN/MoS₂/BN interface is about 60 ± 27 MW/m²K, which is significantly higher than MoS₂/SiO₂ structures. We plotted temperature maps of MoS₂ FET and BN encapsulated MoS₂ FET, and found that the latter has significantly lower temperature, which allows higher voltages going through the device, thus providing improved performance. This demonstrates the fully BN encapsulated structure offers great heat dissipation for MoS₂. This work not only opens new opportunities for studying thermal transport mechanism in 2D heterostructure devices, but sheds light on engineering high-performance 2D FETs with low energy dissipation.