2D crystal semiconductors: electron transport and device applications

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Two-dimensional crystals have provided a new and rich playground to interrogate electronic behavior in solids. In addition to their unique aspects on dimensionality and symmetry, the explosion on 2D crystal studies in the literature has largely benefitted from the fact that the surface atoms in the 2D crystals interact with the rest of the world primarily via van der Waals interaction. The weak van der Waals interaction with the surroundings makes it possible for an isolated 2D layer to often behave like an "ideal" material in a homogenous dielectric environment, which means it does not suffer from broken bonds and reconstructed surfaces thus a different band structure from the bulk as for a surface of 3D materials. To interrogate effects of dimensionality in 3D materials, quantum wells/wires/dots are buried in a 3D platform with sufficiently high-quality surfaces/interfaces; for example, GaAs quantum well sandwiched between epitaxial AlGaAs barriers, Si nanowire coated with thermal SiO_2. High-quality surface passivation for 2D materials is still desired, for example, the widely hailed hBN encapsulation to maximize charge carrier mobility or electron-hole radiative recombination lifetime; however, it is not absolutely necessary to observe some of the basic properties of these 2D materials. Perhaps one of the most impactful realities is that one can set up a laboratory to prepare an infinite number of 2D materials and heterostructures for less than $100k, which is in stark contrast to the high capital needs to prepare 3D materials of "comparable" quality.

In this context, we ask the following questions on the family of 2D semiconductors. What are the fundamental similarities and differences in band structure, carrier transport, thermal conductivity between the 2D and 3D semiconductors? What are the unique applications that 2D semiconductors offer? In this tutorial, I will discuss several examples.