Understanding and Engineering Electronic and Optoelectronic Properties of 2D Materials and Their Interfaces

By

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In the pursuit of further miniaturization beyond Moore’s law, a tremendous amount of efforts has been dedicated to exploring the potential of two-dimensional (2D) materials as a candidate active material for nanoscale electronic devices. 2D materials indicate a group of solid state materials that possess strong in-plane covalent bonds while individual atomic layers are held together by weak van der Waals (vdW) interactions. Hence, the bulk crystals can be exfoliated into their few-layer or even atomically thin single-layer form via micro-mechanical exfoliation techniques, giving rise to unique and exotic properties due to the quantum confinement effect that may open up numerous possibilities in the future electronics. However, many different types of problems need to be solved to make electronic devices based on 2D materials competitive with or even superior to the conventional Si-based electronics. For example, as the 2D material-based devices become smaller and smaller down to the nanometer scale, the electrical contacts must also be reduced in scale which may lead to different characteristics from those of the macroscopic counterparts. In addition, reliable capabilities of developing artificial 2D heterostructures composed of dissimilar 2D materials will be required to achieve 2D structures with specific properties suited for a specific target application.

Thus, to realize and further advance 2D nanoelectronic devices developed in research laboratories into the consumer electronics market, profound understanding and sophisticated engineering of the unavoidable interfaces—between metal-2D material and 2D material-2D material—is critical. To this end, this thesis is devoted to acquiring fundamental knowledge of nanoscale metal-2D semiconductor (SC) and 2D SC-2D SC junctions wherein major topics explored are: (1) electronic and optoelectronic behaviors at the nanoscale junction of metal-MoS₂ and their dependence on the layer number (thickness), (2) realization of voltage selectable photodiodes based on a lateral in-plane MoS₂-WSe₂ heterojunction, and (3) interfacial properties and (opto)electronic characteristics of a phosphorene-MoS₂ vertical vdW p-n junction.

The first part of this thesis explores the layer number dependent electrical characteristics of the MoS₂-metal nanoscale junction using current imaging of MoS₂ nanosheets consisting of regions of varying different thicknesses using conductive and photoconductive spectral atomic force microscopy (C- and PCS-AFM). The second part of this thesis investigates the spatially resolved transverse electrical properties of the monolayer WSe₂-MoS₂ lateral p-n heterostructures at their nanoscale junctions with metals both in the dark and under laser illumination. The last part of this thesis explores a new type of 2D vertical heterostructures that simultaneously possess desirable properties of constituent materials, paving the path for
overcoming intrinsic shortcomings of each component material to be used as an active material in nanoelectronic devices.

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