Materials Science & Engineering Thesis Defense

Neutron Transmutation Doping of Two-Dimensional Materials

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Abstract

Doping is the cornerstone of Semiconductor technology, enabling the functionalities of modern digital electronics. Two-dimensional (2D) transition metal dichalcogenides (TMDCs) have direct bandgaps, strong many-body interactions, and promising applications in future quantum information sciences, optoelectronic, spintronic, and valleytronic devices. However, their wafer-scale synthesis and precisely controllable doping are challenging. Secondly, extrinsic effects such as substrate disorder and surface adsorbates make it difficult to readily differentiate dopant features from intrinsic defects. Heavy metal substitutional dopants like Rhenium in TMDCs are electron donors and exhibit narrow subgap emissions up to higher operating temperatures. Electrostatic gating can control these dopants' charge states, showing promise for quantum photonic devices. Although highly desirable, Rhenium doping is difficult due to high dopant formation energies.

Moreover, there is no fixed framework to identify low doping concentration, which impedes their process integration for future commercialization. This work utilizes the Neutron Transmutation Doping technique to control the doping uniformity and introduce Rhenium and Tin dopants in Tungsten- and Indium-based Chalcogenide crystals. Fine-tuning over 0.001% doping level is achieved. Gamma spectroscopy and Secondary Ion Mass Spectrometry revealed ultra-low doping levels ranging from 0.005-0.01% with minimal error. A well-defined bound exciton emission induced by Rhenium dopants in monolayer WSe_2 and WS_2 at 77K is shown along with specific annealing regimes to minimize the defects induced in the Neutron Transmutation process. This work demonstrates a framework for Neutron Transmutation Doping in 2D materials for the first time, which can be a scalable process for controlling doping and doping-induced effects in 2D materials.

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Zoom Link: https://asu.zoom.us/j/8137578473