Abstract

The emergence of two-dimensional (2D) transition metal dichalcogenides (TMDCs), particularly SnS_2 and MoS_2, has sparked significant interest in the field of advanced materials due to their unique layered architecture and atomic-scale thickness. These materials exhibit exceptional electrical, optical, and chemical properties, rendering them highly suitable for a wide range of applications, including sensors, photodetectors, and various optoelectronic devices. However, the full potential of SnS_2 and MoS_2 is often hindered by common challenges such as large-area controlled growth, limited optical absorption in pristine materials, and slow response and recovery times attributed to inefficient charge transfer dynamics.

To address these challenges, we employed a thermal chemical vapor deposition (CVD) technique to optimize the growth conditions for high-quality SnS_2 and MoS_2 films. By systematically adjusting parameters, we achieved vertically aligned structures and uniform layers, laying the groundwork for enhanced device performance. Comprehensive characterization techniques, including scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDX), X-ray photoelectron spectroscopy (XPS), Raman spectroscopy, and photoluminescence (PL) were utilized to analyze and confirm the structural, morphological, and optical properties of the synthesized materials. Based on the results from these analyses, we propose a detailed growth mechanism in which in-plane SnS_2 and mixed MoS_2 flakes acts as a seed layer for the initial development of vertically aligned SnS_2 and MoS_2, ultimately leading to the formation of an interconnected three-dimensional network of these flakes.

We developed a highly sensitive gas sensor based on vertically aligned SnS_2 flakes, which exhibited exceptional selectivity toward NO_2 over various other toxic and combustible gases[Kumar et al., 2022]. The sensor demonstrated stable performance and strong selectivity, supported by electronic structure calculations. To further enhance gas sensing capabilities, we implemented defect and interface engineering techniques, specifically inducing optimal sulfur vacancies in the SnS_2 lattice through nitrogen plasma treatment[Kumar et al., 2023a]. This vacancy engineering significantly improved electronic conductivity and increased the active surface area for gas adsorption, resulting in a remarkable sensitivity to NO_2 and complete recovery at 120°C.

In parallel, we explored the functionalization of mixed MoS_2 flakes for NO_2 gas sensing. Recognizing the limitations of pristine MoS_2, which suffers from low response and slow recovery times, we modified the material through nitrogen doping and decoration with silver nanoparticles. The resulting nitrogen-doped MoS_2 (N-MoS_2) and silver-decorated nitrogen-doped MoS_2 (Ag-N-MoS_2) sensors exhibited substantial improvements in NO_2 sensing performance. Notably, the Ag-N-MoS_2 sensor demonstrated nearly double the response of pristine MoS_2 at 100°C, illustrating the synergistic effects of nitrogen doping and silver decoration.

Finally, we investigated the application of MoS_2 in optoelectronic systems through the development of a self-powered broadband photodetector utilizing a van der Waals heterostructure composed of MoS_2 and WS_2. The fabricated heterostructures exhibited enhanced responsivity, detectivity, and response times compared to pristine MoS_2, showcasing the potential of these materials in next-generation optoelectronic applications. Furthermore, the anticipated challenges and future perspectives in the rapidly evolving research on SnS_2 and MoS_2 for sensing applications are similarly explored.