

Architecture-Dependent Emergence of Self-Powered Gas Sensing in Junction Engineered WSe₂ Device

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Summary:

Self-powered gas sensing in two-dimensional (2D) semiconductors remains limited by weak zero-bias response. Here, we investigate architecture-dependent NO₂ sensing in WSe₂ devices ranging from monolayer to stacked and networked configurations. A pronounced zero-bias response emerges only in heterogeneous networks, further enhanced under illumination. Further, with a mild response in the stacked system and no response for the single monolayer device. The results reveal a transition from bulk to junction-mediated transport governing sensing behaviour. This study establishes structural heterogeneity as a key design parameter for energy-efficient gas sensors.

Keywords: WSe₂, Self-powered gas sensor, Chemical Vapour Deposition, Junction effects, Photo-assisted sensing.

Background, Motivation and Objective

Self-powered gas sensors are essential for next-generation low-power and distributed sensing systems, particularly in applications such as wearable electronics, environmental monitoring, and remote sensing. However, achieving reliable gas detection at zero external bias in two-dimensional (2D) semiconductors remains challenging due to inefficient carrier separation and the lack of strong intrinsic electric fields [1-3]. As a result, most reported devices rely on external bias to achieve measurable sensitivity, which increases power consumption and limits their practical deployment in autonomous platforms.

In conventional device designs, sensing performance is often enhanced through engineered interfaces or external driving fields [4, 5]. While such approaches improve carrier transport and sensitivity, they introduce additional fabrication complexity and do not fundamentally address the limitations of zero-bias operation. An alternative route is to exploit intrinsic variations within the material system itself, where structural non-uniformity can give rise to spatially varying electronic landscapes, local potential barriers, and distributed internal fields that influence charge transport.

In this work, we investigate how device architecture, from monolayer to stacked and networked WSe₂ configurations governs gas sensing behaviour under zero-bias conditions. By systematically comparing these architectures, we aim to

establish the role of junction formation and percolative transport pathways in enabling self-powered sensing. This study provides insight into how structural heterogeneity can be utilized as a design strategy to achieve energy-efficient gas sensing without relying on externally engineered interfaces.

Description of the New Method or System

Here, we have synthesized different configuration of WSe₂ by optimising different growing parameters in Chemical Vapour Deposition (CVD) method. Two electrode devices were fabricated first by patterning electrodes by photolithography method on the CVD grown flakes followed by metal deposition (Au/Ti) by e-beam deposition technique. WSe₂ devices were fabricated in three configurations: (i) monolayer flake, (ii) stacked few-layer flake, and (iii) percolative networks composed of interconnected flakes with varying thickness and orientation. The network architecture introduces a high density of inter-flake junctions arising from thickness variation, twist, and grain boundaries. These junctions are hypothesized to generate spatially distributed built-in electric fields, enabling carrier separation and modulation of transport pathways without external bias.

Results

Gas-sensing measurements toward NO₂ gas were performed under zero-biased dark and illuminated conditions. Monolayer devices exhibit negligible response at zero bias (Fig. 1(a)) and

weak sensitivity under applied bias. Stacked few layer structures show limited zero-bias response as shown in Fig. 1(b), indicating partial contribution from interfacial effects. In contrast, networked WSe₂ devices demonstrate a pronounced response at zero bias shown in Fig. 1(c), significantly enhanced under illumination. This behaviour suggests that sensing is governed by junction-mediated percolative transport, where gas adsorption modulates local barrier heights and transport pathways. The observed trend across device architectures highlights a transition from bulk-dominated to junction-controlled sensing mechanisms. Fig. 1 (d-f) demonstrates the schematic of the device configuration with the band alignment diagram for the devices.

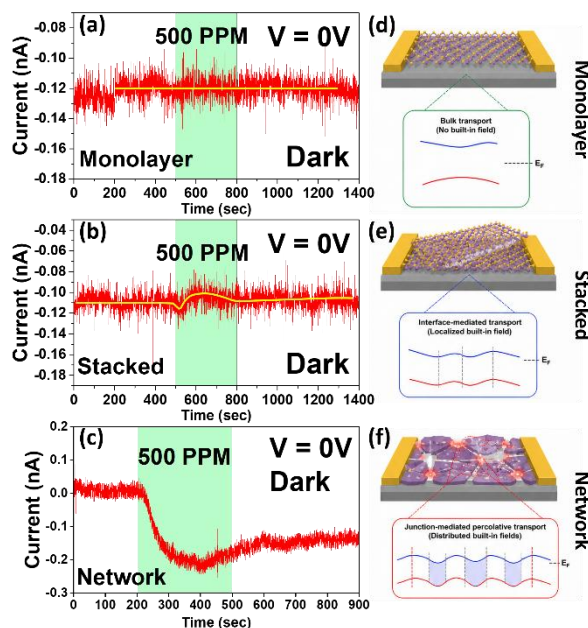


Fig. 1. Gas sensing response for 500 PPM of NO₂ gas at zero bias condition in dark for (a) Network, (b) Stacked (c) Monolayer WSe₂ device. Schematic and band diagram for the (d) Network, (e) Stacked and (f) Monolayer device.

Furthermore, photoexcitation enhances the sensing response across all device types, with the most significant improvement observed in the network architecture. This enhancement is

linked to the interplay between photogenerated carriers and gas-induced modulation of local potential barriers, leading to increased sensitivity under illumination.

Conclusion

The presented results demonstrate that structural heterogeneity in WSe₂ enables a distinct sensing mechanism based on junction-mediated percolative transport, allowing measurable gas response under zero-bias conditions. The systematic comparison across device architectures highlights a transition from bulk-dominated to junction-controlled behaviour, with networked systems exhibiting the most pronounced response. Furthermore, photoexcitation enhances sensitivity by coupling photogenerated carriers with gas-induced modulation of local potential barriers. These findings establish an alternative pathway toward self-powered gas sensing in 2D materials and provide design guidelines for energy-efficient sensing platforms based on architecture-driven transport engineering.

References

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