

# MoS<sub>2</sub>-InSe heterostructure synthesized via Liquid Phase Exfoliation for NO<sub>2</sub> sensing

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## Summary:

Designing sensitive NO<sub>2</sub> gas sensors is essential for detecting and mitigating hazardous effects on health and the environment, such as respiratory difficulties, acid rains, and industrial pollution. Conventional metal oxide based NO<sub>2</sub> sensors exhibit low selectivity and high operating temperatures. Two-dimensional materials are now the focus. Meanwhile, bare TMD sensors have shortcomings such as high LOD and poor response in humid conditions. This study presents a highly sensitive InSe-MoS<sub>2</sub> heterostructure based NO<sub>2</sub> sensor, with remarkable responses, even in the presence of ambient moisture (50% RH).

**Keywords:** Gas sensor, TMDs, NO<sub>2</sub>, LPE, nanomaterials

## Background, Motivation and Objective

Nitrogen dioxide (NO<sub>2</sub>) is a major air pollutant caused by combustion activities, including automobile emissions and industrial activity. Accurate and prompt NO<sub>2</sub> detection is crucial because of its detrimental impacts on the environment and human health, including respiratory problems and its part in the emission of pollution such as acid rain and smog. Metal oxide gas sensors (MOX) have been utilized extensively in the past, however they have limitations such as high operating temperatures and low selectivity. For enhanced sensing capabilities, two-dimensional (2D) materials like graphene and transition metal dichalcogenides (TMDs) like Indium selenide (InSe) and Molybdenum disulfide (MoS<sub>2</sub>) have recently drawn interest. InSe and MoS<sub>2</sub> have garnered significant interest due to their exceptional properties. Various research works have demonstrated the potential of InSe and MoS<sub>2</sub>-based sensors for detecting gases including NO<sub>2</sub>. However, bare InSe and bare MoS<sub>2</sub> sensors face challenges like sluggish responses in presence of ambient humidity. Producing heterostructures from TMD materials can actually improve the sensing performance [1,2]. In this study, a highly sensitive InSe-MoS<sub>2</sub> heterostructure for NO<sub>2</sub> sensing is presented with superior performance with anti-humidity capabilities, exhibiting high responses.

## Materials and Methods

InSe and MoS<sub>2</sub> are obtained using the liquid phase exfoliation (LPE) process, which involves

exfoliating 10 mg of InSe and 10 mg of MoS<sub>2</sub> in IPA solution, respectively. The resulting exfoliated solutions were drop casted onto three silicon substrates with gold interdigitated electrodes. The Pristine MoS<sub>2</sub> sensor is made using a first substrate coated with an exfoliated MoS<sub>2</sub> solution. The second substrate was coated with an exfoliated InSe solution, resulting in a pristine InSe sensor, while the third is a hybrid sensor composed of a InSe-MoS<sub>2</sub> heterostructure coated with the two previous solutions layer by layer forming heterojunction of InSe and MoS<sub>2</sub>.

## Results

Fig. 1 (a,b and c) illustrates morphology of InSe, MoS<sub>2</sub> and heterostructure respectively. As seen from the Field Emission Scanning Electron Microscopy (FESEM) images, the deposited sensors depict flaky morphology and heterostructure shows the complete covering of the substrate layer by layer. Also, the InSe nanoflakes can be seen in the form of flower-like structures (in red circles) (Fig. 1 (a)). The samples were further characterized using Scanning Electron Microscopy (ESEM). Color mapping of the samples show successful layering of InSe with MoS<sub>2</sub> nanoflakes as shown in Fig. 2 (a). Fig. 2 shows EDX spectrum of the InSe-MoS<sub>2</sub>. We tested Pristine InSe, Pristine MoS<sub>2</sub> and InSe-MoS<sub>2</sub> Heterostructure sensors towards 1 ppm of NO<sub>2</sub> at different operating temperatures - (RT), 100°C, 150°C, 200°C and 250°C in presence of 50% R.H. The sensor based on InSe-MoS<sub>2</sub> heterostructure exhibited

the highest response of 48% compared to Pristine sensors.

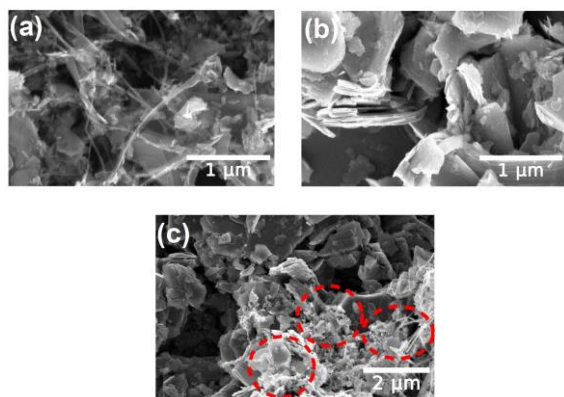


Fig. 1. FSEM images of (a) Pristine InSe, (b) Pristine MoS<sub>2</sub>, (c) InSe-MoS<sub>2</sub> (Red circles indicate InSe nanoflakes).

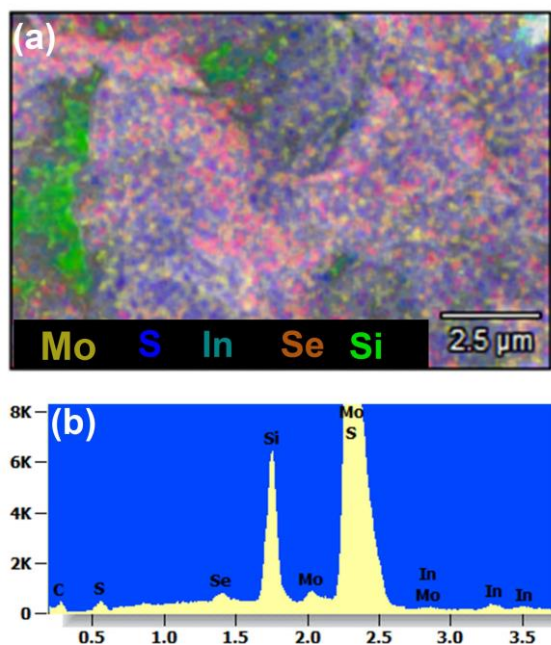


Fig. 2. (a) Color mapping of MoS<sub>2</sub>-InSe heterostructure (b) EDS spectrum of MoS<sub>2</sub>-InSe heterostructure

The optimum temperature came out to be 200°C. Fig. 3 (a) illustrates the sensor resistance dynamics towards 1 ppm of NO<sub>2</sub> at 200°C (50% of R.H.). The pristine InSe sensor showed 6% response and pristine MoS<sub>2</sub> sensor showed 41% response to 1 ppm of NO<sub>2</sub>, very less than the responses shown by the best sensor at all temperatures. The sensor responses are stable and repeatable. Fig. 3 (b) demonstrates the sensor response for lower concentrations of NO<sub>2</sub> at optimum temperature of 200°C with 50% R.H. A detailed selectivity and operating temperature study will be presented at the conference.

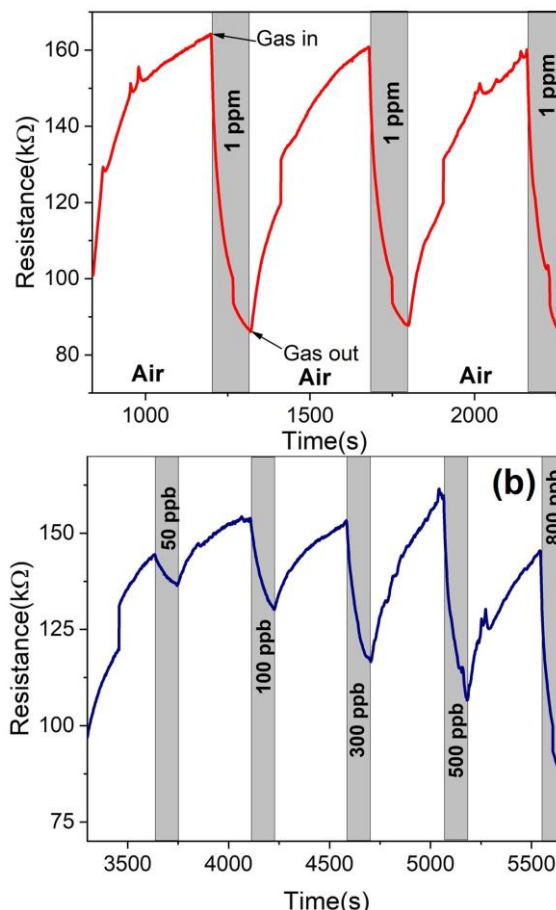


Fig. 3. (a) Resistance dynamics of InSe-MoS<sub>2</sub> sensor towards 1 ppm of NO<sub>2</sub> (50% of R.H.) at optimum temperature (b) InSe-MoS<sub>2</sub> sensor response towards lower concentrations of NO<sub>2</sub> (50% of R.H.).

## Conclusions

This study presents a highly sensitive InSe-MoS<sub>2</sub> heterostructure for NO<sub>2</sub> sensing, achieving a remarkable 48% response under 50% R.H.

## References

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