# PR190003

# Miniaturization of Gas Sensors by Realizing Nanostructures and Thin Films

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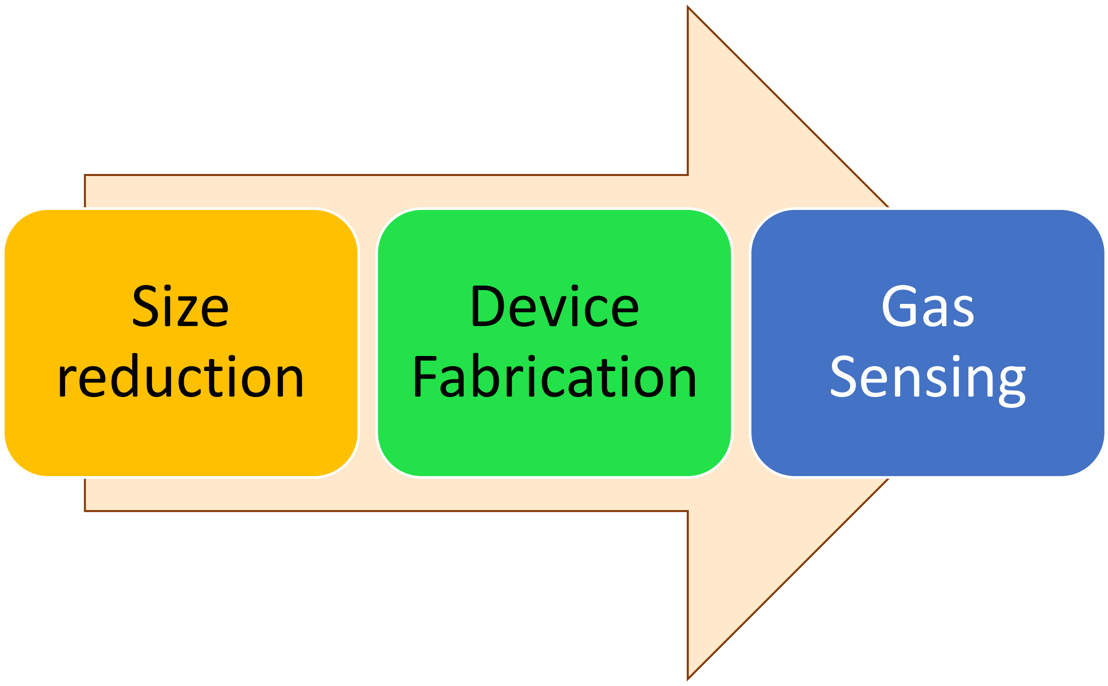
## Project Description and its implementation

**Aim of the project:**

The main interest of the project is to realize miniaturized sensing devices to sense different gases by realizing thin films and nanostructures.




Representation of the process flow

**Introduction:**

The attraction of this proposed research lies on the potentiality of miniaturization of the deviceby nano-electro-mechanical systems (NEMS) nanofabrication techniques for demonstrating gas sensing using 2D molybdenum dichalcogenides ($MoX_2$; X=S, Se, Te).

The proposed work mainly focuses on developing and demonstrating new device concepts, nanoscale mechanically resonating gas sensors using $MoX_2$ nanosheets. The work may be extended to study the in-depth device concepts and different cost-effective techniques. This proposal finds a concrete application of 2D $MoX_2$ in gas sensing while the previous studies reported had addressed sensitivity issues. The new sensor device concepts that are being focused are incorporation of nanoparticles in $MoX_2$ gas sensors, forming heterostructures using different 2D-TMDs, use of graphene and so on. The main focus will be to analyze different ways of improving their sensitivity, selectivity, stability and time of response to make use of enhanced functional properties of such nanoscale 2D $MoX_2$. Interestingly, this research will set a new trend in optomechanical studies of free standing 2D $MoX_2$ nanosheets.

Transparent metal oxide (TMO) materials have established a wide range of applications in optoelectronics, electrochromic windows, light emitting diodes (LED), flat panel displays, gas/vapor sensors, ultra-violet (UV) luminescence, photocatalytic degradation, photodiodes and solar cells etc. They form key materials in industrial photonic development owing to their excellent optical and electrical properties. Even though, the popular TMO materials namely tin oxide ($SnO_2$), cadmium oxide (CdO) and indium oxide ($In_2O_3$) have higher transmittance and low resistivity, their use is limited due to their high-price, toxicity and arduous preparation process. In this view, zinc oxide (ZnO) which is a familiar transparent semiconductor can be an alternative TMO material, offering wide optical bandgap (3.36 eV) and large binding energy (60 meV) [1]. Moreover, ZnO is attracting much attention in the fabrication of optoelectronic devices like UV photodetectors due to its superior transmittance in near-UV and visible range with a good conducting behavior upon illumination of UV light.

**Materials realized:**

The original top-down approach of mechanical exfoliation of 2D materials has produced the highest quality samples, but the method is neither high throughput nor high-yield.

Erbium (Er)-doped ZnO thin films were deposited on glass substrates by nebulizer spray pyrolysis with different doping concentrations (0 wt%, 1 wt%, 3 wt% and 5 wt%). The deposited films are polycrystalline with a hexagonal structure with a (002) predominant plane. The Er-doped ZnO films have greater surface roughness than the undoped ZnO film. The optical transmittance of the undoped ZnO film is about 80% in the visible range. The optical bandgap of the undoped ZnO thin film is 3.29 eV, which is very close to the bulk ZnO. From photoluminescence spectra, sharp UV emission is observed at 385 nm for all the prepared films. The response of the films to ammonia ($NH_3$) vapor is high when the Er concentration is 3% or less, meanwhile for higher concentrations of Er, the response is low. All the deposited Er-doped ZnO films show short response time and recovery time with regard to $NH_3$.

**Gas Sensing:**

The novel idea of using mono-layered sheets of $MoX_2$ as free-standing or suspended mechanical resonators is of great challenge due to their behavior at molecular level during the fabrication of complete circuits which can be addressed step by step.

For the heterostructure photodiode, the intrinsic electric field at the p-type ($Cu_2O$) and n-type (AZO) interface were responsible for the separation of generated charge carriers resulting in an enhanced photocurrent. The films prepared using methanol as a solvent achieved high transparency (93%) and found to have the optimum bandgap value of 3.30 eV. The incorporation of $Al3^{+}$ ion into the Zn sites enhanced the number of charge carriers. Heterojunction ($Ag/AZO/Cu_2O/ITO$) photodiodes exposed to the pure methanol solvent film (S5) showed a current of $2.15\times10^{-5}$ A under dark at a bias voltage of 5V. This is significantly higher compared to the value of $2.35\times10^{-6}$ A for the film (S1). Pure methanol is demonstrated as an ideal solvent to achieve superior morphological, structural, optical, PL emission and photodiode properties.

**Research Collaborator:**

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**List of publications and Outcome:**

Kumar, K. Deva Arun, S. Valanarasu, Joice Sophia Ponraj, Brian Jeevan Fernandes, M. Shkir, S. AlFaify, Prashantha Murahari, and K. Ramesh. "Effect of Er doping on the ammonia sensing properties of ZnO thin films prepared by a nebulizer spray technique." Journal of Physics and Chemistry of Solids 144, (2020): 109513. https://doi.org/10.1016/j.jpcs.2020.109513

Kumar, K. Deva Arun, Paolo Mele, Joice Sophia Ponraj, Kumar Haunsbhavi, S. Varadharajaperumal, D. Alagarasan, H. Algarni, Basavaraj Angadi, Prashantha Murahari, and Karuppannan Ramesh. "Methanol solvent effect on photosensing performance of AZO thin films grown by nebulizer spray pyrolysis." Semiconductor Science and Technology 35, no.8 (2020): 85013-85048 https://doi.org/10.1088/1361-6641/ab9208