Temperature dependent electrical properties of solution processed ZnO nanorods decorated with MoS_2 nanosheets

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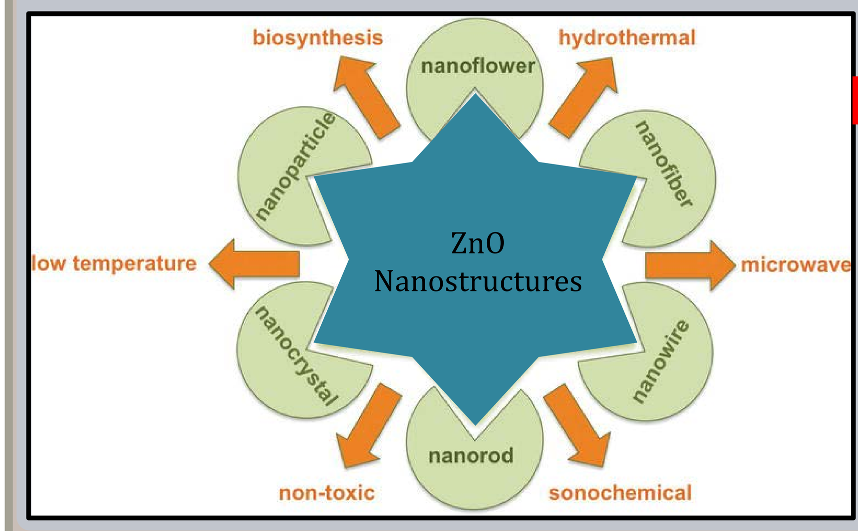
1. Introduction

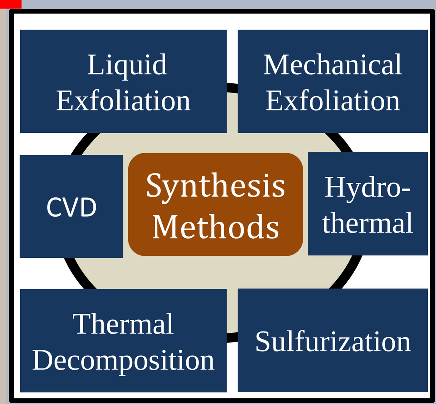
ZnO NRs (1D)

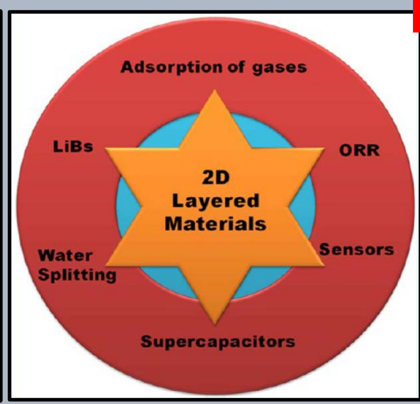
- Band Gap = 3.7 eV
- Exciton binding Energy = 60 meV
- Biocompatible, biosafe, biodegradable
- Hexagonal wurtzite and cubic zinc blende



MoS_2 NSs (2D)

- Tunable Band Gap
- Layered semiconductor sandwiched by relatively weak van der Waals forces
- Promising candidate for next generation gas sensing devices
- Maximum surface to mass ratio, high sensitivity and increased selectivity





MoS_2/ZnO Composite

- Improved sensitivity
- Layered semiconductor sandwiched by relatively weak van der Waals forces
- Promising candidate for next generation gas sensing devices
- Maximum surface to mass ratio, low noise, high sensitivity and increased selectivity
- Scalability, low cost and high yield production
- More cost advantages result from the relatively easy low temperature production concept

Objective

- Temperature-dependent current-voltage (*I-V*) measurement of ZnO NRs and MoS_2 nanosheets decorated ZnO
- Active surface area of 450 μm² each
- Studied the underlying conduction mechanism and barrier height
- Barrier Height was calculated using Thermionic Emission Model
- Effect of temperature on the electrical behavior was discussed
- Fabrication of p−n heterostructures is an effective way to modulate the intrinsic electronic properties of MoS_2 nanosheets (NSs),

Keywords: MoS_2/ZnO NRs Nanocomposite, TMDCs, Wet Chemical Method, Liquid Exfoliation, p-n junction Heterostructure, *I-V* Measurement, Thermionic Emission Model

2. Methodology

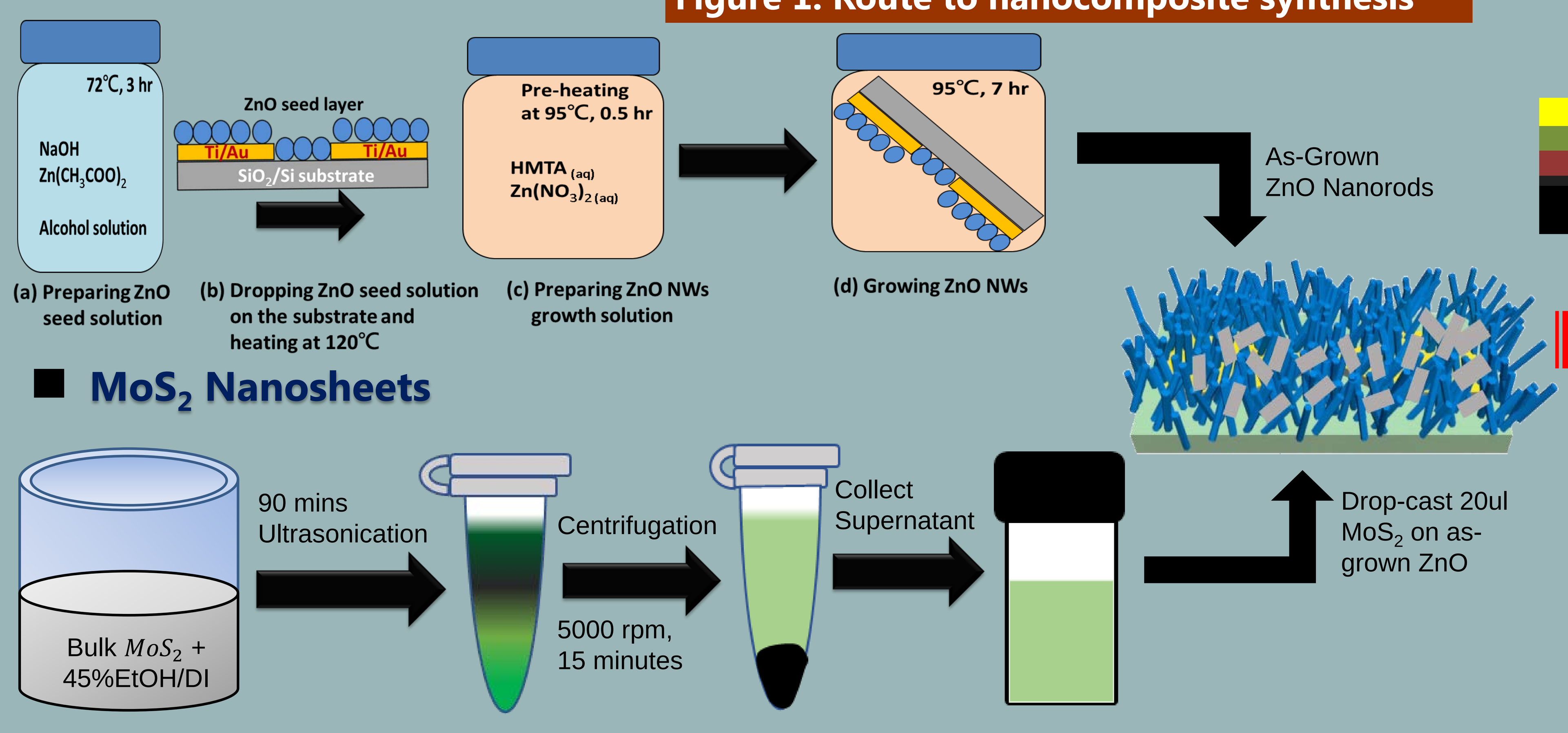


Figure 1. Route to nanocomposite synthesis

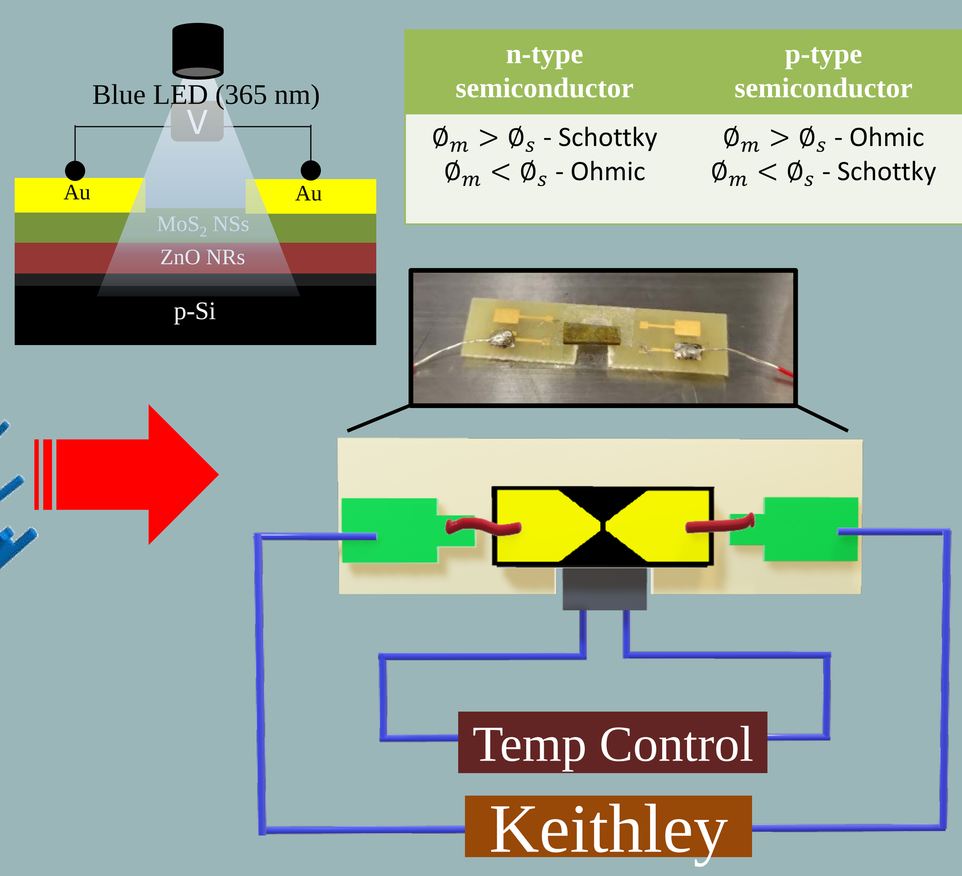


Figure 2. *I-V* measurement setup

n-type semiconductor	p-type semiconductor
$\phi_m > \phi_s$ - Schottky $\phi_m < \phi_s$ - Ohmic	$\phi_m > \phi_s$ - Ohmic $\phi_m < \phi_s$ - Schottky

Applied Voltage (V)	Current (A)	Temperature (°C)
3.0	0.2451	50
4.15	0.3065	75
5.5	0.3599	100

Table 1. Parameters needed for the temperature variation with applied current

Parameters Used

- Bias Voltage = 5V
- Temperature Used (°C) = RT, 50, 75, 100
- LED Wavelength = 365 nm
- LED Power = 0.1 mA/cm²
- Current Compliance = 30 mA
- Irradiation Time = 5 hours
- Humidity(RH) = 60-70%
- Active surface area of 450 μm²

3. Results and Discussions

A. Morphology and Properties

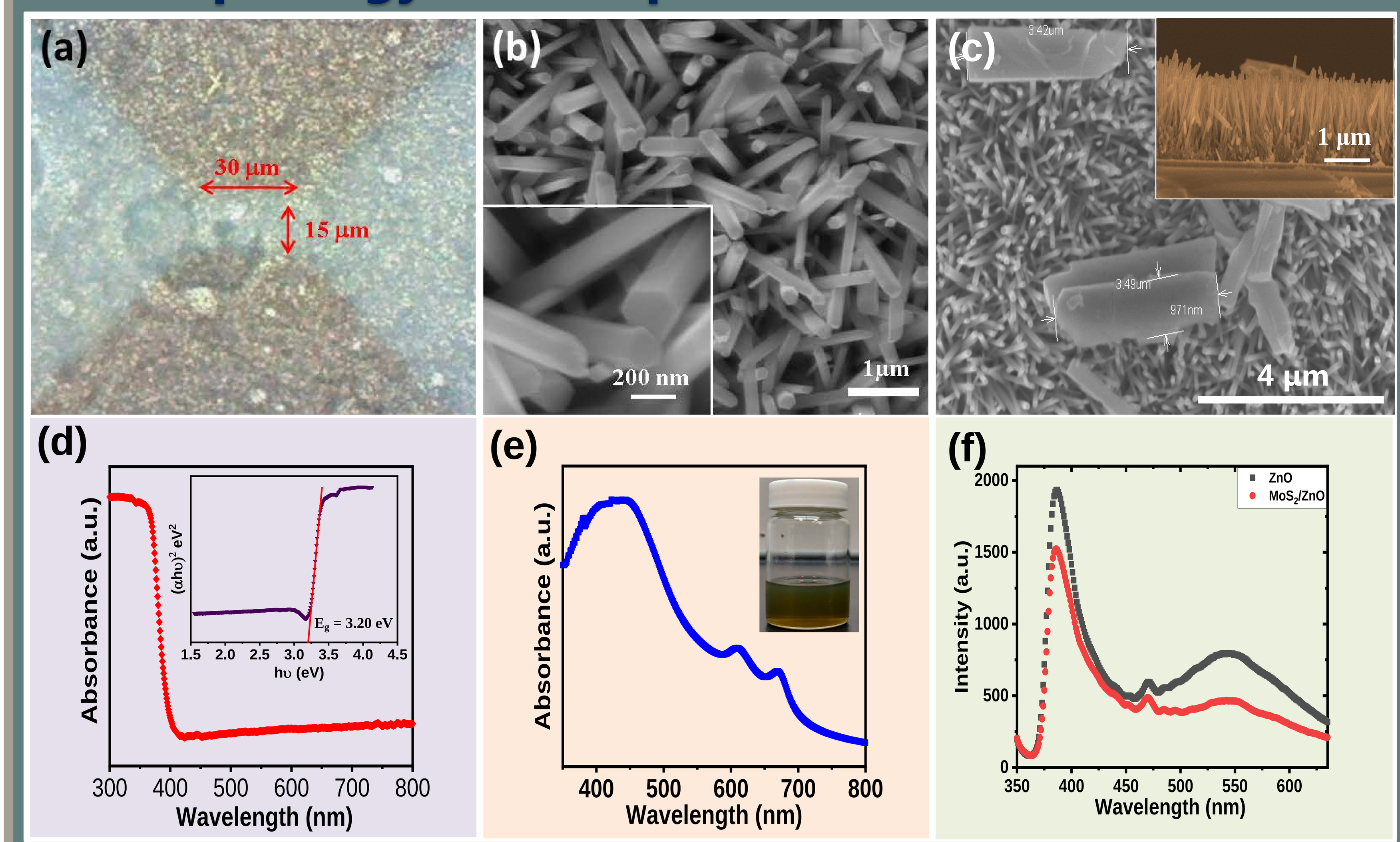


Figure 3. (a) An optical microscope image of a gas sensor showing electrodes. SEM images of (b) ZnO NRs (c) MoS_2/ZnO composite. UV-Vis plots for (a) ZnO NRs (e) MoS_2 NSs (f) PL results for bare ZnO and MoS_2/ZnO composite

B. *I-V* Measurement

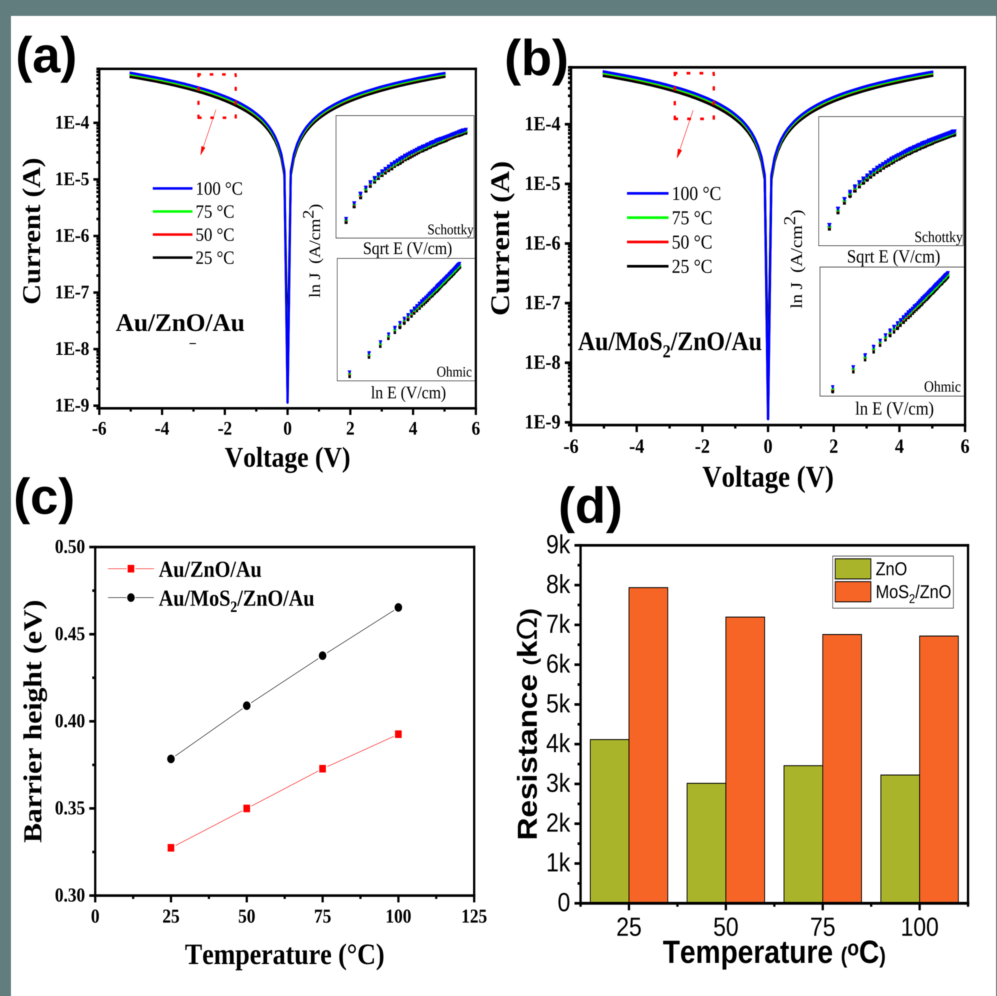
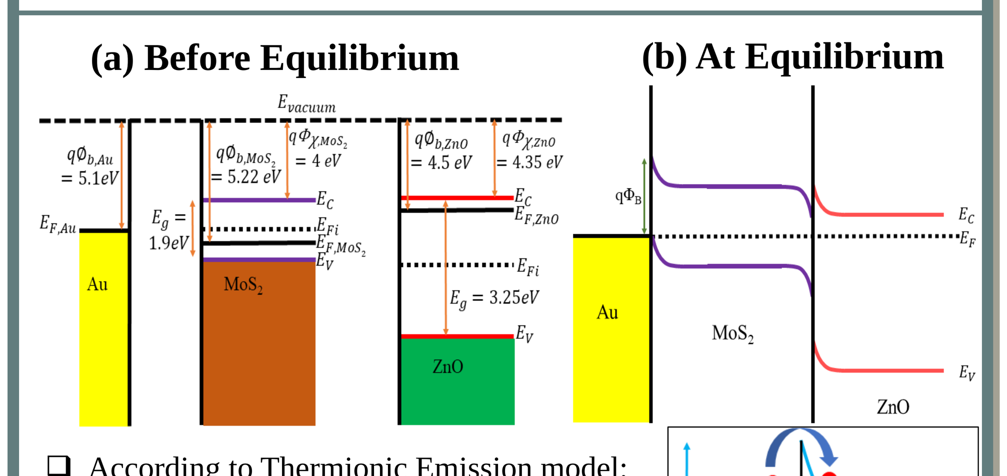


Figure 4. Temperature dependent *I-V* curves of the (a) ZnO NRs (b) MoS_2/ZnO (c) Calculated values of Schottky barrier height (d) R vs T histogram chart for both samples

C. Analysis

- Figure 3(a) shows low magnification optical image demonstrating the active device area
- SEM images clearly depicts the presence of uniform ZnO NRs with MoS_2 NSs randomly distributed on the pre-patterned Si wafer. Cross sectional SEM confirms the NSs presence
- Incorporation of MoS_2 NSs effects the decrease in PL intensity which is mainly attributed to the charge transfer of lower to higher band gap materials
- Because of relatively narrow band gap, MoS_2 can absorb visible region of sunlight and when combined with ZnO creates a p-n junction



❑ According to Thermionic Emission model:

$$I = I_S[\exp\left(\frac{qV}{nkT}\right) - 1]$$

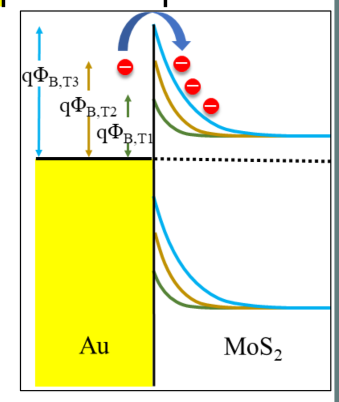
where, I_s = saturation current obtained from y-intercept; V=Bias Voltage=5V; T=Temperature

❑ Schottky Barrier Height can be calculated as:

$$\phi_B = \frac{kT}{q}\ln\left(\frac{AA^*T^2}{I_S}\right)$$

where, A = Effective Device Area = 450μ²

$\Phi_B \propto Temperature$



Conduction = Ohmic
Contact = Schottky

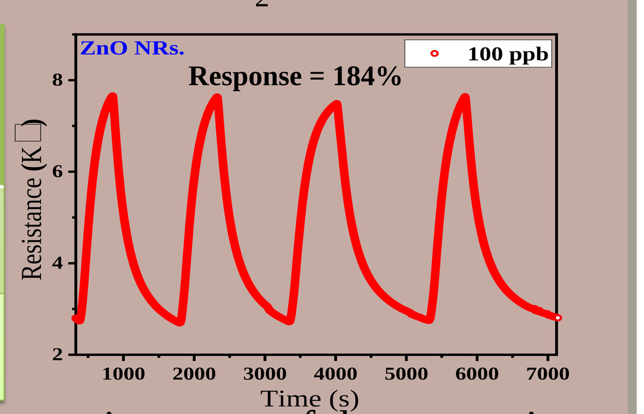
4. Conclusions

- We have demonstrated a facile fabrication of MoS_2/ZnO hetero-nanostructures via a wet chemical route
- The unique structure of MoS_2/ZnO hetero-nanostructures also provides guidance for other 2D materials that might be used in gas sensing applications
- Study of the current-temperature dependence shows that at high-temperature, current is thermally active and successively decreases that can be explained by considering a change of material morphology
- Increasing the temperature up to 100°C shows a little effect in output current as compared to room temperature, which thereby shows high functionality of device at room temperature.

5. Future Work

- Metal oxide semiconductors can detect the ppb level concentration of NO_2

Type of semiconducting material	Reducing gas (CO)	Oxidizing gas (NO_2)
n-type	Resistance decrease	Resistance increase
p-type	Resistance increase	Resistance decrease



- An optimal conductometric gas sensor should meet the requirements of large sensing response, low working temperature and high selectivity to the target analytes