







Eq. (3) is Scherer formula,  $t$  is crystallite size,  $\beta$  is the full width at half maximum and  $\lambda$  is the wavelength of X-ray used (1.5406 Å).

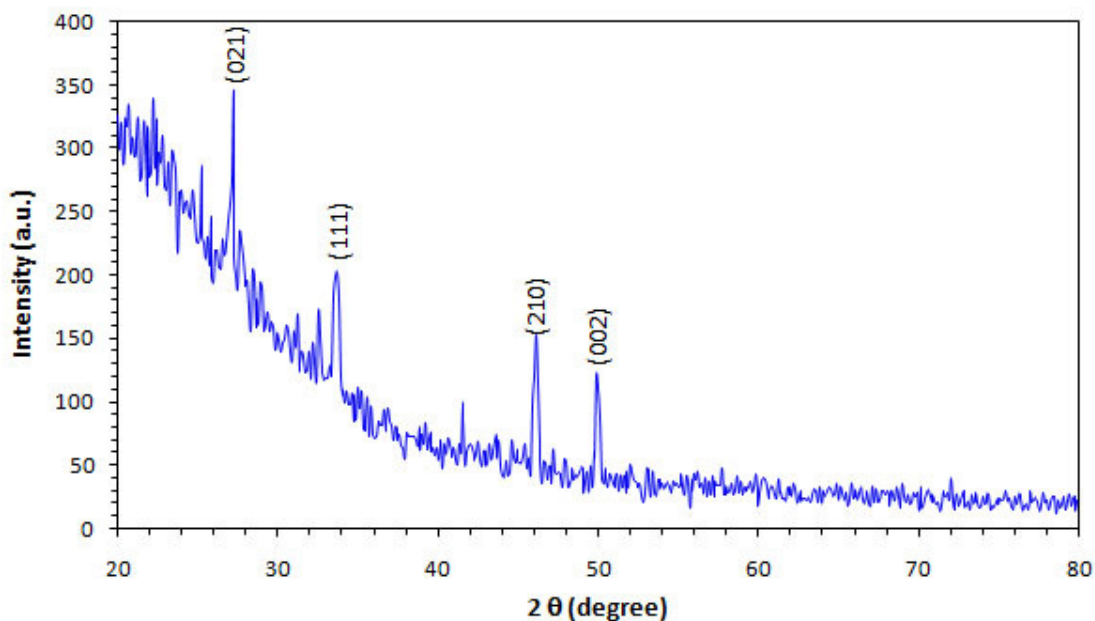


Figure 2. X-ray diffraction spectra of MoO<sub>3</sub> thin film.

#### b. Surface Morphology

To observe the surface morphology, scanning electron micrographs (SEM) of a thin film sample were taken. Figure 2 shows the SEM of the MoO<sub>3</sub> thin film sample. It is observed that the substrate is well covered by a non-uniform film with spherical and hexagonal shaped particles. Excess solute precipitate gets deposited on some parts of the substrates. This may be due to non-optimized spray rate.

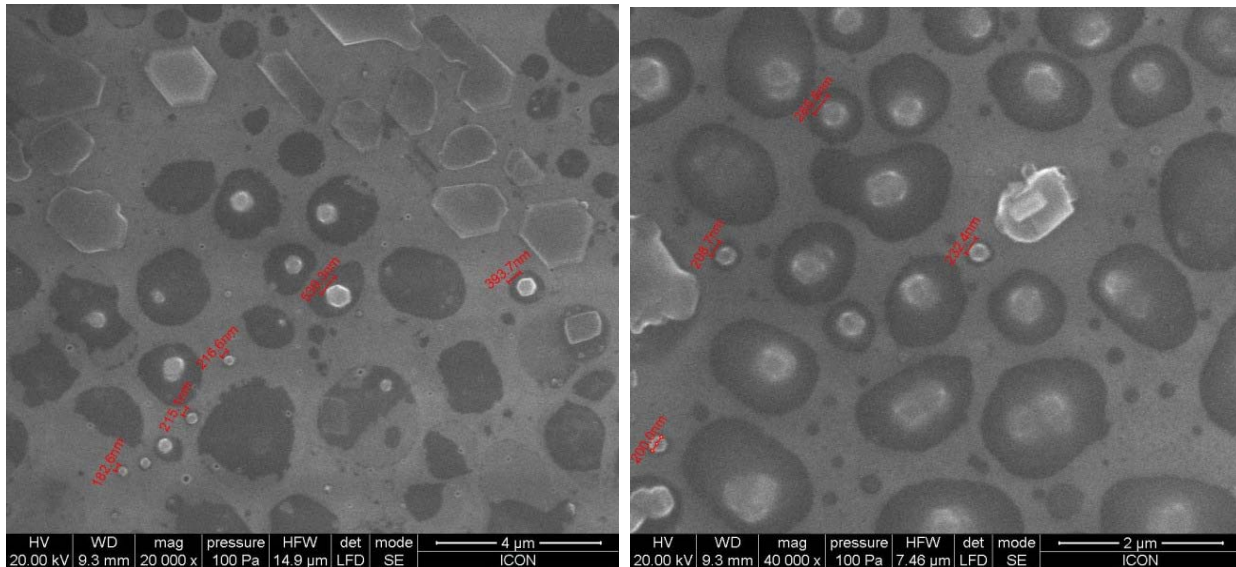


Figure 2. Scanning electron micrographs of MoO<sub>3</sub> thin film.

### c. Optical Properties

The absorption spectra of thin films were recorded in the wavelength range 290–1100 nm run at room temperature. The sharp of the absorption edge suggests a single phase. The band gap energy calculated from the absorption spectra is 3.59 eV, for polycrystalline MoO<sub>3</sub> thin a film is widely reported [27].

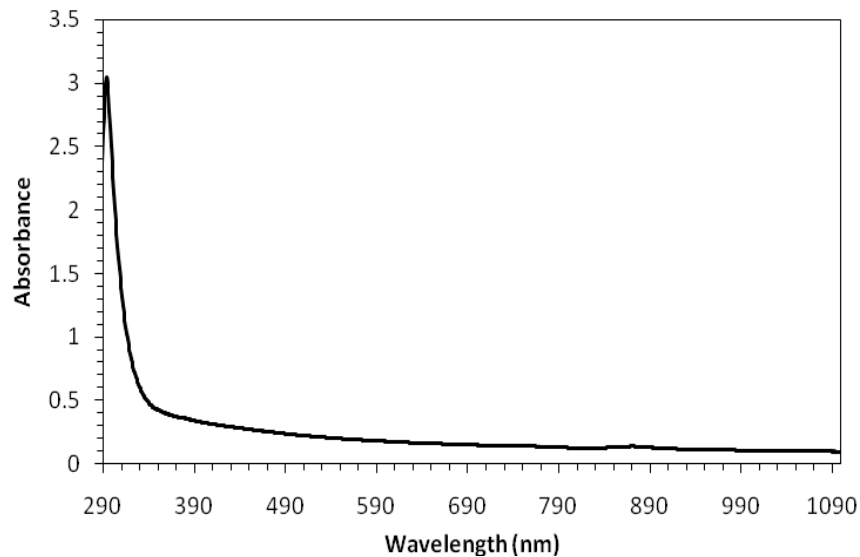


Figure 3. UV-vis spectra of MoO<sub>3</sub> thin film.

### d. Electrical Properties of MoO<sub>3</sub> Thin Film

#### i. I-V Characteristics

Figure 4 depicts the I-V characteristics of MoO<sub>3</sub> thin film at room temperature in air ambient. I-V characteristics observed to be symmetrical in nature, indicating the ohmic nature of contact.

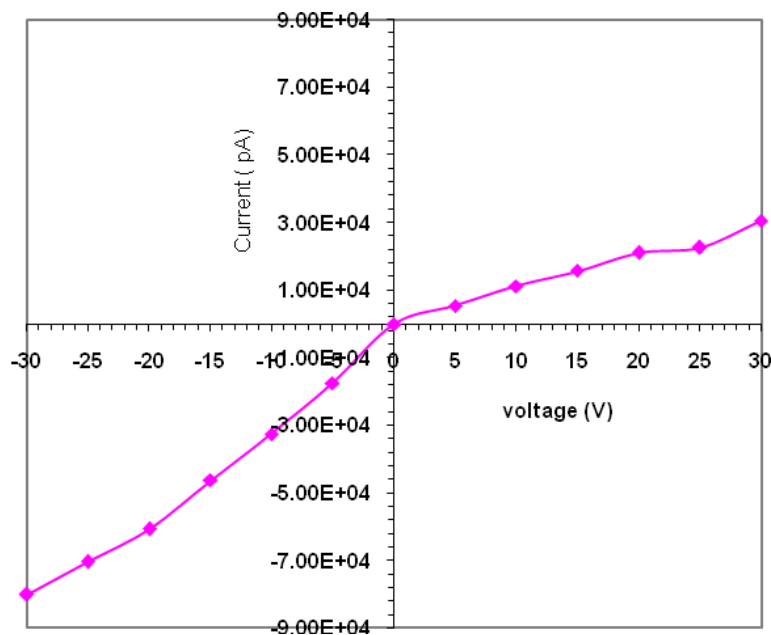


Figure 4. I-V characteristics of MoO<sub>3</sub> thin film.

## ii. Electrical Conductivity

Fig. 5 shows the dependence of conductivity of MoO<sub>3</sub> thin film in air ambience. The conductivity of the film goes on increasing with increase in temperature, indicating negative temperature coefficient (NTC) of resistance. This shows the semiconducting nature of the films.

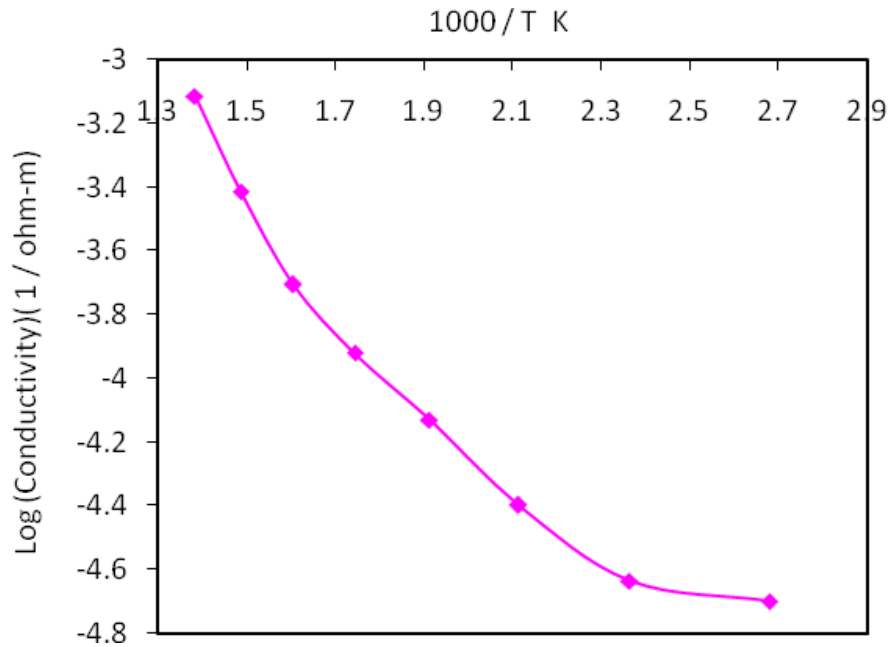


Figure 5. Variation of conductivity with temperature.

#### e. Gas Sensing Performance

The conductance of the sensor in dry air was measured by means of conventional circuitry by applying constant 10 V voltage and measuring the current by picoammeter. The conductance was measured both in the presence and absence of test gas. The gas response (s) is defined as the ratio of change in conductance in gas to air to the original conductance in air

$$S = (G_g - G_a) / G_a \quad (4)$$

The selectivity is defined as the ability of a sensor to respond to certain gas in the presence of other gases [28, 29].

#### i.) Variation of Gas Response with Operating Temperature of MoO<sub>3</sub> Thin Film

Figure 6 presents the variation in the gas response to various gases (1000 ppm) with operating temperatures ranging from 100° to 400°C. It is noted from the graph that response increases with increasing temperature, and attains a maximum at 300°C for H<sub>2</sub>S and at 200°C for ethanol and decreases with further increase in operating temperature.

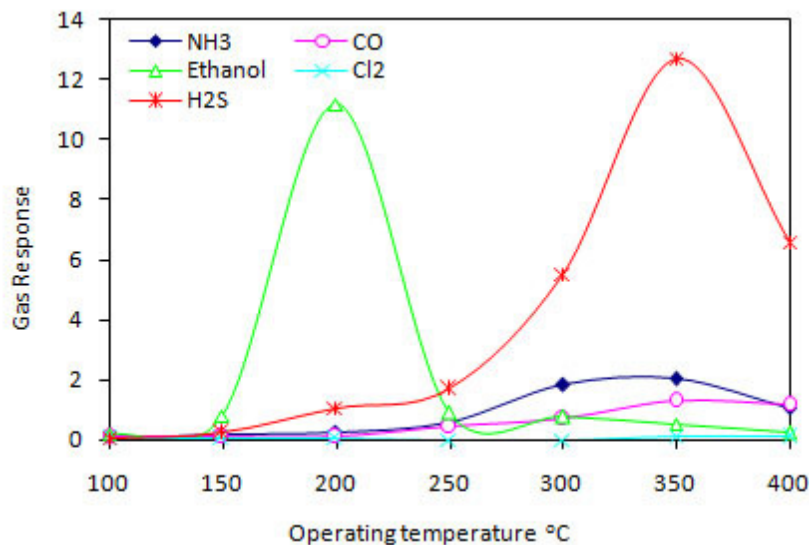


Figure 6. Variation of gas response with temperature.

ii.) Selectivity of MoO<sub>3</sub> Thin Film

Figure 7 presents the bar diagram indicating selectivity of MoO<sub>3</sub> thin film at 350°C to H<sub>2</sub>S gas and at 200°C to ethanol against the other gases. The sensor is the most selective to H<sub>2</sub>S gas against the other gases.

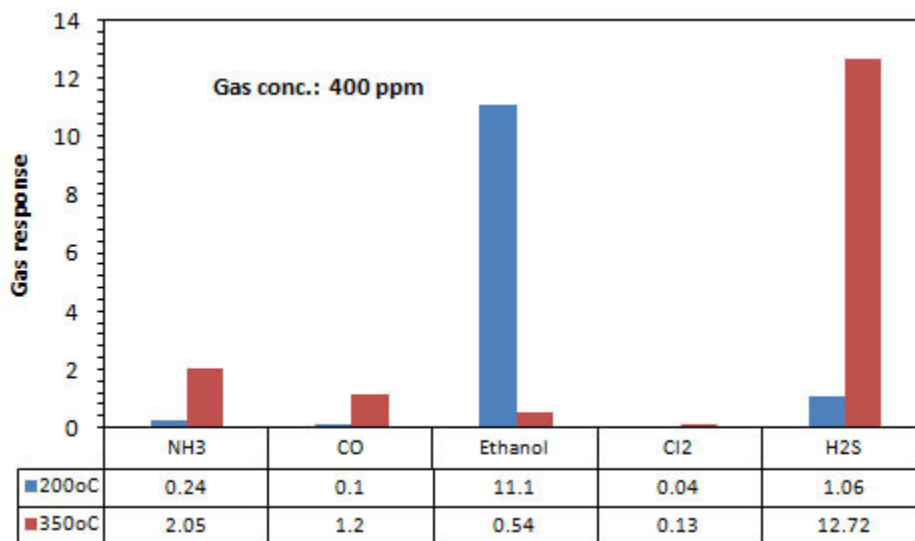


Figure 7. Selectivity of MoO<sub>3</sub> thin film.



### iii.) Variation of Sensitivity with Gas Concentration

To test the H<sub>2</sub>S gas concentration characteristics, the sensor was exposed to H<sub>2</sub>S gas of different concentrations at a constant operating temperature. The sensor responses to H<sub>2</sub>S in concentration range (40-480 ppm) are shown in figure 8 at 350°C operating temperature. The response values were observed to increase continuously with increasing the gas concentration up to 400 ppm. The rate increase of response was relatively larger up to 400 ppm and then saturates after 400 ppm. Thus the active region of the sensor would be between 40-400 ppm.

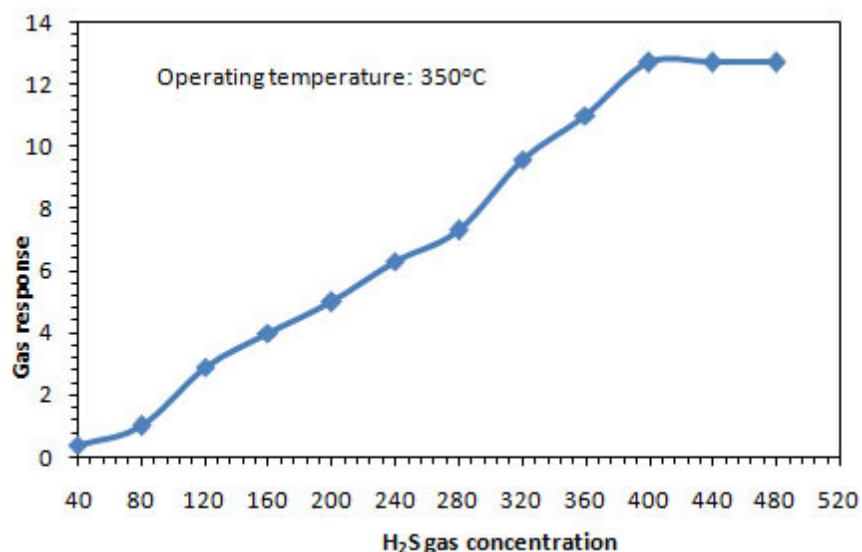


Figure 8. Variataion in sensitivity with H<sub>2</sub>S gas concentration.

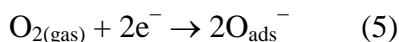
### iv.) Response and Recovery Time

The time taken for the sensor to attain 90% of maximum change in resistance on exposure to gas is the response time. The time taken by the sensor to get back 90% of the original resistance is the recovery time [30]. The response and recovery time of MoO<sub>3</sub> thin film was 14s and 40s respectively. The large recovery time would be due to lower operating temperature. At lower temperature O<sub>2</sub><sup>-</sup> species is more prominent adsorbed on the surface, it is less reactive compared to other species of oxygen, O<sup>-</sup> and O<sup>2-</sup>.

### v.) Gas Sensing Mechanism

It is well known that the gas sensing mechanism in the oxide based materials is surface controlled, wherein; the grain size, surface states and oxygen adsorption play a significant role. The larger surface area usually offers more adsorption– desorption sites and thus the enhanced

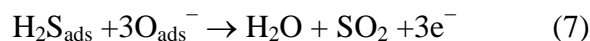
sensitivity [31, 32]. The atmospheric oxygen gets adsorbed on the surface, and depending upon the temperature of operation; different oxygen species are formed on the surface. The gas response by metal oxide semiconductor, in general, can be described as



Initially, (Eq. (5)) the atmospheric oxygen acquires electron from the conduction band of MoO<sub>3</sub> and forms O<sub>ads</sub><sup>-</sup> species on the surface thus decreasing the conductance of the MoO<sub>3</sub>.

Further, the high surfaces to volume ratio of nanosized particles offer larger number of sites for the adsorption of the oxygen species. It is known that the gas response depends directly on the number of O<sub>ads</sub><sup>-</sup> species. The reducing gas (R), reacts with O<sub>ads</sub><sup>-</sup> and forms RO (Eq. (6)) with releases of electron back to the conduction band. In the process the conductance again increases. Therefore, sensitivity in general, depends on the reaction (Eq. (5)) that is, availability of R and O<sub>ads</sub><sup>-</sup> species. The rejuvenation of the conductance takes place on removal of R and the presence of ambient oxygen (Eq. (5)).

More specifically, in the presence of H<sub>2</sub>S gas, the reaction (Eq.(7)) takes place thereby forms H<sub>2</sub>O and SO<sub>2</sub> gas by releasing electrons back to the conduction band, thus increasing the conductance of the sensor. Again on removal of H<sub>2</sub>S the reaction (Eq. (5)) takes place leading to a decrease in the conductance [33]. This can be simply described as in Eq. (7),



#### IV. CONCLUSION

A simple spray pyrolysis method is used to prepare MoO<sub>3</sub> thin films. The technique is simple and inexpensive and it may be useful for the production of metal-oxide thin film gas sensors. XRD analysis confirmed that the synthesized materials on thin film to be that of the MoO<sub>3</sub>. The band-gap energy calculated from an absorption spectrum was 3.59 eV. This value matches exactly with the reported value. The response of the MoO<sub>3</sub>-based sensor was observed to be maximum at 300°C for H<sub>2</sub>S and at 200°C for ethanol. The sensor showed good selectivity to H<sub>2</sub>S gas against NH<sub>3</sub>, Cl<sub>2</sub>, CO and ethanol.

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