Chapter 6 | Summary and Conclusions

The thesis reports on the Preparation and Characterization of Nanocrystalline Surfactant Mixed Metal Oxide Thin Films for Gas Sensor Applications. The main findings of the present work are given below:

**SnO\textsubscript{2}-TX100 Thin Films**

- SnO\textsubscript{2} thin films have been prepared using Chemical Spray Pyrolysis technique in conjunction with surfactant TX-100. Films were deposited by adding 1% TX-100 (liquid) to SnCl\textsubscript{4} solution and then amount of TX-100 was increased to 2%, 3%, 4%, 5% and 6%.

- The deposited films have been characterized using various characterization techniques. XRD analysis of the deposited films showed decrease in crystallite size with percentage of TX-100 up to 4%. Beyond 4% of TX-100, the crystallite size increased. The crystallite size became minimum for SnO\textsubscript{2} with 4% TX-100. SEM images have shown the formation of grain boundaries with the addition of TX-100. The grain boundaries became more prominent in the film with 4% TX-100. UV-Visible spectroscopy analysis showed the shift of band edge towards shorter wave length region indicating the increase in the optical band gap ($E_g$). This was maximum (3.8 eV) for SnO\textsubscript{2} composite films with 4% TX-100. I-V measurements
have shown the maximum resistance for films with 4% TX-100.

- The gas sensitivity of the deposited SnO$_2$-TX-100 composite thin films has been studied. The gas sensitivity for bare SnO$_2$ was about 30%, it has increased with percentage of TX-100. Film with 4% TX-100 has shown maximum sensitivity of 70%. When the percentage of TX-100 was more than or less than 4%, the sensitivity is found to decrease. We conclude that the decrease in crystallite size, formation of grain boundaries, increase in band gap, and increase in resistance of the film are the factors that influenced the enhancement in the sensitivity.

- We herein report the successful enhancement of gas sensitivity of SnO$_2$ composite thin films optimize the percentage of TX-100 for maximum sensitivity. This part of the work has been published in SSRG International Journal of applied Physics Vol.3.Issue5 (2016)1-5.
SnO$_2$-PEG6000 Thin Films

- SnO$_2$ thin films have been prepared using Chemical Spray Pyrolysis technique in conjunction with surfactant PEG 6000. 0.01M of PEG solution was prepared in ethanol. Films were deposited by adding 1% PEG solution to SnCl$_4$ solution and then percentage of PEG was increased to 2%, 3%, 4%, 5% and 6%.

- XRD analysis of the deposited films showed no change in the crystallite size except for the films with 4% PEG. In this film the crystallite size is about 5nm, and the material became more crystalline. SEM images have showed the formation of grain boundaries only in the film with 4% PEG. UV-Visible spectroscopy analysis showed the shift of band edge towards shorter wave length region indicating the increase in the optical band gap ($E_g$). $E_g$ was maximum (3.82 eV) for SnO$_2$ composite films with 4% PEG. I-V measurements have shown the maximum resistance for films with 4% PEG and in the order of mega ohm.

- The gas sensitivity of the deposited SnO$_2$-PEG composite thin films has been studied. The gas sensitivity for bare SnO$_2$ was about 30%. The increase in percentage of PEG has decreased the sensitivity to less than that for bare SnO$_2$ (less than 30%).
But for the film with 4% PEG there is an abrupt increase in the sensitivity to more than 60%. Beyond this percentage of 4% the sensitivity decreased to less than 30%. Though there is a decrease in sensitivity, response and recovery time has improved (fast)

- We herein, report the successful enhancement of gas sensitivity of SnO$_2$-PEG-6000 composite thin films and the critical value of PEG600 for maximum sensitivity. This part of the work is under the process for communication.

### Design and Development of Gas Sensor Setups

- We designed and developed two gas sensors setup. Those are quite simple, cost effective, reliable and sensitive to detect various gases. The workability of these setups is clearly shown in the gas response characteristic curve that is electrical resistance verses time.

- Our miniaturized gas sensor setup is simple, cost effective and portable. This setup has been proposed to measure the gas response of different gases in terms of the variation in resistance of the sensing element. It can operate between a temperatures ranging from room temperature to 1500C. The
workability of this setup has been tested using SnO$_2$, SnO$_2$-TX100, SnO$_2$-PEG6000 thin films for H$_2$S gas. It can be extended to other sensing materials and also for other gases of interest. This part of the work has been published in the IOSR Journal of Physics Vol. 7. Issue 2 (2015) 39-45

- Our laboratory setup for gas sensing is simple, table top, cost effective and simple. Conveniently the sensor element (thin film) can be loaded using spring loaded contacts. This setup has been proposed to measure the gas response of different gases in terms of the variation in resistance of the sensing element. It can operate between a temperatures ranging from room temperature to 4000°C. The workability of this setup has been tested using SnO$_2$, SnO$_2$-TX100, SnO$_2$-PEG-6000 thin films for H$_2$S gas. It can be extended to other sensing materials and also for other gases of interest. This part of the work has been published in the IOSR Journal of Chemistry Vol.8. Issue 12 (2015)37-44

Scope for Future Work

- A great deal of work has already been done to enhance the sensitivity and tune the response and recovery time of metal oxide gas sensors. Material design for good selectivity is an
issue attracting the attention of the researchers. So far there is no single gas sensor existing today that is selective to a particular gas.

- Metal oxide gas sensors normally work at an elevated temperature, therefore fabricating a battery operated gas sensor is an issue. This issue can be addressed by preparing materials that can sense gases at room temperature.