Design and Development of Chemiresistive Sensor for the Selective Detection of CH_4 and CO

A thesis submitted

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by

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Abstract

The selectivity of CO and CH_4 remains an impediment to researchers working on metal oxide-based sensors as the sensing mechanism is analogous for both gases. With this objective, an attempt has been made to realize selective sensing of CH_4 and CO gases by proper activation techniques. Low ppm gas detection with reduced cross-sensitivity using metal oxides have been a herculean task among researchers. Therefore, the thesis deals with selective sensing of gases which has been realized by the exploration of different material combinations with proper activation techniques. The incorporation of dual activation technique has brought down the limit of detection and increased the selectivity of CO and CH_4. The baseline drift of the sensor is another challenge that has to be rectified in designing such sensors. Taking into account all these objectives, the present work implements Pd-doped ZnO nanomaterials with in-situ grown photocatalyst ($Zn_5OH_8Cl_2.H_2O$) sites, which are highly productive in providing a sensor with strong absorption reaction and propelling the surface conversion kinetics. The method can be extended to other metal oxides like In_2O_3 for the selective detection of CO and CH_4. The in situ formation of photocatalytic materials along with dual-activated (optical and thermal activation) metal oxide and its role in selectivity have not been explored elsewhere. Detailed material optimization of Pd-doped ZnO and Pd-doped In_2O_3 is obligatory as the sensing materials play a pivotal role in the dual activation platform. The dual activation incorporates the benefits of both temperature and optical excitation on metal oxide-based sensors, highlighting the innumerable advantages and nullifying the disadvantages of both methods. By exploiting this principle, selective sensing of CH_4 and CO at low concentrations with good sensitivity, response time, and recovery time is explicated. The sensing material resulted in selective modulation of sensing characteristics with a minimum baseline drift. The optimization of the packaging technique to obtain the realiable performance has been scrutinized in the thesis. The new packaging technique to minimize the loss from the sensing substrate in terms of conduction and radiation has been explored. The method can be extended to a variety of substrates for designing a proper platform for gas sensor applications. As a direct consequence, a reliable, robust, cost-effective CO and CH_4 sensor has been realized. Stimulation and optimization of the sensing material, fabrication of the integrated micro heater and sensing electrodes, opto-thermal excitation, detailed packaging, and characterization

are discussed in the thesis. The thesis consists of six chapters:

Chapter-1: Introduction

The chapter highlights the literature review on metal oxides based gas sensors. Detailed discussions regarding the baseline drift, low detection limit, and reliability of the metal oxide-based sensors are described in this section. A detailed survey is also conducted for optical and dual-activated gas sensors. This chapter introduces the nanocrystalline metal oxide based CH_4 and CO sensor and role of noble metals on the sensing properties

Chapter-2: Synthesis and Characterization of Nanocrystalline ZnO

The chapter focuses on synthesizing of ZnO nanomaterials for the selective detection of CO and CH_4. The detailed description and characterization using SEM, XRD, PL, and XPS data are discussed in the chapter. Based on the results, surface morphology, defects, electrical and optical characteristics have been explained in the chapter. The results also give an estimate of the concentration of the defects which gives an insight into the sensing characteristic of the synthesized nanomaterial.

Chapter-3: Dual-Activated ZnO Nanomaterials for Selective Detection of CO and CH_4

The chapter focuses on dual activation and its effect on sensing characteristics. During dual activation, the surface of the sample is under the influence of Opto-Thermo activation, therefore, activation energy is decreased leading to low-power sensing operation. An elaborate discussion of the same is included in the chapter.

Chapter 4: Synthesis and Characterization of Dual Activated Nanocrystalline In_2O_3 for Selective Sensing of CH_4 and CO

The chapter describes the synthesis and characterization of In_2O_3 for the selective detection of CH_4 and CO. The role of dual activation has been analyzed with its effect on the sensing characteristics for In_2O_3. SEM, PL, XPS, and XRD characterization have been done for analysing the results.

Chapter 5: Design, Fabrication, and Packaging of Pd-ZnO based CO and CH_4 Sensor

The chapter focuses on the design, fabrication, and packaging of the sensing device. The COMSOL stimulation of the same was carried out prior to the fabrication of the device. Finally, the device was fabricated by using different methods and tested. The packaging of the device was carried out to reduce the loss of heat by means of conduction, convection, and radiation. A detailed investigation is carried out to evaluate the performance of the packaged sensor.

Chapter-6 Conclusion and Future Scope of the Work

The chapter presents the summary, conclusion and future scope of the work.