CHAPTER 6

Summary and Conclusions

6.1 Summary and Conclusion

In the present work fabrication and characterization of gridded gate Pt/SiO_2/Si MOS sensor has been proposed for detection of hydrogen and hydrogen containing gases. In the recent years the several impact on the environment due to the burning of fossil fuels has attracted the modern world for clean energy source; Hydrogen being a know used as a clean energy source in many industries like chemical, food, semiconductor, petroleum, research laboratory etc. It is well known fact that hydrogen is inflammable, explosive as well as hazardous gas. In order to have a safe working environment its continuous monitoring is required. Hydrogen sensors form an integral part of any such systems incorporating hydrogen as a fuel. Over the past several years much attention has been focused on the development of micro gas sensors for various applications ranging from detection of toxic gases to monitoring of the gases that are used in industries for manufacturing purposes. The demand for better environmental control and safety and that with less expensive way has commenced the increased activities in the field of solid state gas sensors.

Single crystal silicon has remained the best choice among the researchers for sensor fabrication due to its intrinsic mechanical stability and the feasibility of integrating sensing and the signal processing electronics on the same substrate. Though silicon has the highest material cost per unit area, but this cost often be compensated by the small feature size possible in a silicon implementation. Furthermore, the reduction in terms of of power consumption and the mass production capabilities of the IC technology based on the silicon are the main driving force for fabrication of Si- based IC compatible sensors. Keeping this in view, Silicon has been used as substrate throughout the present work.

Chapter 1 has been designed for Introduction and literature survey to justify the scope of the thesis outlined. Chapter 2 has described the theory of MOS sensor. The Pt/SiO_2/Si MOS gas sensor has been fabricated on p-type <100> silicon wafer. In Chapter 3 the detail procedure of device fabrication has been discussed in section 3.4 of Chapter 3. The various fabrication and measurement facilities available in the laboratory are also discussed in this chapter. The C-V measurement set-up has been discussed for detection of test gases in section 3.3.1, Chapter 3. The C-V and G-V response of the sensor as a function of signal frequency with varying concentration of test gases (H_2, NH_3, CH_4 and H_2S) have been studied. The interface trap charges have been evaluated towards test gases (H_2, NH_3, CH_4 and H_2S) at various frequencies. The sensitivity 'S' of the sensor is defined as:

$$S\% = ((C_{air} - C_{gas})/C_{air})x100 = \left(\frac{\Delta C}{C}\right)x100 \quad \text{(in terms of capacitance)}$$

and

$$S\% = ((G_{pi}-G_{pgas})/G_{pi})x100 \quad \text{(in terms of conductance)}$$

Chapter 5 has described the effect of RF oxygen plasma on SiO_2 film surface. The surface analysis has been carried out by Atomic Force Microscopy (AFM). Comparative study between plasma treated and non plasma treated sensors has been carried out in terms of sensitivity (%) vs bias voltage and fixed charge density variation with various concentrations. The details of work are presented in Chapter 3, 4 and 5. Following are the conclusions which have been extracted from this work.

1. A Gridded Pt gate MOS sensor has been developed for detection of hydrogen and hydrogen containing gases to obtain better sensitivity and tested at H_2, NH_3, CH_4 and H_2S.
2. The C-V and G-V measurements have been carried out at various frequencies (15 KHz, 25 KHz and 50 KHz) and test gas concentrations both. It has been found that MOS sensor exhibited better sensitivity at lower frequency.
3. The low frequency conductance method provides the better information of interface trap charge density. And it has been found that interface trap charge density increases with decrease in frequency. Further, it has also been observed that interface trap charge density decreases with increase in hydrogen concentration.
4. The porous structure of the Pt gate film as detected from SEM and AFM studies (Fig. 4.1 and Fig. 4.2, Chapter 4) may be the reason of enhanced sensitivity towards hydrogen.
5. The sensitivity of gridded gate Pt/SiO_2/Si MOS sensor for hydrogen (~90% in terms of change in capacitance) is found to be more as compared to other gases

NH_3 (85%), CH_4 (45%) and H_2S (68%). And the sensitivity (in terms of change in conductance) is found to be maximum for H_2 (45.66%) as compared to other test gases NH_3 (27.88%), CH_4 (23.4%), and H_2S (14.7%)

6. It has been observed that gridded gate $Pt/SiO_2/Si$ MOS sensor is much more sensitive to very low concentration of NH_3 (25 ppm), CH_4 (50 ppm) at room temperature (27 ^{0}C) and for H_2S (10 ppm) at 120 ^{0}C temperature.
7. The high sensitivity of gridded $Pt/SiO_2/Si$ MOS structure to H_2 is attributed to the side wall diffusion of H_2 molecules, improved diffusion and dissociation of hydrogen molecules, increase in surface area of Pt film due to large porosity found in the film, high polarizability of SiO_2, spill-over mechanism and increase in fixed charge density with H_2 concentration.
8. To the best of authors' knowledge it is the first time that the gridded gate $Pt/SiO_2/Si$ MOS sensor has been fabricated and it is found that sensitivity of gridded gate MOS structure improves drastically towards H_2 and H_2 containing gases.
9. To the best of authors' knowledge it is the first time that the gridded gate $Pt/SiO_2/Si$ MOS sensor has been fabricated with plasma treated SiO_2 film and tested towards H_2. The goal of this experiment was to study the combined effect of gridded gate structure with RF oxygen plasma treated SiO_2 on C-V characteristics, fixed charge density, (%) sensitivity, grain size and average roughness and it is found that sensitivity towards hydrogen improves drastically for oxygen plasma treated sensors. The comparative study among the plasma treated and non plasma treated sensors has also been discussed. The sensitivity (in terms of change in capacitance) was found to be maximum for S4 sensor (~91%) as compared to non plasma treated sensor (S1) (~73%).
10. The sensitivity was found to be increased with increase in plasma exposure time. The maximum sensitivity has been recorded ~91% in case of 40 W, 8min. plasma exposure. This is due to large grain size, large porosity and more roughness found in the film. However, in case of 50 W, when plasma exposure duration exceeds beyond 4 min., the oxide surface gets damaged (confirmed by AFM study) probably ion sputtering of the surface may take place.

6.2 Scope for Future work

A number of questions have evolved from the present work which is needed further investigations and these are outlined below as the scope for future work.

1. Volatile organic compounds are the major pollutant adversely affecting the quality of the indoor air. This causes a very serious impact on human health as they are considered to be carcinogenic, mutagenic or teratogenic. In view of the consequences of these toxic, hazardious and explosive gases on the environment and human health, gas sensors are needed that can rapidly and reliably detect and quantify these gases at safe level much before the occurance of any fatal accident. The gridded gate Pt/SiO_2/Si MOS sensor can be tested towards these (VOCs) like methanol and propanol.
2. In addition to H_2, NH_3, H_2S and CH_4 further studies can be made for other hydrocarbons like acetylene (C_2H_2), ethane (C_2H_6) and other toxic gases like CO_2, CO and SO_2 using low conductance method.
3. Gate oxide other than SiO_2 can be used.
4. Plasma grown SiO_2 can be used to develop gridded gate Pt/SiO_2/Si MOS capacitor gas sensor and hence in true sense IC compatible sensors can be developed.
5. Electron Beam (e-beam) and Atomic Layer Deposition (ALD technique) for metal deposition (gate electrode) can be used.