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SENSING CHARACTERISTICS OF SnO_2 THIN FILM GAS SENSORS

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Abstract. *The Pt-doped SnO_2 thin film detector sensitivities for different gases including the propane, carbon dioxide, acetone, and oxygen have been investigated incorporating the structural evolution of the thin film. The crystallographic structure of the SnO_2 layer significantly varied with increasing the Pt concentration and grain size of the film decrease with Pt content. The highest gas sensitivity of the films is exhibited for the oxygen gases. In addition, the oxygen sensitivity of the sensors increases with the Pt concentration up to a specific operating temperature. This variation may be due to the different contributions of the spillover and Fermi energy control mechanisms to sensor sensitivities. The present results have depicted that the sensor design should be carefully configured to promote the sensing responses of the gas sensors.*

Keywords: *Sensors, gas sensor, oxygen sensor, tin oxide*

1. INTRODUCTION

The fabrication of low-cost, fast response gas sensors is requirements for the effective application of gas sensors [1],[2]. SnO_2 is a commonly used material for the fabrication of a gas sensor [3]. Tin oxide (SnO_2) with having 3.6eV bandgap is an N-Type semiconductor [3] and it is commonly used material for the fabrication of a gas sensor [4]. In general, the sensitivity of the material depends on the chemisorption with the target gases and it is affected by the operating temperature and the dopant concentration [5]. In addition, the sensor capability is decreased when grain size of metal oxide increases [6]. SnO2 sensor sensitivity property is directly related with crystalline structure of SnO2, surface doping element, environmental, and operational conditions [7, 8]. However, there are limited studies on correlations between doping elements and operation temperature. In present study, SnO_2 thin films were fabricated with different concentrations of platinum (Pt) on the films and the sensing property of the films were measured at different operating temperatures.

2. EXPERIMENTAL DETAILS

Si wafers were used for fabricating the thin films during the study. The standard RCA cleaning process was applied for cleaning the wafers. Then, SiO_2 layer was grown on the Si substrate by wet oxidation technique at 1000°C in a diffusion furnace (Qingdao Sun Red Electronic Equipment Co.). The SnO_2 layer was deposited on the oxide layer at the base pressure of $6.0x10^{-4}$ Pa. The thickness of the SnO2 layer was measured as 120 nm with a spectroscopic reflectometer (Angstrom Sun Technologies). One of these samples was kept as a virgin film. Pt was coated on the surface of the films by sputter at 250W for 3 seconds (China Rare Metal Material Co.). Both virgin and Pt doped films were annealed at 600°C. The crystal structure of SnO2 films was analyzed with Rigaku Multiflex XRD (scan speed of 3.5°/ min.) After that, the surface morphology of the films was investigated by a Scanning Electron Microscope (Zeiss EVO HD15). After all these processes, the interdigital electrodes were formed with sputter again.

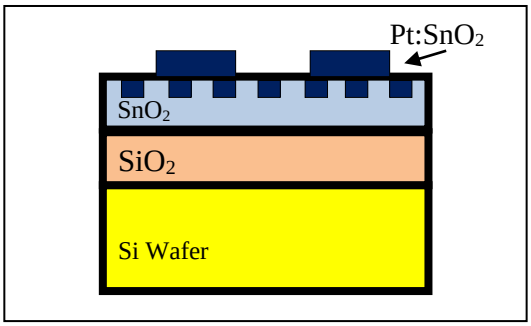

Figure 1. Schematic diagram of gas sensors

Figure 1 shows the cross-sectional diagram of the obtained sensors. Current-Voltage characteristics of the samples were measured via Keithley 4200 – SCS. The experimental setup for the sensing characteristics test of the device was given in Figure 2. In this system, the sensitivity of the sensors was examined at different

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operating temperatures (up to 425°C) and various concentrations of O_2. Gas concentrations were adjusted between 1000 and 4000 ppm by Alicat Scientific MC-100SCCM mass flow controller.

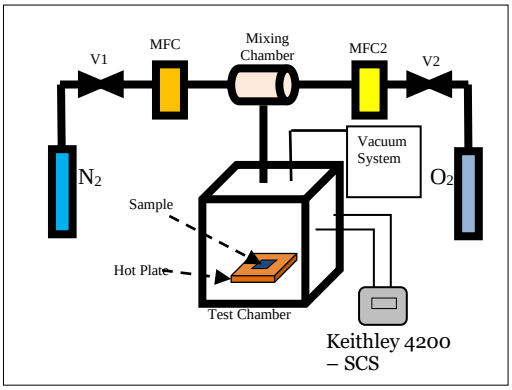

Figure 2. Experimental setup to test the sensitivity of films

3. Results and Discussion

XRD patterns of virgin SnO2 films and Pt doped films are shown in Figure 3. The results compared with ICDD card no: 77-042 and 20-1293. It was observed that the obtained peaks were matched with the tetragonal phase of tin-oxide, and triclinic phase Sn3O4. Also, the Pt doping affected the crystal structure of the SnO2 layer.

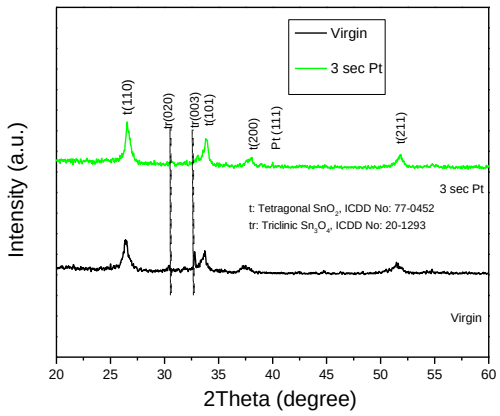

Figure 3. XRD patterns of SnO2 films

When Pt concentration increase, the triclinic phase of tin-oxide cannot be observed anymore. In addition, the grain sizes were calculated, and it was found out that Pt lowered the grain size. The calculated atomic concentration of Pt and grain sizes of the samples is shown in Table 1.

Table 1. Some characteristics of virgin and 3 seconds Pt-doped SnO2 samples

Samples	Grain Sizes (nm)	Atomic Conc. of Pt (%)
Virgin	27.1	0.0
3 sec Pt	20.1	0.449

The SEM images were taken in order to investigate the morphologies of the films. In all cases, tin-oxide films were monitored as polycrystalline structure.

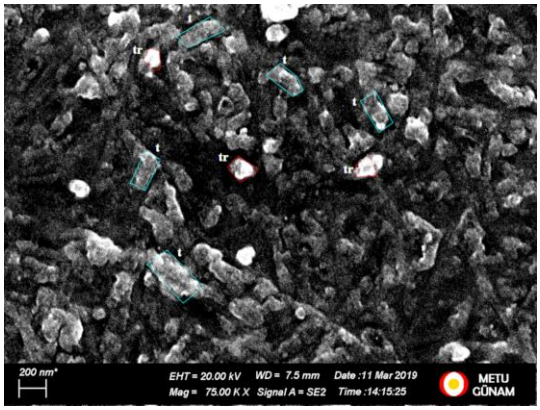

Figure 4. SEM image of virgin thin film

In Figure 4, some brightness area was observed. This situation may be originated by different oxidation state of Sn (Sn_3O_4 formation) which was confirmed by XRD.

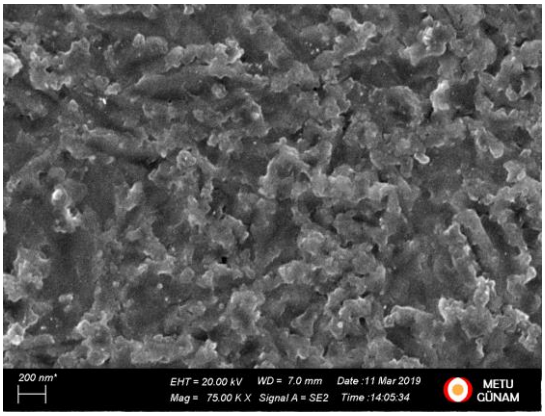

Figure 5. SEM image of 3-second thin film

Figure 6 and Figure 7 indicated that the sensitivity change of each film under a different concentration of the oxygen gas. While the oxygen concentration was increased, the resistance of the sensors was also increased linearly, and they were not effective below 150°C. The doped Pt adsorbed and cleaved the oxygen molecules , so atoms “spill over” onto the surface of the SnO2 [9]. Therefore, the Pt additions caused the sensitivity increase. In current study, the best result was obtained the range in between of 325°C and 360°C. This temperature was the optimum point for all the

measurements, especially in the 2000 ppm gas concentration.

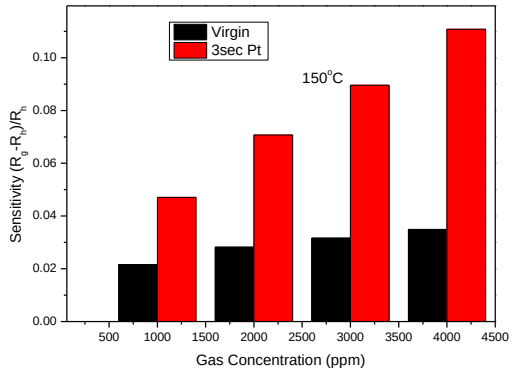

Figure 6. Oxygen sensitivity of SnO2 films at 150°C

It was observed that above 350°C the sensitivity started to decrease for all samples, as it can be seen in Figure 8.

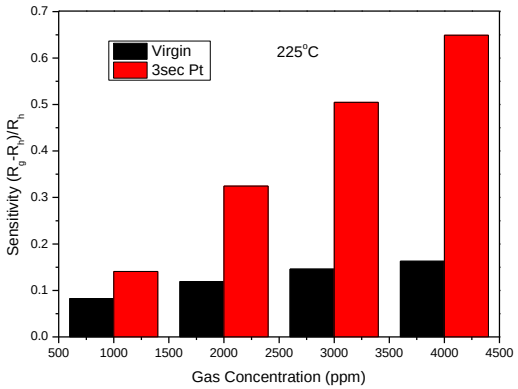

Figure 7. Oxygen sensitivity of SnO2 films at 225°C

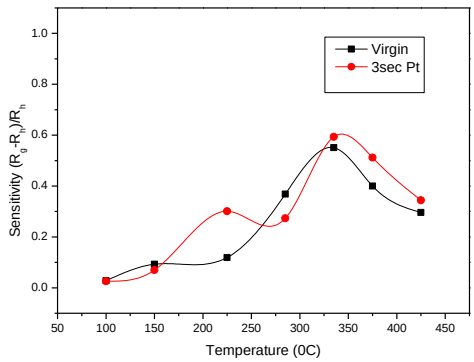

Figure 8. Temperature dependence on sensitivity at 2000 ppm gas concentration

Figure 9 illustrated the selectivity of the sensors. Oxygen, carbon dioxide, propane, and acetone were used as the target gas for testing the selectivity. In addition, nitrogen was used as the reference gas in all measurements. The selectivity of the sensors was measured under 2000 ppm gas concentration and it was found that Pt affected the sensor response for different gases. However, virgin and 3-seconds Pt doped SnO2 sensors had a good selectivity for the oxygen gas.

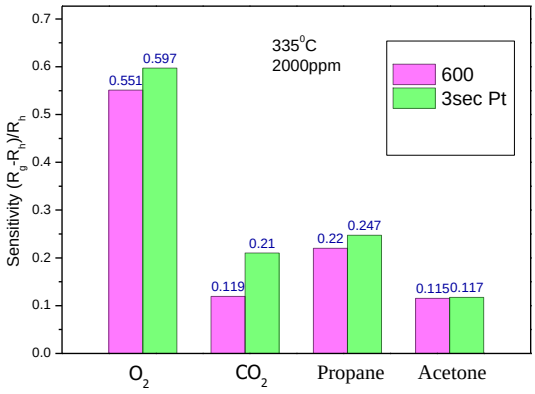

Figure 9. Sensitivity of the films for different gases at 335°C

4. Conclusion

In summary, Pt doped SnO_2 sensors were successfully fabricated and their sensitivity and selectivity were measured at different temperature under various gas concentration. Pt played critical role during the study: Pt doping eliminated triclinic phases (unwanted phase) of SnO_2, so that sensitivity of sensors was increased. Also, Pt lowered the grain size of SnO_2 which was related with selectivity. In addition, the best operating temperature to sense the oxygen gas was found as in the range between 325°C and 360°C. The produced sensors were also selective for other gases but not as effective as for oxygen detection.

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