RESEARCH PAPER

Sensor Utilizing ITO-Silicon Substrate for Gas Detection

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ABSTRACT

An effective and size-controlled DC-sputtering approach that produces high-quality thin films and a large deposition area was used to create the In_2O_3-Sn/Si gas sensor. ITO thin-film structural, optical, and electrical characteristics were thoroughly examined and studied at various doping concentrations. Atomic force microscopy and X-ray diffraction were used to analyze the surface morphology and structure of ITO thin films. According to the XRD process, these films have a polycrystalline structure and are best oriented in the (222), (440), and (400) directions. Crystalline size was shown to decrease as doping levels increased. All of the films had transmittances that were highly transparent (more than 85%) when measured in the wavelength range of 300 nm to 900 nm. Measurements have been made of the sensitivity to NH_3 and NO_2 gases. Sensitivity to NH3 is higher in In_2O_3 doped with Sn. Measurements of sensitivity to NO_2 gas show that In_2O_3 doped with Sn is more sensitive to NO_2 than to NH_3.

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INTRODUCTION

ITO (indium tin oxide) is a semiconductor with a wide band gap, low resistivity and high optical transparency in the visible spectrum, good adherence to the substrate surface, and high chemical inertness. It can appear in two stable modifications, centered cubic body and rhombohedra (rh), which can be stabilized by selecting the right synthesis method or deposition conditions. [1]. The most researched techniques for creating In_2O_3 nanostructures were physical methods like R.F. sputtering, D.C. sputtering, thermal evaporation, and ion beam deposition. According to In_2O_3,[2], the majority of recommended techniques for creating high-quality polycrystalline films involved high-temperature treatment. High temperatures, on the other hand, weaken film surfaces and thicken interfaces, which degrades optical characteristics [2].

High-quality In_2O_3 thin films were successfully grown using the D.C. process. By regulating the composition of the deposition structure and in situ doping, it significantly contributes to the reduction of chemical contamination Furthermore, by simply altering the deposition

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conditions, it is a flexible and effective method for producing nanoparticles with the required size and composition [3].because of its high sensitivity, straightforward construction, and affordability, ITO has long been used as a gas sensing material to identify flammable, hazardous, and polluting gases [3]. Recently, studies have concentrated on lowering the working temperature through doping and increasing gas sensitivity [4].

MATERIALS AND METHODS

Target Preparation

High purity (99.99%) indium oxide powder and tin oxide (Sn) powder from Fluke Company are available in varying doping concentrations of 4%, 8%, and 12%. To ensure that the combination was evenly spread, the powder was mechanically blended for six hours. To ensure that the target would not crack, the resulting powder was ground once more and the additional material was employed as glue. Using a compressor, the target was inserted and compressed less than 20 tons to create a target that was 2.7 cm in diameter and 0.7cm in thickness. The target was then sintered for two hours at 800°C. To guarantee a high-quality deposit, the obtained target was as dense and uniform as feasible.

RESULTS AND DISCUSSION

X-ray diffraction result

Annealing temperatures effect

The annealing temperature plays an important role in determining the structure of In_2O_3 thin film which is fabricated on glass substrate. Fig. 1a-c show the XRD measurement results of different In_2O_3 films formed at annealing temperature 300°C on glass substrate (at deposition time 3-hour, voltage operator 2Kv, distance between target and substrate 4cm, sputter gas pressure $4*10^{-4}$ Toor). It can be seen that the film is amorphous as deposited of In_2O_3. When the annealing temperature is 300°C two different located at 2θ =30. Corresponding to (222) plane and at 2θ = 37 which corresponding to plane (400) of In_2O_3 as show in Fig. 1. Since sputtered particles typically have kinetic energies of several electron volts, this kinetic energy enhances the surface migration of sputtered particles arriving at the substrate surface and greatly affects the crystalline nature of the films, making it possible to deposit polycrystalline films even at room temperature through sputtering. This explanation explains why the films exhibit a crystalline nature even at lower processing temperatures [1,2]. The intensity increasing with increasing annealing temperature up to

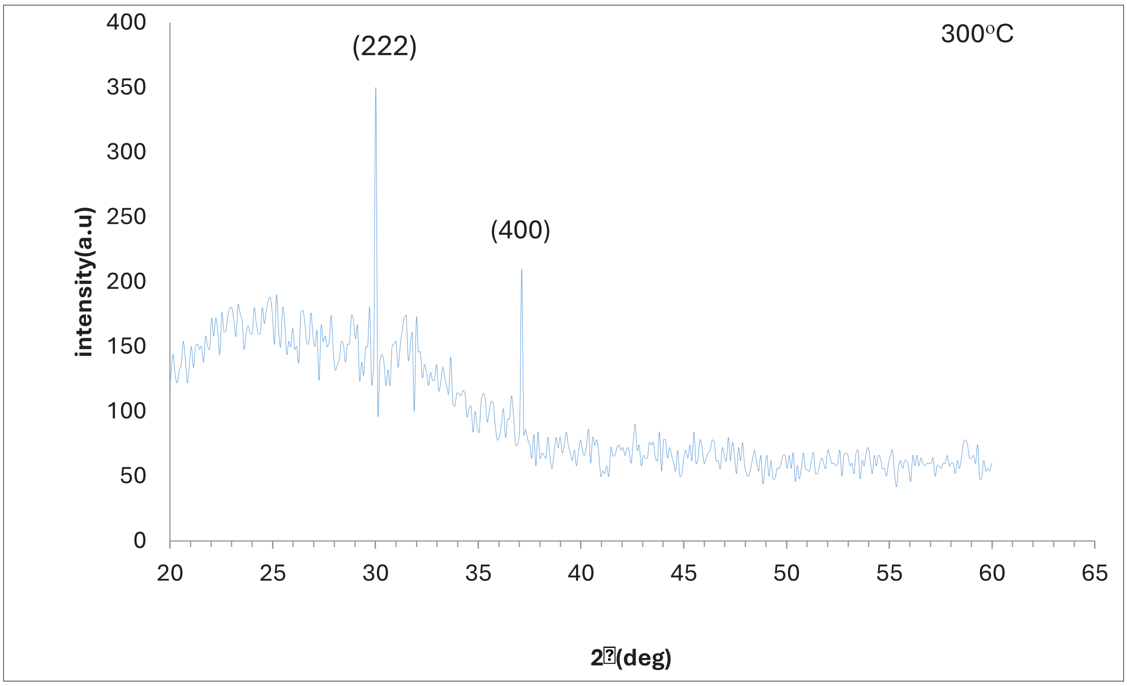

Fig. 1. XRD of In_2O_3 annealed at 300°C.

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300°C. With increasing annealing temperature and narrowing Full Width at half [5]. Maximums (FWHM) of peak and increasing in grain size which is according with finding of other workers [4].

Surface morphology atomic force macroscopic (AFM)

Annealing temperature effect

In_2O_3 has been growing on glass substrate.

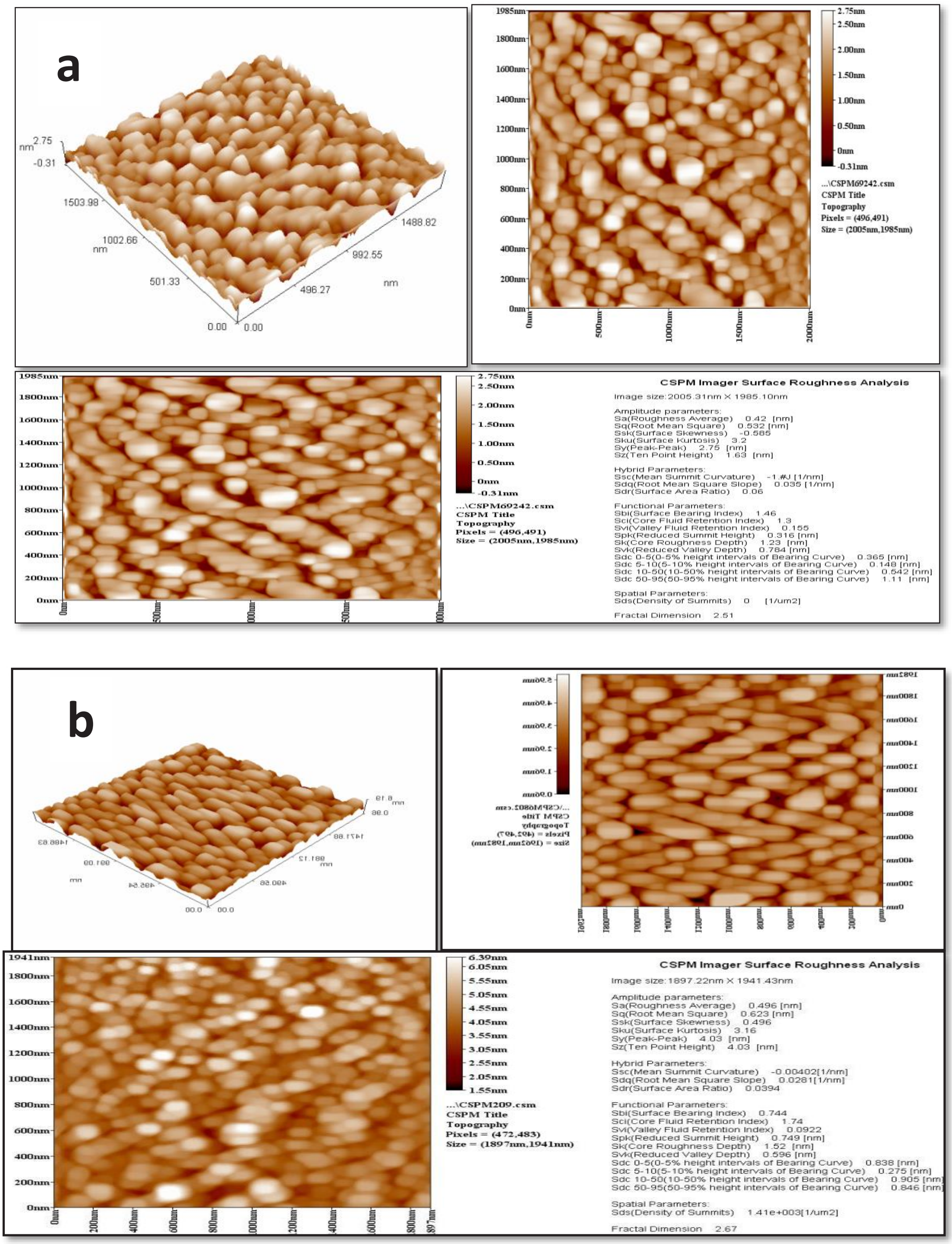

Fig. 2. Three- dimensional AFM images of the In_2O_3: Sn with 4wt% thin films at Annealing temperature a) 500 °C b)400 °C.

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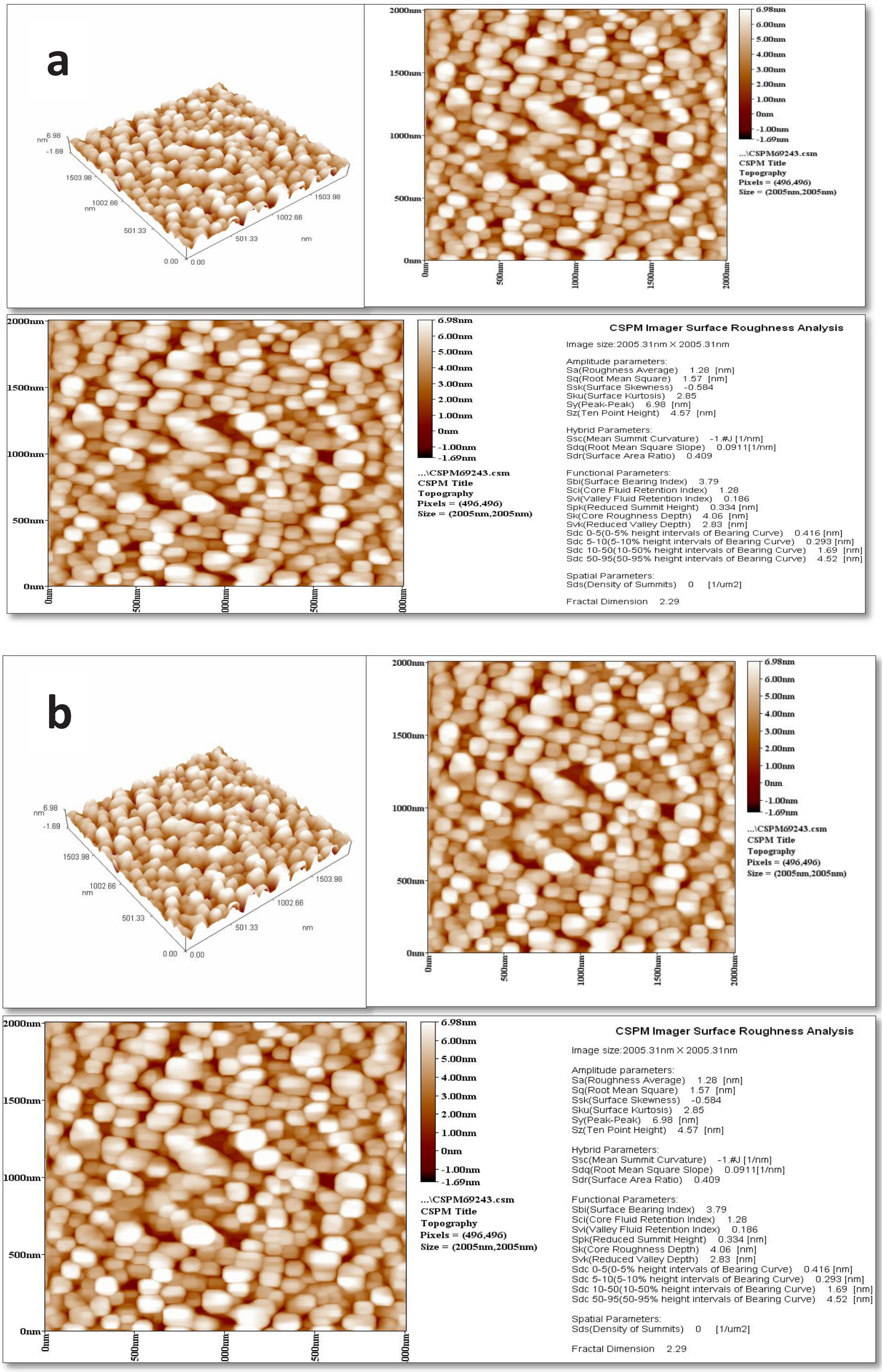

Fig. 3. Three- dimensional AFM images of the In_2O_3:Sn with a) 8wt% thin films at annealing temperature 400 ^{o}C b) 12wt% thin films at annealing temperature 500 ^{o}C.

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Figs. 2 and 3 shows the AFM images of the In_2O_3 thin films deposited at different annealing Temperature (300°C, 400°C and 500°C). It can be seen that the crystalline of the films improves and the crystallite size become larger with increasing annealing temperate and that is shown by XRD analysis, also the degree of surface roughness increasing [7]. From the topographic images it can be seen that the films deposited at 400°C appears to be more uniform than that sample deposited at 300°C, 500°C. The RMS roughness decreases with increasing annealing temperature 500C probably because of particle or grain coalescence at a higher deposition temperature [8].

Optical properties of the In_2O_3: Sn (ITO) thin films

Transmission of the In_2O_3: Sn (ITO) thin films

Studying the optical transmittance of the prepared film is of great interest due to its valuable scientific meaning. The optical transmittance spectra depend on the crystalline structure of the prepared films and also on the surface morphology. In order to improve In_2O_3optical properties. The optical properties of the In_2O_3: Sn (ITO) thin films have been investigated by the transmission spectra and were measured in the wavelength range from (300 nm to 900 nm), and study the effect of different deposition parameters such as the annealing temperature, doping concentration optical properties of the thin film. The optical transmission of In_2O_3 films on glass substrate prepared by DC- sputtering were measured by UV- Vis spectrophotometer. For film preparation with 520 nm thickness and at different annealing temperature (300- 500) °C and at deposited, reveal that the transmittance depends stronger on the temperature as shown in Fig. 4. it also found that the average transmittance of the In_2O_3 film exceeded 90% in the near – infrared region. for all the films analyzed it is observed that the optical transmittance decreases slightly with increasing annealing temperature this is in consistent with increasing of the surface roughness promoting the increasing of the surface scattering of the light. Both densification and agglomeration of the crystallites at the highest temperature are responsible for this behavior according to the results [9].

Sensing properties

Gas sensitivity

The gas sensitivity of un-doped and doped In_2O_3

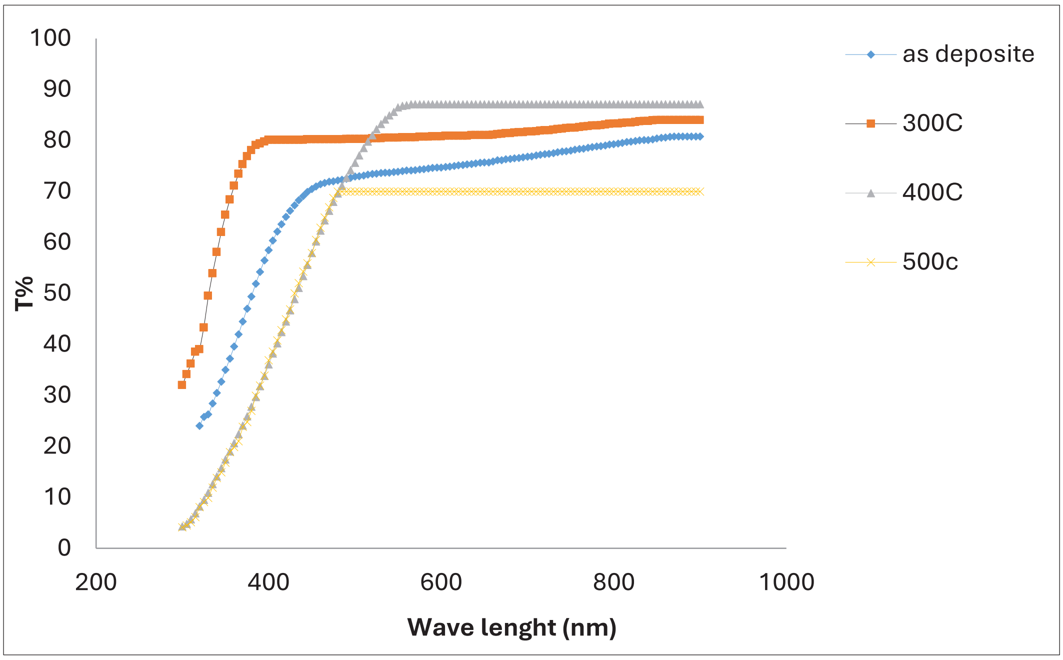

Fig. 4. UV-VIS transmittance spectra of In_2O_3/glass films at different annealing temperature (300 °C, 400 °C, 500 °C).

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films is calculated from measuring the resistance change in thin films in air and in gas. The change in surface resistance in presence of gas with time Fig. 5 show the gas sensitivity of pure In_2O_3 films deposited on silicon substrate at different annealing temperature (300,400,500°C). At pure In_2O_3show increasing in the sensitivity reach to (80%) which belong to temperatures 300,400)

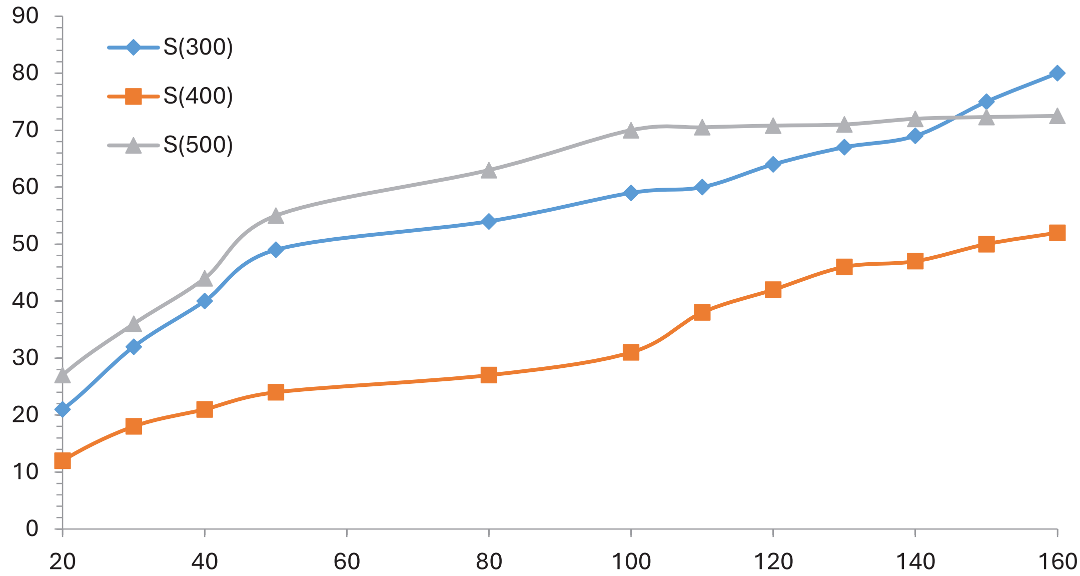

Fig. 5. Sensitivity of In_2O_3pure films with different annealing temperature for NH_3 gas.

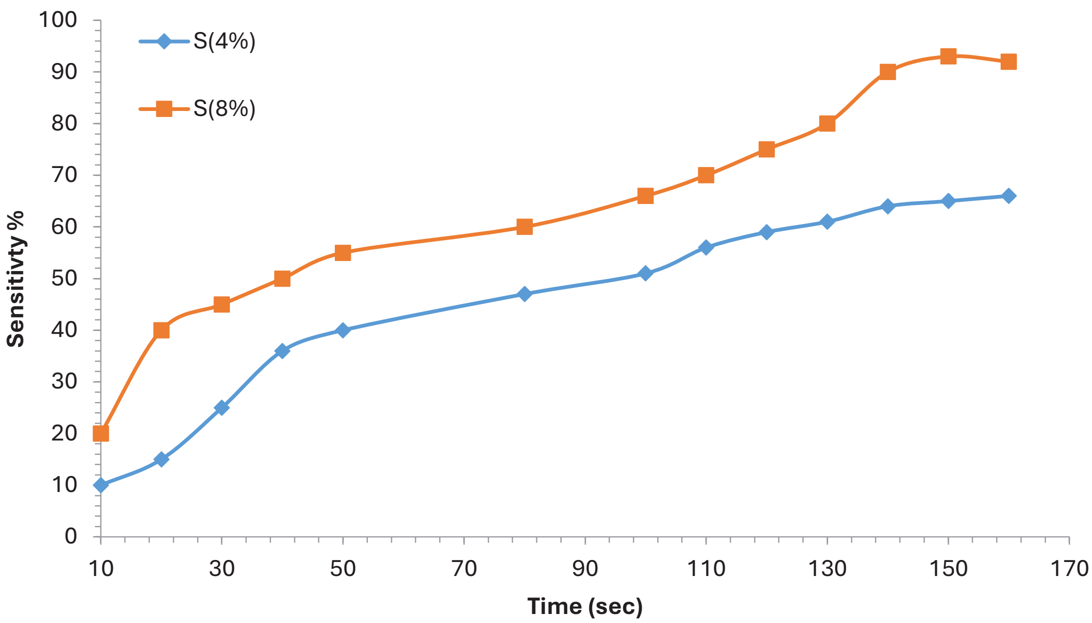

Fig. 6. Sensitivity of In_2O_3 doped Sn films for NO_2 gas.

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respectively, this may be due to increasing temperature at 500ºC reach to (70%).

The sensitivity of ITO with tin concentrations of 4.8 weight percent for NO_2 gas with concentrations of 10ppm is shown in Fig. 6. It is evident that the sensitivity increases with doping concentration because the grain size decreases with increasing doping concentration, increasing the film's sensitivity [12,20,21].

CONCLUSION

ITO is amorphous as deposited, according to the XRD results, but the annealed ITO thin films at 300°C for 30 minutes have a good crystalline cubic structure. The polycrystalline structure of the ITO films is observed to have (222), (400), and (440) planes of high peak intensities. The structure of In_2O_3 doped with tin (Sn) thin films is less crystalline than that of un-doped samples, and the transmittance of thin films doped increases as the doping concentration increases In_2O_3 doped deposited on silicon (p-type) has sensitivity to NH_3, NO_2 gas, and the sensor In2O3 doped with Sn exhibits good sensitivity to NH_3.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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