A selective NH$_3$ gas sensor based on (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ nanocomposites thin films at various operating temperatures

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Abstract

The pulsed laser deposition (PLD) technique was used to prepare the (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ nanocomposite thin films with different ratios of $x=0$, 0.2 and 0.4wt and deposited on glass substrates. The films were subsequently annealed in the air for two hours at 300 °C. The (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ nanocomposite was confirmed to have formed by the x-ray diffraction (XRD) investigation. According to field emission scanning electron microscopy (FESEM), the created (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ particles were spherical in shape. Energy Dispersive X-Ray Analysis (EDX) is used to confirm the elements in composite films. Atomic Force Microscopy (AFM) analysis shows that the produced films had grains size between 37.68 - 49.57nm and root mean square (RMS) roughness of 4.92 - 8.22nm. The prepared films have a direct energy gap between 2.06 and 3.36 eV, according to UV-visible (UV-Vis) spectrometer data. The films have been tested for NH$_3$ sensing under various operating temperatures. The observed variations in the gas sensing response's thin film resistance are suggestive of either n-type or p-type conductivity. When reducing gas is present, the resistance of (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ films increases when $x=0$, 0.2wt, indicating that the films are p-type, however, the thin film exhibits the reverse behavior at $x=0.4$wt, indicating that it is n-type. Additionally, all films produced showed a significant sensitivity to NH$_3$ gas at 95 ppm concentration. The Ag$_2$O thin film had a sensitivity of 50.5% at an operating temperature of 200°C with response and recovery times of 22.5 and 39.6 seconds, respectively. Furthermore, composite thin films showed greater sensitivity than pure silver oxide thin films.

Key words: Ag$_2$O- SnO$_2$, Nanocomposites, NH$_3$ gas sensor, Operating temperatures, Pulsed laser deposition.

Introduction

Ammonia (NH$_3$) is a very hazardous, flammable chemical gas that's widely used in the food-processing, pharmaceutical, and chemical sectors. These systems could leak, posing health risks. The detection of NH$_3$ in traces is crucial for industrial production, environmental safety, and human health$^1$. Utilizing metal oxide semiconductor (MOSs) nanoparticles as the foundation of the sensor is an impressively effective way to increase the reaction speed, sensitivity, and selectivity of gas detecting characteristics. Researchers have conducted numerous works and investigated a variety of sensitive materials with the goal of understanding the sensing of NH$_3$ at room temperature$^{2-7}$. One of many MOSs. Ag$_2$O is a p-type semiconductor with a direct band gap of 1.2 eV.
because of its stability, non-toxicity, low cost and sensitivity to gases, it is a preferred material for use in gas sensors. Additionally, optoelectronic applications can make use of silver oxides in the mechanics of conduction, the oxygen vacancies in silver oxide are crucial. Tin dioxide (SnO$_2$), an n-type wide band gap semiconductor ($E_g = 3.6$ eV) has been widely utilized in the detection of ammonia.

Recently, surface modification, doping, and the blending of semiconducting metal oxides have increased the sensitivity and selectivity of nanomaterials for semiconductor oxides. Depending on the kind of oxides and the type of reactive gas, the mixing procedure of oxides impacts the sensitivity and selectivity features. Due to changes in the surface of the manufactured composite, a particular mixture can yield good properties of one gas and poor properties of another. Due to the improved gas-sensing performance of n-type oxides and p-type semiconductor oxides toward target gases, this combination has received a lot of attention, such as producing a nanocomposite from the mixture of n-type In$_2$O$_3$/p-type CuO by the chemical spray pyrolysis process to improve NO$_2$ gas sensor applications. Low-concentration NO$_2$ gas sensing using n-type TiO$_2$/p-type Ag$_2$O composite nanorods made using the sputtering decoration process. To fulfill the needs for low-level acetone detection, a gas sensor based on n-type ZnO/p-type CuO composite nanostructure (ZCS) has been developed.

However, the composite p-type Ag$_2$O/n-type SnO$_2$ for sensor application has only been examined by a small number of researchers such as Yang and co-workers was reported to enhance H$_2$S-sensing capability, nanocasting was used to create mesoporous Ag$_2$O/SnO$_2$. For applications in H$_2$ gas detection, SnO$_2$/Ag$_2$O ceramic nanocomposite (CNP) was created using the sol-gel process was studied by Rizi and co-workers. Sputtering techniques and co-sputtering, respectively, are used to create monolayer and two-layer n-type SnO$_2$/p-type Ag$_2$O composite thin films for NO$_2$ gas sensor applications were explored by Liang and co-workers. Thus, further research is still necessary.

In this study, we used pulse laser deposition (PLD) to create an (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ nanocomposite. The impact of composition variations of (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ on structural morphology, compositional, and optical features are investigated using XRD, FESEM, AFM, EDX, and UV-Vis analysis. Further research was done on the ammonia gas detecting behaviors of synthesized films at various operating temperatures and the effects of varying ratios of x (0, 0.2, and 0.4wt), compared to pure Ag$_2$O sample. As a result, the main objective of this research is to enhance the gas sensitivity for NH$_3$ of based on (Ag$_2$O)$_{1-x}$(SnO$_2$)$_x$ nanocomposite sensors at low temperatures.

Materials and Methods

Ag$_2$O and SnO$_2$ powders were combined in various ratios of x = 0.0, 0.2, and 0.4wt using a hydraulic piston, the mixtures were crushed into pellets measuring 25 mm in diameter and 4 mm in thickness. These pellets were sintered for one hour at 100 °C. The deposition was carried out using a turbo rotary pump at 2 $10^{-3}$ mbar.

All pellets were exposed to radiation using a 532 nm Q-switched Nd: YAG laser (Model HF-301, Huafei Technology, China) operating at 300 mJ and 300 laser pulses per second (6 Hz) with a pulse width of 10 ns. The thickness of the thin films was around 200±10 nm. Nanocomposite thin film preparation is completed by annealing films at 300 °C for 2 hours.

The Tolansky interferometer technique is used to measure a thin film thickness. The UV/Visible Spectrophotometer SP-8001, manufactured by Metertech in Taiwan, was used to measure the samples' optical characteristics. By analyzing the XRD pattern produced by the Philips X-ray diffractometer model PW 1710 (= 1.5405 Å for Cu K), the structural characterization of the samples was completed. Energy Dispersive X-Ray (EDX) Analyses and the SUPRA 55 VP field emission scanning electron microscope (FESEM) were used to evaluate the materials' surface morphology and elemental analysis. Through the use of an atomic force microscope (AFM) in tapping mode, the grain size and surface roughness are examined. Finally, the synthesized composite film's sensitivity to NH$_3$ gas was tested at various Ag$_2$O ratios and different operating temperatures.
Results and Discussion

XRD analysis

Fig. 1 shows the x-ray diffraction patterns of (Ag$_2$O)$_{1-x}$ (SnO$_2$)$_x$ composite thin films deposited on glass substrate at different ratios (x = 0, 0.2 and 0.4 wt) , which were obtained by pulsed laser deposition and annealed at 300 °C for two hours.

Fig 1a shows typical peaks that correspond to the trigonal (hexagonal axis) Ag$_2$O (011) and (004) peaks positioned at 2θ = 38.16° and 77.5° respectively (PDF card no. 96-150-9685). In addition, it can be seen that Ag$_2$O has been deposited alongside the elements Ag and another oxide AgO, which are present at 2θ = 44.36° and 64.53°, respectively. However, compared to other materials, Ag$_2$O exhibits a greater peak of hexagonal crystal lattice along the orientation (011). The quality of the crystal structure is represented by the quality of the XRD peaks; a more intense peak of Ag$_2$O denotes better crystallinity.

Moreover, the mixed tetragonal structure of SnO$_2$ can be shown in Figs b and c, based on the diffraction peaks (110), (101) that are situated at 2θ = 26.62° and 33.94°, respectively. (JCPDS 01-077-0447) with Ag$_2$O's hexagonal structure provided evidence that an Ag$_2$O-SnO$_2$ nanocomposite had formed. Moreover, it is noted that the peak intensities of the tetragonal SnO$_2$ increased as the ratio of SnO$_2$ increased from 0.2 to 0.4wt, indicating a reduction in the degree of crystallization of the hexagonal structure Ag$_2$O.

Based on the Scherrer equation below, the average crystallite size of nanocomposite (Ag$_2$O)$_{1-x}$ (SnO$_2$)$_x$ thin films was calculated for all peaks:

$$D = K \lambda / \beta \cos \theta$$

where D is crystallite size, k is a constant (0.9), λ the X-ray wavelength 1.5418 Å, θ is Bragg's diffraction angle and β is the angular line width of half maximum intensity. XRD results shown in Table 1.

![Figure 1. XRD patterns for the various ratios of the prepared films (Ag$_2$O)$_{1-x}$ (SnO$_2$)$_x$ nanocomposite.](image)

<table>
<thead>
<tr>
<th>Sample</th>
<th>20 (Deg.)</th>
<th>dhkl (Å)</th>
<th>FWHM (Deg.)</th>
<th>hkl</th>
<th>Phase</th>
<th>CS (nm)</th>
<th>Average CS (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X=0</td>
<td>38.161</td>
<td>2.358</td>
<td>0.3938</td>
<td>(011) Hexagonal (Ag$_2$O)</td>
<td>21.3487</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.3571</td>
<td>2.042</td>
<td>0.3936</td>
<td>(200) Cubic (Ag)</td>
<td>21.787</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>64.5761</td>
<td>1.44</td>
<td>0.3936</td>
<td>(301) Monoclinic (AgO)</td>
<td>23.866</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>77.5447</td>
<td>1.230</td>
<td>0.48</td>
<td>(044) Hexagonal (Ag$_2$O)</td>
<td>21.220</td>
<td>22.055</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.624</td>
<td>3.348</td>
<td>0.2952</td>
<td>(110) Tetragonal (SnO$_2$)</td>
<td>27.643</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>33.941</td>
<td>2.641</td>
<td>0.2952</td>
<td>(101) Tetragonal (SnO$_2$)</td>
<td>28.125</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38.149</td>
<td>2.359</td>
<td>0.3936</td>
<td>(011) Hexagonal (Ag$_2$O)</td>
<td>21.347</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.367</td>
<td>2.041</td>
<td>0.3936</td>
<td>(200) Cubic (Ag)</td>
<td>21.788</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X=0.2</td>
<td>64.53</td>
<td>1.444</td>
<td>0.5904</td>
<td>(301) Monoclinic (AgO)</td>
<td>15.907</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>77.44</td>
<td>1.231</td>
<td>0.72</td>
<td>(004) Hexagonal (Ag$_2$O)</td>
<td>14.137</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26.624</td>
<td>3.348</td>
<td>0.2932</td>
<td>(110) Tetragonal (SnO$_2$)</td>
<td>27.832</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>33.941</td>
<td>2.641</td>
<td>0.2948</td>
<td>(101) Tetragonal (SnO$_2$)</td>
<td>28.164</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38.149</td>
<td>2.359</td>
<td>0.3927</td>
<td>(011) Hexagonal (Ag$_2$O)</td>
<td>21.396</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>44.367</td>
<td>2.041</td>
<td>0.3936</td>
<td>(200) Cubic (Ag)</td>
<td>21.788</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X=0.4</td>
<td>64.53</td>
<td>1.444</td>
<td>0.5904</td>
<td>(301) Monoclinic (AgO)</td>
<td>15.907</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>77.44</td>
<td>1.231</td>
<td>0.72</td>
<td>(004) Hexagonal (Ag$_2$O)</td>
<td>14.137</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AFM analysis

When x=0, 0.2, and 0.4wt, (Ag₂O)ₓ₋ₓ(SnO₂)ₓ nanocomposite AFM photos are displayed in Fig 2. The outcomes demonstrate that the films are nanocrystal line and have a rough surface. Ag₂O has a root mean square (RMS) roughness of 4.92 nm and grain size of about 41.98 nm (Fig 2a). Additionally, it is found that when x=0.2 and 0.4wt with high roughness, grain size is reduced for the (Ag₂O)ₓ₋ₓ(SnO₂)ₓ nanocomposite thin film sensor structure, which is recognized to be crucial for achieving improved gas sensing response characteristics (Figs. 2b and c)²⁸-²⁹. AFM results are displayed in Table 2.

Figure 2. AFM images for the prepared films (Ag₂O)ₓ₋ₓ(SnO₂)ₓ nanocomposite at various ratios and their granularity cumulating distribution.

Table 2. AFM parameters for the prepared (Ag₂O)ₓ₋ₓ(SnO₂)ₓ nanocomposite films at various ratios, including Grain size, Roughness average, and RMS roughness.

<table>
<thead>
<tr>
<th>(Ag₂O)ₓ₋ₓ(SnO₂)ₓ</th>
<th>Grain size (nm)</th>
<th>Roughness Ave. (nm)</th>
<th>RMS Roughness (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>x=0 pure Ag₂O</td>
<td>41.98</td>
<td>3.813</td>
<td>4.92</td>
</tr>
<tr>
<td>x=0.2</td>
<td>37.68</td>
<td>6.157</td>
<td>8.22</td>
</tr>
<tr>
<td>x=0.4</td>
<td>49.57</td>
<td>4.294</td>
<td>5.17</td>
</tr>
</tbody>
</table>

FESEM analysis

Fig. 3 shows FESEM micrographs of (Ag₂O)ₓ₋ₓ(SnO₂)ₓ films made by the PLD method. These films are made up of spherical nanoparticles. Using the software Image J, the average diameters of (Ag₂O)ₓ₋ₓ(SnO₂)ₓ nanocomposite particles were estimated which were 15.92, 13.33, and 15.77 nm when x = 0, 0.2 and 0.4wt respectively.

When x=0.2wt as, the (Ag₂O)ₓ₋ₓ(SnO₂)ₓ films include modest amounts of smaller nanoparticles.
with regular shapes. As a consequence raising the ratio of x causes the mean diameter of the nanoparticles to grow, which is consistent with AFM and XRD results.

Figure 4. Field emission scanning electron microscopy images for the prepared films $(\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x$ nanocomposite at various ratios.
EDX Analysis

The prepared samples’ elemental composition was investigated using EDX analysis, with the findings shown in Fig 4.

Fig 4a the area has strong and weak peaks for oxygen and silver atoms, respectively, according to the EDX study. The development of silver oxide is indicated by the extremely low oxygen signal.

The EDX spectra of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) at \(x=0.2\) and 0.4wt, respectively, are shown in Figs 4b and c, confirm the existence of the tin, silver, and oxygen elements that make up their composites. Additionally, it was discovered that Sn peak intensities increase with increasing the ratio of \(x\), whereas Ag peak intensities in EDX spectrum data decrease, indicating the successful incorporation of \(\text{SnO}_2\) into the composites. Table 3 lists the elements that have been found, together with their atomic and weight percentages, for all samples.

The peak at 2.12 keV is the distinctive peak of Au that can be seen in all samples that have been coated with Au in order to improve picture resolution using a FESEM instrument. In contrast, the glass substrate’s Si characteristic peak lies at a wavelength of roughly 1.7 keV.

![EDX Analysis](image)

Table 3. EDX results for the prepared films of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposite at various ratios.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Elements</th>
<th>Wight %</th>
<th>Atomic %</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Ag}_2\text{O})</td>
<td>O</td>
<td>11.43</td>
<td>40.16$^\text{[1]}$</td>
</tr>
<tr>
<td></td>
<td>Ag</td>
<td>88.57</td>
<td>49.84</td>
</tr>
<tr>
<td>(x=0.2)</td>
<td>O</td>
<td>24.15</td>
<td>64.28</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>31.57</td>
<td>17.46</td>
</tr>
<tr>
<td></td>
<td>Ag</td>
<td>68.43</td>
<td>18.26</td>
</tr>
<tr>
<td>(x=0.4)</td>
<td>O</td>
<td>23.75</td>
<td>62.54</td>
</tr>
<tr>
<td></td>
<td>Sn</td>
<td>45.84</td>
<td>17.27</td>
</tr>
<tr>
<td></td>
<td>Ag</td>
<td>54.16</td>
<td>20.19</td>
</tr>
</tbody>
</table>
UV-Visible analysis

When x=0, 0.2, and 0.4wt, the \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites’ absorption behavior was examined using UV-visible spectroscopy. The normalized absorption spectra of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites, which were recorded at room temperature in the wavelength range of 300-800 nm, are shown in Fig 5.

It is clear from Fig 5a that in \(\text{Ag}_2\text{O}\) nanostructures, the absorption edge arises at 385 nm. As a result, the \(\text{Ag}_2\text{O}\) thin film’s absorption edges show a blue-shift relative to their bulk, which is explained by the quantum confinement effect\(^{31}\). The absorption edges of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites for x=0.2 and 0.4wt were also nearly shifted to 375 and 366 nm, respectively, as illustrated in Figs 5b and c. According to the UV-Vis absorption spectra, the optical absorption edges of the \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposite shift towards a lower wavelength area with an increasing weight ratio of \(\text{SnO}_2\). As a result, when compared to \(\text{Ag}_2\text{O}\) nanostructures, the blue shifts appeared in \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites.

\[
\alpha h\nu = A(h\nu - E_g)^{1/2} \quad \text{-------------------2}
\]

Where \(h\nu\) is the energy of a photon, A is a constant, and \(E_g\) is the optical band gap. Plotting the square of the optical absorption coefficient as a function of photon energy and extrapolating the linear region to the energy axis allows us to calculate the optical band gap values from Eq 2, as shown in Fig 6. When x=0, 0.2, and 0.4wt, respectively, the obtained energy band gap values are 2.06eV for \(\text{Ag}_2\text{O}\) film and 3.24 and 3.36eV for \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites\(^{32-33}\). The band gap energy of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites shifted to the blue due to the reduction in particle size compared to pure \(\text{Ag}_2\text{O}\) thin film\(^{24}\).

Gas Sensor analysis

The reactions between semiconductor and atmospheric gases, which result in a change in the semiconductor resistance, are the basis for the semiconductor’s sensing abilities. Adsorption of gases at the surface is the process that causes a change in conductivity. At first, oxygen in the air adsorbs and pulls electrons out of the semiconductor’s conduction band. There are numerous potential processes that can happen when the desired gas concentration is injected. For an n-type semiconductor, the resistivity rises due to electron capture by an oxidizing gas and falls with the presence of a reducing gas due to electron capture.
transfer into the conduction band, whereas the opposite is true for a p-type semiconductor.\(^{34}\)

Gas sensing are described in terms of the dynamic change in resistance and the gas-sensing response. For p-type semiconductors, the response is defined as the ratio of change in resistance, \(R / R_a\); for n-type semiconductors, \(R / R_g\), where \(R_a\) and \(R_g\) represent the resistance in air and the resistance when the gas is present respectively.\(^{7}\)

The dynamic variation in conductance caused by the insertion of gas pulses was used to determine the gas-sensing response, which was then displayed against various temperatures. Figs 7 to 9 shows the dynamic response of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) thin films at various temperatures between 80 and 250 °C toward 95 ppm of \(\text{NH}_3\) gas (at gas-on shown by blue arrow and gas-off shown by red arrow). When exposed to reducing gas, the resistances of the \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) thin film with \(x=0\) and 0.2wt rise, showing the behavior of a p-type semiconductor. The behavior of \(x=0.2\)wt is not noticeably different from the behavior of the pure \(\text{Ag}_2\text{O}\) thin film. However, when exposed to reducing gas, the resistance of the \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) thin film with \(x=0.4\)wt decreases, indicating n-type semiconductor characteristics. It is obvious that the p-type \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) thin film, when \(x=0.2\)wt, has a substantially stronger gas sensing response with a shorter response and recovery time than the pure \(\text{Ag}_2\text{O}\) thin film and when \(x=0.4\)wt. Additionally, it is evident that between \(x=0.2\) and 0.4wt, \(\text{Ag}_2\text{O}\) thin films' resistance increases.

![Figure 7. Changes in Ag\(_2\)O film resistance to NH\(_3\) gas at various operation temperatures.](image)

![Figure 8. Changes in (Ag\(_2\)O\(_{0.8}\)Sn\(_{0.2}\)) film resistance to NH\(_3\) gas at various operation temperatures.](image)

![Figure 9. Changes in (Ag\(_2\)O\(_{0.6}\)Sn\(_{0.4}\)) film resistance to NH\(_3\) gas at various operation temperatures.](image)
Table 4 shows the sensitivity, response time, and recovery time for thin films formed of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) against the reducing \(\text{NH}_3\) gas at various working temperatures (80, 130, and 200°C). The response and recover times of each sensor to the (95 ppm) \(\text{NH}_3\) gas were less than 29.7 seconds and less than 86 seconds, respectively.

### Table 3. Sensitivity, response time, and recovery time for \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) films toward \(\text{NH}_3\) gas at various operating temperatures.

<table>
<thead>
<tr>
<th>(Ag₂O)₁₋ₓ(SnO₂)ₓ</th>
<th>Operating temp.(°C)</th>
<th>S%</th>
<th>Response time</th>
<th>Recover time</th>
</tr>
</thead>
<tbody>
<tr>
<td>x=0  (Ag₂O)</td>
<td>80</td>
<td>17</td>
<td>24.3</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>35.5</td>
<td>23.4</td>
<td>41.1</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>50.5</td>
<td>22.5</td>
<td>39.6</td>
</tr>
<tr>
<td>x=0.2</td>
<td>80</td>
<td>22.1</td>
<td>21.6</td>
<td>46.8</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>38.0</td>
<td>20.7</td>
<td>49.5</td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>78.4</td>
<td>19.8</td>
<td>51.3</td>
</tr>
<tr>
<td>x=0.4</td>
<td>80</td>
<td>10.2</td>
<td>34.2</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>130</td>
<td>46.1</td>
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<td>54</td>
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<tr>
<td></td>
<td>200</td>
<td>68.6</td>
<td>24.3</td>
<td>45.3</td>
</tr>
</tbody>
</table>

The alteration of \(\text{NH}_3\) gas sensitivity with the composite ratio \((x)\) for \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposite thin films is shown in Fig 10. According to Eranna G.\(^{35}\) the surface roughness increases as the particle size lowers, increasing the surface area exposed to the gas target. It is also noted from AFM analysis that the surface roughness of \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposite is greater than the pure \(\text{Ag}_2\text{O}\). Therefore, the nanocomposite with concentration \(x=0.2\)wt has more surface roughness compared to the nanocomposite with concentration \(x=0.4\)wt. Furthermore, as-sensing capabilities of \((\text{Ag}_2\text{O})_{1-x}\) \(\text{SnO}_2)_x\) films have been increased compared to pure \(\text{Ag}_2\text{O}\) at \(x=0.2\) and 0.4wt. Additionally, at operating temperatures of 200 °C, the sensitivity achieved its highest values at 78.3% for \((\text{SnO}_2)_{1-x}(\text{Ag}_2\text{O})_x\) when \(x=0.2\)wt. Because it has the roughest surface with the smallest particle size, which has a substantial impact on how gas is sensed\(^{36}\).

**Conclusion**

Ammonia gas sensors based on \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposites with different ratios of \(x=0, 0.2,\) and 0.4wt were prepared by the PLD method and their structural, optical, and gas sensor properties were characterized. According to the XRD data, the thin film of the \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\) nanocomposite has a lattice made up of a mixture of hexagonal \(\text{Ag}_2\text{O}\) and tetragonal \(\text{SnO}_2\) structures. An EDX examination revealed the presence of silver, tin, and oxygen in \((\text{Ag}_2\text{O})_{1-x}(\text{SnO}_2)_x\), which is how those elements are combined to produce the composites. The quantum confinement effect is responsible for the \(\text{Ag}_2\text{O}\) thin film's absorption edge's blue-shift when compared to its bulk, as seen by the UV-visible spectroscopy. Plus, with \(x=0, 0.2,\) and 0.4wt, respectively, the obtained energy band gap...
values of (Ag_2O)_x(SnO_2) thin films are 2.06, 3.24, and 3.36 eV. All film nanoparticles had a spherical shape, as shown by FESEM and AFM analyses. According to AFM analysis, the films' RMS roughness ranged from 4.92 to 8.22 nm and their grain sizes ranged from 37.68 to 49.57 nm. Plus, the thin film prepared at x=0.2wt has the lowest grain size (37.68nm) and maximum RMS roughness (8.22nm), which has a substantial impact on the gas sensitivity of films. Consequently, at 200 °C, (Ag_2O)_x(SnO_2) had the maximum sensitivity to NH_3 gas, at 78.4%. When compared to the sensitivity of pure Ag_2O, this sensitivity value is significantly higher.

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Authors’ Declaration

- Conflicts of Interest: None.  
- We hereby confirm that all the Figures and Tables in the manuscript are ours. Furthermore, any Figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.  
- Ethical Clearance: The project was approved by the local ethical committee in University of Baghdad.

Authors’ Contribution Statement

All authors contributed to the completion of this work. N. M. A., preparing the samples and performing the tests. A. A. B. wrote the manuscript, analysis the data and evaluated the information.

References


مستشعر غاز NH₃ الانتقائي المرتكز على الأغشية الرقيقة للمركبات النانوية (SnOₓ)ₓ(Ag₂O)₁₋ₓ عند درجات حرارة تشغيل مختلفة

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الخلاصة

تم استخدم تقنية ترسيب الليزر النبضي (PLD) للتحضير الأغشية الرقيقة (Ag₂O)₁₋ₓ(SnO₂)ₓ من النسب الوزنية المتمثلة على 300 درجة مئوية. تم تأكيد تشكيل المركب (Ag₂O)₁₋ₓ(SnO₂)ₓ من خلال تحقيقر حيود الأشعة السينية (XRD) وفقاً للحصولاء الإلكتروني المنحني (EDX). كانت جزيئات (Ag₂O)₁₋ₓ(SnO₂)ₓ التي تم إنشاؤها كروية الشكل. تم استخدام تحليل مطياف تشتت الأشعة السينية (AFS) لتحديد درجات حرارة تشغيل المختلفة. تم إنشاء الأغشية الرقيقة للمركبات النانوية (SnOₓ)ₓ(Ag₂O)₁₋ₓ، (FESEM) لتحديد خصائصها. تأكدت الأغشية الرقيقة المصنوعة من أوكسيد الفضة النقي حساسية بنسبة 92.9٪ عند درجة حرارة تشغيل 222 درجة مئوية مع أوقات استجابة واسترداد تبلغ 0.9 و 25.7 ثانية على التوالي. العلمات المفتاحية: Ag₂O-SnO₂، Ag₂O₁₋ₓ(SnO₂)ₓ، درجات حرارة تشغيل، ترسيب الليزر النبضي.