SnO2 thin film structural properties and optical characteristics

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ABSTRACT

This paper examines the structural and optical properties of thin-film nanoparticles based on tin dioxide (SnO2). SnO2 is an n-type semiconductor with a wide band gap (3.6–3.8 eV), widely used in gas sensors, photocatalytic, and optoelectronic devices. In this study, SnO2 nanoparticles were obtained using sol-gel and thermal evaporation methods, and their structure and morphology were studied using X-ray diffraction, atomic force microscopy, and scanning electron microscopy. X-ray diffraction data from the tetragonal phase of the films showed that the polycrystalline structure has a similar structure. Annealing at elevated temperatures (200–600 °C) resulted in sharpening of diffraction peaks, increased crystallinity, and increased particle size. AFM and SEM analyses revealed grain size in the range of 76–98 nm, i.e., temperature increases with surface flatness improvement. Optical analysis revealed SnO_2 films exhibiting high transmittance (≈90%) and low reflectivity, which supports this function. The study demonstrated that results from SnO_2-based films in gas sensors, solar cells, and optoelectronics applications can be recommended as a promising material

Keywords: SnO_2, thin film, sol-gel, thermal evaporation, annealing temperature, nanoparticles, X-ray diffraction, AFM, SEM, optical conductivity, reflection breaking, breaking indicator, crystal structure, morphology, optoelectronics

Introduction In recent years, semiconductor metal oxide gas sensors, solar cells, photochemical and photoconductive devices, liquid crystal displays, and lithium-ion batteries have found widespread use [1-3]. Tin dioxide (SnO2) is an n-type dioxide.

It has a wide energy range (3.6-3.8 eV) with a strong semiconductor.

The gas sensor has unique electronic, magnetic, and optical properties [4-6].

Due to its chemical and mechanical stability, it has a wide range of properties. It is one of the most widely used metal oxide semiconductors [4]. SnO2, In2O3, ZnO, and WO3 are used in the production of H2S, H2, CO, CH4, C3H8, and the determination of trace gases such as NO2. N-type semiconductors are the most commonly used material in gas sensing devices [7]. SnO2 properties that determine its potential application to different stages of production history, synthesis routes, and methods. In addition to the chemistry of the material, the morphology of the powders influences their physical and chemical properties.

Various methods have been used to produce tin dioxide thin films, including sputter pyrolysis [9], chemical vapor deposition [10], thermal evaporation [11], and pulsed laser deposition [12]. This method, thermal evaporation in a vacuum, has proven to be simple, reproducible, and inexpensive. Furthermore, this method provides processing temperature reductions, good uniformity, controlled stoichiometry, flexibility for forming dense monoliths, thin films, nanoparticles, and suitability for application over large areas [8]. However, it has attracted significant interest in scientific and industrial circles only in the last two decades, as several other methods have made relatively large gains in their advantages. Sol-gel dip coating formation is typically a low-temperature process. It

requires less energy and causes less pollution [14]. In this paper, we presented the formation process and properties of thin films of SnO2 nanoparticles obtained by the sol-gel method.

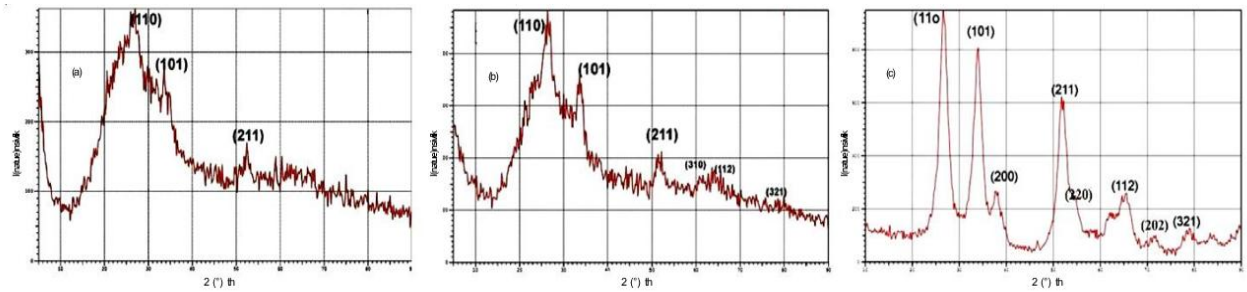
EXPERIMENTAL: Tin dioxide thin films structure wavelength l = 1.54060 Ohm was CuKa from radiation used without. To study the infrared spectra of the obtained nanoparticles with KBr disks, an X-ray diffractometer (6000 Shimadzu) was used: to record spectra in the range of 4000–400 cm-1, an FTIR-8400S Shimadzu was used.

Electronic spectra were obtained using a UV/VIS-1650 PC Shimadzu spectrophotometer with a wavelength range of 200–1100 nm. SnO2 nanoparticle size and surface atomic power distribution were measured using a scanning probe AFM microscope (CSPM-5000). Preparation of tin dioxide nanoparticles: Tin dioxide nanoparticles were obtained by thermal evaporation [15]. To obtain SnO2, tin was thermally evaporated in a vacuum at 850°C for 15 min using a vacuum setup. After 5 min, air was slowly introduced into the resulting film through the vacuum setup. The resulting film reacted with air to form tin oxide.

Thin film slides: A quartz slide is used as a substrate for depositing SnO2. This process can be described by the following steps: (1) The quartz substrate is washed

clean the surface Clean the base from oil and dust with distilled water and dust-free powder. (2) Quartz slides Place the quartz stage in a clean beaker with hydrochloric acid (for 5 minutes). (3) Then place the quartz stage in a clean beaker with ethanol (for 15 minutes). (4) Finally, place it in an ultrasonic oven with distilled water for 15 minutes, then dry. Place the clean quartz stage in a vacuum chamber, leaving an 8 cm distance between the base and the stage, add a certain amount of tin oxide powder to the stage, close the lid of the vacuum chamber and turn it on. After creating a vacuum, the stage heats up and evaporates for 15 minutes, resulting in the formation of a SnO2 film. SnO2 Nanoparticle Characterization: X-ray Diffraction in Air. Crystalline Growth of Tin Dioxide Nanoparticles Obtained by the Sol-Gel Method at Different Annealing Temperatures (200, 400, and 600) °C for 90 Minutes. The nature of growth, definition, and understanding are used. Annealing temperature plays a key role in determining the structure of SnO2 nanoparticles. X-ray diffraction patterns of SnO2 nanoparticles exhibit high diffraction peaks, indicating good crystallinity. In the JCPD specification, diffraction peaks are designated as (110).

(101) and (211) in SnO2 from the public tetragonal structure under the influence of [the above data]. All annealed SnO2 are clearly polycrystalline with a tetragonal structure. The diffraction pattern of SnO2 obtained at 200 °C shows three distinct peaks (110), (2θ = 25.89, 33.83, and 52.03°), respectively. (101) and (211) are shown. A thin film annealed at 400 °C shows (2θ = 25.71, 33.94, 52.42, 63.02, 66.43), and (110), (101), (211), respectively. Other distinct peaks appear (310), (112), and (321). They (600 °C) when annealed, (2nd = 26.70, 33.991, 38.05, 51.98, 54.5, 51.99, 54.5) in (110), (101), (200), (211), (220), (112), (202) and (321) are located four good peak appearance will be. 78.8 °), suitable as before.



1-rasm. (a) 200, (b) 400 va (c) 600 °C da 90 daqiqa davomida turli tavlanish haroratida SnO2 yupqa plyonkali nanozarrachalarning XRD naqshlari

As can be seen in Figure 1(ac), an increase in the intensity of the (110) orientation is observed, which may be due to the thermal treatment, which increases the mobility of atoms during lattice rearrangement processes. Thermal energy transferred to the atoms can reduce the defectiveness of SnO2 nanoparticles and improve their quality. This leads to a decrease in the full width at half maximum (FWHM) of the reflection peaks, which narrow

with increasing particle size (Figure 1c), which is related to the overall size of the nanoparticles.

Morphology. Atomic force microscopy (AFM): The surface morphology of SnO2 nanoparticles was analyzed using atomic force microscopy. Figure 2 shows the surface morphology of SnO2 nanoparticles annealed at 200, 400, and 600 °C. A conventional three-dimensional AFM image is shown. The average grain size (76-98 nm) was found. The macroscopic force atom. The results show that the grain size increases with increasing temperature, which is associated with improved particle crystallinity. Figure 2 also shows a diagram of the distribution of SnO2 grain size cumulation during annealing.

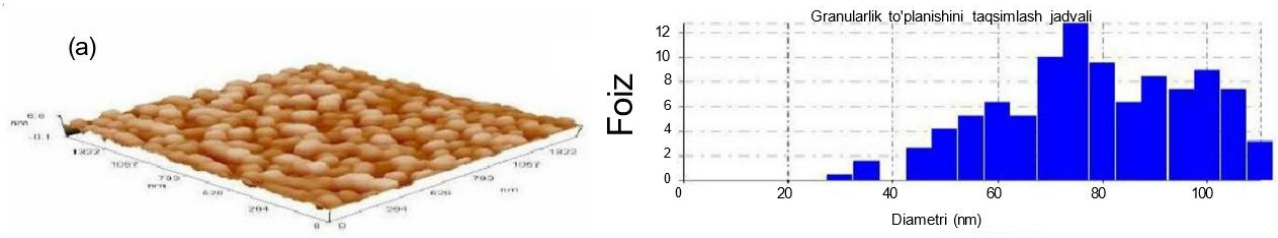


Figure 2. (a) 200, (b) 400, and (c) 600°C for 90 min for annealed SnO2 nanoparticles atomic force macroscopic image

SEM images according to surface morphology: 200, 400, and 600°C SEM images of thin-film SnO2 nanoparticles as a function of temperature.

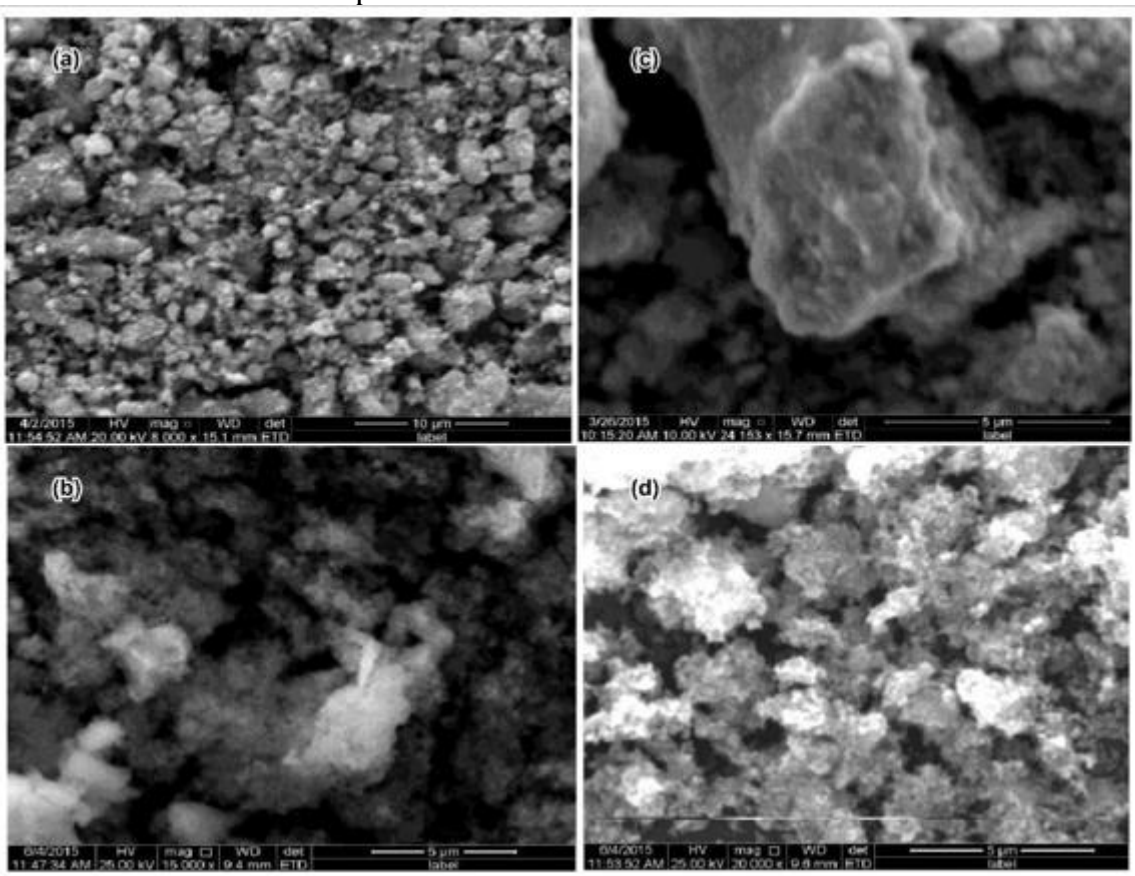


Figure 3. SEM images of SnO2 thin film nanoparticles: (a) as-prepared, annealed at (b) 200, (c) 400, and (d) 600 °C for 90 minutes.

Sol-gel methods with as-prepared sintering are shown in Figure 3.

It can be seen that the nanoparticles have multiple agglomerates on the surface, with individual clusters growing. At lower temperatures, particles sintered at (as-

prepared and 200 °C) consist of a large number of smaller particles, respectively (Figures 3a and 3b). Conversely, particles sintered at higher temperatures (400 and 600 °C) consist of a smaller number of larger particles, respectively. As found (Figure 3c and Figure 3d), this sintering process was then associated with small grain growth and combination. Transmission, reflectance, and fracture index: 90-minute annealing at temperatures (200, 400, and 600°C) for SnO2 thin films. Figures 25-7 show the effect. The films were found to exhibit high light transmittance in the long-wavelength region, reaching 90% in the visible range, and reflectivity.

SnO2 depends on the annealing temperature. The increase in orientation is associated with the increase in orientation. This may be due to the heat treatment, which increases atomic mobility during lattice rearrangement processes. Thermal energy transferred to the atoms reduces defects and improves quality. In the UV region (350 nm from low), the main absorption is associated with the decrease in optical reflectance.

The increase in fracture toughness at the softening temperature is due to the decrease in orientation. This internal fence may be due to the heat treatment, which increases atomic mobility during lattice rearrangement processes.

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