SNO2 THIN FILMS WITH HEATING SONOCHEMICAL METHOD

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Abstract

The sonochemical deposition of SnO2 is a method widely spread in the literature to make thin films due to its lower cost and higher efficiency. This work shows the evaluation variations in drying temperature in the described process for dye-sensitized solar cells (DSSCs) application. The thermal treatment at 450°C for 1 hour with 10°C/min. This study suggests that the increment of temperature for the drying process increases the cell performance, significantly affecting power conversion efficiency and impedance. The samples were characterized with X-ray diffraction, ultraviolet and visible analyses, scanning electron microscopy, Fourier transform infrared spectroscopy, and Cell Test. The results showed high transmittance in visible and infrared between 400 nm and 1200 nm, high reflectance in visible between 400 nm and 700 nm, and a direct Band Gap between 3.51 eV to 3.76 eV.

Keywords: Sonochemical deposition, Thin films, PV cells, DSSCs, SnO_2

1. Introduction

Solar energy is one of the most used renewable energies, and the production of solar panels is expensive because refining Silicon (Si) requires high temperatures to make mono and polycrystalline solar cells for photovoltaic energy (PV) (Silva *et. al.*, 2024). The research of new thin films to cause less environmental impact for solar energy, one of the most used materials is SnO_2 (tin oxide), and the methods to make thin films are widespread in the literature. The method for this research is Sonochemical deposition, this method uses water to deposit a thin layer on FTO glass (fluorine tin oxide glass) with an ultrasound bath. This process requires a low time to make the solution and deposit the film, but requires a long time to dry because it uses a significant volume of water to dry later (Lima *et. al.*, 2024; Nunes *et. al.*, 2023). The cost of production is low to make large amounts of thin films, and the efficiency is similar to other methods like Spin Coating, Spray Pyrolysis, or Sol-Gel (Alsulami and Alsalme, 2025; Chandralekha *et al.*, 2024; Su *et. al.*, 2021).

2. Methodology

All reagents were used without further purification. The solution uses the following reagents: 5,57 *m*M of tin oxide and 15 mL of deionized water. To mix the solution, the reagents are placed in a beaker and mixed. The mixed solution is placed in an ultrasound bath for 15 minutes. When the procedure described above was done once, one FTO glass was put on another 50 ml Beaker, and the solution was placed in this beaker. The drying process lasts until the water has completely evaporated and the film is completely formed. To test the efficiency of drying with controlled external temperature, a hot air oven is used to control the temperature. The tests are made at room temperature, 40, 45, 50, 55, 60°C, to measure the change in the drying process speed. The solution is submitted to a drying test for the proportion of mass lost at each temperature. Besides, the FTO was removed from the beaker after complete evaporation of the solvent, and was submitted for calcination for 1 hour at 450°C. For DSSCs assembly, the calcined thin film with 0,50 cm^2 was immersed in a dye solution, composed of an isopropyl alcohol solution containing 3.0×10^{-4} M of ruthenizer 535-bis

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TBA, for 24 hours. The open cell sandwich has the dyed thin film for photoanode, iodolyte AN-50 electrolyte, and commercial counter electrodes containing fluorine-doped tin oxide (FTO) with platinum coating. The FTO, counter electrodes, ruthenizer 535-bisTBA, and iodolyte AN-50 electrolyte were purchased from Solaronix (Switzerland). Table 1 describes all samples with calcination temperature and drying temperature. Figure 1 describes the methodology used in this work.

Tab. 1: All samples with calcination temperature and drying temperature.

Sample Name	Calcination Temperature	Drying Temperature
A)	450°C	Room Temperature
B)	450°C	40°C
C)	450°C	45°C
D)	450°C	50°C
E)	450°C	55°C
F)	450°C	60°C

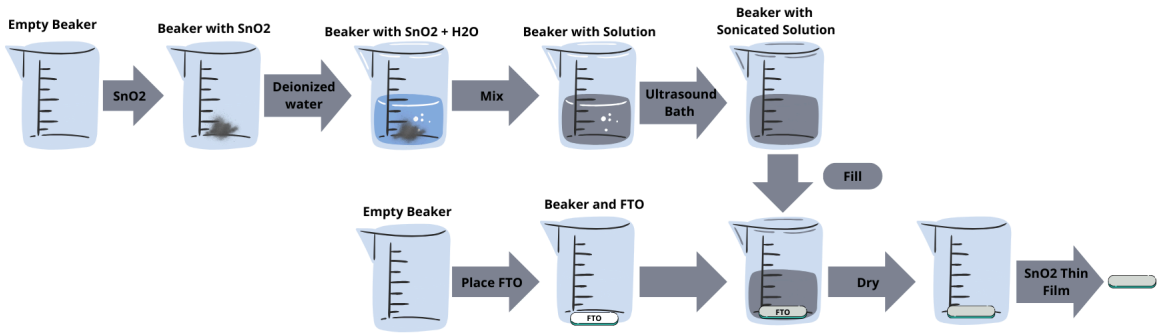

Figure 1: Scheme of the methodology.

3. Results and Discussion

3.1 Drying Study

Figure 2 describes the drying analysis of the solution used in the methodology at the temperatures used in this work. Through this analysis, it was possible to obtain the total percentage of evaporated solution after four hours of the drying process. 0.76% at A) room temperature, 4.98% at B) 40°C, 11.79% at C) 45°C, 13.38% at D) 50°C, 38.10% at E) 55°C, and 23.12% at F) 60°C. According to the obtained data, the E) 55°C and F) 60°C are the best temperatures for drying the solution.

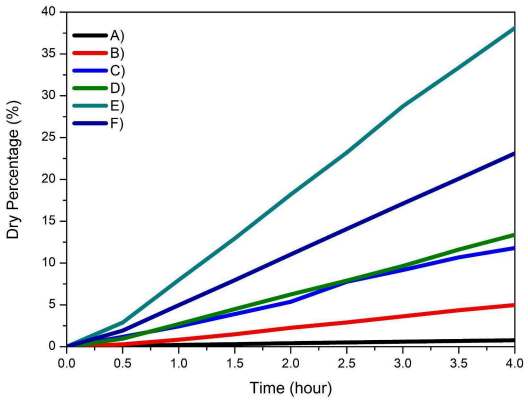

Figure 2: Different drying temperatures over time

3.2 X-Ray diffraction (XRD)

Figure 3 has the XDR spectra for the four layers, from 20° to 100°. The material used on methodology has (SnO_2) (110) at 30.964°, (101) at 39,549°, (200) at 44.747°, (211) at 61.480°, (220) at 64.774°, (002) at 68.469°, (310) at 73.216°, (112) at 76.805°, (301) at 78.751° and (202) at 85.321°. The grain size is 19.3814 nm (Abboura *et. al.,* 2025; Ahmed, 2011; Chellamuthu *et. al.*, 2025; El-Etre and Reda, 2010; Lima *et. al.*, 2024; Mohammad *et. al*, 2025; Saleh *et. al.,* 2025; Shi and Lin, 2011).

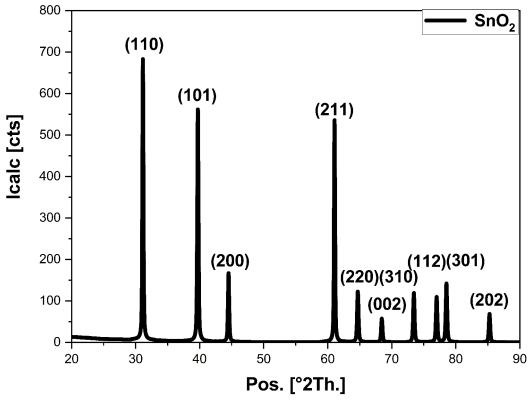

Figure 3: DRX spectra analysis of the powder in solution.

3.3 Uv-Vis Analysis

The Uv-Vis analysis is important for characterizing and studying the optical properties of thin films for solar cells in UV, under 400 *nm* of wavelength, visible, above 400 *nm,* and under 700 *nm*, and infrared, above 700 *nm*. The transmittance is the optical property that represents the transmission of the light beam through the film and substrate. The absorbance is the optical property that represents the absorption of the light beam through the film and substrate. The reflectance is the optical property that represents the reflection of the light beam through the film and substrate. The maximum transmittance values on Figure 4 were 55°C with 54.45%, 45°C with 49.73%, 40°C with 47.21%, 60°C with 34.48%, AB with 24.46% and 50°C with 23.35%. The increase in transmittance in the visible spectrum is similar to (Abboura *et. al.,* 2025; Alsulami, 2025; Chandralekha *et. al.*, 2024; Chellamuthu *et. al.*, 2025; El-Etre and Reda, 2010). The maximum absorbance values on Figure 4 were 50°C with 4.06 a.u., 45°C with 2.65 a.u., 60°C with 1.51 a.u., 40°C with 1.4 a.u., 50°C with 1.33 a.u., and AB with 1.31 a.u.. The absorbance in the visible spectrum is similar to (Abdullah, 2021; Alsulami, 2025; Begum *et. al.*, 2025; Mohammad *et. al.*, 2021; Saleh *et. al.,* 2025). The maximum reflectance values on Figure 4 were 40°C with 51.64%, AB with 43.95%, 60°C with 41.90%, 45°C with 37.43%, 50°C with 33.82% and 55°C with 27.85%.

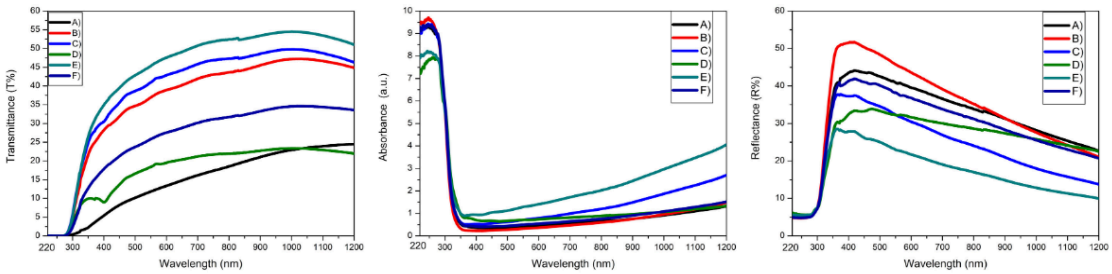

Figure 3: Transmittance, Absorbance, and Reflectance values for the Samples

3.4 Band Gap

For SnO_2 films, the directed band gap is between 3.5 *eV* and 3.99 *eV* (Ahmed, 2011; Jithin, 2021; Shi and Lin, 2011). The direct band gap for films obtained with the methodology was determined from Kubelka-Munk analysis (Figure 5). Direct band gap values for films were 3.67 *eV* for A) room temperature, 3.76 *eV* for B) 40°C, 3.66 *eV* for C) 45°C, 3.51 *eV* for D) 50°C, 3.51 *eV* for E) 55°C, and 3.64 *eV* for F) 60°C. The band gap values that were in agreement with the values found in the literature associated a SnO_2, 3.6 *eV* at room temperature (Abboura *et. al.,* 2025; Alsulami, 2025;; Chellamuthu *et. al.*, 2025; Jithin *et. al.,* 2021; Saleh *et. al.,* 2025).

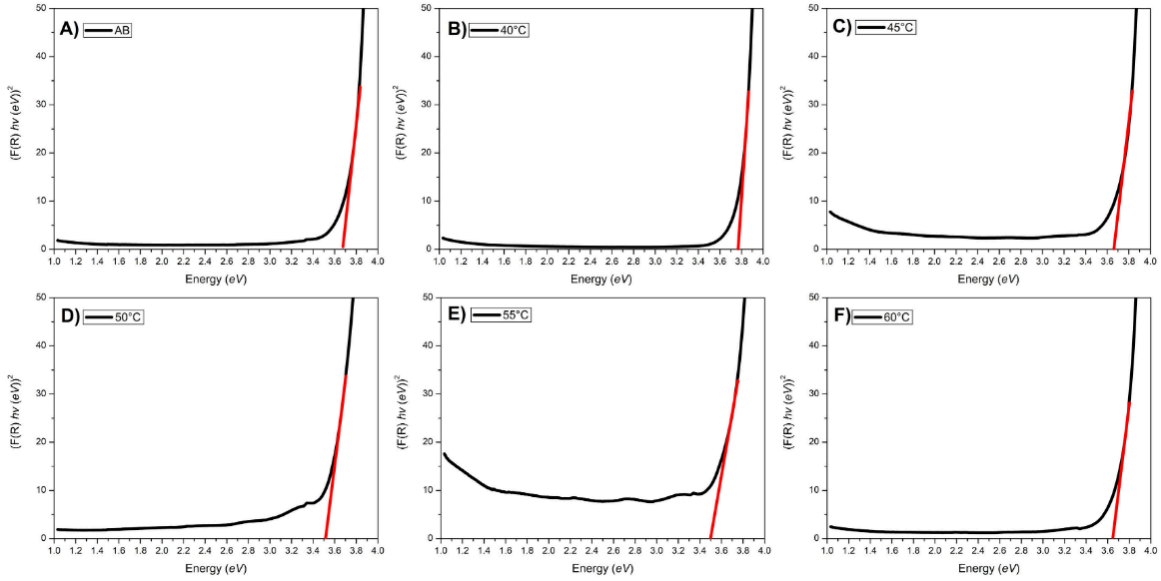

Figure 5: Direct band gap

3.5 SEM Analysis

The Figure 6 shows the SEM analysis for all samples (A) room temperature, (B) 40°C, (C) 45°C, (D) 50°C, (E) 55°C, (F) 60°C, the analysis show on (A) the high porosity and on (B) when the temperature increase these factor is lower on (C) and on (D) when the porosity it's lowest comparing the other samples, when the temperature increases from 55°C to 60°C the porosity increases until (F), if the temperature increase more, the appearance of porosity causes small cracks in the thin film, and if the temperature is increased again, the appearance of large cracks is observed. The porosity it's an important factor to DSSCs, because, with more porosity, the dye fixes better on the thin film, requiring less exposure time to the same. The SEM of A), E), and F) samples is similar to (Abdullah *et. al.*, 2021; Chellamuthu *et. al.*, 2025).

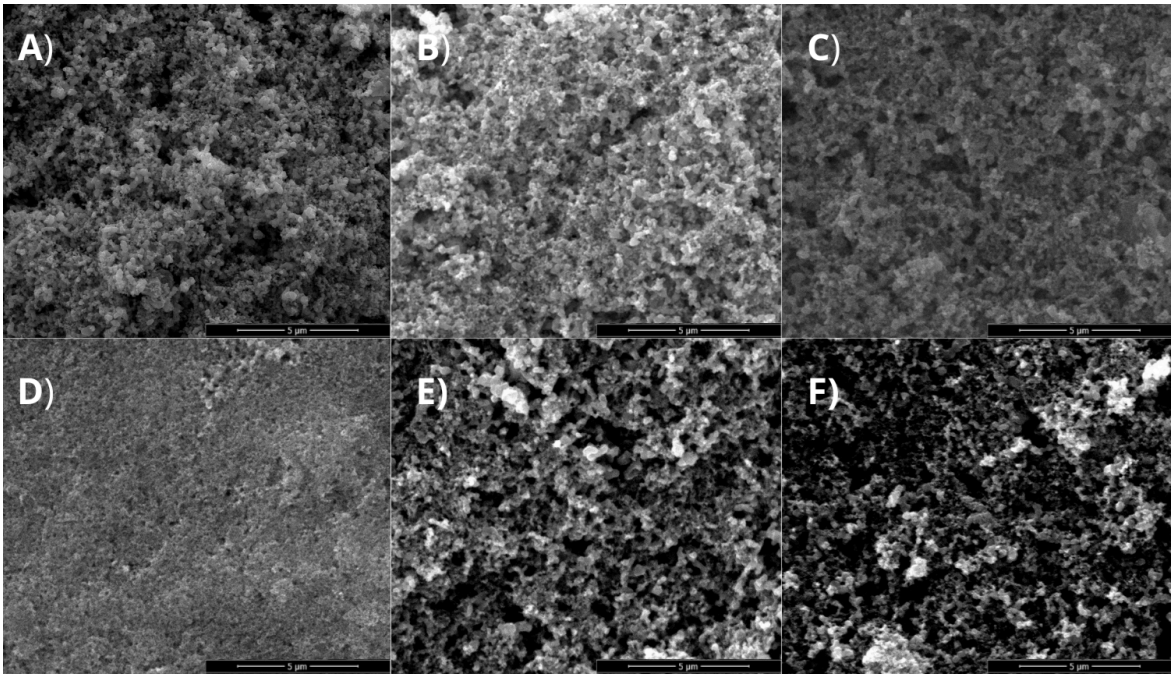

Figure 6: SEM analysis of the (A) Room Temperature, (B) 40°C, (C) 45°C, (D) 50°C, (E) 55°C, (F) 60°C

3.6 Cell Test

The Figure 7 shows the IV plot graphics for all samples (A) room temperature, (B) 40°C, (C) 45°C, (D) 50°C, (E) 55°C, (F) 60°C, the analysis show the Current curve and Power, together with the I_{oc} and V_{oc} values from samples is F), C) and D), the E) sample have better power then B) and A). The maximum values from the test are I_{oc} 0.074 *m*A/cm^2 and V_{oc} 0.212 V for A); I_{oc} 0,06 *m*A/cm^2 and V_{oc} 0.348 V for B); I_{oc} 0.12 *m*A/cm^2 and V_{oc} 0.48 V for C); I_{oc} 0.11 *m*A/cm^2 and V_{oc} 0.468 V for D); I_{oc} 0.14 *m*A/cm^2 and V_{oc} 0.582 V for E); and I_{oc} 0.09 *mA*/cm^2 and V_{oc} 0.731 V for F). Several factors can alter the result of a cell, as observed in the drying temperature which can increase or decrease the efficiency of the cell based on the evaporation rate, which in turn implies a greater disturbance to the environment than sample A), the behavior of the cells is similar to that found in the literature (Lima *et. al.*, 2024; Nunes *et. al.*, 2021). The E) 55°C cell behaviour is similar to (Naffouti and Kamoun-Turk, 2025).

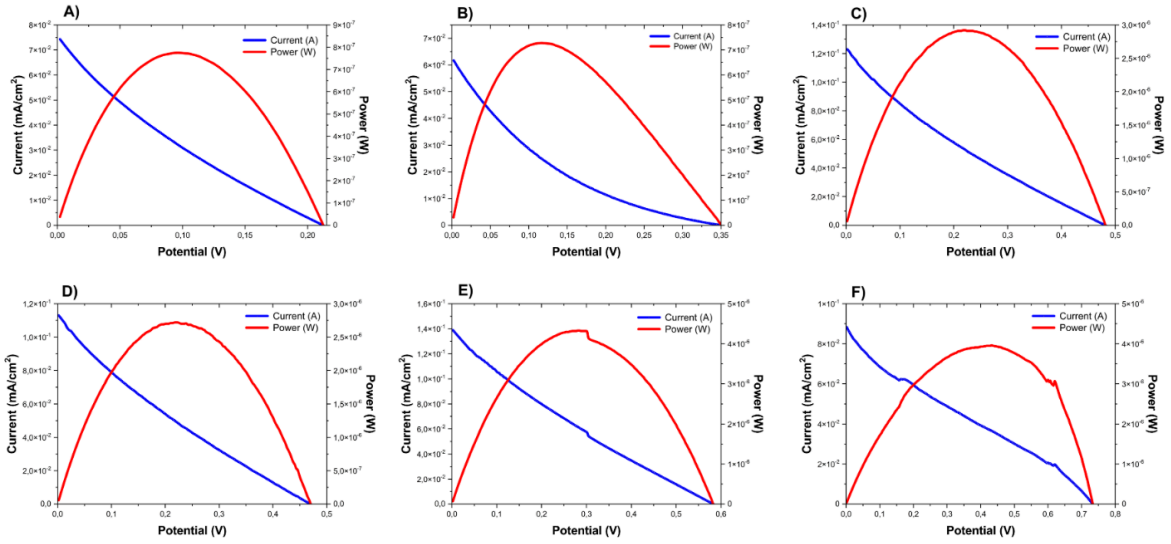

Figure 7: Solar Cell Test of the (A) Room Temperature, (B) 40°C, (C) 45°C, (D) 50°C, (E) 55°C, (F) 60°C

4. Conclusion

The sonochemical deposition method successfully deposited the SnO_2 films, as observed by the analysis. The Uv-Vis analysis noted an increase in the transmittance of the films as the drying temperature increased. Absorbance increased significantly for samples E) and F). Increasing the drying temperature causes a significant decrease in the reflectance of the samples. With the change in drying temperature, the band gap had changes related to the increase and decrease in its value between the samples, with emphasis on C) and D) samples, which have the better band gap values. The SEM analysis proved the difference in the microstructure of the film with different temperatures, modifying the properties of the film, with emphasis on the organization and porosity of the film.

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