

Optimization of optoelectronic performance in magnetron-sputtered ITO thin films via coupled regulation of Ar:O₂ ratio and sputtering power

Biao Cheng

Kashi University

XiongWie Li

Kashi University

Mieradilijiang Muhetaier

Kashi University

ZhiKuan Wu

Kashi University

Shumin Yang

shumin6666@126.com

Kashi University

Research Article

Keywords: Indium tin oxide (ITO), Sputtering power, Deposition time, Ar/O₂ ratio, Optoelectronic properties

Posted Date: September 17th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10514041/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.
[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

This study systematically investigates the effects and underlying mechanisms of varying the argon-to-oxygen (Ar/O_2) ratio, sputtering power, and deposition time on the optoelectronic properties of indium tin oxide (ITO) thin films. The films were deposited via magnetron sputtering, during which the Ar/O_2 ratio was adjusted to 100:2 (1.96%), 93:1 (1.06%), 99:1 (1%), 100:1 (0.99%), and 100:0 (0%). The sputtering power was varied from 80W to 130W in increments of 10W, while the deposition time ranged from 180s to 900s at intervals of 180s. The electrical and optical properties of the prepared films were systematically characterized using X-ray diffraction (XRD), atomic force microscopy (AFM), Hall effect measurements, a four-point probe tester, and ultraviolet-visible (UV-Vis) spectrophotometry. The results reveal that the sputtering power plays a decisive role in determining crystallinity and exhibits a "dual effect" on the electrical performance. Furthermore, the oxygen partial pressure effectively tailors the crystal orientation preference and regulates the carrier concentration via modulation of the oxygen vacancy concentration. Ultimately, the optical transparency is governed by the oxygen partial pressure, which concurrently determines both the oxygen vacancy concentration and the density of defect states within the films.

1. Introduction

Indium tin oxide (ITO) thin films are widely recognized as a critical transparent conductive electrode material. As a heavily doped, highly degenerate n-type semiconductor, ITO possesses a wide optical bandgap exceeding 3.5 eV, a resistivity as low as $10^{-4} \Omega \cdot \text{m}$, and a visible light transmittance of over 85%. In addition, it exhibits excellent chemical corrosion resistance and favorable processability, rendering it indispensable in display, protection, and energy-related applications^[1–4]. Owing to its exceptional optoelectronic properties^[5–13], ITO thin films have found extensive utilization in solar cells, display devices, and gas sensors^[14–16]. Notably, ITO is most widely employed in the fields of human–computer interaction and information display. In these applications, faster screen response speed and lower energy consumption are key to achieving superior display quality and more sensitive touch responsiveness. Consequently, the fabrication of high-quality ITO thin films serves as the fundamental prerequisite for ensuring such device performance.

It has been demonstrated by numerous studies that sputtering conditions play a crucial role in the preparation and performance of ITO thin films, with factors such as power^[17–19], gas pressure^[18,20], temperature^[21,22], target crystallinity^[23], and gas ratio^[24,25] collectively influencing film quality. However, a systematic and in-depth investigation into the optoelectronic properties of ITO thin films under the combined effects of sputtering power, Ar/O_2 ratio, and deposition time remains lacking. To address this research gap, the present study fabricates and comprehensively characterizes ITO thin films under a variety of sputtering parameters, with particular emphasis on different deposition times and Ar/O_2 ratios. A systematic examination of the influences exerted by these three core process parameters on the electrical properties of ITO thin films is of significant practical importance.

2. Experiment Method

Prior to deposition, the glass substrates were successively ultrasonically cleaned in acetone, ethanol, and deionized water for 20 min each, and then dried in a vacuum oven before being placed into the vacuum deposition chamber. Before deposition, the target was pre-sputtered for 180s to remove surface contaminants. During the sputtering process, the sputtering power was set to values ranging from 70W to 130W in increments of 10W, with various Ar/O₂ ratios of 100:2, 93:1, 99:1, 100:1, and 100:0. The working pressure was maintained at 0.4 Pa, and the target-to-substrate distance was fixed at 55 mm.

The phase structure and preferred orientation of both the ITO target and the deposited films were characterized by XRD. The surface morphology of the ITO thin films was examined using AFM. The sheet resistance of the films was measured by a four-point probe method. Electrical properties, including resistivity, carrier concentration, and Hall mobility, were evaluated at room temperature (RT) using a Hall effect measurement system. In addition, the optical transmittance of the ITO thin films was recorded over the wavelength range of 300–800 nm by means of a UV-Vis.

3. Result and Discussion

The effect of deposition time was first examined. As shown in Fig. 1(a), with the sputtering power and Ar/O₂ ratio held constant, the sheet resistance of the films decreased from 307.2 Ω/□ to 37.2 Ω/□ as the deposition time increased from 180s to 900s, representing a reduction of 87.9%. It was observed that prolonged deposition time led to increased film thickness (*d*) and consequently reduced sheet resistance^[13]. Subsequently, the influence of the Ar/O₂ ratio was investigated under fixed sputtering power and deposition time. Fig 1(b) presents the sheet resistance values of the films deposited at various Ar/O₂ ratios. The lowest sheet resistance was obtained at an Ar/O₂ ratio of 100:0 (0% O₂). When the oxygen proportion was increased to 100:1 (0.99%) and 99:1 (1%), the sheet resistance rose moderately to 107.8 Ω/□, still maintaining a relatively low level. However, upon further increasing the oxygen proportion to 93:1 (1.06%) and 100:2 (1.96%), the sheet resistance surged dramatically to 449.5 Ω/□, which was approximately five times higher than that of the sample deposited at 100:1. This result indicates that excessive oxygen severely deteriorates the electrical conductivity of ITO thin films.

Fig 2(a) presents the electrical performance parameters of the films deposited at a sputtering power of 125W, with deposition times ranging from 180s to 900s and an Ar/O₂ ratio of 100:1. As the deposition time increased, the resistivity decreased from $7.648 \times 10^{-3} \Omega \cdot \text{cm}$ to $1.131 \times 10^{-3} \Omega \cdot \text{cm}$, while the carrier concentration increased from $4.843 \times 10^{19} \text{ cm}^{-3}$ to $2.468 \times 10^{20} \text{ cm}^{-3}$. This continuous increase in carrier concentration with prolonged deposition time is attributed to the improved film continuity, which facilitates more sufficient formation of oxygen vacancies and reduces defect density, thereby providing a greater number of free electrons. However, at a deposition time of 900s, the increase in carrier concentration became less pronounced, approaching saturation. This phenomenon indicates that the film has reached near-complete densification^[26]. Meanwhile, the Hall mobility increased from 16.88 cm²/(V·s) to 22.38 cm²/(V·s), peaking at 25.46 cm²/(V·s) at 720s, before declining slightly to 22.38

cm²/(V·s) at 900s. Fig 2(b) illustrates the electrical performance parameters of the films deposited at a sputtering power of 80W for 900s under varying Ar/O₂ ratios. The carrier concentration exhibited pronounced fluctuations with decreasing oxygen content, reaching its maximum value under oxygen-free conditions. This behavior can be explained by the fact that under low-oxygen conditions, the films suffer from severe oxygen deficiency, which generates a large number of oxygen vacancies in the lattice and releases electrons, whereas the carrier concentration is unexpectedly lower under a small amount of oxygen. In contrast, the mobility first decreased and then increased with varying oxygen content, reaching its highest value at the Ar/O₂ ratio of 100:2. Based on these findings, the subsequent deposition experiments were conducted with a fixed time of 900s and Ar/O₂ ratios adjusted to 100:0, 100:1, and 100:2, respectively.

The electrical properties of the films deposited under an Ar/O₂ ratio of 100:0 were further analyzed as a function of sputtering power, as shown in Fig. 3. At low power levels (<100W), the kinetic energy of the sputtered particles is relatively low, resulting in poor surface diffusion on the substrate. In the absence of oxygen replenishment under pure Ar atmosphere, although the oxygen vacancy concentration is extremely high, the films tend to grow amorphously, giving rise to a high density of grain boundaries that strongly scatter charge carriers. Consequently, despite a moderate carrier concentration (on the order of 10²⁰ cm⁻³), the mobility remains extremely low, leading to a relatively high resistivity. At high power levels (≥110W), the energy of the sputtered species is significantly enhanced, allowing for sufficient surface diffusion and promoting highly crystallized film growth. The grains grow larger while the grain boundary density decreases, resulting in a sharp increase in mobility, reaching a peak value of 28.7 cm²/(V·s) at 110W. Meanwhile, the elevated power enhances the plasma density, which facilitates more efficient sputtering of Sn atoms from the target and their substitutional incorporation into In³⁺ sites. Concurrently, oxygen vacancies are stabilized by the high-energy environment, maintaining the carrier concentration at a high level of 2.1-2.6 × 10²⁰ cm⁻³. The combination of these two effects yields the lowest resistivity (0.85 × 10⁻³ Ω·cm) and a sheet resistance as low as 65 Ω/□.

Under the Ar/O₂ ratio of 100:1, the influence of sputtering power on the electrical properties was systematically examined. At low power levels (70-90W), the sputtered particles possess insufficient kinetic energy, resulting in amorphous film growth with a high density of grain boundaries that severely scatter charge carriers, thereby limiting the mobility. Although oxygen vacancies and Sn doping provide a certain carrier concentration of approximately 2.2 × 10²⁰ cm⁻³, the grain boundary potential barriers significantly impede carrier transport, leading to a relatively high resistivity (>2 × 10⁻³ Ω·cm). At 100W, the crystallization threshold is reached. This power level marks the first instance where the critical condition for crystallization is satisfied, as evidenced by the sharp increase in XRD diffraction peak intensity, indicating the onset of significant film crystallization. However, the carrier concentration at this stage is anomalously high (3.10 × 10²⁰ cm⁻³), which induces intense ionized impurity scattering, and the mobility only increases to 14.0 cm²/(V·s), far from optimal. This observation suggests that the onset of crystallization does not necessarily imply optimal electrical performance, as defects and excess carriers still constrain the mobility. The optimal power level is identified at 110W. A modest increase in power

provides sufficient surface diffusion energy, promoting grain growth and reducing grain boundary density. Concurrently, the carrier concentration decreases to $1.39 \times 10^{20} \text{ cm}^{-3}$, thereby weakening ionized impurity scattering. As a result, the mobility nearly doubles to $32.6 \text{ cm}^2/(\text{V} \cdot \text{s})$, and the resistivity drops to $1.38 \times 10^{-3} \Omega \cdot \text{cm}$. At excessively high power levels (120-130 W), energetic particle bombardment may introduce antisite defects and lattice stress, causing the mobility to decline to approximately $20 \text{ cm}^2/(\text{V} \cdot \text{s})$, while the carrier concentration rebounds to $2.1 \times 10^{20} \text{ cm}^{-3}$, leading to a slight increase in resistivity. These results demonstrate that 110W represents the optimal balance under this specific gas atmosphere.

Under the Ar/O_2 ratio of 100:2, the power level of 110W remains the optimal choice within this condition, yet the overall electrical performance is significantly inferior to that achieved under 100:0 or 100:1 atmospheres. At low power levels (70-90 W), the excessive oxygen introduces a large number of oxygen interstitials into the films. These interstitial atoms compensate for oxygen vacancies, thereby reducing the concentration of free electrons. Concurrently, they react with Sn to form SnO_x segregation, which diminishes the donor efficiency of Sn and introduces strong scattering centers that severely impede carrier transport. As a result, both the carrier concentration and mobility are extremely low, leading to a relatively high resistivity. At high power levels, although the energetic particles promote crystallization and partially eliminate oxygen interstitials, leading to a recovery of carrier concentration at 110W to a level close to that observed under 100:1, the residual excess oxygen still persists. The SnO_x segregation and oxygen interstitial scattering cannot be completely eliminated, and consequently, the mobility remains substantially low. The optical transmittance of the films deposited under different conditions is presented in Fig. 4. Fig 4(a) shows the transmittance spectra for the films deposited at an Ar/O_2 ratio of 100:0. With increasing sputtering power, the films become more crystalline and denser, with fewer defects, which reduces optical scattering losses across almost the entire wavelength range of 300-800 nm. At low power levels, the electrical performance is relatively poor, yet the optical performance reaches its optimum; at high power levels, the electrical properties are substantially improved, but the optical performance deteriorates markedly. This observation indicates that under oxygen-free conditions, there exists a strong trade-off between electrical and optical properties.

Fig 4(b) presents the transmittance spectra for the Ar/O_2 ratio of 100:1. The highest transmittance is achieved at 110W, exceeding 93% particularly in the visible region of 450-650 nm. Notably, the transmittance at high power levels is generally superior to that at low power levels, which is completely opposite to the trend observed under the 100:0 condition. Fig 4(c) displays the transmittance spectra for the Ar/O_2 ratio of 100:2. The films deposited at 80W and 90W exhibit relatively high transmittance, especially in the visible-to-near-infrared region of 450-800 nm. Although the transmittance at 130W is the lowest in the visible region, it is anomalously high in the short-wavelength region, which may be attributed to a blue shift of the band edge induced by high-power deposition. Furthermore, as shown in Fig. 4(c), the excessively high oxygen partial pressure at 100:2 leads to substantial compensation of oxygen vacancies. At high power levels, energetic particle bombardment generates a large number of defects, while excess oxygen atoms enter the lattice as interstitials, causing severe lattice distortion and

optical scattering. The carrier concentration in the 100:2 condition is relatively low; however, the band-tail states introduced by interstitial oxygen defects enhance short-wavelength absorption. This explains why, at 130W, the average transmittance under 100:2 (75%) is even lower than that at 70W, indicating that the combined effect of high power and excessive oxygen leads to severe degradation of optical performance. Fig 4(d) presents the average transmittance values along with their standard deviations, revealing significant differences in average transmittance under various Ar/O₂ ratios. In particular, at the high-power boundary of 130W, the performance discrepancies among films deposited under different conditions become more pronounced. At a power of 110W, the average transmittances over the 400-800 nm range for the Ar/O₂ ratios of 100:0, 100:1, and 100:2 are 84%, 87%, and 79%, respectively. Among these, the 100:1 condition exhibits the smallest standard deviation at 110W, indicating the most stable optical performance. This stability arises from the optimal balance between oxygen-vacancy compensation and interstitial oxygen defects: sufficient oxygen is available to form a high-quality lattice, while excess oxygen is not introduced to create interstitial defects. Such differences are closely related to the surface structure of the ITO thin films.

Based on the foregoing analysis of the optical and electrical properties, the Ar/O₂ ratio of 100:1 represents the optimal condition that achieves the best balance between electrical conductivity and optical transparency. Fig 5 presents the XRD patterns of the films deposited under the Ar/O₂ ratio of 100:1 at power levels ranging from 70W to 130W, with the characteristic diffraction peaks of the crystal planes clearly indexed. The phase composition of the ITO target is identical to that of the films, predominantly consisting of (211), (222), (400), (440), and (622) planes. The ITO target exhibits a polycrystalline structure, with X-ray diffraction peaks mainly corresponding to (211), (222), (400), (440), and (622). Under the 100:1 condition at 120W, the ITO thin film achieves the optimal crystallinity and the most favorable balance between the (222) and (400) crystallographic orientations, as reflected by the I₂₂₂/I₄₀₀ intensity ratio. Consequently, this film exhibits the highest Hall mobility, the lowest resistivity, and a satisfactory optical transmittance of approximately 85%, representing the best comprehensive optoelectronic performance. When the I₂₂₂/I₄₀₀ ratio approaches 1.04, the ITO thin film attains an optimal equilibrium between the (222) and (400) orientations.

Table 1 I₂₂₂/I₄₀₀ intensity ratios of the ITO thin films deposited at different sputtering power levels.

Power	I_{222}	I_{400}	I_{222}/I_{400}
70W	12	8	1.500
80W	39.02	35.02	1.114
90W	71.84	65.94	1.089
100W	95.86	91.86	1.044
110W	125.702	122.202	1.029
120W	141.297	136.916	1.032
130W	166.248	160.248	1.037

4. Conclusion

Based on the above experimental findings, this study proposes a physical model elucidating the interrelationship among the structural, electrical, and optical properties of ITO thin films. Under a given gas atmosphere, the influence of sputtering power on the film performance is not linear but follows a trajectory of "structural disorder → ordered optimization → defect proliferation." Sputtering power modulates the kinetic energy of the incident particles, which on one hand promotes crystallization and grain growth, while on the other hand, the oxygen partial pressure concurrently regulates the carrier concentration and defect scattering intensity by controlling the oxygen vacancy concentration and interstitial oxygen defect density. Through the combined effects of these two process parameters, the ITO thin films deposited at 110W under an Ar/O₂ ratio of 100:1 achieve an optimal balance, delivering both satisfactory electrical performance and high optical transmittance. At this condition, the I_{222}/I_{400} orientation balance, crystallinity, defect density, and carrier concentration are synergistically optimized, which collectively determine the mobility, resistivity, and transmittance of the films. Beyond this optimal power level, lattice defects and internal stress regain dominance, leading to a subsequent degradation of the overall performance.

Declarations

Conflict of Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contribution

Biao Cheng and Xiongwei Li prepare figures and experiment. Shumin and Mieradilijiang provided suggestion

References

1. Li Y X, Zhang Y B, Wang X J, et al. ITO-less silicon heterojunction solar cells based on nanocrystalline silicon carrier collectors[J]. *Solar Energy Materials and Solar Cells*, 2025, 282. <https://doi.org/10.1016/j.solmat.2025.113422>.
2. Raaif M, El-Hossary F M, Abd El-Moula A A, et al. A comparative study of the optical, electrical, and wettability properties of amorphous and nanocrystalline ITO/Cu/ITO multilayer thin films prepared by DC pulsed magnetron sputtering[J]. *Applied Physics a-Materials Science & Processing*, 2025, 131(8). <https://doi.org/10.1007/s00339-025-08717-2>.
3. Tchenka A, Amiri L, Bousseta M, et al. Investigation of the structural, optical, thermoelectric and electrical properties of ITO/Cu/ITO multilayer[J]. *Applied Physics a-Materials Science & Processing*, 2025, 131(4). <https://doi.org/10.1007/s00339-025-08426-w>.
4. Yamada H, Toyosaki Y, Sawa A. Orthorhombic ITO epitaxially stabilized on a perovskite oxide substrate[J]. *Applied Physics Letters*, 2025, 126(14). <https://doi.org/10.1063/5.0256689>.
5. Kiliszkiwicz M, Domaradzki J, Posadowski W, et al. Effect of sputtering power and oxygen partial pressure on structural and opto-electronic properties of Al-doped ZnO transparent conducting oxides[J]. *Applied Surface Science*, 2024, 670. <https://doi.org/10.1016/j.apsusc.2024.160601>.
6. Li X-Y, Lu F-H. Effects of sputtering power and air/Ar ratio on the structural, electrical, and optical properties of Zr-N-O thin films deposited by air-based reactive sputtering[J]. *Journal of Alloys and Compounds*, 2025, 1044. <https://doi.org/10.1016/j.jallcom.2025.184562>.
7. Kaur D, Wadhwa R, Nisika, et al. Interfacial-Mixing and Band Engineering Induced by Annealing of CdS and a-Ga₂O₃ n-n-Type Thin-Film Heterojunction and Its Impact on Carrier Dynamics for High-Performance Solar-Blind Photodetection[J]. *ACS Applied Electronic Materials*, 2023, 5(7): 3798-3808. <https://doi.org/10.1021/acsaelm.3c00527>.
8. Wang Y, Li H, Cao J, et al. Ultrahigh Gain Solar Blind Avalanche Photodetector Using an Amorphous Ga₂O₃-Based Heterojunction[J]. *ACS Nano*, 2021, 15(10): 16654-16663. <https://doi.org/10.1021/acsnano.1c06567>.
9. Ye L, Zhou S, Xiong Y, et al. Self-powered Pt/a-Ga₂O₃/ITO vertical Schottky junction solar-blind photodetector with excellent detection performance[J]. *Optics Express*, 2023, 31(17). <https://doi.org/10.1021/acsnano.1c06567>.
10. Raaif M, El-Hossary F M, El-Moula A a A, et al. A comparative study of the optical, electrical, and wettability properties of amorphous and nanocrystalline ITO/Cu/ITO multilayer thin films prepared by DC pulsed magnetron sputtering[J]. *Applied Physics A*, 2025, 131(8). <https://doi.org/10.1007/s00339-025-08717-2>
11. Wang S, Cao L, Luo F, et al. Enhanced structural and electrical stability of nanostructured Al-doped ITO thin films at high temperatures[J]. *Journal of Materials Science: Materials in Electronics*, 2026,37(15). 37(15). <https://doi.org/10.1007/s10854-026-17552-x>.

12. Tchenka A, Amiri L, Bousseta M, et al. Investigation of the structural, optical, thermoelectric and electrical properties of ITO/Cu/ITO multilayer[J]. *Applied Physics A*, 2025, 131(4).
<https://doi.org/10.1007/s00339-025-08426-w>.
13. Kamiya O, Onai Y, Kato H-O, et al. ITO films deposited by facing target sputtering[J]. *Journal of Materials Science: Materials in Electronics*, 2007, 18(S1): 359-362. <https://doi.org/10.1007/s10854-007-9240-6>.
14. Damgaci E, Kartal E, Gucluer F, et al. Impact of Temperature Optimization of ITO Thin Film on Tandem Solar Cell Efficiency[J]. *Materials*, 2024, 17(11). <https://doi.org/10.3390/ma17112784>.
15. Etefa H F, Dejene F B. The effect of indium tin oxide nanoparticles (ITO NPs) incorporated with ZnO NPs based on structural, optical and application for flexible dye sensitized solar cells (FDSSCs)[J]. *Optical Materials*, 2024, 156. <https://doi.org/10.1016/j.optmat.2024.115962>.
16. Etefa H F, Dejene F B, Urgessa Z N, et al. Enhancing structural and optical properties of titanium dioxide nanoparticles (TiO₂ NPs) incorporating with indium tin oxide nanoparticles (ITO NPs): effects of annealing temperature[J]. *Journal of Experimental Nanoscience*, 2024, 19(1).
<https://doi.org/10.1080/17458080.2024.2362656>.
17. Alabdan H I, Alsahli F M, Bhandari S, et al. Monolithic Use of Inert Gas for Highly Transparent and Conductive Indium Tin Oxide Thin Films[J]. *Nanomaterials*, 2024, 14(7).
<https://doi.org/10.3390/nano14070565>.
18. Li M Y, Mo C C, Chen J L, et al. Effects of power on ion behaviors in radio-frequency magnetron sputtering of indium tin oxide (ITO)[J]. *Plasma Science & Technology*, 2024, 26(7).
<https://doi.org/10.1088/2058-6272/ad3599>.
19. Nowsherwan G A, Hussain I, Azhar M, et al. Exploring the impact of variable sputtering power on the morphological, optoelectronic, and thermoelectric properties of Fe-ITO thin films[J]. *Zeitschrift Fur Naturforschung Section a-a Journal of Physical Sciences*, 2025, 80(5): 373-384.
<https://doi.org/10.1515/zna-2024-0111>.
20. Zhang Y, Qin Y, Huo W X, et al. Control of threshold voltage in IGZO/ITO thin-film transistors through tuning oxygen partial pressure[J]. *Journal of Alloys and Compounds*, 2025, 1029.
<https://doi.org/10.1016/j.jallcom.2025.180711>.
21. Zhang T, Fan Y L, Zhang X X, et al. In-situ coating technology for enhancing high temperature performance of ITO thin film resistance temperature detectors[J]. *Ceramics International*, 2025, 51(18): 26968-26975. <https://doi.org/10.1016/j.ceramint.2025.04.123>.
22. Zhao N, Wang Y S, Hou J W, et al. Piezoresistive performance improvement of doped ITO thin-film strain gauges at ultra-high temperature by two-step annealing[J]. *Ceramics International*, 2025, 51(23): 40648-40656. <https://doi.org/10.1016/j.ceramint.2025.06.303>.
23. Yang S, Sun B, Liu Y, et al. Effect of ITO target crystallinity on the properties of sputtering deposited ITO films[J]. *Ceramics International*, 2020, 46(5): 6342-6350.
<https://doi.org/10.1016/j.ceramint.2019.11.110>.

24. Kim S, Jung J, Kim Y, et al. Effect of Hydrogen Gas Ratio on the Characteristics of Pulsed DC-Magnetron Sputtered ITO Films in Amorphous/Crystalline Silicon Heterojunction Solar Cells[J]. Journal of Nanoscience and Nanotechnology, 2017, 17(5): 3229-3232. <https://doi.org/10.1166/jnn.2017.14098>.
25. Zhang J L, Yuan Y D, Yang X T, et al. Band offsets of ITO/amorphous GaO x heterojunction determined by x-ray photoemission spectra[J]. Journal of Physics D-Applied Physics, 2023, 56(8). <https://doi.org/10.1088/1361-6463/acb800>.
26. Choi S K, Lee J I. Effect of film density on electrical properties of indium tin oxide films deposited by dc magnetron reactive sputtering[J]. Journal of Vacuum Science & Technology A: Vacuum, Surfaces, and Films, 2001, 19(5): 2043-2047. <https://doi.org/10.1116/1.1371326>.

Figures

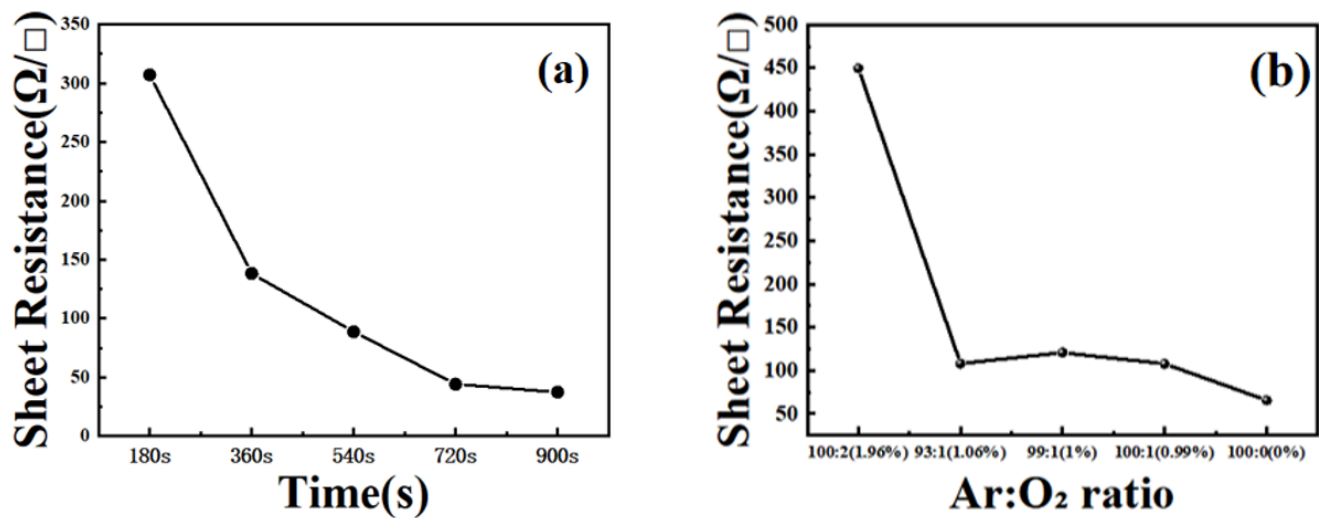


Figure 1

(a) Sheet resistance of ITO thin films deposited at an Ar/O₂ ratio of 100:1 and a sputtering power of 125W as a function of deposition time ranging from 180s to 900s.

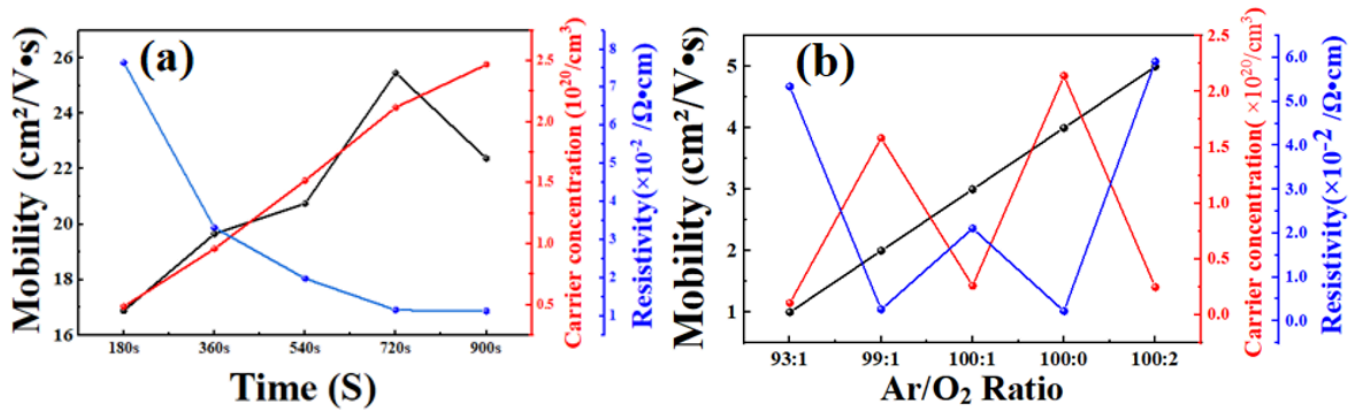


Figure 2

(a) Resistivity, carrier concentration, and Hall mobility versus deposition time (180-900 s) for films deposited at Ar/O₂ = 100:1 and 125W.

(b) Resistivity, carrier concentration, and Hall mobility versus Ar/O₂ ratio for films deposited at 80W for 900s.

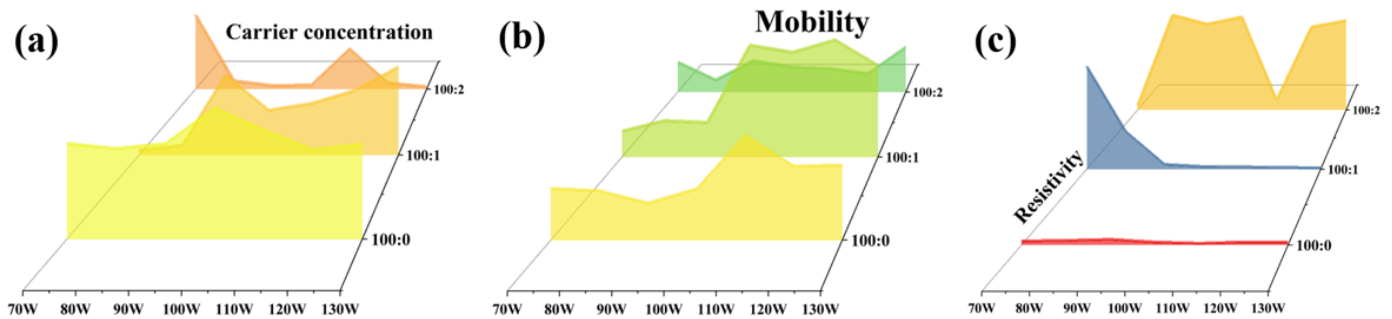


Figure 3

(a) Carrier concentration, (b) Hall mobility, and (c) resistivity of ITO thin films deposited at various Ar/O₂ ratios as a function of sputtering power.

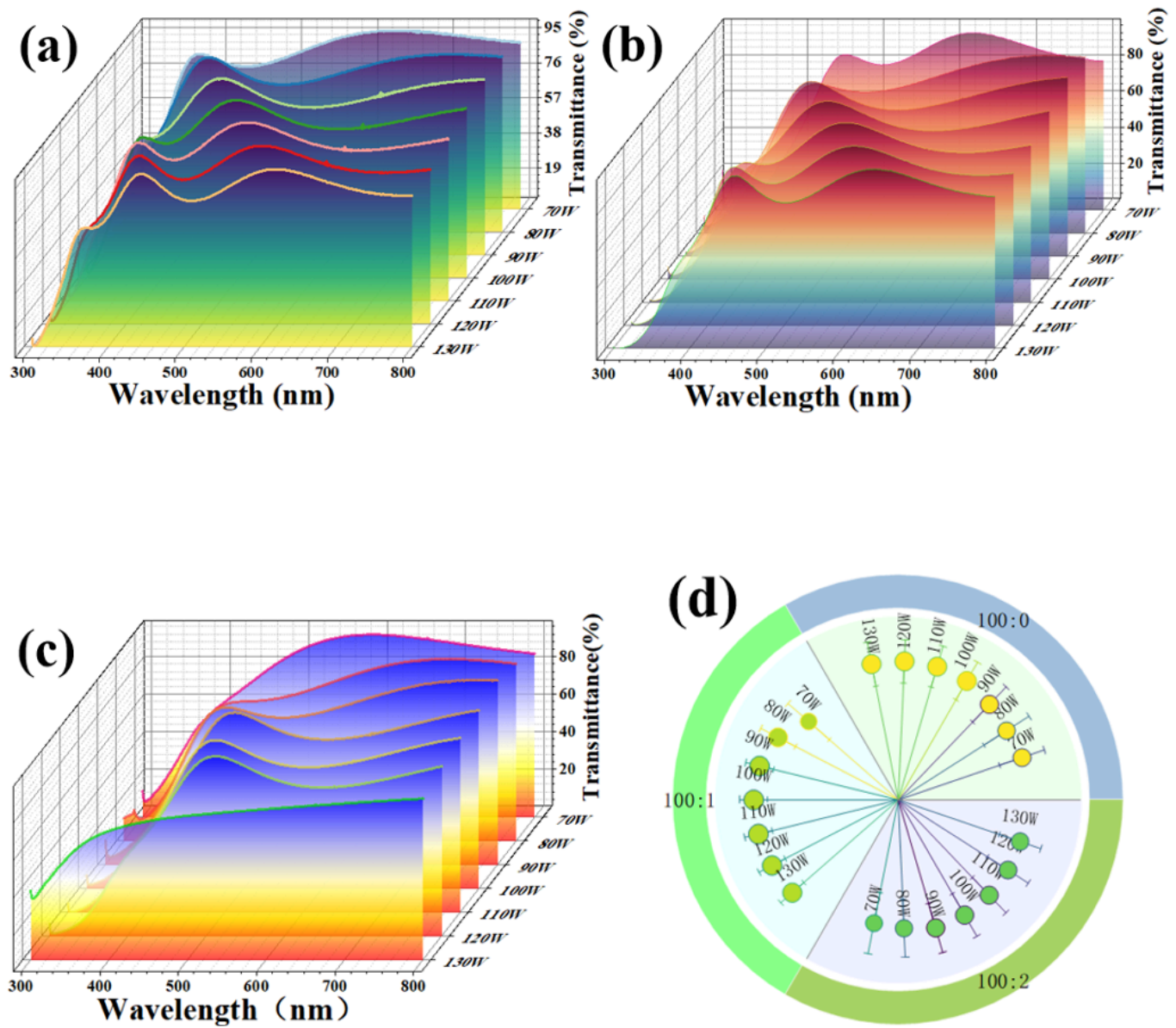


Figure 4

(a-c) Transmittance spectra of ITO thin films deposited under Ar/O₂ ratios of 100:0, 100:1, and 100:2, respectively; (d) average transmittance and standard deviation for different Ar/O₂ ratios.

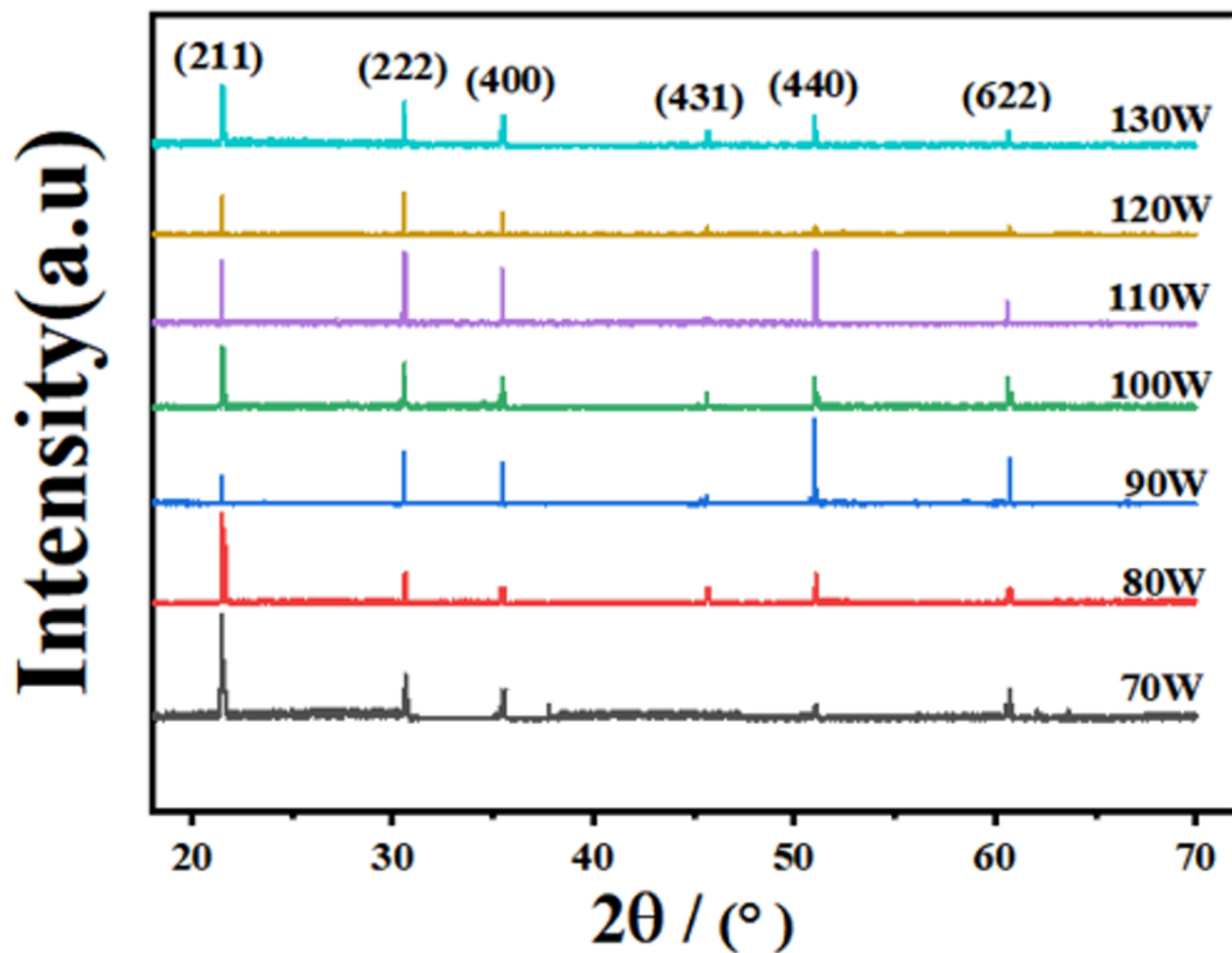


Figure 5

XRD patterns of ITO thin films deposited at an Ar/O₂ ratio of 100:1 with sputtering power levels ranging from 70W to 130W.

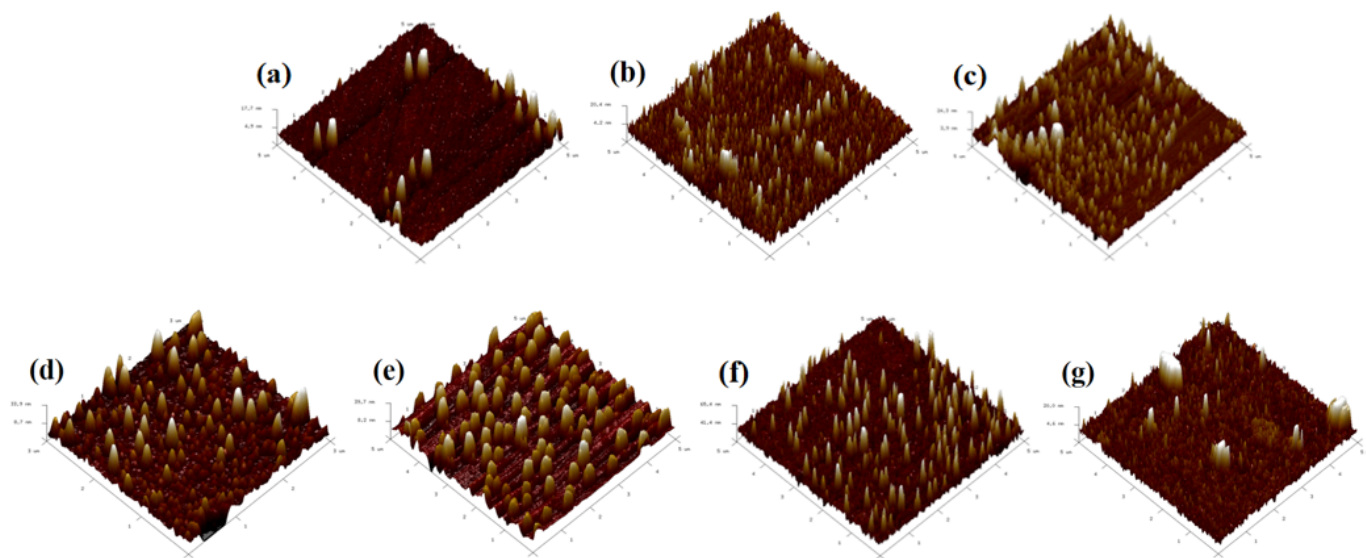


Figure 6

presents the AFM images of the films deposited under the Ar/O₂ ratio of 100:1 at power levels ranging from 70W to 130W. It is clearly observed that with increasing sputtering power, the crystalline quality of the film surface improves progressively, accompanied by more uniform grain growth and distribution. Among all the deposition conditions, the film deposited at 110W exhibits the optimal surface morphology.