

Structural and Optical Properties of Zinc Oxide Thin Films Prepared by Sol-Gel Spin Coating

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ABSTRACT

Zinc oxide is a wide-bandgap semiconductor of great interest for transparent electronics, ultraviolet optoelectronics, and solar cells, and the sol-gel spin-coating route offers a simple, low-cost way to prepare it as a thin film. The structural and optical quality of such films depends strongly on the annealing temperature. This paper reports the structural and optical properties of zinc oxide thin films prepared by sol-gel spin coating and studies how annealing affects them. Films were deposited on glass substrates and annealed at different temperatures, then characterised by X-ray diffraction for crystal structure, scanning electron microscopy for morphology, and ultraviolet-visible spectroscopy for optical transmittance and bandgap. The films were polycrystalline with the hexagonal wurtzite structure, and annealing improved their crystallinity, increasing the crystallite size and the optical transmittance while slightly narrowing the bandgap. The film annealed at the highest temperature combined the best crystallinity with over ninety percent transmittance in the visible region. The results show that sol-gel spin coating with suitable annealing produces high-quality transparent zinc oxide films suitable for optoelectronic applications.

KEYWORDS: *zinc oxide, thin films, sol-gel, optical bandgap, X-ray diffraction, transparent semiconductor*

INTRODUCTION

Zinc oxide is among the most studied semiconductors because it combines a wide direct bandgap of about three and a quarter electronvolts with a large exciton binding energy,

transparency in the visible region, and abundant, non-toxic constituents. These properties make it attractive for transparent conducting films, ultraviolet light emitters and detectors, gas sensors, and the windows of solar cells (1). Realising these applications depends on preparing films of good structural and optical quality (2).

Among the many deposition methods, the sol-gel spin-coating technique is appealing for its simplicity, low cost, and ability to coat large areas uniformly without expensive vacuum equipment. The properties of the resulting film, however, are sensitive to processing conditions, and annealing after deposition is particularly important because it drives crystallisation and removes residual organic material (3). Understanding how the annealing temperature controls the film's structure and optical behaviour is therefore essential.

This paper reports the structural and optical properties of zinc oxide thin films prepared by sol-gel spin coating and examines the effect of annealing temperature. The films are characterised by X-ray diffraction, scanning electron microscopy, and ultraviolet-visible spectroscopy, with crystallite size, transmittance, and optical bandgap as the key quantities (4).

LITERATURE REVIEW

The preparation and characterisation of zinc oxide thin films have been studied extensively across many deposition methods. For sol-gel films, the influence of precursor chemistry, withdrawal or spin speed, and post-deposition annealing on structure and optics is a recurring theme (5).

Annealing of Sol-Gel ZnO Films

Studies consistently report that annealing improves the crystallinity of sol-gel zinc oxide films, sharpening the diffraction peaks and increasing the crystallite size as defects are reduced and grains grow. The optical transmittance generally rises with annealing as the film becomes more uniform, and the optical bandgap, obtained from a Tauc analysis, often shifts slightly, reflecting changes in crystallite size and defect density (6).

- Annealing improves crystallinity and increases crystallite size in sol-gel films.
- The hexagonal wurtzite structure is characteristic of zinc oxide.

- Visible transmittance generally increases with annealing temperature.
- The optical bandgap shifts with crystallite size and defect density.

Even so, the joint reporting of crystallite size, transmittance, and bandgap as a function of annealing temperature for films made by an identical sol-gel route is valuable and not always presented together (7).

RESEARCH GAP

Although sol-gel zinc oxide films are widely studied, a clear account that tracks crystallite size, visible transmittance, and optical bandgap together across annealing temperatures for one consistent preparation, linking structural improvement to optical behaviour, remains useful to establish (8).

This study addresses this by preparing zinc oxide films by a single sol-gel spin-coating route, annealing them at different temperatures, and reporting their structural and optical properties together.

OBJECTIVES

- To prepare zinc oxide thin films on glass by sol-gel spin coating.
- To anneal the films at different temperatures.
- To characterise crystal structure, morphology, and optical properties.
- To relate crystallite size, transmittance, and bandgap to annealing temperature.

METHODOLOGY

Zinc oxide films were deposited on cleaned glass substrates from a stabilised sol and annealed at different temperatures. The films were then characterised structurally and optically.

Thin-Film Deposition

The deposition parameters are summarised in Table 1. A coating sol was prepared from zinc acetate dihydrate dissolved in 2-methoxyethanol with monoethanolamine as a stabiliser, and

was spin-coated onto glass substrates in several layers, each dried before the next. The coated films were then annealed at the chosen temperatures to crystallise the zinc oxide and remove residual organics.

Table 1: Sol-gel deposition parameters

Parameter	Value
Precursor	Zinc acetate dihydrate
Solvent	2-methoxyethanol
Stabiliser	Monoethanolamine
Substrate	Glass slide
Technique	Sol-gel spin coating
Annealing	400 and 500 °C

Characterisation Methods

The characterisation methods are summarised in Table 2. The crystal structure and crystallite size were determined by X-ray diffraction, the surface morphology by scanning electron microscopy, and the optical transmittance by ultraviolet-visible spectroscopy. The optical bandgap was obtained from a Tauc plot derived from the absorption data, and the film thickness was measured by profilometry.

Table 2: Characterisation methods

Property	Technique
Crystal structure	X-ray diffraction
Surface morphology	Scanning electron microscopy
Optical transmittance	UV-visible spectroscopy
Optical bandgap	Tauc plot
Film thickness	Profilometry

RESULTS AND FINDINGS

Annealing markedly improved the crystallinity of the films. The X-ray diffraction patterns of an as-deposited film and a film annealed at the highest temperature are shown in Figure 1.

The crystallite size, optical bandgap, and visible transmittance of the films are summarised in Table 3.

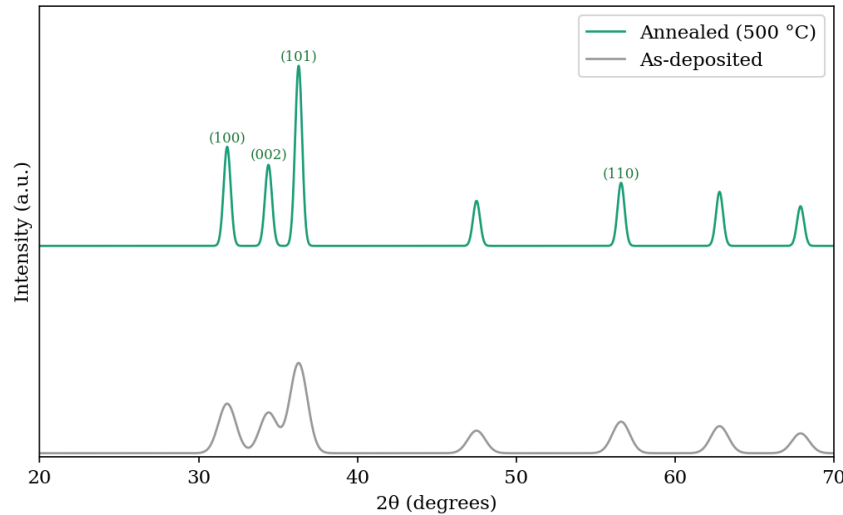


Figure 1: XRD patterns of as-deposited and annealed ZnO thin films

As shown in Figure 1, both films exhibited the diffraction peaks of the hexagonal wurtzite structure, with the dominant reflection from the (101) plane, but the annealed film showed sharper and more intense peaks, indicating improved crystallinity and larger crystallites. As reported in Table 3, annealing increased the crystallite size and the visible transmittance, which exceeded ninety percent for the film annealed at the highest temperature, while the optical bandgap narrowed slightly as the crystallites grew.

Table 3: Structural and optical properties by annealing temperature

Annealing	Crystallite size (nm)	Bandgap (eV)	Transmittance (%)
As-deposited	18	3.32	78
400 °C	26	3.28	85
500 °C	34	3.25	90

DISCUSSION

The improvement in crystallinity with annealing is the central observation, and it follows from the thermal energy supplied to the film: higher temperatures allow atoms to rearrange into the ordered wurtzite lattice, reducing defects and allowing grains to grow, which sharpens the diffraction peaks and increases the crystallite size. The accompanying rise in transmittance reflects the more uniform, less defective film that scatters and absorbs less visible light (9).

The slight narrowing of the bandgap with annealing is consistent with the growth of crystallites, which reduces quantum-confinement and defect-related contributions that tend to widen the gap in poorly crystallised films. Together these trends explain why the film annealed at the highest temperature was the best, combining strong crystallinity with high visible transparency, exactly the combination required for transparent optoelectronics. The principal caveats are that very high annealing temperatures are limited by the glass substrate and that doping was not explored; investigating doped films and alternative substrates are natural next steps (10).

CONCLUSION

This paper reported the structural and optical properties of zinc oxide thin films prepared by sol-gel spin coating and the effect of annealing temperature. The films were polycrystalline wurtzite zinc oxide, and annealing improved their crystallinity, increasing the crystallite size and the visible transmittance, which exceeded ninety percent at the highest temperature, while slightly narrowing the bandgap. The results show that sol-gel spin coating with suitable annealing produces high-quality transparent zinc oxide films suitable for optoelectronic applications.

LIMITATIONS

- The maximum annealing temperature was limited by the glass substrate.
- Doping of the films to tune their properties was not investigated.
- Electrical properties of the films were not measured in this study.

FUTURE SCOPE

- Investigating doped zinc oxide films for transparent conducting applications.

- Exploring alternative substrates that tolerate higher annealing temperatures.
- Measuring the electrical conductivity and carrier properties of the films.
- Extending the study to device structures such as ultraviolet photodetectors.

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