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| Research Article

Zinc Oxide Nanostructure coating on glass substrate for solar still optimization by structural, optical and surface analysis

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Annotation

The solar still is a compelling technology for water desalination, especially in dry regions where a lack of freshwater is a significant challenge. Nevertheless, heat loss and poor absorption of solar radiation by the glass cover limit the efficiency of traditional solar stills. Considering the performance of solar stills, coating glass substrates with nanostructures with varying properties can also improve performance by enhancing light absorption and reducing reflection. ZnO with good transparency in the visible range and superior photocatalytic properties was deposited on glass substrates through the sol-gel spin coating method and annealed to produce crystalline ZnO films at 600 °C. ZnO-coated glass was characterized further using X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM), and UV-Vis Spectroscopy to reveal some of its structural, optical, and surface properties. The investigation revealed a distinct reduction in reflection (20-25%→5-10%) and improved light transmission over a broad energy spectrum region, especially in the UV region while maintaining transparency throughout the visible and infrared spectra. The structure was observed to be hexagonal wurtzite with crystallite size in the range of 14.03 nm to 21.53 nm, which resulted in better conductivity and photocatalytic properties. These characteristics make ZnO-coated glass a favourable alternative for the performance enhancement of solar stills by accelerating the evaporation rate and improving water purification performance. The findings of this study suggest that ZnO coatings have the potential to mitigate the challenges posed by conventional solar stills and present a cost-effective, large-scale approach to improve solar desalination technologies.

Keywords: ZnO ; Solar Still ; ZnO/glass ; Nanostructures

Introduction

Solar stills can be an interesting technology for the desalination of water, especially in arid areas where fresh water is a concern [1][2][3]. This is based on solar energy utilised to evaporate water, [4]and the vapour is later condensed and collected for usage. Despite their advantages, traditional solar stills are limited by heat loss and low glass cover solar radiation absorption [5]. Solar radiations are transmitted through the top surface of the solar stills, which needs to be transparent as well as have as low reflection as possible [6], and one of the most critical determinants for the efficiency of solar stills is the physical properties of the glass top surface [7][8].

The application of ZnO (Zinc Oxide) coatings has resulted in improved light absorption and reduced reflection, thereby significantly enhancing the performance of optical devices[9] [10][11]. Zinc oxide (ZnO) has advantageous optical properties, including high transparency over the visible spectrum and excellent photocatalytic behaviour[12] [13][14], which make it a wide-bandgap semiconductor. ZnO coatings on the glass substrate can minimize the reflection of solar radiation and maximize its transmission, which can optimize the performance of the solar still [15][16].

Although there has been increasing interest in using ZnO coatings within the area of solar energy applications, this area has so far attracted minimal attention in the context of its application to solar stills, where reflection reduction and light transmission increase directly impact efficiency improvement. On the other hand, a detailed understanding of the structural, optical, and surface characteristics of ZnO coatings on glass substrates remains scarce. Common existing studies mainly investigate the role of ZnO in solar cells or solar collectors, which is far less the case when exploring ZnO coatings on the performance of solar still systems.

The application of ZnO coatings for optical applications has been extensively studied in the literature. For example, ZnO thin films can minimize reflectivity and enhance light yield in numerous photovoltaic applications. ZnO films are used in solar technology as transparent conductive oxides to improve energy conversion efficiency (Jain et al.)[17]. ZnO coatings on glass have also been investigated to boost the performance of solar thermal systems by increasing heat absorption and decreasing reflection (Verma et al.)[18]. Another study has shown that ZnO coatings provide photocatalytic properties, which can eliminate surface contaminants and thus maintain the transparency of the glass and its ability to let sunlight through even with time and age (Zhang et al.)[19]. Although these studies showed various advances, the properties, particularly structural integrity, optical features, and surface morphology, of ZnO coatings in solar stills are less studied.

Therefore, the primary goal of this study was to investigate the application of ZnO coatings on glass substrates to enhance the performance of solar stills. In particular, the research aims to analyse the structural, optical, and surface behaviour of ZnO-coated glass and its role in improving solar stills' efficiency.

Materials and Methods

This research utilizes Zinc acetate dihydrate, Sodium Hydroxide, methanol, and distilled water as materials. Zinc acetate dihydrate serves as a precursor, while methanol functions as a reagent. Distilled water serves as a solvent. All chemical reagents utilized in this experiment were procured from commercial sources as assured grade and were employed as supplied without additional processing. This experiment employs the sol-gel method to synthesize ZnO nanoparticles. In this experiment, zinc acetate dihydrate served as the zinc precursor. Combining 0.2M zinc acetate dihydrate with methanol at ambient temperature. Subsequently, the solution was subjected to ultrasonic mixing at 25℃ for 120 minutes, resulting in a clear and transparent sol devoid of precipitate and turbidity. Subsequently, 0.02 M NaOH was introduced to the solution and subjected to ultrasonic stirring for 60 minutes. As seen in Figure 1 below. Maintain the sol undisturbed until the white precipitates settle at the bottom. Following precipitation, the precipitate was filtered and washed with excess methanol to eliminate the starting material. Precipitates were desiccated at 80℃ for 15 minutes on a hot plate. Subsequent to the annealing of these precipitates at 400℃ for 30 minutes. The solution was then spin-coated onto cleaned glass substrates at optimized speeds (3000 rpm) to achieve uniform thin films. After deposition, the films were subjected to a heat treatment process at 500°C for 1 hour to convert the sol-gel layer into crystalline ZnO. This annealing process improved the crystallinity and optical properties of the film.

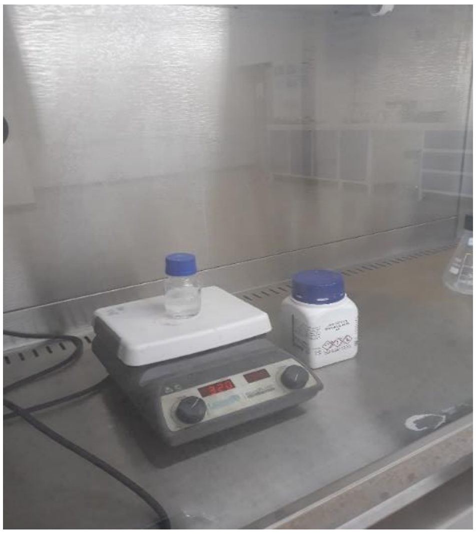


Fig. 1A. synthesis ZnO Nanoparticle

The ZnO-coated glass substrates were characterized using several techniques, including X-ray Diffraction (XRD) to confirm the crystalline structure, Scanning Electron Microscopy (SEM) for surface morphology, UV-Vis Spectroscopy to evaluate optical transmission and reflection; these characteristics helped to understand the impact of the ZnO coatings on the optical performance, particularly in terms of reduced reflection and enhanced light transmission, which are crucial for optimizing solar stills. The sol-gel spin coating method proved to be a cost-effective and scalable approach to enhance the efficiency of solar applications by improving the optical properties of glass substrates.

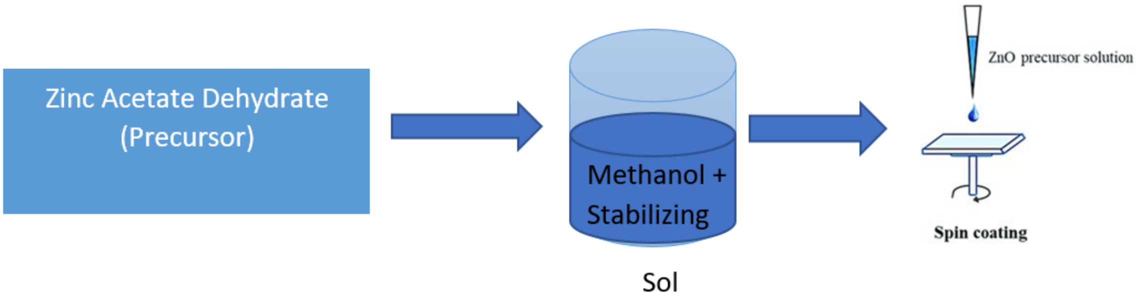


Fig.1B. A schematic view of the sol-gel process for the ZnO thin film processing.

Results

Structure results

ZnO thin film is on a glass substrate. Its XRD analysis is shown in Fig (2), which indicates that the thin film plane structure and peaks represent the hexagonal wurtzite crystal system of ZnO that determines crystallinity. The sharp diffraction peaks detected at certain 2θ angles confirm the presence of well-formed crystallographic planes, with (100), (002), (101), (110) and (103). Crystallite sizes range from 14.03 nm to 21.532 nm, and larger crystallites, specifically at 61.3841°, could lead to better thermal conductivity. That is helpful for solar stills, as it can assist in transferring heat for water evaporation. However, movies have different microstrain values ranging from 0.35% - 0.93%, with maximum strain at 34.3444. Accordingly, this indicates internal stresses. Such strains can lead to material degradation, such as cracking or a loss of structural integrity, especially under thermal cycling in solar stills, which could affect the long-term durability of the film. Also, the FWHM of specific peaks has increased, especially at 56.3116°, which is attributed to the defects or grain boundaries, giving rise to reduced photocatalytic efficiency and promotion of electron-hole recombination. Although these possible problems may arise, the growth of the sample at high crystallinity[20], particularly on some planes, implies that the ZnO thin film would effectively absorb sunlight and heat. Solar still systems using the properties of this category have an essential role in improving the evaporation rate and increasing efficiency in water purification or seawater desalination. In summary, the improved properties of the ZnO thin film make it a promising means of improving solar still performance while reducing strain, defects, and microstrain, which will be crucial in ensuring efficiency for long-term water purification

No.	Pos. [°2Th.]	d-spacing [Å]	FWHM [°2Th.]	Crystallite Size [nm]	MicroStrain only [%]
1	31.7006	2.82266	0.4881	19.2366	0.733668
2	34.3444	2.61118	0.6711	14.02907	0.930632
3	36.1914	2.48205	0.4881	19.46744	0.637487
4	56.3116	1.63379	0.9761	10.42786	0.783377
5	61.3841	1.51039	0.4881	21.53193	0.350732

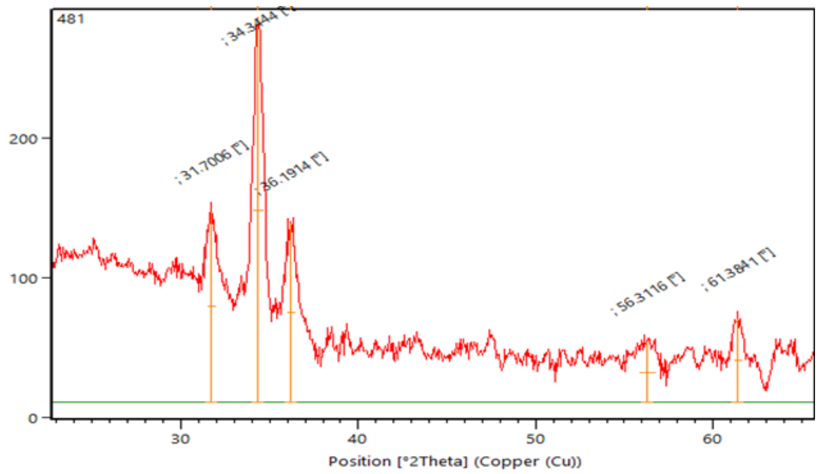


Fig. 2. XRD Spectra results of ZnO / Glass

Morphology results

Fig (3) shows an SEM image of the surface morphology of ZnO thin film on glass, showing the formation of smooth and granular structures, and a high-magnification SEM image shows a surface with some tiny pores and nanostructures. While the film is relatively uniform, it does have some light surface artefacts. Also, the granular structure containing porous regions is essential for increasing the surface area, which is highly required for thermal conductivity and photocatalytic activity. The tiny round nanostructures observed were suspected to enhance the photocatalytic performance of the ZnO film, allowing the film to be used in water purification through photocatalysis. The porosity increases the surface area, improving solar absorption and evaporation efficiency in a solar still and enhancing distillation. Moreover, the smooth regions of the film imply homogeneous heating, which is essential for the effective evaporation of water. The surface morphology obtained from the SEM images, as shown in Fig 3, suggests that the ZnO thin film is suitable for significantly improving the performance of solar still by improving the evaporation rates and water purification performance due to its thermal and photocatalytic properties.

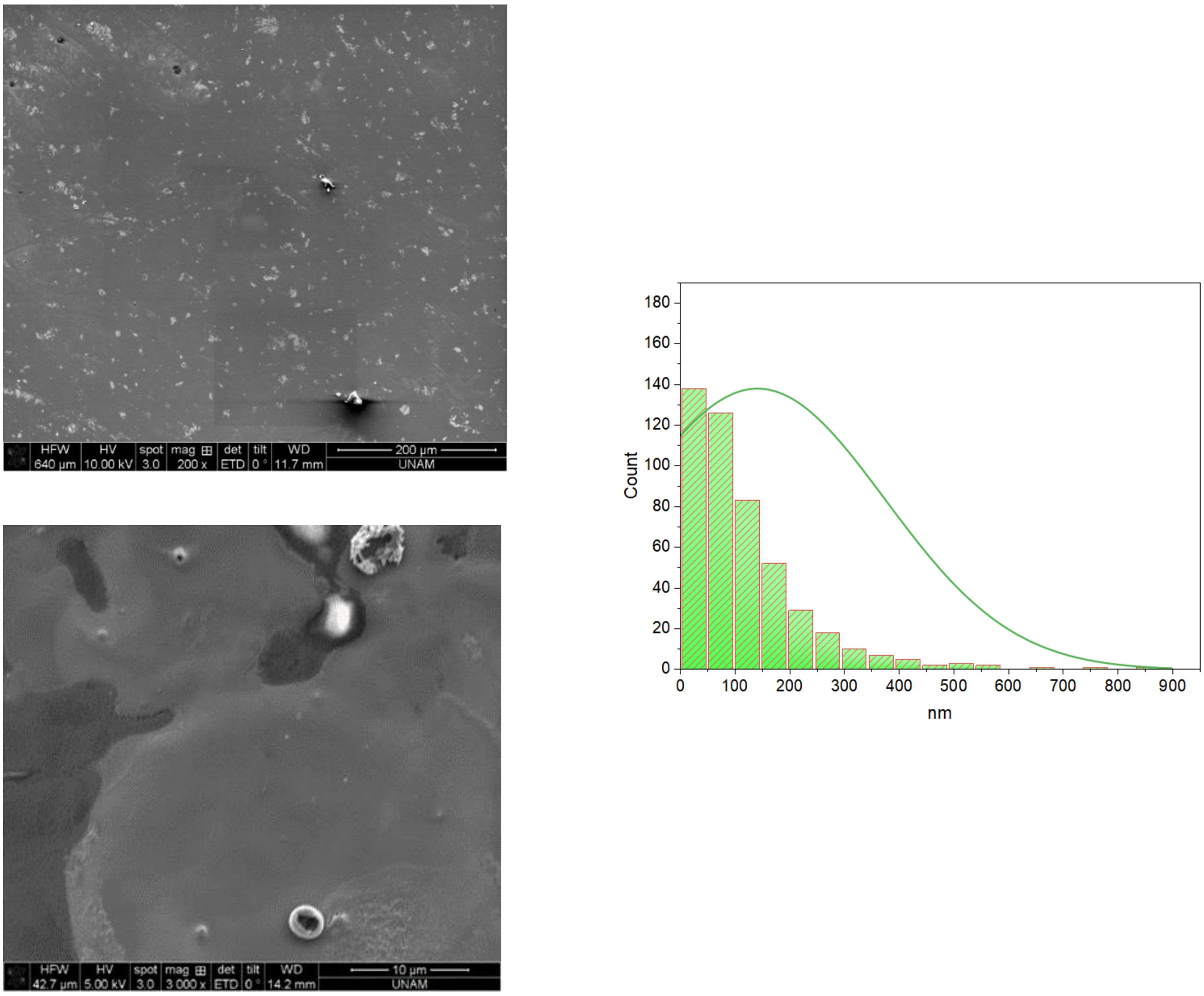


Fig. 3. SEM Images of ZnO / Glass with Size Analysis

Optical results

UV-Vis analysis

The UV-Vis spectrum of the prepared ZnO thin film exhibits the optical properties of the ZnO that are indispensable in applying the solar still. The film showed a strong absorbance in the UV region (400-500 nm),

The band gap was founded from the Tauc equation;

$$(ah\nu) = B(h\nu - Eg)n \quad (2)$$

a is absorption coefficient, hν photon energy, Eg energy band gap, A a constant.

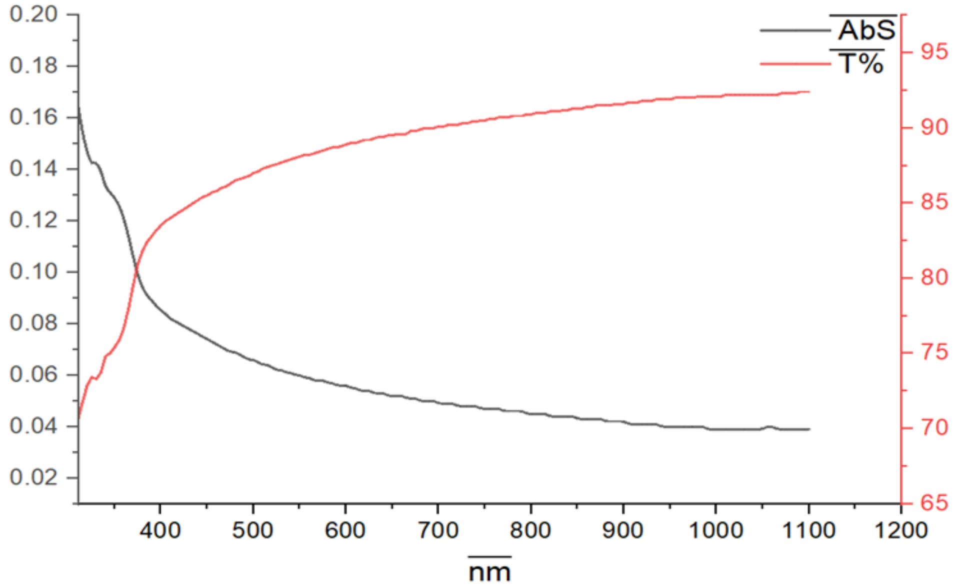
By plotting $(\alpha h\nu)^2$ versus hν and extrapolating the linear portion of the curve to zero absorption, the energy.

the bandgap (3.35 eV) of ZnO

Such effective UV absorption enables the film to trap solar energy, especially from the UV-A and UV-B regions, and ultimately convert it to heat. From the transmittance curve (in red), you can see that the transmittance is low in the UV region, which indicates that most of the light in the UV range is absorbed. Still, the absorption decreases drastically as the wavelength increases in the visible and infrared area. The ZnO thin film has a moderate transmittance in the visible region (400-

700 nm), indicating that it can still transmit light in the visible light range. In comparison, the film is still highly transparent in the infrared region (above 700 nm) and does not effectively trap infrared heat.

The combination of UV absorption and infrared capacity allows the ZnO thin film to absorb solar heat efficiently, but the captured heat can then be partly lost as infrared radiation. However, the high infrared transmittance can cause low thermal retention in solar stills that may restrict long-term evaporation. Still, this relatively small improvement over the solar cells does present an advantage over them because of the high UV absorption, which is mainly responsible for increased evaporation rates in the solar still, which will lead to improved water purification or desalination effect. By applying benefits related to the improvement of infrared absorption or thermal insulation, it can be noted that heat retention in a solar still is a key factor that increases the reliability of water desalination.



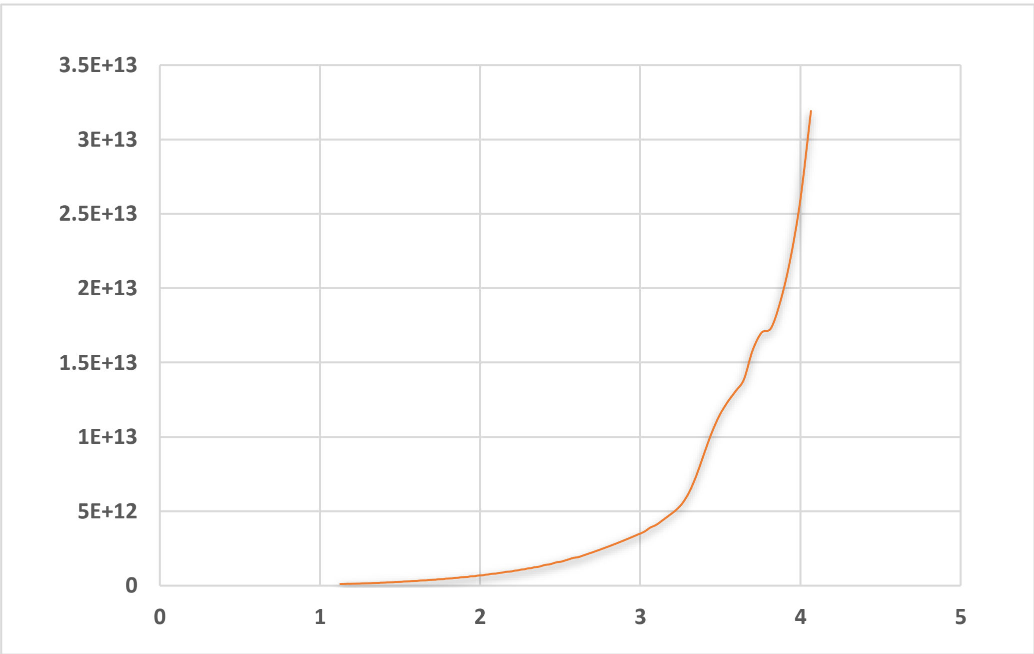


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Fig.4.UV-Vis analysis of ZnO thin film coating on glass surface

Reflection Analysis

Fig (5) shows the reflection spectra for one type of glass without a ZnO coating (red line) and one with a ZnO coating (blue line). The glass alone, without the ZnO coating, has comparatively high reflective properties, reaching 20-25% in the visible spectrum (400 nm-600) (displayed as blue in the figure). The high reflectivity here leads to less light transmissivity, making solar applications such as solar stills less effective. In comparison, the reflection of ZnO-coated glass is considerably reduced to 5-10% over the entire spectrum. The decline in reflection allows more sunlight to go through the glass, enabling it to absorb solar radiation better. This helps solar stills since a large amount of energy gathers to stay in contact with the water, speeding up heating and evaporation. Hence, the ZnO coating effectively minimizes the energy loss from the surface and thus significantly elevates the overall performance of solar stills for water vaporization.

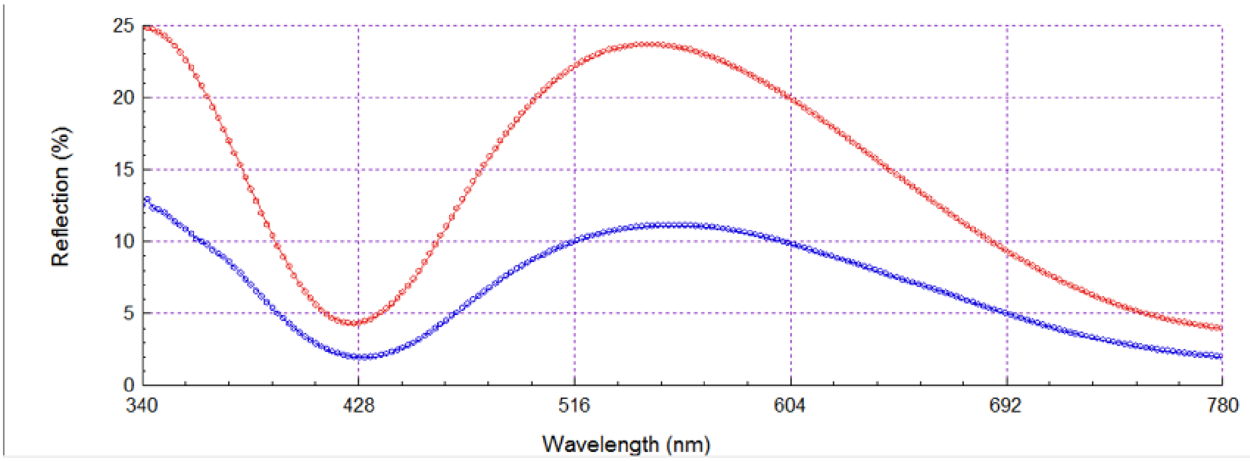

Fig.5. Reflection spectra for (a) glass without coating (b) glass with ZnO coating

Conclusion

ZnO nanostructure deposition on glass substrates has been employed in this study to improve the performance of solar stills. The result also indicated that structural, optical and surface properties for the ZnO coated glass were examined and showed improved light absorption, reduced reflection and enhanced thermal conductivity—ZnO thin films showed high structural uniformity and effective UV light harvesting properties to maximise solar still performance. Notwithstanding minor challenges in microstrain and thermal management, the ZnO coatings resulted in vastly enhanced evaporation rates and water purification performance. ZnO-coated glass substrates seem promising for solar still improvement, particularly in dry regions where water desalination is essential. Future work may study thermal insulation optimization and defect reduction for long-term durability and efficiency improvement.

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