# Fabricating and characterizing of ZnO nanostructure solar cells

# صناعة وقياس خصائص غشاء ZnO بتركيب نانوي للخلايا الشمسية

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## Abstract

Zinc oxide (ZnO) thin film on crystalline silicon (c-Si) substrate has been deposited by RF sputtering method to use it for fabricating a solar cell. Structural properties of ZnO films studied using high resolution X-ray diffraction (HRXRD) analysis of the films which show that the films have polycrystalline nature with orientation (002). Small crystallite size of prepared films was calculated using Scherrir formula that indicates our films are within Nano scale. In addition, optical properties have been done via scanning electron microscopy (SEM) which used to describe the surface morphology and Photoluminescence (PL) measurements which revealed that the energy bandgap of prepared films were in the UV emission at 380 nm. Finally, thickness of the films was measured with Filmetric (F-20). Our findings were the fabricated ZnO films are successful in simple and low cost method with high quality and unexpected nanostructure behavior. Good current-voltage behavior with high conversion efficiency of 14.5 % has been obtained.

**Keywords:**( ZnO , nanostructure, solar cells, thin films )

## ملخص البحث

في هذا البحث تم ترسيب أوكسيد الخارصين (ZnO) على السيليكونِ البلّوريِ (c-Si) بواسطة منظومة الترسيب ( RF sputtering) لصناعة خلية شمسية. دَرستْ الخصائص التركيبية لغشاء ZnO بأستعمال اشعه سينية عالية الوضوحية (HRXRD) لتحليل الاغشية والذي بين بأن الاغشية لَها طبيعةُ (polycrystalline) بالتوجيهِ (002). الحجم البلوري الصغير للأفلامِ المُحَضّرةِ تم حسابه بأستعمال صيغةِ Scherrir والتي تُشيرُ إلىان الاغشية المرسبه هي ضمن مِقياسِ النانو. بالإضافة، الى الخصائص البصرية عُمِلتْ عن طريق استعمال جهاز مَسْح المجهر الألكترونيِ (SEM) االذي يُستَعملُ لوَصْف السطحِ, وتم استخدام مقياس ((Photoluminescence (PL) لمعرفة فجوة الطاقةَ للأفلامِ المُحَضّرةِ والتي كَانتْ في المنطقة UV في 380 nm. أخيراً، قِيسَ سُمك الأفلامِ بواسطة ((Filmetric (F-20). وفق هذه النتائج فان ترسيب اغشية ZnO تمت بنجاح وبكلفةِ بسيطةِ ومنخفضةِ بطريقة التركيب النانوي عالي النوعية. امكن الحصول على فولطيةِ وتيار عاليين وبكفاءةِ تحويلِ وصلت الى 14.5 %.

## 1. Introduction

Good properties of ZnO were reported with special emphasis on the use of ZnO as transparent conductive electrode in thin film solar cells. Also, ZnO has specific properties such as low costs, nontoxicity, high transparency in VIS/near IR spectral region, good contacts to the active semiconductors (absorb layers), and others [1,2]. These properties make ZnO as a one of promising semiconductor materials to use in many scientific and industrials areas such as piezoelectric transducers, optical waveguides and conductive gas sensors [3]. In the past decades, silicon (Si) had also attracted considerable interests due to the characteristics of low costs, high resistance, strong absorbability, and its potential application in the development of Si-based optoelectronic devices [4]. The surface of one dimensional ZnO is very sensitive to the changes in surface chemistry and hence can be utilized to fabricate highly sensitive ZnO electrochemical sensors.

Many industrial and commercial activities involve the monitoring and control of the environment, with applications ranging from domestic gas alarms and medical diagnostic apparatus to safety, environmental and chemical plant instrumentation. The largest barrier to achieve an improved process or environmental control often lies at the interface between the system and the environment to be monitored, i.e. a sensor without significant advances in control and instrumentation will not be possible [5]. Various techniques have been employed to prepare ZnO films including the sol-gel process, chemical deposition, Direct Current (DC) and Radio Frequency (RF) sputtering, and pulsed laser deposition [6]. The RF sputtering technique has drawn considerable attention since the resulting films properties can be controlled by changing the sputtering condition [5]. In this work, the development of sputtered zinc oxide thin film deposited using RF magnetron sputtering technique on silicon Si (n-type) (111) with metallic zinc target of 99.98 % was employed. The film thickness of 800 nm is deposited at room temperature under high pressure has a significant role in the solar cells applications.

## 2. Experimental procedure

One-side-polished c-Si wafer n-type (111) with resistivity of 0.75 $\Omega.cm$ and thickness of 280µm was used as substrate silicon wafer. To ensure that the wafer does not contain any native oxides; the samples were dipped in a 2% HF solution for 10 second to remove the oxide, and subsequently rinsed in de-ionized water (distilled water). Then the reflectance was measured using Filmetric (F20); and surface morphology examination was carried out using scanning electron microscopy (SEM). The surface roughness was characterized by atomic force microscopy (AFM). The doping type was determined using the hot probe technique. Resistivity and doping concentration measurements were carried out using the Hall Effect. Then, the wafer was cut into small pieces by cutter machine to prepare it to the manufacturing processes.

## 3. Results and discussion

### 3.1 Structural properties

Figure 1 shows the XRD pattern of the one sample deposited ZnO thin film on Si substrate with magnification power (1µm, 2µm, 3µm and 5µm) which confirmed the formation of crystalline ZnO. The XRD spectrum of ZnO film shows mainly the ZnO (002) diffraction peak at 2T = 34.36° with FWHM of 0.54° for the deposited ZnO thin film on Si. This indicates that the film preferentially grew along c-axis orientation, perpendicular to the substrate with the lattice parameters of a = 3.2535 Å and c = 5.2151 Å. In order to attain the detailed structure information, the crystalline size (diameter of the spherical particle) D calculated fromScherrer formula [7]:

$$D=0.9\ \lambda / B \cos\theta \qquad \ldots\ldots. (1)$$

Where, $\lambda$ is the X-ray wavelength, $\theta$ is Bragg angle of (002) peak, and B is FWHM value. The crystalline size of ZnO on Si is 4.7 nm which demonstrates that the crystalline becomes moreuniform and bigger in size. The average uniform strain for the lattice along the c-axis in the randomly oriented ZnO film deposited on Si substrate has been estimated from the lattice parameters using the Equation:

$$Mismatch = \frac{a_{film} - a_{substrate}}{a_{substrate}} * 100\% \qquad \ldots\ldots. (2)$$

where $a_{film}$ and $a_{substrate}$ are the lattice constant of ZnO and Si respectively. The lattice mismatch equal to - 0.23 % for the ZnO thin film deposited on Si substrate.

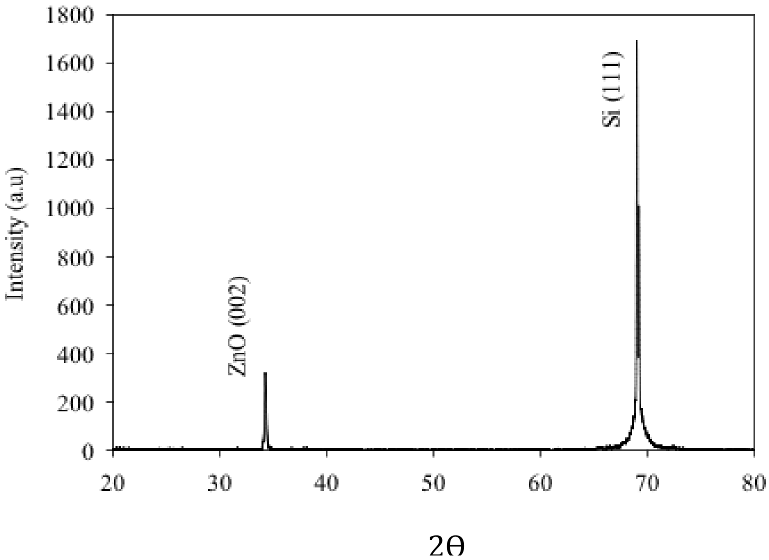


Figure 1: The XRD pattern of ZnO (002) thin film deposited using RF magnetron sputtering technique on silicon (111) substrate

ZnOnanostructure (like flower) has been grown on a bare c-Si (111), where the Figure 2 shows the SEM images of the ZnO. It can be seen that the ZnO film with uniform shape and flat surface morphology can be obtained. It can be seen that the whole surface is formed by similar geometrical texturing of ZnO seed to reconstruct the top layer with nanostructure like the flower.

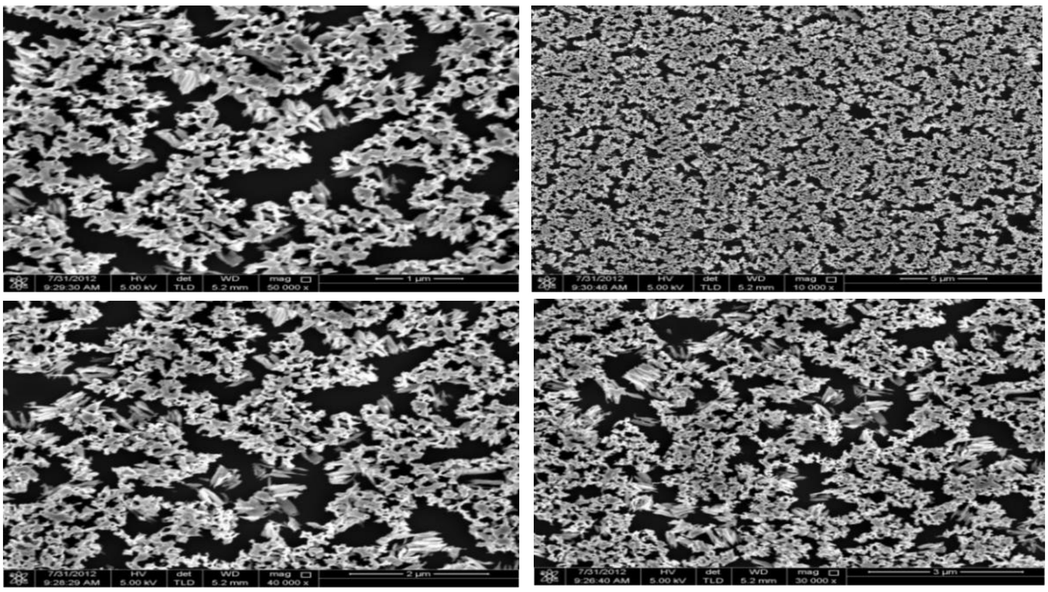

Figure 2: SEM surface morphology ofZnO layer grown on c-Si(111) substrate with many magnification power (1µm, 2µm, 3µm and 5µm)

The surface roughness of sample has been determined using atomic force microscopy as shown in Figure 3 below. The root mean square (RMS) roughness value is about 12 nm over a 10 × 10 $\mu m^2$ scan area. It can be seen that ZnO layer consists of some columnar structure grains; this most probably due to relatively temperature growth rate of the ZnO film and which is in agreement with the SEM results.

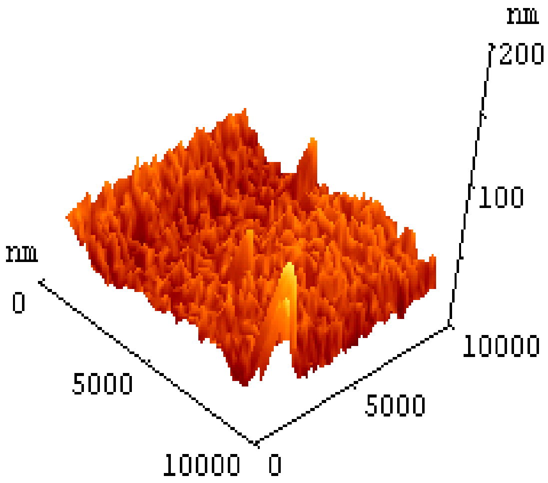


Figure 3: AFM image in three dimensions (3-D) of ZnO layer grown on c-Si(111) substrate

## 3.2Optical properties

ThePhotoluminescence(PL) spectrum of the prepared ZnO thin film on Si is shown in Figure 4. Two luminescence peaks can be observed in the sample, the first peak is the UV emission corresponding to the near band edge emission (NBE) which is due to the electronic transition from near conduction band to valence band. The other one is in the visible region which may be due to the defect related deep level emission. The UV emission peak was found to be at 390 nm for the sample. Second luminescence peak shows a broad band peaked at 740 nm was observed for the sample. Using PL spectra the$E_g$ value was found to be 3.16 eV for ZnO thin film on Si. This result that there is a blue shift to the bulk ZnOEg value which equals to 3.25 eV. In summary, the high quality ZnO film on Si substrate was fabricated. The low grain size and smoothly surface observed in the ZnO sample. ZnO film has two PL peaks with high intensity in UV region at 390 nm make it promising to use in near UV optoelectronic devices.

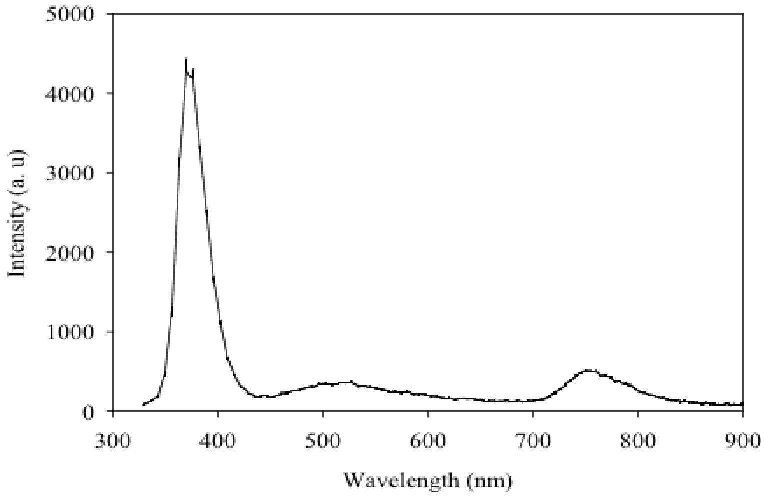


Figure 4: Photoluminescence spectrum of ZnO film with wavelength range (300 nm-900 nm)

Figure 5 show the refractive index and transmitted curves as a function of wavelength of ZnO thin film which reflects that the film has a wide transmittance curve in visible region of electromagnetic radiation.

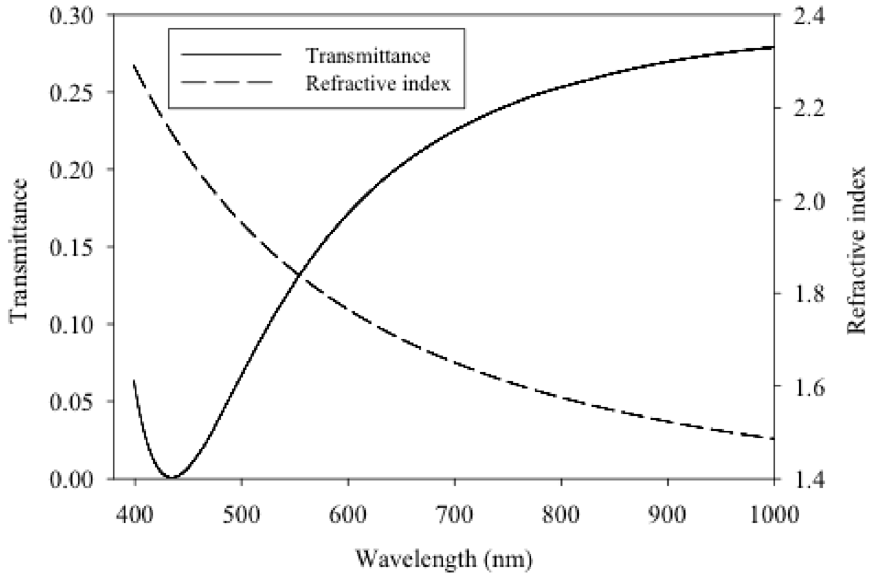


Figure 5: Transmission and refractive index of ZnO based on c-Si

The dataof the open circuit voltage, short circuit current density, fill factor and efficiency have been measured by solar module analyzer. Current density-voltage output in Figure 6 shows the open circuit voltage $V_{oc}$=0.6 V of the ZnO / c-Si and 0.51 V of the c-Si; and these are very attractive values to produce high efficiencies of ZnO / c-Si (15.3 %) and (8.84 %) of c-Si solar cells.

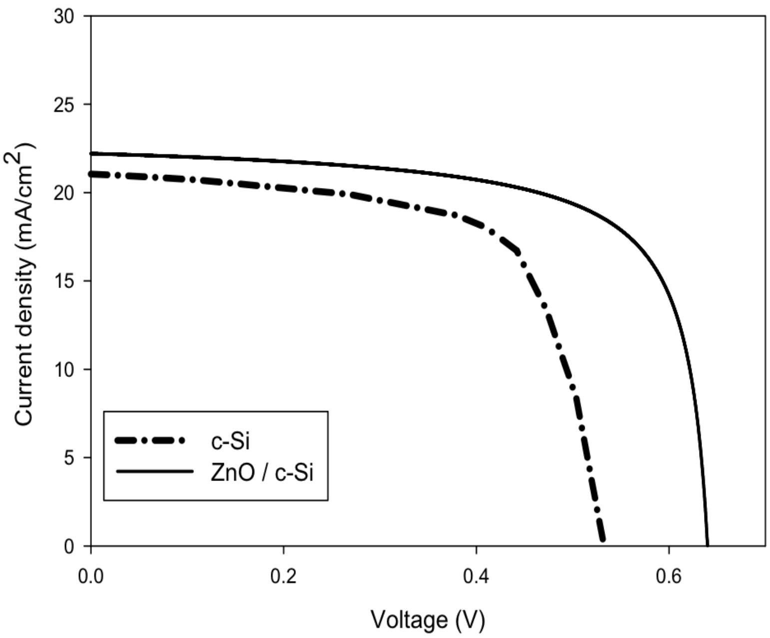


Figure 6:  Current density-voltage of ZnOand silicon as grown c-Si solar cell

Present work, in terms of voltage and current density of ZnO / c-Si, showed good results compared with the experimental work of c-Si as shown in Table 1.

**Table 1:** Fill factor and efficiency of c-Si and ZnO / c-Si under input power of 84 $mW/cm^2$.

| Samples | Vm (V) | Jm ($mA/cm^2$) | Voc (V) | Jsc ($mA/cm^2$) | FF | Effi% |
|---|---|---|---|---|---|---|
| c-Si | 0.46 | 16.14 | 0.51 | 20.2 | 72.1 | 8.84 |
| ZnO / c-Si | 0.5 | 30.48 | 0.6 | 32.66 | 77.3 | 15.3 |

## 4. References

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