Increasing efficiency of sensors based on ZnO nano-films

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Abstract

In this article, the sol-gel method is used to generate an Zinc Oxide (ZnO) thin film on a glass substrate at different annealing temperature. Using fractal analysis, the increase of annealing temperature on the characteristics of the surface morphology of ZnO thin films were calculated at different temperatures and the effect on the sensor morphology of ZnO thin films was studied. It was observed that with increasing annealing temperature, interface width and lateral correlation length decreases from 350˚C to 450˚C and increas from 450˚C to 550˚C, also roughness exponent is decreased. Finally the best temperature for sensors was 450˚C.

Keywords: Zinc Oxide (ZnO), thin film, sol-gel, morphology, sensor.

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1. Introduction

ZnO with wurtzite structure (HCP) because of stochiometry deviation due to extrinsic defects such as oxygen vacancy is a semi-conductor type and had very good electronic and optical properties. (Jordi, 2001)The energy gap of the material was 3.37 eV and its excitation energy of 60 electron volts at ambient temperature. ZnO thin films having a nanoscale microstructure, due to increased surface to volume ratio, will have very good sensory properties. (kireev, 1988-Y. Shimizu et al, 1999)

Using ZnO as a gas sensor was reported by Seiyama and colleagues in 1962. (Radecka et al, 1998) ZnO is one of the most applicable sensor metal oxide (MOS). (Wilwy et al, 1994) This material shows greater sensitivity than more gases in medium and high temperatures of 400-500. Among gases in which ZnO sensor sensitivity examined included hydrogen, LPG, CO, Methane, Ethanol, propanol, ammonia, oxygen, trimethylamine, benzene, acetone, toluene and xylen. (Radecka et al, 1998-Yamoze, 1991) Recently, ZnO has attracted more attention for the scientific communities as a material for the future. Studies on zinc oxide has been started since 1935 and more attention to this material in recent years have been paid due to the advancement of techniques for development and production of high-quality ZnO crystals that a factor is considered on the supply of electronics and optoelectronics based on this material. (Golshahi, 2010)

In this paper, ZnO thin films prepared by sol-gel method at different annealing temperatures were investigated and the effect of increasing the efficiency of sensors based on ZnO nanoparticles was studied.

2. Results and discussions

2.1. Describing Micromorphology of sensor surface based on ZnO nanofilms

Using a variety of methods in real space such as atomic force microscopy, one can obtain information on surface height. This information is usually numerical data analyzed by various methods, including the method of calculating root mean squares with deviation from the reference level. Root mean square is called deviation from the reference level or the interface width (w). (K Chu et al, 2006)

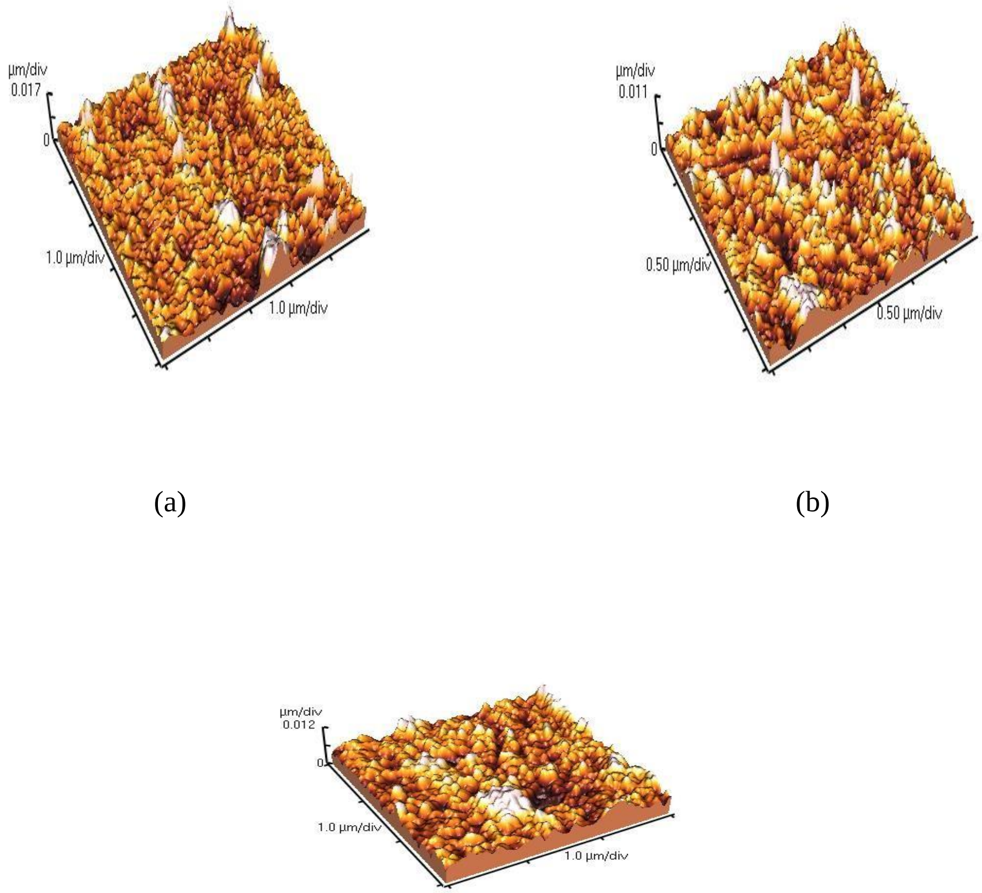
Where h(i,j), the height of the surface measured by AFM at the point (i,j), N×N the total number of points at which the surface heights have been measured then the interface width w (or rms) value of the surface roughness is defined as:

$$w=\frac{1}{N}\sqrt{\sum_{i,j=1}^{N}(h(i,j)-<h(i,j)>)^2} \qquad (1)$$

where <h(i,j)> is the average overall surface points:

$$<h(i,j)>=\frac{1}{N^2}\sum_{i,j=1}^{N}h(i,j)$$

The interface width (w) is used as part of quantitive analysis of AFM images to describe the morphology of surface.Figure (1) shows Three-dimensional AFM images of the films under study at different temperatures.



(a) (b)

(c)

Fig. 1. AFM image of ZnO thin films with 512×512 pixels at different temperatures (a) 350˚C, (b) 450˚C, (c) 550˚C.

2.2. Fractal analysis of ZnO thin films

It is well know that roughness parameters based on conventional theories depend on the sampling interval of the special measuring instrument used. By adopting the method of fractal geometry this problem is overcome, since the fractal models contain topography parameters which are independent of the resolution of the instrument used. (Jeng et al, 2003) The concept of fractal dimensionality, in contrast of traditional techniques, has proven very successful both I applying to a wide range of complex surface geometries and in advancing our understanding of how the geometry affects the physical properties of the system. (Pfifer et al, 1989) Several algorithms have been used to determine the value of fractal dimension D_f based upon AFM images. In order to study the fractal properties of ITO thin films, we computed from our AFM images the height-height correlation function.

Statistical analysis can quantitatively inspect the characteristics of the surface morphology and study kinetic growth process. Statistical characteristics can be described in details with the height-height correlation function H(r). If d the horizontal distance between two adjacent pixels then the height-height correlation function H(r) is calculated along the fast scarn direction (x direction) through the formula: (Sinha et al, 2004)

$$H_{exp}(r=md)=\frac{1}{N(N-m)}\sum_{j=1}^{N}\sum_{i=1}^{N-m}[h(i+m,j)-h(i,j)]^2 \qquad (2)$$

The height-height correlation functions were calculated by using the Eq. (2) from the AFM images with 512×512 pixels. In the calculation, m was set to be 128.

For self-affine surfaces, the dynamic scaling hypothesis suggests that the height-height correlation function H(r) has the scaling from:

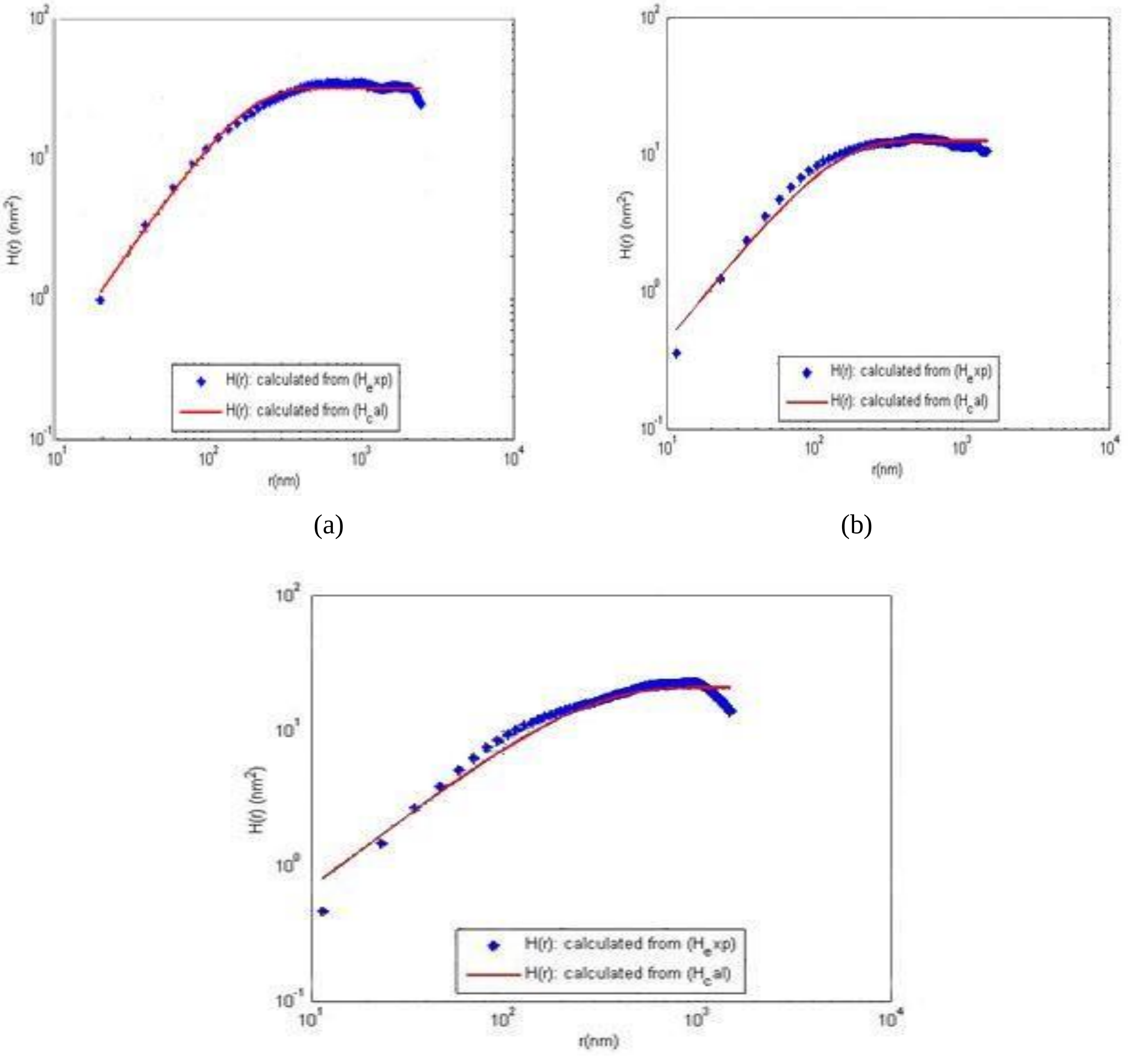
$$H(r)=\begin{cases} \rho^2 r^{2\alpha} & for\ r \ll \xi \\ 2w^2 & for\ r \gg \xi \end{cases}$$

Where is the average local slope, α the roughness exponent which describes how locally ‘wiggly’ the sample surface is, or to what degree the surface is randomly fluctuated in short range and ξ is the lateral correlation length which is defined as the largest distance in which the height is still correlated. The roughness exponent α is directly related to the fractal dimension D_f of the random surface by $D_f=E+1-\alpha$ with $0<\alpha<1$, where E+1 is the dimension of the embedded space (E=1 for a profile; E=2 for a plan). A larger value of α corresponds to a locally smooth surface structure while a smellier one corresponds to more locally jagged morphology. (H J QI et al, 2003-Ioannou-Sougleridis et al, 2004)

In the short-range scale, the ln-ln plot of the curve of ln H(r) with respect to ln r is a straight line, namely, H(r) is proportional to $r^{2\alpha}$. The roughness exponent α can be extracted from the fitting of H(r) in this scale (slope=2α). The plane section of curve is dependent on the interface width (w). The value of ξ can be obtained by fitting the curve of H(r) with the following equation: (Sinha et al, 1988)

$$H_{cal}(r)=2w^2\{1-\exp[-(\frac{r}{\xi})^{2\alpha}]\} \qquad (3)$$

Fig. 2. Shows the calculation and experimental height-height correlation function H(r) vs. position r for different annealing temperatures (350˚C, 450˚C and 550˚C) ZnO thin films.



(a)

(b)

(c)

Figure (2) shows experimental and calculation height-height correlation H(r) in terms of r for films annealed at temperatures a.350˚C, b.450˚C, c. is 550°C, that solid lines H(r) show calculation mode and marked lines H(r) show experimental mode.

By introducing error function representative the difference between experimental and calculation correlation function (equation (2) and (3)) and optimizing the error function that presents quantitive adaptation of the two graphs, one can achieve the physical parameters of surface such as ξ, α and w. The error function is defined as follows:

$$E=\frac{1}{N-1}\sum_{j=1}^{N}[logH_{exp,j}-logH_{cal,j}]^{2} \qquad (4)$$

Where N is the number of data point and $H_{cal,j}$ and $H_{exp,j}$ are calculation and experimental height-height correlation functions respectively.

Results of optimizing error function is indicated in table (1) As observed, H(r) shows linear area for a small quantity of r. This specifies that function follows power rule in the area. For r be enough great, the function reaches almost fixed value. Inflection point (Saturation point) determines lateral correlation length correlation. Observe that by increasing annealing temperature from 350˚C to 450˚C, plane section of curve for large values r with a small lateral correlation length and roughness quantity shift to displace to left and move down respectively. It indicates roughness surface of thin films by increasing annealing temperature from 350˚C to 450˚C. Conversely this temperature changes from 450˚C to 550˚C so that it is compatible with observation of AFM images. The results show that roughness exponent is in range of 0.66- 0.74.The interface width and correlation length for two modes reach to minimum value at temperature 450˚C and change in range of 2.47-3.98 and 178.35-121.86 respectively. By comparing results of table)1), it was observed that best value for sensors temperatures in terms of calculated parameters is 450˚C.

Table (1) Coarse level, coarse characteristic, and correlation length at different temperatures.

Annealing temperature (˚C)	ξ(nm)	W(nm)	α
350˚C	178.3545	3.9761	0.7446
450˚C	121.8569	2.4742	0.7247
550˚C	164.5961	3.1556	0.6610

3. Conclusions

Zinc oxide thin films were deposited by sol-gel method. Characteristics of surface morphology of ZnO thin films were calculated at different annealing temperatures and the effect of surface morphology of ZnO thin films on the solar cell was studied. Parameters of ZnO thin films at different annealing temperatures showed that by increasing annealing temperature from 350 to 450 C, plane section of curve for large values r with a small lateral correlation length and decreasing of roughness quantity shift to displace to left and move down and it indicates roughness surface of thin films by increasing annealing temperature from 350 to 450˚C and conversely it changes from 450 to 550 C. Finally the best temperature for sensors was 450˚C.

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