Sputtering Pressure Dependence of Zinc Oxide Thin Films Deposited on Teflon Substrate

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***Abstract*—We report on the characteristics of the Zinc Oxide (ZnO) thin films deposited onto polytetrafluoroethylene (Teflon) substrate by using radio frequency (RF) magnetron sputtering technique. The effect of deposition pressure on the structural, optical and electrical properties of ZnO thin film were investigated. The structural, optical, and electrical properties of the film were investigated by field-effect scanning electron microscope (FESEM), JASCO UV-VIS/NIR spectrophotometer, and current voltage (I-V) measurement respectively. The surface morphology reveals that deposited ZnO consists of nanoparticles. We found that the thickness and deposition rates of thin films were decreased. Also, the thin films showed the optical transmittance between range 45% to 85%. Optical measurements indicate the existence of band gap allowed optical transition with corresponding energy gap in the range of 3.28-3.34 eV. The sputtering pressure also found to affect the resistivity and conductivity of the ZnO thin films.**

Keywords:ZnO thin films, teflon substrate, RF magnetron sputtering, sputtering pressure, electrical and optical properties.

I. Introduction

Zinc oxide (ZnO) is a wide direct band gap (3.37eV) compound semiconductor [1, 2] of the II-VI semiconductor group with a hexagonal wurtzite crystalstructure [3] having large exciton binding energy (60meV) at room temperature [2-4]. ZnO is a semiconductor that has several properties including good transparency, high electron mobility, and strong room temperature luminescence [5,6].

Generally, the ZnO thin films deposited on flexible substrate have some special qualities including more rugged, thinner, light weight, and low process temperature. In particular, it also easy bending and resistant to impact damage except for favorable optical and electrical qualities [4, 7, 8]. At present, the flexible substrates that are normally used can be given as polycarbonate (PC), polyethersulfhone (PES), polyethylene naphthalate (PEN), polyethylene terephthalate (PET), polyimide (PI), poly propylene carbonate (PPC), and polytetrafluoroethylene (Teflon) [7-9]. In this work, we choose Teflon as our flexible substrates because it has more improved performance in the highest transmittance and lowest resistivity compared to other flexible substrates.

There are many techniques used to deposited ZnO thin films including thermal evaporation, molecular beam evaporation (MBE), chemical vapor deposition (CVD), sol-gel processing, pulsed laser deposition, direct current (DC) and radio frequency (RF) magnetron sputtering [10-15]. Among these growth methods of ZnO thin film, RF magnetron sputtering process is widely used to prepare thin films, which has advantages, properties of high deposition rate, good film adhesion and suitable method for the growth of uniform and transparent ZnO thin film [7, 12, 13, 16]. Besides that, RF magnetron sputtering is preferred due to its producibility of high quality films at lower substrate temperature a show as room temperature.

ZnO thin films is suitable for different practical applications such as transparent, conducting electrodes, sensors, solar cells, and thin film transistor (TFT) [17-19]. The films also have widely been used as surface acoustic wave devices (SAW) and bulk acoustic devices because of its strong piezoelectric effect [20, 21]. Previous studies in our group have successfully deposited ZnO on Teflon substrate at different temperature [9]. In this paper, the effects of the sputtering pressure on the ZnO thin films deposited on Teflon substrates are studied for its structural, optical and electrical properties.

II. Experiment Procedure

A. Substrate Cleaning

Before thin films deposition, the Teflon substrates were cleaned using the standard cleaning method. Thesubstrates were cleanedusingacetone, methanol, and deionized (DI) water byultrasoniccleanerfor10minutes each in sequence.

B. ZnO Thin Films Deposition

The RF magnetron sputtering system was used to deposit the ZnO thin films. ZnO (99.99%) was used as the target with the diameter of 4 inches and thickness of 0.25 inches. The sputter chamber was pumped to the background pressure of $5x10^{-4}$ Pa using a turbo molecular pump. During the sputtering process, the RF power was fixed at 200W while the substrate temperature was kept at 40°C [9]. Pure inert gas, Argon/Ar (99.99%) of 45sccm was inserted. The samples were deposited at different pressures varied from 5 to 15mTorr. The deposition was done in 1 hour.The sputtering conditions during the deposition of ZnO thin films are given in Table 1.

TABLE I. SUMMARY OF PARAMETERS DURING THE DEPOSITION OF ZnO THIN FILMS BY RF MAGNETRON SPUTTERING

Sputtering target	ZnO (99.99%) (4 inches diameter and 0.25 inches thickness)
Substrate	Teflon
Argon, Ar gas flow rate	45 sccm
Background pressure	$5x10^{-4}$ Pa
Sputtering pressure	5, 10, 13, and 15 mTorr
Heating temperature	40°C [9]
Sputtering power	200W
Deposition time	3600 sec

C. Characterization

The structural properties were characterized by using the field-effect scanning electron microscope (FESEM) and the thickness of the thin films were measured bysurface profiler. The optical properties, and electrical properties and were investigated by using JASCO UV-VIS/NIR spectrophotometer andcurrent voltage (I-V) measurement respectively. The summary of the overall process in this work is shown in Figure 1.

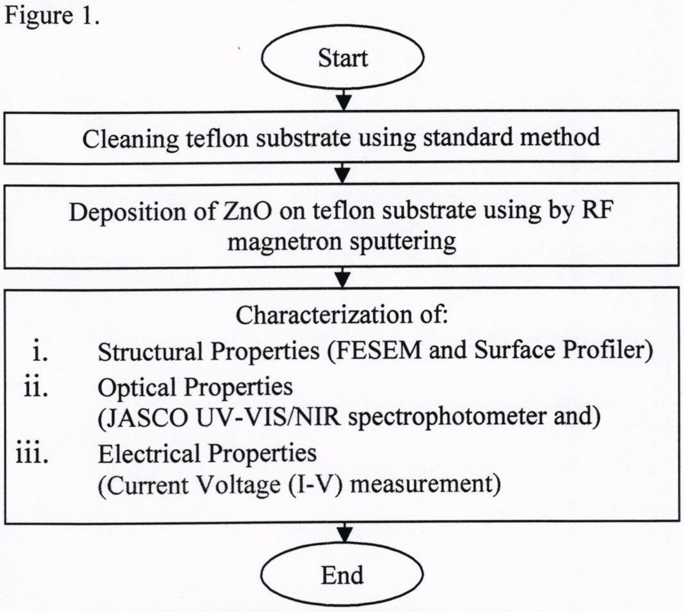
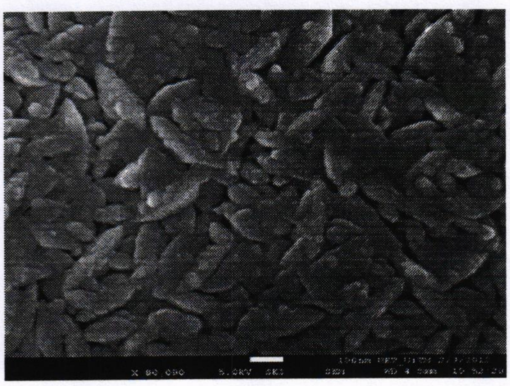


Figure 1 : Flow chart of thin films ZnO deposition process

III. RESULT AND DISCUSSION

(a)



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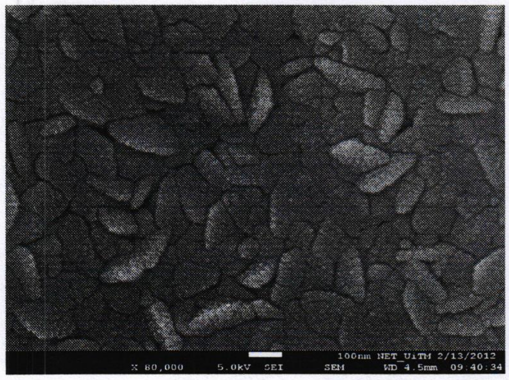

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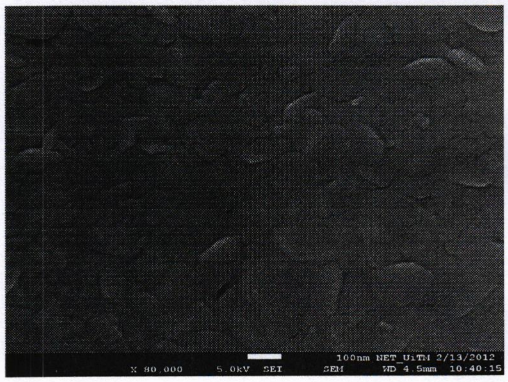

(d)

Figure 2 : FESEM images of deposited ZnO thin films at different substrate pressures (a) 5mTorr (b) 10mTorr (c) 13mTorr and (d) 15mTorr

Figure 2 (a), (b), (c), and (d) show that the FESEM images of the deposited ZnO films at the different pressures of from 5mTorr, 10mTorr, 13mTorr, and 15mTorr respectively. It shows that all deposited thin films consist of nano scale particles forming small compact grains. Figure 2(a) showed the sample deposited at 5mTorr exhibits columnar structured grains with quite relatively compact grains. When the sputtering pressure was increased,the size of the grains change to more expand and seen as rupture as shown in Figure 2(d). This might due to the high bombardment of the growing film surface by energetic particles transferring their energy and momentum to condensing ZnO species on the surface of substrate during sputtering process. Furthermore, the energy of particles arriving at the substrate is lower due to the large number of collisions [22].

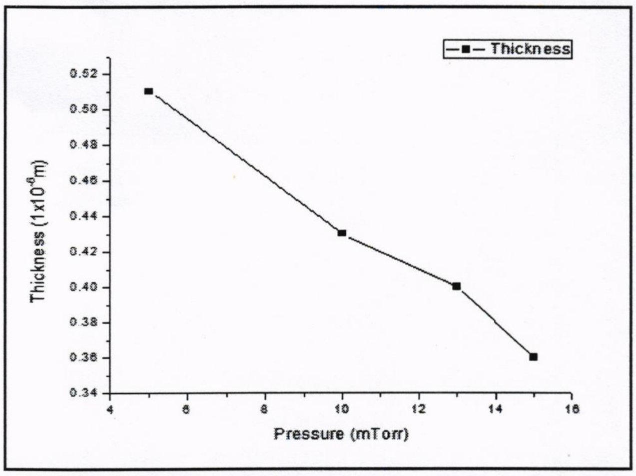

Figure 3 : Relation between thin films thickness (μm) and pressure (mTorr)

Figure 3 showed relation betweenthe thin films thickness (μm) and pressure (mTorr). It can be seen that the thickness of ZnO film decreases with increasing pressure. When the pressure increases, the zinc atoms generated by sputtering and the probability of the zinc atoms arriving on the substrate decreased. It indicates that at the higher pressure will result in a lower deposition rate and thickness which are 6.0 nm / min and 0.36 μm respectively as shown in Table 2.

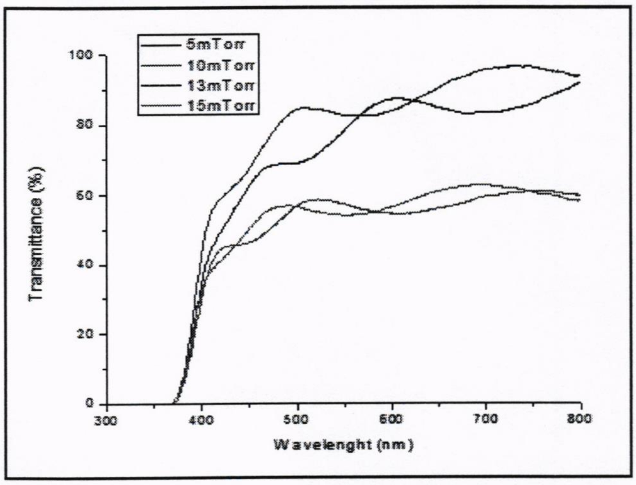

Figure 4 : Optical transmittance spectra of ZnO thin films deposited on Teflons substrate under varioussputtering pressures

The wavelength dependence of optical transmittance spectra of the ZnO films deposited at different pressure are shown in Figure 4. It indicates that the ZnO thin films have a transmittance in visible wavelength between 45% and 85% influenced by sputtering pressure although not having any specific specific trend. The absorption due to an interband transition of ZnO occurs in the wavelength range from 370nm to 800nm. The energy band gap of ZnO thin films was determined using absorption spectra with the help of relation:

$$(\alpha h\upsilon)^2 = A^2(hv - E_g) \qquad (1)$$

where α is the absorption coefficient, hυ is the photon energy, E_g is the optical energy band gap, and A is a constant [17]. From the measurement of the thickness and transmittance that were taken, the absorption coefficient, α can be obtained using the following formula:

$$\alpha = 1/t \ln 1/T \qquad (2)$$

where t is the thin film of thickness and T is the transmittance. Using this relation, the optical energy band gap, Eg can be determined using Tauc's plot by extrapolating the linear curve to the photon energy, hυ axis as shown in Figure 5.

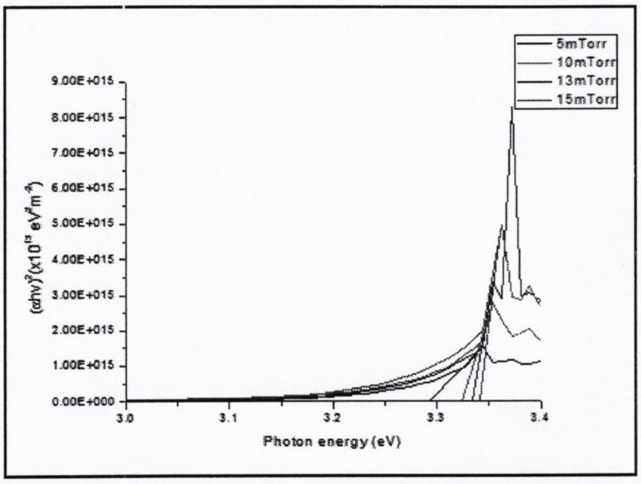

Figure 5 : Optical energy band gap of ZnO thin films deposited on Teflons under various sputtering pressures

The increase of the optical energy band gap with the increase in sputtering pressure is observed as shown in Table 2. The band gap increases from 3.28eV to 3.34eV due to the increase of crystallite size[23].

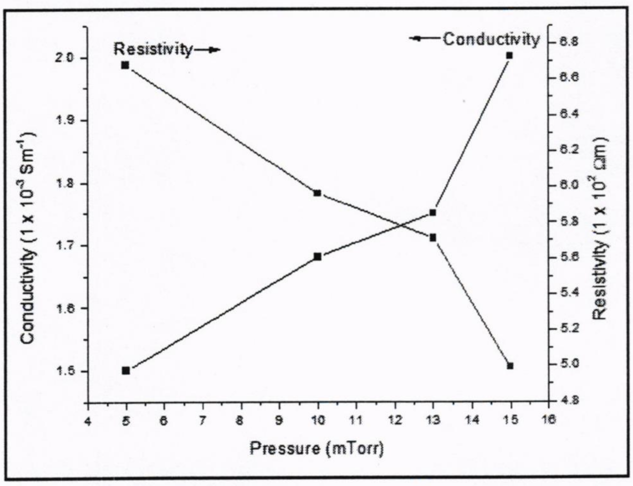

Figure 6 : Relation between conductivity (1×10^{-3} Sm^{-1}), resistivity (1×10^{2} Ωm) and pressure (mTorr)

The conductivity and resistivity of the deposited ZnO thin films is shown in Figure 6 calculated from the equation (3) below.

$$\rho = \left(\frac{V}{I}\right)\left(\frac{wt}{l}\right) = \frac{1}{\sigma} \quad (3)$$

where ρ is the resistivity, σ is the conductivity, V is the applied voltage, Iis a current measurement, t is the thin films thickness, *w* is the electrode width and *l* is the length between electrodes. It can be seen from Figure 6 that the conductivity of the thin films increases as the pressure increases. The conductivity and resistivity calculated for sample of 15mTorr was to be about 2.00 x 10 $^{-3}$ Sm $^{-1}$ and 4.95×10 ^{2} Ωcm respectively. Table 2 shows the results of characteristics information of the deposited ZnO thin films.

TABLE II. SUMMARY OF ZNO THIN FILMS CHARACTERISTICS DEPENDENCE ON THE SPUTTERING PRESSURE

Sputtering Pressure (mTorr)	Thickness (1×10^{-6} m)	Deposition Rate (nm/min)	Conductivity (1×10^{-3} Sm^{-1})	Resistivity (1×10^{2} Ωm)	Bandgap (eV)
5	0.51	8.5	1.50	6.68	3.28
10	0.43	7.2	1.68	5.96	3.32
13	0.40	6.7	1.75	5.71	3.33
15	0.36	6.0	2.00	4.99	3.34

IV. CONCLUSION

In conclusion, this work reported the effect of the sputtering pressureon the characteristics of ZnO thin films deposited on Teflon substrate. From the results, the structure of the deposited films was found to be microstructure consisting of nanoparticles. The shape of the nanoparticles change and the size is seen to expend with the increasing pressures whereas the thickness decreases. The transmittance of the thin films showed no trend regarding to the pressure which ranged from 45% to 85%. The optical bang gap shows as little increment with the increasing pressure. The conductivity increases with the increasing sputtering pressure with the highest conductivity and the lowest resistivity is2.00 x 10 $^{-3}$ Sm $^{-1}$ and 4.95×10 ^{2} Ωcm respectively. In order to produce better optical and electrical properties, the dopant process with certain materials such as aluminium, Al or Vanadium, V need to be done in conjuction with the ZnO thin films applications in future.

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