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Characterization of ZnO Thin Film as Piezoelectric for Biosensor Applications

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Abstract: Biosensor is an analytical device that consists of immobilized biological sensitive materials. When these materials are in contact with certain transducers, the sensor is able to convert biological signal into an electrical signal, hence allowing for certain measurement to be conducted. These sensors have the capability to detect certain human traits such as DNA, tissues, enzyme, antibody and antigen. To increase the biosensor performance, especially the interaction between the sensor and biological elements, high uniformity and good optical transmittance sensors are strongly important. Therefore, this paper will presents early characterization of biosensors using Zinc Oxide (ZnO) piezoelectric thin film deposited as sensing layer on Silicon substrate. We investigated the thin film surface morphology and optical characterization using Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), and UV-Visible Spectrophotometer. We found that the surface roughness of the thin film varied from 1.1 NM to 4 NM and the grain size increased with the increase of annealing temperature, thus provide high surface uniformity that will enhance the sensitivity and specificity of the sensor.

Keywords: biosensor; piezoelectric; ZnO, sensitivity

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1. Introduction

As we know, DNA cannot be observed by the naked eye, smell or tasted by human being. Therefore, a small scale device such as biosensor is needed to characterize the DNA structure. There were various types of biosensor developed over the few decades. The detection methods used for most of this biosensor are based on electrochemical, optical, fluorescent and acoustic wave technique [1]. Among all the mechanism, optical and electrochemical based biosensor is said to be the most widely used in current biosensor applications. However, these conventional biosensors have several disadvantages such as high complexity, less sensitivity and high cost of performing an analysis. To overcome this problem, the technique and mechanism choose in constructing the biosensor is very important.

When compared to their competition, acoustic wave biosensors which is based on piezoelectric mechanism is said to more versatile, highly sensitive, reliable, reusable, and small, and easily designed. In terms of thin film application in developing the sensor, ZnO has been proved to be more suitable due to the good electrical and optical properties and also lower cost material in comparison to ITO (Indium Thin Oxide). Therefore, the project will focus on the preparation of the ZnO thin films as piezoelectric layer prepared by sol gel technique [2]. All these developments have been made with a view to achieve higher sensitivity, smaller device size, reliability, and low cost device.

2. Experimental Section

Figure 1. Process Flow of the Experiment

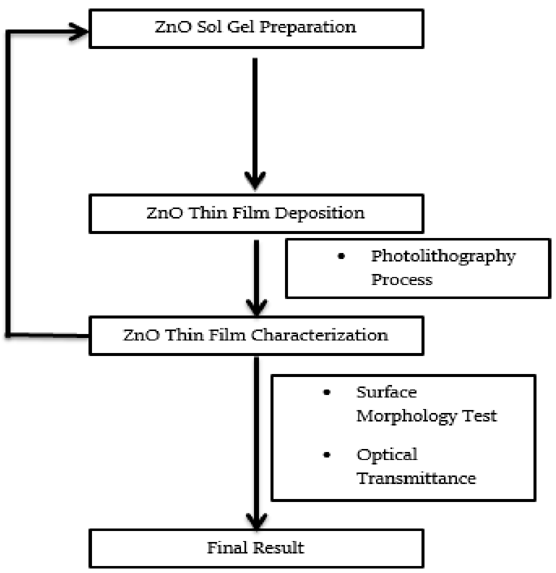


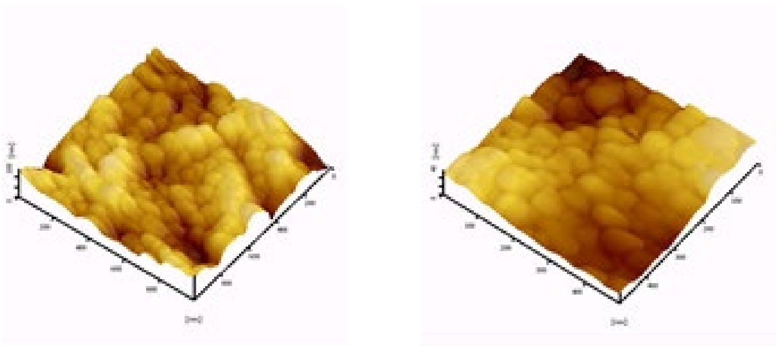
Figure 1 shows the process flow of the procedure required in conducting the experiment. The ZnO thin films were deposited onto wafer substrate by a sol gel through spin coating technique. The mixture of Zinc Acetate Dehydrate (ZAD) as the main precursor, 2-Methoxyethanol as the solvent and MEA as the stabilizer were used in the sol gel preparation. 20ml of 2-Methoxyethanol were stirred and heated with 0.878g ZAD powder at 60^{0}c and 1000rpm for 20 minutes. The MEA was then added drop by drop until the solution becomes transparent and clear. After that, the solution was kept at room temperature for 24 hours before it can be used. The wafer is first cleaned using RCA 1 and RCA 2 as well as DI water to completely remove the contaminations such as dust or particle. After that, the wafer will undergo oxidation process before being placed inside the spin coater for the next steps. The sol gel solution will be dropped on top of the wafer sample for the coating purpose. Note that, the quantity of the sol gel dropped is depending on the sample sizes. After the spinning is done, the sample will undergo the soft bake and hard bake to make sure the ZnO thin films are fully stick on top of the wafer sample surface. The sample will be annealed with temperature 300^{0}c and 500^{0}c for 2 hours. The steps will be repeated until the desired thickness is achieved and the characterization can be executed.

3. Results and Discussion

3.1. Surface Morphology

Figure 2 shows the image of Atomic Force Microscopy (AFM) for the ZnO thin film prepared by the sol gel method and annealed at 300^{0}C and 500^{0}C respectively. The scanning scales for the entire sample were taken from 0.5µm × 0.5µm to 1µm × 1µm and the images obtained were composed to 512 × 617 pixel dimensions. From the observation, image (a) shows the island surface structure with the thickness of 100nm while image (b) shows the homogenous surface structure with the thickness 40 nm. The grain sizes and root mean square (rms) were observed using the AFM surface analysis as shown in the Table 1 below. The RMS value shows good agreement from previous study with approximately ~4nm and the value also increase with the increasing of the annealing temperature for both cases [3]. The average roughness (R_a) indicate the surface of the thin film more corrugate with annealing temperature 300^{0}c as compared to 500^{0}c.

Figure 2. 3D image of Atomic Force Microscopy (AFM) annealed at **(a)** 300^{0}C. (**b**) 500^{0}C.



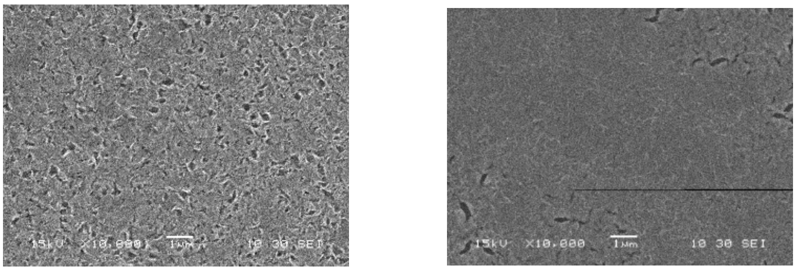
(a) (b)

Table 1. The parameter of ZnO thin films annealed with different annealing temperature.

Solvent	Annealing Temperature (^{0}C)	Mean Diameter of Grain Size (NM)	Root Mean Square (RMS) (NM)	Average Roughness, R_a (NM)
2-Methoxyethanol	300	5.07	1.701	1.314
2-Methoxyethanol	500	5.97	4.539	3.579

The annealing temperature is important in order to produce a homogenous surface structure. SEM images in Figure 3 show that the particular structure becomes larger and denser as the annealing temperature is increased. These results also strengthen the previous study on the effect of the annealing temperature to the morphological structure of the ZnO thin films that state the similar achievement [4]**.** In detail, the increasing in annealing temperature resulting in the higher of the packing density of the ZnO thin films which may be due to the disappearing gap between particles [2]. The surface seems to be exhibiting the kind of fiber stripe particle while annealed at 300^{0}c and at 500^0**c** provides great flatness of surface structure. Several studies have been conducted similar to the cross sectional observation of the thickness and some identification of the nano-void and nano-pores which may diminish the physical quality of the thin films [5].

Figure 3. (**a**) SEM image of ZnO thin film annealed at 300^{0}C. (**b**) SEM image of ZnO thin film annealed at 500^{0}C.

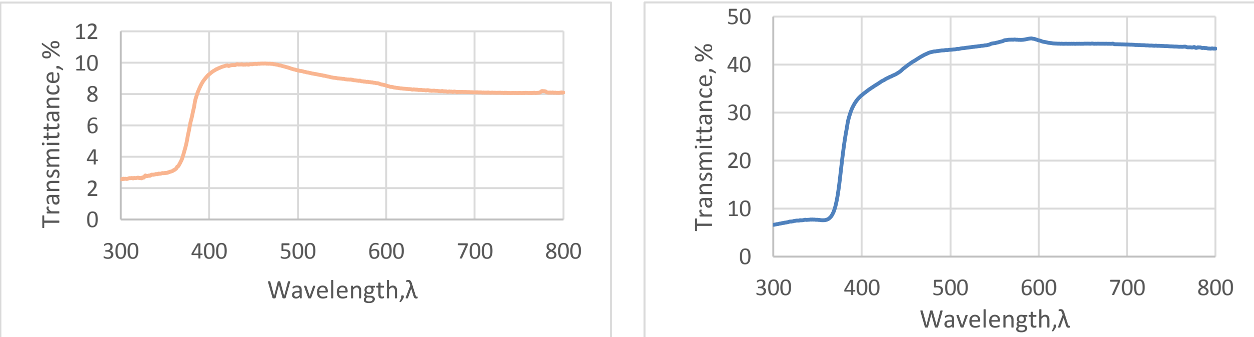


(a) (b)

3.2 Optical Transmittance

Figure 4 below presents the ZnO thin film transmittance spectra heat treated with different annealing temperature. The range of the wavelength is taken from 300nm to 800nm. From the graph, the potential cutoff wavelength takes place from 370nm – 385nm. Both graphs exhibited sharp absorption edge at the cutoff wavelength range. This phenomenon happens because at the cutoff wavelength, the ability of the electron of the valence band to move to the conduction band increased resulting in an extreme drop off wavelength. The result obtained also proved that at the range of UV region (200nm – 400nm), the transmittance wavelength will decrease dramatically resulting in sharp absorption edge [5]. As observed from both graphs, the thin film generated great optical transmittance which is 45.2% with thin film annealed at 500^0C. However, the ZnO thin film annealed at 300^0C shows the lowest optical transmittance. This is due to the fact that the thin film was unable to absorb great optical transmittance because of high surface roughness. This result strengthens the theoretical explanation about the surface roughness discussed from the previous section and the effect of the surface roughness with the ability to absorb great optical [5].

Figure 4. ZnO thin films transmittance spectra annealed (a) 300^0c, (b) 500^0C.



(a) (b)

4. Conclusions/Outlook

The thin films of ZnO piezoelectric has been successfully prepared with sol gel technique. All samples exhibited acceptable results with different annealing temperature. Almost all of the parameters with an annealing temperature of 500^0c show good agreement with the previous study which contributes planar surface of thin film with average roughness of 3.5 NM. Even though the transmittance spectra shows low level of transparency, the potential cut off wavelength still takes place between 370nm – 385 NM which is the usual cutoff wavelength of ZnO.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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