

INFLUENCE OF SUBSTRATE MATERIALS ON THE STRUCTURAL PROPERTIES OF ZnO THIN FILMS PREPARED BY RF MAGNETRON SPUTTERING

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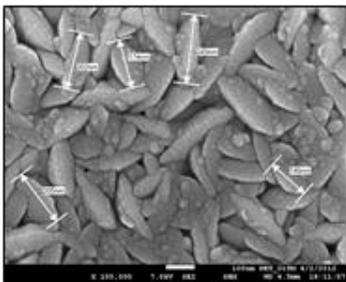
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Graphical abstract



Abstract

ZnO films were deposited on glass and SiO₂/Si substrate by RF magnetron sputtering technique using high purity ZnO target at various RF power. The structural properties of ZnO thin film deposited on glass and SiO₂/Si substrate were studied. The structural properties of the films were carried out by the surface profiler and field emission scanning electron microscope (FESEM). It was found that the average grain size of ZnO increases with increasing RF power and ZnO deposited on SiO₂/Si substrate with RF power between 50-150 Watt gave the lower average grain size which is desired for the gas sensor applications.

Keywords: ZnO thin films, RF magnetron sputtering, substrate materials, structural properties

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1.0 INTRODUCTION

The common substrate materials used for gas sensor applications are glass [1, 2] and silicon [3]. In order to deposit nanostructured ZnO for gas sensor applications, a proper selection on the substrate material used is crucial in order to get a high quality ZnO thin film. The difference in lattice parameter and crystalline structure between the substrate and ZnO films also may affect the growth behaviour of ZnO films [4].

There are various types of glass which includes quartz, fused silica and borosilicate glass [5]. Glass is transparent therefore it is particularly used for devices

with optical detection principles. Furthermore glass is chemically inert therefore it is well suited to be used for high temperature application. Chaabouni *et al.* [6] made comparison on the sensitivity of ZnO gas sensor on glass and silicon substrate. They reported that the sensitivity of ZnO based gas sensor deposited on glass substrate is higher compared to the ZnO gas sensor grown on silicon substrate. The reason is that ZnO thin film deposited on amorphous substrate has higher surface roughness.

Silicon on the other hand has an excellent mechanical properties and open the possibilities of the device for the integration with the integrated circuit (IC)

technologies for the possibilities of miniaturization [7] or integration with electronic circuitry [8]. Silicon is also considered as a cheap substrate [9, 10] and well lattice matched with ZnO [11]. Jin *et al.* reported the deposition of aluminium doped ZnO on silicon substrate [12]. Wang *et al.* also reported the deposition of ZnO on silicon by RF magnetron sputtering method and found that ZnO deposition on silicon gives smooth surface and good adherence [13].

In this paper the effect of substrate material on the structural properties of the deposited ZnO films deposited at various RF power were studied. Selection of substrate material is important to determine the quality of the ZnO active layer for gas sensor application. The best substrate material that gave the lower value of grain size will be suggested since a lower grain size material produced a higher sensitivity value of gas sensor.

2.0 EXPERIMENTAL METHOD

Two types of substrates were used in this research namely the microscope glass and p-type silicon. The microscope glass has a thickness of ± 1.0 mm whereas p-type silicon wafer has a thickness of 525 ± 25 μm , resistivity of 1-10 ohm.cm and orientation of (100). Glass substrate was subjected to ultrasonic cleaning using acetone, followed by cleaning with methanol and distilled water whereas the silicon substrates were subjected to cleaning process using acetone, methanol and diluted hydrofluoric acid. Later thermal oxidation of Si substrates was done to develop SiO₂ layer on p-Si. The ZnO thin film was subsequently

deposited onto the glass and SiO₂/Si substrate using high purity (99.999%) ZnO target. During the growth, argon (Ar) gas (99.99%) was introduced into the reaction system and the Ar flow rate was kept at 45 sccm. The pressure inside the chamber and the total sputtering time were at 8 mTorr and 60 min respectively. The RF power used varies from 50 to 250 Watt. After the deposition, the samples were annealed at 500°C for 1 hour and with 1L/min oxygen flow rate. The thickness of ZnO thin films was measured using surface profiler (Dektak 150+). A JEOL JSM-7000F field emission scanning electron microscope (FESEM) operating at 5 keV was used to characterize the morphology of the deposited ZnO thin films.

3.0 RESULTS AND DISCUSSION

The average thickness and deposition rate of ZnO thin film deposited on different substrate is shown in Table 1. It was observed that for both types of substrate (i.e. glass and SiO₂/Si), the thickness and deposition rate were increased with the increased of RF power. Similar trend were reported by Son *et al.* [14], who stated that deposition rates of the films increased with the increasing sputter power. This phenomenon can be explained by the fact that the number of the sputtered ZnO molecules at the target surface increases due to the enhancement of bombardment by argon ions as RF power increased [15]. Moreover, the kinetic energy of the ZnO molecules arriving at substrate increases with increasing RF power [16].

Table 1 The average thickness and deposition rate of ZnO thin film on glass and SiO₂/ Si substrate

RF power (watt)	Thickness (nm)		Deposition rate (nm/min)	
	Glass	SiO ₂ /Si	Glass	SiO ₂ /Si
50	85.92	74.37	1.43	1.239
100	159.54	155.91	2.66	2.60
150	249.18	390.23	4.15	6.50
200	335.51	467.02	5.59	7.78
250	567.55	629.04	9.46	10.48

Figure 1 shows the selected micrographs of the ZnO thin films deposited on glass and SiO₂/Si substrate. In overall it was found that the surface morphology appears to be sensitive to RF power since different surface morphologies exist in every sample. As the RF power increases it was found that the spherical shape grains transform to a combination of spherical and flakes like shape grain which is undesirable for the gas sensor applications. As the RF power increases also,

the length of the flakes like shape grain increases. Kim *et al.* also found that the grain size of ZnO increases with the increased of RF power [17]. This is might be due to a slight increase in temperature as the RF power used increased. The temperature increased provides energy for the grain growth. The summary of the grain size measured by FESEM is shown in Table 2.

It was found that with increasing RF power the average grain size increases. The reason is that when

RF power increases, the thickness and the substrate temperature also increases. These two effect favor the grain growth of ZnO [18]. It was noticed also that as the RF power increases, the microstructure start to form a combination of small sphere and large flake particle. Higher RF power will induce a higher deposition rate and with the increase of deposition rate, the nucleation site also increases. This nucleation site is as much as the deposition rate therefore the grain size shrink and form a small particle. On the other case, the already deposited particles obtain more kinetic energy as the RF power increases and thus

causes the grain to get bigger [19]. This phenomenon explains the combination of small and large particles existence in samples deposited with a high RF power. It is also observed that regardless of substrate material used, the size of ZnO grain size increased with the increased of RF power used. In this work, the purpose of getting a smaller grain size ZnO thin film is to increase the sensitivity of gas sensor. It was reported by few researchers that the use of nanostructured materials can rapidly increase the sensitivity of gas sensor [20-22].

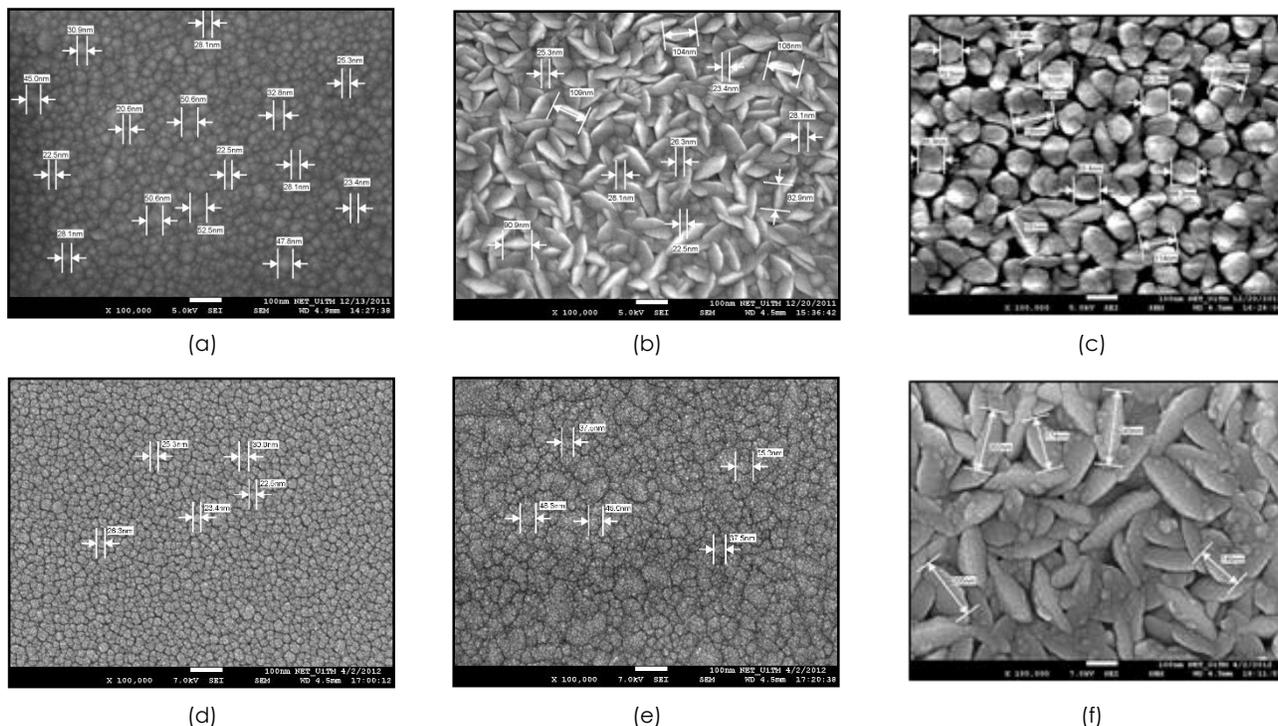


Figure 1 Selected micrographs of ZnO thin film deposited on glass ((a)50 Watt, (b) 150 Watt, (c)250 Watt) and SiO₂/ Si Substrate ((d)50 Watt, (e) 150 Watt, (f)250 Watt) (Magnification: 100k and Acceleration Voltage: 5&7 keV)

Table 2 Average grain size measured by FESEM for ZnO deposited on different substrates

RF power (watt)	Average grain size by FESEM (nm)	
	Glass	SiO ₂ /Si
50	33.91	25.50
100	47.59	29.26
150	62.12	33.96
200	87.75	107.31
250	103.47	161.60

4.0 CONCLUSION

ZnO thin films were prepared by RF magnetron sputtering method at various RF power on two different substrate namely glass and SiO₂/Si substrate. From the structural study, it was found that with increasing RF power the thickness of ZnO layer and the average grain size increases. It was also concluded that ZnO deposited on SiO₂/Si with RF power variation from 50-150 Watt gave the lower grain size value. Since the sensitivity of gas sensor is highly dependence on the surface reaction effect therefore ZnO thin films deposited onto SiO₂/Si substrate with RF power between 50-150 Watt that produce a smaller grain size ZnO was suggested to give a higher sensitivity value. However further investigation is needed to prove this statement and the results will be reported elsewhere.

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