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Study of the Substrate Effect on the Microstructural Properties of Zinc Oxide Thin Film

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Abstract: Nanostructured zinc oxide (ZnO) thin films are synthesized on silicon as well as glass substrate using RF sputtering technique. The substrate temperature during deposition is varied from room temperature to 200 ^{o}C. The chamber pressure during deposition is kept constant at 20 x 10^{-3} torr. The scanning electron microscope (SEM) and atomic force microscopy (AFM) is used to study the influence of substrate on microstructural and morphological properties respectively. As the substrate temperature increases from room temperature to 200 ^{o}C the grain size on silicon substrate is increases from 35 to 57 nm while there is no signification variation is observed in grain size on glass substrate. The smoothness of surface is measured in terms of average roughness value using atomic force microscopy. The average roughness value of deposited ZnO thin film on silicon substrate varies from 2.88 nm to 2.53 nm while it varies from 2.09 nm to 2.39 nm on glass substrate as substrate temperature varies from room temperature to 200 ^{o}C. The minimum average roughness on silicon and glass is obtained at 100 ^{o}C and at room temperature respectively.

Keywords: Zinc Oxide, R.F. Magnetron Sputtering, Substrate Temperature, Morphological, And Microstructural Properties.

1. Introduction

Zinc oxide (ZnO) is wide band gap semiconductor (approx.3.4ev) and it also contains large exciton binding energy approx. 60 meV at room temperature [1]. ZnO is available in three different types of crystal structure. Wurtzite structure is thermodynamically stable under ambient conditions while Rochelle salt structure can be obtained at comparatively high pressure. The zinc blended structure is only stable by growth on cubic structure [2]. ZnO is extensively studied and widely used material for different types of applications including photocatalyst [3-4], optoelectronics [5], nanogenerator [6], because of its commendable properties. It is also use as transparent conducting electrode in flat panel display because of its transparency to visible light [7] and as gas sensor [8]. Zinc oxide is second largest used material for gas sensing applications after tin oxide as reported by Giovanni Neri [9]. It is not only used as gas sensor but it's also used as bio sensor [10-11] because of its bio compatibility. Several techniques for synthesis of ZnO thin films are reported by various researches. However the commonly used methods are r.f sputtering, chemical route for synthesis, thermal oxidation PLD. These studies show that the ZnO properties extensively depend upon the method and deposition conditions. However sputtering process is used widely because it is not only compatible with CMOS process but it is also used for synthesis of uniform properties film with desired orientation. In the present work an attempt is made to study the influence of substrate temperature on microstructural and morphological properties of ZnO.

2. Experimental Procedure

2.1 Silicon Wafer and Glass Substrate Cleaning

The cleaning is one of important step prior to thin film synthesis. In this work glass and p-type silicon wafer are used as a substrate to analyze its influence on deposited thin film properties. In the first step of substrate degreasing, the glass and silicon substrate are kept in teflan boat and heated on hotplate in the presence of TCE (trichloroethylene) at 75^{0}C for 30 minutes for removing oily and greasy components which is commonly present during the silicon wafer production. For removing hard ions and trichloroethylene residues the substrates are heated on hotplate at in acetone at 75°C for 30 minutes. In the last step, the substrate is heated for 30 minutes in the methanol for removing remaining residues and soft ions. The piranha solution i.e. mixture of H_2SO_4 and H_2O_2 in ratio of 3:1 is used for substrate cleaning after .substrate degreasing. The hydrofluoric acid (HF) is used to remove native oxide layer from silicon. Lastly substrates are cleaned using DI water and heated at 120 ^{o}C in oven prior to deposition.

2.2. ZNO Thin Film Deposition

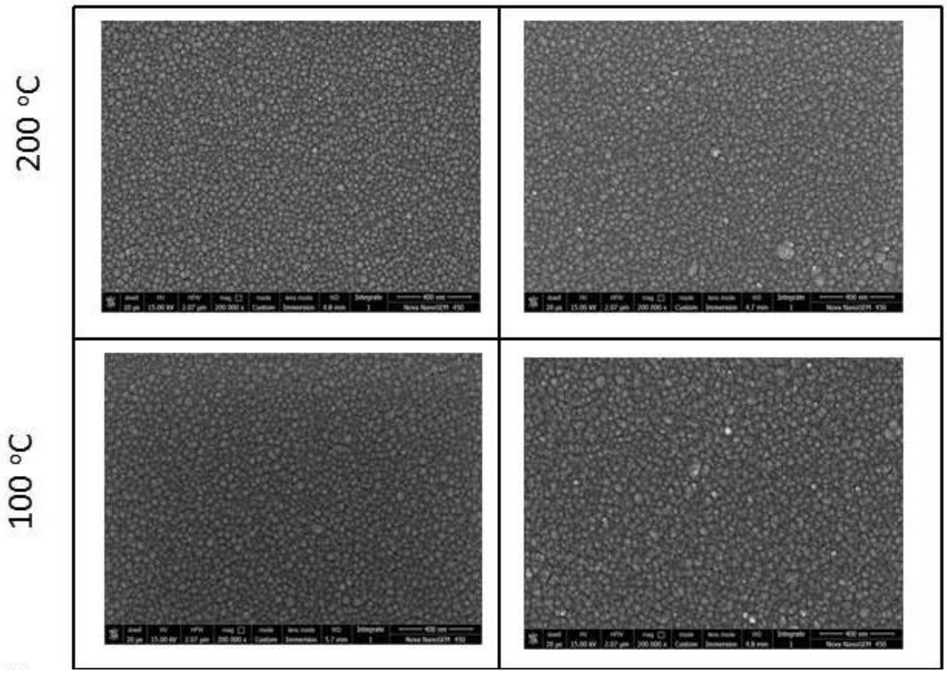
The sputtering procedure is commenced by evacuating the chamber to pressures lower than 5 x 10^{-5} torr. Turbo molecular pump backed by a rotary pump is used for evacuation. Same rotary pump is also used to get the roughing vacuum inside the chamber before connecting the turbo molecular pump. Once the chamber has reached ultimate vacuum, it is flushed with high purity argon (99.99%) many times to drive out any trace of the residual gases inside the chamber. Argon is regulated at 30 sccm by mass flow controller and oxygen is allowed inside the chamber and maintained at 21 sccm for reactive sputtering. The pressure inside the chamber is maintained at 20 x 10^{-3} torr. The magnetron target assembly is mounted in horizontal configuration. A high purity (99.99%) ZnO target is used for the sputtering. The pre sputtering time is kept about 10 minutes in order to clean the target surface from debris and deposits a fine layer of zinc oxide on the chamber walls thus preventing further contamination due to outgassing from the surface. It also stabilizes the flux or sputtering rates of species from the target and particularly, if the target is a composite as in the case of zinc oxide target. The sputtering conditions for the growth of ZnO films are elucidated in Table 1. The sputtering time for the deposited films is kept constant at 60 min while the substrate temperature is varied room temperature to 200 ^{o}C. The films microstructure is studied using FESEM (NOVA) while films morphologies are analyzed using Bruker make atomic force microscopy (AFM).

r.f power	**400 W**
Operating pressure	20 mtorr
Substrates	p-type silicon <100> with resistivity 4Ω.cm
	Glass
Oxygen flow rate	21 sccm
Argon flow rate	30 sccm
Pre sputtering time	10 minutes
Sputtering time	1 hr.
Target	Zinc oxide
Target Purity	99.9%
Experiment	ZnO thin film is deposited on glass and silicon substrate by varying substrate temperature from room temperature to 200 ^{o}C.

Table 1 Deposition Conditions for Zinc Oxide Thin Films

2. Results and Discussion

Zinc oxide microstructure is studied using FESEM (NOVA). Microstructure of the deposited films is determined using scanning electron microscopy (SEM). Fig. 21 (a) –(c) shows the SEM image of the ZnO deposited at room temperature, 100 ^{o}C and 200 ^{o}C respectively on different substrates namely silicon and glass. It shows that all deposited films consist of spherical grains and all grains are uniformly distributed across the surface.



(a) (b)

Fig. 1 SEM micrograph for the zinc oxide films deposited at different temperature (a) Silicon (b) Glass

The morphology of the deposited microstructure is determined using Bruker atomic force microscopy (AFM). Fig. 2 (a) - (c) shows the AFM surface morphology of ZnO deposited at room temperature, 100 ^{o}C and 200 ℃ on different substrates namely silicon and glass. The average roughness is calculated using AFM. Fig. 23 shows the relation between substrate temperature and roughness.

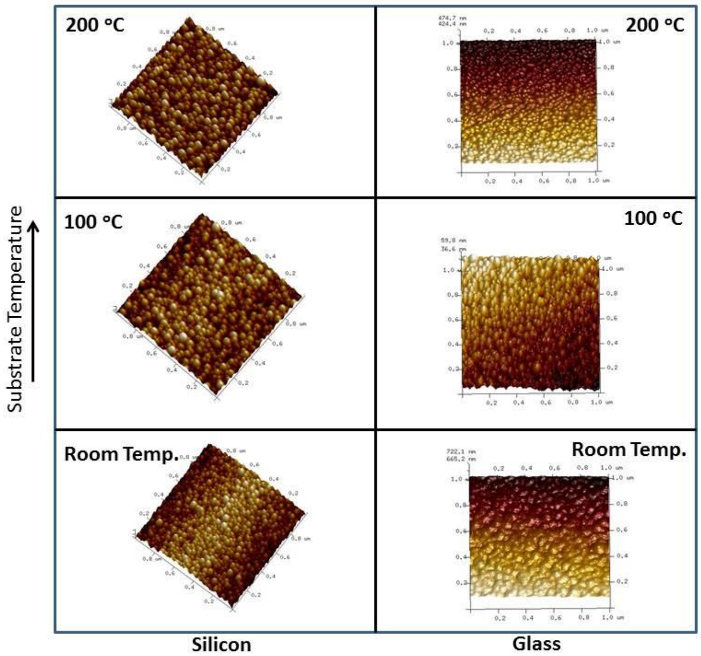


Fig. 2 AFM Micrograph of Zinc Oxide Microstructure on Different Substrate with Different Substrate Temperatures (A) Room Temperature (B), 100 ^{O}c And (C) 200 ^{O}c

It reveals that for structure deposited on silicon, as the substrate temperature during deposition increases the average roughness value decrease which shows that high temperature favours the smoother surface while opposite trend is observed for structure deposited on glass. However further increase in substrate temperature the roughness increases. Similar results for structure deposited on silicon are reported by Shufang Wang *et al [25].* Minimum value of average roughness 2.17 nm for sample deposited on silicon is obtained at 100 ^{o}C.

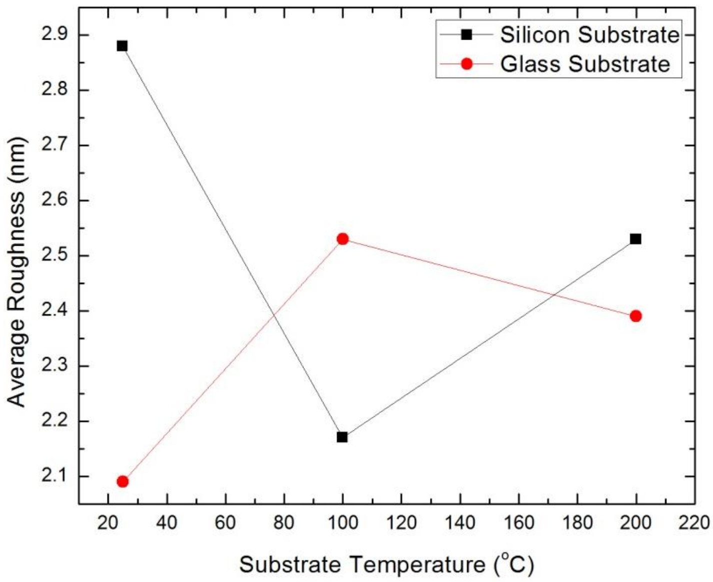


Fig. 3 Dependence of Surface Roughness on Substrate Temperature

The grain size of ZnO nanostructure is determined using AFM. Fig 4 shows the relation between grain size and substrate temperature and it shows that as the substrate temperature increases the grain size also increases for film deposited on silicon substrate while there is no significant variation in grain size for the film deposited on glass substrate. Smallest grain size of 35 nm is obtained for the film deposited on silicon substrate at room temperature. The grain size of the film increases with substrate temperature for silicon substrate during deposition because adatoms mobility also increases with temperature. The rise in adatoms mobility with temperature allows their deposition at more thermodynamically stable site which results grain size increases. Similar observation for tin oxide films on silicon substrate is reported by shobi *et al* [26].

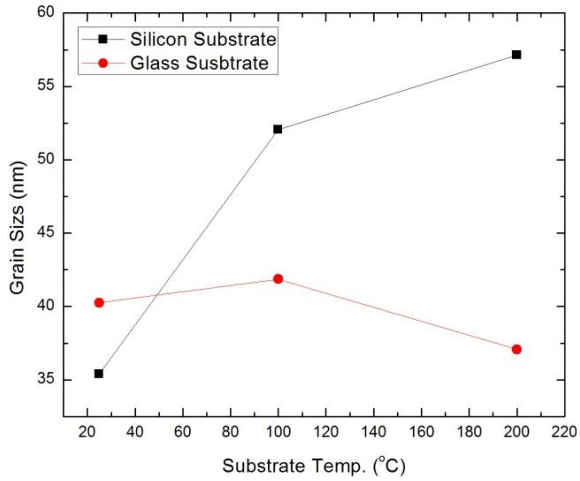


Fig. 4 Dependence of Grain Size on Substrate Temperature

3. Conclusion

Zinc oxide thin films are deposited by varying the substrate temperature using reactive r.f. sputtering. The deposition temperature during deposition is varied from room temperature to 200 °C while the sputtering time is kept deposition time constant at 60 min. The morphology of the film is determined using SEM and AFM. SEM results reveal that all deposited films consist of spherical grains and all grains are uniformly distributed across the surface. The grain size and surface roughness of the deposited films are determined using AFM. The grain size of the deposited films increases with increase in grain size. Smallest grain size of 35 nm is obtained for the room temperature deposited film. AFM results show that the average value of roughness varies from 2.88 nm to 2.53 nm for the film deposited at room temperature and 200 ^{o}C i.e. surface roughness can be tuned by varying deposition temperature.

4. References

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