A Feasibility Study of Nano-grained ZnO Piezoelectric Thin Film Fabrication

Ruirui Zhang, Eunju Lee and Giwan Yoon, *Non-Member, KIMICS*

Abstract— C-axis-oriented ZnO thin films were successfully deposited on p-Si (100) in an RF magnetron sputtering system. Deposition conditions such as deposition power, working pressure, and oxygen gas ratio $O_2/(O_2+Ar)$ were varied. Crystalline structures of the deposited ZnO films were investigated by a scanning electron microscope (SEM) technique. Results show that the deposition parameters can have a strong impact on the preferred orientations and grain sizes of the deposited ZnO films.

Index Terms— C-axis orientation, Grain size, RF Magnetron sputtering, ZnO thin film.

I. INTRODUCTION

Zinc oxide (ZnO) is a wide-band gap semiconductor material showing a huge potential for electronics, optoelectronics, and nano/biosensors applications. Also, the ZnO nanostructures (nanowires, nanobelts) can be used for various nano devices and systems mainly because ZnO has both semiconducting and piezoelectric properties. In spite of these advantages, unfortunately, the synthesis of nanoscale ZnO structures seems to have some difficulties, giving some limitations to the fabrication of the nanoscale electromechanical coupled devices. From this standpoint, it is worth finding out a new approach to synthesize nanoscale structures (grains, wires, belts) in a cost-effective and easy-controllable way. On the other hand, ZnO films can be deposited by many methods, such as chemical vapor deposition(CVD)[1], metal organic chemical vapor deposition(MOCVD), molecular beam epitaxy(MBE)[2-3] and RF or DC magnetron sputtering[4]. Among them, the sputtering method is considered as one of the most preferred ways for the deposition of ZnO films because it provides a good adhesion on a substrate, uniform and dense crystal structure, and also smooth surface.

In this work, a feasibility study to achieve nano-grained ZnO films has been done through deposition process optimization. Several ZnO thin films were prepared in an RF magnetron sputtering system under various processing conditions, followed by the characterization of the deposited films. The effects of the deposition power, working pressure, and oxygen gas ratio particularly on the preferred orientations and grain sizes of the deposited ZnO films were investigated.

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II. EXPERIMENT

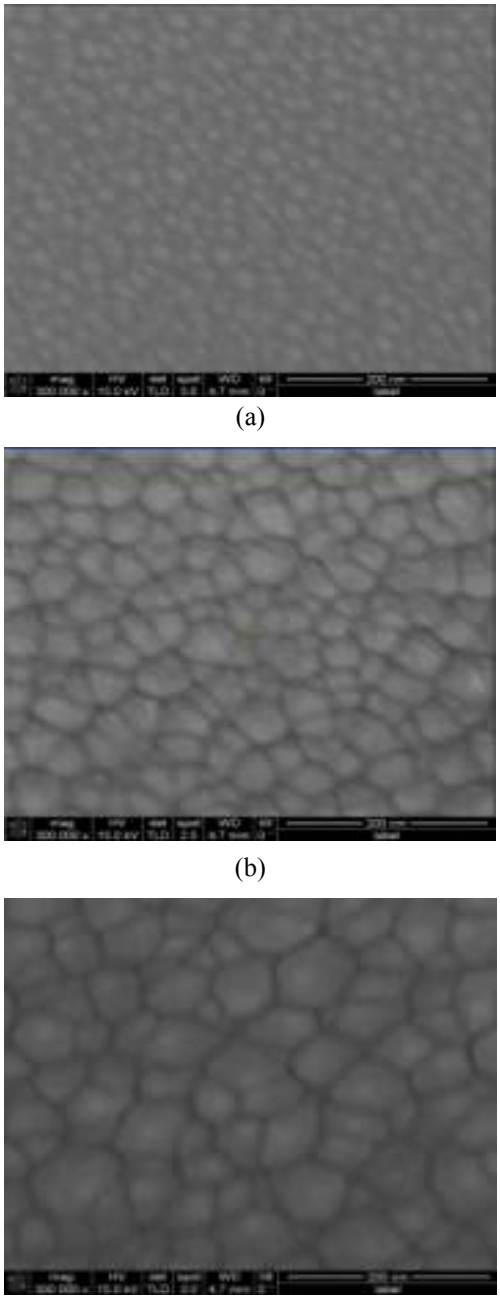
ZnO thin films were deposited in an RF magnetron sputtering system using a 4-inch-diameter ZnO target (purity: 99.999%). The distance between target and substrate was 10cm. The base pressure was kept to be less than 2.0×10^{-6} Torr, and the substrate temperature was fixed at room temperature. In order to study the effects of the process conditions on c-axis orientation and grain size of the deposited ZnO films, the several different deposition powers (70w, 140w, 240w), working pressures (5mTorr, 10mTorr, 20mTorr) and oxygen gas ratios $O_2/(O_2+Ar)$ (0%, 20%, 33%, 50%) were used in the experiment.

III. RESULTS AND DISCUSSION

A. Effects of the deposition powers

In order to study the effects of deposition power, the working pressure and oxygen gas ratio were kept constant at 10mtorr and 33% and the power was varied from 70w to 240w. Fig.1 and Fig.2 show the SEM top-view and cross-section-view images of the ZnO films prepared at different powers (70w, 140w, 240w), respectively. It can be seen that there is a strong dependence between the grain size and deposition power. The grain size of the thin films tends to increase with the increase of the deposition power. Also, the c-axis preferred orientation seems

to be improved as the deposition power increases. This is believed to be due to the fact that the higher deposition power can induce higher substrate temperature, which seems to be related to the ZnO film nucleation. [5]



(a)

(b)

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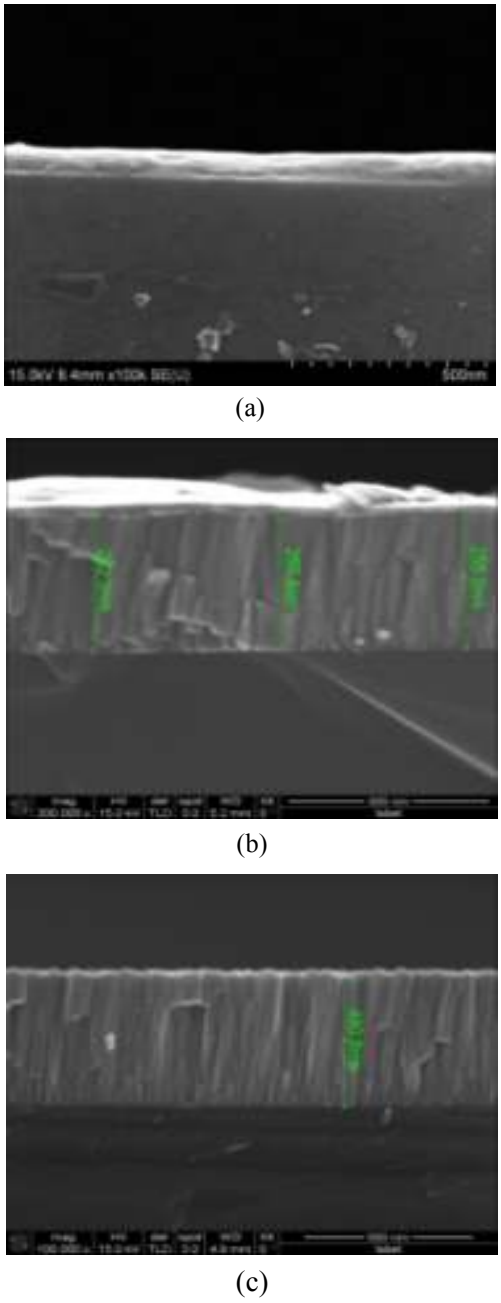
Fig.1 SEM top-view images of the ZnO thin films deposited at different powers: (a) 70w, (b) 140w, (c) 240w



(a)

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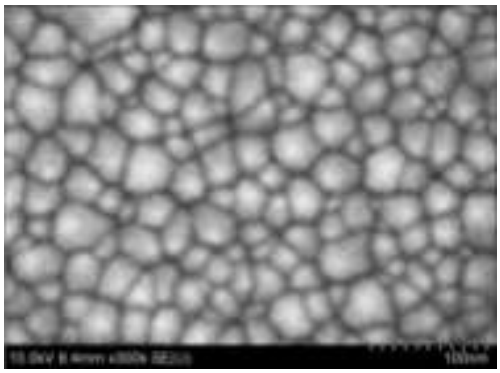
Fig.2 SEM cross-section-view images of the ZnO thin films deposited at different powers: (a) 70w, (b) 140w, (c) 240w

B. Effects of the working pressures

Fig.3 and Fig.4 show the SEM top-view and cross-section-view images of the ZnO thin films deposited at different working pressures (5mTorr, 10mTorr, and 20mTorr), respectively, where the deposition power of 140w and the oxygen gas ratio of 33% were fixed constant. As a result, the grains of all the ZnO thin films deposited at different

pressure from 5mTorr to 20mtorr showed highly preferred c-axis orientation. In addition, with an increase in the working pressure, the grain size of the deposited ZnO films tends to slightly decrease. This may be attributed to the reduced kinetic energy of the sputtered atoms due to the increased sputtering pressure. This result also indicates that the sputtering pressure may not have a significant influence on the crystalline grain growth and property of the deposited ZnO thin films.



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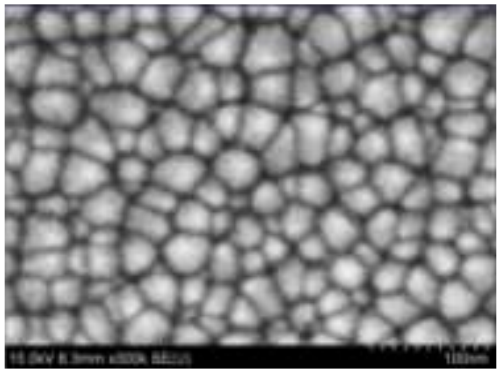

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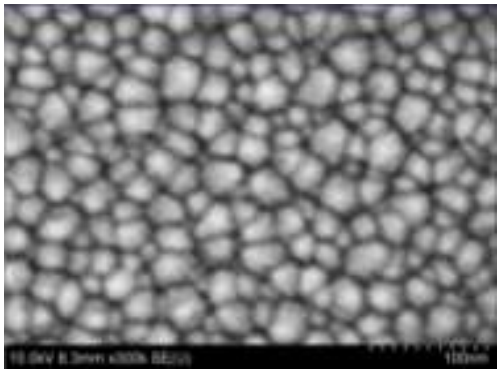

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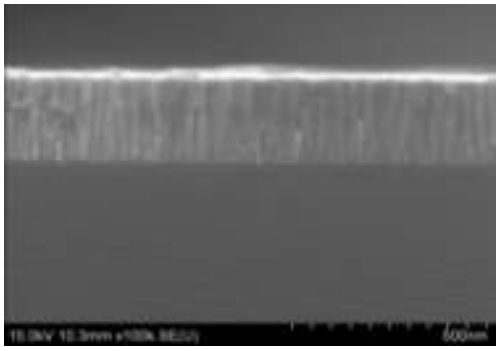
Fig.3 SEM top-view images of the ZnO thin films deposited at different working pressures: (a) 5mTorr, (b) 10mTorr, (c) 20 mTorr



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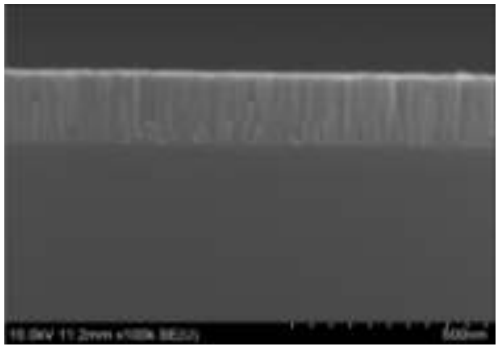

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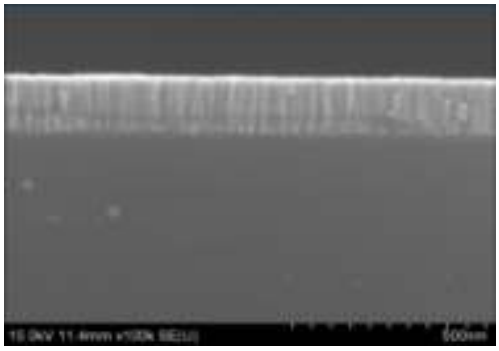

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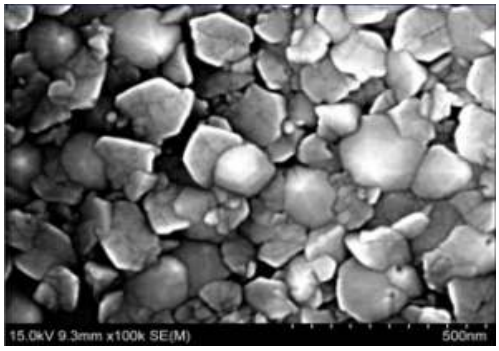
Fig.4 SEM cross-section-view images of the ZnO thin films deposited at different working pressures: (a) 5mTorr, (b) 10mTorr, (c) 20mTorr

C. Effects of the oxygen gas ratios

In order to study the effects of oxygen gas ratio on the orientation and grain size of ZnO films, the oxygen gas ratio, $O_2/(O_2+Ar)$, was varied from 0% to 50% while the working pressure and power were kept constant at 10mtorr and 140w. As shown in Fig.5 and Fig.6, the results indicate that the ZnO films deposited in the O_2 and Ar mixture ambient exhibit much smaller grain sizes and superior c-axis orientations as compared to that in the pure Ar ambient. It is concluded that the addition of O_2 during the deposition can improve the crystalline property of ZnO thin films.



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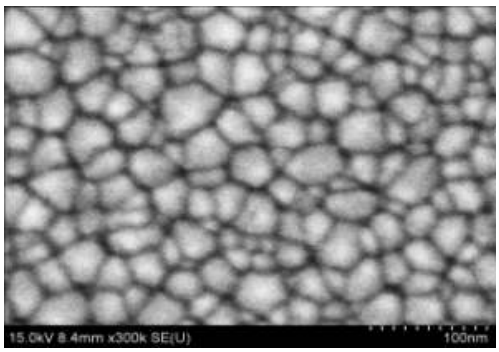

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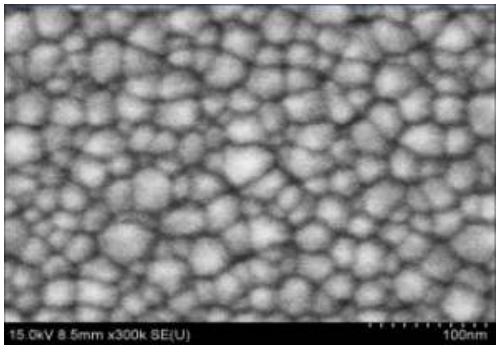

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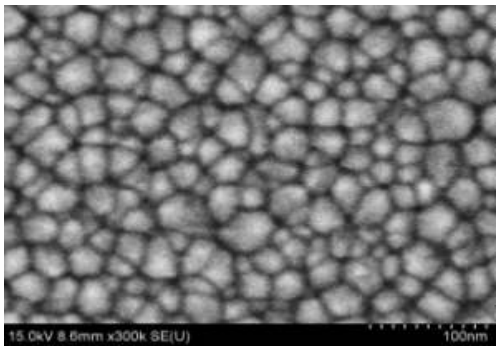
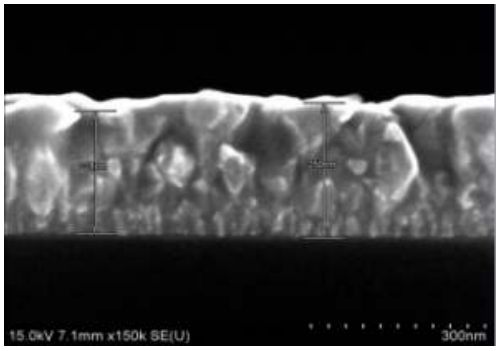


(d)

Fig.5 SEM top-view images of the ZnO thin films deposited at different oxygen gas ratio, $O_2/(O_2+Ar)$: (a) 0%, (b) 20%, (c) 33%, (d) 50%



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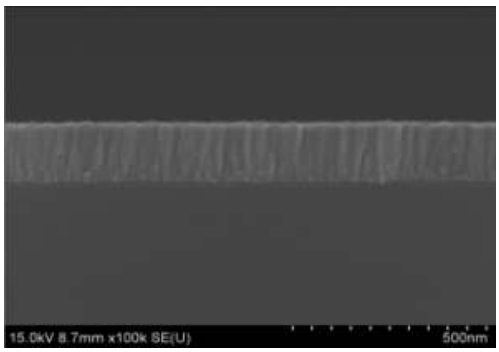

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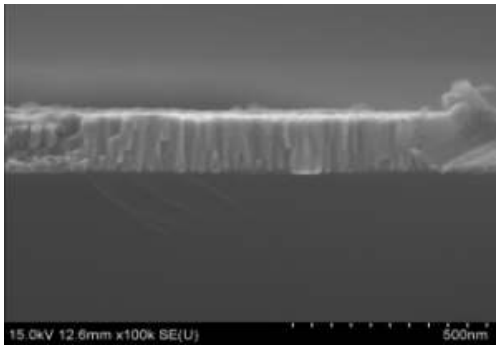

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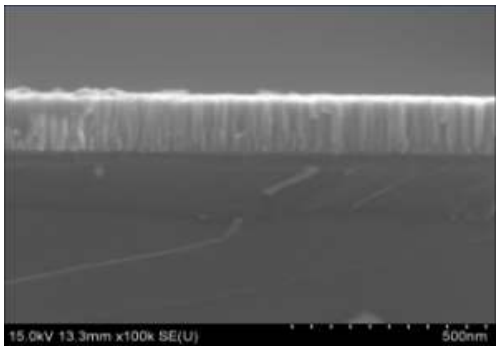

(d)

Fig.6 SEM cross-section-view images of the ZnO thin films deposited at different oxygen gas ratio, $O_2/(O_2+Ar)$: (a) 0%, (b) 20%, (c) 33%, (d) 50%

In addition, the grain size was observed to slightly decrease with increasing $O_2/(O_2 + Ar)$ from 20% to 50%.

IV. CONCLUSION

ZnO thin films have been successfully deposited on Si wafer in an RF magnetron sputtering system. The effects of the sputtering parameters such as deposition power, working pressure, and oxygen gas ratio $O_2/(O_2 + Ar)$ on the preferred orientations and grain sizes of the deposited ZnO films were investigated. Crystalline structures of the deposited films were investigated by a scanning electron microscope (SEM) technique. Results showed that the deposition parameters could have a strong impact on the preferred c-axis orientation and grain sizes of the deposited ZnO films.

ACKNOWLEDGMENT

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