

# Fabrication of aligned ZnO nanoplatelets using AlN film as an interfacial layer

S. P. Ghosh<sup>1</sup>, K. C. Das<sup>1</sup>, J. P. Kar<sup>1\*</sup>, S. N. Das<sup>2</sup>, G. Bose<sup>3</sup>, J. M. Myoung<sup>4</sup>

<sup>1</sup>Dept. of Physics, National Institute of Technology, Rourkela, 769008, India,

<sup>2</sup>Dept. of Physics, Burdwan Raj College, Burdwan, 713104, India

<sup>3</sup>Dept. of Electronics and Instrumentation Engineering, ITER, SOA University Bhubaneswar, 751030, India

<sup>4</sup>Dept. of Materials Science and Engineering, Yonsei University, Seoul 120749, Republic of Korea

## Abstract

Vertically aligned ZnO nanoplatelets were grown by aqueous chemical growth (ACG) method using aluminum nitride (AlN) film as an interfacial layer on silicon wafer; whereas, ZnO nanorods were grown by the identical process on the bare silicon wafer. Prior to ZnO nanostructure growth, the morphological properties of the RF sputtered AlN films were systematically studied. The thin nanoplatelets, grown on the AlN surface, have hexagonal shape with flat surface. The thickness and diameters of the nanoplatelets were 50-80 nm and 2  $\mu\text{m}$ , respectively. The morphological and microstructural properties of the nanoplatelets were evaluated by SEM and XRD characterization techniques. The formation of nanoplatelets on the surface of AlN film is due to the presence of aluminum complexes.

**Keywords:** ZnO, Nanostructures, AlN films, Morphology

## Introduction

Semiconducting nanostructures have stimulated intensive research interest for fundamental studies and its applications as building blocks of various nanoscale devices [1-3]. Among these, ZnO nanostructures have drawn considerable interests due to their high surface to volume ratios, wide bandgap and a large exciton binding energy with high crystalline quality. Extensive research is going on the bottom-up growth of ZnO nanostructures such as nanowires, nanotubes, nanobelts, nanoplatelets, nanosprings on different type of substrates for electronic and medical applications [1, 2]. Among these nanostructures, ZnO nanoplatelets have drawn considerable interests for the fabrication of sensors, dye-sensitized solar cells (DSSC), optical

---

\* Corresponding author, Email: [karjp@nitrkl.ac.in](mailto:karjp@nitrkl.ac.in), Ph.: 0661-2642732

and photocatalytic applications due to their nanometer scale thickness [4-7]. High surface to volume ratios of nanoplatelets enhances high dye adsorption that in turn gives rise to the increase in light collection. Furthermore, this type of 2-D nanosheets is also suitable for the fabrication of high performance/energy storage, data storage devices, which is much required in recent days.

To synthesize ZnO nanosheets, several high temperature approaches have been implemented like vapor transport and thermal evaporation processes [8, 9]. However, these processes have many drawbacks such as expensive apparatus, high thermal budget, complicated process and low yield. In comparison to these processes, aqueous chemical growth (ACG) looks an attractive approach due to its low thermal budget, simplicity and low cost [10]. In addition, this method also allows the growth of nanostructures in large-scale on an arbitrary substrate that opens a new path for their versatile applications. It is found that the most suitable (less lattice misfits) substrates for ZnO growth are  $\text{ScAlMgO}_4$  and sapphire, but these substrates are expensive and technologically incompatible to complementary metal oxide semiconductor (CMOS) process [11]. To widen the electronic device applications, the current research is more focused to silicon substrate, which has the advantages of CMOS process compatibility, low cost, good thermal conductivity, high crystalline quality, and availability of large size wafer [12]. Recently, ZnO platelets have grown either using an additional precursor or using aluminum substrates [13, 14]. However, the stability of aluminum in chemical ambient, the selective growth of ZnO platelets, contaminations due to additional precursors is the major disadvantages of these techniques. To overcome these limitations, aluminum nitride (AlN) film is introduced as an interfacial layer between the ZnO nanoplatelets and silicon. The advantages of AlN films are high chemical stability, high thermal conductivity, high dielectric constant and CMOS process compatibility. In this paper, the growth and the morphological characterizations of ZnO nanoplatelets on AlN/Si substrates is reported.

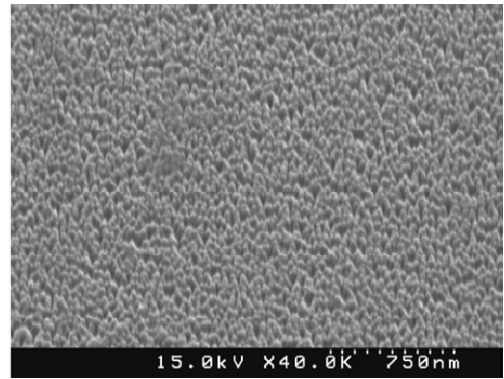
## **Experimental**

An equimolar (0.005 M) aqueous solution of zinc nitrate [ $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ ] and hexamethyltetramine (HMT,  $\text{C}_6\text{H}_{12}\text{N}_4$ ) was used for the hydrothermal growth of ZnO nanostructures at 85 °C for 4 h. Prior to the growth of ZnO platelets, AlN films were deposited on silicon wafers by RF reactive magnetron sputtering with a pure aluminum target and a mixture of argon and nitrogen gases ( $\text{Ar}:\text{N}_2 = 1:4$ ) at a working pressure and RF power of  $6 \times$

$10^3$  mbar and 400 W, respectively. The substrate temperature during the growth of AlN film was fixed at 200 °C. The wafers were placed inside the solution to collect deposits from the hydrothermal reaction. After the growth of white layer ZnO nanostructures, the samples were thoroughly washed with DI water and dried in air. Thereafter, the nanoplatelets were annealed at 600 °C for 30 minutes in oxygen ambient. Morphological investigations of ZnO nanoplatelets were carried out using field-emission scanning electron microscopy (FESEM, Hitachi S-4200) and Rigaku (DMAX-2500H) X-ray system. In addition, the microstructures of ZnO nanostructures were observed using high-resolution transmission electron microscopy (HRTEM, JEOL JEM-2100F).

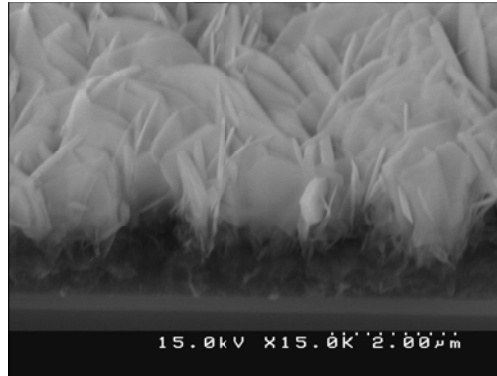
## Results and Discussion

Figure 1 shows the SEM image of RF magnetron sputtered AlN films on Si substrate. The films were c-axis oriented, smooth with homogeneous grain growth as reported elsewhere [15]. In order to investigate the morphology of ZnO nanostructures on AlN film with respect to bare silicon, half of the AlN film is etched out from the wafer by standard wet chemical etchant. Thereafter, ZnO nanostructures were grown on partly coated Si wafer. It is found that

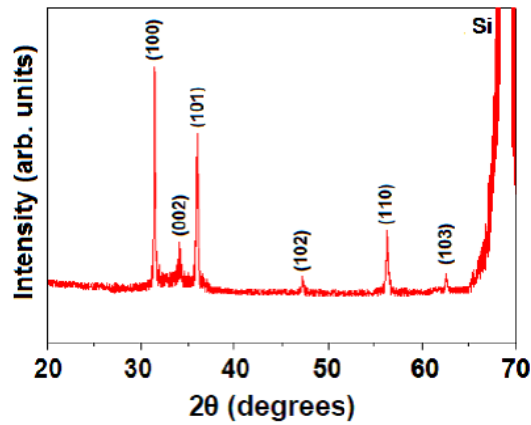


**Fig. 1 SEM image of sputtered AlN film on Si substrate.**

randomly oriented ZnO nanorods were grown on the bare silicon. The average length and diameter of ZnO nanorods were 3-4  $\mu\text{m}$  and 200-300 nm, respectively. On the other hand, ZnO nanoplatelets were grown on the AlN film, where the thickness and diameter of the nanoplatelets was found to be around 50-80 nm and 2  $\mu\text{m}$ , respectively. It is also found that the dimension of nanoplatelets and the nanorods increased significantly at the edge of the AlN film. Magnified cross-sectional SEM image [Figure 2] depicts the vertical alignment of honey-comb type nanoplatelets. Figure 3 shows the XRD pattern of ZnO nanoplatelets, where (100) peak is much stronger than the (002) peak. This indicates that unlike ZnO nanorods, the growth of ZnO nanoplatelets is restricted along c-axis.



**Fig. 2 SEM image of vertically aligned ZnO nanoplatelets.**



**Fig. 3 XRD pattern of ZnO nanoplatelets.**

## Conclusion

Vertically aligned network of ZnO nanoplatelets were selectively grown on AlN/Si film by aqueous chemical growth at low temperature without any catalyst, whereas randomly oriented ZnO nanorods were obtained on the bare Si substrates. The nanoplatelets were of hexagonal shape with flat surface. The c-axis growth of ZnO nanostructures was restricted by the accumulation of Al complexes on the Zn-terminated polar surface and the growth along the lateral direction taken place. This method is compatible for the CMOS process and has the potential for selective growth of high quality ZnO nanoplatelets for futuristic electronic applications.

## References

1. Heo, Y.W.; Norton, D.P.; Tien, L.C.; Kwon, Y.; Kang, B.S.; Ren, F.; Pearton, S.J.; Laroche, J.R. *Mater. Sci. Eng. R* 2004, 47, 1. **DOI:** [10.1016/j.mser.2004.09.001](https://doi.org/10.1016/j.mser.2004.09.001)
2. Lu, J.G.; Chang, P.; Fan, Z. *Mater. Sci. Eng. R* 2006, 52, 49. **DOI:** [10.1016/j.mser.2006.04.002](https://doi.org/10.1016/j.mser.2006.04.002)
3. Wang, Z.L. *Mater. Today* 2004, 7, 26. **DOI:** [10.1016/S1369-7021\(04\)00286-x](https://doi.org/10.1016/S1369-7021(04)00286-x)
4. Wang, N.; Lin, H.; Li, J.B.; Zhang, L.Z.; Li, X.; Wu J.; Li, C.F. *J. Am. Ceram. Soc.*, 2007, 90, 635. **DOI:** [10.1111/j.1551-2916.2006.01418.x](https://doi.org/10.1111/j.1551-2916.2006.01418.x)
5. Ambade, S.B.; Mane R.S.; Ghule, A.V.; Takwale; M.G.; Abhyankar, A.; Cho, B.W.; Han, S.H. *Scripta Materialia* 2009, 61, 12. **DOI:** [10.1016/j.scriptamat.2009.02.011](https://doi.org/10.1016/j.scriptamat.2009.02.011)
6. Shafiei, M.; Yu, J.; Arsat, R.; Kalantar-zadeh, K.; Comini, E.; Ferroni, M.; Sberveglieri, G.; Wlodarski, W. *Sensors and Actuators B* 2010, 146, 507. **DOI:** [10.1016/j.snb.2009.12.028](https://doi.org/10.1016/j.snb.2009.12.028)
7. Sun F.; Qiao X.; Tan, F.; Wang, W.; Qiu X. *App. Surf Sci.* 2012 (Article in press). **DOI:** [10.1016/j.apsusc.2012.09.144](https://doi.org/10.1016/j.apsusc.2012.09.144)
8. Chen, S.J.; Liu, Y.C.; Shao, C.L.; Mu, R.; Lu, Y.M.; Zhang, J.Y.; Shen, D.Z.; Fan, X.W. *Adv. Mater.* 2005, 17, 586. **DOI:** [10.1002/adma.200401263](https://doi.org/10.1002/adma.200401263)
9. Umar, A.; Hahn, Y.B. *Nanotechnology* 2006, 17, 2174. **DOI:** [10.1088/0957-4484/17/9/016](https://doi.org/10.1088/0957-4484/17/9/016)
10. Kar, J.P.; Das, S.N.; Lee, S.W.; Ham, M.H.; Choi, J.H.; Myoung, J.M. *Chem. Eng. Comm.* 2009, 196, 1130. **DOI:** [10.1080/00986440902897491](https://doi.org/10.1080/00986440902897491)
11. Kar, J.P.; Das, S.N.; Choi, J.H.; Lee T.I.; Myoung, J.M. *Appl. Surf. Sci.* 2010, 256, 4995. **DOI:** [10.1016/j.apsusc.2010.03.040](https://doi.org/10.1016/j.apsusc.2010.03.040)
12. Kar, J.P.; Lee, S.W.; Lee; W.; Myoung, J.M. *Appl. Surf. Sci.* 2008, 254, 6677. **DOI:** [10.1016/j.apsusc.2008.04.046](https://doi.org/10.1016/j.apsusc.2008.04.046)
13. Gao, P.; Ying, C.; Wang, S.; Ye, L.; Guo, Q.; Xie, Y. *J. Nanoparticle Res.* 2006, 8, 131., **DOI:** [10.1007/s11051-005-5130-0](https://doi.org/10.1007/s11051-005-5130-0)
14. Ye, C.; Bando, Y.; Shen, G.; Golberg, D. *J. Phys. Chem. B* 2006, 110, 15146. **DOI:** [10.1021/jp061874w](https://doi.org/10.1021/jp061874w)
15. Kar, J.P.; Das, S.N.; Choi, J.H.; Lee, T.I.; Seo J.; Lee, T.; Myoung, J.M. *Appl. Surf. Sci.* 2011, 257, 4973. **DOI:** [10.1016/j.apsusc.2010.12.158](https://doi.org/10.1016/j.apsusc.2010.12.158)