Available online at www.sciencedirect.com
SCIENCE DIRECT®
Applied Surface Science 236 (2004) 192–197
applied surface science
www.elsevier.com/locate/apsusc

Preparation of GaN films on ZnO buffer layers by rf magnetron sputtering

Hyoun Woo Kim*, Nam Ho Kim

School of Materials Science and Engineering, Inha University, Incheon 402-751, Republic of Korea

Accepted 15 April 2004

Available online 20 June 2004

Abstract

We have deposited the GaN films on Si(0 0 1) substrate using the ZnO buffer layers at room temperature by the radio frequency (rf) magnetron sputtering method. The ZnO buffer layer thickness affected the structural properties of GaN films. With a sufficiently thick ZnO layer, we have obtained a *c*-axis-oriented GaN/ZnO thin film on Si with the XRD full-width at half-maximum (FWHM) of 0.22° and root-mean-square (RMS) surface roughness of about 22 Å.

Keywords: Sputter; GaN; ZnO; Room temperature; Thin film

1. Introduction

The growth and properties of GaN films have been intensively studied over the last few years due to their potential applications in optoelectronic devices as well as in high-power and high temperature electronic devices [1–5]. However, the production of high quality GaN is complicated by the lack of a lattice-matched and industrially usable substrate material. The ZnO buffer layer may have some potential advantages for this application, because ZnO has a lattice mismatch of only 1.8% with GaN [6] and high quality ZnO is expected to grow on various substrates by the development of technologies.

Although GaN films have been grown by sputtering [7–12] and ZnO films have been used as a buffer in preparing the GaN films [13–20], to our knowledge, the growth of GaN film on ZnO buffer by the sputtering method has not been reported to date. Since GaN films grown on silicon (Si) substrate pave the way for integration of devices with the mature Si integrated circuits technology, in spite of the large thermal and lattice mismatch between Si and GaN, we have used a Si(0 0 1) substrate. In this study, we deposit the GaN thin film on ZnO/Si(0 0 1) substrates at room temperature by the rf magnetron sputtering method and investigate the effect of ZnO buffer layer thickness on the structural properties.

2. Experimental

A schematic diagram of the radio frequency (rf) sputtering system used in our experiments is previously reported [21]. Before loading into the reactor, the Si(0 0 1) substrate was cleaned in acetone for

* Corresponding author. Tel.: +82 32 860 7544; fax: +81 32 862 5546.
E-mail address: hwkim@inha.ac.kr (H.W. Kim).

0169-4332/$ – see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.apsusc.2004.04.029

10 min, HF (20:1) for 1 min and then rinsed in deionized water for 1 min. In this experiment, we have used a ZnO (99.99% purity) and a GaN (99.99% purity) target with a diameter and a thickness of 75 and 6 mm, respectively.

The sputtering was carried out at room temperature in a 30 sccm Ar (99.99% purity) gas flow by supplying a 13.56 MHz rf power. The distance between target and substrate was about 80 mm. The ZnO films as a buffer layer were grown on Si(1 0 0) substrates at an rf power of 100 W and a pressure of 5.0×10^{-2} Torr and deposition was carried out for 30–90 min. When the deposition times were 30, 60, and 90 min, respectively, the thicknesses of deposited ZnO films were measured to be 20, 60, and 300 nm. Subsequently, the GaN films were grown at an rf power of 50 W and a pressure of 5.0×10^{-2} Torr for 30 min.

The structural properties of the films were analyzed by X-ray diffraction (XRD, X'pert MRD-Philips) using Cu Kα1 radiation ($\lambda = 0.154056$ nm), scanning

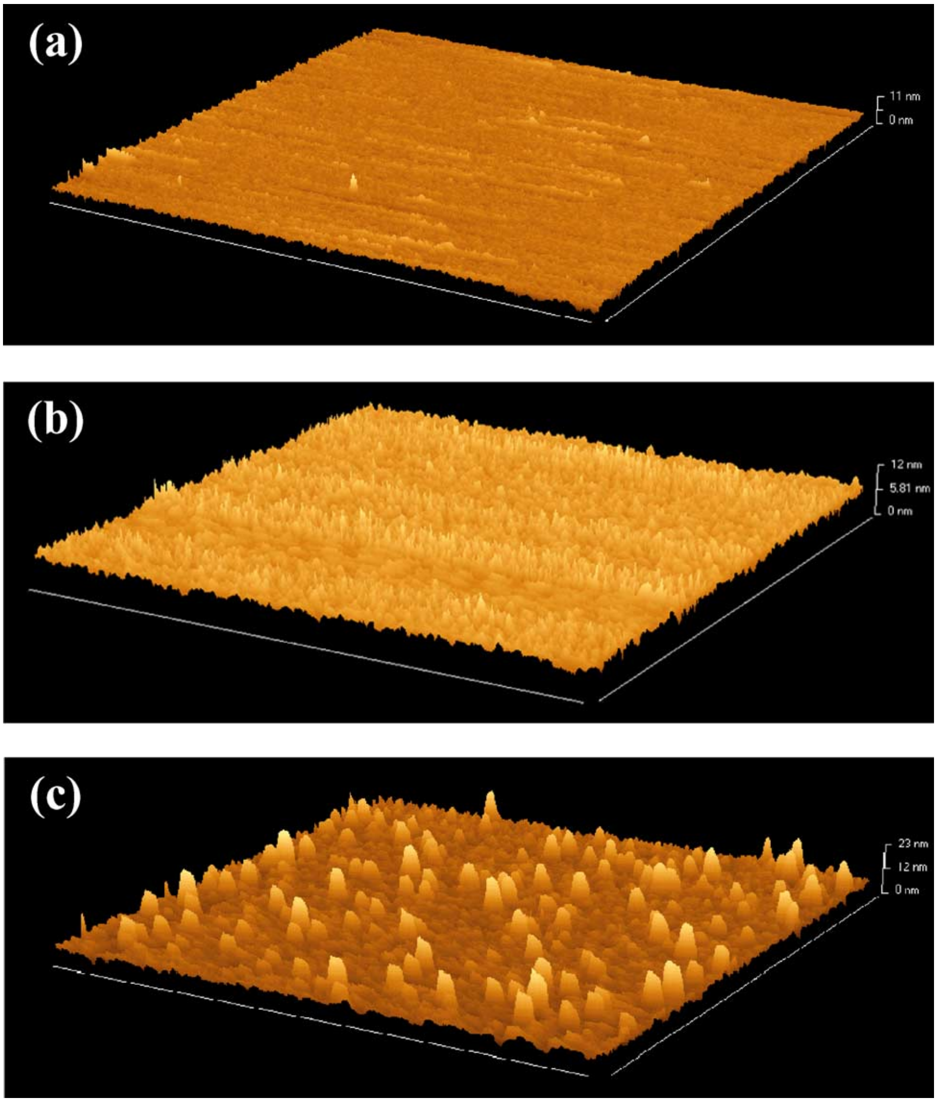

Fig. 1. AFM topographies of (a–c) GaN film surfaces and (d–f) ZnO buffer layer surfaces. The thicknesses of ZnO buffer layers are: (a, d) 20 nm; (b, e) 60 nm; and (c, f) 300 nm.

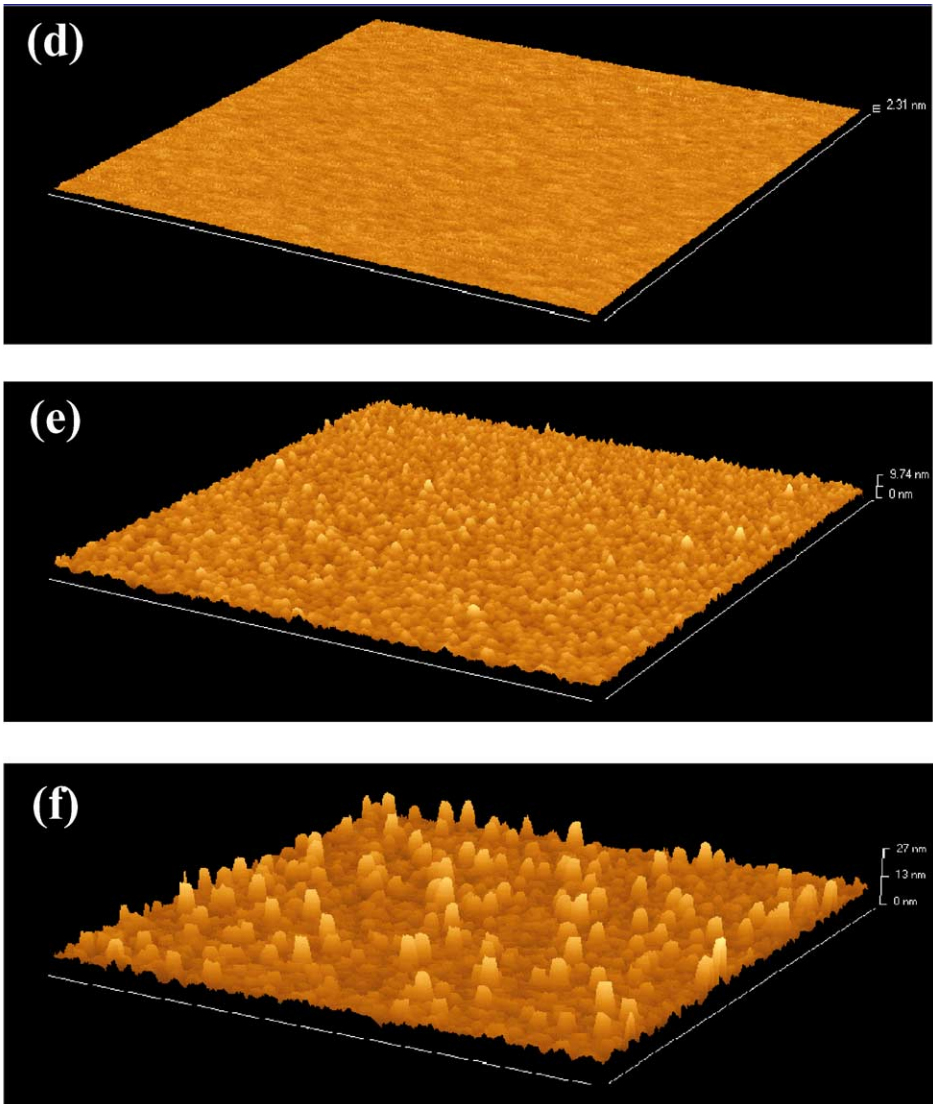

Fig. 1. (*Continued*).

electron microscopy (SEM, Hitachi S-4200), and atomic force microscopy (AFM, Nanoscope III, Digital Instruments) with a scan size of 5 μm × 5 μm.

3. Results and discussion

Fig. 1a–c shows the AFM topographies of GaN film surfaces, respectively, with ZnO buffer layer thicknesses of 20, 60, and 300 nm. The root-mean-square (RMS) surface roughnesses of the GaN surfaces are measured to be about 7.0, 9.4, and 22.2 Å, respectively, with the ZnO buffer layer thicknesses of 20, 60, and 300 nm. Fig. 1d–f shows the AFM topographies of ZnO buffer layer surfaces prior to depositing the GaN layers, respectively, with ZnO thicknesses of 20, 60, and 300 nm. The RMS surface roughnesses of the ZnO surfaces are measured to be about 1.6, 10.0, and 25.1 Å, respectively, with the ZnO thicknesses of 20, 60, and 300 nm. Fig. 2 reveals that the RMS

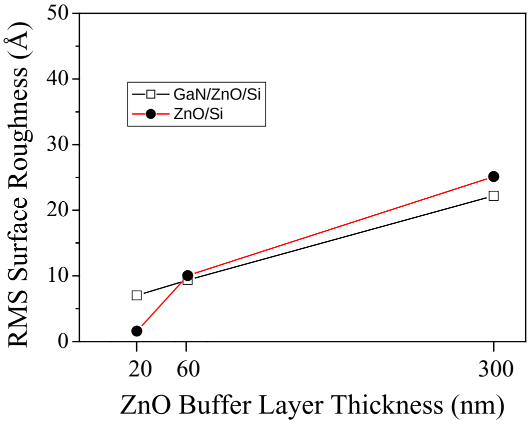

Fig. 2. AFM RMS surface roughness of GaN layer and ZnO buffer layer surfaces by varying the ZnO buffer layer thickness.

surface roughnesses of both GaN and ZnO surfaces increase with increasing the thickness of the underlying ZnO buffer layers. In addition, the RMS surface roughness of the GaN and ZnO surfaces are similar (within a 12% difference) especially at ZnO thicknesses of 60–300 nm, indicating that the surface roughness of GaN surface may be related to that of the ZnO surface.

Fig. 3 shows the plain-view SEM images of GaN thin film, with the ZnO thickness ranging from 20 to 300 nm. The average grain sizes on top of GaN surfaces with ZnO thicknesses of 60 and 300 nm, respectively, are estimated to be about 48 and 56 nm using the linear intercept method [22], indicating that the grain size on top of the GaN film slightly increases with increasing the ZnO thickness in the range of 60–300 nm. It is noteworthy that some larger grains with an average diameter of about 100 nm are clearly observed on the surface of GaN film when the ZnO buffer layer thickness is 300 nm. Since the larger grain size may induce the rougher surface, the SEM images agree with AFM measurement.

Fig. 4 shows a typical cross-sectional SEM image of GaN film when the ZnO thickness is 60 nm. The GaN film consists of columnar-structured grains, possibly representing the oriented grains. In addition, the average diameter of the columnar grains is about 30–60 nm, almost agreeing with the plain-view SEM images. Fig. 5 shows the θ–2θ XRD patterns of the GaN/ZnO/Si structure, with the Si(0 0 2) peak eliminated for clarity. The θ–2θ scan data with the ZnO thickness of 20 nm indicate that the film is surmised to be an amorphous phase due to the absence of a strong diffraction peak. The θ–2θ scan data with the ZnO thickness of 60–300 nm exhibit a noticeable (0 0 2) peak of ZnO and GaN with the hexagonal structure. The GaN(0 0 2) peak is usually overlaid on ZnO(0 0 2) peak due to the close lattice mismatch [14,18,19]. Since the relative intensity of the (0 0 2) diffraction peak is significantly strong compared to the

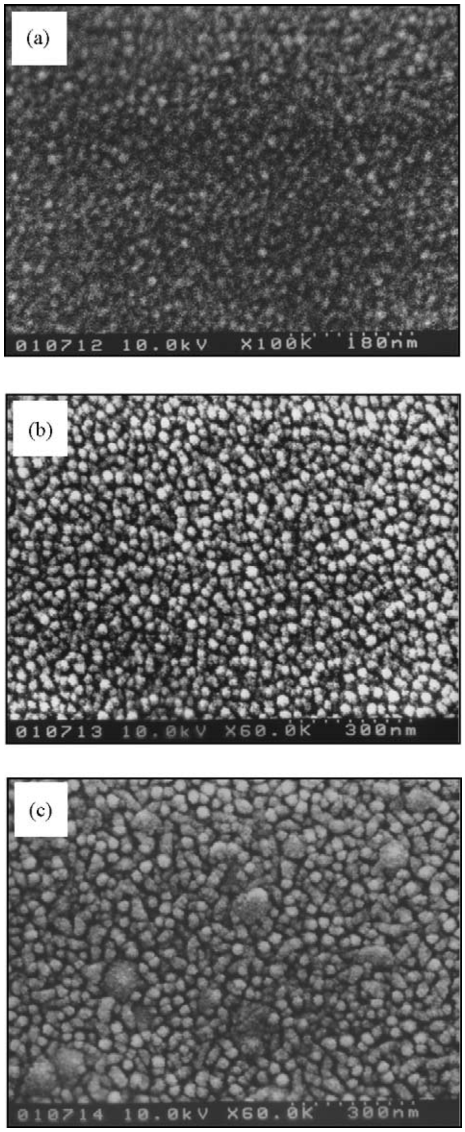

Fig. 3. Plain-view SEM images of GaN film with the ZnO buffer layer thickness of: (a) 20 nm; (b) 60 nm; and (c) 300 nm.

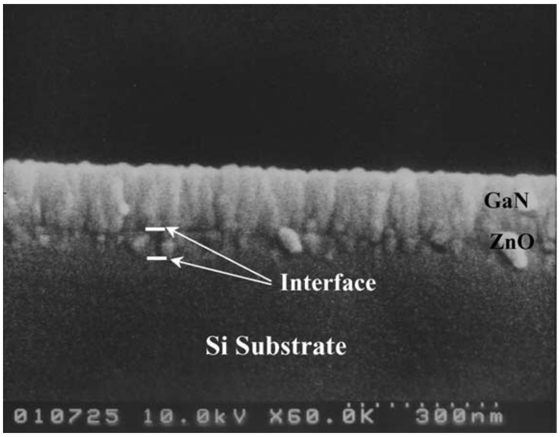

Fig. 4. Cross-sectional SEM image of GaN film when the ZnO buffer layer thickness is 60 nm.

neighboring (1 0 1) peak and other almost invisible peaks, we surmise that the *c*-axis oriented GaN/ZnO films with a few (1 0 1) normal planes are obtained with the thick ZnO buffer layer of 60–300 nm. XRD patterns also indicate that the intensity of the (0 0 2) diffraction peak becomes stronger with increasing the ZnO buffer layer thickness. When the ZnO thickness is 300 nm, the full-width at half-maximum (FWHM) of (0 0 2) diffraction peaks is about 0.22°.

In the present work, thicker ZnO buffer layer induces the rougher ZnO surface. We surmise that the GaN grains grow conformally with the underlying ZnO grains, because GaN has the same crystal structure as ZnO with almost the same lattice constant.

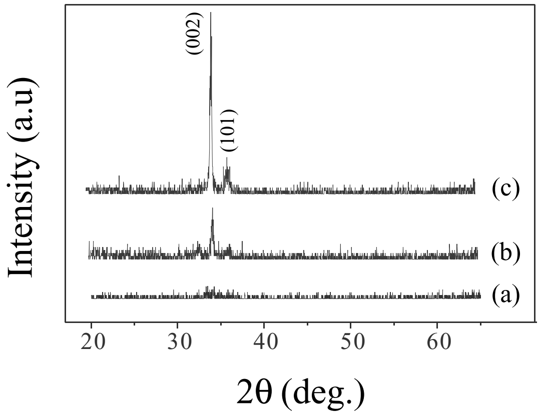

Fig. 5. XRD patterns of the GaN thin film deposited on ZnO/Si, with the ZnO buffer layer thicknesses of: (a) 20 nm; (b) 60 nm; and (c) 300 nm.

Accordingly, thicker ZnO buffer layer results in the rougher GaN surface. Although the detailed mechanism on the correlation of *c*-axis orientation and surface roughness is still under investigation, we reveal that the surface roughness and crystallinity of GaN film can be controlled by varying the ZnO buffer layer thickness.

4. Conclusion

We have successfully prepared the GaN films on ZnO/Si(0 0 1) substrates at room temperature by the rf magnetron sputtering. AFM and XRD, respectively, reveal that the RMS surface roughness and *c*-axis orientation of GaN layer increase with increasing the thickness of the underlying ZnO buffer layer. By employing a 300 nm–thick ZnO buffer layer, we have obtained the GaN/ZnO/Si film structure with the XRD FWHM of 0.22° and RMS surface roughness of 22.2 Å. The first preparation of GaN film on ZnO/Si structure using the sputtering technique at a low temperature will shed light on their potential applications.

Acknowledgements

This work was supported by grant no. R05-2001-000-00843-0 from the Basic Research Program of the Korea Science & Engineering Foundation.

References

[1] S. Strite, H. Morkoc, J. Vac. Sci. Technol. B 10 (1992) 1237.
[2] H. Morkoc, S. Strite, G.B. Gao, M.E. Lin, B. Sverdlov, M. Burns, J. Appl. Phys. 76 (1994) 1363.
[3] R.F. Davis, J. Vac. Sci. Technol. A 11 (1993) 829.
[4] H. Morkoc, S.N. Mohammed, Science 267 (1995) 51.
[5] M.W. Shin, R.J. Trew, Electron. Lett. 31 (1995) 498.
[6] S.-K. Hong, H.-J. Ko, Y. Chen, T. Hanada, T. Yao, J. Cryst. Growth 214–215 (2000) 81.
[7] S. Zembutsu, M. Kobayashi, Thin Solid Films 129 (1985) 289.
[8] T.L. Tansley, R.J. Egan, E.C. Horrigan, Thins Solid Films 164 (1988) 441.
[9] K. Kubota, Y. Kobayashi, K. Fujimoto, J. Appl. Phys. 66 (1989) 2984.
[10] J. Ross, M. Rubin, T.K. Gustafson, J. Mater. Res. 8 (1993) 2613.

[11] S. Nonomura, S. Kobayashi, T. Gotoh, S. Hirata, T. Ohmori, T. Itoh, S. Nitta, K. Morigaki, J. Non-cryst. Solids 200 (1996) 174.
[12] N.A. Preschilla, N.M. Elkashef, R.S. Srinivasa, S. Major, Surf. Coat. Technol. 108–109 (1998) 328.
[13] T. Ueda, T.-F. Huang, S. Spruytte, H. Lee, M. Yuri, K. Itoh, T. Baba, J.S. Harris Jr., J. Cryst. Growth 187 (1998) 340.
[14] M. Dinescu, P. Verardi, C. Boulmer-Leborgne, C. Gerardi, L. Mirenghi, V. Sandu, Appl. Surf. Sci. 127–129 (1998) 559.
[15] A. Strittmatter, A. Krost, V. Trück, M. Straßburg, D. Bimberg, J. Bläsing, T. Hempel, J. Christen, B. Neubauer, D. Gerthsen, T. Christmann, B.K. Meyer, Mater. Sci. Eng. B 59 (1999) 29.
[16] A. Hoffmann, J. Holst, A. Kaschner, H. Siegle, J. Christen, P. Fischer, F. Bertram, K. Hiramatsu, Mater. Sci. Eng. B 59 (1999) 163.
[17] K.S.A. Butcher, P. Afifuddin, P.-T. Chen, M. Godlewski, A. Szczerbakow, E.M. Goldys, T.L. Tansley, J.A. Freitas Jr., J. Cryst. Growth 246 (2002) 237.
[18] R.P. Wang, H. Muto, Y. Yamada, T. Kusumori, Thin Solid Films 411 (2002) 69.
[19] R.-P. Wang, H. Muto, T. Kusumori, Opt. Mater. 23 (2003) 15.
[20] S. Gu, R. Zhang, J. Sun, L. Zhang, T.F. Kuech, Appl. Phys. Lett. 76 (2000) 3454.
[21] H.W. Kim, N.H. Kim, Mater. Sci. Eng. B 103 (2003) 297.
[22] H. Engqvist, B. Uhrenius, Int. J. Refract. Metals Hard Mater. 21 (2003) 31.