OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 16, No. 3-4, March-April 2022, p. 159 - 163

Improved structure and optical properties of GaN epilayer on Si(111) using AlN pressure modulation grown by MOCVD

FUCHENG LIU[1], NAISEN YU[1,2,3,*], SHIYU DU[1], LIANG ZHAO[1], YUNFENG WU[1,*]
[1]*School of Physics and Materials Engineering, Dalian Minzu University, Dalian 116600, PR China*
[2]*Guangxi Key Laboratory of Precision Navigation Technology and Application, Guilin University of Electronic Technology, Guilin 541004, PR China*
[3]*School of Materials Science and Engineering, Jiangsu University of Science and Technology, Zhenjiang 212000, PR China*

GaN films were grown on Si(111) substrate using AlN pressure modulation method by metal organic chemical vapor deposition (MOCVD). The films grown using AlN pressure modulation method demonstrate higher structural and optical quality than the traditional fixed AlN pressure way. It was assumed that the AlN pressure modulation layer way can effectively promote the lateral growth. It will provide a new way to improve quality for GaN film with a great potential application.

(Received July 31, 2021; accepted April 7, 2022)

Keywords: GaN films, AlN pressure

1. Introduction

As one of promising substrates, the growth of GaN film on Si has been extensively explored in various potential applications [1-6]. However, the main problem is that high quality GaN film is hard to grow due to the large lattice and thermal expansion coefficients mismatch [7-9].

Many groups have adopted various methods to improve the quality of GaN layer on Si [10-12]. It has been shown that the AlN layer can improve the GaN film quality. Thus, optimizing the growth conditions of AlN is very meaningful for obtaining high quality GaN film.

Herein, we demonstrate using the AlN pressure modulation method to grow the GaN. The films grown using AlN pressure modulation method demonstrate higher structural and optical quality than the traditional fixed AlN pressure way. It was assumed that the AlN pressure modulation layer way can effectively promote the lateral growth. It will provide a new way to improve quality for GaN film with a great potential application.

2. Experimental procedure

Aixtron MOCVD 2000HT system was adopted to grow GaN. Fig. 1 showed the schematic structures of GaN samples grown on Si with different AlN interlayers. Different AlN pressure conditions were used to grow GaN films. Three GaN samples labeled with sample A, B and C under different AlN pressure conditions were grown. Fixed AlN pressure with 100 mbar and 200 mbar was adopted for sample A and sample C, the total thickness is around 80 nm. For the AlN pressure modulation growth, 20 nm AlN layer was firstly growth with the pressure of 100 mbar. Then the reactor pressure was increased to 200 mbar, 40 nm AlN was grown. Finally, the 20 nm AlN top layer was grown with the reactor pressure of 100 mbar. After growth AlN film, in-situ SiNx mask layer with the same growth conditions was deposited. The partial coverage of the surface for SiNx lay can terminate and bend threading dislocations. At last, 1 μm GaN layers were grown with different AlN pressure conditions.

High resolution X-ray diffraction was performed by Philips MRD system. Atomic force microscope (AFM Veeco D3100) was adopted to investigate the morphology. Photoluminescence (PL) measurements were carried out by using the 325 nm He–Cd laser. Raman scattering spectroscopy was recorded to explore the stress state of the GaN films grown by different AlN conditions. For the ultraviolet response performance, simple devices were fabricated by using symmetric ITO ditch electrode with width of 0.1 mm. The as-grown GaN sample was fixed on the prepared ITO/glass substrate by clip.

3. Results and discussion

Fig. 2 displays the in-situ traces of optical reflectivity for the whole growth process of GaN epilayer on the different AlN pressure layers. It shows the process involving the transition from the three-dimensional (3D) mode to the two-dimension mode growth. The dash line denotes the starting of the GaN epilayer growth for sample B. It can be clearly seen that is shorter than that of other samples. The results indicate that modulation AlN pressure can increase transition time and enhance lateral growth for

GaN film. It is well accepted that prolong this process will improve GaN quality. Our results indicate that modulation AlN pressure can increase transition time from 3D-2D process and enhance lateral growth for GaN film.

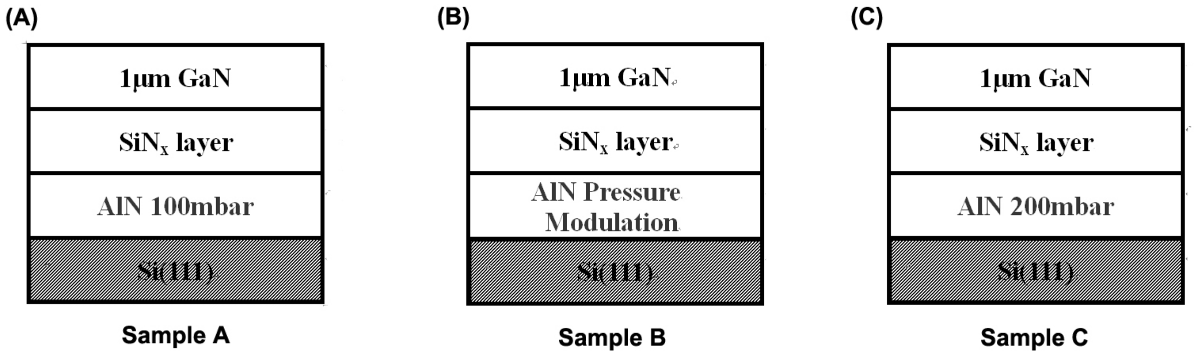

Fig. 1. Schematic structures of GaN films grown with different AlN pressure layers

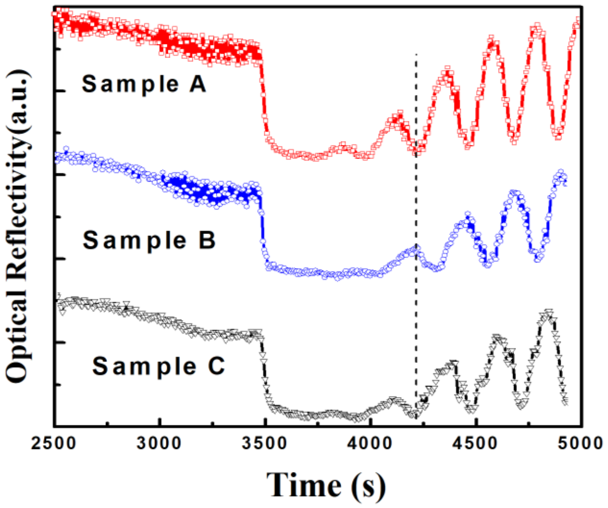

Fig. 2. In situ optical reflectivity for GaN epilayer on the AlN layer (a) 200 mbar, (b) 100 mbar and 200 mbar pressure modulation layer (c) 100 mbar (color online)

The film quality of all samples was characterized by XRD. The FWHM and estimated thread dislocation density according to previous reports [16] were listed in Table 1. It can be seen that the FWHM of sample B for both symmetric (002) and asymmetric (102) is much smaller than that of sample A and C. The results indicated that the AlN pressure modulation can improve crystalline quality for GaN on Si than the traditional AlN fixed pressure way. Combing with the in situ traces of optical reflectivity results, it is suggested that the lateral growth is promoted for reduction of dislocations.

Table 1. FWHM of symmetric (002) and asymmetric (102) rocking curves for sample A,B and C

Sample	(002) FWHM(arc sec)/ Screw dislocation density($10^8 cm^{-2}$)	(102) FWHM(arc sec) Edge dislocation density($10^9 cm^{-2}$)
Sample A	510/5.2	528/2.0
Sample B	492/4.8	498/1.8
Sample C	534/5.7	588/2.5

The topographies of GaN films grown by different AlN layers were shown in the Fig. 3. All the samples display a uniform surface. Meanwhile, clear atomic step flow patterns can also be clearly observed. The root-mean square (RMS) roughness for sample A, B and C are 0.63 nm 0.61 nm and 0.87 nm, respectively.

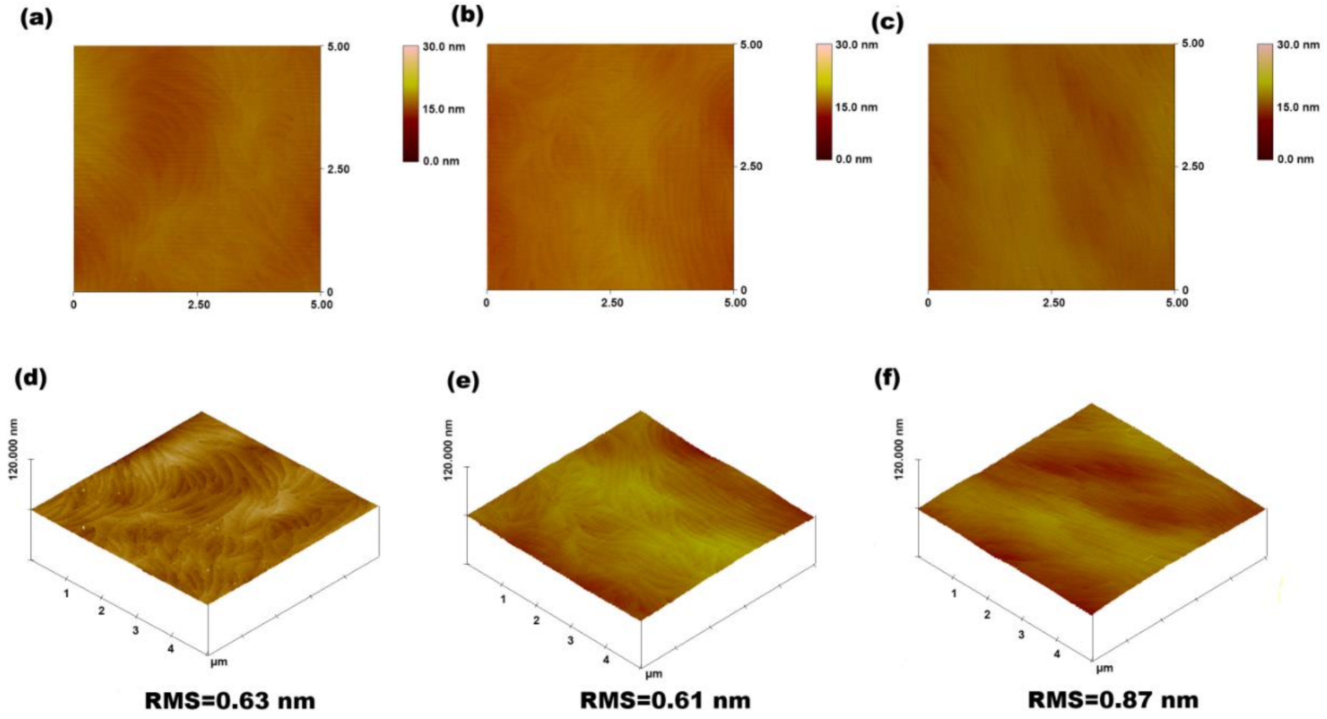

Fig. 3. Surface topography 2D and 3D of GaN thin layers with different AlN pressure conditions. (a),(d): Sample A,(b),(e): Sample B (e), (f): Sample C

Fig. 4 demonstrates the PL spectra for three GaN samples. All the GaN samples grown by different AlN conditions show the peak around 365 nm. The highest PL peak intensity can be found for sample B. The result indicates that the GaN film grown by AlN modulation layer can get better optical quality.

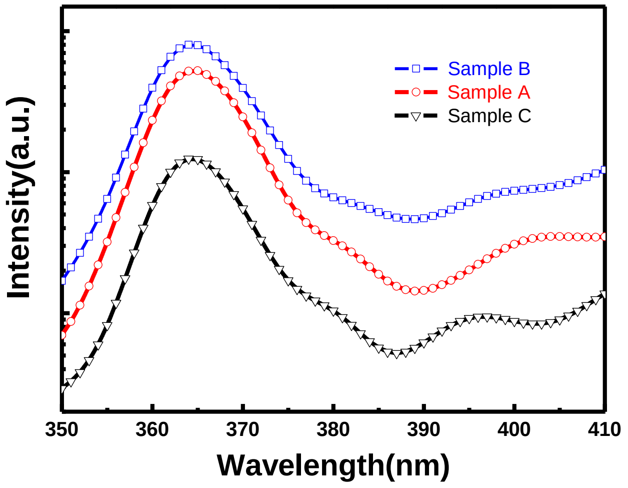

Fig. 4. Photoluminescence (PL) for the three GaN films with different AlN pressure conditions (color online)

Raman scattering was carried out and the spectra in the range of 550-580 nm mainly including GaN E_2(high) phonon mode, it was shown in Fig. 5. Meanwhile, the GaN E_2(high) phonon peak is related to residual stress. For the stress-free GaN, the E_2(high) peak at 567.5 cm^{-1}. Thus, residual tensile stress in the GaN layer can be calculated by:

$$\Delta\omega=4.3\sigma_{xx}\ cm^{-1}GPa^{-1}$$

$\Delta\omega$ is the shift of the E_2(high) peak induced by the strain and σ_{xx} is the in-plane biaxial stress [9]. The GaN E_2(high) peak for sample A, B and C were at 564.9 cm^{-1}, 565.4 cm^{-1} and 564.5 cm^{-1}, respectively. It can be found that sample B suffers from smallest residual tensile stress, it was estimated to be 0.49 GPa. Likewise, the tensile stress for sample A and C can be calculated to be 0.60 GPa and 0.70 GPa, respectively. The Raman results showed that the AlN pressure modulation layer can improve stress GaN on Si. It was assumed that AlN pressure modulation lay can compensate more tensile strain that using fixed AlN way.

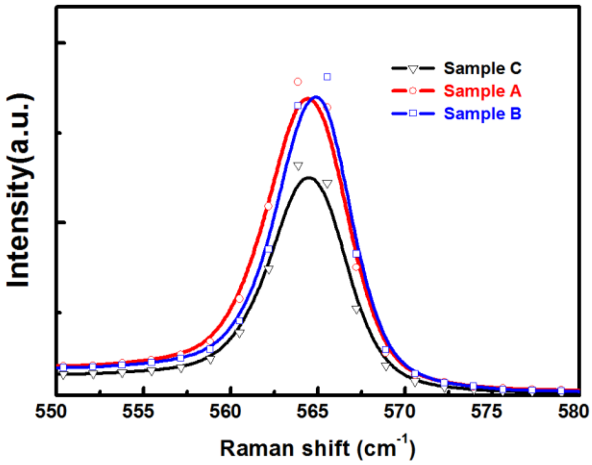

Fig. 5. Raman spectra for the three GaN films with different AlN pressure conditions (color online)

Fig. 6 exhibits the time response of the fabricated photodetectors under 365 nm UV illumination. It can seen that all the devices have photoresponse to the UV light. The response time was listed in the Table 2. The sample B shows fast rise and decay time. The UV response results indicate that the response performance is also improved by the AlN pressure modulation layer. It can be attributed to the lower dislocation density in the sample B, which will promote electron-hole pairs migrate and recombine with faster time [16].

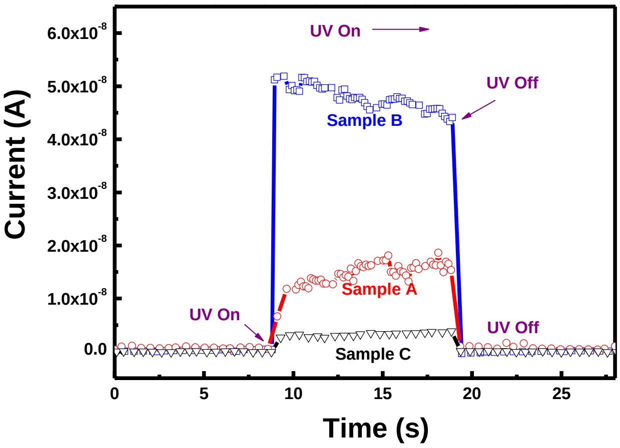

Fig. 6. Time photocurrent response under 365 nm UV light source at 3 V bias for three GaN films with different AlN pressure conditions (color online)

Table 2. Photoresponse time for sample A,B and C

Sample	Rise time (s) Current: 10%-90%	Decay time(s) Current: 90%-10%
Sample A	0.87	0.44
Sample B	0.11	0.42
Sample C	0.40	0.43

It was assumed that the AlN pressure modulation layer way can effectively promote the lateral growth.

4. Conclusion

In this work, high material quality and device performance of GaN on Si (111) are achieved using the AlN pressure modulation method. It can be attributed to the AlN pressure modulation way can reduce the dislocation density and tensile stress, thus improving the response performance. It will provide a new way to improve the quality for GaN film with a great potential application.

Acknowledgments

This work was supported by LiaoNing Revitalization Talents Program (no. XLYC1807004), Joint Research Fund Liaoning-Shenyang National Laboratory for Materials Science (2019JH3/30100005, 2019010281 -JH3/301), Guangxi Key Laboratory of Precision Navigation Technology and Application, Guilin University of Electronic Technology (No. DH2020015), Open Foundation of Zhenjiang Key Laboratory for high technology research on marine functional films (ZHZ2019005), The Sun Bird Undergraduate Research Project of Dalian Minzu University (no. tyn2021405), and Training Program of Innovation and Entrepreneurship for Undergraduates in Dalian Minzu University (202112026572).

References

[1] X. Q. Shen, T. Takahashi, T. Ide, M. Shimizu, Phys. Status Solidi C **11**, 473 (2014).
[2] X. Lu, J. Ma, Z. J. Liu, H. X. Jiang, T. D. Huang, K. M. Lau, Phys. Status Solidi A **211**, 775 (2014).
[3] C. Liu, A. Kumamoto, H. Sodabanlu, M. Sugiyama, Y. Nakano, Phys. Status Solidi A **211**, 775 (2014).
[4] T. D. Huang, J. Ma, X. Lu, Z. J. Liu, X. L. Zhu, K. M. Lau, Phys. Status Solidi C **11**, 890 (2014).
[5] N. Onojima, N. Hirose, T. Mimura, T. Matsui, Appl. Phys. Lett. **93**, 223501 (2008).
[6] J. Bodzenta, B. Burak, A. Jagoda, B. Stańczyk, Diam. Relat. Mater. **14**, 1169 (2005).
[7] X. Q. Shen, T. Takahashi, T. Ide, M. Shimizu, Phys. Status Solidi B **252**, 1075 (2015).
[8] X. Chen, Y. H. Xing, J. Han, W. J. Huo, L. J. Zhong, M. Cui, Y. M. Fan, B. S. Zhang, Chinese J. Lumin. **35**, 727 (2014).
[9] G. A. Mustafaev, V. A. Panchenko, A. G. Mustafaev, N. V. Cherkesova, Photonics Res. **12**, 680 (2018).
[10] Q. Chen, R. Song, C. H. Chen, X. J. Chen, Solid. State Commun. **172**, 24 (2013).
[11] P. Bogusławski, Krzysztof Rapcewicz, J. J. Bernholc, Phys. Rev. B **61**, 10820 (2000).
[12] J. Kioseoglou, E. Kalesaki, L. Lymperakis, G. P.

Dimitrakopulos, Ph. Komninou, Th. Karakostas, Phys. Status Solidi A **206**, 1892 (2009).

[13] J. R. Gong, M. F. Yeh, C. L. Wang, J. Cryst. Growth. **247**, 261 (2003).

[14] T. D. Huang, X. L. Zhu, K. M. Lau, IEEE Electr. Device L **33**, 1123 (2012).

[15] T. Mitsunari, H. J. Lee, Y. Honda, H. Amano, J. Cryst. Growth **431**, 60 (2015).

[16] J. C. Zhanga, D. G. Zhao, J. F. Wang, Y. T. Wang, J. Chen, J. P. Liu, H. Yang J. Cryst. Growth **268**, 24 (2004).

---

*Corresponding author: yunaisen@dlnu.edu.cn;
yfwu@dlnu.edu.cn