H-5-1
Extended Abstracts of the 2009 International Conference on Solid State Devices and Materials, Sendai, 2009, pp895-896

Improvement in a-GaN crystal quality by investigating different buffer layer

Hsiao-Chiu Hsu [1] , Yan-Kuin Su[2]
[1] National Cheng-Kung University, Institute of Microelectronics,
1 University Road, Tainan, Taiwan 701, R.O.C
Phone: +886-919-839392 E-mail: audreyhsu1981@gmail.com
[2] National Cheng-Kung University, Institute of Microelectronics,
1 University Road, Tainan, Taiwan 701, R.O.C

1. Introduction

Current commercial GaN-based light emitting diodes (LEDs) are grown on c-plane of the hexagonal wurzite structure. However, the these devices are suffered a reduced efficiency and a redshift emission wavelength due to the quantum confined Stark effect.[1] On the other hand, it is also difficult to produce green light emitting diodes. Nonpolar GaN, growing direction is perpendicular to c-plane, can be avoided from the spontaneous and piezoelectric polarization effects.

Until now, some groups had demonstrated the nonpolar GaN lasers[2] and high efficiency nonpolar LEDs[3], including green LED. But nonpolar GaN devices had suffered the high threading dislocation (TDs) problem (10^{10} cm^{-2}) and rough surface due to the planar anisotropic nature of growth mode. In order to get high-quality nonpolar GaN with a smooth surface, most research groups used a low-temperature (LT) grown-GaN[4] or an AlN layer[5] as a buffer layer prior to the high-temperature (HT) grown-GaN similar to a conventional c-plane GaN.

In this work, we developed the direct growth method and studied different buffer layer for the smooth and pit-free surface of a-plane GaN layer by metal organic chemical vapor deposition (MOCVD).

2. Experiment procedure

In our experiments, all a-plane GaN films were grown on r-plane sapphire (within ±1°) using MOCVD reactor. Trimethylgallium (TMGa), ammonia (NH3) and disilane (Si_2H_6) were the precursors with hydrogen as the carrier gas. The growth process was concluded as follows: r-plane sapphire was heated in hydrogen gas at 1050°C for 10mins and implanted in ammonia gas for nitridation process at 1150°C. At first, we grow different buffer layer such as LT-GaN, HT-GaN and SiNx layer respectively, the details of growth condition were mentioned later, and observed the surface morphology after overlaying GaN layer. The overlaying GaN was direct-grown at 1150°C, 60mTorr and in a low V/III ratio (~50) for 90mins, resulting in the growth rate of 1.9μm/hr. In this experiment, we used scanning electron microscopy (SEM) and atomic force microscopy (AFM) to observe the surface morphology. The high resolution X-ray diffraction (HR-XRD) is used to verify the quality of a-GaN layer.

3. Result and discussion

In this section, we grow GaN layer with different temperature and compared the surface morphology after overlaying GaN layer. The V/III ratio (550) and deposited time (10 mins) were both fixed, while the growth temperature varied from 540°C to 1150°C. Both top and cross-sectional view of the samples are measured by SEM and shown in Fig. 1. Fig. 1 (a) and Fig. 1 (b) show the plane-view of GaN with nucleation layer grown at temperature of 540°C and 1150 °C, respectively. It is obvious that when rising the growth temperature to 1150°C, the surface becomes smoother and the less pits. Fig.1 (c) and (d) are the relative cross-sectional images of Fig. 1 (a) and (b), respectively. It is also observed that there are more voids in the bottom of the bulk film at lower growth temperature. The result shown that HT-GaN buffer layer could lead to smooth surface, also indicated there was less TDs in a-GaN film. However, there still were some inverse-pyramidal pits in a-GaN with HT-GaN (1150°C) buffer layer. In next section, we also studied other buffer layer to improve the roughness of a-GaN film.

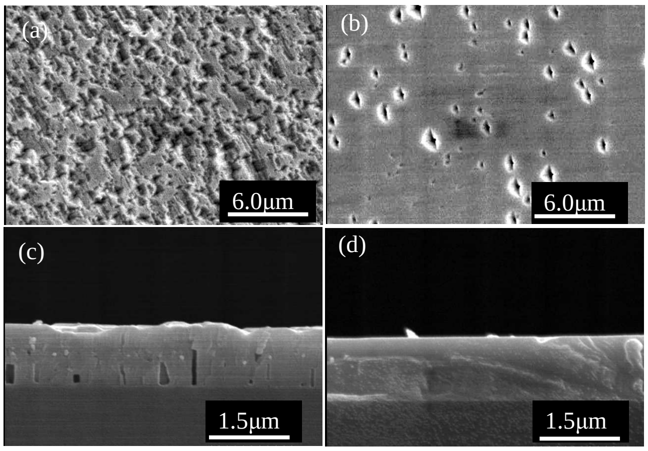

Fig. 1 (a) and (c) : Plane-view and cross-sectional SEM image of GaN grown at 540°C, respectively. (b) and (d) : Plane-view and cross-sectional SEM image of GaN grown at 1150°C, respectively.

In order to improve the film quality, some groups used an *in situ* SiN_x layer as a nanomask[6], deposited on r-sapphire before the nucleation layer, leading to the full recovery of the GaN surface from three-dimensional (3D) to two-dimensional (2D). In the experiment, *in situ* SiN_x interlayer was deposited by injecting ammonia (NH3) and disilane (Si_2H_6) at 600°C and 600Torr, resulting in around 10nm. Then, a HT-GaN as the buffer layer was deposited and a-GaN was overlaid following the same growth condition we mentioned in experiment procedure. Fig. 2 shows plane-view SEM and AFM images of overlaying GaN layer grown with and without *in situ* SiN_x interlayer, respectively. Compared Fig. 2(a) and Fig. 2(b), we found there were almost no pits when overlaying GaN with *in situ* SiN_x interlayer. The rms roughnesses measured by AFM were 11.82nm and 4.04nm for samples grown with and without SiN_x interlayer, respectively. The deposition of the SiN_x interlayer causes a 3D-2D growth mode transition means that roughed the surface first by forcing it into a 3D growth mode and then coalesced with 2D lateral-growth mode. However, Fig. 2(c) and Fig. 2(d) both shown that some stripe feature along c-direction ([0001]), resulting in rough surface and many pits in a-GaN film. In order to reduce the morphology of stripe features, we are also investigated the effect of HT-GaN buffer layer grown under different V/III ratio in next section.

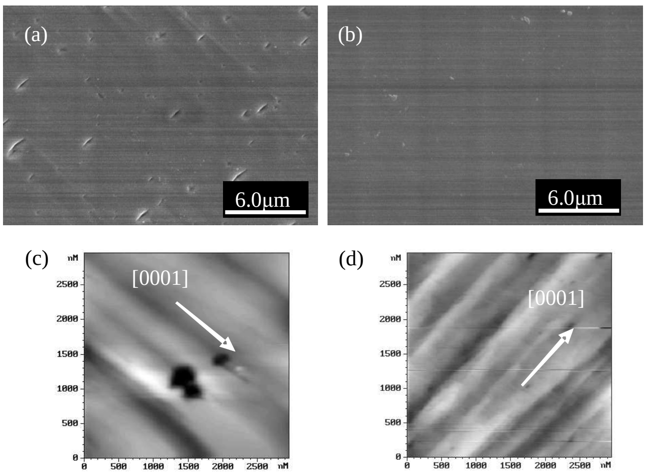

Fig. 2. (a) and (c) plane-view SEM and AFM images of GaN grown without SiN_x interlayer, respectively. (b) and (d) plane-view SEM and AFM images of GaN grown with SiN_x interlayer, respectively.

In this section, we were investigated the optimized V/III ratio of HT-GaN layer to improved the film quality. In this experiment, we deposited 10nm SiN_x interlayer on r-sapphire and grew HT-GaN with different V/III ratio for 600s at 60Torr. Then, 2μm-a-GaN layer is overlaid following the same growth procedure. We also used HRXRD to verify the film quality. Fig. 3(a) and Fig. 3(b) show plane-view SEM images of overlaying GaN layer grown under V/III ratio of 50 and 770, respectively. From Fig. 3, we could found that both of HT-GaN under different V/III ratio shown smooth surface and no inverse-pyramidal pits in a-GaN film. The FWHM measured by HR-XRD of HT-GaN with different V/III ratio from 50 to 770 were 202.3/201arcsec to 170/198.2arcsec along c- /m- ($[1\bar{1}00]$) direction. Therefore, the data indicated that SiN_x / HT-GaN with high V/III ratio is the optimized buffer layer for leading to a-GaN film quality. We found that HT-GaN buffer layer with high V/III ratio was more suitable to form the rough nucleation layer and easily transfer to lateral growth when overlaying a-GaN than low V/III ratio.

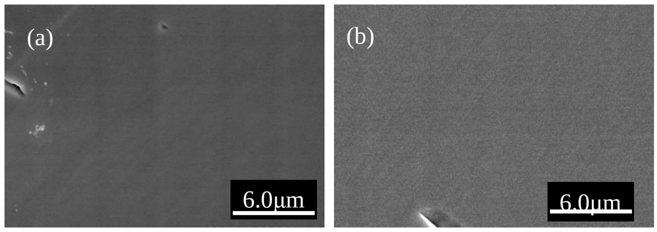

Fig. 3. Plane-view SEM image of GaN grown on the buffer layer of SiN_x / HT-GaN (a) with V/III ratio equal to 50, (b) V/III ratio equal to 770, respectively.

3. Conclusions

We investigated different buffer layer (or nucleation layer), including growth temperature and V/III ratio of GaN layer and *in situ* SiN_x interlayer, to improving the film quality of a-GaN on r-sapphire by MOCVD. We found that the inverse-pyramidal pits is reduced by implanting *in situ* SiN_x interlayer, a nanomask deposited on r-sapphire and the film quality is improved by growing HT-GaN layer with high V/III ratio as a buffer layer prior to fully coalesced a-GaN by lateral growth mode.

Acknowledgements

This work was supported by TDPA program and in part by National Science Council of the Republic of China (R.O.C.) in Taiwan under Contract Nos. (TDPA 97-EC-17-A-07-S1-105 and NSC 97-2623-E-168-001-IT)

References

[1] D. A. B. Miller, D. S. Chemla, T. C. Damen, A. C. Gossard, W. Weigmann, T. H. Wood, and C. A. Burrus: Phys. Rev. Lett. **53** (1984) 2173.
[2] K. Okamoto, J.Kashiwagi, T.Tanaka, and M. Kubota: Appl. Phys. Lett. **94** (2009) 071105.
[3] D. Iida , A. Miura, Y. Okadome, Y. Tsuchiya, T. Kawashima, T. Nagai, M. Iwaya, S. Kamiyama, H. Amano, and I. Akasaki: Phys. Stat. Sol. (a), **204** (2007) 2005 .
[4] 8) X. Ni, Y. Fu, Y. T. Moon, N. Biyikli, and H. Morkoc: J. Cryst. Growth, **290** (2006) 166.
[5] F. Wu, M. D. Craven, S. H. Lim, and J. S. Speck: J. Appl. Phys. **94** (2003) 942.
[6] T.S. Ko, T.C. Wang, H.M. Huang, J.R. Chen, H.G. Chen, C.P. Chu, T.C. Lu, H.C. Kuo, S.C. Wang: J. Cryst. Growth, **310** (2008) 4972.