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
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 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 (NH$_3$) and disilane (Si$_2$H$_6$) 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.
to two-dimensional (2D). In the experiment, in situ SiN\textsubscript{x} interlayer was deposited by injecting ammonia (NH\textsubscript{3}) and disilane (Si\textsubscript{2}H\textsubscript{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\textsubscript{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\textsubscript{x} interlayer. The rms roughnesses measured by AFM were 11.82nm and 4.04nm for samples grown with and without SiN\textsubscript{x} interlayer, respectively. The deposition of the SiN\textsubscript{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\textsubscript{x} interlayer, respectively. (b) and (d) plane-view SEM and AFM images of GaN grown with SiN\textsubscript{x} interlayer, respectively.](image)

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\textsubscript{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- ([1100]) direction. Therefore, the data indicated that SiN\textsubscript{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\textsubscript{x} / HT-GaN (a) with V/III ratio equal to 50, (b) V/III ratio equal to 770, respectively.](image)

3. Conclusions

We investigated different buffer layer (or nucleation layer), including growth temperature and V/III ratio of GaN layer and in situ SiN\textsubscript{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\textsubscript{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.

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