Structure of V-defects in a-GaN films grown on r-sapphire substrate

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Abstract. The a-GaN films were successfully grown on the r-sapphire substrate by MOCVD method. The structure of V-defects was investigated by AFM and SEM. The dependence of V-defects density on growth temperature of a-GaN film at a constant hydrogen flow through a TEG source was studied. The influence of V/III ratio on V-defects structure was investigated. Methods of V-defects density minimisation were purposed.

1. Introduction

InGaN/GaN films growth in nonpolar a-orientation is an important scientific and technological goal. It is known that the polarization effect leads to GaN bulk and surface changes in the band structure [1]. The films grown in a-nonpolar a-orientation usage can reduce the effect of the built-in field on the injected charge carriers distribution, reduce the nonradiative recombination rate, and improve the emitting devices efficiency, including laser diode. However, there were few difficulties in a-GaN growing and one of them is high density of structural defects due to significant mismatch between a-GaN and r-sapphire, mechanical strains and other factors. One type of such defects are V-defects. V-defects are pits on the surface, usually with a crystalline faceting. V-defects are well studied for the c-plane [2,3], and also V-defects were studied for semipolar GaN on a SiC substrate [4]. One the goals for this work was to expand the understanding of the formation of V-defects for a-GaN grown on r-sapphire.

In this research was investigated the structure of V-defects by AFM and SEM. Also, the dependence of V-defects density on growth temperature of a-GaN film at a constant hydrogen flow through a TEG source and the influence of V/III ratio on V-defects structure was studied. Optimized conditions for V-defects density minimization were purposed.

2 Experiment

a-GaN films were grown by MOCVD on r-sapphire substrates under reduced pressure (80 torr) with preliminary surface nitridisation. The source for III and V components were triethylgallium (TEG) and ammonia (NH\textsubscript{3}), respectively. The layered gas flow in the quasi-laminar regime in the horizontal reactor was carried out through a porous input. The upper gas mixture flow considered of N\textsubscript{2}, and NH\textsubscript{3} and the lower flow – H\textsubscript{2} and TEG. As source of donor and acceptor impurities, hydrogen sulphide(H\textsubscript{2}S) (0.5% mixture in argon) and bis(cyclopentadienyl) magnesium (Cp\textsubscript{2}Mg), respectively, were used. Preliminary, the sapphire surface was nitride at temperature 950 °C for 10 minutes.
3 Results and discussion

Using the X-ray and Raman scattering spectrum, it was confirmed that the grown films are single-crystal a-GaN. The measured half-width of the rocking curve is 1200-1400 arcsec.

For defects identification SEM and AFM were used. The form, symmetry and depth of the most common defects allow to identify them as V-defects.

Unlike V-defects on c-plane, on the a-plane, the direction of such defects is perpendicular to the growth direction. On the figure 1 the SEM imagines of V-defects structure before and after wet etching is represented. It can be seen, that there were not facets observed. This can be explained by intense overgrowth of c-directed facets of defects.

Figure 1 represents appearance of the V-defects before and after wet etching. The structure of this defect can be explained by its formation mechanism. The V-defects formation mechanism is associated with two competing processes – growth and decomposition of the film. On a semi-polar orientation, the V-defects nucleation place is the dislocations emergence that formed the nanotube. In such place, there is a change in the equilibrium conditions of growth. According to the crystals etching theory [4] at the site dislocation emergence on the surface, the free energy of the etching pits formation increases, respectively, with the crystal growth. In this place the V-defects appearance probability is significant.

![Figure 1](image1.png)

**Figure 1.** The SEM V-defect imagine: (a) before wet etching, (b) after wet etching in KOH

Figure 2 shows the image of this part of the defect obtained with the help of AFM. After etching, a structure appears in the form of terraces similar to those observed in the semi-polar direction [5]. However, the length of these terraces is much higher. It can be assumed that the angle of nanotubes, formed V-defects on a-GaN, is greater. This explains the great length of the terraces and the tail of the defect that appeared after etching. Also a possible explanation is the formation of groups of oblique V-defects by analogy with what is observed for lateral V-defects on InGaN.
According to the theory and experimental investigation\cite{6,7}, the V-defects concentration depends on the V / III ratio and decreases with its increase. In this paper, the confirmation for it was detected for a-GaN. The lowest V-defects concentration was obtained, at all other parameters being equal, and at a maximum V / III ratio – 1000, it was $2 \cdot 10^4 \, \text{cm}^{-2}$.

4 Conclusion

a-GaN was successfully grown on r-sapphire by MOCVD. Using the X-ray and Raman scattering spectrum, it was confirmed that the grown films are a-GaN single-crystal films. The dominant type of defects on the film surface was investigated by SEM and AFM: they were the defects similar by nature to V-defects on the c-plane. Using the wet etching, the defects internal structure was investigated. It was shown that, by analogy with semi-polar films, these defects were formed at the emergence areas inclined dislocations formed into nanotubes, while the geometry and internal structure of V-defects differ from those for c-plane and semi-polar films. The V-defects concentration dependence versus the V / III ratio was investigated and it is similar to the results obtained for the c-plane, which confirms once more the general nature for these defects. Additionally, the investigations of V-defects formation and influence on the electrical and crystallographic characteristics of the a-GaN films improve the injection efficiency and reduce the proportion of non-radiative carrier recombination and

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