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Selective growth of micro scale GaN initiated on top of stripe GaN

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We report on the growth and characterization of the nano- and micro scale GaN structures selectively grown on the vertex of GaN stripes using the metal organic vapor phase epitaxy method and conventional photolithography technique. The triangular shaped nano- and micro GaN structures which have semi-polar {11-22} facets were formed only on the vertex of the lower GaN stripes. Crystalline defects reduction was observed by transmission electron microscopy for upper GaN stripes. We also have grown the InGaN/GaN multi-quantum well structures on the semi-polar facets of the upper GaN stripes. Cathodoluminescence images were taken at 366, 412 and 555 nm related to GaN band edge, InGaN/GaN layer and defects, respectively.

Key words: GaN, Micro structure, Selective area growth, Semi-polar.

Introduction

The energy bands of III-nitride-based structures grown along the [0001] direction of the wurtzite structure are strongly affected by a substantial quantum confined stark effect (QCSE) and piezoelectric polarization [1-3]. The fields can cause significant separation of the electron and hole carrier wave functions and a red shift of the recombination energy. Internal electric field caused by spontaneous polarization and piezoelectric effect can be eliminated by growing devices on non- or semi-polar facets of GaN crystals based on selective area growth (SAG) of III-nitrides [4-6]. Recently, three-dimensional GaN micro structures with non- or semi-polar micro facets are utilized as base structures for the development of white light sources by the growth characteristics that the indium composition and growth rate of InGaN layers varied depending on crystalline orientations [7-8]. However, in these methods, laterally propagated threading dislocations initiated from the interface between substrate and GaN template can reach the inclined semi-polar facets where on InGaN/GaN multi quantum wells (MQWs) be grown. In this case, the deterioration of radiative recombination efficiency by the threading dislocations is unavoidable. Therefore, new methods for the formation of three dimensional GaN microstructures are needed to suppress the propagation of threading dislocations.

In this work, we propose a novel technique for the selective growth initiated only on top area of triangular shaped GaN stripes (hereafter, we call it lower GaN stripes). This approach can be effective growth method to realize literally three dimensional structures which available for many applications. The evolution of well aligned selectively grown GaN stripes (hereafter, we call it upper GaN stripes) which including {11-22} facets was realized only on top of the lower GaN stripes by selective epitaxial MOVPE (metal organic vapor phase epitaxy) growth. Reduction of threading dislocation and relaxation of strain can be expected because of small window area for the selective growth. The detailed fabrication process for the formation of the upper GaN stripes on top of the lower GaN stripes will be introduced. Distribution of crystalline defects was evaluated by transmission electron microscopy (TEM) and room temperature cathodoluminescence (CL).

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Experimental

Fig. 1 shows a schematic illustration of the fabrication procedure for the upper GaN growth on top of the lower GaN stripes. Firstly, the lower GaN stripes were selectively grown by the MOVPE on a GaN template with SiO_2 stripe patterns (window : 3 μm, mask : 7 μm) oriented along the <1-100> direction. TMG

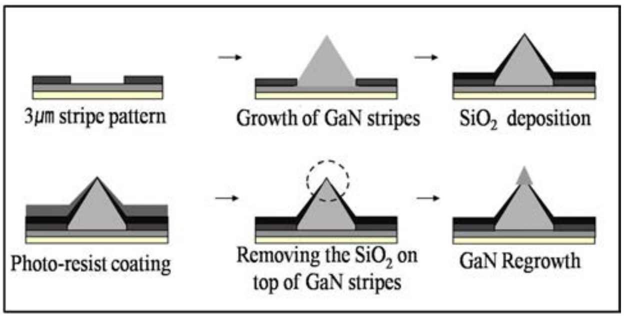

Fig. 1. Schematic illustration of the formation process for GaN stripes.

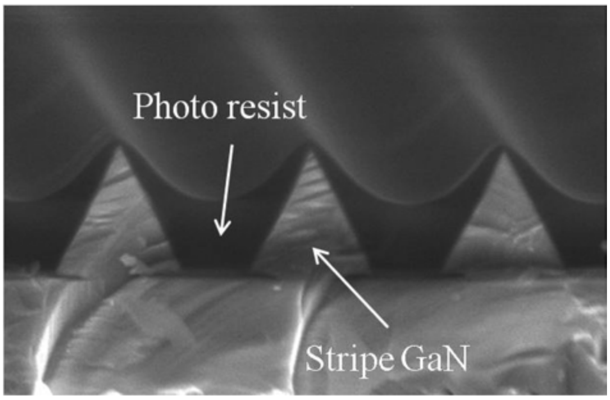

Fig. 2. Cross-sectional SEM image of the photo-resist coated on the lower GaN stripes.

(trimethylgallium) and NH_3 were used as precursors for the gallium and nitrogen sources. Reactor pressure was maintained at 760 torr and N_2 was used as carrier gas. The typical flow rates of TMG and NH_3 were 82 μmol/min and 3 slm, respectively. The growth temperature and growth time were 770 °C and 90 min, respectively. After the formation of the lower GaN stripes, SiO_2 film was deposited on the lower GaN stripes and followed by photo-resist (PR) coating as shown in Fig. 2. Thickness of the PR near top of the lower GaN stripes is thinner than other areas because of inclined facets of the lower GaN stripes. Chemical bonding of composites of the PR near top of the lower GaN stripes can be changed by relatively short duration of UV exposure while the other thick part of the PR may not have enough time to be completely changed. Because of the difference in chemical structure and thickness, the PR only near the top area can be removed by proper develop time. Final selective growth was performed at 770 °C after removing the SiO_2 on top of the lower GaN stripes. Typical flow rates of TMG and NH_3 were 82 μmol/min and 3 slm, respectively. The growth time was varied from 1 to 60 min with constant reactor pressure of 760 torr. Apart from the growth of the GaN micro-structures, we also performed a growth of GaN/InGaN multi-quantum well (MQW) structure on the semi-polar {11-22} facets of the upper GaN stripes to evaluate the possibility of applications of this new process to LEDs, LDs and other waveguide structures. The MQW structure was consisted of eight periods of InGaN/GaN layers grown at 800 °C and finally capped with 0.2 μm -thick GaN layer. We have also performed CL measurements on grown samples at room temperature.

Results and Discussion

Fig. 3 shows SEM images of the lower GaN stripes before the final selective growth and the upper GaN stripes depending on the growth time. The upper GaN stripes have triangular shape and the overall size

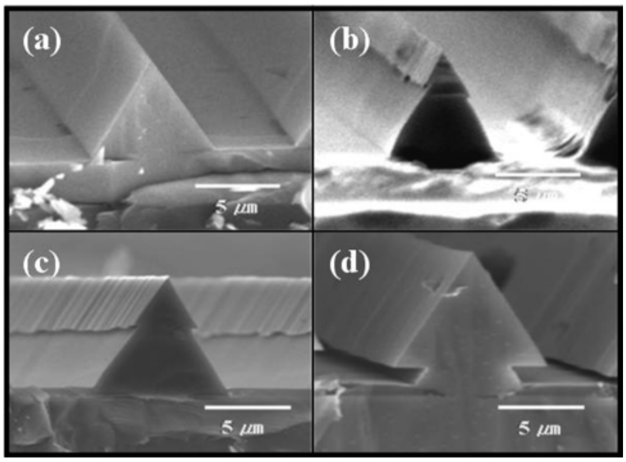

Fig. 3. SEM images of (a) lower GaN stripe before selective growth. The inclined side wall {11-22} facets show very smooth surface. Other images show the upper GaN stripe depending on the growth time of (b) 1 minute (c) 10 minutes (c) and (d) 60 minutes.

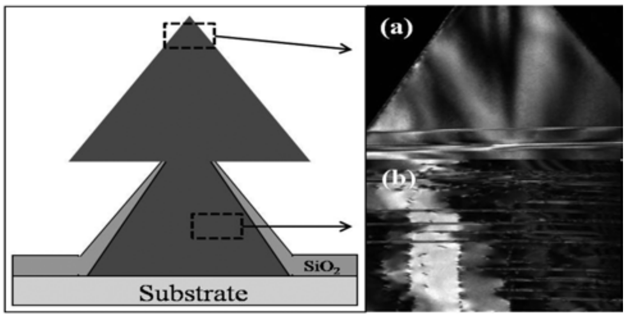

Fig. 4. TEM images of the (a) upper GaN stripe and (b) lower GaN stripe (scanning area are marked by square).

increased with growth time. The growth rate in the direction of <11-22> gradually decreased with the growth time; from 2.5 nm/s (1 minute) to 0.5 nm/s (60 minutes). The entire surface area on which epitaxial growth take place will be increased with growth time and this would be the main reason of the reduced growth rate. It is seen that the surface roughness of the upper GaN stripes is worse than that of the lower GaN stripes. This might be caused by the undulated boundary lines of SiO_2 films. It is necessary to optimize the photolithography process to get a smooth facet surface.

Fig. 4 shows TEM image of the GaN stripes (60 minutes grown sample). Many kinds of crystalline defects (including threading dislocation, edge dislocation, stacking fault) are seen in the lower GaN stripes. However, the crystalline defects are remarkably reduced in the upper GaN stripes. This result is attributed to the efficient blocking of the laterally propagating threading dislocations by SiO_2 mask and small window area for the selective growth. Although there are some stacking faults in the upper GaN stripe, but this new process is found to be an effective method to reduce crystal defects. Fig. 5 shows the cross

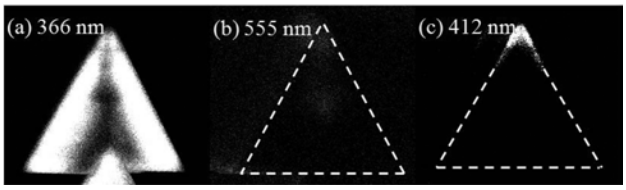

Fig. 5. Monochromatic CL images of the upper GaN stripe and the InGaN/GaN MQWs structure taken at (a) 366 nm, (b) 555 nm and (c) 412 nm.

sectional monochromatic CL images of the upper GaN stripe and InGaN/GaN MQW structure grown on the upper GaN stripe. Fig. 5(a) shows a monochromatic CL image taken at 366 nm corresponding to the band edge emission of GaN. Crystal quality of the selectively grown GaN is gradually improved as the thickness of {11-22} facets increased. However, the central area shows rather weak emission efficiency because of the crystal defects threading through the window area of the SiO_2 mask. Monochromatic CL image taken at 555 nm is shown in Fig. 5(b). Emitting area is mainly distributed in the central part of the upper GaN stripes where containing lots of crystal defects. Generally, yellow luminescence is attributed to the deep donor states caused by Ga vacancy (or a related complex), carbon incorporation from metal organic sources and other origins [9-12]. These results could confirm that the yellow luminescence is closely related to crystal defects even though there are many arguments about the exact origin. Fig. 5(c) shows a monochromatic CL image taken at 412 nm corresponding to the radiative transition of InGaN/GaN MQW. Spatially confined strong emission is observed near the top area of the upper GaN stripes. This quantum wire-like emission can be attributed to thicker quantum well width and higher indium composition in the top area compare to the other area in the {11-22} facets. The spatial inhomogeneous of quantum well thickness and indium composition is caused by the inhomogeneous growth rate and indium incorporation efficiency on the inclined {11-22} facets during the growth of InGaN/GaN MQW structure [13].

Conclusions

Literally three dimensional GaN stripes only on top of the lower GaN stripes were successfully fabricated by newly developed process. However, more precise control of the photolithography process is needed to get smooth side facet for the application of high performance optical devices. Reduction of threading dislocation density was confirmed by TEM in the selectively grown upper GaN stripes. It is confirmed that the crystal quality of the upper GaN stripes is gradually improved as the thickness of {11-22} facets increased. MQW structure grown on the upper GaN stripes shows spatially confined emission near the top region of the MQW structure. Although more optimized process to reduce crystal defects including threading dislocations in the central area of the three dimensional GaN stripes is needed, this new method would be the effective approach for the increase of radiation efficiency in optical devices such as LEDs and LDs because the selective growth was performed on semi-polar {11-22} facets. Furthermore, this method can be applied for the fabrication of optical waveguides and non-phosphor white LEDs based on three dimensional structures with less crystal defects and strain by the small window area for the selective growth.

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