Defect selective passivation in GaN epitaxial growth and its application to light emitting diodes

Citation: Appl. Phys. Lett. 95, 211103 (2009); doi: 10.1063/1.3266859
View online: http://dx.doi.org/10.1063/1.3266859
View Table of Contents: http://apl.aip.org/resource/1/APPLAB/v95/i21
Published by the American Institute of Physics.

Related Articles
Design and optimization of a light-emitting diode projection micro-stereolithography three-dimensional manufacturing system
Size-dependent efficiency and efficiency droop of blue InGaN micro-light emitting diodes
A bright cadmium-free, hybrid organic/quantum dot white light-emitting diode
Interplay of polarization fields and Auger recombination in the efficiency droop of nitride light-emitting diodes
Precise relationship between voltage and frequency at the appearance of negative capacitance in InGaN diodes

Additional information on Appl. Phys. Lett.
Journal Homepage: http://apl.aip.org/
Journal Information: http://apl.aip.org/about/about_the_journal
Top downloads: http://apl.aip.org/features/most_downloaded
Information for Authors: http://apl.aip.org/authors
Defect selective passivation in GaN epitaxial growth and its application to light emitting diodes

M.-H. Lo,1,2 P.-M. Tu,1 C.-H. Wang,1 Y.-J. Cheng,1,2,a) C.-W. Hung,1 S.-C. Hsu,2 H.-C. Kuo,1 H.-W. Zan,1 S.-C. Wang,1 C.-Y. Chang,3 and C.-M. Liu4

1Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, 1001 Ta Hsueh Rd., Hsinchu 300, Taiwan
2Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan
3Institute of Electronics, National Chiao Tung University, 1001 Ta Hsueh Rd., Hsinchu 300, Taiwan
4Sino-American Silicon Products Inc., Hsinchu 300, Taiwan

(Received 4 August 2009; accepted 28 October 2009; published online 24 November 2009)

A defect selective passivation method to block the propagation of threading dislocations in GaN epitaxial growth is demonstrated. The defect selective passivation is done by using defect selective chemical etching to locate defect sites, followed by silicon oxide passivation of the etched pits, and epitaxial overgrowth. The threading dislocation density in the regrown epilayer is significantly improved from $1 \times 10^8$ to $4 \times 10^7$ cm$^{-2}$. The defect passivated epwafer is used to grow light emitting diode and the output power of the fabricated chip is enhanced by 45% at 20 mA compared to a reference one without using defect passivation. © 2009 American Institute of Physics. [doi:10.1063/1.3266859]

GaN based light emitting devices have attracted great attention in last few years due to its importance in solid state lighting applications. Researchers are actively investigating various approaches to improve device performance. The devices are often epitaxially grown on foreign substrates, for example sapphire. The as grown GaN epitaxial layer has vices are often epitaxially grown on foreign substrates, for various approaches to improve device performance. The de-

![Defect selective passivation process flow](image)

**FIG. 1.** (Color online) [(a)-(d)] Defect selective passivation process flow.
The etch pit density counting all the individual pits is about 4 \times 10^8 \text{ cm}^{-2}. For large pits, SiO_2 only fills the side walls leaving a mechanical polishing step in Figs. 1(a)–1(c). Small pits are filled with SiO_2 only fills the side walls leaving a void in the center. The subsequent MOCVD epitaxial overgrowth covers the whole wafer with flat surface. A LED structure with 2 \mu m Si-doped n-GaN, ten pairs of InGaN/GaN multiple quantum wells (QWs), and a 30 nm Mg-doped p-GaN were grown on the template. The QW emission wavelength is at 425 nm.

To assess the TD reduction, a tunneling electron microscope (TEM) image was taken as shown in Fig. 3(a). The TD density can be estimated by directly counting the TD lines in the plane-view micrograph. The TD density estimated at the dashed line right below defect passivation layer is about 1 \times 10^9 \text{ cm}^{-2}. This number is slightly larger than the KOH etch pit density 5 \times 10^8 \text{ cm}^{-2}. The discrepancy is due to the fact that there can be multiple TDs under an etch pit as can be seen in Fig. 3(a). The TD density is significantly reduced to 4 \times 10^7 \text{ cm}^{-2} at the dashed line near the QW region. SiO_2 passivations at etched pits do effectively block the propagation of TDs. The SEM image however also shows that SiO_2 fillings do not occur on top of all TDs.

The optical characteristic is investigated by cathodoluminescent (CL) and SEM cross section images as shown in Figs. 4(a) and 4(b). These two images are taken by simply switching detection mode from cathodoluminescent detection to scattering electron detection under the same magnification condition and thus have one to one location correspondence. The CL intensity changes dramatically across SiO_2 passivation boundary. The bright CL spots are mostly located at the regrown GaN right on top of SiO_2 passivation masks. The intensity of bright CL spot is so high that when it
enhancement. A simplified two-dimensional array of inverted hexagonal pyramid SiO$_2$ masks is used to model the defect passivation. Various geometries with 0.7–1 μm lateral size, 0.5–1 μm height, and 3–4 μm center to center spacing are calculated and show a variation of light extraction enhancement from 10%–25%. It shows that light extraction enhancement cannot be totally neglected in the total 45% output power enhancement. The output power enhancement from TD defect reduction is not as large as the above measured CL intensity enhancement. It has been reported that InGaN quantum well emission is less sensitive to TD defects. LEDs using GaN or AlGaN active layer is however very sensitive to TD defects and really requires the reduction of TD.\textsuperscript{14,15}

In summary, we have demonstrated a defect selective passivation method to reduce TD density and used it to fabricate a LED. The defect passivation SiO$_2$ masks are self-aligned to the TD defect pits created by KOH defect selective etching without photolithography patterning and can significantly reduce TD density from $1 \times 10^9$ to $4 \times 10^7$ cm$^{-2}$. The SiO$_2$ masks also improve the light extraction efficiency in LED application. TEM image shows that some defects are resistive to KOH etching and propagate all the way to the top surface. Further improvement can be made by exploring additional etching chemicals that are complementary to KOH in defect selective etching to increase the coverage rate of defect selective passivation.

This work was financially supported by Sinica Nano-program and in part by the National Science Council of Republic of China (ROC) Taiwan under Contract NSC97-2112-M-001-027-MY3.