Extended Abstracts of the 2017 International Conference on Solid State Devices and Materials, Sendai, 2017, pp309-310

G-2-02

Ultraviolet light emitting diodes grown on Si-implanted GaN template

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Abstract

GaN-based ultraviolet light emitting diodes (UV LEDs) grown on GaN template layer with selective-area Si ion implantation were demonstrated. GaN-based films grown on the Si-implanted GaN (SIG) layer exhibited selective growth and subsequent lateral growth over the Si-implanted area. This growth model behaves like ELOG (epitaxial lateral overgrowth of GaN) mechanism to reduce the density of threading dislocations (TD) in the overgrown area. Experimental results indicated that UV LEDs grown on the SIG template exhibits significant improvement in light output power compared with those of LEDs grown on implantation-free GaN template. This difference are mainly attributed to the fact that average TD density observed from the GaN-based layers grown on the SIG is markedly lower than on the implantation-free GaN template.

1. Introduction

Ultraviolet (UV) light sources have extensive commercial applications including curing, lithography, skin tanning, sterilization of water, catalysis for air purification, sensing, and 3-dimension printer. AlGaN-based light-emitting diodes (LEDs) are promising for UV light sources owing to their advantages which include safety and compact size. Approaches for improving light output power of AlGaN-based UV LEDs including hole-blocking and electron-blocking layer [1], heavily Si-doped GaN transition layer [2], and epitaxially laterally overgrown on GaN [3] have been demonstrated. Nakamura et al. studied the technology about epitaxially laterally overgrown GaN used to optical devices [3-4]. In the search for improved internal quantum efficiency, one of the key are recognized on the issue of crystalline quality such as threading dislocation (TD) density in the GaN-based epitaxial layers. ELOG is a well-known technique to reduce the TD density in the GaN-based epitaxial layers grown on sapphire substrate and thereby improve the light output power of GaN-based emitters [5]. The conventional ELOG process uses striped SiO_2 film to be the mask layer for the epitaxially laterally overgrown on GaN/sapphire template. In this study, selective-area Si implantation performed on GaN layer to create damaged surface regions that lead to lattice distortion from the neighboring implantation-free regions. The damaged regions behave like the SiO_2-masked area in the ELOG template. In other words, the GaN epitaxial layers regrown on the SIG templates exhibited selective growth on the implantation-free area and subsequent lateral overgrowth on the Si-implanted area. Experimental results indicated that average TD density observed from the GaN-based layers grown on the SIG is markedly lower than on the implantation-free GaN template. In addition, the GaN-based UV LEDs grown on SIG templates exhibited significant improvement in light output power compared with the LEDs grown on the implantation-free GaN templates.

2. Experimental

In this study, unintentionally doped (u-GaN) templates were grown on c-face (0001) sapphire substrates in a vertical metalorganic vapor phase epitaxy system (MOVPE). The layer structure of u-GaN template consisted of a 30nm-thick GaN nucleation layer and a 2μm-thick u-GaN layer grown at 560℃ and 1050℃, respectively. A 90 nm-thick SiO_2 layer was deposited on the u-GaN layer to avoid channeling effect during ion implantation. A 6 μm-thick photoresist (PR, AZ 4620) layer, which served as mask layer to shade ion flux, was coated on the SiO_2/u-GaN wafers. Fig. 1 shows the layer structure of PR/SiO_2/u-GaN wafers used in the subsequent selective-area ion implantation. Si ion (Si^{+28}) implantation was performed on the PR/SiO_2/u-GaN wafers to fabricate Si-implanted stripes on the u-GaN layer. The dosage and acceleration energy of Si ions were $1 \times 10^{16}/cm^2$ and 70 keV, respectively. The Si implanted layer had an average depth of approximately 60 nm from the u-GaN surface. PR layer was developed with A μm-wide opening through photolithography while the masked area had a width of B μm. In this study, A had four different values, i.e., 8, 7, 6, and 3, which correspond to four different B values, i.e., 3, 4, 5 and 20, respectively. Thus, the UV LEDs grown on SIG templates were labeled as LED-3x8, LED-4x7, LED-5x6, and LED-20x3, respectively. For comparison, the u-GaN templates without Si implantation were also prepared for subsequent epitaxial growth of UV LEDs. After Si-implantation, the SiO_2 layer and photoresist were removed from the u-GaN templates, GaN-based UV LEDs emitting at 375nm were grown by metalorganic vapor phase epitaxy system (MOVPE) on the Si-implanted GaN templates. After the epitaxial growth, standard device fabrication procedures including etching and metal deposition were conducted to fabricate the LED chips for characterization [6].

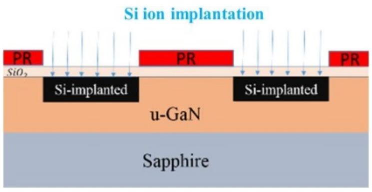

Fig. 1 Layer structure of PR/SiO_2/u-GaN wafers used in the subsequent selective-area ion implantation.

3. Results and Discussion

Fig. 2 shows typical TEM (transmission electron microscopy) images taken from the GaN layer epitaxially grown on the SIG templates. The TEM inspection revealed dense TDs originating from the u-GaN/sapphire interface and extending along growth direction, i.e., <0001> direction, as shown in Fig. 2(b). However, the TDs were markedly interrupted by the Si-implanted region. As a result, the average TD density in the epitaxial layers could be significantly reduced compared with those of GaN epitaxial layers grown on Si implantation-free regions.

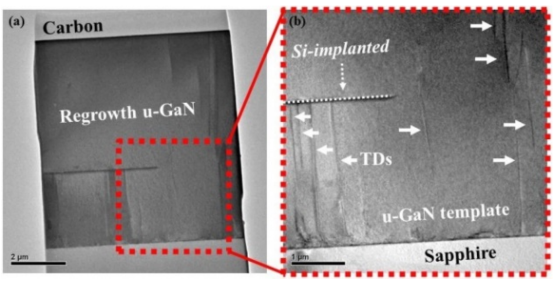

Fig. 2 Transmission electron microscopy (TEM) images taken from the LED-4x7 sample at the boundary between the regrown GaN layer and the Si-implanted regions.

Fig. 3 shows the light output powers (L_{OP}) versus injection currents of UV LEDs. It is clear that UV LEDs exhibit relative higher L_{OP} compared with the reference samples. One suggests that the enhancement in L_{OP} could be attributed to the lower TD-related defect states in the LED structure. This results are consistent with the TEM inspection that the GaN epitaxial layers regrown on the SIG templates exhibited selective-area growth on the implantation-free area and subsequent lateral overgrowth on the Si-implanted area to cause the reduction of TD density in the GaN-based layers.

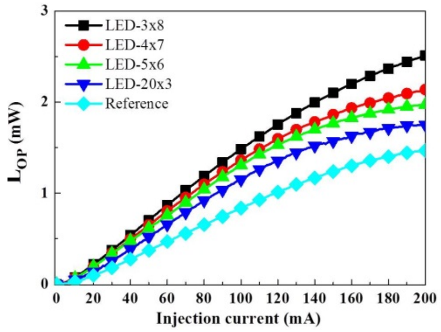

Fig. 3 The light output power (L_{OP}) versus injection current of all samples.

4. Conclusions

GaN epitaxial layers grown on the Si-implanted GaN templates exhibiting ELOG mechanism have been demonstrated. The preliminary results showed that relative lower TD density in the GaN-based epitaxial layers can be achieved and thereby result in an enhancement of L_{OP} for the UV LEDs grown on Si-implanted GaN templates compared with those of LEDs grown on implantation-free GaN templates. Detail results including optical and electrical properties regarding the UV LEDs grown on the Si-implanted GaN templates will be presented in the forthcoming conference.

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