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350.9 nm UV laser diode grown on sapphire substrate

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The combination of a low-temperature-deposited AlN interlayer technology and lateral seeding epitaxy (Hetero-ELO) yielded crack-free and low-dislocation-density AlGaN. The AlGaN over the grooves has a dislocation density as low as 2×10^7 cm^{-2} due to the lateral growth effect, in contrast with a high dislocation density of 5×10^9cm^{-2} over terrace region. We demonstrated a UV-laser diode grown on this low-dislocation-density AlGaN. The ridge stripes of the UV-LD were aligned on this low-threading-dislocation-region. The lasing wavelength under pulsed current injection at room temperature was 350.9 nm.

1 Introduction

Recently, high efficiency opto-electronic devices in the blue and the green region using group III nitride semiconductors have been developed by achieving the breakthroughs: improvement of crystalline quality using a low-temperature-deposited (LT-) buffer layer technique [1] and realization of conductivity control of nitrides [2–4]. In these devices, GaInN-based quantum wells grown on the GaN layer are usually used as an active layer.

UV laser diodes (UV-LDs) are being recognized as a leading edge technology for frontier applications, such as super high-density optical storage, chemical sensing and as a light source for fine lithography. Recently, UV-LDs were reported in which an AlGaInN and GaN/AlGaN MQW active layer grown on a low-dislocation-density GaN layer by epitaxial lateral overgrowth was used [5, 6]. However, this type of device structure is not applicable at significantly shorter wavelengths, because AlGaN cladding layers with a high AlN molar fraction cause serious cracking when they are grown on the GaN layer [7, 8]. We succeeded in growing crack-free, thick and high-crystalline quality AlGaN by an LT-AlN interlayer technique [9]. TEM study showed that pure screw-type and mixed-type dislocations in the AlGaN films were reduced, while high-density pure edge-type dislocations were contained as high as 10^9 cm^{-2} in these films [10]. Therefore, the fabrication of highly luminescent AlGaN was difficult.

In order to reduce all types of threading dislocations in GaN, additional growth technique named "epitaxial lateral overgrowth" has been performed and led to the success of growing partially very low dislocation density GaN [11]. Unfortunately, due to a strong adhesion of Al on the mask surface, it is difficult to apply epitaxial lateral overgrowth technique to grow AlN containing alloys. Moreover, these techniques also have a problem of crack generation for AlGaN growth. We succeeded in reducing all types

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of threading dislocations on a periodically grooved GaN layer covered with an LT-AlN interlayer (hetero-ELO). AlGaN over the grooved regions has a low dislocation density.

We have fabricated on a pulsed operation of UV-LD [12] using a GaN/AlGaN MQW active layer grown on the thick and crack-free AlGaN underlying layer having a low threading dislocation density. In this paper, we describe the details of the fabrication procedure and the characteristics of the UV-LD with a GaN/AlGaN MQW active layer.

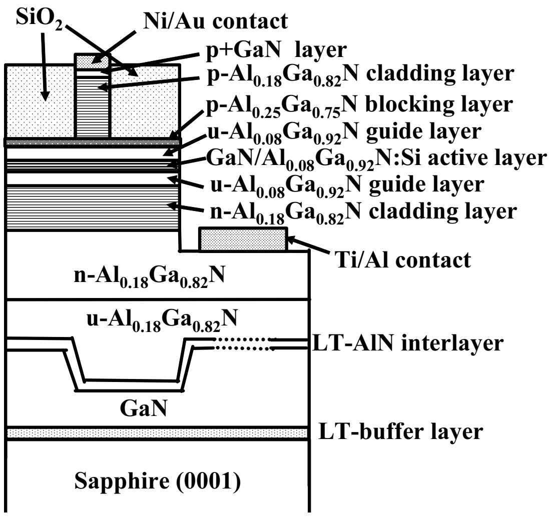

Fig. 1 Schematic view of sample structure.

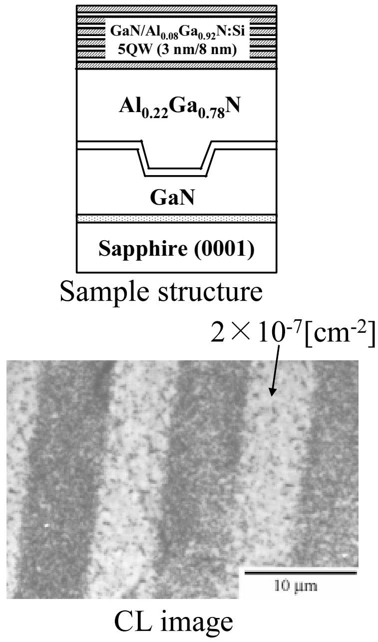

Fig. 2 Cathodoluminescence image of GaN/AlGaN grown on AlGaN using hetero-ELO technology.

2 Experiments

Figure 1 shows the device structure of UV-LD with a separated confinement heterostructure of a GaN/AlGaN MQW active layer grown on the low-dislocation-density AlGaN obtained hetero-ELO technology. All the nitride layers in this device were epitaxially grown on a sapphire substrate by organometallic vapor phase epitaxy. After depositing the LT-buffer layer with the thickness of about 20 nm at 500 °C, 3 µm-thick GaN was grown at 1100 °C. Grooves along the <1 $\bar{1}$ 00> direction were formed by conventional photolithography and Cl_2 reactive ion etching (RIE).

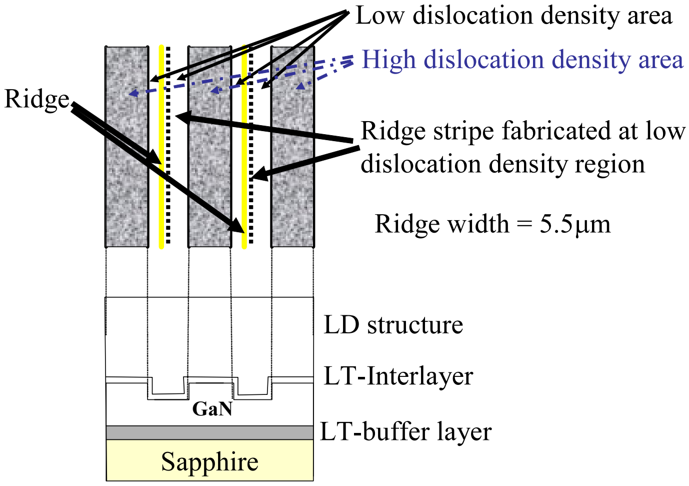

Fig. 3 The active region of the UV-LD was aligned on this low-threading-dislocation-density.

The width, spacing and depth of the grooves were 10 µm, 10 µm and 1.5 µm, respectively. Then LT-AlN with the thickness of 20 nm, which is effective for suppressing crack generation, was deposited at 500 °C on the GaN surface with the periodic grooves. The thickness of both the unintentionally doped $Al_{0.18}Ga_{0.82}N$ layer and the Si-doped n-$Al_{0.18}Ga_{0.82}N$ contact layer with electron concentration of 2×10^{18} cm^{-3} was 4 µm each. The AlGaN over the

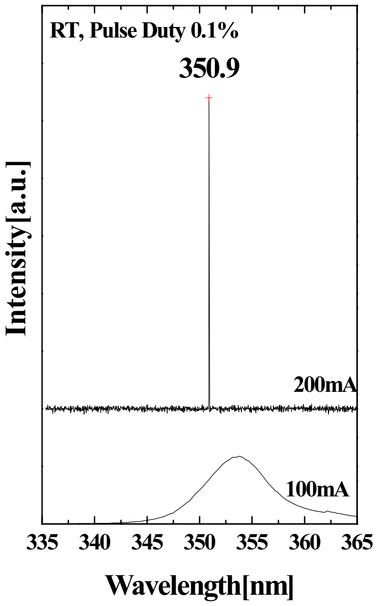

Fig. 4 Electroluminescence spectra under RT pulsed condition at injection currents of 100 mA and 200 mA.

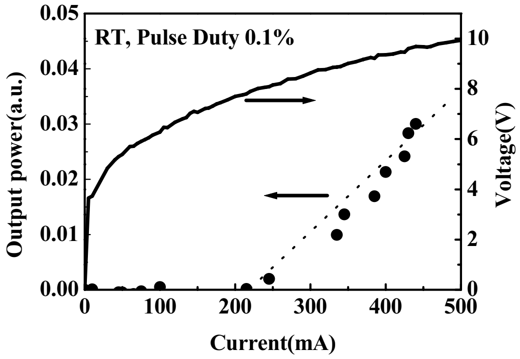

Fig. 5 L-I curve and V-I curve of UV-LD under pulsed condition at RT.

grooved regions has a low dislocation density less than 2×10^7 cm^{-2}. In cathodoluminescence mapping of the AlGaN using hetero-ELO technology as shown in Fig. 2, clear contrast was observed. In Fig. 2, the dark area corresponds to the terrace regions, while the bright areas with a dark spot correspond to the groove regions. In the dark regions, the density of threading dislocation is about 5×10^9 cm^{-2}, while that in the groove regions is 2×10^7 cm^{-2}. Then, an unintentionally doped $Al_{0.08}Ga_{0.92}N$ guide layer (120 nm), MQW active layer with three pairs of GaN (3 nm)/$Al_{0.08}Ga_{0.92}N$:Si (8 nm), an unintentionally doped $Al_{0.08}Ga_{0.92}N$ guide layer (120 nm), a p-type $Al_{0.25}Ga_{0.75}N$ (20 nm) blocking layer, a p-$Al_{0.18}Ga_{0.82}N$ (700 nm) cladding layer and a p+-GaN (20 nm) contact layer were successively stacked. The ridge stripes of the UV-LD were aligned on this low-threading-dislocation-region as shown Fig. 3. The laser cavity mirrors were formed by cleaving. The width of the ridge and a cavity length were 5.5 µm and 500 µm, respectively. A Ni/Pt/Au was evaporated on to the p^+-GaN contact layer, while a Ti/Al was deposited onto the n-$Al_{0.10}Ga_{0.90}N$ contact layer. Electrical and optical characterizations were performed at room temperature (RT) under the pulsed conditions with 1 µs width and 1 kHz repetition which correspond to the duty ratio of 0.1%.

Figure 4 shows the electroluminescence spectra of an UV-LD with injection currents of 100 mA and 200 mA. The peak spontaneous emission at 353.8 nm with full-width at half maximum of 6.0 nm was observed when the injection current was 100 mA. Upon increasing the injection current up to 200 mA, a strong and sharp lasing spectrum distinctly appeared at the wavelength of 350.9 nm. Figure 5 shows L-I and V-I curves of this UV-LD. The point of inflection of L-I curves was checked in about 200mA. Measurement of these curves was making equipment drive in the terminus of the pulse width of injection current. Therefore, it is threshold current higher than the injection current when the lasing spectrum appeared under the influence of the heat by current pouring. The corresponding current density at 200mA is 7.3 kA/cm^2. The operating voltage is 7.7 V at forward current of 200 mA. In order to realize the LD with continuous wave operation, the operating voltage must be reduced.

3 Conclusion

We have fabricated UV-LD having GaN/AlGaN MQW on thick, crack-free, low-dislocation density AlGaN grown by the combination of the hetero-ELO and LT-interlayer. The lasing wavelength was 350.9 nm under pulsed current injection at room temperature.

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