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Extremely Long Lifetime Blue-violet Laser Diodes Grown Homoepitaxially on GaN Substrates

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1. Introduction

The lifetime of laser diodes (LDs) depends heavily on the dislocation density. GaN grown by epitaxial lateral overgrowth (ELO-GaN) has been proven to be effective in reducing the dislocation density [1-3], and we have reported that LDs fabricated on ELO-GaN with a dislocation density of $\sim 3 \times 10^6$ cm^{-2} yielded a mean time to failure (MTTF) of 15,000 h under 30 mW continuous wave (cw) operation at 60 °C [4]. Furthermore, the authors have recently reported the characteristics of LDs homoepitaxially grown on GaN substrates, and demonstrated the extension of low dislocation density of around 1.0×10^5 cm^{-2} over an area 150 μm wide, along with high-quality cleaved facets [5]. When the dislocation density is reduced to the low 10^5 cm^{-2} level, only a small number of dislocations will be present in the laser stripe, and LDs with extremely long lifetimes will be achievable.

In this paper, the relationship between laser lifetime and dislocation density is investigated using a newly developed GaN substrate. The growth pit technique is employed to evaluate the dislocation density [6]. A blue-violet laser with few or no dislocations in the stripe region is demonstrated and verified to have an extremely long lifetime.

2. Experimental

Laser structures were grown by metalorganic chemical vapor deposition on a GaN substrate newly developed by Sumitomo Electric Industries, Ltd. The substrate used was a (0001) n-type GaN substrate with 10 μm core regions arranged in the <1-100> direction with 400 μm periodicity. The detailed laser structure has been reported elsewhere [7]. The 1.5 μm-wide ridge stripes were formed on the low dislocation density region, and the p-type and n-type electrodes were evaporated onto the p-GaN contact layer and back of the n-GaN substrate, respectively. The cavity length was 600 μm. The front and rear facets were coated with a 5% anti-reflective film and a 95% high-reflectivity film, respectively. The spatial distribution of dislocations in the GaN substrate was determined by the growth pit technique.

3. Results and discussion

3-1 Distribution of dislocation density

The dislocation densities in the epitaxial layer are plotted in Fig. 1 as a function of distance from the core center. A schematic diagram of a cleaved facet is provided in the same figure. The distribution of dislocation density between the cores is concave up. It should be noted that the area of low dislocation density ($<1.0 \times 10^6$ cm^{-2}) extends for over 150 μm, and the minimum density is 2.8×10^5 cm^{-2}. This number implies the presence of only 3 to 9 dislocations in a laser stripe with area $\sim 1.0 \times 10^{-5}$ cm^2. These values are an order of magnitude lower than for ELO-GaN. Aggregatory growth pits were observed at intervals of 20 μm around the cores, while in the central region between the cores the dislocations were observed at intervals of 60 μm. Therefore, it is possible that a number of laser stripes will contain no dislocations at all considering the 1.5 μm width of these LDs.

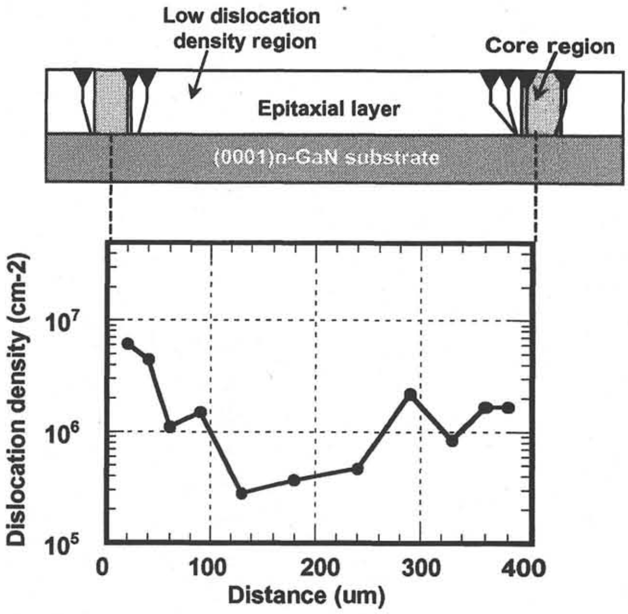

Fig.1 Corresponding dislocation density at the surface.

3-2 Characteristics of LDs

Typical light output power versus current (L-I) and voltage versus current (V-I) characteristics under cw operation at 25 °C are shown in Fig. 2. An illustration of the LD chip structure is also provided. The emission wavelength was approximately 410 nm, and the threshold current, operating current, and operating voltage at 30 mW operation were 28.8 mA, 45.9 mA, and 5.1 V. These values are almost the same as for lasers with an identical layered structure grown on ELO-GaN. The slope efficiency for the GaN substrate is 1.6 W/A, which is higher than that for ELO-GaN (1.5 W/A), suggesting that the cleaved facets of the GaN substrate are of high quality.

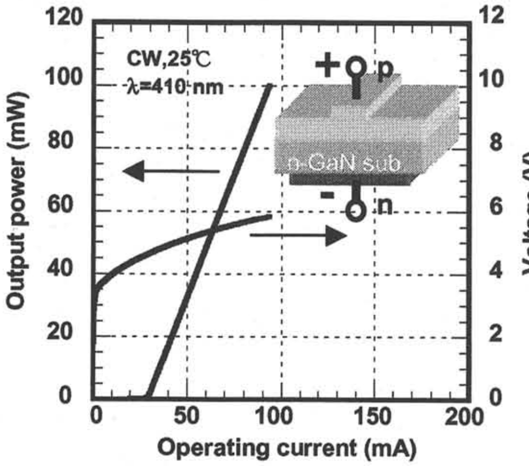

Fig.2 Typical L-I and V-I characteristics.

If the laser stripes do not contain dislocations, highly reliable LDs should be obtained. Fifteen LDs selected randomly from several wafers were subjected to a lifetime test, and the results for two LDs are shown in Fig. 3. The lifetime is defined as the time at which the operating current reaches 120% of the initial current. The test was performed under 30 mW cw operation at 60 °C. The LDs have been operating for more than 600 h. Notably, the aging curves exhibit no appreciable degradation. The increase in the

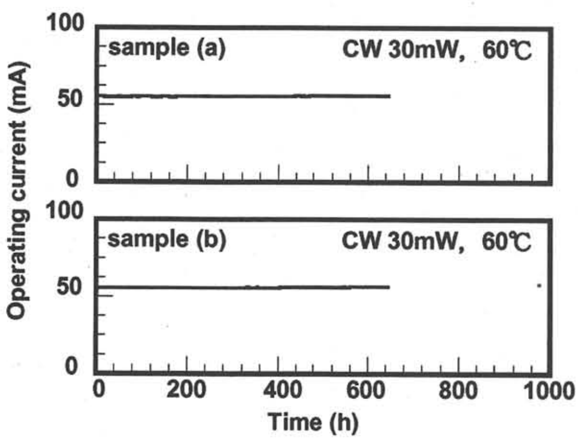

Fig.3 Lifetime test of Blue-violet Lasers under 30mW cw operation at 60℃

operating current at 500 h divided by the initial operating current, ΔI, can be used as an indicator of device lifetime. The values of ΔI for LDs (a) and (b) in Fig. 3 are 0.3 and 1.0%, respectively. The most reliable LD fabricated on ELO-GaN with an MTTF of over 15,000 h exhibited a ΔI of 3.0 to 4.0%. As the ΔI values for the present LDs are up to a magnitude lower, a lifetime of over 100,000 h can be expected. This result demonstrates that LDs with extremely long lifetimes can be realized by excluding dislocations from the laser stripe.

4. Conclusions

The relationship between laser lifetime and dislocation density was investigated using a newly developed GaN substrate. Blue-violet lasers with no appreciably degradation due to aging were demonstrated for the first time, attributed to the inclusion of very few or no dislocation in the laser stripe region.

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