High power and wide wavelength range AlInGaN laser diodes

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ABSTRACT

For high speed and multiplayer recording of high-density optical disc system, we fabricated higher power violet LDs. Moreover, we fabricated high power blue LDs with an emission wavelength of 445nm for the blue light source of full color laser displays. At a result, the characteristics of these violet and blue LDs have been achieved the practically acceptable level. These LDs are useful for optical memory devices and full color laser displays.

Key words: AlInGaN, laser diode, high power, violet, blue

1. INTRODUCTION

Ten years has passed since the first demonstration of GaN-based violet laser diodes (LDs) by current injection 1995 [1]. We have been developing longer lifetime and higher output power LDs by using GaN substrates by using laterally overgrown GaN (ELOG) [2] which has lower the dislocation density. The commercialization of high power LDs with an optical output power of 30 mW has been started in 2000 [3]. However, for high-speed and multiplayer recording, even higher power LDs is expected. Therefore, we fabricated higher power violet LDs and evaluated these LDs characteristics. Moreover, we developed high power blue LDs with an emission wavelength of 445nm, which was proposed to apply as the light source for full color laser displays. In this paper, we report the fabrication of high power violet (405nm) and blue (445nm) LDs and the detail of these LDs characteristics.

2. DEVICE STRUCTURE

In the beginning, GaN-LDs were fabricated by using sapphire substrates with the dislocation densities of 10^8-10^{10} cm^{-2}. The estimated lifetime of these LDs was below a few hours even under low-power CW operation. After that, the lifetime of GaN-based LDs was dramatically improved by using the epitaxially laterally overgrown GaN (ELOG) technology on sapphire substrate. As a result of that, the commercialization of violet LDs with an optical output power of 30mW has been started [3]. However, it was necessary to change the substrate for the higher power and reliability. The n-type free-standing GaN substrates have various advantages for high-power LDs such as low thermal resistance, easy cleavage, and constructing simple process. In this paper, we fabricated the high-power GaN-based LDs grown on the n-type free-standing GaN substrates [3, 4] with the threading dislocation density of 10^5-$10^6 cm^{-2}$. InAlGaN films were grown by the metalorganic chemical vapor deposition (MOCVD) method. Figure 1 shows a basic schematic structure of high power GaN-based LDs. The LD structure was separate confinement hetero-structure multiple quantum well (SCH-MQW) with buried ridge-waveguide. It consisted of n-type cladding layer, n-type waveguiding layer, MQW active layer, p-type electron blocking layer, p-type waveguiding layer, p-type cladding layer, and p-type contact layer. The area of ridge-geometry LD was modified to decrease the operating current density at higher output power. N-electrode was evaporated onto the bottom of n-type GaN substrate. The laser cavity was formed by cleaving the facets along (1-100) face. In this work, all LDs were mounted on the conventional package (5.6 mm stem).

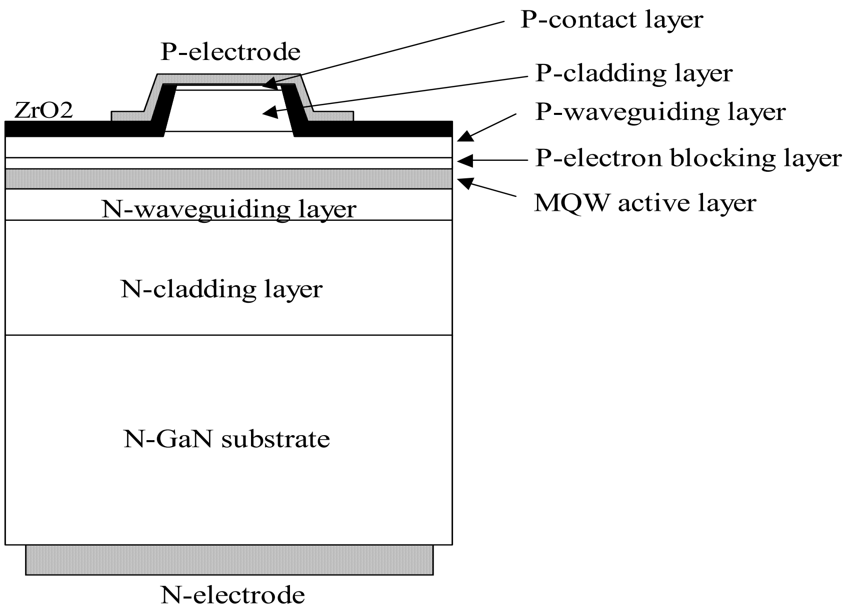

Figure 1 Schematic structure of GaN-based LD.

3. VIOLET LDS

In this section, we describe high power violet LDs for high-speed and multiplayer recording of the optical disk. The InGaN MQW LD structure was grown on the free-standing GaN substrates.The InGaN MQW LD structure consisted of a 2-µm-thick cladding layer of n-type AlGaN, a 0.15-µm-thick waveguiding layer of undoped GaN, an active layer of two pair (InGaN / InGaN) MQW structure, a 10-nm-thick electron blocking layer of p-type AlGaN, a 0.15-µm-thick waveguiding layer of undoped GaN, a AlGaN / GaN modulation-doped strained-layer superlattice (MD-SLS) cladding layer consisting of 100 pairs of 2.5-nm-thick Mg-doped GaN layers separated by 2.5-nm-thick undoped AlGaN layers and a 15-nm-thick layer of p-type GaN.

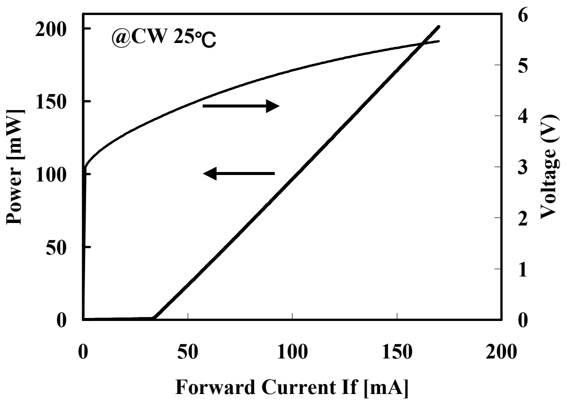

Figure 2 Typical L-I and V-I characteristics of LDs with a lasing wavelength of 405 nm under 25ºC-CW operation.

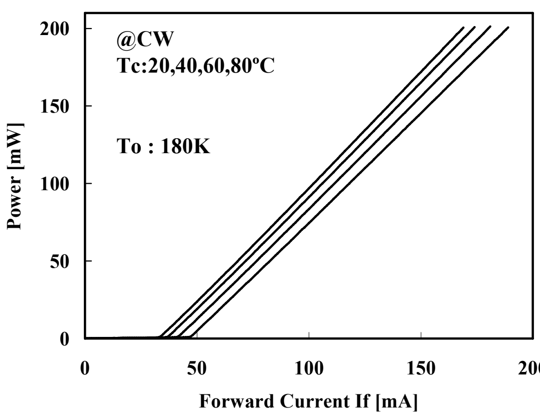

Figure 3 Temperature dependence of L-I characteristics.

The structure of the buried ridge-geometry InGaN MQW LD was optimized in order to maintain the linearity of the optical output power versus current (L-I) characteristics. N-electrode was evaporated onto the bottom of n-type GaN substrate. The laser cavity was formed by cleaving the facets along (1-100) face. The front and rear facets were coated with anti-reflection and high-reflection film, respectively.

Figure 2 shows the typical current-voltage (I-V) characteristics and the light output power per facet of the lasing wavelength 405 nm LD as a function of the forward dc current (L-I) at 25 ºC. There were no kinks up to the optical output power of 200mW. The operating current and voltage at an output power of 160 mW were 143 mA and 5.2 V, respectively.

Figure 3 shows the temperature dependence of the L-I characteristics from 20 ºC to 80 ºC. The linearity of the L-I characteristics was maintained up to high temperature 80 ºC. The characteristic temperature (To) was estimated to be 180K.

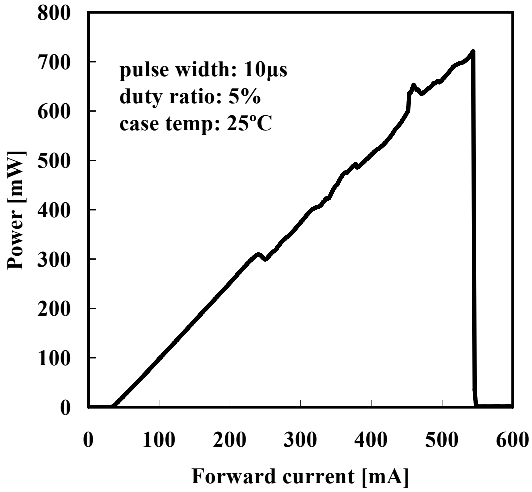

Figure 4 Result of Catastrophic Optical Damage (COD) test.

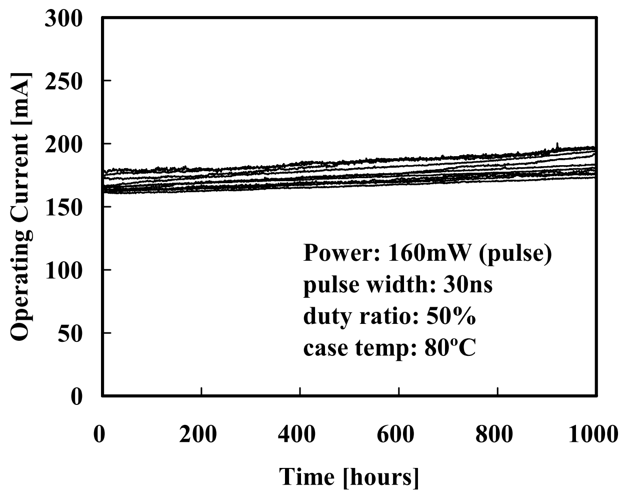

Figure 5 Result of lifetime test of single mode violet LDs under 160 mW pulsed operation at 80 ºC.

Figure 4 shows the result of Catastrophic Optical Damage (COD) test. There was no catastrophic damage up to the optical output power of 700 mW.

The lifetime test of single transverse mode violet LDs were carried out under the optical output power of 160 mW pulsed operation at a case temperature of 80 ºC. After 1,000 hours of operation, the operating current of these LDs were maintained steady degradation, as shown in Figure 5.

4. BLUE LDS

In this section, we describe blue LDs. The blue LDs are expected to be adopted as the light source for the full color laser display system. Full color display systems based on laser light sources have advantages in terms of its extremely wide color expression. The high power red LDs already have been realized. And high power second harmonic generation (SHG) green lasers have been developed. On the other hand, in blue region, the laser light source was not yet developed to a practical level from the viewpoint of optical output power and reliability till fairly recently. Nowadays, the development of blue LDs has progressed rapidly.

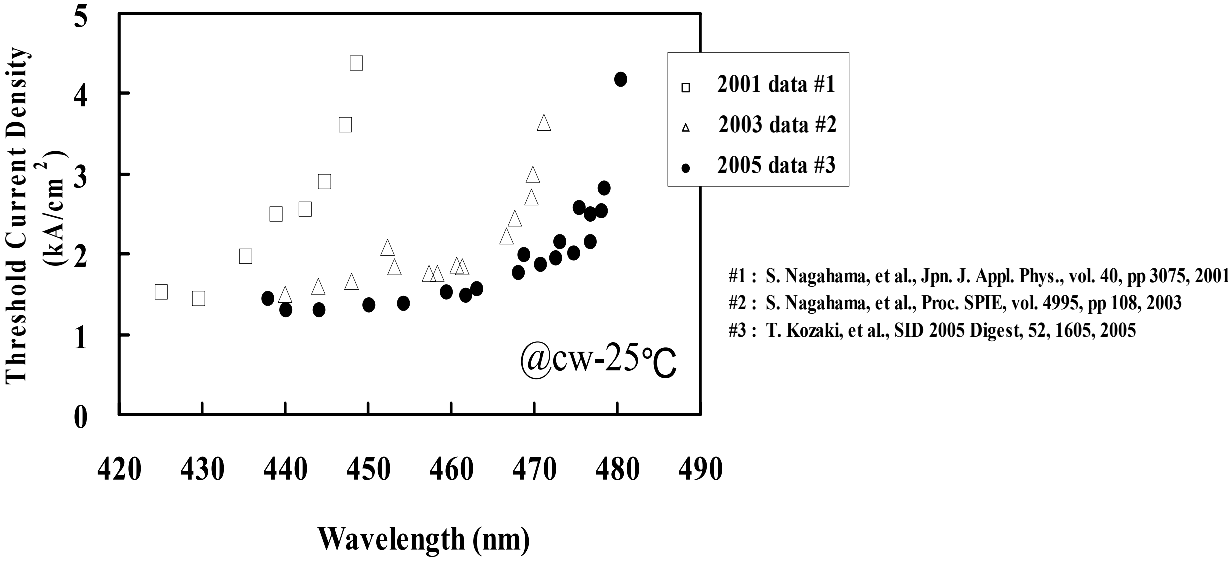

Figure 6 Emission wavelength dependence of the threshold current density of LDs.

The relationship between the lasing wavelength and the threshold current density was studied by changing the In mole fraction of InGaN well layers. Figure 6 shows the emission wavelength dependence of the threshold current density of LDs under CW operation at 25 ºC. From this figure, all data have same tendency. The threshold current density was strictly dependent on its lasing wavelength. It is thought that the high threshold current density is due to the poor crystal quality of epi layer. It is difficult to maintain the crystal quality with the longer wavelength range LDs because of generated dislocation at the active layer by the lattice coefficient mismatch between GaN and InGaN films with the higher In mole fraction. We have modified LD structure and growth condition. As a result, the longer wavelength LDs has been realized year by year [5,6]. We have already succeeded in expanding the lasing wavelength blue-green (482nm) range under CW operation [7]. And we have succeeded fabricating low threshold current density of LDs below 450nm.

We describe the high-power blue (445nm) LDs with the multi transverse mode. The structure and growth condition of epi layers have been reported previously [7]. The structure of the buried ridge-geometry InGaN MQW LD was modified in order to decrease the operating current at higher output power. These LD's aperture size was approximately 7 µm x 1 µm. N-electrode was evaporated onto the bottom of n-type GaN substrate. The laser cavity was formed by cleaving the facets along (1-100) face. The front and rear facets were coated with low-reflection and high-reflection film, respectively.

Figure 7 shows the typical current-voltage (I-V) characteristics and the optical output power per facet of the lasing wavelength 445 nm LD as a function of the forward dc current (L-I) at 25 ºC. The operating current and voltage at an output power of 300 mW were 338 mA and 5.0 V, respectively.

Figure 8 shows the emission spectra of 445nm blue LD measured at an output power of 300 mW under CW operation at 25 ºC. The multi longitudinal mode emission can be observed around 445 nm.

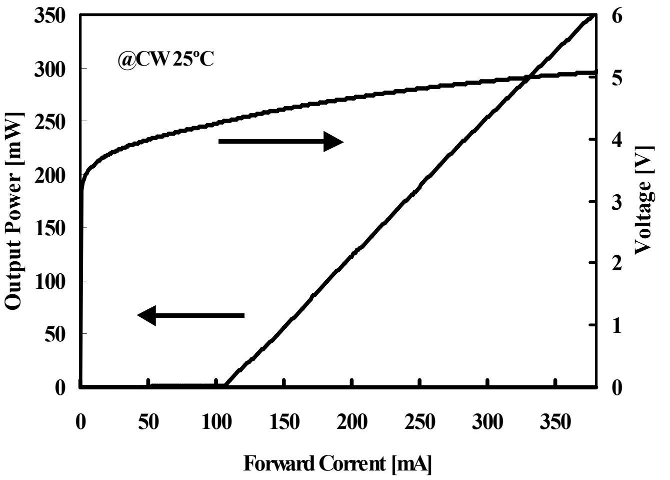

Figure 7 Typical L-I and V-I characteristics of LDs with a lasing wavelength of 445 nm under 25ºC-CW operation.

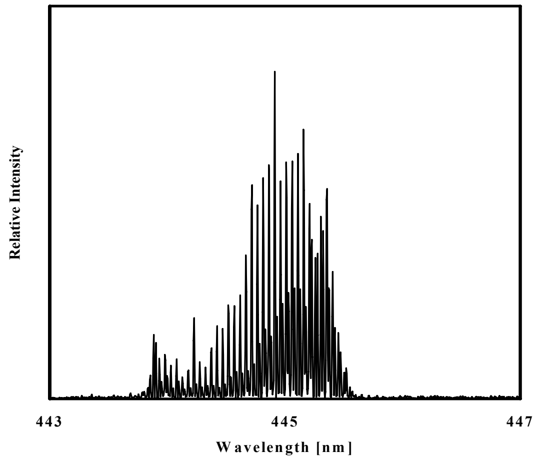

Figure 8 Emission spectra of 445nm blue LD measured at an output power of 300 mW under CW operation.

The lifetime test of multi transverse mode blue LDs were carried out under the optical output power of 300 mW CW operation at a case temperature of 25 ºC. The operating current of these LDs were stayed steady degradation, as shown in Figure 9. The lifetime is defined as the time required for the operating current of the LD to reach 1.3 times the initial operating current. After 1,000h of operation, the lifetime was estimated to be over 10,000 hours.

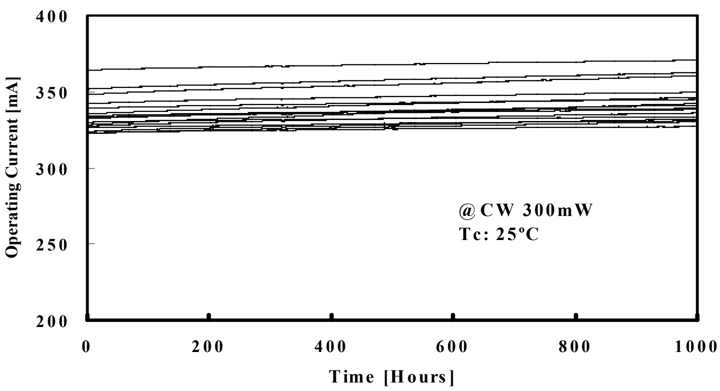

Figure 9 Result of lifetime test of multi mode blue LDs under 300 mW CW operation at 25 ºC.

5. CONCLUSION

In summary, for high-speed recording and multiplayer recording of high-density optical disc system, we fabricated higher power violet LDs. Moreover, we developed high power blue LDs with an emission wavelength of 445nm for the blue light source of full color laser displays. We evaluated the detail of these LDs characteristics. At a result, the characteristics of these violet and blue LDs have been achieved the practically acceptable level. It is thought that these LDs are useful for optical memory devices and full color laser displays.

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Biography

Shin-ichi Nagahama was born on April 11, 1967 in Tokushima, Japan. I obtained B.E. and Ph.D. degrees from the University of Tokushima, Japan in 1991 and 2003, respectively. I joined Nichia Corporation in 1991. In 1992, I started the research of light emitting devices using group-III nitride materials. I developed the first group-III nitride-based violet laser diodes (LDs) in 1995. Since then, I have been working on developing the group-III nitride-based LDs form ultraviolet to pure blue region. Now, I am a general manager of LD development department in Nichia Corporation.