Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.114-115

E-2-5

High Power operation of GaN-based laser diode with high slope efficiency

Kyosuke Kuramoto, Akihito Ohno, **Tomoo Yamada, **Hiroaki Okagawa,
Zempei Kawazu, Kazushige Kawasaki, * Nobuyuki Tomita,
*Katsuomi Shiozawa, *Kyozo Kanamoto, *Hiroshi Watanabe,
Masayoshi Takemi, Tetsuya Yagi, **Hiroaki Murata and Akihiro Shima

High Frequency & Optical Device Works., Mitsubishi Electric Corporation
4-1, Mizuhara, Itami, Hyogo, 664-8641, Japan
Phone: +81-727-80-2523 E-mail: kuramoto@lsi.melco.co.jp
*Advanced Technology R&D Center, Mitsubishi Electric Corporation
**Mitsubishi Cable Industries, Ltd.

1. Introduction

Recently, recordable DVD systems with capacity of 4.7GB such as DVD-R or DVD+R have been in widely spread use. The systems are suitable for standard definition motion pictures, but do not have enough capacity for high definition pictures. Blu-ray Disc with 20GB or HD-DVD with 15GB is expected for the next generation disk recording systems, and GaN-based laser diodes (LDs) with a wavelength of 405 nm are key devices for them. The most important issue of the system users might be the writing speed, because the higher recording speed realizes the shorter burning time of the recording disk. A shorter pulse width of recording signal with a higher laser output power enables a higher writing speed. In that mean, high-power operation of the LD is strongly required.

Generally speaking, high power operation of the LD necessitates large injection current. The series resistance of GaN-based LDs is five times or more as large as those of the conventional LDs, such as AlGaInP-based LDs. It makes the input power larger. This causes a heat generation in the active region of the LD, leading a kink in the light output power versus current characteristics (P-I), which inhibits high power operation [1]. Moreover large input power degrades the device reliability [2]. Therefore reduction of the input power of the GaN–based LD is strongly required in order to realize the high-power operation. One method to overcome these problems is improvement of the slope efficiency of the LD. In this paper, we demonstrate the LD with high slope efficiency, which enables 300 mW operation at high temperature of 80°C .

2. Structure

The structure of the LD is schematically shown in Fig. 1. The device has a double-channel type ridge structure. A c-plane free-standing GaN wafer is used as a substrate. The active layer is composed of three InGaN multiple quantum wells (MQWs). The front facet is uncoated and has the reflectivity of about 20%, and the rear is coated with the high reflectivity of 95%. The cavity length is 600 µm. The chip is mounted on the heat-sink with a junction up configuration.

It is known that the Mg-doped p-type layer has large optical absorption originated from Mg-related state [3]. In order to reduce optical absorption in p-type layer, Mg doping density should be low. But the low density doping increases the resistance of the layer. Therefore we chose the Mg doping density as the resistance of p-layer become minimum, but this doping density is not optimum value for optical absorption.

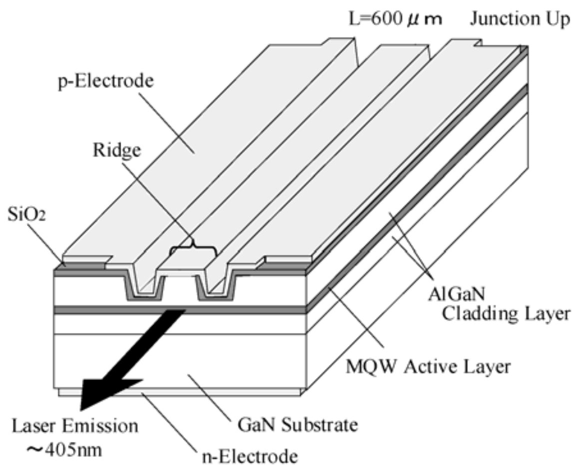

Fig.1 Schematic drawing of the ridge waveguide laser

The slope efficiency, Se, of the LD is given by the following equation;

$$\mathrm{Se} = \frac{1.24}{\lambda_L} \times \frac{1}{1+\frac{1-\mathrm{Rr}}{1-\mathrm{Rf}}\sqrt{\frac{\mathrm{Rf}}{\mathrm{Rr}}}} \times \frac{\ln(\frac{1}{\mathrm{RfRr}})}{2\alpha \times \mathrm{Lc} + \ln(\frac{1}{\mathrm{RfRr}})} \times \eta_i$$

where λ_L, R_f, R_r, L_c, η_i and α are lasing wavelength, front facet reflectivity, rear facet one, cavity length, internal efficiency, and average internal loss, respectively. Since the slope efficiency is a function of α x L_c, reduction of the optical internal loss α is effective to increase the slope efficiency.

It is well known that indium composition in InGaN well layer is spatially varied [4]. This causes the in-plane band gap fluctuation of the layer. As a result of this fluctuation, carrier density becomes non-uniform in the layer, and the region with the small carrier density might be the absorption region, not the gain region. The existence of the absorption region enlarges an absorption coefficient of the layer. It is essential in the GaN-based LDs. The average internal loss α is in proportion with the optical confinement factor in the well layer. Therefore reducing an optical confinement factor might be effective for decreasing an optical internal loss and achieving high slope efficiency.

3. Experiment

Figure 2 shows a relation between the measured slope efficiency of the LDs and the optical confinement factor (Γ_{MQW}). The confinement factor is the sum of those in each of three well layers, and calculated by Beam Propagation Method. Γ_{MQW} is adjusted by changing the thickness and the Al composition of cladding layers. All LDs are designed so as to have almost the same optical confinement factor in p-type layer in order to reject the influence of the optical loss in p-type layer.

The slope efficiency increases as the Γ_{MQW} decreases. This indicates that the reduction of Γ_{MQW} contributes to the reduction of optical internal loss.

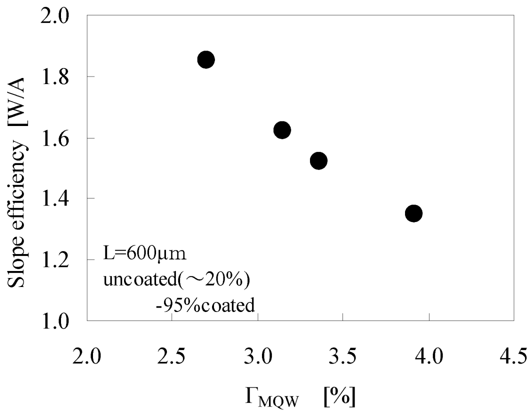

Fig.2 Relation between slope efficiency and Γ_{MQW}

4. Characteristics

Fig.3 shows the P-I characteristics of the LD with Γ_{MQW} of 2.70% at 80°C, CW condition. The threshold current and slope efficiency at 80°C are 47.3mA and 1.85W/A, respectively. High slope efficiency is obtained in spite of relatively high front facet reflectivity of 20%. To the best of our knowledge, this is highest slope efficiency recorded for GaN-based LDs with a cavity length around 600 μm. The operating current at 80°C with a light output power of 300mW is 209mA, and the lasing wavelength is approximately 407nm.

Fig.4 shows far field patterns of the LD. The full widths at half maximum of parallel and perpendicular to the junction plane are 9.1° and 20.1° at 70mW, respectively, corresponding to an aspect ratio of 2.2 . This small aspect ratio is as a result of weak confinement of light perpendicular to the junction plane.

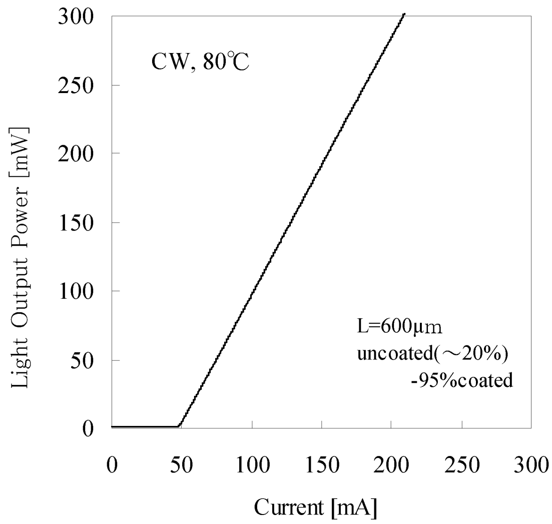

Fig.3 Light output power versus current characteristics

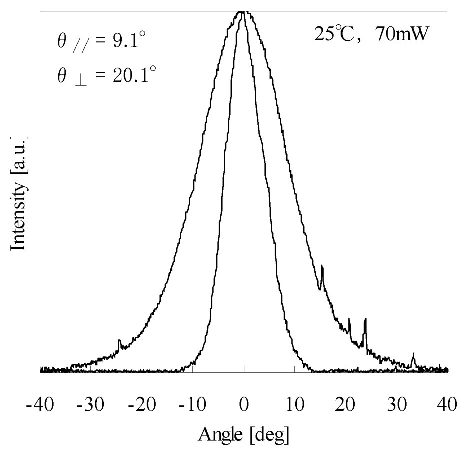

Fig.4 Far-field patterns under CW operation at 70mW

5. Conclusions

We have revealed that reducing the confinement factor in InGaN wells is effective in order to improve the slope efficiency. High slope efficiency of 1.85 W/A and low current operation over 300mW at 80°C has been realized by this method. The LD is suitable for the high speed Blu-ray Disk or HD-DVD drives with higher writing speed.

References

[1] Y. Yoshida et al., SSDM 2003, p.176
[2] T. Tojyo et al., Jap. J. Appl. Phys. **40**, p.3206 (2001)
[3] M.Kuramoto et al, Proc. 4th Internat. Symp.Blue Laser and Light Emitting Diodes, 2002; Phys. satat. sol. (a) 192, p.329 (2002)
[4] S. Chichibu et al, Appl. Phys. Lett. **71**, p.2346 (1997)