報　　告

GaN系短波長半導体レーザ

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GaN-based Short Wavelength Semiconductor Lasers

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要　　旨

GaInN/GaN多重量子井戸（Multi Quantum Well：MQW）層を活性層としたGaN系光分離閉じ込め（Separate Confinement Heterostructure：SCH）構造短波長半導体レーザ（Laser Diode：LD）の室温連続発振の開発に成功した．レーザ発振波長は410 nmで室温連続発振動作寿命は20時間以上であった．

Abstract

The room temperature continuous wave operation (RT-CW) of GaN-based separate confinement heterostructure (SCH) laser diodes (LDs) using GaInN/GaN multiple quantum wells (MQWs) have been successfully achieved. The RT-CW laser operation has been realized at the wavelength of 410 nm and the lifetime of RT-CW operation is longer than 20 hours at 1 mW output.

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1. INTRODUCTION

III-V nitride compound semiconductors are potential materials for high efficient optical devices in the ultraviolet to red spectral region. Excellent uniform epitaxial layers of GaN and nitride alloys were grown on sapphire substrates using an AlN buffer layer by metalorganic vapor phase epitaxy (MOVPE).[1] High-quality GaInN/GaN multiple quantum wells (MQWs) structure of GaN-based superlattices enhanced the optical efficiency by nearly two-orders of magnitude in comparison with bulk GaInN.[2] The high efficient GaInN/GaN MQW LEDs have been commercialized for UV, blue and green light sources.

Akasaki, et al. reported for the first time the laser irradiation from GaInN laser diode by current injection at room temperature (RT) in 1996.[3] Recently, III-V nitride semiconductor laser diodes (LDs) have been improved to the grade of a digital versatile disk (DVD) application. The MQW separated confinement hetero-structure (SCH) laser diodes have been realized with longer than 10,000 hours lifetime under continuous wave (CW) operations at RT.[4]

In this paper, we will report the improvements of the GaN-based LDs by applying GaInN/GaN optical guide. The RT CW operation also has been achieved in the range of hours in the lifetime.

2. EXPERIMENTS

The GaN-based epitaxial layers were basically grown by atmospheric metalorganic vapor phase epitaxy (MOVPE). The sources of Al, Ga, In, and N were the common gases such as trimethylaluminum (TMA), trimethylgallium (TMG), trimethylindium (TMI), and ammonia (NH_3), respectively. The Si and Mg dopants were incorporated using silane (SiH_4) and biscyclopentadienylmagnesium (bis-Cp_2Mg).

One of the schematic structures of GaInN/GaN MQW-SCH LDs is shown in Fig. 1. The LDs consisted of n-GaN contact layer, n-$Al_{0.07}Ga_{0.93}N$ cladding layer, n-GaInN/GaN optical guide double layers, GaInN/GaN MQW active layer, p-GaInN/GaN optical guide double layers, p-$Al_{0.07}Ga_{0.93}N$ cladding layer, and p-GaN contact layer which were grown on sapphire substrate with low temperature (LT) buffer layer. The number of MQWs was two to six. The conventional optical guide layers consisted of GaN. However, we applied GaInN/GaN optical guide layers, because an optical confinement factor of GaInN optical guide layer is superior to that of GaN. The LD structures were mesa or ridge geometry. The widths mesa or ridge were 2 to 5 μm. the cavity lengths were 300 to 700 μm. The mirror facets were fabricated by reactive-ion-beam-etching (RIBE) and the high-reflection (HR) mirror coats were TiO_2/SiO_2 dielectric multi layers.

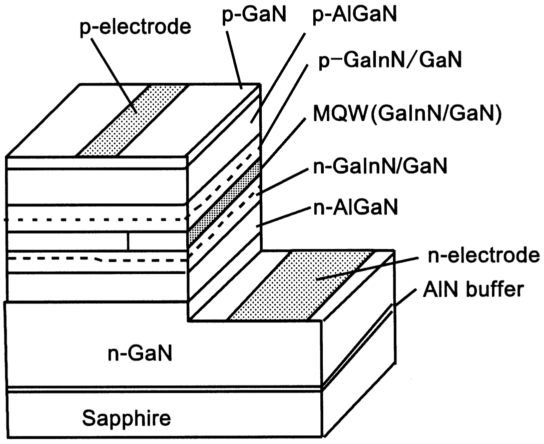


Fig.1 Schematic layer structure of LDs

3. RESULTS AND DISCUSSION

The threshold current (I_{th}) of the double-guide-layer SCH LDs was 60-70 mA at RT-CW operation. The current-output-voltage (I-L-V) characteristics under the RT-CW operation are shown in Fig. 2. The operation voltage for the threshold current was approximately 8 V.

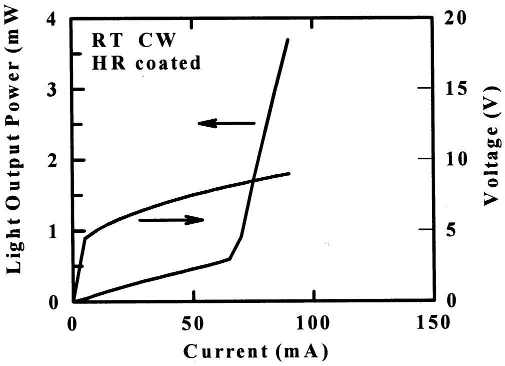


Fig.2 I-L-V characteristics under RT

The RT-CW emission spectrum is shown in Fig. 3. The laser wavelength was 408 nm and its full width at half maximum (FWHM) was 0.03 nm.

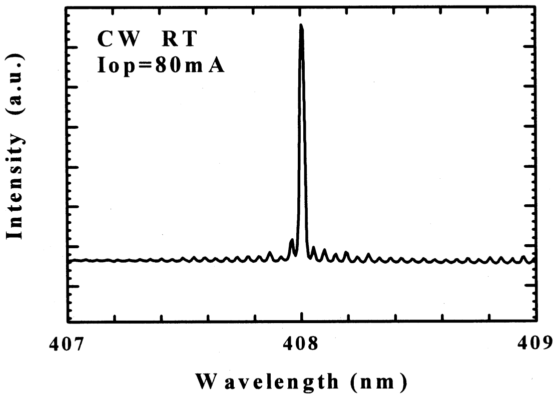


Fig.3 RT-CW emission spectrum

One of the preliminary lifetime evaluations is shown in Fig. 4.

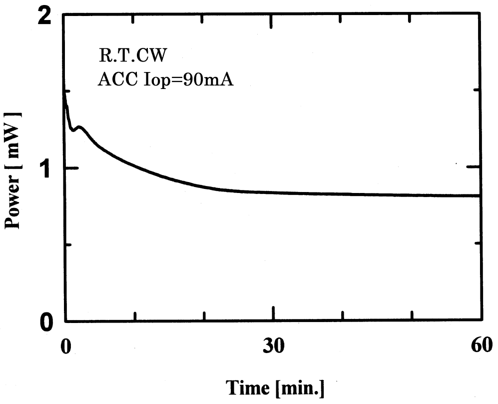
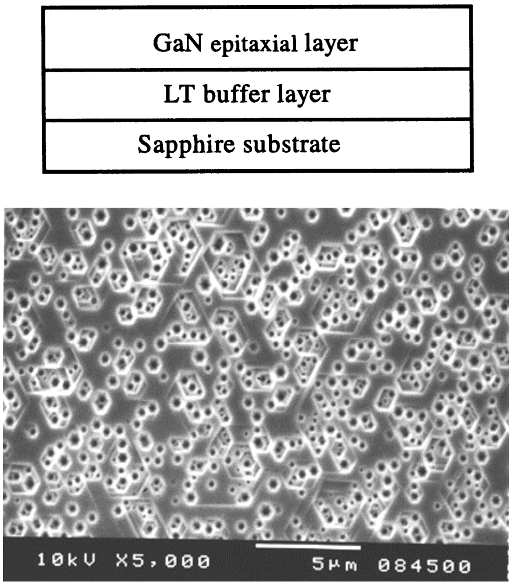


Fig.4 Preliminary aging test at around 1mW under RT-CW operation

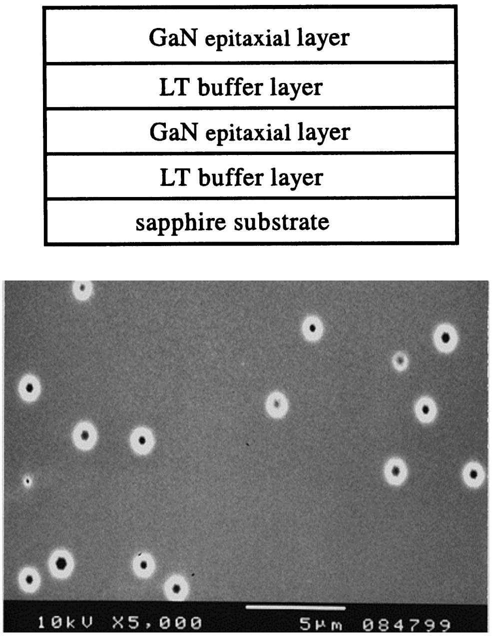
The longer lifetime could be expected by reducing dislocation in LD epitaxial layers. The multi low-temperature (LT) buffer layers were effective for reducing dislocation. The density of etch pits in the epitaxial layers could be reduced from 1x10^8 cm^{-2} to 5x10^6 cm^{-2} using the multi LT buffer layers as shown in Fig. 5 (a), (b).

We applied the LT-multi buffer layers to the laser diode for the first time as shown in Fig. 6. We have confirmed that the LT-multi buffer layers could increase the operating lifetime of LDs as shown in Fig. 7.



EPD:1x10^8 cm^{-2}

Fig. 5 (a). Etch pit density with LT-single buffer layer.



EPD:5x10^6 cm^{-2}

Fig. 5 (b). Etch pit density with LT-multi buffer layers.

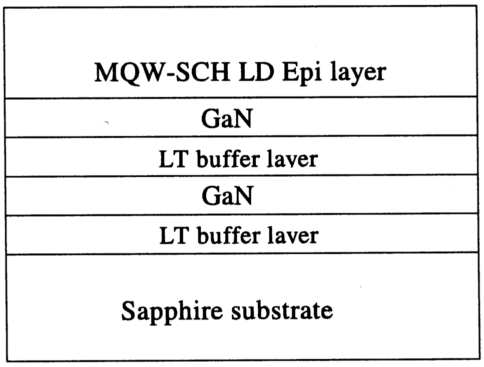


Fig. 6 Schematic LD grown on multi-LT-buffer layer.

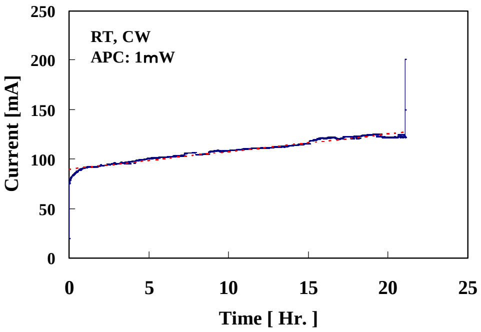


Fig.7. Aging test at 1mW under RT-CW Operation

4. CONCLUSION

We have succeeded in CW operation of GaInN/GaN MQW-SCH laser diodes at RT. The low threshold current of 60 mA (2.4 kA/cm2) was achieved by introducing the GaInN/GaN optical guide layer and the loss reduction. The lifetime of CW operation is longer than 20 hours at 1 mW output.

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