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Characteristics of GaN-based VCSELs with conducting AlInN/GaN DBR

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1. Introduction

VCSELs (Vertical-Cavity Surface-Emitting Lasers) emitting light along the crystal growth direction are expected as superior light sources to conventional LEDs (Light Emitting Diodes) and edge emitting lasers in some respects. Advantages of the VCSELs are two dimensional arrays, low power consumption, high speed modulation and so on. In 1979, Prof. Iga's group realized an electrically injected VCSEL for the first time [1], and now GaAs-based VCSELs are available in market. Currently, semiconductor DBRs (Distributed Bragg Reflectors) are used as the top and bottom DBRs in GaAs-based VCSELs [2-4]. This allows vertical current injection through the devices, resulting in low resistance and low threshold current. Now, GaAs-based VCSELs are indispensable in optical communication and laser printers.

On the other hand, GaN-based VCSELs are under development. We achieved RT-CW operations of GaN-based VCSELs with conducting bottom AlInN/GaN DBRs [5-6]. The use of conducting DBRs is expected to contribute more uniform carrier distribution in lateral direction. In this report, lateral carrier distributions with conducting DBRs were investigated, and VCSELs with the conducting bottom DBRs are characterized.

2. Experiments

2.1 LEDs with bottom DBRs

We fabricated two types of LEDs with undoped bottom AlInN/GaN DBRs or conducting bottom AlInN/GaN DBRs in order to evaluate lateral carrier distributions. The conducting DBRs were obtained by modulation doping of Si and graded interfaces [6]. The purpose of measuring LEDs was to compare the carrier distribution without an influence of the lasing modes when current was injected into devices. The structures of the fabricated LEDs are shown in Fig.1. Arrows in Fig.1 indicate current flows. Note that the two types of LEDs were grown around the same time and fabricated at the same time. In the LED with conducting DBR, n-type backside electrodes were additionally deposited at the final step. The aperture diameters of the LEDs were 8 μm and 15 μm. An NFP (Near Field Pattern) image was taken at each diameter, which should correspond to the carrier distribution injected into the active layer. Furthermore, I-V-L characteristics of the LEDS were measured under RT-CW condition.

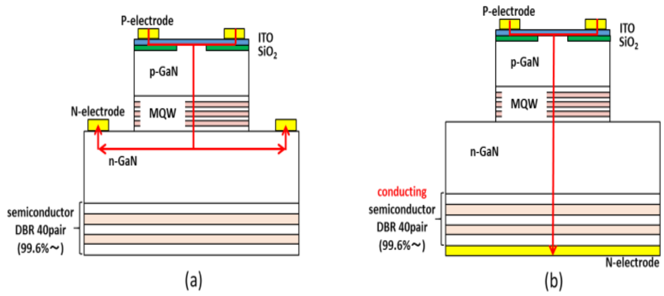

Fig.1 Schematic diagrams of the LEDs with (a) an undoped bottom AlInN/GaN DBR and with (b) a conducting bottom AlInN/GaN DBR.

2.2 VCSELs with conducting bottom DBRs

Next, we fabricated VCSELs with undoped bottom DBRs and with conducting bottom DBRs. Fig.2 shows structures of the VCSELs. Note that the two types of VCSELs were grown around the same time and fabricated at the same time.

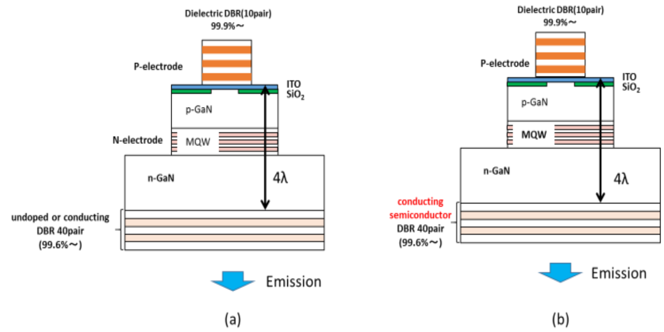

Fig.2 Schematic diagrams of VCSELs with (a) an undoped bottom AlInN/GaN DBR and with (b) a conducting bottom AlInN/GaN DBR.

Both the VCSELs contain 4λ cavities and 10-pair Nb_2O_5/SiO_2 top DBRs. The I-V-L characteristics of these VCSELs were measured under RT-CW condition. The light output power values were obtained from the bottom DBRs which showed lower reflectivity values.

3. Results and discussion
3.1 LEDs with bottom DBRs
Fig.3 shows the NFP images of the LEDs at current of 15 mA. The optical intensities of the LEDs with the conducting DBRs were more uniform than those with undoped DBRs. In other words, the carrier distributions along the lateral direction were improved by using the conducting bottom DBRs. However, as the aperture sizes were increased, carrier distribution seemed not so uniform even with the conducting DBR. This is because an intracavity contact through an ITO electrode was still used at the top side.
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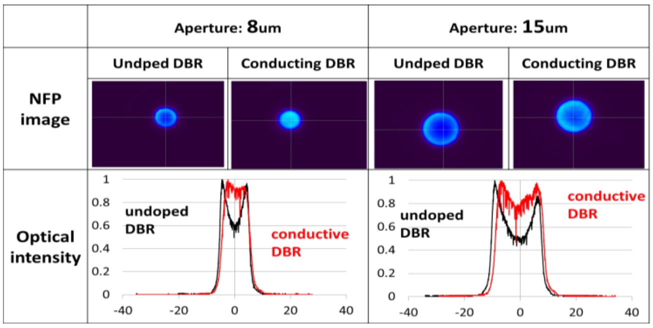

Fig.3 NFP images and optical intensity profiles of LEDs with undoped DBRs and with conducting DBRs. The aperture sizes were 8 μm and 15 μm.

Fig.4 shows the I-V-L characteristics of 8 μm aperture LEDs with the undoped DBR and the conducting DBR. While a differential resistance of the LED with the undoped DBR was about 130 Ω, that with the conducting DBR was about 80 Ω, showing about a 40 % reduction. At the same time, a LOP (Light Output Power) of the LED with the conducting DBR was about 60 % of those with the undoped DBR.

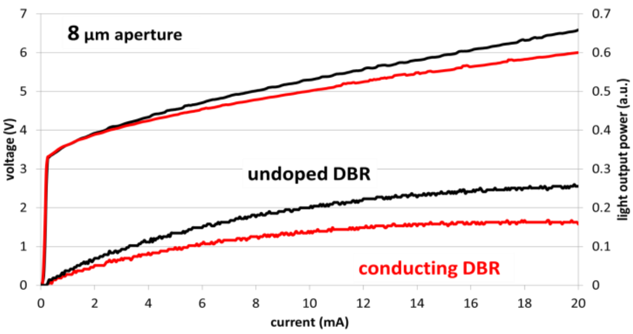

Fig.4 I-V-L characteristics of LED with conducting DBR and LED with undoped DBR. The aperture size was 8 μm.

3.2 VCSELs with conducting DBR
The I-V-L characteristics of the VCSELs with the undoped bottom DBR and the conducting bottom DBR are shown in Fig.5. The LOP values of the 8 μm aperture VCSELs with the conducting DBR and with the undoped DBR were 4.4 mW and 2.6 mW, respectively. Correspondingly, the LOP value with the conducting DBR was lower than that with the undoped DBR. Si doping at the DBR could result in an inferior quality of an active layer on the DBR.

Note that the highest LOP values were obtained from the VCSELs with the aperture size of 8 μm. As the aperture sizes were increased, the LOP values of both the VCSELs were decreased.

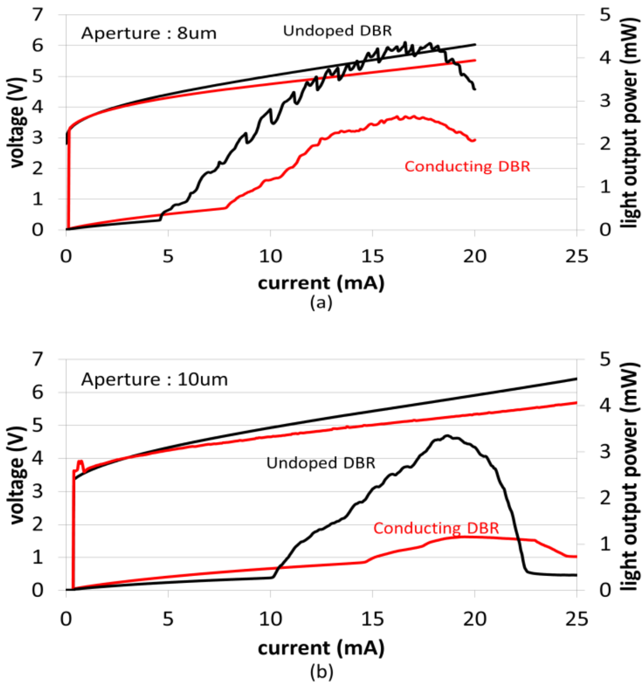

Fig.5 I-V-L characteristics of (a) 8 μm aperture and (b) 10 μm aperture VCSELs with undoped DBR and with conducting DBR.

4. Conclusion
By using the conducting bottom AlInN/GaN DBR in GaN-based VCSEL, the lateral carrier distribution was more uniform and device resistance was also lower. At the same time, threshold current was higher and the LOP was also lower. So far, the conducting DBR is useful to improve such electrical properties, but resulting in inferior optical properties. Further improvements are necessary in future.

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