Electroluminescence from p-GaN/n-InGaN MQW hexagonal microprism fabricated by selective area MOVPE

T. Akasaka, S. Ando, and N. Kobayashi
NTT Basic Research Laboratories, 3-1 Morinosato Wakamiya, Atugi, 243-0198 Japan
E-mail: akasaka@will.brl.ntt.co.jp

Nitride semiconductors, including AlN, GaN, InN and their alloys, are attractive candidates for application to optoelectric devices in the visible and UV ranges, because of their wide and direct bandgaps. Several groups have achieved the room-temperature CW operation of InGaN lasers [1-3]. So far, we have proposed micron-size GaAs and GaN hexagonal facet lasers by using selective area metalorganic vapor phase epitaxy (MOVPE). These hexagonal facet lasers consist of hexagonal microprisms (HMPs) with side lengths of 8-50 microns. The HMPs have six smooth and damage-free vertical facets, and due to their internal total reflection we can use the HMPs as ring cavity lasers. Extremely low threshold lasing of GaAs/AlGaAs HMPs has been achieved by photo-pumping at R.T. [4]. We have also achieved lasing of GaN HMPs by photo-pumping at R.T. [5].

To realize lasing of GaN based HMPs by current injection, some problems in selective area MOVPE must be solved. The major problem is maintaining the vertical facets during the p-type (Mg) doping of GaN selectively grown on masked substrate. There is the possibility of changing the facet orientation by Mg doping. The regrowth usually suffers from unintentional doping. In this study, we successfully fabricated HMPs, including p-GaN and InGaN multi-quantum well (MQW), by selective area MOVPE. Good I-V characteristics with low differential resistivity as well as strong violet electroluminescence (EL) were obtained from these HMPs.

The samples were prepared as follows: First, an n-GaN(1.3-μm-thick)/n-$Al_{0.1}Ga_{0.9}N$(0.7-μm-thick) double-layer was formed by MOVPE on a (0001) sapphire substrate by using a low-temperature AlN buffer. Then, a 50-nm-thick SiO_2 mask with openings was coated on the double-layer. Finally, the HMPs consisting of either n-GaN/p-GaN or n-GaN/InGaN MQW/p-AlGaN/p-GaN were grown by selective area MOVPE operated at 300 Torr. The sample structures are shown in Fig. 1. Ni/Au contact metal was formed on almost the entire p-GaN of the HMPs. Al contact metal was formed on the under-lying n-GaN/n-$Al_{0.1}Ga_{0.9}N$ double-layer.

Figure 2 shows a cross-sectional SEM micrograph of an n-GaN/p-GaN HMP. The side wall is {11-20} facet which is completely vertical to the substrate. The surface morphology of the {11-20} vertical facet is completely smooth and flat. As previously reported [5], GaN HMPs with {1-100} vertical facets were grown at 76 Torr. However, at 300 Torr, we found that {11-20} vertical facets are preferentially formed.

The I-V characteristic of the n-GaN/InGaN MQW/p-AlGaN/p-GaN HMP is shown in Fig. 3. In the HMP, the side length of hexagon is 50 μm. The InGaN MQW is 15 periods of 5-nm thick n-$In_{0.01}Ga_{0.99}N$ and 2.5-nm thick n-$In_{0.11}Ga_{0.89}N$. The overall area of Ni/Au p-contact metal is 4.2E-5 cm^2. The turn-on voltage and the forward differential resistance is 2.6 V and 17 Ω (7.1E-4 Ωcm^2) at 0.1 A (7.8 V). This differential resistance value is almost comparable to that of a conventional InGaN stripe laser fabricated on sapphire [6]. The reverse current is sufficiently low (4.4E-5 A at -10 V). These results indicate that both good p-n junction and p-GaN with low-resistance are formed within the HMP.

EL spectra are measured as a function of the injected current (Fig. 4). The peaks of the EL spectra are about ~410 nm. This wavelength was essentially the same as that of photoluminescence. The FWHM of the EL spectrum was as narrow as 23 nm at 0.1 A.

In conclusion, the HMPs consisting of either n-GaN/p-GaN or n-GaN/InGaN MQW/p-AlGaN/p-GaN were grown successfully by selective area MOVPE. Good I-V characteristics with low differential resistivity as well as strong violet EL were obtained from the InGaN MQW HMPs. In the future, the InGaN MQW growth conditions will be optimized, and a gain or index guided laser structure will be applied in order to achieve lasing by current injection.

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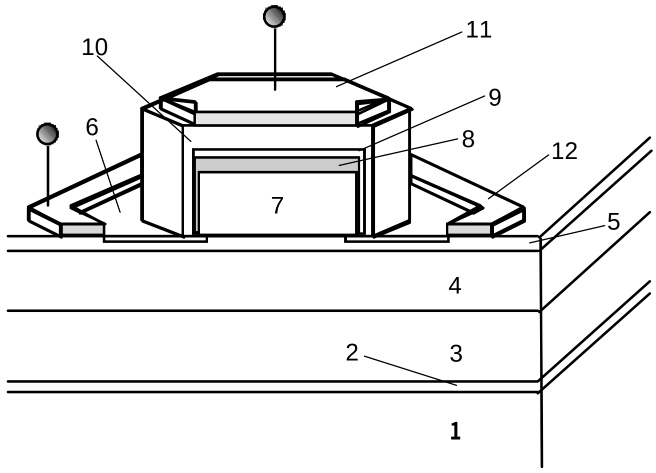

Fig. 1 Schematics of GaN/InGaN MQW HMP.
1: Sapphire(0001) substrate
2: AlN buffer 20 nm thick
3: n-GaN 1300nm thick
4: n-$Al_{0.1}Ga_{0.9}N$ 700 nm thick
5: n-GaN cap 30 nm thick
6: SiO_2 mask
7: n-GaN 900nm thick
8: $In_{0.01}Ga_{0.99}N$(5nm)/$In_{0.11}Ga_{0.89}N$(2.5nm) 15 MQW
9: p-$Al_{0.2}Ga_{0.8}N$ 20 nm thick
10: p-GaN 600 nm thick
11: Ni/Au p-contact
12: Al n-contact.

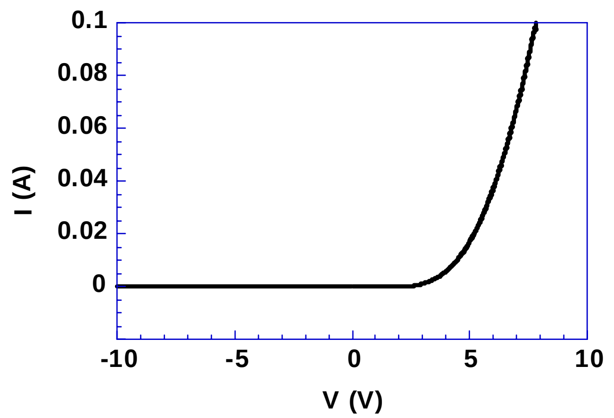

Fig. 3 I-V characteristics of the n-GaN/InGaN MQW/p-AlGaN/p-GaN HMP. The overall area of Ni/Au p-contact metal is 4.2E-5 cm^2.

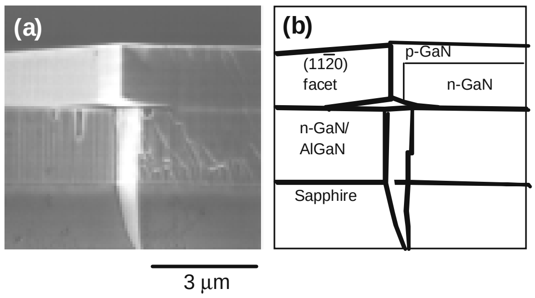

Fig. 2 (a) A cross-sectional SEM micrograph of an n-GaN/p-GaN HMP.
(b) Schematics of the micrograph.

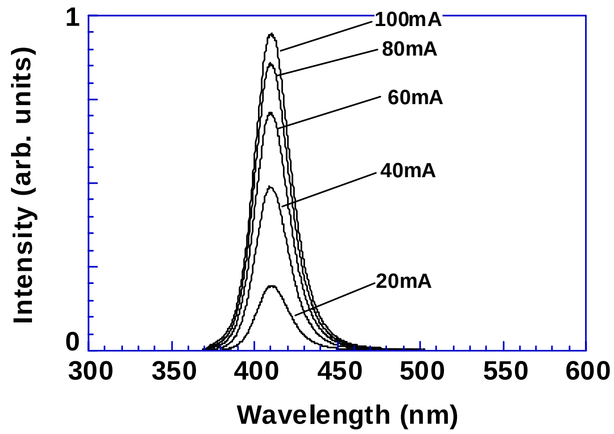

Fig. 4 Dependence of EL spectra of the n-GaN/InGaN MQW/p-AlGaN/p-GaN HMP on the injected current.