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# InGaN-based horizontal cavity surface emitting laser diode with selectively grown cavity and outer micromirrors

Tetsuya Akasaka, Toshio Nishida, Toshiki Makimoto and Naoki Kobayashi

NTT Basic Research Laboratories, NTT Corporation.
3-1 Morinosato-Wakamiya, Atsugi, Kanagawa 243-0198, Japan
Phone: +81-46-240-3459 E-mail: akasaka@will.brl.ntt.co.jp

## 1. Introduction

Group III-nitrides, such as AlN, GaN, InN, and their alloys, are attractive for application to optoelectronic devices in the visible and UV ranges, because these semiconductors have wide and direct bandgaps. The mirror facets of group III-nitride-based lasers have been fabricated by either cleavage or dry-etching. Selective-area metalorganic vapor phase epitaxy (SA-MOVPE) is another promising method for fabricating mirror facets [1, 2]. We have employed SA-MOVPE to fabricate micrometer-sized semiconductor lasers named hexagonal microfacet (HMF) lasers [1]. InGaN-based HMF lasers have achieved current-injected lasing at room temperature (RT) [2]. These InGaN-based HMF lasers were fabricated by patterned dry-etching of an InGaN-based laser wafer and subsequent regrowth of Mg-doped GaN layers to form the cavity mirrors consisting of the vertical {11-20} microfacets [2]. In this work, we fabricated an InGaN-based horizontal cavity surface emitting laser diode (HCSELD). This HCSEL is a Fabry-Perot laser diode that has a pair of cavity mirrors consited of selectively grown vertical {11-20} microfacets and outer micromirrors consisted of the selectively grown inclined {11-22} microfacets. The outer micromirrors direct the laser beam upward. Successful room-temperature lasing of the InGaN based HCSELDs has been achieved by current injection.

## 2. Experimental

The MOVPE apparatus was a vertical type. The InGaN-based HCSELDs were prepared as follows: First, group III-nitride multilayers for a conventional separate confinement heterostructure (SCH) InGaN multi-quantum well (MQW) laser diode were grown on a (0001)Si oriented n-type 6H-SiC substrate. The structures of these group III-nitride multilayers are described in a previous report [2]. Next, trenches were formed on the group III-nitride multi-layers by electron cyclotron resonance (ECR) dry-etching and conventional photolithography. The depth of the trenches was typically 1.5 μm. The SiC substrate was exposed at the bottom of the trenches. The stripes surrounded by the trenches were along [11-20] directions of the group III-nitride multilayers. Then, the SA-MOVPE regrowth of a 500-nm-thick Mg-doped GaN layer was performed to fabricate both the Fabry-Perot cavity mirrors and the outer micromirrors of the HCSELDs. The Mg-doped GaN layer was selectively grown on both the top (0001) surface and the dry-etched side walls of the group III-nitride layers. The Mg-doped GaN layer was not regrown on the SiC surface at the bottom of the trenches, because sticking probability of Ga containing precursors to the SiC surface is comparatively low under the conditions used in this study [2]. Figure 1 shows a cross-sectional schematic of the specimen at this stage. There is a set of the Fabry-Perot cavity mirrors at both edges of the stripe. The outer micromirrors face the Fabry-Perot cavity mirrors. These outer micromirrors can deflect laser beams emitted from the Fabry-Perot cavity mirrors upward. Next, the specimen was annealed in nitrogen at 700 C to activate the Mg acceptors electrically. Then, Al thin films were formed on the outer micromirrors to increase their reflectivity. Finally, p-type contact metals, Pd/Au, were evaporated onto the (0001) surfaces of the regrown Mg-doped GaN layers. These metals were formed into a stripe by conventional photolithography. Their lengths, i.e. the cavity lengths of the lasers, were from 300 to 1000 μm. The n-type contact metals, Ti/Au, were evaporated onto the whole backside of the SiC substrate. The lasers were driven under pulsed current injection at RT. The pulse duration was 300 ns and the repetition frequency was 1 kHz. The laser structures were observed with a scanning electron microscope (SEM).

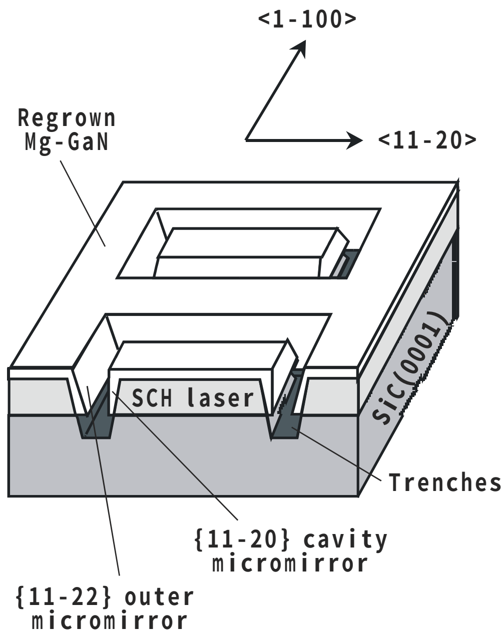


Figure 1: Schematic of the sample structure showing after selective-area regrowth of the Mg-doped GaN layer.

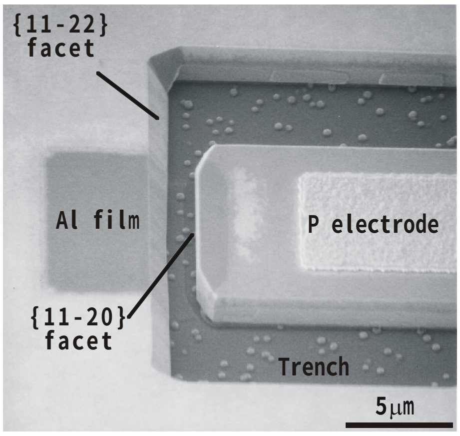


Figure 2: Bird's-eye-view SEM photograph of an InGaN-based HCSELD. The photograph shows one side of the HCSELD around the Fabry-Perot cavity mirror and the outer micromirror.

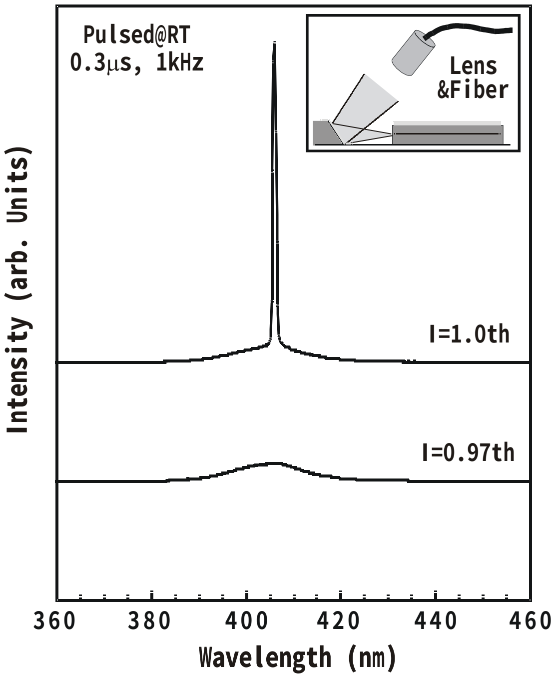


Figure 3: Emission spectra obtained from an InGaN-based HCSELD below and above the lasing threshold.

**3. Results and discussion**

Figure 2 shows an SEM bird's-eye-view photograph of an InGaN-based HCSELD. The photograph shows one side of the HCSELD around a Fabry-perot cavity mirror and an outer micromirror. It can be seen that the Fabry-Perot cavity mirror and the outer micromirror consist of a vertical {11-20} microfacet and an inclined {11-22} microfacet of the regrown Mg-doped GaN layers, respectively. The set of the {11-20} Fabry-Perot cavity mirrors of an HCSELD are vertical to a SiC substrate and parallel to each other. Note that, unlike dry-etched microfacets, these grown microfacets are essentially smooth and have little angle deviation. These are the great advantages over dry-etched microfacets. The dark-contrast area, including the center region of the outer micromirror, corresponds to an evaporated Al film that has reflectivity over 90 % for blue-ultraviolet lights. The angle between the inclined{11-22} outer micromirror and the SiC substrate surface is 62 deg. Therefore, geometrically, laser beams are emitted at an angle of 58 deg. to the substrate surface.

The InGaN-based HCSELDs lased at RT by current injection. Spectra obtained below and above the lasing threshold are shown in Fig. 3. These spectra were measured by using a lens and a fiber as shown in the inset. The narrowing of the spectrum can be seen at current density above the lasing threshold. The lasing wavelength is approximately 400 nm.

**4. Conclusions**

InGaN-based horizontal cavity surface emitting laser diodes (HCSELDs) were fabricated by dry-etching of SCH laser multilayers followed by selective-area regrowth of Mg-doped GaN layers. These HCSELDs have cavity mirrors of grown {11-20} microfacets and outer micromirrors of grown {11-22} microfacets. The outer micromirrors direct laser beams upward. The HCSELDs lase at RT by current injection.

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References

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