GaN Based Laser Diode with Focused Ion Beam Etched Mirrors

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A GaN based laser diode with Fabry-Perot resonator mirrors fabricated by focused ion beam etching was demonstrated for the first time. It shows lasing by pulsed current injection at room temperature. The threshold current and the lasing wavelength are 0.75 A and around 410 nm, respectively.

KEYWORDS: GaN based laser diode, focused ion beam etching, Fabry-Perot resonator mirror

1. Introduction

Tremendous effort has been made to fabricate a nitride based laser diode (LD)1–12 for the application of a short wavelength coherent light source. The application of nitrides is not limited to light emitters such as LDs and light emitting diodes. Recently, we found that GaN based multi-quantum wells (MQWs) showed the quantum confined Stark effect (QCSE).13 The QCSE can be applied to realize a wavelength selective electroabsorber (EA),14 in which, the absorption wavelength can be controlled by changing the bias through the device. Therefore, the integration of a LD with such an EA will lead to the realization of new functional optical modulators. In order to realize such novel devices, it is profitable to establish a fine patterning fabrication technique on a nanometer scale for nitride based semiconductors. By utilizing such a fine patterning technique, LD and EA can be integrated in an identical epitaxial wafer. Focused ion beam (FIB) etching is one of the most suitable methods for fine patterning. Recently, the specific merit of the FIB process for fine patterning was performed. First, both side edges of the LD of size 32 μm×10 μm were etched with an ion beam current of 4.7 nA. Second, those of 32 μm×1.2 μm size were etched with an ion beam current of 650 pA. Finally, those of 32 μm×1.2 μm size were etched with an ion beam current of 131 pA. The etching time for the first and second steps was about 15 min, while that of the third step was 60 min. In order to realize vertical etching, the sample stage was tilted to about 2° for each side edge during etching. The root mean square roughness of the side edge before and after FIB as measured by AFM was 3 nm and 0.6 nm, respectively, which is much better than that for mirrors fabricated by cleaving or RIE. The SEM image of one of the side edges of the MQWs-SCH LD after FIB etching is shown in Fig. 1(b). No facet coating was performed.

2. Experiments and Results

The MQWs-SCH LD structure was grown on a sapphire (0001) substrate by organometallic vapor phase epitaxy (OMVPE). It consists of a low-temperature-deposited AlN buffer layer about 30 nm thick, an n-type GaN:Si layer about 5 μm thick, an Al0.07Ga0.93N:Si layer about 0.6 μm thick as a cladding layer, an 80-nm-thick n-GaN:Si optical waveguide layer, an active layer, an 80-nm-thick p-GaN:Mg optical waveguide layer, a 0.6-μm-thick p-Al0.07Ga0.93N:Mg cladding layer, and a p-GaN:Mg contact layer 0.1 μm thick. The free electron concentrations of all Si doped layers were 1×1018 cm−3 at room temperature (RT), while free hole concentrations at RT of the p-waveguide layer and the p-cladding layer were 3×1017 cm−3 and that of the p-contact layer was 1×1018 cm−3. The active layer consists of five pairs of 2-nm-thick Ga0.9In0.1N well layers and 4-nm-thick Ga0.97In0.03N barrier layers. On top of the MQWs, 20-nm-thick p-Al0.15Ga0.85N:Mg was grown. A 5-μm-wide ridge was formed by chlorine based reactive ion etching (RIE). The widths of the p-electrode and the n-electrode were 3 μm and 200 μm, respectively. Au/Ni was used for the p-electrode, while Al/Ti was used for the n-electrode. After cleaving the wafer along the (1100) plane of the sapphire substrate, FIB etching was performed. Figure 1(a) shows a schematic of the structure of the LD and the FIB etching process. FIB etching was performed with a focused Ga+ ion beam accelerated at 30 kV. In this study, three different steps in the FIB process were performed. First, both side edges of the LD of size 32 μm×10 μm were etched with an ion beam current of 4.7 nA. Second, those of 32 μm×1.2 μm size were etched with an ion beam current of 650 pA. Finally, those of 32 μm×1.2 μm size were etched with an ion beam current of 131 pA. The etching time for the first and second steps was about 15 min, while that of the third step was 60 min. In order to realize vertical etching, the sample stage was tilted to about 2° for each side edge during etching. The root mean square roughness of the side edge before and after FIB as measured by AFM was 3 nm and 0.6 nm, respectively, which is much better than that for mirrors fabricated by cleaving or RIE. The SEM image of one of the side edges of the MQWs-SCH LD after FIB etching is shown in Fig. 1(b). No facet coating was performed.

The characteristics of the MQWs-SCH LD were measured at RT under a pulsed current condition with a pulse width and a repetition rate of 100 ns and 1 kHz, respectively. Figure 2 shows the light output power versus current (L-I) characteristic of the MQWs-SCH LD after FIB etching. The threshold current was found to be 0.75 A, which corresponds to a threshold current density of 30 kA/cm2. The threshold current was the same before and after FIB etching. Figure 3 shows the emission spectra of the MQWs-SCH LD with FIB etched mirrors for a driving current below 0.96×Ith at threshold and above 1.15×Ith threshold current. Above threshold, lasing occurred at around 410 nm.

3. Summary

A GaN based MQWs-SCH LD with Fabry-Perot resonator mirrors fabricated by FIB etching was demonstrated for the first time. It shows lasing by pulsed current injection at room temperature with a lasing wavelength of 410 nm. Therefore, the FIB process is quite promising for the fabrication of nitride-based novel optical integrated nano scale devices within an identical wafer.
Fig. 1. (a) Schematic view of the MQWs-SCH LD and the FIB process from the side and from the top. (b) SEM photograph of the FIB etched side edge of the MQWs-SCH LD.

Fig. 2. L-I characteristic at room temperature of the MQWs-SCH LD with FIB etched mirrors. Pulse width and repetition rate of the driving current were 100 ns and 1 kHz, respectively.

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Fig. 3. Emission spectra of MQWs-SCH LD with FIB etched mirrors operated with driving currents from 0.96 $I_{th}$ to 1.15 $I_{th}$.