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Reactive Ion Beam Etching and Overgrowth Process for Fabrication of InGaN Inner Stripe Laser Diodes

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1.Introduction

Wide gap III-V nitride lasers have many attractive applications such as in optical data storage, due to their shorter wavelength. Room temperature lasing operation, under a pulsed current, of InGaN lasers has been realized by Nakamura *et al.*[1], Akasaki *et al.*[2] and Itaya *et al.*[3], respectively. Recently, continuous-wave operation at room temperature was achieved by Nakamura *et al.*[4]. However, for application to optical data storage systems, the device characteristics such as threshold current, thermal resistivity and fundamental transverse mode must be improved, therefore advanced laser structures such as current and optical confinement structures become necessary. In the fabrication process of such structures, dry etching and overgrowth techniques are considered to be the key technologies.

In this study, we described the dry etching and overgrowth (OG) techniques used to fabricate these advanced laser structures; InGaN inner stripe (IS) lasers were fabricated using these techniques. We will also report on the first lasing operation, by pulsed current injection, at room temperature in such lasers.

2.Experimental

All samples were grown on a sapphire (0001)C-face substrates by atmospheric pressure metalorganic chemical vapor deposition (MOCVD). Details of the MOCVD have been described elsewhere[3].

Dry Etching Process

The dry etching was performed by conventional electron cyclotron resonance-reactive ion beam etching (ECR-RIBE). GaN layers grown on sapphire were used in this study. We investigated the RIBE characteristics of GaN in Cl_2, at pressures of 2.5×10^{-4}-1.0×10^{-3} Torr, constant microwave power of 200W, and acceleration voltages of 300-800V. The temperature of the samples were controlled at 100-200°C. The etch rate was monitored by *in situ* laser interferometry.

The etch damage of GaN was estimated using x-ray photoelectron spectroscopy (XPS) and Rutherford backscattering spectroscopy (RBS) ion channeling.

Overgrowth Process and IS Laser Fabrication

Figure 1 shows a schematic of the InGaN inner stripe laser fabricated in this study. This device has a separate confinement heterostructure (SCH)[3] .The p-GaN etch stop layer and the n-GaN current blocking layer were continuously grown consecutively on this wafer.

After the first growth, the surface of the n-GaN was partially etched by RIBE until p-GaN was exposed, in order to form groove stripes for current confinement. After dry etching, the laser wafer was dipped in HF and H_3PO_4 to remove the dry etching residues. A p-GaN layer was then overgrown by MOCVD. The behavior of Mg diffusion during overgrowth was examined by secondary ion mass spectrometry (SIMS).

The characteristics of the IS lasers were measured under pulsed current injection at room temperature.

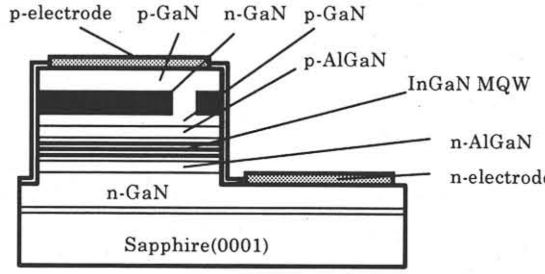

Fig.1 Schematic cross section view of an InGaN based IS laser diode.

3.Results

Dry Etching

The etch rate of GaN was 1100Å/min, at a Cl_2 pressure of 0.38 mTorr and an ion acceleration voltage of 500V, which is five times smaller than that of GaAs. The etch rates of GaN were found to increase with beam voltage, to depend weakly on Cl_2 pressure and the substrate temperature. These dependencies are different to those of GaAs. Ion assistance seems to be playing a significant role in the etching of GaN. It is considered that the limiting step in the etching of GaN is the breaking the GaN bonds.

The etched GaN surfaces were measured by XPS and a large Cl2p peak was detected. The O1s and Ga2p3/2 peaks were broad and a chemical shift of these peaks was observed. These facts suggest that complex layers consisting of oxide and chloride are formed on etched GaN surfaces. These layers were able to remove by HF and H_3PO_4 rinsing.

The etched GaN was also measured by RBS after HF and H_3PO_4 rinsing. The surface peak of etched GaN was larger than that of *as grown* GaN. This fact indicates that lattice damage is introduced by RIBE. This lattice damage could not be removed by HF and H_3PO_4 rinsing.

Overgrowth Process and IS Laser Fabrication

Figure 2 shows an SEM photograph of a cross section of the fabricated laser. The etched groove stripes were buried completely and smooth surfaces were obtained.

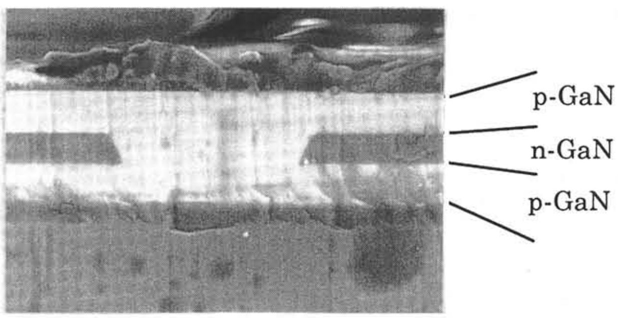

Fig. 2 SEM photograph of the fabricated laser.

Profiles of Mg content were measured by SIMS for the samples before and after overgrowth. Mg diffusion from the p-GaN etch stop layer to n-GaN layer was observed for the samples before overgrowth. The concentrations of Mg in n-GaN layer gradually decreased from interface. Further Mg diffusion also occurred during overgrowth from the p-GaN overgrowth layer into the n-GaN block region. The increase of the Mg content in the n-GaN current blocking layers gives rise to an increase in the shunt current flowing through the blocking layers. Due to this, it is considered that the thickness of n-GaN must be optimized.

Figure 3 shows typical light output vs. current characteristic of a fabricated laser. The threshold current was 1.1A which corresponds to a threshold current density of 20kA/cm^2.

Figure 4 shows the emission spectra of this laser. At injection currents below the threshold, spontaneous emission at a peak wavelength of 402 nm was observed. Above the threshold, strong stimulated emissions were observed. Two sharp stimulated emissions at 414nm and 417nm become dominant at a current of 1.7 A.

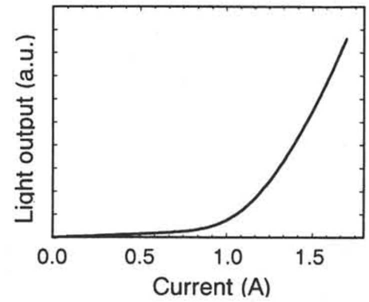

Fig.3 Light output vs. current characteristic of the InGaN IS laser.

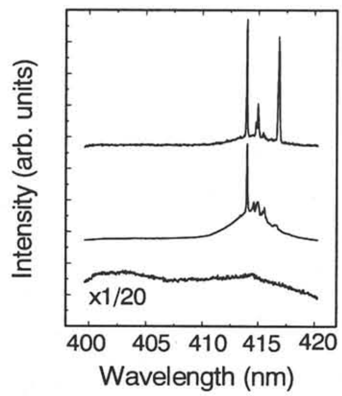

Fig.4 Emission spectrum of the InGaN IS laser.

4. Conclusions

The ECR-RIBE and overgrowth processes were developed as key process for fabrication of advanced structure lasers. The InGaN inner stripe lasers were fabricated by these processes. Lasing under room temperature pulsed operation was realized. Further optimization of process conditions will improve the performance of these lasers.

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