Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 59-61

ZnSe-Based Laser Diodes on p-GaAs with Current Confinement by Nitrogen Ion Bombardment

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Laser diode action has been observed from a ZnSe-based laser diode (LD) on p-GaAs substrate with current confinement structure by nitrogen ion (N^+) bombardment. N^+ bombardment produces high-resistivity layer applicable for a current blocking layer of a LD. Threshold current value of the LD by using the bombardment technique is about one third lower than a conventional LD without ion bombardment having the same contact area.

1. Introduction

In recent years, research of ZnSe-based II-VI compounds have been remarkably developed in doping[1-4]. Based on these techniques, ZnSe-based LDs have been demonstrated by many research groups[5-9].

ZnSe based LDs on n-GaAs contain a problem of ohmic contact to p-type ZnSe layer. In injecting holes into p-type layer, tremendous heat is produced because of large contact resistance due to schottky barrier and small area for hole injection restricted in the contact. To reduce the heat in a LD, we fabricated a LD on p-GaAs. The LDs on p-GaAs have, however, a difficulty in confining a flow of current. Electrons injected from stripe-shape electrode widely spread in the n-type layer, since resistivity of n-type top layers are much lower than that of p-type layers. To confine current flow in a ZnSe-based LD on p-GaAs, We produced current blocking layer in the n-type layer by N^+ bombardment.

In this paper, we report the fabrication of high-resistivity layer in n-ZnSe layer by N^+ bombardment and the characteristics of ZnSe-based LD on p-GaAs with current confinement structure by N^+ bombardment.

2. N^+ bombardment into n-ZnSe

To obtain a high-resistivity layer to block a flow of current in a ZnSe-based LD, we used ion bombardment method with N_2 gas.

The sample used for fabricating high-resistivity layer was a Cl-doped n-ZnSe layer grown by molecular beam epitaxy (MBE). The substrate used was semi-insulating GaAs and carrier concentration of the sample was 9×10^{17} cm^{-3} at room temperature (RT).

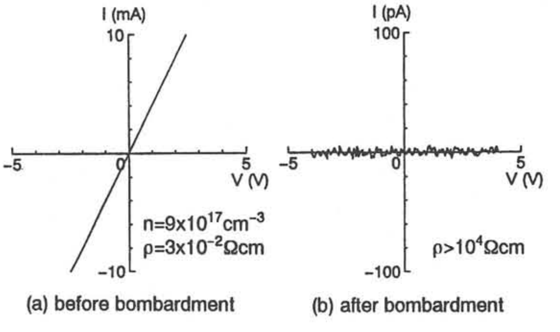

Fig. 1. The I-V characteristics of n-ZnSe layers.
(a) before bombardment.
(b) after bombardment.

The bombardment was carried out at room temperature with an angle of 7° off from <100> direction. Ohmic contact was fabricated by depositing drops of In-Hg alloy followed by an annealing step in Ar-H_2 (10%) gas at 300 °C for 30 s.

By bombarding at an ion energy of 350 keV, N atom penetrated into ZnSe 0.8-μm deep from an analysis of secondary ion mass spectroscopy. Fig. 1 shows the current-voltage (I-V) characteristics of n-ZnSe layers before and after the bombardment. Before bombardment, the n-ZnSe layer was very conductive and the resistivity was about 3×10^{-2} Ωcm. By bombarding, defects were created by the high energy ions and the conductivity was greatly reduced. After bombardment with a dose of 1×10^{15} atom/cm^2, the resistivity of ZnSe layer was increased to over 10^4 Ωcm. This high-resistivity layer can be sufficiently applied for current blocking layer of a LD because of large difference of conductivity between the bombarded and the unbombarded layer.

3. ZnSe-based LD with current confinement structure

The LD was grown directly on (100) p-GaAs by MBE. The structure of the LD is a separate confining heterostructure as shown in Fig. 2. ZnSe-$ZnS_{0.07}Se_{0.93}$ waveguide structure contains a $Zn_{0.65}Cd_{0.35}Se$ single-quantum-well (SQW) at the pn junction. The thickness of the SQW is about 10 nm, and the thicknesses of ZnSe and $ZnS_{0.07}Se_{0.93}$ layers are 0.3 and 0.8 μm, respectively. Cl doping[1] and nitrogen radical doping[2-4] were employed to obtain n- and p-type layers, respectively. Carrier concentrations of n- and p-type layers are about $7x10^{17}$ cm^{-3} and $4x10^{17}$ cm^{-3} at RT, respectively. On the top of the LD, heavily Cl-doped n^+-ZnSe layer ($n = 2x10^{19}$ cm^{-3} at RT) was fabricated to obtain low contact resistance.

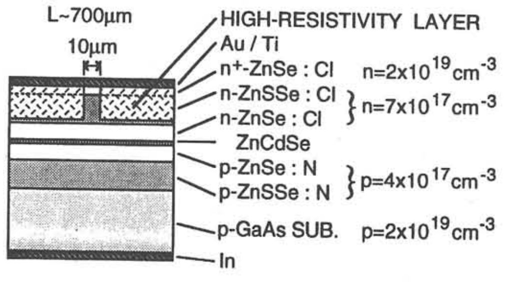

Fig. 2. Schematic illustration of a ZnSe-based LD on p-GaAs with current confinement structure.

Before the bombardment, contacts were fabricated by means of evaporation. Electrode materials for n-type top layers and p-GaAs substrates are Au/Ti[10] and In metal, respectively. Electrodes were alloyed at 300 °C for 5 min to obtain low contact resistance. N^+ was bombarded into the n-type layer at ion energy of 350 keV through a mask whose stripe width was 10μm. N^+ bombardment introduced high-resistivity layer except the masked area, whose thickness was approximately 0.8 μm. LD chips were formed by 700-μm-long cleaved resonator structure and mounted on Cu heat sink with junction up.

For comparison, contact-stripe LD without N^+ bombardment was also fabricated from the same wafer of the LD with current confinement structure described above. A polymer mask was used to fabricate a contact-stripe on the LD. Chip size and contact size are same in these LDs. The difference between two types of LDs is the existence of high-resistivity layer in n-type layer to confine a current.

LDs were operated under pulsed current injection. The current duration was 0.6 μs and duty cycle was 10^{-4} at 77 K, typically. Fig. 3 shows spontaneous and stimulated emission spectra from the LD with current confinement structure. Either LD emitted coherent light in the wavelength of 529 nm at 77 K, In operation at 30% of threshold current (I_{th}), the LD emitted green incoherent light and

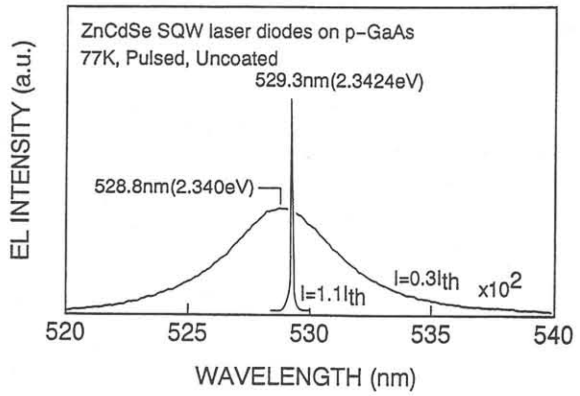

Fig. 3. Spontaneous and stimulated emission spectra for a LD with current confinement structure under pulse current injection at 77 K.

FWHM of the emission was about 22 meV. In operation at $1.1I_{th}$, the LD emits coherent light and the FWHM of the emission was greatly reduced to 0.3 meV nearly equal to the limit of our monochrometer.

Fig. 4 shows the output power from one facet versus current (L-I) characteristics of both the LD. The I_{th} of the LD with carrier confinement structure was 290 mA, which is one third lower than that of the contact-stripe LD without bombardment (I_{th} = 840 mA), though having the same contact area. This results indicates that current confinement is efficiently achieved with the high-resistivity layer obtained by N^+ bombardment. The value of I_{th} for the LD with carrier confinement structure is still large compared to previous report[7]. The reason is that the thickness of the high-resistivity layer (0.8 μm) was too thin to obtain sufficient current confinement in the

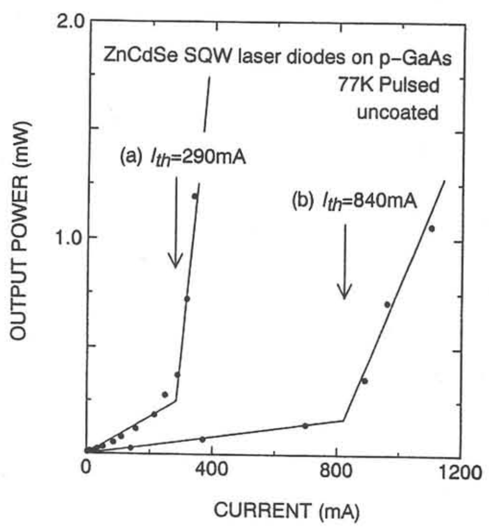

Fig. 4. Output power from a facet versus current characteristics of LDs.
(a) The LD with current confinement structure.
(b) The contact-stripe LD without bombardment.

n-type layer (total thickness is 1.1 μm, see Fig. 2), so the current spread in the n-ZnSe waveguide layer and the density of current decreased. Optimization of the high-resistivity layer is necessary for further confinement of the current in the LD.

The output power of the LD with current confinement structure from a facet exceeded 50 mW. The LD emit coherent light at the temperature of up to 150 K in spite of uncoated facet.

Fig. 5 shows the temperature dependence of the I_{th} of the LD with highly-reflective coatings on the facet (90%-50%). LD action was achieved at the temperature of up to 220 K. A characteristic temperature (T_0) was 96 K at the temperature from 77 to 220 K.

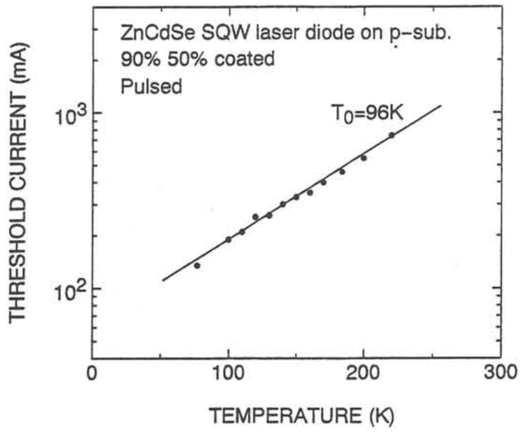

Fig. 5. Temperature dependence of I_{th} of the LD with current confinement structure. (90%-50% coating)

4. Conclusion

In summary, we have demonstrated the production of high-resistivity layer by N^+ bombardment into n-ZnSe layer and fabricated ZnSe-based LDs on p-GaAs with current confinement by N^+ bombardment. The current in the LD was confined and the I_{th} value reduced by one third compared to the contact-stripe LD. Optimization of the high-resistivity layer will be necessary to obtain a LD with better properties.

Acknowledgements

The authors would like to thank Drs. T.Nitta and K.Kanai for their continuous encouragement.

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