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High Power Operation of AlGaAs/GaAs Large-Optical-Cavity Laser Diode with ZnS_xSe_{1-x} ($x=0.06$) Layer Grown by Adduct-Source MOCVD Method

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High power operation of a large-optical-cavity (LOC) AlGaAs laser diode with a ridge-waveguide buried by a ZnSxSel-x (x=0.06) layer has been achieved. In order to produce a reliable high-power laser, we have developed the growth of a lattice-matched ZnSxSel-x (x=0.06) layer by adduct-source metalorganic chemical vapor deposition (MOCVD) and a self-aligned fabrication process by a reactive ion beam etching (RIBE) method for ZnSxSel-x etching. An extremely stable transverse mode operation up to 100mW is obtained with a low threshold current of 30mA at an oscillation wavelength of 780nm. A maximum output as high as 150mW is achieved.

1. Introduction

For high power operation with stable transverse mode, AlGaAs/GaAs laser diodes are implemented to combine a low threshold current, high quantum efficiency, a proper reduction of optical power density at the facets[1,2], and a tight optical confinement[3,4].

We have previously reported that a ZnSe epitaxial layer grown by adduct-source MOCVD is useful for an index-guided structure because of its waveguide without light absorption[5].

On the other hand, interface diffusion at the ZnSe/GaAs heterointerface due to misfit dislocations has been reported[6]. It has also been reported that thermal stability of the heterointerface is extremely improved in the lattice-matched ZnSxSel-x(x=0.06)/GaAs system[6,7]. Complete lattice matching at the ZnSxSel-x/GaAs interface is therefore important in obtaining a high power operation when the ZnSxSel-x epitaxial layer is used in a laser structure as shown in a schematic cross section of Fig. 1.

In this work, the following techniques are used to produce a high performance, high power laser;

(1) An LOC structure is adopted for reducing optical power density in the active layer[8]. Injection blocking and index guiding properties of the ZnSxSel-x layer[5] permit operation of the LOC laser diode without significant increase of the threshold current.

(2) An adduct-source MOCVD method enables one to grow a lattice-matched ZnSxSel-x (x=0.06) epitaxial layer of high quality even at a low growth temperature of 275°C.

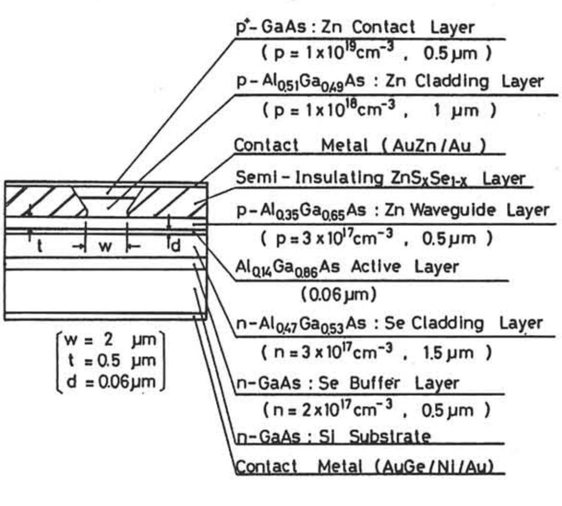

Fig. 1. Schematic cross-sectional drawing of the LOC laser diode with ZnSxSel-x (x=0.06) layer grown by adduct-source MOCVD.

This technique is effective in both stabilizing the ZnSxSel-x/GaAs interface and reducing thermal strain in the active region due to the different thermal expansion coefficients of ZnSxSel-x and GaAs.

(3) A RIBE method[9] is used for ZnSxSel-x etching to obtain a smooth, flat surface so that heat generation at the active region can be dissipated effectively into a heat sink.

By using these advantageous techniques, high power operation with stable transverse mode is achieved for an output power as high as 100mW with an average threshold current of 30mA. Futhermore, this laser structure is suitable for providing a simple self-aligned process.

2.Device Fabrication

Fig. 2 shows the fabrication process in this work. A two-step MOCVD growth was used to fabricate the laser. In the first step, an LOC structure, which consists of six epitaxial layers (active layer thickness of 0.06 μm), was grown on a (100) oriented n-GaAs substrate.

After the first growth, a ridge-stripe in the (011) direction was defined by etching down to 0.5 μm off the active layer using a SiO_2 mask. On this stage, the SiO_2 film overlaps the edges of the ridge-stripe. [Fig. 2-(2)]

In the second MOCVD growth, a ZnSxSel-x (x=0.06) layer was grown on the etched wafer at 275 ℃ using an adduct of dimethylzinc (DMZn)-dimethylselenium (DMSe), H_2Se and H_2S as source materials. The transport rates of the adduct, H_2Se and H_2S were 74 μmol/min, 233 μmol/min and 580 μmol/min, respectively. Under this condition, the growth rate was 2.2 μm/min. A single crystalline ZnSxSel-x (x=0.06) layer grows on an outside region of the ridge-stripe, while a polycrystalline layer grows on the ridged region covered with the SiO_2 film. [Fig. 2-(3)]

To remove the polycrystalline layer, a RIBE technique was used. As shown in Fig. 2-(3), before the RIBE process, the wafer was coated by a photoresist cured at 250 °C for 2 hours. The upper surface was nearly flat. This wafer was etched by the RIBE technique using a mixture of Cl_2 (75%) and Ar (25%) gas. The RIBE was carried out under gas pressure of 4×10^{-3} Torr, microwave power of 100W and an ion extraction voltage of 500V. The etching rate for the ZnSxSel-x layer and the SiO_2 film was 400Å/min and 120Å/min, respectively. The SiO_2 film thus acted as the etching stop layer. The surface of the wafer was etched flatly as shown in Fig. 2-(4).

After a metalization process, the reflectivity of the front facet was adjusted to 4% by an Al_2O_3 layer and the rear facet to 95% by an a-Si/Al_2O_3 stacked reflector. The laser diode chip was mounted in the p-side-down configuration on a Si heat sink.

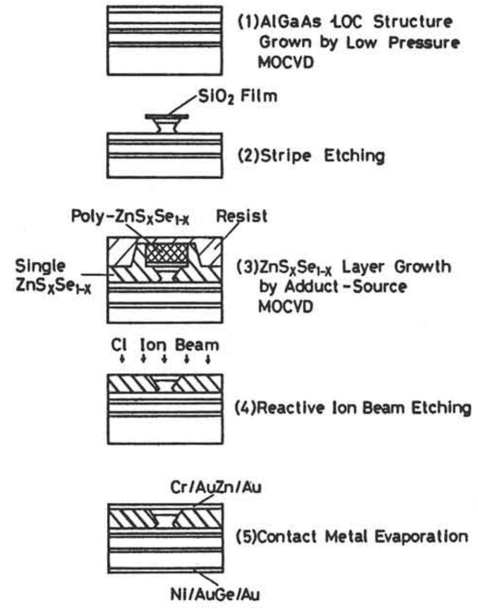

Fig. 2. Fabrication process.

3. Experimental Results

3-1. ZnSxSel-x epitaxial layer

Fig. 3 shows full width at half maximum (FWHM) of the line width of X-ray rocking curves as a function of a sulfer content (x) in ZnSxSel-x layers grown by adduct-source MOCVD. The line width has a minimum value of 40 sec at x=0.06 which indicates that this layer is closely lattice matched to GaAs.

To study the lattice matching effect in more detail, the optical property of the film was investigated. Fig. 4 shows photo-luminescence (PL) spectra measured at 4.2K for (a) the ZnSe layer and (b) ZnSxSel-x (x=0.06) layer on GaAs (100) substrate. Both the ZnSe and ZnSxSel-x (x=0.06) were grown at 275 °C to a thickness of 2 μm. The PL spectrum for the ZnSe layer shows a sharp band-edge-emission (442.5nm) and broad deep-level emissions, while the PL spectrum for the ZnSxSel-x (x=0.06) layer shows only a sharp and strong band-edge-emission (438.5nm). Its intensity is 30 times greater than that of the ZnSe layer.

As shown clearly in Fig. 4, deep transitions at 477nm (Y) and 492nm (S) (which have been attributed to dislocation and dislocation associated impurities) are drastically reduced in the lattice-matched ZnSxSel-x (x=0.06) film. The lattice matching effect will ensure thermal stability at the ZnSxSel-x/GaAS heterointerface[6]. This feature is important for high power operation

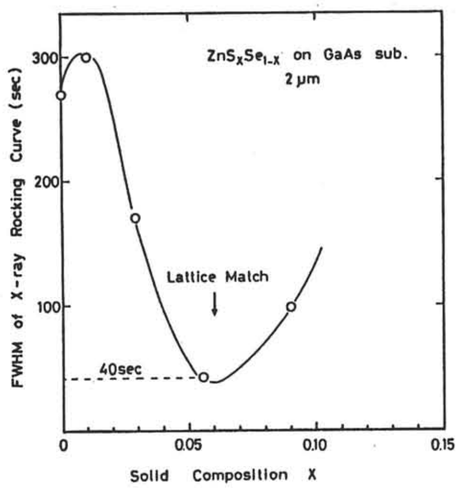

Fig. 3. Line width (full width at half maximum) of X-ray rocking curves as a function of composition x in ZnSxSel-x epitaxial layers grown by adduct-source MOCVD.

of a ridge-waveguide laser diode buried by a ZnSxSel-x layer.

3-2. Device Characteristics

Fig. 5 shows typical light output power versus injection current (L-I) characteristics under CW operation at 300K. The ridge width (w) is 2.0 μm and the remaining thickness of the waveguide layer (t) is 0.5 μm. The average threshold current is 30mA. A maximum CW output power of 150mW is obtained and catastrophic optical damage (COD) level is estimated 6.5×10^{6} MW/cm^{2}, which is equal to or higher than the previously reported value[3]. Fig. 5 also shows the lateral far-field patterns at different power levels. The stable fundamental transverse mode operations parallel to the junction plane are observed up to 100mW. The FWHM of the beam divergence is typically a stable 19 degrees through the whole power range. From this angle with a ridge width (w), the real refractive index step along the junction plane is an estimated 2×10^{-2}. Also, single longitudinal mode operation is maintained to beyond 100mW. The lasing wavelength is 780nm at 10mW and 783.5nm at 100mW.

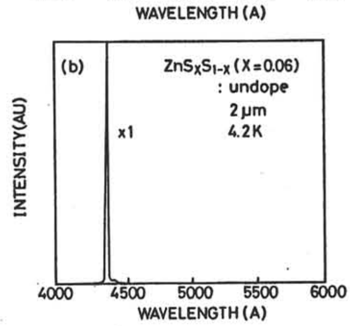

Fig. 4. PL spectra excited by He-Cd laser (325nm, 10mW) at 4.2K: (a) ZnSe on GaAs (100) (b) ZnSxSel-x (x=0.06) on GaAs (100) grown by an adduct-source MOCVD at 275°C.

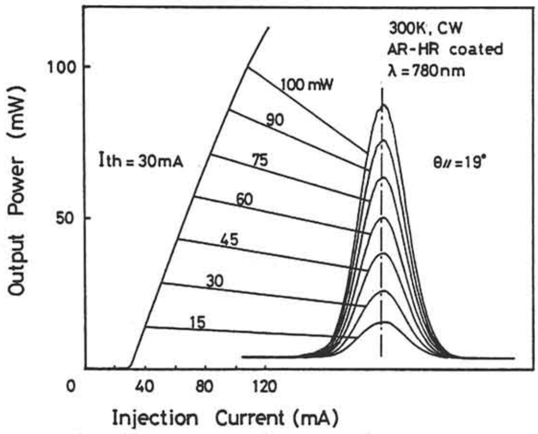

Fig. 5. CW output power versus injection current characteristics and far-field patterns in parallel to the junction plane.

This stable transverse and longitudinal mode oscillation at high power levels is the result of effective formation of the real refractive index step by the ZnS_xSe_{1-x} (x=0.06) layer.

CW operation is achieved at temperatures above 100°C. From the thermal dependence of the threshold current, the characteristic temperature (T_θ) is 134K (20-70°C).

The MOCVD technique is advantageous for growing uniform and thin films such as a superlattice. The quantum structure in the active region will permit high maximum output power operation with a low threshold current[10, 11].

4. Conclusion

A high power LOC ridge-waveguide AlGaAs laser diode with an adduct-source MOCVD grown ZnS_xSe_{1-x} (x=0.06) burial layer has been developed by a simple and reproducible process using RIBE. As a result of tight optical confinement by the lattice-matched ZnS_xSe_{1-x} (x=0.06) layer, a stable transverse and longitudinal mode oscillation has been obtained up to 100mW with a lasing wavelength of 780nm. Thermal stability of the lattice-matched ZnS_xSe_{1-x}/GaAs interface will provide a reliable high-power laser diode.

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