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High-Power Single Mode Operation of Index-Guided Inner Stripe (I^2S) Laser by MOCVD

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A novel index-guided inner stripe (I^2S) laser, whose transverse mode is stabilized by real refractive index change in the lateral direction, has been developed by two-step metalorganic chemical vapor deposition (MOCVD) technique. The laser operates in a stable fundamental transverse and single longitudinal mode up to 42mW or more. The maximum output power as high as 64mW and the differential quantum efficiency as high as 48% per front facet are obtained for the coated device.

1. Introduction

Metalorganic chemical vapor deposition (MOCVD) has the capability of growing uniform epitaxial layer on large area wafers with the high controllability of layer composition and thickness. So MOCVD technique has been regarded as promising mass production technique for laser diodes and another compound semiconductor optical devices. Recently, several types of index-guided lasers grown by MOCVD technique have been reported to operate in fundamental transverse mode.[1-11] However, most of them adopts the so-called loss-stabilized structure, where the transverse mode is stabilized by light absorption to the GaAs current confinement layer. As for these loss-stabilized lasers, the stripe width as narrow as around 2μm is necessary to obtain stable fundamental transverse mode under high power operation. But as the stripe width narrows, quantum efficiency becomes lower by enhanced light absorption effect. To solve this problem, a new built-in waveguide structure was employed in this work.

In this paper we report stable high power operation of GaAs/AlGaAs laser with a new built-in waveguide structure, index-guided inner stripe (I^2S) lasers, grown by MOCVD.

2. Device Fabrication

A schematic diagram of the I^2S laser structure is shown in Fig.1. The laser has self-aligned structure with a real refractive-index step in the lateral direction. The I^2S laser is prepared by two-step MOCVD technique. The growth was performed in horizontal reactor with RF-heated graphite susceptor under atmospheric pressure. Trimethylgallium (TMG), trimethylaluminum (TMA) and arsine (AsH_3) were used as source materials. Diethylzinc (DEZ) and hydrogenselenide (H_2Se) were used as p-type and n-type dopants, respectively.

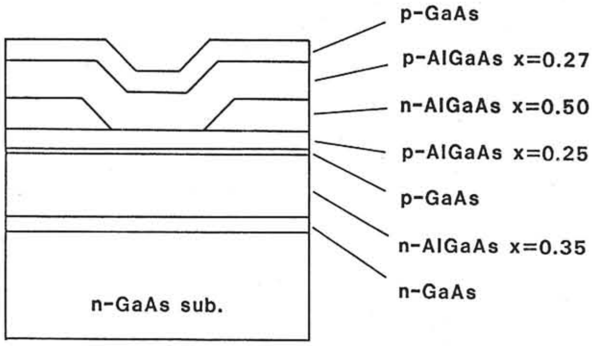

Fig.1 Schematic diagram of the I^2S laser.

In the first step growth, five layers with an asymmetric double heterostructure were grown successively on a (100) oriented Si-doped n-GaAs substrate; an n-GaAs buffer layer ($n=2\times10^{18}cm^{-3}$, 1.0µm), an n-$Al_{0.35}Ga_{0.65}As$ cladding layer ($n=2\times10^{17}cm^{-3}$, 2.0µm), a p-GaAs active layer ($p=2\times10^{18}cm^{-3}$, 0.12µm), a p-$Al_{0.25}Ga_{0.75}As$ waveguiding layer ($p=7\times10^{17}cm^{-3}$, 0.5µm), and an n-$Al_{0.5}Ga_{0.5}As$ blocking layer ($n=2\times10^{17}cm^{-3}$, 1.0µm). Then the channel groove with 3µm width along the <01$\bar{1}$> direction was formed by chemical etching in $6H_2SO_4:H_2O_2:H_2O$ (5°C) solution. The n-$Al_{0.5}Ga_{0.5}As$ blocking layer was etched off completely at the channel. In the second step growth, two layers were grown on the etched wafer; a p-$Al_{0.27}Ga_{0.73}As$ cladding layer ($p=1\times10^{18}$, 1.5µm) and a p-GaAs contact layer ($p=1\times10^{19}$, 1.0µm). This second growth on the AlGaAs channel is possible by use of the MOCVD technique. After the metallization and cleaved processes, the laser chip of 250µm length was mounted on a Si heat-sink in the junction-up (n-side down) configuration. The reflectivity of the front facet was adjusted to 14% by SiO_2 coating and that of the rear facet to 90% by a-Si/SiO_2 stack reflector.[12]

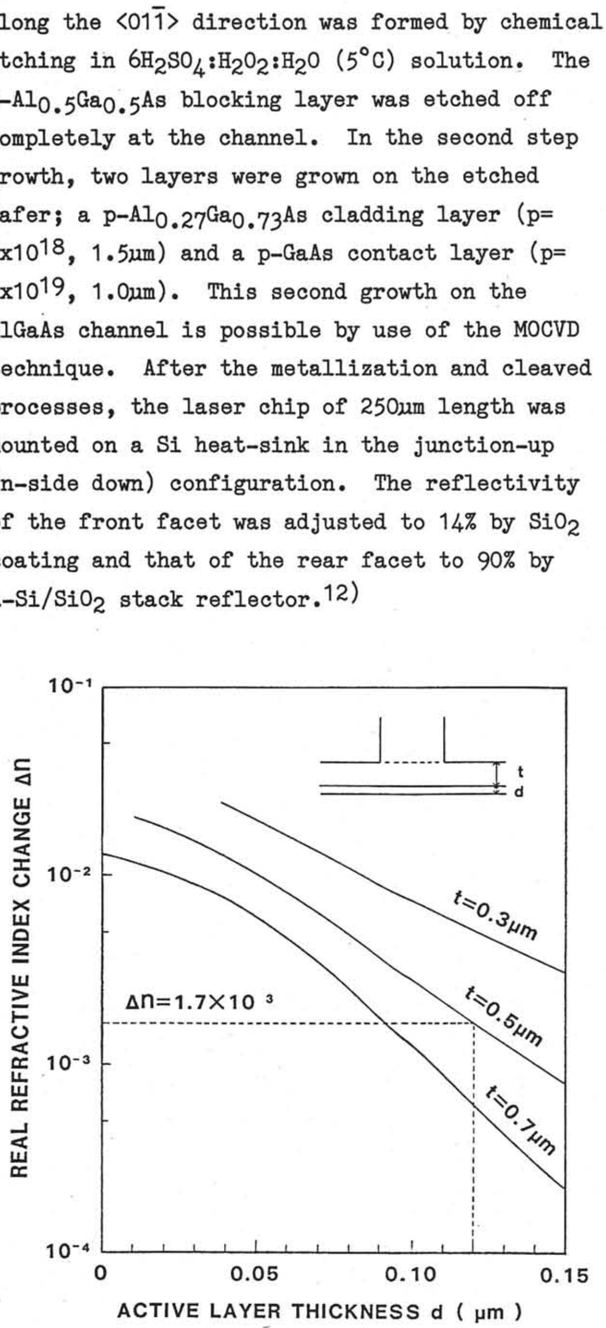

Fig.2 Real refractive index change as a function of active layer thickness.

3. Device Characteristics

In the I^2S structure, an effective index step is formed in the lateral direction, because the n-$Al_{0.5}Ga_{0.5}As$ blocking layer has smaller refractive index than p-$Al_{0.27}Ga_{0.73}As$ cladding layer. Fig.2 shows the result of the calculation of the lateral index change (Δn) as a function of the active layer thickness (d), with a parameter of the waveguiding layer thickness (t). The calculation was based upon simple equivalent refractive index method. For the I^2S laser with t=0.5µm and d=0.12µm, Δn is given 1.7×10^{-3} as shown in Fig.2. This value is sufficient to stabilize the transverse mode. The condition which permits only fundamental transverse mode oscillation is shown in Fig.3 as a function of the active layer thickness (d) and stripe width (W). Each curve in Fig.3 represents the cut-off condition of the first order mode for different waveguiding layer thickness. Fundamental mode is permitted only the underside of the solid curve. For t=0.3 and 0.5µm, all modes are cut off in the region less than d=0.04 and 0.01µm, respectively. For the I^2S laser with d=0.12µm and t=0.5µm, which is demonstrated in this work, the fundamental transverse mode is obtained even for relatively wide stripe width (about 4µm).

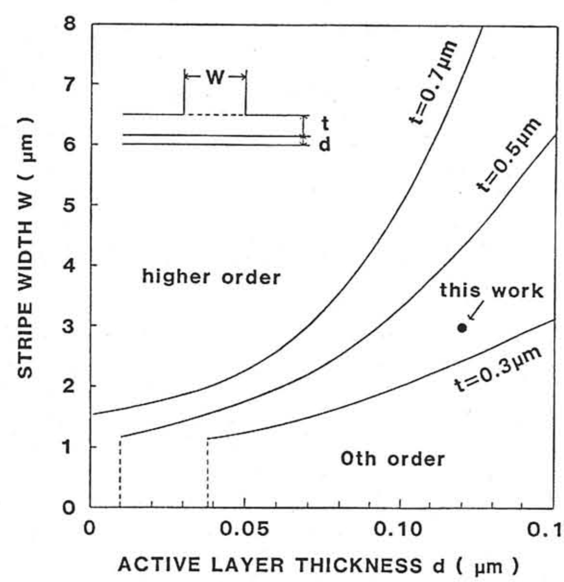

Fig.3 Conditions of single mode operation for I^2S laser.

Far-field patterns of the I^2S laser with $d=0.12\mu m$ and $W=3\mu m$ were measured on several output power level from 7mW to 42mW. The typical patterns are shown in Fig.4. The laser oscillates in a single fundamental transverse mode through all power levels. The full angle at half-maximum in parallel($\theta_{\parallel}$) and perpendicular ($\theta_{\perp}$) directions are typically 10.9° and 33.5°, respectively. This value of $\theta_{\parallel}$ corresponds to the beam spot size of around $3\mu m$, which is consistent with the width of the channel groove. Fig.5 (a) and (b) show near-field patterns under the threshold and the lasing condition, respectively. From Fig.5(a), it is indicated that the blocking layer acts effectively as optical confinement layer. In the lasing mode (Fig.5(b)), the optical fields are confined only in the channel groove. The laser operates in extremely stable fundamental transverse mode as was expected from the calculation because the laser structure is satisfied fundamental (0th order) mode condition as shown as a dot in Fig.3. Fig.6 shows the CW output power versus current characteristics. The external differential quantum efficiency of the front facet is 48%. Taking account of high carrier concentration ($2x10^{18}cm^{-3}$) and thickness ($0.12\mu m$) of the active layer, this value seems to be rather high. The internal loss , which includes not only absorption loss but also scattering loss or radiation loss, is estimated to be $26cm^{-1}$ from the measurement of the threshold current difference between before and after the facet coating. The maximum CW output power as high as 64mW is obtained in spite of the relatively thick active layer. Output power versus current characteristics shows no kink up to 50mW as shown in Fig.6. Lasing spectra under CW condition are shown in Fig.7. Stable single longitudinal mode is maintained up to 42mW. The lasing wavelength is changed from 883.8nm at 7mW to 890.4nm at 42mW. This shift in wavelength

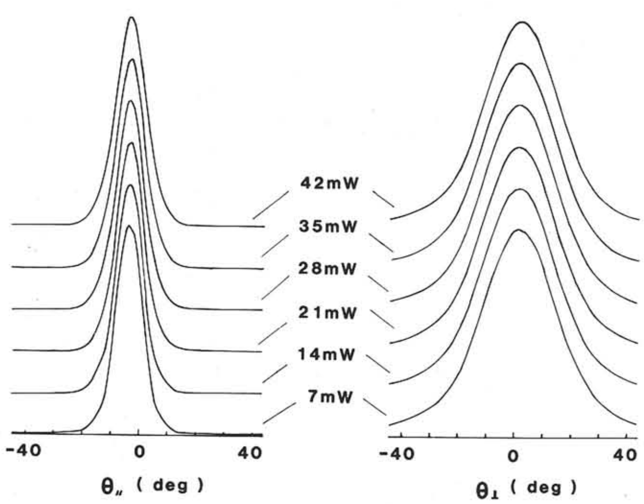

Fig.4 Far-field patterns for the I^2S laser under CW operation.

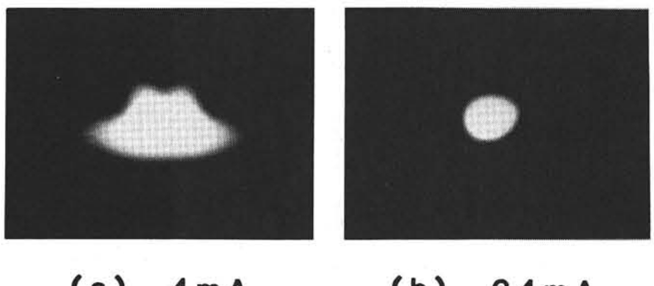

Fig.5 Near-field patterns for the I^2S laser (a) under the threshold and (b) the lasing condition.

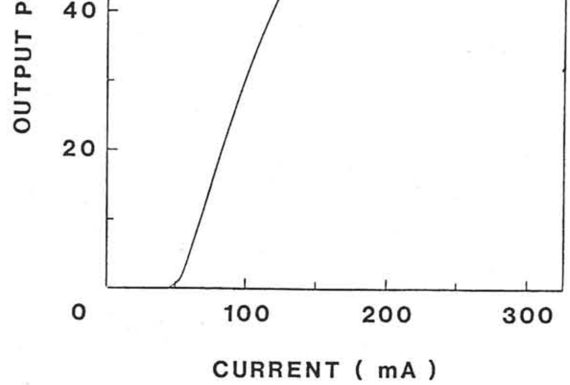

Fig.6 Light output power versus current characteristics

can be explained by junction temperature rising, which is estimated to be about 25°C.

4. Conclusion

A novel built-in waveguide laser with a real refractive index-guide, index-guided inner stripe (I^2S) laser, has been developed by use of two step MOCVD technique. Highly stable transverse mode and the single longitudinal mode were maintained up to 42mW or more because of tight optical confinement owing to lateral real index step. High differential quantum efficiency of 48% and high output power of 64mW were obtained even in junction-up configuration.

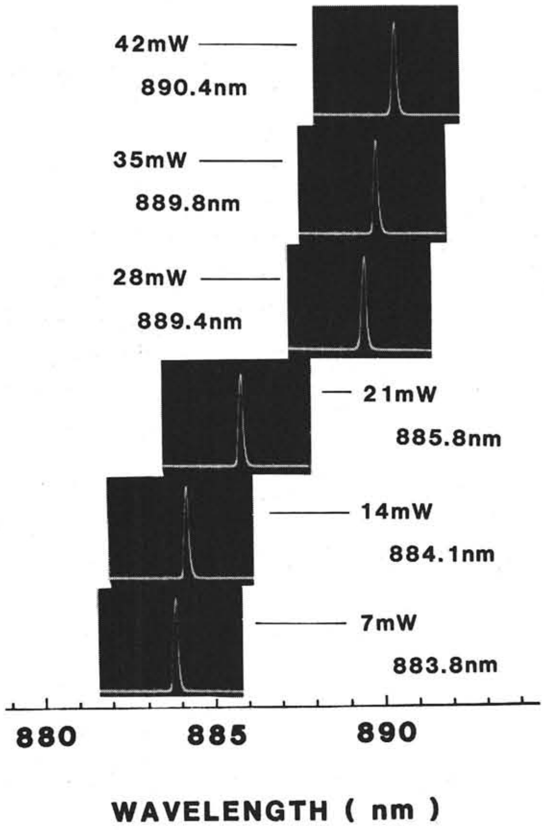

Fig.7 CW lasing spectra at different light output

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