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A New Transverse-Mode Stabilized GaAlAs Laser with a Slab-Coupled Waveguide Grown by MOCVD

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A novel transverse-mode stabilized GaAlAs laser with a slab-coupled waveguide grown by metalorganic chemical vapor deposition has been developed. The structure is characterized by real refractive index guiding, which resulted in 10 mA threshold current reduction, compared with the previously reported loss stabilized lasers. The laser exhibited stable fundamental transverse mode oscillation and linear light current characteristics with average threshold current as low as 40 mA. Excellent uniformity in device characteristics has been achieved with standard deviations of 1.85 nm for lasing wavelength and 2.09 mA (5.2 %) for threshold current.

1. Introduction

Metalorganic chemical vapor deposition (MOCVD) attracts increasing attention as a powerful technique for large scaled laser diode production, since it is potentially suited for uniform thin film growth on large substrates with high throughput.[1-3] Recently, GaAlAs laser diodes are in growing demand for digital audio disc players, high density optical disc memories and short haul optical communication systems. For the above applications, lasers with fundamental transverse mode oscillation are required.

We have developed a novel transverse-mode stabilized GaAlAs laser with a slab-coupled waveguide structure. Figure 1 shows a schematic of the laser structure. Unlike the previously reported ECO (Embedded Confining layer in Optical guide) laser,[4] the n-GaAs current blocking layer plays no essential role in stabilizing the transverse mode. In this modified ECO (m-ECO) structure, a thin GaAlAs (x=0.35) layer, whose refractive index is larger than the GaAlAs (x=0.45) cladding layer, is introduced sufficiently near the active layer inside the stripe channel. This configuration forms a so-called slab-coupled waveguide.[5]

The m-ECO structure has the following advantages. (1) The real refractive index guided structure has lower laser internal loss, compared with the loss stabilized conventional ECO laser.[4] (2) The m-ECO structure is favorable for high power operation, because the optical field sufficiently

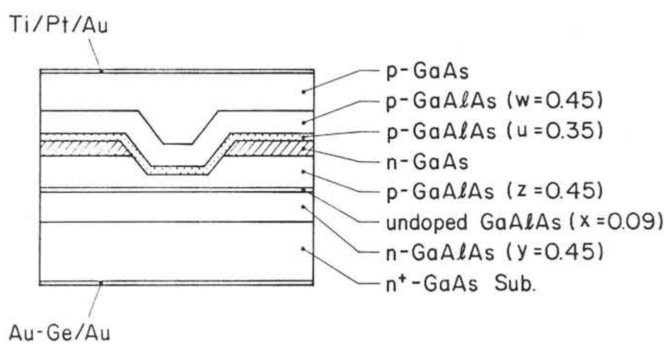

Fig.1 Schematic of the laser structure.

spreads into the cladding layer, as in a large optical cavity structure.[6] (3) The structure with a flat active layer is attractive, compared with a structure grown on a mesa- or channeled substrate,[7-10] because a high quality active layer can be obtained by deep substrate etching and by introducing a thicker buffer layer.

2. Device fabrication

The GaAlAs layers were grown in an rf-heated vertical MOCVD reactor under atmospheric pressure. Source materials were trimethylgallium (TMG), trimethylaluminum (TMA) and arsine (AsH_3). Diethylzinc (DEZ) and hydrogenselenide (H_2Se) were used as p-type and n-type dopants, respectively. Growth temperature was 750 °C.

The m-ECO structure requires two-step MOCVD growth. In the first growth step, five layers were grown on a (100) oriented Si-doped GaAs substrate; an n-GaAs buffer layer ($n=1\times10^{18}$ cm^{-3}, 2 μm), an n-GaAlAs (x=0.45) cladding layer ($n=1\times10^{17}$ cm^{-3}, 1.5 μm), an undoped GaAlAs (x=0.09) active layer (0.08 μm), a p-GaAlAs (x=0.45) cladding layer ($p=2\times10^{18}$ cm^{-3}, 1.5 μm) and an n-GaAs current blocking layer ($n=5\times10^{18}$ cm^{-3}, 0.5-1.0 μm). The p-GaAlAs cladding layer is sufficiently thick (1.5 μm) that optical absorption in the GaAs current blocking layer is minimized.

A channel stripe along the $(1\bar{1}0)$ direction was etched through the n-GaAs current blocking layer by using an H_2SO_4:H_2O_2:H_2O (8:1:1, 20 °C) etch. In the second growth step, the rest of the layers were grown on the channeled wafer; a p-GaAlAs (x= 0.35) guiding layer ($p=2\times10^{18}$ cm^{-3}, 0.25 μm) and a p-GaAs contact layer ($p=9\times10^{18}$ cm^{-3}, 4-5 μm). This second growth, which involves epitaxial growth on GaAlAs with high AlAs mole fraction (x=0.45), was successfully made by MOCVD without any difficulty, while it is very difficult in liquid phase epitaxy.[11)]

Figure 2 shows a cross-sectional scanning electron microscope (SEM) photograph of an m-ECO laser. The channel bottom width ranges from 2.5 μm to 3 μm. Ohmic contacts were formed with Ti/Pt/Au for the p-side and Au-Ge/Au for the n-side of the device.

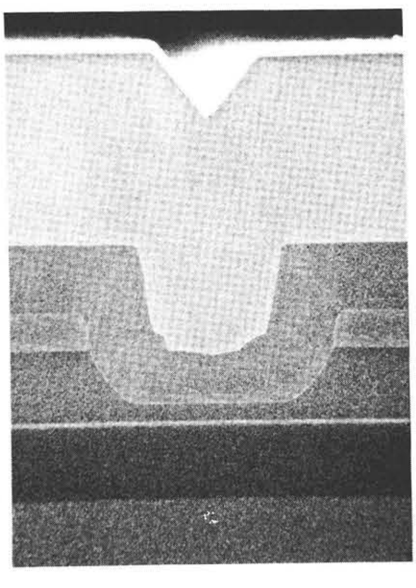

Fig.2 A cross-sectional SEM photograph of an m-ECO laser.

3. Device characteristics

The m-ECO structure can realize a sufficient effective refractive index step required for transverse mode guiding with practically attainable dimensions. Figure 3 shows the effective refractive index step Δn_{eff} as a function of guiding layer-active layer spacing h, with a parameter of guiding layer thickness t for active layer thickness d=0.08 μm. The structure with t= 0.25 μm, h=0.4 μm and d=0.08 μm gives an effective refractive index step Δn_{eff} on the order of 10^{-3}, which is large enough for transverse mode guiding.

Figure 4 shows stripe width w, at which the first order mode is cut-off, as a function of h with a parameter of t for d=0.08 μm. Fundamental transverse mode oscillation can be achieved for less than 3 μm stripe width with h=0.4 μm and t= 0.25 μm. Experimental results for the lasers with t=0.25 μm are also shown in Fig.4. Open circles represent fundamental transverse mode oscillation and closed circles represent higher order mode oscillation. These experimental results are in good agreement with the calculated curve.

There can be another possibility to give rise to an effective refractive index step, that is, to

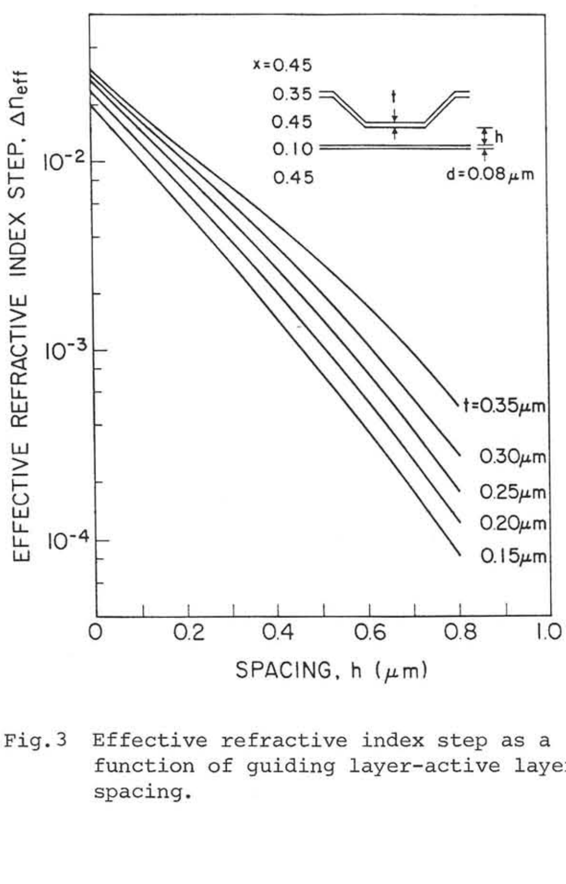

Fig.3 Effective refractive index step as a function of guiding layer-active layer spacing.

fill the channel only with a thick guiding layer, for example, an x=0.40 GaAlAs layer. However, in this structure, cut-off occurs near the dimensions required for obtaining a sufficient effective refractive index step, which makes the waveguide design difficult.

Figure 5 shows light-current characteristics for an m-ECO laser under CW operation. Average

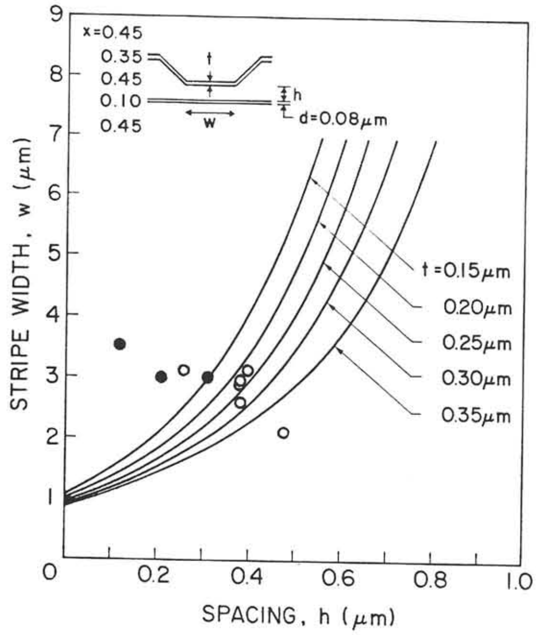

Fig.4 Dimensions of m-ECO lasers for fundamental transverse mode oscillation.

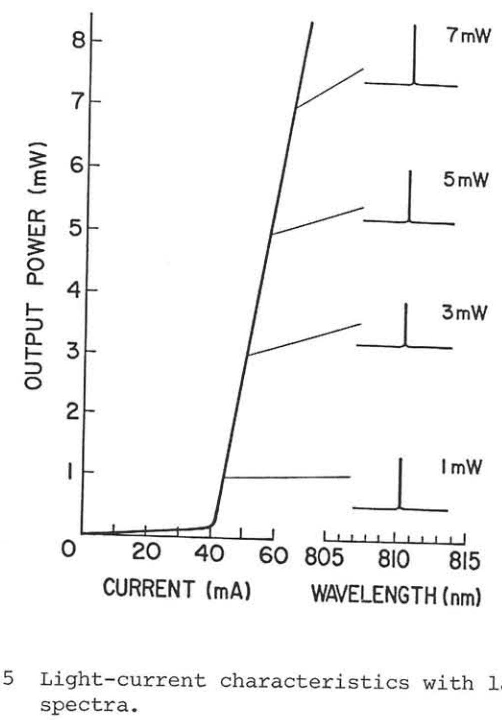

Fig.5 Light-current characteristics with lasing spectra.

threshold current as low as 40 mA and differential quantum efficiency as high as 22 %/facet were obtained for 250 μm-long cavity. Compared with the loss stabilized conventional ECO lasers,[4] 10 mA threshold current reduction was achieved. The measured laser internal loss was 26 cm^{-1} for the m-ECO lasers, while the conventional ECO lasers had larger values ranging from 40 cm^{-1} to 75 cm^{-1} due to light absorption in the GaAs current blocking layer. This laser internal loss reduction is effective for reducing the threshold current of the m-ECO laser.

Lasing spectra for the m-ECO laser are also shown in Fig.5. The laser exhibited single longitudinal mode oscillation at above 1 mW/facet output power. This single longitudinal mode behavior is characteristic of index guided lasers.

Figure 6 shows far-field profiles for an m-ECO laser. These Gaussian-like profiles, unchanged with increasing output power, indicate that stable fundamental transverse mode oscillation is achieved. Beam divergences parallel and perpendicular to the junction plane were $\theta_{\parallel}=7°$ and $\theta_{\perp}=23°$, respectively. The beam divergence perpendicular to the junction plane is much smaller than the calculated value of 38° for a simple double heterostructure laser. The large mode size implies that the m-ECO structure is advantageous for obtaining high output power. The maximum output power for m-ECO lasers with Al_2O_3 facet coating was 50 mW/facet under CW operation.

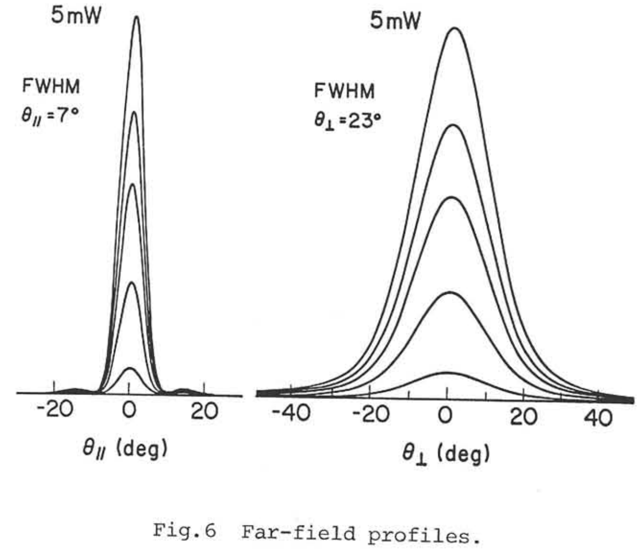

Fig.6 Far-field profiles.

The m-ECO lasers exhibited quite uniform device characteristics. Figures 7 (a) and (b) show the variations in lasing wavelength and threshold current for the lasers cleaved from one wafer, respectively. The standard deviations were 1.85 nm for lasing wavelength and 2.09 mA (5.2 %) for threshold current. These values are comparable to those for simple proton stripe double heterostructure lasers grown by MOCVD.[2,3]

4. Conclusion

A novel transverse-mode stabilized GaAlAs laser with a slab-coupled waveguide grown by MOCVD has been developed. This modified ECO (m-ECO) laser exhibited stable fundamental transverse mode oscillation and linear light-current characteristics with average threshold current as low as 40 mA. The real refractive index guiding resulted in 10 mA threshold current reduction, compared with the loss stabilized conventional ECO laser. Small beam divergence perpendicular to the junction plane ($\theta_{\perp}$=23°) implies that the m-ECO structure is potentially suitable for high power operation. The m-ECO laser exhibited excellent uniformity for device characteristics with standard deviations of 1.85 nm for lasing wavelength and 2.09 mA (5.2 %) for threshold current. With these characteristics, the m-ECO structure is quite promising as a transverse mode stabilized laser grown by MOCVD.

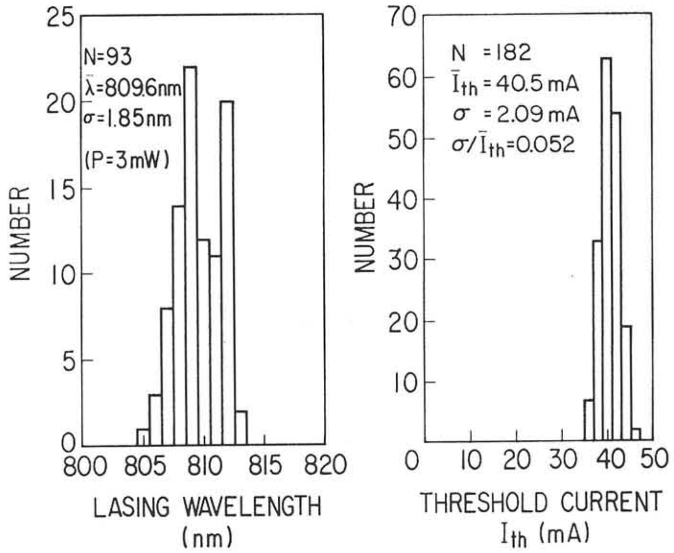

Fig.7 Variations in (a) lasing wavelength and (b) threshold current.

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