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A Novel Self-Aligned Laser with Small Astigmatism Grown by MO-CVD

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A novel self-aligned AlGaAs laser with bent active layer fablicated by two step metalorganic chemical vapor deposition (MO-CVD) has been developed. The transverse mode is stabilized by a large effective refractive index change provided by the steep bends of the active layer. As a result, low threshold current (40mA) and small astigmatism (<1μm) have been achieved. The laser operates in the fundamental transverse mode and single longitudinal mode untill the output power reaches its COD level.

1. Introduction

Metalorganic chemical vapor deposition (MO-CVD) draws considerable attention as a promising crystal growth technique for semiconductor lasers, since it has the capability of uniform epitaxial growth on a large substrate with sharp heterostructure interface. In recent years, many types of transverse-mode-stabilized AlGaAs lasers have been reported.[1-7] To realize low threshold current, some of these lasers[1-2] employ the inner current-confinement stripe that consists of an etched groove in a GaAs current blocking layer, and their transverse mode is stabirized by the light absorption in this layer. These types of lasers, so-called loss-stabilized lasers, have rather large astigmatism because the optical wave of these lasers is guided by the changes in both the real and imaginary parts of the effective complex refractive index along the junction plane. For the practical use such as reading and writing on the optical discs or laser beam printers, it is desireble to minimize the astigmatism because large astigmatism requires beam tailoring by specific lens. On the other hand, several transverse-mode-stabilised lasers grown on substrates with shallow channels or mesas have been also reported.[3-6] These lasers have theoretically small astigmatisms originating from the real-index-guiding caused by bending of the active layer. But they have no self-aligned current confinement structure, which is very important in order to obtain good reproducibility of the device characteristic.

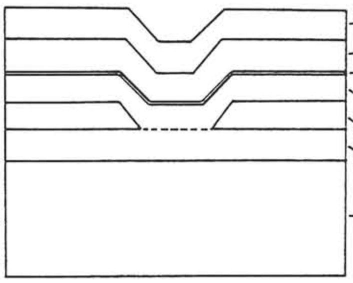

Fig.1 Schematic illustration of an SBA laser

In this paper we report on a novel self-aligned structure laser with bent active layer (SBA laser) grown by two step MO-CVD. The transverse mode of the laser is stabilized by a large refractive index change produced by bends in the active layer grown on a U-grooved substrate , which results in small astigmatism (<1μm).

2. Device fablication

The AlGaAs double-hetero wafer of the SBA laser was grown by two step MO-CVD. The growth was performed in vertical reactor with RF-heated graphite susceptor under atmospheric pressure. The groth temperature was 700°C. Trimethylgallium (TMG) and trimethylaluminum (TMA) were used as group Ⅲ sources. 10 % hydrogen-diluted arsine (AsH_3) was used as group Ⅴ source. Diethylzinc (DEZ) and hydrogenselenide (H_2Se) were used for p-type and n-type doping, respectively. The total gas flow rate was 6 liters/minute and [Ⅴ/Ⅲ] mole ratio was 12-20.

Figure 1 shows the schematic illustration of the SBA laser. In the first step growth, a p-GaAs buffer layer ($p=1x10^{18}$ cm^{-3}, 1μm), a p-AlGaAs buffer layer (x=0.43, $p=8x10^{17}$ cm^{-3},1μm) and an n-GaAs current blocking layer ($n=6x10^{18}$ cm^{-3}, 1μm) were grown on the (100) oriented p-type GaAs substrate (Zn-doped, $p=1x10^{19}$ cm^{-3}). P-AlGaAs buffer layer was employed to avoid the absorption loss for the lasing emission by the GaAs substrate. After the first-step growth , U-grooved stripe along the $[01\bar{1}]$ direction was formed by preferential etching of the GaAs current blockin layer down to the AlGaAs buffer layer using $NH_4OH:H_2O_2$=20:1 etchant at 10°C. The etching speed in the AlGaAs(x=0.43) layer is much lower than that in GaAs. So we can control the etching depth quite easily, since the AlGaAs layer acts as a stopper layer. The use of preferential ethcant is advantageous in the case of mass production. Four epitaxial layers were grown on this U-grooved substrate in the second-step growth ; a p-AlGaAs cladding layer (x=0.43, $p=8x10^{17}cm^{-3}$, 1μm), an undoped AlGaAs active layer (x=0.07,0.08 μm), an n-AlGaAs cladding layer (x=0.43, $n=1x10^{17}$ cm^{-3}, 1.3μm) and an n-GaAs contact layer ($n=6x10^{18}$ cm^{-3}, 1μm). Although an AlGAAs buffer layer is exposed at the bottom of the groove, epitaxial growth on this layer can be performed without any difficulty by utilizing MO-CVD, while it is difficult by LPE (liquid phase epitaxy). An SEM photograph of cleaved cross-section of the SBA laser is shown in Fig.2. As is seen in this photograph, the regrown layers reflect the cross-sectional shape of the grooved substrate, which is a feature of MO-CVD. Therefore the active layer bends along the surface of grooved substrate and flat portion is produced just above the bottom of the U-groove. We adjusted the width of the flat portion of the active layer, which act as a lasing region, about 2.5um. After the MO-CVD growths, the metal electrode of Au-Ge-Ni/Au and Ti/Au were formed on the n-GaAs contact layer and the p-GaAs substrate, respectively. Then the laser chips were mounted in a junction-up configuration.

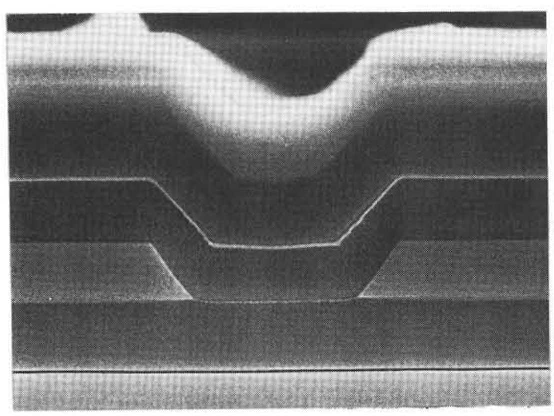

Fig.2 A cross-sectional SEM photograph of an SBA laser

3. Device characteristic

As is already mentioned, the transverse mode of the SBA laser is stabilized by the bends of the active layer. In the case of small bending angle (15°), mode analysis for the lasers with bent active layer has been made.[5] But the mode characteristics of the SBA laser, whose bending angle of the active layer is very steep (about 50°), would rather resemble to that of the burried heterostructure (BH) laser.[8] According to the analysis for BH lasers,[9] the effective refractive index change parallel to the junction plane (Δn) of the SBA laser is estimated to be around $5x10^{-2}$. This value is large enough to stabilize the transverse mode. Precise mode analysis for the SBA laser will be presented in another occasion.

Figure 3 shows light output power versus current (P-I) characteristics of the SBA laser under CW operation at room temperature. The kink-free linear P-I characteristics with differential quantumn efficiency of 20 %/facet and the threshold current as low as 40 mA were obtained for the uncoated device with 250 um cavity length. The threshold current is lower compared with loss-stabilized lasers[1-2] or other real-index-guided laser[3-6] grown on etched substrates by MO-CVD. This low threshold current is attributed both to sufficient current confinement by the inner stripe and to rigid optical guiding owing to the steep bends of the active layer. Figure 3 also shows the lasing spectra of the SBA laser. Single longitudinal mode was maintained until the output power reached its COD (catastrophic optical damage) level, which exeeds 15 mW/facet.

Figure 4 shows the far field patterns of the SBA laser. Beam divergence parallel and perpendicular to the junction plane ($\theta_{\parallel}$,$\theta_{\perp}$) are 14° and 28°, respectively. This small aspect ratio ($\theta_{\perp}/\theta_{\parallel}$=2) is favorable for the practical use of the laser diodes. In fig.5, we show the output power dependence of the far-field pattern parallel to the junction plane ($\theta_{\parallel}$). There appears no change in the profile with increasing output power. This implies that stable oscillation in fundamental transverse mode is maintained up to above 12 mW.

Figure 6 shows the temperature dependence of the threshold current under CW condition. The characteristic temperature T_o, where the threshold current (I_{th}) is supposed to increase with temperature in proportion to exp(T/T_o), are 185 K below 50° C and 115 K above 50° C. The value 185 K below 50° C is excellent as compared with the other type of lasers. This high value may be also attributed to rigid light confinement in the lateral direction.

In fig.7 we show the data to determine the astigmatism of the SBA laser. The measurement was performed by observing the near field pattern focused by double objective lens (x40,NA=0.5 and x20,NA=0.4) changing the position of the laser. The figure illustrates plots of lateral spot size defined by $1/e^2$ value of the peak intensity versus the deviation from the position which gives the

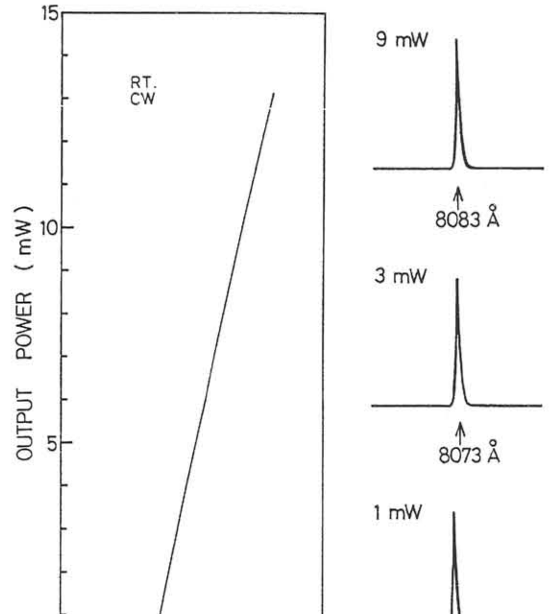

Fig.3 P-I characteristics and lasing spactra of SBA laser

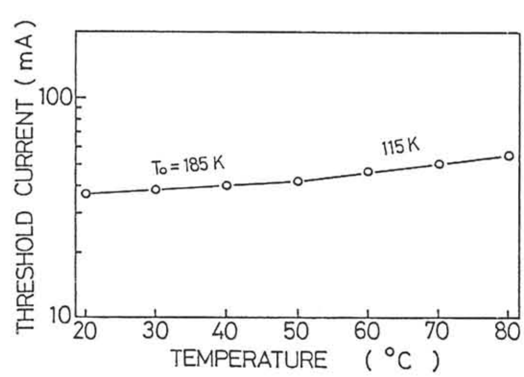

Fig.6 Temperature dependence of threshold current

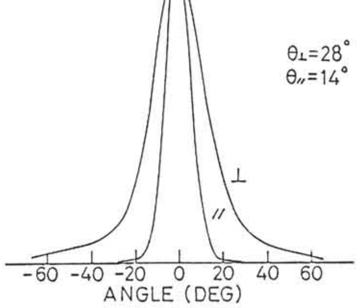

Fig.4 Far-field patterns

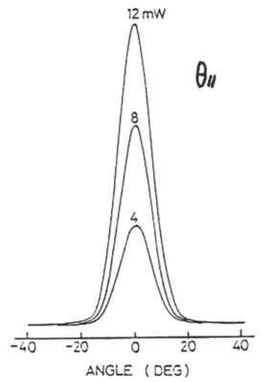

Fig.5
Power dependence of far-field pattern ($\theta_{\parallel}$)

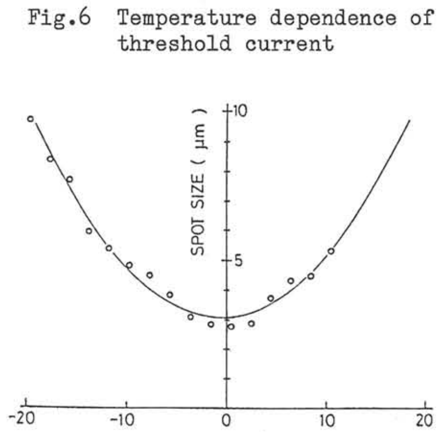

Fig.7 Plots of lateral spot size versus deviation

minimum vertical spot size. From this measurement, it is confirmed that the astigmatism of the SBA laser is within 1 µm. This value is very small compared with ordinary loss-stabilized lasers.

4. Conclusion

A novel self-aligned-structure laser with bent active laser (SBA laser) has been developed by use of two step MO-CVD technique. The laser oscillates in a single longitudinal mode with stable transverse mode up to 15 mW, and linear light output versus current characteristics with threshold current as low as 40 mA were obtained. Furthermore, it was confirmed that the SBA laser has very small astigmatism within 1 µm due to lateral light confinement by the steep bends of the active layer. This small astigmatism should be very attractive for the practical use of the laser diode.

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