Tunneling regenerated high power Dual-Wavelength laser diodes

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ABSTRACT

A Novel structure of high power dual-wavelength semiconductor laser diode is proposed and fabricated. Two laser structures are cascaded by a high doping tunnel junction during the epitaxial growth. The lasers can emit at wavelength of 951nm and 987nm at the same time. Without facet coating, the output power of the dual-wavelength laser is as high as 3.1W at 3A. And the slope efficiency of these devices is about 1.21A/W. Much higher output power can be reached for those dual-wavelength lasers when modifying the structure. The external differential quantum efficiency of different cavity length devices is analyzed.

Key words: Tunnel junction, laser diode, dual wavelength

I. INTRODUCTION

Enhancement of semiconductor laser output power and radiance is very important for applications such as diode pumped solid sate lasers, or micro-machines. Considerable effort has recently been devoted to the increase of laser diode output power. For some applications, arrays of closely spaced lasers, with easily separable wavelengths are desirable. Monolithic stacking of injection lasers is of great interest for high power, aperture-limited applications and as an alternative to array design [1]. Most state of the art technology for the monolithic stacking lasers is using wafer-bounding technology to bound different color lasers on one chip or using multiple times epitaxial growth [2]. It would be desirable and advantageous to integrated two lasers in one single chip by one-step epitaxial growth. G.D.Shen reported a high power 980nm laser diode with multi-active region by one step growth [3], which cascade several active emitting layers together by tunnel junctions. The vertically cascaded multi-active layers are easy way to get different color laser diodes if we change the active layer materials, And it has potential for special applications such as medical and DVD/VCD pick up head system [4]

In this letter we demonstrate a new monolithic high power laser structure with two quantum well laser regions at different lasing wavelength, which separated by one highly doped reverse biased tunnel junctions during the one step epitaxial growth. This approach offers higher emitter density, reduced complexity, and lower cost as compared to a conventional stack technology.

II. DEVICE STRUCTURE AND FABRICATION

The device structure was grown in a horizontal reactor with rotating graphite susceptor of low-pressure metalorganic chemical deposition (MOCVD) system. The material precursors include trimethylaluminium (TMAl), trimethylgallium (TMGa), trimethylindium (TMIn) and arsine (AsH_3). SiH_4 diluted in hydrogen and liquid CCl_4 are used as donor and acceptor dopants respectively. All samples are annealed after growth in N_2 atmosphere at about 450℃ for about 10 minutes to avoid carbon passivation due to hydrogen incorporation. The first LD segment was grown on an n-GaAs buffer layer with the active region of $In_{0.22}Ga_{0.78}As$/AlGaAs quantum well, designed for emission at wavelength about 990nm. Atop a 1.5 um cladding layer of $Al_{0.44}Ga_{0.56}As$, Tunnel junction (TJs) segment was grown as a $p^{++}n^{++}$ GaAs with thickness of the layers approximately 12nm and 45nm. The doping levels were approximately $5X10^{19}cm^{-3}$ Carbon and $4X10^{18}$ cm^{-3} Mg for the junction. The tunnel junction here serving as quasi-Ohmic contacts provide the effective current connection of the two quantum well lasers. The second LD segment was grown after the tunnel junction with the active

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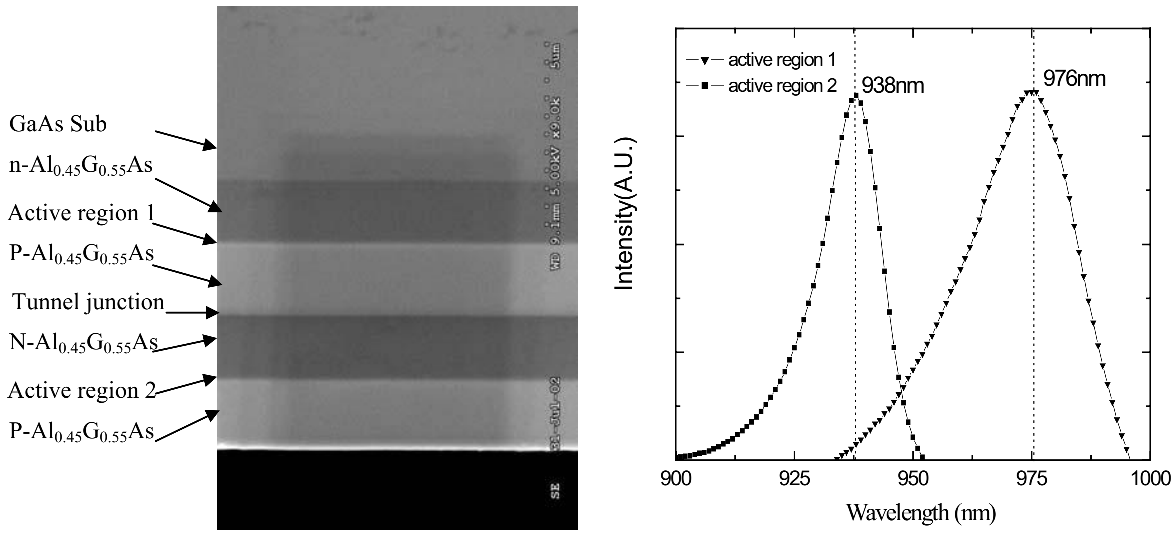
region of $In_{0.16}Ga_{0.84}As$/AlGaAs quantum well, which designed for emission at wavelength about 950nm. The cladding layers up and down the tunnel junction are both thick as 1.5um to avoid the twin wave-guide effect. Fig.1 (a) schematically show the SEM section picture of the device structure. The photoluminescence spectrum results show the first LD segment active region emit at wavelength 938nm and the second LD active region emit at wavelength 976nm (shown as Fig.1 (b)).

90μm width ridge wave-guide laser diodes are fabricated what we called a stripe dual-wavelength laser diode. After growth of 200nm thick SiO_2, the 90μm p-type contact window is etched, and then Ti/Au was deposited for ohmic contact, and by lapping to 90um and polishing, the last step is to form the n type AuGeNi ohmic contact. All of the laser chips were cleaved and diced from the wafer, and mounted p-side down on a copper sink with indium solder. The length of cavity is about 800μm.



(a) (b)

Fig1 (a) SEM section photo of the dual-wavelength laser diode cascaded by tunneling junction. (b) Photoluminescence spectrum of the dual-wavelength laser diode cascaded by tunneling junction.

III. RESULTS AND DISCUSSION

The output power and voltage against current characteristics, far field angle, spectrum for the dual-wavelength laser diode at room temperature is shown in Fig.2. The threshold current of the laser is 210mA, the output power is as high as 3.1W at 3A current. The slope efficiency is 1.21A/W. The Far field pattern shows the fundamental transverse mode operation and the Vertical and parallel far field angle is 36.0 and 10.2 degree respectively. The spectrum clearly indicates that the laser emit at two wavelength of 951nm and 987nm respectively. The temperature dependent output power against operation current characteristics (P-I) also is investigated, the laser diode can still work well at $90^{o}C$, and the characteristic temperature of the dual wavelength laser diode is 93K, which is in the same level of the single wavelength laser diode.

Because the fundamental optical gain for the lasers can be provided by AlGaAs, or InGaAs, or AlGaInP quantum well materials which all is lattice matched to the GaAs substrate, It is very easy to expand the accessible wavelength range to 0.63-1.1μm and get a multi-wavelength laser diode.

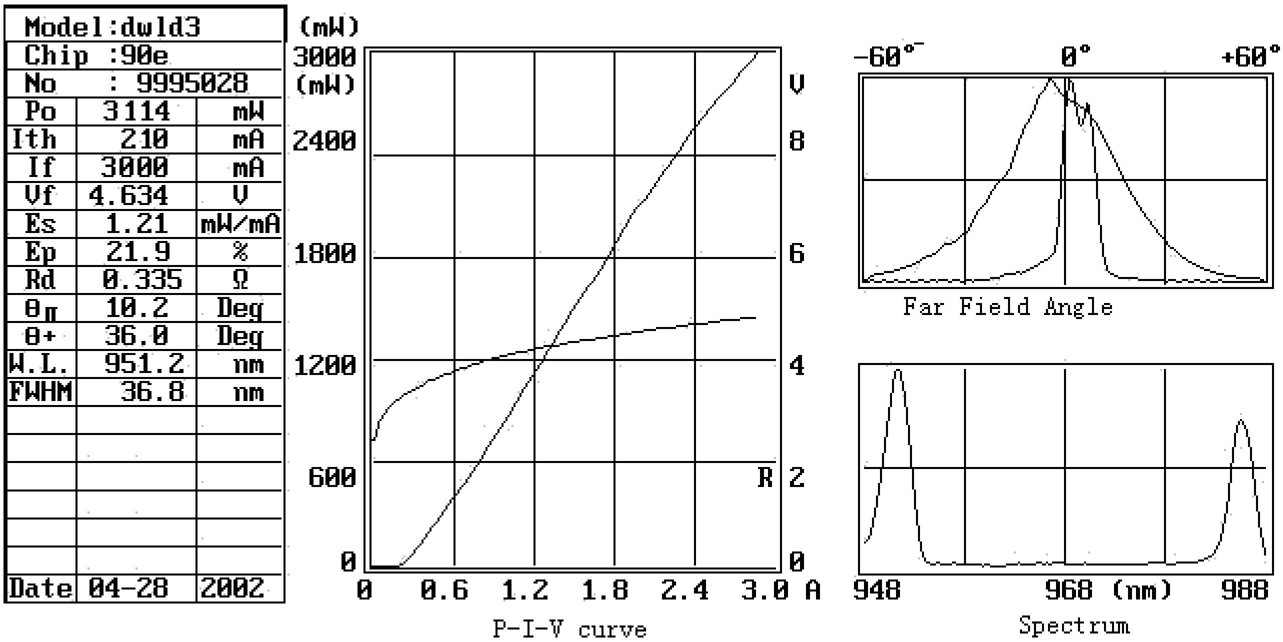


Fig.2 output power and voltage against current characteristics, far field angle, spectrum for the dual-wavelength laser diode at T=20^{o}C.

IV. EXTERNAL DIFFRENTIAL QUANTUM EFFICIENCY

Dual wavelength laser chips with different cavity lengths were also fabricated and tested. Fig.3 shows the threshold current density as a function of cavity length of dual wavelength laser diode. The results indicate that the threshold current density decrease as the cavity length increasing, it's the same as the change rule of single wavelength laser diode.

Fig.4 shows the external differential quantum efficiency as a function of cavity length for laser diodes with dual wavelength. The external differential quantum efficiency of the laser diode increase with increasing internal quantum efficiency or decreasing internal optical loss as seen in the following relationship [5],

$$\eta_d = \eta_i \frac{\alpha_m}{\langle \alpha_i \rangle + \alpha_m} \tag{1}$$

Where η_d is the external differential quantum efficiency, η_i is the internal quantum efficiency, α_m is the mirror loss and α_i is the internal optical loss of the laser. The mirror loss can be defined as

$$\alpha_m = \frac{1}{L}\ln\left(\frac{1}{R}\right) \tag{2}$$

Where L is the length and R is the facet reflectivity. Substituting equation 2 into equation 1 and rearranging gives

$$\frac{1}{\eta_d} = \frac{1}{\eta_i} \frac{\langle \alpha_i \rangle}{\eta_i \ln\left(\frac{1}{R}\right)} L \tag{3}$$

Fig.5 shows the reciprocal of external differential quantum efficiency as a function of length for laser diodes with dual wavelength. The internal efficiency can be extracted from the y-intercept of figure 5 using equation 2; the internal quantum efficiency for dual wavelength laser diode is 1.73. It is doubled compared with the single wavelength traditional laser diode. The reason of the large external quantum efficiency is that the injected carriers can emit photon in the first LD region, and then the same carriers tunnelling through into the second LD region, and emit photons again. The internal optical loss is about 5.6/cm. It is in the same level as the traditional single wavelength 980nm laser diode. It means that the absorb loss in tunnel junction area is weak.

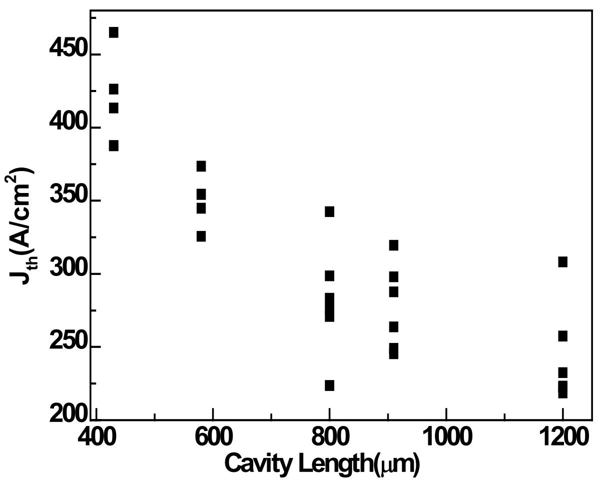


Fig.3 Cavity length vs. Threshold current density.

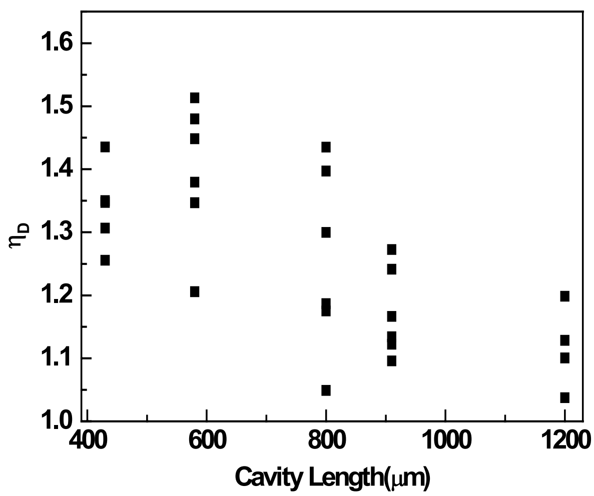


Fig.4 Cavity length vs. External quantum efficiency.

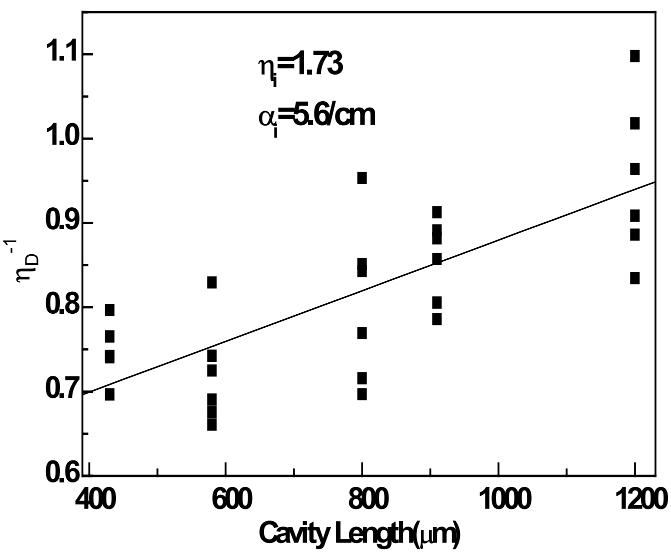


Fig.5 Inverse external differential quantum efficiency as a function of device cavity length.

CONCLUSION

In summary, a novel dual wavelength laser diode has been fabricated by one step MOCVD growth. The laser can emit at wavelength of 951nm and 987nm at the same time. Without facet coating, the output power of the dual-wavelength laser is as high as 3.1W at 3A. And the slope efficiency of these devices is about 1.21A/W. Much higher output power can be reached for those dual-wavelength lasers when modifying the structure, for example, there can be two or two more LD region for the first wavelength and for the second wavelength, and then each wavelength will get much higher output power. The internal quantum efficiency of the dual wavelength laser diode is 1.73, which almost doubled compared with the traditional single wavelength laser diode. This new devices may be applicable for some more useful integrated multicolor laser diodes.

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