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Scientific Research

Base Width Variations and its Effects on Frequency Response of Double Hetero-structure Long Wavelength Transistor Laser

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ABSTRACT

In this paper we investigate the effects of base width variation on performance of long wavelength transistor laser. In our structure with increasing the base width, the cut off frequency increases until 367 nm with 24.5 GHz and then abruptly fall. In 100 nm base width, we have 17.5 GHz cut off frequency, and overall ac performances become optimized, although, other parameters like optical losses and threshold current density are not optimized.

Keywords: Transistor Laser; Quantum Well; Long Wavelength; Optical Confinement Factor

1. Introduction

Transistor lasers (TL) have been recently received considerable attentions due to their promising applications in photonic and optoelectronic circuits [1]. Incorporated within the base region of the TL is one (or more) quantum wells QW, which plays an important role in device behavior. Using carrier confinement within the QW region, stimulated emission in room temperature with lower threshold current density can be achieved. Recently, multiple QW-TLs have been shown for their superior optical and electrical performances. Among other key structural factors affecting on the device performance is the position of the active region [2]. Since the first successful demonstration of the laser emission (1µm wavelength) at room temperature in 2006 [3] using strained InGaAs QW in GaAs base layer, several experimental and theoretical studies have been appeared in literature, albeit for the same emission wavelength, i.e. near IR. In order to take the full advantage of TLs for directly-modulated high-speed systems, however, we need laser emission with wavelengths around 1.3µm for minimum dispersion or 1.55µm for minimum attenuation [4], called Long Wavelength Transistor Laser (LWTL). Despite their similarities in behavior and structure, the TLs differ from the conventional diode lasers (DL), particularly in terms of highly-doped base region. **Figure 1** schematically displays the structure of our LWTL.

We have assumed N-InP/p–$In_{0.53}(Al_{0.4}Ga_{0.6})As_{0.43}$/N-InP double Hetero-structure TL in which the base and emitter/collector regions are treated as the waveguide and the cladding layers, respectively. An undoped, compressively strained $In_{0.58}Ga_{0.42}As$ QW of 8 nm is placed in the middle of the base region.

In the following section, we first explain our calculation approach has been described. The simulation results for optical confinement factor, optical losses and frequency response are shown and discussed in section three. We also use experimental data to compare our results with other works [5]. Finally, we conclude in section 4.

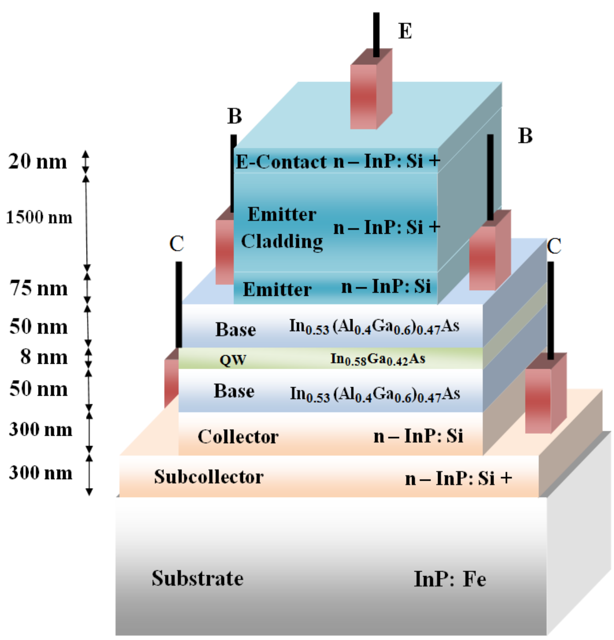

Figure 1. Structure of Transistor Laser in our model.

2. Model

2.1. Description

Under forward bias condition, the minority electrons are injected from emitter to the base region where they diffuse toward the collector junction. Carriers capture by QW into the QW results in a discontinuity in the slope of carrier density profile. Assuming direct gap material for the QW, the captured electrons can be radiatively recombined with holes to produce stimulated emission if electron density reaches the threshold value [6].

2.2. Parameter

Illustrate in **Figure 2** is the charge control model for LWTL in which we assumed the base width (W_B) is the main variable in this work. The width of QW is W_{qw} and its distance from emitter junction is X_{qw}. In addition, we located the QW in the middle of the base region to ensure symmetric beam profile for the TL. NB and N_{qw} are the base doping concentration and the bounded carrier density in QW, respectively.

Bulk charge life time, τ_{rb0}, is the recombination life time of carriers in the base region except QW. It related to the bimolecular radiative recombination coefficient, B_{rad} [7]:

$$\tau_{rb0} = \frac{1}{B_{rad} N_B} \quad (1)$$

Electron capture time in QW, τ_{cap}, includes the transit time of electrons from emitter junction to the edge of QW and their capture by the QW. Assumed uniformed diffusion constant throughout the base region [8], the first term in τ_{cap} can be calculated as:

$$\tau_{cap} = \frac{X_{qw}^2}{2D} \quad (2)$$

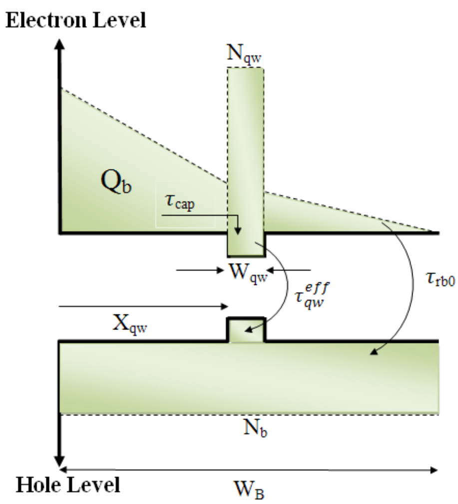

Figure 2. Charge control model for LWTL.

where D is the diffusion constant. The second term is a small time (<1 ps) which is necessary for electrons to be captured to the virtual states of the QW.

Effective recombination lifetime in QW, τ_{qw}^{eff} is relative to stimulated emission life time (τ_{st}) and spontaneous emission life time (τ_{qw}) [6]:

$$\frac{1}{\tau_{qw}^{eff}} = \frac{1}{\tau_{qw}} + \frac{1}{\tau_{st}} \quad (3)$$

3. Results

As previously described, we focused on the base width variations and its effects the TL behavior including the optical confinement factor and optical loss. Other structural parameters have been extracted from experimental data [5].

3.1. Optical Confinement Factor

Optical Confinement Factor (OCF) has significant impact on the DC and AC characteristics of LWTLs. One can distinguish between two separate waveguides, one of them related to QW and the other related to the rest of the base region.

Using a modified approach similar to the method described by [9], we calculated the OCF values for aforementioned regions of QW and base region. The results are illustrated in **Figure 3** as a function of the base width. It is evident that large waveguide results in higher values for the OCF.

3.2. Optical Losses

The optical losses of the base region can be individually

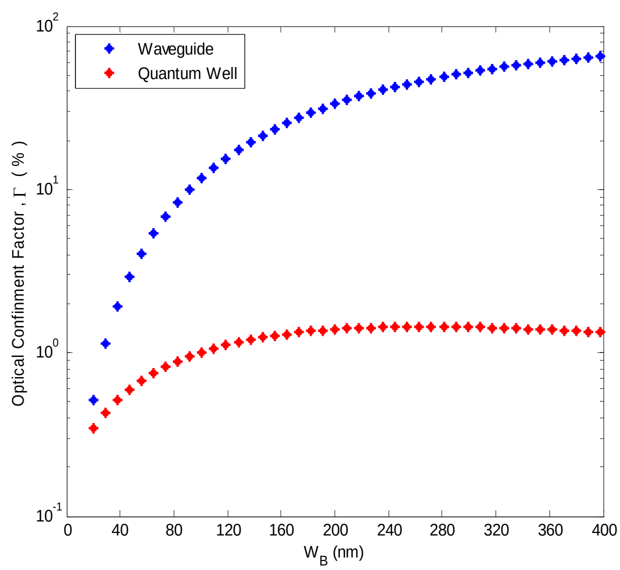

Figure 3. Optical Confinement Factor variations due to base width variations.

calculated for intrinsic loss due to inter valence band absorption and mirror loss. Mirror loss can be simply calculated by:

$$\alpha_m = \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right) \quad (4)$$

where R_1, R_2 are the facet reflectivity and L is cavity length. Using experimental sample parameters, we have assumed $R_1 = R_2 = 0.3$ and cavity length of 800μm.

On the other hand, the intrinsic loss in active region related to optical confinement factor in QW (Γ_{QW}) and waveguide (Γ_{WG}) which reads:

$$\alpha_i = \left(\Gamma_{WG} + \Gamma_{QW}\right) k_p N_B \quad (5)$$

where N_B is the base doping concentration, k_P is the inter valence band absorption (IVBA) coefficient. We assumed $k_P = 4\times10^{-17}$ cm^{-2} and $N_B = 1\times10^{19}$ cm^{-3} as the base doping concentration while OCF for QW and waveguide is varied with the base width.

The total optical losses can be, therefore, calculated as the sum of intrinsic and mirror losses:

$$\alpha_T = \alpha_m + \alpha_i \quad (6)$$

As can be seen in **Figure 4**, an increase in the base width can cause more optical loss in the base region.

3.3. Frequency Response

We used the procedure that was described in [6] to simulate the frequency response of the device in conjunction with the approach described in [7] for calculation of parameters. The results are illustrated in **Figure 5**.

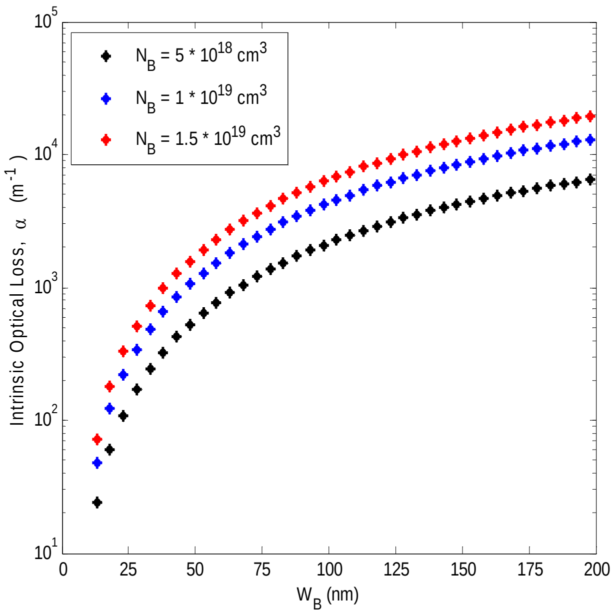

Figure 4. Intrinsic optical loss variation due to base width variation.

Frequency response of LWTL has significant effects on performance and application of LWTL. In **Figure 5** we see that in base width lower than 100 nm, the maximum of absolute amplitude of frequency response becomes lower, and also has lower cut off frequency.

In upper 100 nm base width, the frequency response become sharp but cut off frequency become larger.

According to the **Figure 6** we see a discontinuity on the cut off frequency around 367 nm base widths in this structure. With increase of base width above 100 nm, the frequency response becomes worse. Also the type of system can be changed. In base width above 367 nm, we have band pass filter and under that amount, we have low pass filter. In design of LWTL we have trade-off between several performances and applications of LWTL, but this is reasonable using 100 nm for base width.

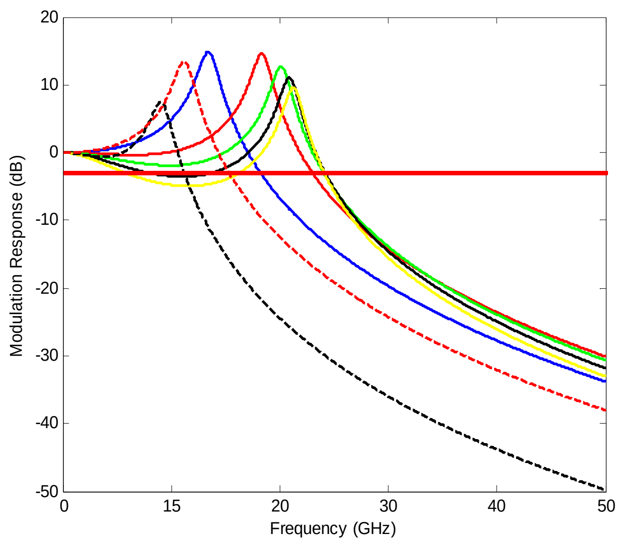

Figure 5. Frequency response of LWTL with different base width.

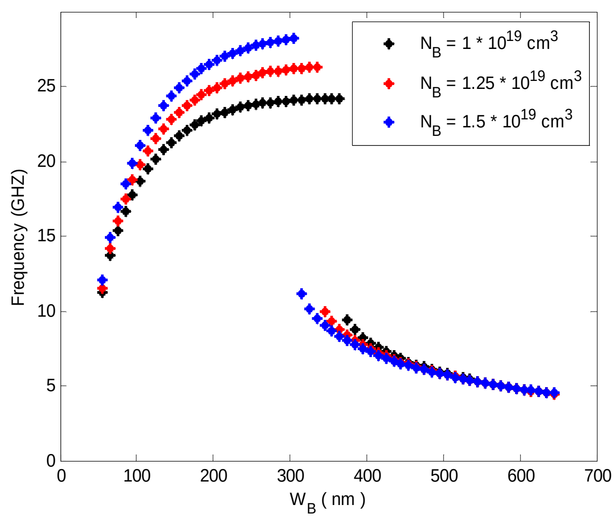

Figure 6. Cut frequency of LWTL with different base width.

According to the **Figure 6** we see a discontinuity on the cut off frequency around 367 nm base widths in this structure. Also, with change base doping concentration (N_B) this base width changed but discontinuity on cut off frequency exist. With increase of base width above 100 nm, the frequency response becomes worse. Also the type of system can be changed. In base width above 367 nm, we have band pass filter and under that amount, we have low pass filter. In design of LWTL we have trade-off between several performances and applications of LWTL, but this is reasonable using 100 nm for base width.

4. Conclusions

In transistor laser, like conventional transistor used in electrical circuits, base width has significant effect on AC and DC performance of device. Change in base width causes to change several parameter of transistor, like frequency response, transient response, and DC characteristic of device. For the verification of our model, we use an experimental structure with emission wavelength of 1.55μm. We changed base width and observed its effects on optical confinement factor and optical loss and frequency response. With increase of base width, OCF become better but optical loss increases, so we cannot increase base width so much. In frequency response, with increase base width we have discontinuity in cut off frequency around 367 nm and electron transient time and bulk recombination become dominant. In near 367 nm base width we have 24.5 GHz cut off frequency which is the maximum value it can reach. But the frequency response has not suitable form because of sharp response. Also the type of filter in this system become change and in base width above 367 nm we have band pass filter with sharp response. In design and also by trade off with this result and figures, 100 nm base widths have optimum performance, but with different applications it can be changed. In this base width we have 17.5 GHz cut off frequency.

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