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Analysis of Extinction Ratio of an EAM Integrated with Distributed Reflector Laser using Wirewidth Modulated Active Regions

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Abstract

In this paper, an electro absorption modulator has been integrated with Distributed Reflector laser using variation of wire width of quantum wire structures. There is a large blue shift observed in quantum wire structure when wire width is reduced. This property has been utilized to design quantum wire EAM integrated with quantum wire Distributed Reflector laser for 1.55μm optical communication. The calculation shows that a 50 nm wire width EAM section with five quantum wire stack is sufficient to provide 20 dB extinction ratio under a reverse bias of 0.12 V.

Keywords : Distributed Reflector laser, Electro-absorption Modulator, Extinction-ratio, Monolithic integration, Quantum confinement effect, Quantum wire.

1. Introduction

The demand for higher data rate is increasingly pushing optical communication technology towards monolithic integration of source and modulator devices operating at the low loss window of 1.55 μm [1]. It is required to develop a useful and simple fabrication technique for monolithic integration to secure a high yield and uniformity in device performance. Monolithic integration using GaInAsP/InP allows active and passive optical components to be interconnected by a network of waveguides in the most compact assemblies. Overall, GaInAsP/InP monolithic integration has huge potential for delivering devices with novel functionality for all-optical networks [2].

An integration platform must be available that requires simple fabrication and growth procedures in order to minimize processing requirements and maximize device yields. Several viable platforms such as selective area growth (SAG) [3], butt-joint regrowth [4], quantum-well intermixing (QWI) [5], and offset quantum-well (OQW) platforms [6] have been demonstrated for GaInAsP/InP material system.

In this work, an integration technique involving wire width modulation has been analyzed which has superiority over conventional integration methods on several aspects [2]. First of all, the simultaneous fabrication of multiple devices is possible only by varying the wire width during electron beam lithography and etching [2]. Another attractive feature is very short transition length between adjacent devices which is less than a period of 240 nm. This provides possibility of high density integration [2].

Much interest has been concentrated on the integration of Modulators with the lasers for fast photonic communication. Among various types of external modulators, electro-absorption modulators (EAMs) are an attractive choice for high-frequency modulation [7]. The electro absorption (EA) type using quantum confinement stark effect (QCSE) has a large potential for practical use because of simplicity of its device physics as well as its high structural feasibility for monolithic integration with lasers. The performance of EAMs can be improved by increasing the degree of confinement of the carriers. Quantum-wire (QWR) structures attract a great deal of interest because these are expected to show improvement in semiconductor lasers and other optoelectronic devices [7].

QWR EAM has the potential for a considerable enhancement of the extinction ratio (ER) since it is naturally tuned to the polarization of the QWR laser integrated in the same chip. Again, in integrated laser-EAM structures, the coupling efficiency is high and unlike other discrete EAM devices, it has a low insertion loss even at large ER [7]. Ohira et al. [8] have reported the experimental realization of compressively strained (CS) QWR distributed feedback (DFB) lasers integrated with QWR distributed Bragg reflectors (DBRs) exploiting the wire width dependence of the blue shift of the effective band gap energy. In this work, the same technique has been used for the integration of EAM with Distributed reflector (DR) laser.

2. Theoretical Background

In quantum-wire (QWR) structures, the transition energy shifts from the ground-state level of quantum-film due to the lateral quantum confinement effect [2]. In particular, QWR fabricated by dry etching and regrowth method, larger blue shifts are observed than predicted by the biaxial strain model [2]. This large energy blue shift can be utilized for the monolithic integration of various types of photonic devices. The energy blue shift dependence on the QWR width was calculated by Ullah et al. [2].

Figure 1 shows a schematic diagram of the dependency of the transition energy on wire width to demonstrate the concept of integration utilizing wire width modulation. In the Figure, the wire width has been narrowed from left to right and as a result the transition energy has increased, i.e. $E_{tran1} < E_{tran2} < E_{tran3}$. The wire width itself can be controlled by electron beam lithography followed by an embedding growth. The very first example of this integration technique is the DR laser where a DBR mirror of narrow QWR structure is integrated with wire like DFB laser [2].

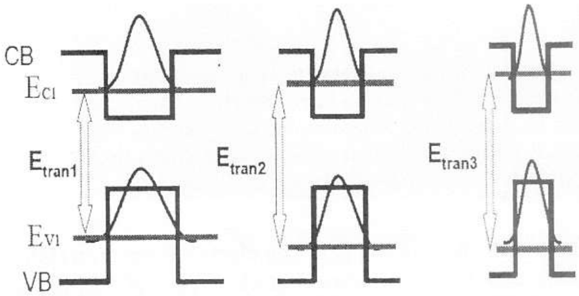


Fig. 1: Transition energy dependency on wire width

Modulation utilizing the blue-shift of the effective bandgap with reduction in wire width requires calculating the transition energy for every particular wire width. Eight-band K.P model [9] has been utilized to calculate the band gap. Further it is necessary to evaluate the absorption coefficient of the active sections which can be calculated by equation (1):

$$\alpha = \alpha_0 \exp(\frac{h\nu - E_g}{E_0}) \tag{1}$$

Here $h\upsilon$ is Photon Energy, α_o is absorption coefficient of the quantum well, E_0 is the transition energy of the quantum well and E_g is transition energy of the quantum wire.

The waveguide loss α_{wg} is related to the mirror loss α_M and external loss α_{EX} by equation (2):

$$\alpha_{wg} = \frac{W}{\Lambda}\alpha_M + (1 - \frac{W}{\Lambda})\alpha_{EX} \tag{2}$$

Here W is wire width and Λ is grating period. The mirror loss (α_M) and external loss (α_{EX}) related to the confinement factor, ξ_{AC} of the active section according to equation (3):

$$\alpha_M = \xi_{AC}\alpha + (1 - \xi_{AC})\alpha_{EX} \tag{3}$$

Extinction ratio (ER) of an EAM can be defined as the on/off ratio of the modulator and can be evaluated by equation (4).

$$ER = 10 \log e\Gamma\Delta\alpha L(\frac{W}{\Lambda}) \tag{4}$$

Here Γ is confinement factor of the QWR layers, $\Delta\alpha$ is the change in absorption coefficient, L is device length and Λ is grating period.

3. Device Modeling

Figure 2 shows the schematic diagram of the proposed DR laser integrated with EAM containing 5QWR vertical stack. The diagram shows the front view of the DR laser consisting of an active DFB section with wire like active regions in the middle and a passive DBR grating section at the right with QWR structure.

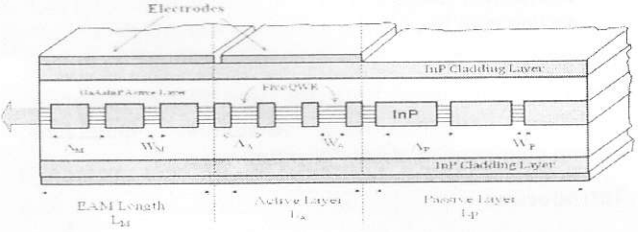


Fig. 2: Schematic structure of a Quantum wire EAM integrated with quantum wire laser and DBR reflector containing 5 quantum wire.

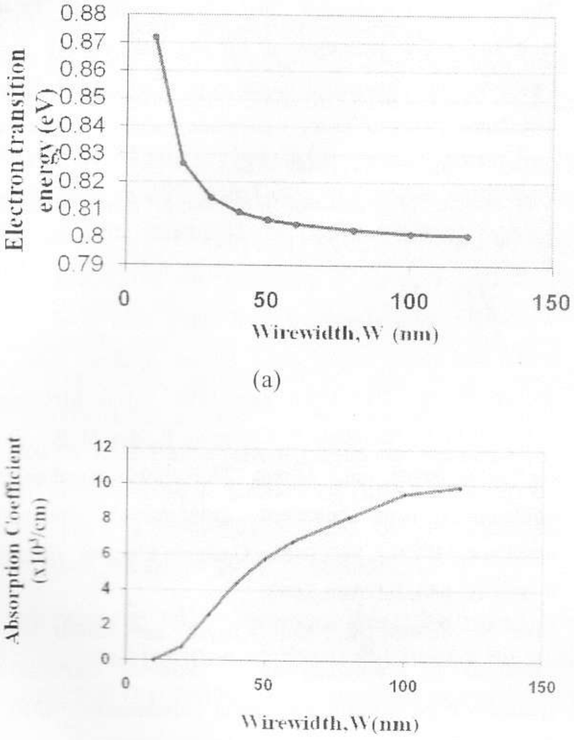
In Figure 2, L_A, Λ_A W_A, L_P, Λ_P, W_P, L_M, Λ_M and W_M denote the section length, grating period and the width of the active section, passive section and the EAM section respectively. These sections were integrated by utilizing the lateral quantum confinement effect by modulating the wire like active regions. In the proposed design of the integrated circuit a simulation program has been utilized and all of the calculated data have been presented graphically.

EAM should be designed in such a way so that it posses high extinction ratio. For an error free high speed communication around 20dB extinction ratio is necessary. Therefore in this work we have designed an integrated EAM for 20 dB extinction ratio.

First of all, transition energy of the EAM section with respect to active laser section is necessary to determine. In this work quantum wire structure has been considered. Therefore, transition energy 'E_g' for different wire width has been calculated and the result has been shown in Figure 3(a). In the same manner, absorption of the EAM section is an important parameter for designing and it should not be a high value when EAM is not under reverse bias. Absorption coefficient for different quantum wire width has also been calculated according to equation (1) and has been plotted in Figure 3(b).

A typical EAM should have high transition energy under zero field condition while the energy should reduce by a large amount with the application of an electric field perpendicular to the plane. Also the value of α should have low value at zero biased condition and it should increase by a large amount at biased condition so that the modulator can absorb the incident wave when an electric field is applied across the device. These two requirements can be met simultaneously by using very narrow wires.

EAM integrated with DR laser has quantum wire section as active laser section which is about 90nm wide. From Figure 3(a) it is seen that transition energy increases as wire width '*W*' decreases. However, this increment is significant around 50 nm and below. Figure 3(b) shows the calculated value of absorption coefficient α with quantum wire width. It is seen that at the laser section with 90 nm wire width, the absorption coefficient is over 8000 cm^{-1}. It reduces below 6000 cm^{-1} for 50 nm wire width. is quite low for this range of W. Figure 3(b) illustrates that W of 20-50 nm can provide moderately low α which is lower than 6000cm^{-1}. Now it is required to calculate the extinction ratio for different wire width and find the optimum wire width for the EAM section.



(a)

(b)

Fig. 3: Variation of E_g and α with wire width W

To calculate the extinction ratio, the variation of transition energy with reverse bias at EAM is required. Figure 4 shows the transition energy for a wire width of 10 to 120 nm. The electric field on the quantum wire stack has been varied from 0.06 V to 0.12 V. It is seen that the change in E_g is very much prominent at wider W region. This is due to the fact that for wide wire regions higher cross sectional area of the active sections are affected by the applied electric field. Another important point is E_g decreases very much as the applied electric field increases. The transition energy changes from 0.872eV to 0.8672eV for 10 nm wire width, 0.8065eV to 0.7962eV for 50 nm wire width and 0.8011eV to 0.7894eV for 120 nm wire width for a applied electric field of 0.12 V.

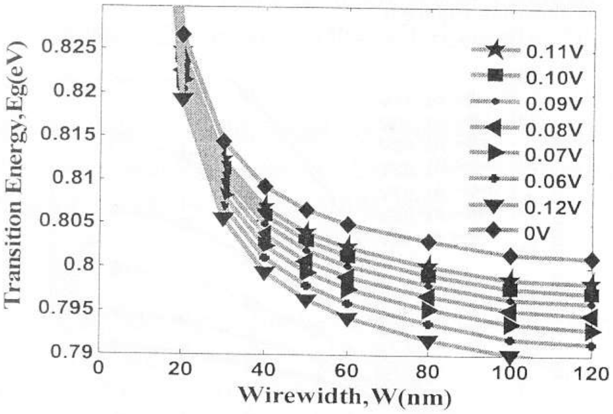


Fig. 4: Transition energy variation for different wire width at varying electric field

Now Figure 5 shows the variation of absorption coefficient $\Delta\alpha$ with wire width for different applied electric fields. Here $\Delta\alpha$ is defined as the difference of absorption coefficient at a certain electric field with absorption coefficient without any electric field. This Figure also shows that change in $\Delta\alpha$ is very high for wider *W* regions. At 50nm width, a value of $\Delta\alpha$ as high as 10724.67 cm^{-1} is possible by applying only 0.12V electric field.

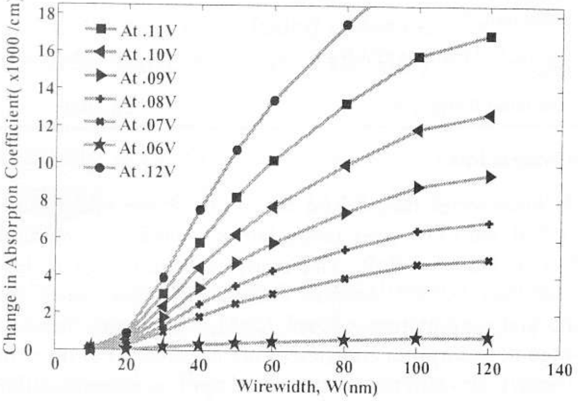


Fig. 5: Variation of absorption coefficient with varying electric field

Finally, extinction ratio has been calculated and plotted in Figure 6. As can be seen, ER increases with increasing wire width as well as increasing electric field. It should be noted here that waveguide loss has not been considered during extinction ratio calculation. Though ER increases with increasing wire width, the EAM section cannot be made with wide wire width since it will cause more absorption when lasing wavelength passes though EAM section under no bias condition due to small difference in transition energy. Since 20 dB ER is enough to have an error free optical communication, therefore, a wire width of 50 nm is enough to get a 20 dB ER under 0.12 V reverse bias which is shown in Figure 6.

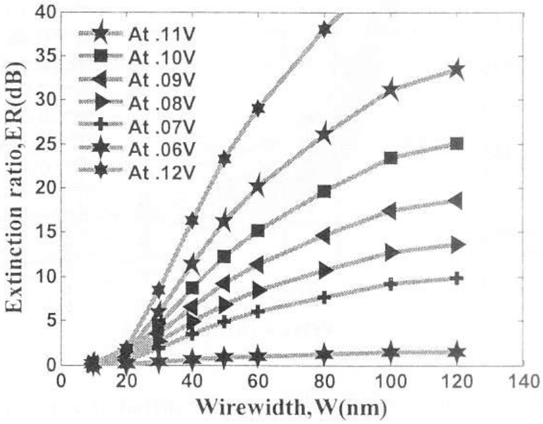


Fig. 6: Extinction ratio variation with electric field for different wire width.

The evaluated parameters for integrated EAM are summarized In Table: I.

Table 1 : Designed Parameters for Integrated EAM

Wire width, W	50 nm
Change in Absorption coefficient, $\Delta\alpha$	10724.67cm^{-1}
Electric field across QWR	0.12V
Extinction Ratio, ER	23.29dB

4. Conclusion

This manuscript focused on the study of the integration of an EAM with DR laser using lateral quantum confinement effect in GaInAsP/InP. The analysis is done for a device containing 5QWR vertical stack. In this work, two important parameters of an EAM, extinction ratio and change in absorption coefficient are considered to determine the wire width and the electric field applied perpendicular to the integrated device. Results demonstrate that the proposed QWR EAM with a wire width of 50 nm having 5 quantum well stack are suitable for integration with QWR DR lasers under a reverse bias operation of 0.12 V.

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