Electroabsorptive Double Ring Resonators for Wavelength Switching Applications

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***Abstract*—The design and analysis of series-coupled double ring resonators with multiple quantum wells as the light guiding medium for wavelength switching applications will be presented. Switching is realized by changing the absorption of the rings. The output intensity at the output port and drop port of the resonator is calculated as a function of device geometry. A theoretical model for the switch which incorporates the change in absorption coefficient due to the applied electric field is presented. It is found that the switching characteristics of the device strongly depend on quantum well and material parameters.**

***Index Terms*—Microring resonator, MQWs, QCSE, WDM**

I. INTRODUCTION

Micro ring resonators are envisioned as a critical component in future VLSI photonic circuits due to its unique properties such as narrow band filtering, high quality factor, and compactness. Channel dropping filters has been demonstrated using ring resonators are passive in the sense that once fabricated, no further adjustments are possible to alter their response. Active devices [2] implemented by using semiconductor material are more versatile since they offer adjustability of the response to compensate for fabrication errors, and also lead to a wider range of applications for ring resonators such as optical modulator [1] and tunable filters [3].

A wide range of transfer functions can be achieved by cascading ring resonators. Higher order rings offer a better isolation between the transmitted and dropped channels [4]. Here, we combine the advantages of active devices and second order rings to realize switching between two ports. We report the design, analysis and optimization of such a switch which uses quantum confined stark effect (QCSE) to switch the light between the two waveguides. The structure shown in Fig.1 consists of two waveguides which are in close proximity and hence evanescently coupled to a double ring-resonator. Both the rings and the straight waveguides consist of $\mathrm{In}_y\mathrm{Ga}_{1-y}\mathrm{As}_{1-x}\mathrm{P}_x$ multiple quantum wells (MQWs) with InP barriers which forms the "i" region of a p-i-n structure. Electrodes are deposited on the top of the ring. In case of ring-resonators having a semiconductor as an active medium, the input wavelength has to satisfy (1) $m\lambda_R = 2\pi R n_{eff}$, where m is the mode number and (2) the photon energy must be smaller than the bandgap so that the absorption is zero or minimum, and hence all the light can be collected at the drop port. This wavelength is termed as resonant wavelength (λ_R). With no applied voltage, λ_R gets coupled to the ring and exit through the drop port (resonance condition). Upon application of voltage to the ring structure, absorption in the ring increases due to QCSE, which simultaneously leads to a change in refractive index in the ring. This breaks the resonant condition and all the light appears at Transmitted port (non-resonance condition). In this work, we present a theoretical model for the switch which incorporates the change in absorption coefficient due to the applied voltage. This work describes the design and optimization of the switch to achieve low voltage switching at 1.55 μm wavelength.

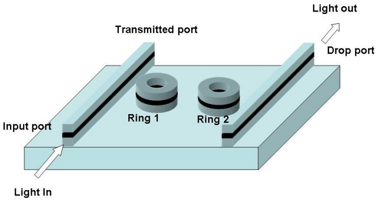

Fig. 1. Perspective view of the structure. The dark region is the multiple quantum well structure, and acts as the light guide.

II. THEORETICAL MODELLING

E_I represents the field at the input port, E_T the field at the transmitted port, and E_D the field at the dropped port. The ratio of transmitted and dropped power to input power can be expressed as

$$\left|\frac{E_T}{E_I}\right|^2 = \left|\frac{c_1\tau_a - \tau_b(1+\tau_a^2)\sqrt{c_1} + \tau_a}{1 - 2\sqrt{c_1}\tau_a\tau_b + c_1\tau_a^2}\right|^2 \tag{1}$$

and

$$\left|\frac{E_D}{E_I}\right|^2 = \left|\frac{j\kappa_a^2\kappa_b\sqrt{c_1} + \tau_a}{1 - 2\sqrt{c_1}\tau_a\tau_b + c_1\tau_a^2}\right|^2 \tag{2}$$

respectively. Here $c_1 = \exp(2j\omega T_R - \alpha_R L)$, T_R is the round trip time of the photon to travel the rings of radius R, ie, $T_R = Ln_{eff}/c$ where $L = 2\pi R$, n_{eff} is the effective refractive index of the ring, and c is the speed of the light. Also, τ_a and κ_a represents the transmission and coupling coefficient for the coupling between straight waveguide and ring, and τ_b and κ_b for the ring to ring region. We assume $\tau^2 + \kappa^2 = 1$ for lossless coupling. The coupling coefficient between the ring and the waveguide, and between the rings is expressed as $\kappa \propto A \exp(-Bg)$ where A and B are constants which depends on the waveguide parameters, and g is the gap between the waveguide/ring.

The transmitted and dropped power is a strong function of n_{eff}, coupling coefficient (κ) and absorption in the waveguide (α). n_{eff} of the ring can be altered by injecting carriers into the "i" region [1],[5]-[7]. In this work, the absorption of the ring is changed by applying an electric field. The effect known as QCSE can easily be achieved in MQW structures by applying voltage. The absorption in a quantum-well due to QCSE is strongly dependent on the well parameters such as the well width, barrier width, material composition (x), applied electric field and the detuning energy between the bandgap of quantum well and incoming photon energy (resonant wavelength). Our aim is to carefully choose these parameters so that for the minimum applied electric field, we obtain maximum absorption change for the resonant wavelength, thus all light appears at the transmitted port.

III. RESULTS AND DISCUSSION

To obtain the QCSE spectrum, the particle energies are calculated under effective well width approximation and exciton binding energies using a variational technique [10] for $\mathrm{In}_y\mathrm{Ga}_{1-y}\mathrm{As}_{1-x}\mathrm{P}_x$/InP QW. Using the resulting particle energies and [9], the final QCSE spectra is evaluated for QWs of thickness ranging from 75Å-150Å, electric field ranging from 0kV/cm to 100kV/cm, and material composition ranging from 0.1 to 0.2 for a TE polarised light. Barrier thickness is chosen so as to decouple the adjacent wells. Any change in absorption will simultaneously lead to an index change, and the resulting index change is calculated using the Kramers-Kronig integration. As an illustration, Fig.2 shows the calculated electro-absorption spectra and the resulting index change for a 150 Å QW under zero electric field and at a field of 60kV/cm. The absorption peak shifts towards longer wavelength at higher field. For the 150 Å QW, the maximum absorption is 645 cm^{-1} at a photon energy of 812.514 meV (1526.127 nm), and the index change Δn is -0.0008 for x=0.2. Higher absorption can be obtained by placing photon energy close to the bandgap. However, this increases the residual absorption, and deteriorates the transmitted to dropped power ratio. Using α=645 cm^{-1} and Δn = -0.0008, transmitted and drop power spectrum for double ring resonator are plotted in Fig.3.

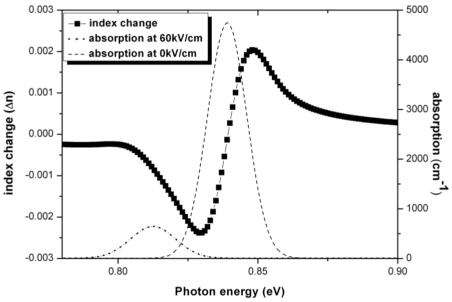

Fig. 2. Calculated absorption spectra at 0 kV/cm and 60 kV/cm, and the corresponding index change.

It is seen that at high absorption, all the signal bypasses the ring and appears at the output port. The isolation between transmitted and dropped port for the resonant wavelength is 25dB at high absorption while an isolation of 20 dB is obtained at low absorption. The switching characteristics will be different for different QWs. We also calculated the absorption of a 75 Å QW and found that the maximum absorption is about 5000 cm^{-1} for x=0.2. However, the background absorption is large and the stark shift is quite small which restricts the use of thinner wells like 75 Å. Thinner wells can be used at the expense of a higher insertion loss. Thus optimizing the well width and material composition is crucial to achieve the required performance. Further details regarding optimization will be presented at the conference.

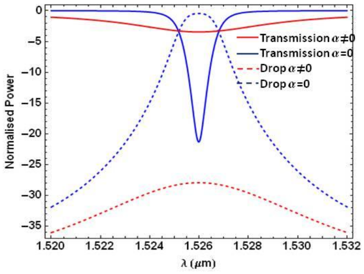

Fig. 3. Switching characteristics at drop port and transmitted port for low and high absorption state.

IV. CONCLUSION

We calculated the switching characteristics of double ring resonators having different QW size and material composition. We found that swtiching is highly dependent on QW parameters, and hence the QW optimization is highly necessary for realizing optimum switching. This switch can be used in WDM networks and in Optical interconnects, and has the unique advantage of monolithic integration with other semiconductor components, compactness and faster switching speed due to the fast modulating mechanism.

REFERENCES

[1] Qianfan Xu et.al., Nature, Vol. 435, No. 19, May 2005.
[2] Kostadin Djordjev et.al., IEEE JLT, Vol. 20, No. 1, Jan 2002.
[3] R. Grover et.al., IEEE PTL, Vol. 16, No. 2, Feb 2004.
[4] B.E. Little et.al., JLT, Vol. 15, No. 6, June 1997.
[5] Michael R. Watts et.al., OFC/NFOEC 2008, PDP14.pdf.
[6] T. Sadagopan et.al., IEEE PTL, Vol. 17, No. 2, Feb 2005.
[7] Stephen J. Emelett et.al., IEEE JLT, Vol. 23, No. 4, April 2005.
[8] B.E. Little et.al., IEEE PTL, Vol. 10, No. 6, June 1998.
[9] Mee K.Chin et.al., IEEE JQE, Vol.29, No.1, Sept.1993.
[10] D.A.B.Miller et.al., Physical Review B, Vol.32, No.2, pp.1043-1060.