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2x2 Optical Switch Based on Silicon-On-Insulator Microring Resonator

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Abstract In near future, silicon-on-insulator (SOI) microring resonator are expected to be basic components for wavelength filtering and switching due to their compact size and wide free spectral range (FSR). In this paper, a 2X2 optical switch by using active microring resonator is proposed. The switch is consists of second order serially cascaded microring coupled to a pair of waveguide. The ON/OFF state of the design is control by electric signal which will vary the refractive index. The device is design to operate at 1.55µm wavelength. With a 500nm x 200nm rib dimensions, the design is proven to have single mode behaviour. Finite-Difference Time-Domain (FDTD) method simulation by RSOFT software is use to characterize the device performance. The results show that the 2X2 optical switch proposed can be an efficient device to be functioning in WDM application.

Introduction

Silicon on insulator (SOI) has a bright future as materials for the integrated photonic system. There are many factors contributed to this such as its high refractive index contrast and low operational cost[1]. In addition, compatibility of the silicon on insulator with the microelectronic fabrication techniques makes it more attractive. Owing this reason, SOI microring resonator has more advantages due to its compactness, fabrication facility and high spectral selectivity [2].

In general, the microring resonator consists of ring waveguide and coupled to a pair of straight bus waveguides. Theoretically, the microring resonator operated by emitting light uniformly from all directions. Light from the cavity can be coupled by evanescently to the waveguide. Meanwhile, the coupling condition is dependent to the microring radius (R), refractive index (n) and the wavelength (λ) of input light. The following equation illustrated the relation between coupling condition and the above three mentioned parameters;

$$m = (2\pi/\lambda).R.n \tag{1}$$

where m is an integer, in order to have a resonance at the emission wavelength.

In this paper we have designed the 2x2 optical switch based on second order serially cascaded active SOI microring resonator coupled to a pair of straight waveguide [3]. We tuned the refractive index of the microring by using the free carier dispersion effect in order to control the coupling condition [4]. Tuning the refractive index of the microring has been done by applied the bias voltage at the PN junction along the microring resonator [5]. The changes of the refractive index influence the resonance condition for the microring. This will make the resonant wavelength shifted as described below:

$$\Delta\lambda_c = \lambda\Delta n/n \tag{2}$$

As earlier mentioned, the refractive index change was obtained by inducing more free carrier in the waveguide region. The induced real refractive index (Δn) produced by carrier dispersion at the wavelength of interest are given by [6]:

At $\lambda_0 = 1.55\ \mu m$:

$$\Delta n = \Delta n_e + \Delta n_h = -[8.8 \times 10^{-22}\ \Delta N_e + 8.5 \times 10^{-18}\ (\Delta N_h)^{0.8}] \quad (3)$$

where: Δn_e Refractive index change due to change in free electrons concentrations.
Δn_h Refractive index change due to change in free holes concentrations.

Fig. 1 shows the proposed configuration of 2x2 optical switch in this paper. The active area is designed by forming p-i-n diode structure integrated in the microring waveguide.

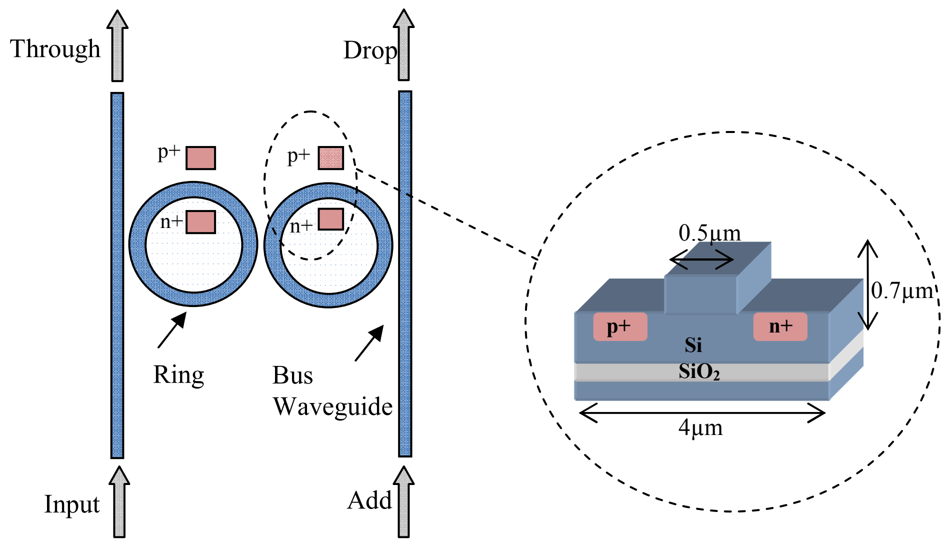

Fig. 1 Schematic layout of the proposed 2x2 optical switch and cross section of active region

Device Design

The 2x2 optical switch based on the active microring resonator fabricated on the SOI wafer is proposed. The active region device has been simulated and characterized by using 2D Athena SILVACO software with common CMOS fabrication process [7]. Meanwhile, the performances of the optical characteristic have been simulated by using FDTD method R-Soft software [8]. The optical swith based on active microring resonator proposed in this report based on two active microring serially cascaded coupled to double straight waveguide. Both of the microring resonator have been designed with 2µm radius.

The gap spacing between the bus waveguide and the microring is 100nm. The submicron rib waveguide has been determine, with the rib height (H) of 700nm, rib width (W) of 500nm and slab height (h) of 200nm. The top and side cladding of the waveguide core is air, thus the high index contrast provides rigid confinement of optical field in the waveguides. The active section of the resonator is form by implanting PN junction at the ring waveguide. The silicon layer is lightly doped with concentration of $1 \times 10^{14}\ cm^{-3}$, whereas both p^+ and n^+ region have uniform concentrations of $5 \times 10^{19}\ cm^{-3}$ with n^+ region is implanted with boron and p^+ with phosphorus.

Result and Discussion

The DC electrical simulations have been performed on the active region of the device. The analyses have been done by applying an external electrical signal to the electrodes. By observing the doping concentrations variations at the waveguide centre (x=2μm, y=3.05μm), it enables us to work out the refractive index changes at a specific drive voltage. From the calculated electron and hole concentration values, the free carrier induced variation in real refractive index can be obtained. Table 1 shows the relationship between drive voltage and the refractive index change at 1.55μm wavelength. In general, the refractive index change increases as the applied voltage is getting higher.

Table 1: Refractive index change for different applied voltage

Drive Voltage (V)	Refractive Index Change (Δn)
0.75V	-0.0001
0.80V	-0.0002
0.85V	-0.0005
0.90V	-0.0011
0.95V	-0.0039
1.00V	-0.0045

Fig. 2 shows the transmission spectra of the proposed device at applied voltages 0V and 0.95V. Changing the refractive index of the microring by applying 0.95V drive voltage causes the changes of resonant wavelength. With the refractive index change of -0.0039, the resonant wavelength was shifted from wavelength 1.55μm to 1.41μm.

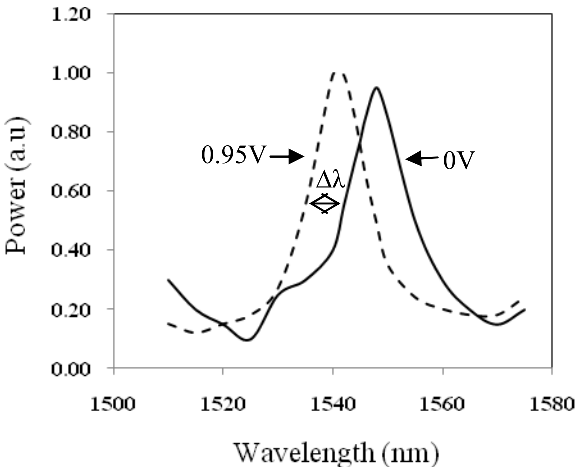

Fig. 2 Transmission spectra of the microring resonator

Fig. 3 shows the functionality of the proposed 2x2 optical switch. The results have been obtained based on applied voltage of 0.95V. Tuning the refractive index of the microring by applying applied voltage will change the resonance condition. Fig. 3 (a) indicates the input wavelength of 1.55μm was propagated from input port1 to output port1 by applying the drive voltage at the active region. However, the propagation of the input wavelength will switch to output port 2 by removing the drive voltage as shown in Fig 3(c). Similarly, when the input wavelength was launched at the input port 2 illustrates in Fig.3 (b) and (d). Results proven our proposed 2x2 optical switch managed to control the propagation of the input wavelength by changing the resonance characteristic through the free charge carrier dispersion effect.

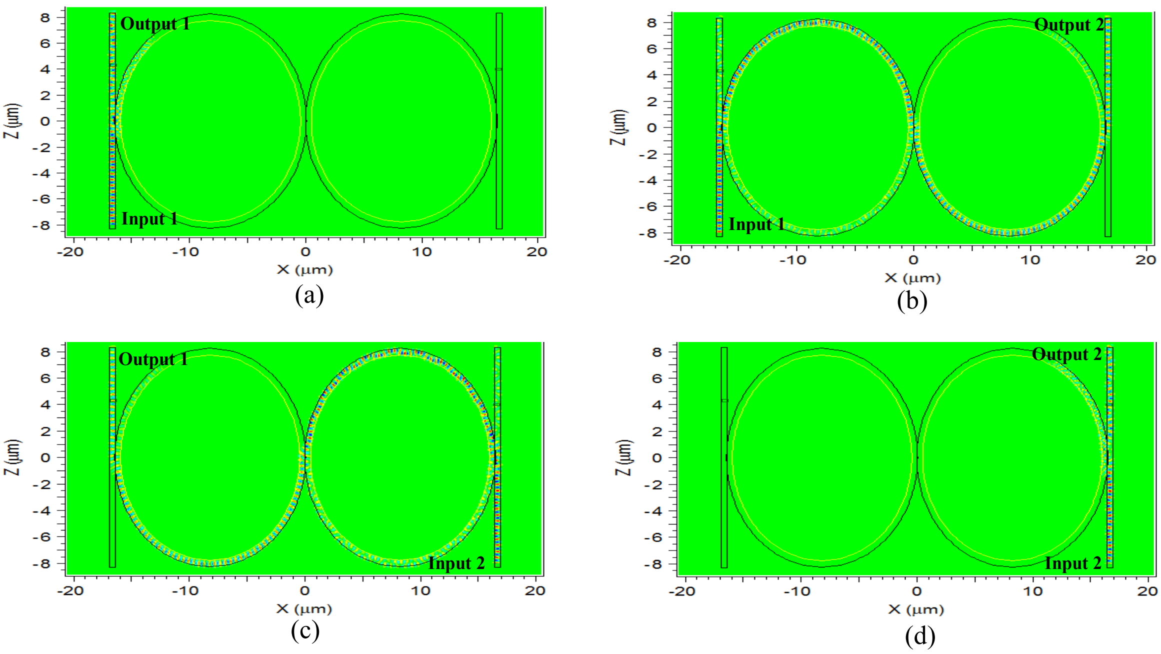

Fig. 3 FDTD simulation result of proposed 2X2 optical switch

Conclusion

The modeling and analyses of 2X2 optical switch SOI microring resonator have been presented. We have shown the active microring resonator as the key element to control the propagation path of the light wave in the proposed switch.

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