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Silicon photonics fabrication tolerance sensitivity study

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KEYWORDS

Silicon photonics, fabrication tolerance, ring resonator, coupled cavity resonator.

SHORT SUMMARY

The low-loss SOI fabrication technology is used to fabricate the silicon photonics chip [1]. Despite, the accuracy of the fabrication process, it has some sort of fabrication errors. This fabrication tolerance has an impact on the fabricated waveguides which in turn affects the response of the devices. This effect should be evaluated to be compensated for in the design process. The fabrication tolerance sensitivity study for the responses of single racetrack ring resonator and nested coupled cavity ring resonator are discussed. The waveguide of the structures on chip is designed for the TM polarization for sensing application. Therefore, a study of the waveguide width fabrication tolerance on the parameters of the TM-mode was presented. A relation between the n_{eff} and n_g of the TM-mode with respect to the waveguide width w and resonance wavelength λ_m were evaluated from a curve fitting. The effects of other fabrication parameters like waveguide length L and coupling gap g are studied.

EXTENDED ABSTRACT

The scope of this work is to study the fabrication tolerance effect on different resonators which composed of an inverted ridge silicon waveguide structure of the schematic cross-section shown in Figure 1.

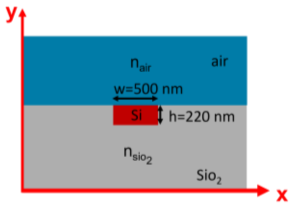

Figure 1 Schematic cross-section of the fabricated silicon waveguide structure in the x-y plane, the core is 500x220 nm of silicon n_{si} =3.45 surrounded by silicon dioxide n_{sio_2} =1.444 from all sides except at the top there is air n_{air} =1 at a wavelength of 1550 nm.

This waveguide structure is used to design a single racetrack and nested coupled cavity ring resonators [2]. The schematic of the single racetrack is shown in Figure 2(a). The light propagates by the longitudinal propagation constant $\beta = (2\pi n_{eff}) / \lambda$, and field attenuation coefficient α. The light couples into/from the racetrack through D.C.1/D.C.2 with through/cross coupling coefficients of a_{ki} / b_{ki} *,where i: 1,2,…. . The* length L of the racetrack resonator is the perimeter of the ring, $2\pi R$, and twice the length of the straight waveguide L_w ($L = 2\pi R + 2L_w$). By considering the block diagram in Figure 2(b) representing the signal flow through the structure, the transmission response are derived as shown in equation 1, where $A = a_{k1}a_{k2}e^{-\alpha L}$.

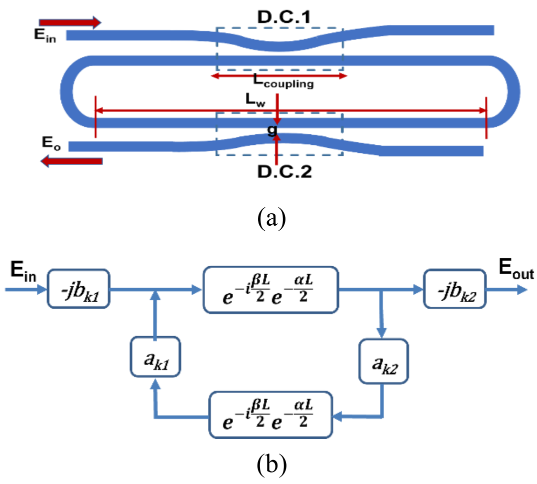

Figure 2 (a) Single racetrack ring resonator structure with straight waveguide of length L_w, and (b) its block diagram representation.

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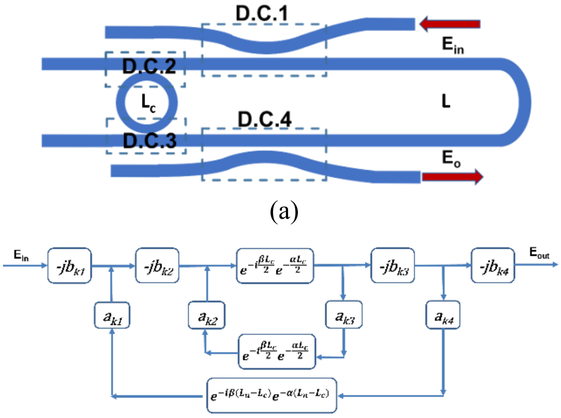
$$T_{out} = \frac{(b_{k1}b_{k2})^2 e^{-\alpha L}}{(1-A)^2 + 4A\,sin^2\left(\frac{\beta L}{2}\right)} \qquad (1)$$

The schematic of the nested ring resonator is shown in Figure 3(a). It consists of one long racetrack resonator (main cavity of length L_n), coupled to the small cavity of length L_c by two DCs (D.C.2, 3) and coupled to the input/output waveguides by another two DCs (D.C.1, 4). The input beam is coupled into the main cavity through the first DC (D.C.1), then coupled to the small cavity through D.C.2 circulating in the resonator until D.C.3 then, a portion of the light is evanescently coupled to the output port through D.C.4 and the other portion goes through the rest of the resonator. By considering the block diagram shown in Figure 3(b) representing the signal flow through the structure, the transmission response are derived as shown in equation 2, where; $A_n = a_{k2}a_{k3}e^{-\alpha L_c}$, $B_n = a_{k1}a_{k4}b_{k2}b_{k3}e^{-\alpha L_n}$, and $\Delta L = L_n - L_c$.



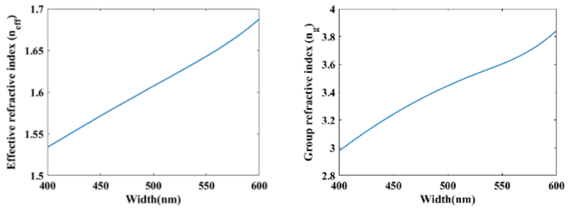
(a)

(b)

Figure 3 (a) Nested coupled cavity ring resonator structure and (b) its block diagram representation

$$T_{out} = \frac{(b_{k1}b_{k2}b_{k3}b_{k4})^2 e^{-\alpha L_c}}{[1 + A_n{}^2 + B_n{}^2 - 2A_n\,cos(\beta L_c) + 2B_n\,cos(\beta L_n) - 2A_nB_n\,cos(\beta \Delta L)]} \qquad (2)$$

Through the fabrication process, the dimensions of the waveguide, the lengths of the resonators and the coupling gap of the directional couplers may be affected within certain tolerance. The study of that effects on the performance of the devices for TM-mode (for sensing applications) gives an indication of the possibility changes in the response after fabrication. Therefore, the effect of changing the waveguide width on the values of effective refractive index n_{eff} and group refractive index n_g of TM-mode is studied. There variations with respect to the waveguide width are illustrated in Figure 4(a) and Figure 4(b), respectively. The n_{eff} increases linearly with the waveguide width but the n_g increases with some sort of non-linearity with the waveguide width.



(a) (b)

Figure 4 (a) Effective refractive index n_{eff}, b) group refractive index n_g for fundamental quasi-TM mode versus waveguide width (w) range from 400 nm to 600 nm at a wavelength of 1550 nm.

A curve fitting is used to get the relation between n_{eff} and n_g with respect to the waveguide width (w) and the wavelength (λ). Equation 3 shows a first order polynomial for n_{eff}, with a root mean square error (RMSE) of 0.0041. Equation 4 shows a first order variation with the wavelength and a second order variation with the waveguide width for n_g with RMSE of 0.0213.

$$n_{eff} = a_e + b_e w + c_e \lambda \qquad (3)$$

$$n_g = a_g + b_g w + c_g \lambda + b_{g_2} w^2 + c_{g_2} w\lambda \qquad (4)$$

From those relations, the changes of the main parameters of the resonators on the main specs, such as free spectral range FSR, the full width at half maximum FWHM and the transmission losses, of the resonator can be detected.

Conclusion

In silicon photonics devices, the fabrication process induced some tolerance for different parameters of the designed structures which affects the responses of the fabricated devices. The fabrication tolerance effects on the inverted ridge waveguide structure and two different resonators structures are accomplished through changing the waveguide widths, the resonator length, and the coupling gap of the resonator.

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