Design and Simulation of Silicon Micro-ring for Optical Mode Converter

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***Abstract* -A Si-based ring structure has been proposed for optical mode converter, 0^{th} to 1^{st} order mode and vice versa, for the first time. Only 1.08 dB (0^{th} to 1^{st}) and 1.48 dB (1^{st} to 0^{th}) conversion losses have been calculated.**

I. INTRODUCTION

To meet the rapid growth of data traffic in network system, recently mode division multiplexing (MDM) is getting considerable attentions [1-2]. To realize MDM mode conversion is required. To convert 0^{th} mode to 1^{st} order mode, MMI structure [2] and Long Period Fiber Bragg Grating (LPFBG) [3] have already been proposed. Unlike MMI structure or LPFBG, we are proposing a ring structure on SOI-wafer to convert 0^{th} mode to 1^{st} order mode and vice versa, where only 1.08 dB and 1.48 dB conversion losses have been calculated respectively. Moreover the proposed structure is ultra small (15 x 15 μm^2) compare with the regular MMI structure.

II. THEORY OF MODE CONVERSION

For mode division multiplexing ring structure has already been proposed [4]. To realize mode division multiplexing mode conversion is necessary. We are proposing ring structure to convert mode (0^{th} to 1^{st} order mode and vice versa) for the first time. This paper presents the design theory and simulation result of the ring based mode converter. Fig. 1 shows the schematic of proposed ring structure on SOI-wafer for optical mode conversion. Here, Si-core (n_1 = 3.48) is covered by SiO_2 (n_2 =1.44). Unlike regular ring resonator the proposed structure has two different straight waveguides. Waveguide "a" of width w_a, supports mode 0, and waveguide "b" of width w_b, supports mode 0 and mode 1. The width of the ring is w_a. Basic concept of the proposed mode converter is conceptualized from the mode coupling theory [5]. Fig. 2 shows the schematic of the asymmetric waveguides "a" and "b" with modal fields' ψ_a and ψ_b and propagation constant β_a and β_b. Here, $\beta_a < \beta_b$. So the mode mismatch is defined by

$$\Delta = \frac{\beta_b - \beta_a}{2}$$

Since, two waveguides are placed close enough, there will be coupling between the waveguides and there will be coupling coefficient, κ between two waveguides. Hence, normal modes will suffer a modification [5] and a new parameter of coupling may be defined as $\gamma = \pm(\kappa^2 + \Delta^2)^{\frac{1}{2}}$

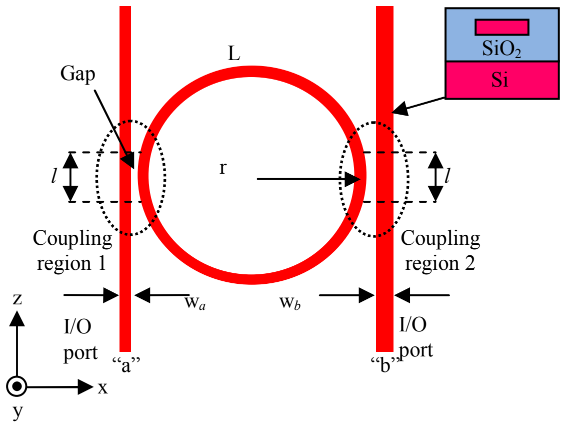

Fig. 1. Proposed ring structure with two different type of coupling region. Here, I/O port widths are different to satisfy the mode accommodation. Device layer is also shown.

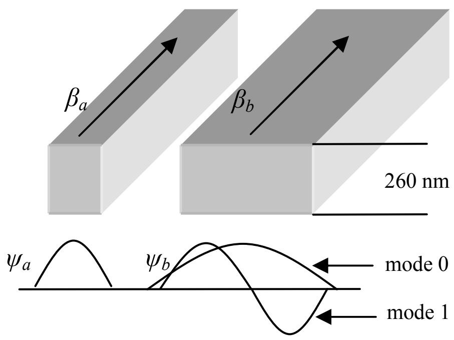

Fig. 2. Straight waveguide assumption in coupling region 2 of the proposed mode converter. Here two waveguides have different width dimension of w_a and w_b.

Using this criterion, modes of the individual waveguides will be converted into two different modes [5-6]. These modes are denoted by β_e and β_o and can be written as

$$\beta_e = \frac{(\beta_a+\beta_b)}{2} + \gamma \text{ , and } \beta_o = \frac{(\beta_a+\beta_b)}{2} - \gamma$$

Here, $\beta_e > \beta_b$, β_a and $\beta_o < \beta_b$, β_a. Using these results we have exploited the dimension of waveguide, w_b in such a way that it will not support β_e, but support β_o. This propagation constant is lower than β_{b1}. Here, β_{b0} and β_{b1} are the fundamental and the first order modes in waveguide, w_b. Propagation constants are calculated using rectangular waveguide geometry [6] and $\beta_{b1} < \beta_o < \beta_a < \beta_{b0} < \beta_e$ are found, which confirms only 1^{st} order mode propagation in waveguide "b" after mode conversion.

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III. Result

Fig. 3 shows the simulated optical field profile of the proposed mode converter. Here mode 0 has been converted to mode 1. Since the ring radius affects the coupling coefficient and resonance inside the ring, the output power of the converted mode also varies with radius. This is shown in Fig. 4. Form this figure we can see that maximum converted power has been achieved for 6.2 µm radius.

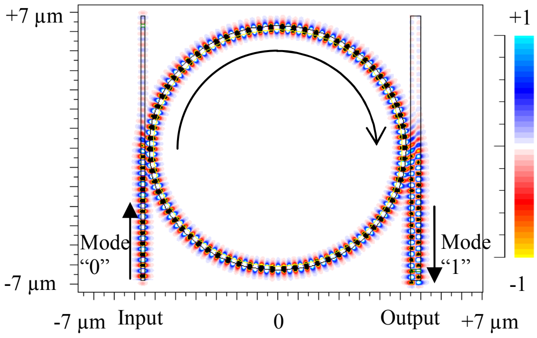

Fig. 3. Electric field (E_y) profile of the proposed mode converter. Here, 0^{th} mode has been converted to 1^{st} mode, which is clearly visible in the profiles.

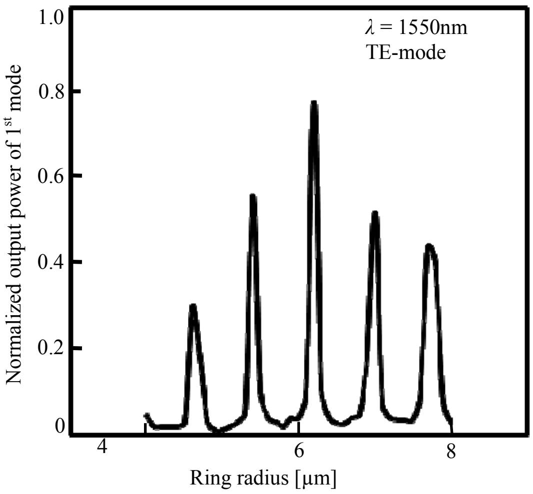

Fig. 4. Effect of ring radius, *r* on converted mode power.

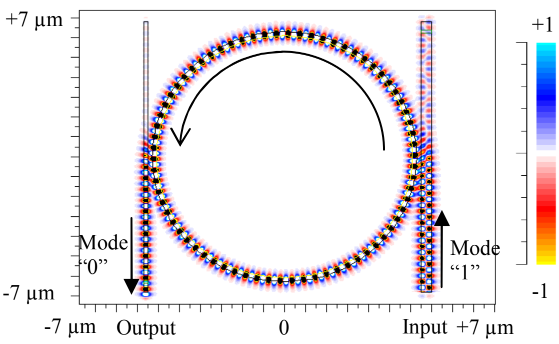

Fig. 5. Electric field (E_y) profile of the proposed mode converter. Here, 1^{st} mode has been converted to 0^{th} mode, which is clearly visible in the profiles.

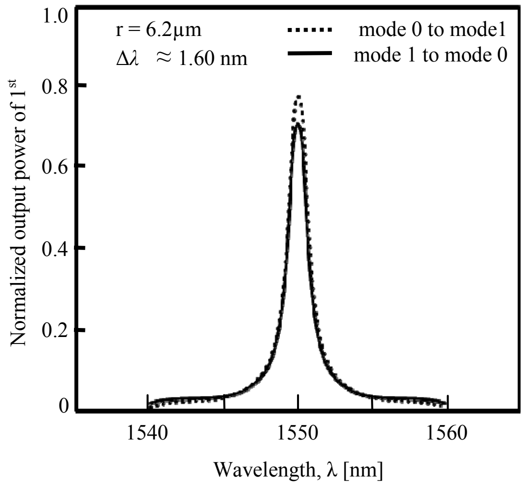

Fig.6. Normalized output power of the converter as function of wavelength λ.

Oscillatory nature of the output power confirms this effect. To understand the duality principle of the proposed mode converter, a simulation has been been done with mode 1 as input to the waveguide and converted output with mode 0 has been found. This is shown in Fig. 5. Next, to understand the effect of wavelength, spectral selectivity, *Q* of the structure has been calculated. It is found as high as ≈ 960. This is shown in Fig. 6.

IV. Conclusion

We have proposed a novel ring structure for optical mode converter. We have showed 0^{th} mode has been converted to 1^{st} mode with just 1.08 dB conversion loss with ring radius of 6.2 µm. The proposed structure is also very small (<225 μm^2). Spectral selectivity of the proposed structure is as high as 960. This structure will be helpful for future MDM transmission technology.

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References

[1] Y. Kokubun et al., "Novel multi-core fibers for mode division multiplexing: proposal and design principle", IEICE Electron. Exp., vol 6, no. 8, pp. 522-528, 2009.

[2] Y. Chaen, et al., "Optical Mode Converter Using Multi-mode Interference Structure," 18th Micro-optics Conf., Tokyo, Japan, Oct. 27 - 30, 2013Y.

[3] N. Hanzawa, et al., "Mode-division Multiplexed Transmission with Fiber Mode Couplers", OW1D.4, Opt. Fiber Conf. 2012.

[4] B. A. Dorin et al., "Two-mode division multiplexing in a silicon-on-insulator ring resonator", Opt. Express, vol. 22, no. 4, pp. 4547-4558, 2014.

[5] Ginés Lifante, "Integrated Photonics: Fundamentals," John Wiley and Sons Inc. USA.

[6] E. A. J. Marcatili, "Dielectric Rectangular Waveguide and Directional Coupler for Integrated Optics", Bell System Technical Journal vol. 48, no. 7, pages 2071–2102, September 1969.