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Low loss, small crosstalk offset crossing structure for large-scale planar lightwave circuits

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Abstract: A low loss, small crosstalk offset crossing structure for a Si wire waveguide is proposed. We analyzed the properties of the structure for both the TE and TM modes by 2-D FDTD (two-dimensional finite difference time domain) simulation. By optimizing the offset crossing structure, a transmission loss of 0.021 dB, and crosstalk of −55.0 dB was achieved with a crossing angle of 20 degrees for the TE mode. A transmission loss of 0.070 dB, and crosstalk of −48.6 dB was also achieved with the same crossing angle for the TM mode. The low losses achieved with a small crossing angle makes this structure very useful for highly integrated optical matrix switches, etc.

Keywords: crossing, optical circuit, Si wire waveguide

Classification: Optoelectronics, Lasers and quantum electronics, Ultrafast optics, Silicon photonics, Planar lightwave circuits

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1 Introduction

Si photonics technology will provide low-cost, compact, highly integrated optical functional devices [1, 2]. Si wire waveguide circuits fabricated on silicon on insulator (SOI) substrates are very compact because of the high index difference. This technology may be suitable for large-scale photonic integrated circuits in network systems. One of the problems for Si wire waveguides is that simple crossing structures have large transmission losses and high crosstalk. As for the simplest crossing at an angle of 90 degrees, the transmission loss and the crosstalk are about 1.0 dB and −12.4 dB, respectively. Thus, this type of crossing is not appropriate for use in an optical matrix switch in a photonic network node because of the large number of waveguide crossings. Several types of crossing structure have recently been reported [3, 4, 5]. However, these methods use crossings with angles of about 90 degrees and the sizes of the crossings are rather large. It has also been reported that crossings at an angle of 60 degrees had better characteristics compared to the conventional ones in [6], but the method used can only be applied to crossings at this angle. To achieve a compact crossing, crossing with a small crossing angle is desirable. But the research on that remains little.

In this paper, we propose a novel offset crossing structure to give a small crossing angle which reduces the transmission loss and crosstalk of the Si wire waveguide. The proposed structure is effective for both the TE and TM modes.

2 Design of offset crossing structure

Fig. 1 shows a schematic drawing of the offset crossing structure [7]. The crossing consists of four waveguides: input, output 1, output 2, and output 3. The crosstalk from output 3 is negligible because it is less than the crosstalk from output 2 at all times. So, we defined the crosstalk as the ratio of the power of the light from output 2 to the power of the input light. We optimized the offset length to minimize the transmission loss and crosstalk for various crossing angles and analyzed its properties for both TE and TM modes using 2-D FDTD simulation. It was assumed that the design wavelength was 1.55 μm, the core width was 0.33 μm, and the refractive indices of the core and the cladding layer were 3.45 and 1.45, respectively. The effective refractive index was 2.73 for the TE mode and 3.07 for the TM mode. The core width was chosen to satisfy the single-mode condition.

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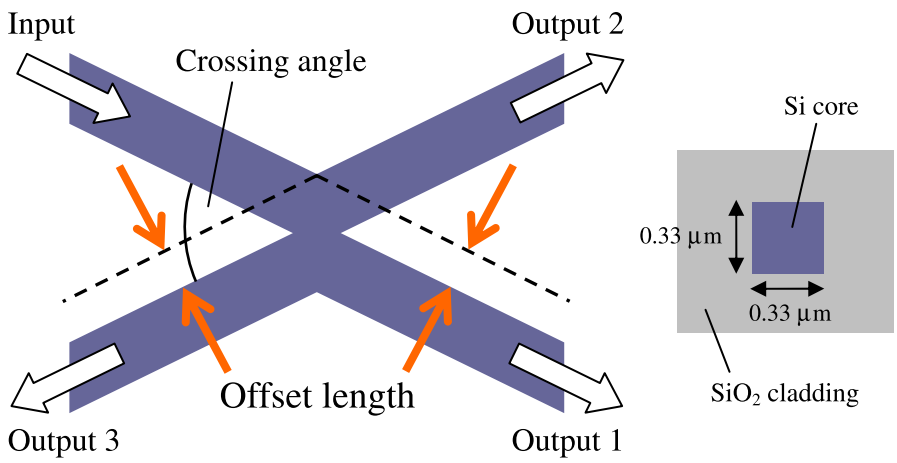

Fig. 1. Design of the offset crossing structure and a cross section of the Si wire waveguide.

3 Simulation results

Fig. 2 (a) shows the transmission loss of the offset crossing structure with the optimized offset and a crossing without offset for the TE mode. The offset crossing structure had lower loss for crossing angles of 20 to 50 degrees. In particular, smaller crossing angles were more advantageous. The crosstalk is shown in Fig. 2 (b). The crosstalk from output 2 reduced drastically with the offset. We couldn't minimize the transmission loss or crosstalk for crossing angle of 60 to 90 degrees. Fig. 2 (c) and (d) show the results for the TM mode. As well as the TE mode, the properties for the TM mode improved for crossing angles from 20 to 70 degrees. For crossing angle of 80 to 90 degrees, there was no improvement.

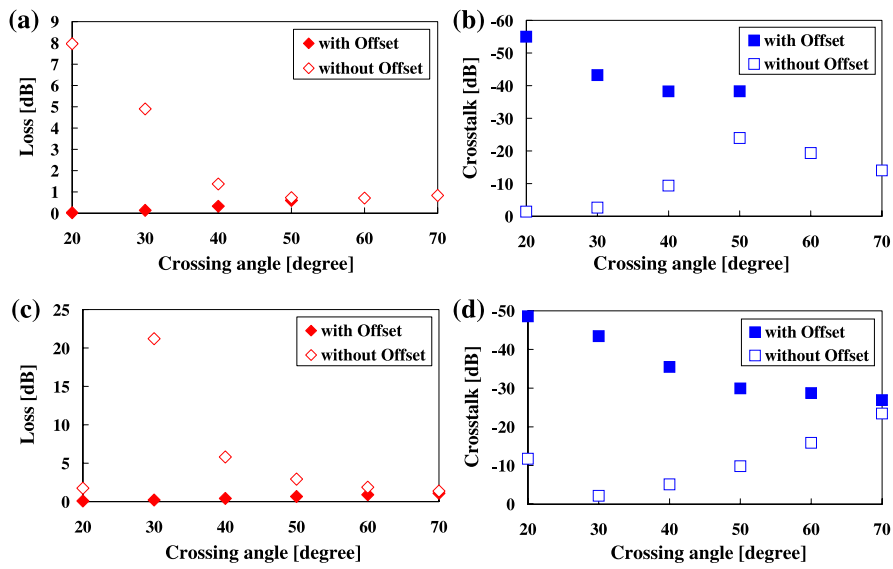

Fig. 2. Transmission loss and crosstalk for offset crossing and a simple crossing without offset. (a) Loss for TE mode, (b) crosstalk for TE mode, (c) loss for TM mode, and (d) crosstalk for TM mode.

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Fig. 3 (a) shows the offset dependences of the transmission loss and the crosstalk with a crossing angle of 20 degrees for the TE mode. The conventional simple crossing with an offset of 0 μm has a large transmission loss of 8.0 dB and crosstalk of −1.4 dB. It is clear that the transmission loss and the crosstalk can be effectively suppressed by selecting an appropriate offset. When the offset is set to the optimum value of 0.214 μm, the transmission loss and crosstalk are 0.021 dB and −55.0 dB, respectively. Fig. 3 (b) shows the result for the TM mode. It is important that the optimum offset is different for the TE and TM modes. The optimum offset for the TM mode is 0.251 μm, with a transmission loss of 0.070 dB and crosstalk of −48.6 dB. Moreover, we evaluated the fabrication tolerance for the TE mode by adding some errors to the core width under the optimum conditions. For errors in the core width of ±0.03 μm, the transmission loss is still less than 0.06 dB and the crosstalk is also less than −40 dB. This result suggests that the offset crossing structure is robust against fabrication errors.

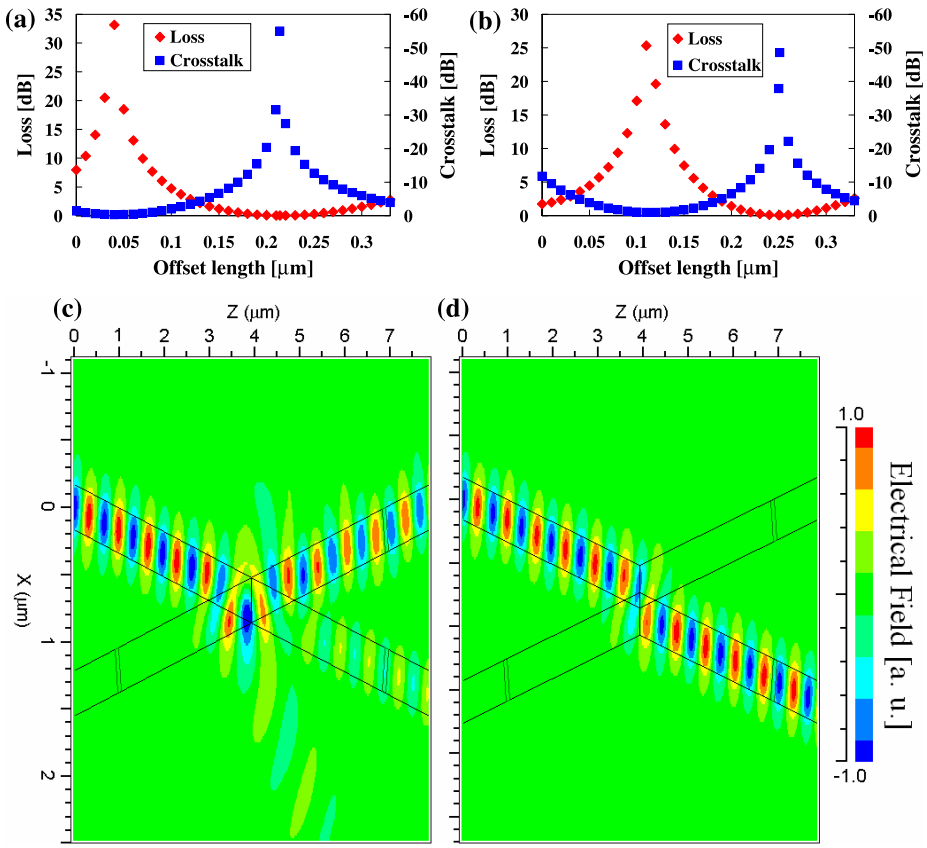

Fig. 3. (a) Transmission loss and crosstalk as functions of the offset with a crossing angle of 20 degrees (a) for TE mode and (b) for TM mode. The light propagation images were calculated by a 2-D FDTD method for a crossing (c) without offset and (d) with the optimum offset.

Simulated light propagation images for a simple crossing and an offset crossing at an angle of 20 degrees by 2-D FDTD are shown in Fig. 3 (b) and

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(c), respectively. The waveguide in the crossing region is considered to be multi-mode waveguide. The input light excites the fundamental and higher order modes and causes multi mode interference. Thus, the transmission loss and the crosstalk are sensitive to the crossing structure. When there is no offset, the input light is reflected from the sidewalls and couples into the wrong waveguide (output 2). Part of the input light radiates away and the rest is transmitted. On the other hand, when the crossing has the optimum offset, the input light propagates smoothly into the correct waveguide (output 1) and radiation in the crossing region is not observed.

4 Conclusion

Both the transmission loss and the crosstalk of a Si wire waveguide crossing were effectively suppressed by using the offset crossing structure. The offset crossing showed better characteristics compared to a conventional simple crossing at small crossing angles. The optimum offset crossing structure at an angle of 20 degrees, showed a transmission loss of 0.021 dB and crosstalk of −55.0 dB for the TE mode, and a transmission loss of 0.070 dB and crosstalk of −48.6 dB for the TM mode. Such a compact crossing is very useful for integrating various optical functions.

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