Efficient Cross-talk Reduction of Nanophotonic Circuits Enabled by Periodic Silicon Strip Arrays

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***Abstract*—We develop a simple and efficient crosstalk reduction approach for Si-based nanophotonic circuits by introducing a periodic array of Si strips between adjacent waveguides. Studies indicate that the coupling length can be extended by more than two orders of magnitude for a waveguide pair with an edge-to-edge distance of ~λ/3. Our approach offers a feasible route toward photonic integrated circuits with an ultra-high packing density.**

Keywords—Crosstalk; Silicon photonics; Photonic integrated circuits; Penetration depth

I. INTRODUCTION

Silicon photonics has been identified as a key enabling technology that could offer a promising solution to the bottleneck in conventional micro-electronics due to its unprecedented features including high bandwidth, low power consumption and reduced cost, as well as its full compatibility with complementary metal oxide semiconductor (CMOS) technology [1]. However, compared to integrated electronics (ICs), photonic integrated circuits (PICs) still suffer from considerably lower packing density. One of the solutions that can potentially increase the density of PICs is to reduce the crosstalk between adjacent components, the leakage of light from one element to its neighbors. By utilizing waveguide supper-lattices design [2] or leveraging nanophotonic cloaking [3], researchers have decreased the waveguide spacing down to ~λ/2 with negligible crosstalk. Here, we develop an alternative approach to reduce the crosstalk in nanophotonic circuits by introducing a periodic array of Si strips between adjacent waveguides. Our design is simple, and neither requires a complex algorithm for structure optimization nor involves sophisticated processes in device fabrication. The approach can be applied to various types of photonic devices as well.

II. CROSSTALK REDUCTION USING SILICON STRIP ARRAY

A recent work reveals that the penetration depth of the evanescent fields into the surrounding medium can be well controlled through engineering the ratio of the permittivities along different directions [4]. Here we apply such a concept to reduce the overlap of the evanescent waves of the guided modes and minimize the crosstalk between neighboring waveguides. Fig. 1 (a) shows schematically the configuration of a coupling system that comprises two horizontally parallel Si ridge waveguides with an edge-to-edge separation of *S*, whereas Fig. 1 (b) illustrates the proposed configuration that incorporates an additional Si strip array embedded between the Si ridge waveguides. Due to the periodic structure consisting of alternating Si strips and air slots, the introduced configuration can be regarded as a highly anisotropic medium with a pronounced permittivity contrast along the horizontal and vertical directions. Here, we will show that the coupling length of the Si ridge waveguides can be dramatically increased through a geometric optimization of the strip array, which leads to a significantly reduced crosstalk.

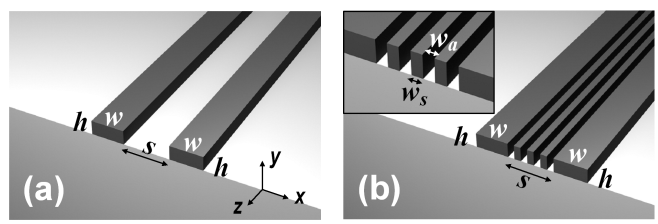

Fig. 1. Schematics of (a) two identical Si ridge waveguides (width *w* and height *h*) separated from each other with an edge-to-edge distance of *S*; and (b) the proposed configuration that comprises a periodic Si strip array inserted in between the Si waveguide pair. The substrates and claddings for the conventional and newly proposed configurations are SiO_2 and air, respectively. The width of the Si strip and the air slot are w_s and w_a, respectively. The refractive indices of SiO_2, Si and air are taken as 1.444, 3.476 and 1 at a working wavelength of 1550 nm.

To quantitatively illustrate the effectiveness of the approach in reducing the waveguide crosstalk, we calculate the coupling lengths (L_c) between two closely spaced waveguides with and without the Si strip array, where the width of the Si ridge waveguide is chosen as 500 nm to ensure the existence of a strongly confined TE mode. L_c is obtained based on the coupled mode theory: $L_c = \pi / | k_s - k_a |$, where k_s and k_a are the wavenumbers of the symmetric and anti-symmetric modes of two coupled waveguides, respectively. Fig. 2 shows the calculated L_c for various strip widths in the coupling system and the corresponding field distributions at optimal L_c. For all the considered cases, the introduction of the strip array could result in a dramatically extended L_c as compared to that of the pure Si pair. L_c is increased by a factor of 2 ~ 8 in a configuration with a single or two strips (Figs. 2(a)-(b)). Whereas considerably larger increases in L_c are observable for a Si array having more than two strips (Figs. 2(c) - (d)). As shown in Table I, the largest L_c achieved by our proposed configuration is more than two orders of magnitude larger than

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that obtained in a conventional Si pair, indicating significant reduction of the waveguide crosstalk. We also note that the width of the Si strip corresponding to such an optimal L_c is 76 nm, which results in an aspect ratio ~ 1:3, making the configuration feasible to fabricate using standard technologies (*e.g.* electron beam lithography combined with inductive coupled plasma etching). The crosstalk-reduction approach also works well over a broad range of wavelengths, as illustrated in Fig. 3. For a single and two strip cases, L_c is increased by a factor of 2 ~ 8 within 1.52 ~ 1.62 μm. While for structures with three or four strips, L_c can be extended by 1 ~ 3 orders of magnitude within the considered wavelength range, which is larger than one meter under the optimized condition (Fig. 3 (d)). In addition, our studies indicate that crosstalk reduction is also achievable for weakly confined Si modes, as shown in Table II. For instance, the optimal L_c of a Si pair with 6 strips is more than one order of magnitude larger than that obtained in the conventional structure. It is worth mentioning that such an optimal L_c can be further increased by introducing more strips. However, the continuously narrowed silicon strip in these scenarios would add additional complexity to the device fabrication. To find a more feasible crosstalk-reduction approach for weakly confined modes and further reduce the waveguide crosstalk, future work needs to be conducted. Among others, adopting a non-periodic Si array, along with a genetic or topological optimization algorithm incorporated into the design process might be a potential solution.

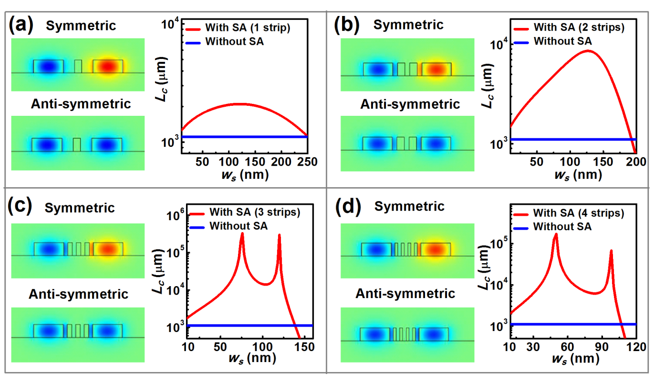

Fig. 2. E_x field distributions of the symmetric and anti-symmetric super-TE-modes in typical coupling systems and the effect of strip width on the L_c for configurations with and without the Si strip array (SA). (a) A single strip; (b) two strips; (c) three strips; (d) four strips. Parameters are w = 500 nm, h = 220 nm, S = 500 nm. The widths of the strip(s) with optimal L_c are w_s = 120 nm for (a), w_s = 126 nm for (b), w_s = 76 nm for (c) and w_s = 48 nm for (d). The field profiles illustrate relatively weak modal overlap between neighboring structures at optimal L_c.

TABLE I
Optimal L_c for different configurations ($w = S = 500$ nm)

Configuration	Optimal L_c
Si pair without array	1.1×10^3 μm
Si pair with a single strip	2.1×10^3 μm
Si pair with two strips	8.5×10^3 μm
Si pair with three strips	3.32×10^5 μm
Si pair with four strips	1.71×10^5 μm
Si pair with five strips	1.07×10^5 μm

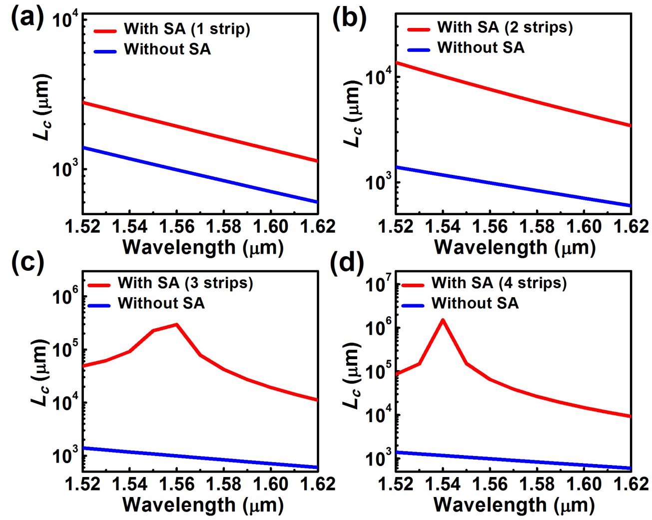

Fig. 3. Dependence of L_c on the working wavelength for configurations with and without (a) a single Si strip (w_s = 126 nm); (b) two Si strips (w_s = 126 nm); (c) three Si strips (w_s = 76 nm); (d) four Si strips (w_s = 48 nm). Other parameters are w = 500 nm, h = 220 nm and S = 500 nm, respectively.

TABLE II
Optimal L_c for different configurations (w = 300 nm, S = 500 nm)

Configuration	Optimal L_c
Si pair without array	14.6 μm
Si pair with a single strip	21.3 μm
Si pair with three strips	68.8 μm
Si pair with six strips	160.4 μm

III. Conclusion

In summary, an efficient approach for reducing the crosstalk between adjacent Si waveguides has been developed, which is realized by introducing an array of Si strips between neighboring waveguides. Studies show that significantly extended coupling lengths are achievable under appropriate design conditions. Our approach is simple to fabricate and works well across a broad band of wavelengths. Moreover, it is applicable to both strongly and weakly confined modes, which is promising for increasing the packing density of PICs.

References

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