Highly Compact Polarization Insensitive Strip-Slot Waveguide Mode Converter

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Abstract: A polarization insensitive strip-slot waveguide mode converter with large fabrication tolerance is proposed based on symmetric multimode interference (MMI). This converter can achieve efficient strip-slot waveguide coupling (TE:94.9%, TM:94.6%) while the dimensions are only 1.18 μm×3μm.

OCIS codes: (130.0130) Integrated optics; (130.3120) Integrated optics devices; (130.2790) Guided waves.

1. Introduction
Both strip and slot waveguides are widely used in integrated photonics to enable various functional devices based on their unique properties of confining and propagating light. Meanwhile, the optical mode mismatch between strip (Gaussian-like mode) and slot (non-Gaussian-like mode) waveguides makes the efficiency of direct strip-slot butt-joint coupling very low. Various strip-slot mode converters have been proposed to enhance the coupling efficiency between strip and slot waveguides [1-6]. All these converters have fabrication difficulties since extremely sharp tips are utilized, which must be well shaped or the coupling efficiency will degrade significantly [2]. Recently, we have proposed a novel strip-slot mode converter based on symmetric multimode interference (MMI) which is fabrication-friendly with a large tolerance for fabrication imperfections [7]. However, all these converters are demonstrated for TE-polarized light, while many integrated photonics applications, for example polarization multiplexing require polarization insensitive converters.

In this paper, we propose a polarization insensitive strip-slot mode converter based on symmetric MMI for efficient coupling between strip and slot waveguides, which also allows large fabrication imperfections while maintaining the compactness of the device.

2. Symmetric MMI based design
The proposed converter [Fig. 1(a)] consists of two parts, the symmetric 1×2 MMI and the taper regions. The whole structure is based on a material platform of silicon-on-insulator (SOI) with SiO2 cladding. The width of the MMI region, Wmmi=1.18 μm, is optimized so that the first two-fold image of MMI with TE-polarized and TM-polarized fundamental mode incidence coincide, and according to which the length of MMI region is chosen, Lmmi=1.32 μm. A slot taper with length of (L−Lmmi) is utilized to connect the multimode region and the slot waveguide. The strip and slot waveguides have the following dimensions: the thickness of top silicon is 250 nm; the widths of the strip and slot waveguide are 400 nm and 620 nm respectively; and the 100 nm slot is located at the center of the slot waveguide. For both TE-polarized and TM-polarized incident light, the optical field evolutions in Fig. 1(b, c) indicate that (i) the proposed converter can convert a strip waveguide mode to a slot waveguide mode with negligible loss though the following procedure: it rebuilds the incident light into two-fold image in the MMI region and then push the field into the slot smoothly by the slot taper; (ii) The slot waveguide mode can be converted to strip waveguide mode though the reversed procedure.

3. Polarization and fabrication insensitivity
As illustrated in Fig. 1(a), the proposed converter needs three characteristic parameters (Wmmi, Lmmi, and L) to determine its structure when the dimensions of the strip and slot waveguides are fixed. Therefore, converters with different characteristic parameter values are utilized for strip-slot waveguide coupling to quantitatively investigate the polarization sensitivity and fabrication tolerance. The strip-slot waveguide coupling efficiencies are plotted in Fig. 2, where Fig. 2(a) indicates that the coupling efficiency increases dramatically as L increases (L <3 μm) and maintains a high value (~95%) for both TE and TM polarizations as long as the converter is longer than 3 μm, and Fig. 2(b, c) shows that the variations of coupling efficiency for both TE and TM polarizations are less than 2% (3%) while Lmmi (Wmmi) deviates ±60 nm from the optimized size. All the analysis above proves that the proposed mode converter can achieve high-efficient strip-slot waveguide coupling for both TE and TM polarizations and the coupling efficiencies are kept well while the converter dimensions varies in a wide range. It can be concluded that the proposed strip-slot mode converter is insensitive to polarization and fabrication imperfections.

4. Conclusion
In summary, we have demonstrated a polarization insensitive strip-slot mode converter with compact size and large fabrication tolerance based on symmetric MMI. The field distribution similarity between two-fold image of MMI coupler and slot waveguide for both TE and TM polarizations makes high-efficient polarization insensitive strip-slot waveguide mode converter possible (TE: 94.9%, TM: 94.6%) while the dimensions are as small as 1.18 \( \mu \text{m} \times 3 \mu \text{m} \). Meanwhile, the intrinsic robustness of MMI devices give rise to large fabrication tolerance for the proposed converter which makes the proposed mode converter an ideal solution for mass produced integrated photonics devices when both TE and TM polarizations are concerned.

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Fig. 1. (a) Top-view SEM picture of the proposed converter; (b) Optical field evolution between strip and slot waveguides of (b) TE and (c) TM polarization. \( P \), optical energy flux density; \( E \), electric field; \( H \), magnetic field. All simulations in this paper are performed with 3D full vector finite element method, while the refractive indices of Si and SiO\(_2\) are set to 3.48 and 1.45, respectively.

Fig. 2. Coupling efficiency with (a) different converter lengths, (b) length and (c) width variation of the multimode region at 1550 nm (wavelength in free space).

Reference: