A Versatile Optical Spot-Size Converter Design

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Abstract *A non-periodic segmented waveguide is used as a versatile optical spot-size converter. Waveguides with different cross-sections can be coupled in a compact way but also more general waveguide excitations can be transformed. An experimental demonstration in Silicon-on-insulator (SOI) is given.*

Introduction

Within future photonic integrated circuits (PICs), waveguides with different cross-sections are likely to coexist. Some functions, especially those depending on material non-linearity, need huge power densities and thus benefit from waveguides with small cross-sections, whereas interconnection waveguides typically require a larger cross-section due to smaller propagation losses. To keep the overall component small, the coupling between non-identical waveguides should also be kept as short as possible. Nowadays adiabatic tapers are frequently used to achieve a good coupling, see Fig. 1., but to guarantee an adiabatic transition, need to be very long. Non-adiabatic waveguide tapers, see Fig. 1, have already been demonstrated in optical waveguides with a low refractive index contrast [1]. The work presented here brings the same principle to a high refractive index contrast material system, such as SOI. These material systems offer better light confinement and smaller optical components and are therefore promising candidates for the realisation of PICs.
An additional advantage of the coupler scheme used here is the possibility to efficiently convert a random multimode waveguide excitation into a monomodal excitation, something which can not be accomplished using adiabatic tapers.

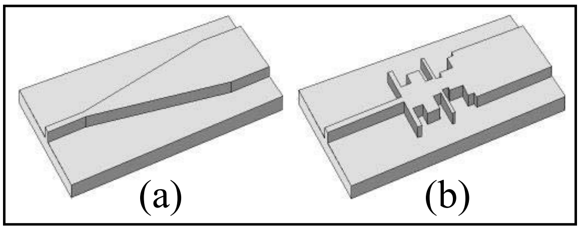

Fig. 1 Scheme of an adiabatic taper (a) and a compact spot-size converter (b).

2-D simulations

As high refractive index contrast easily leads to reflection, a bi-directional and non-paraxial simulation method has to be used to calculate these structures. For reasons of speed and easy modal analysis an Eigenmode Expansion (EME) frequency domain method was chosen above a Finite Difference Time Domain (FDTD) method. CAMFR [2] was used, after an effective index transformation on a typical SOI layer structure (0.22µm Si/ 1.0µm silica/ Si-substrate), resulting in an effective core index of 2.83 for a wavelength of 1.56 µm. For the TE-mode, the dominant electric field component is parallel to the SOI layer structure.

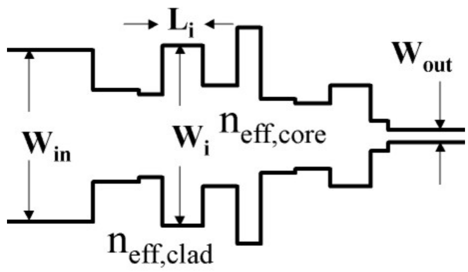

Fig. 2 Scheme of the structure to optimise

The first studied configuration is the coupling between a broad 10-µm SOI waveguide and a narrow 0.56-µm SOI wire, see Fig. 2. N different segments lead to a 2N-dimensional $[L_1,\ldots,L_N,W_1,\ldots,W_N]$ parameter space to search for optima. Two different optimisation algorithms have been applied: a genetic algorithm and an iterative steepest-descent method.
The genetic algorithm starts by generating a set of randomly composed structures with as only constraints upper and lower limits for the parameters L_i and W_i. These structures form the basis for the rest of the genetic calculations. A result is shown in Fig. 3.

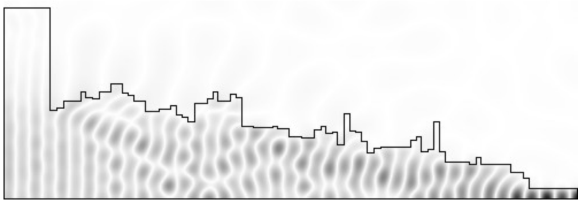

Fig. 3 Field plot (H_y) of a coupler optimised using genetic algorithm with a coupling efficiency of 90%. Because of symmetry, only the upper half of the structure is shown.

More a-priori knowledge is needed when using a steepest descent method. A quasi-adiabatic discretised parabolic taper forms the starting point for the iteration. Each iteration begins with a shortening step: the length L_i of every segment is proportionally decreased while the width is kept constant. Then the lengths are kept constant but by changing each width separately, a local optimum is searched for, using steepest descent optimisation. A result of this method can be seen in Fig. 4.

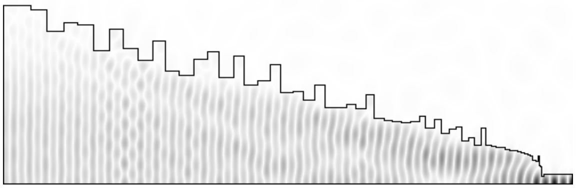

Fig. 4 Field plot (H_y) of a coupler optimised using iterative steepest descent with a coupling efficiency of 95%.

Another configuration studied is the coupling between a photonic crystal (PhC) waveguide and a broad dielectric waveguide, see Fig. 5. The transmission from a forward Bloch mode in a PhC waveguide, created by omitting a row of holes, to each guided mode of a broad 2-µm dielectric waveguide was calculated according to [3]. A genetic algorithm then optimises a structure to change this complex excitation as good as possible into a ground mode excitation of the broad dielectric waveguide. The resulting structure is composed of 13 sections of 100 nm has an efficiency of around 99%. A plot showing the coupling from dielectric to PhC and back to dielectric waveguide is shown in Fig. 5 and has an overall coupling efficiency of 98%.

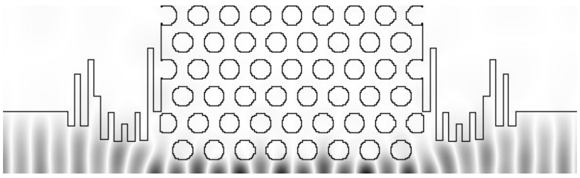

Fig. 5 Field plot of optimised coupling between forward bloch mode of PhC W1 waveguide and a broad dielectric waveguide.

3-D simulations

As the effective index transformation is only approximate, rigorous 3-D simulations are needed before components can be realised. The commercial tool FIMMPROP© was used for this purpose.

As the structure in Fig. 3 is not easily manufactured due to very small features, a similar structure composed of only 10 sections and optimised in 2-D using a genetic algorithm was calculated in 3-D using an SOI layer structure. A local optimisation in 3-D slightly improved the transmission efficiency to 72%. The total length of coupler is 15.4 µm. A width of 10 µm was chosen for the output because a vertical fibre coupler as described in [4] couples to a waveguide of this width. The width of the wire is chosen such that the second mode of the wire is in cut-off.

Realisation

The above coupler has been realised in SOI using 248 nm deep UV lithography. Fabrication details can be found in [5], but a thicker silica layer was used to minimise substrate losses and only the Silicon top layer was etched through.

Measurements on this component showed a coupling efficiency of 70%, coming close to the calculated value. A linear coupler with a length of 25 µm performed worse than the compact spot-size converter.

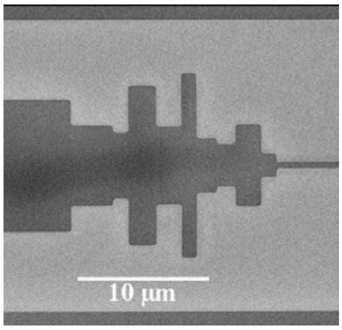

Fig. 6 SEM micrograph of coupler realised in SOI. Widhts of input and output waveguides are respectively 10 µm and 0.56 µm. Total length is 15.4 µm

Conclusions

Non-periodic segmented waveguides are versatile optical spot-size converters. 2-D simulations in combination with optimisation algorithms show good coupling between the ground modes of waveguides with different widths. Also a complex excitation of an input waveguide can be efficiently converted into a useful monomodal excitation.

The same behaviour is also found in 3-D calculations although the achieved efficiency is less in this case. First measurement on components realised in SOI show 70% transmission and a better efficiency than gradual linear tapers of similar, and even longer, length.

References

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