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Topology optimized design of a transverse electric higher order mode converter

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The investigation of methods to support the ever increasing demand for data transfer has continued for years; one such method suggested within the field of optical communication, is space division multiplexing (SDM) [1]. Simultaneously the field of photonic integrated circuits (PICs) is being investigated due to attractive features such as high device density and low operating power [2]. For PICs it is necessary with a toolbox of devices and one such of importance to the processing of on chip SDM is the mode converter. Several schemes have been used to realize such devices [3] [4]. In this paper we present the possibility of employing topology optimization (TO) to design a device that allows for reversible conversion between the transverse electric fundamental even (TE_0) mode and the second higher order odd mode (TE_2). Topology optimization is an iterative inverse design process, where repeated finite-difference time-domain (FDTD) calculations are made in accordance with a sensitivity analysis. This is done using a software package which has been developed in house, and which has shown to deliver low loss designs with a controllable bandwidth in addition to small device footprints [5]. The design is made for fabrication in silicon-on-insulator (SOI) and previous work has shown excellent concordance between simulations and experimental results when employing 3D TO [6].

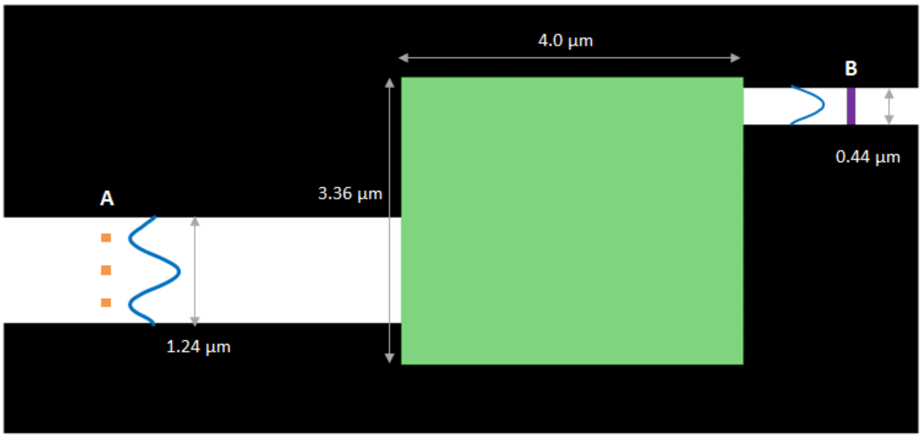

Figure 1 *Starting point structure for topology optimization of the mode converter made in silicon (white) and air (black) on a buffer region of silica (not shown). A second higher order odd transverse-electric mode is excited (orange) at the position A, and is to be converted to the fundamental transverse-electric mode at the objective (purple) at position B. This is done by altering the material distribution in the design domain (green).*

In Figure 1 the starting point structure for the TO is shown. The objective of the optimization is converting the TE_2 mode, excited at position A (orange) in the wide waveguide, to the TE_0 mode output in the narrow waveguide. The TO, redistributing the material, is performed in the 4 µm x 3.6 µm design domain (green) to attain the objective intensity distribution at position B (purple). The design is obtained after approximately 200 iterations.

The optimization is performed in 3D, as this has been found to be necessary for correspondence with fabricated structures. The resolution was 40 nm per pixel and perfectly matched absorbing layers were used as boundary conditions surrounding the structure. The TE_2 mode was excited by three separate sources with spectral widths of~280 nm (full-width half-maximum) centered at~1580 nm placed at the extrema of the mode profile. The silicon slab has a thickness of 340 nm with a relative permittivity of $\varepsilon_{Si} = 3.418$ and the silica buffer underneath has a relative permittivity of $\varepsilon_{SiO2} = 1.444$, from above the structure is surrounded by air. The design domain is restricted to remain uniform in the vertical direction to render fabrication possible.

In Figure 2 the final design is presented along with the structure overlaid with a simulation of the out of plane H-field (H_z). The functionality of the design is clear from Figure 2 and is quantified by the recorded flux presented in Figure 3(a), the TE_0/TE_2 extinction ratio is >19 dB. Figure 3(b) shows the 3D FDTD calculated transmission spectrum for the 280 nm bandwidth of the source revealing a loss of < 0.5 dB near the center wavelength and a 3 dB bandwidth of ~113 nm, the data has been normalized to a spectrum recorded for a straight waveguide.

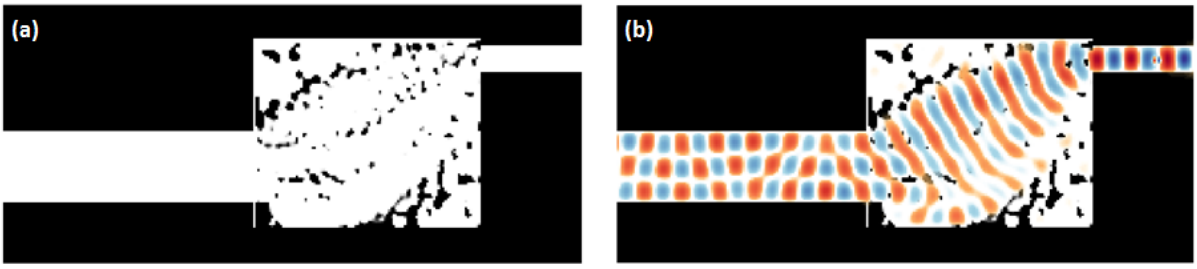

Figure 2 *The design obtained through 3D topology optimization of the structure shown in Figure 1 depicted in black (air) and white (silicon) (a) without and (b) with the 3D FDTD-calculated propagation of the H_z-field through the mode converter at 1580 nm.*

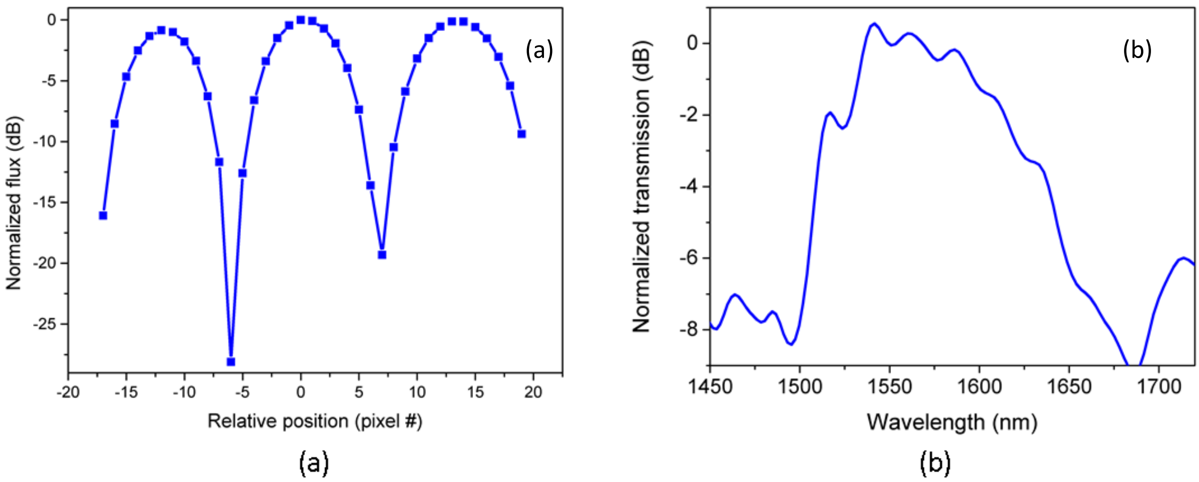

Figure 3 *(a) Power flux recorded at position A in Figure 1 when exciting a fundamental mode at position B, shown as a function of relative position across the waveguide with 0 nm corresponding to the center of the waveguide. (b) 3D FDTD-calculated transmission spectrum of the TE_0 mode obtained after conversion. The spectrum is normalized to that of a TE_0 mode in a straight waveguide.*

Previous work has demonstrated that 3D topology optimized designs are readily fabricated using e-beam revealing experimental results in correspondence with the simulated data [7]. Furthermore this design confirms that the method can, as previously claimed, be extended to function for higher order modes without significant increase in footprint or transmission losses.

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