Coupling Issues in Strongly Confined Nanophotonic Waveguides

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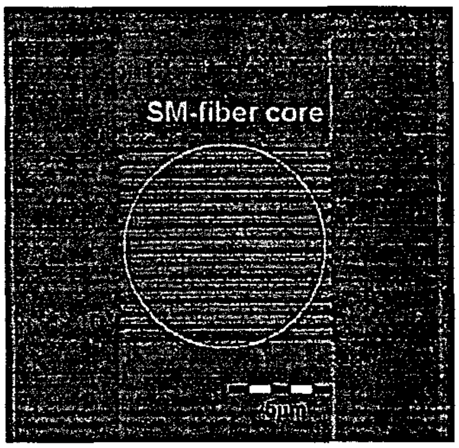
ABSTRACT
We present several devices to couple light efficiently into strongly confined nanophotonic waveguides (surface fibre coupler, compact spot-size converter). These devices are fabricated in SOI using deep-UV lithography.

INTRODUCTION
Although photonic crystals offer many tantalising device applications, their practical use in applications is fundamentally determined by the ease with which light is coupled into these devices. We will present a surface coupler to get light from a single mode fibre into a dielectric waveguide, as well as a compact spot-size converter to couple a broad waveguide to a photonic wire. These devices are fabricated in SOI using deep-UV lithography.

SURFACE COUPLER
The interface between a nanophotonic waveguide and a single-mode fiber is a major problem because of the huge difference in spot size. Some kind of spot-size converter is required to have efficient coupling. We have investigated the use of a compact grating coupler to couple light from/to a butt-coupled fiber, perpendicular to the surface of the chip. The coupler uses a so-called second order grating ($\Lambda=\lambda/n$), etched into a wide ridge waveguide. We have demonstrated a coupling efficiency of 15% from a single mode fibre to a SOI waveguide with a 50 nm bandwidth. Advantages of this grating coupler, compared to edge coupling, are the good alignment tolerances. Also there is no need to cleave or polish facets to couple light in and out, which allows wafer-scale testing. Disadvantages of the coupler are the polarisation dependence and the limited coupling efficiency. In theory, the coupling efficiency can be improved by using more complicated gratings, but these structures are much more sensitive to fabrication errors and therefore difficult to fabricate.



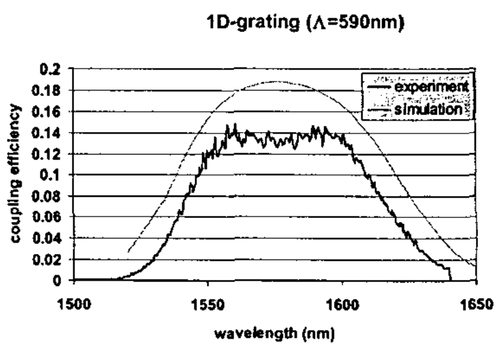


Figure 1. Top view of grating coupler. Wavelength dependence of coupling efficiency.

The wide waveguide can be connected to a narrow photonic crystal waveguide using a 200 µm long adiabatic taper, but more compact solutions can also be used, which we will describe now.

COMPACT SPOT-SIZE CONVERTER
Instead of adiabatically changing one mode profile into another, a more drastic scheme is studied. Between the two different waveguides a number of waveguide sections with random length and random width are placed. By changing the lengths and widths the mode-to-mode transmission is altered. We use an evolutionary optimisation algorithm to optimize the coupling efficiencies. An initial population is randomly composed, using constraints only based on technological and practical limits. For all members of this population the fundamental mode transmission is then calculated using 2D eigenmode expansion. The best individuals are then allowed to mate, meaning that length and width parameters are randomly exchanged between them and slightly altered, i.e. mutated. The offspring is calculated and added to the initial population. This process is repeated until a desired device performance is obtained.

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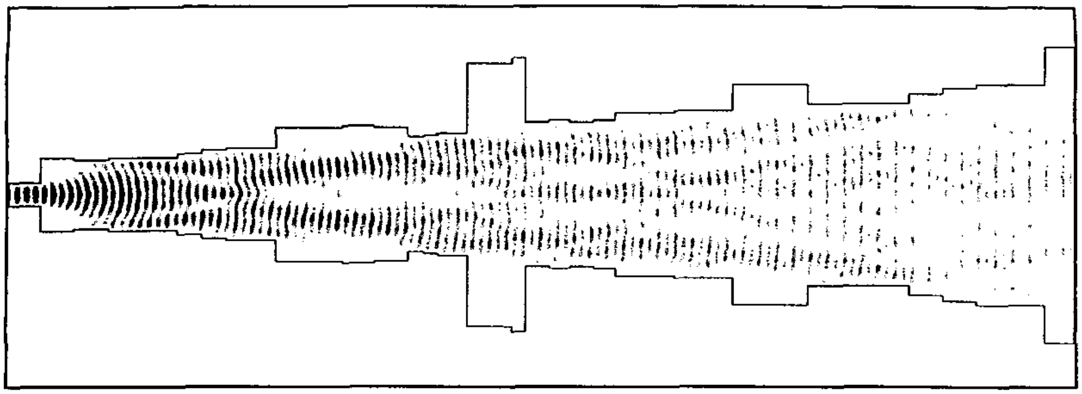

Fig. 2: Field plot (magnetic field) of compact spot-size converter. Input width = 1 μm, output width = 13 μm, total length = 33 μm.

Figure 2 shows a field plot of an optimised compact spot-size converter with a fundamental mode transmission of 94 %, calculated in 2D, using an effective index of 2.7945 (typical for a GaAs/AlOx stack), a wavelength of 1.56 μm and the polarisation such that the magnetic field is pointing out of the picture plane.

DEEP-UV LITHOGRAPHY IN SOI

A difficult aspect of photonic nanostructures is reliable fabrication. For research purposes, e-beam lithography is the method by choice. However, this serial writing technique is far too slow to be used for commercial application. On the other hand, optical lithography lacks the required resolution. Deep UV lithography, as used for advanced CMOS devices, is an optical lithography technique that uses wavelengths of 248 nm or less. Using the state-of-the-art clean room facilities at IMEC in Leuven, Belgium, we have studied the possibilities of deep UV lithography for the fabrication of photonic nanostructures, like photonic crystals and photonic wires. Because of compatibility with CMOS processes, the only viable material for optical structures is Silicon-on-Insulator (SOI). Figure 3 shows some structures fabricated with this technique. These experiments show that linewidths of less than 300 nm and dense lattices with holes down to 180nm can be made with an adequate process window to guarantee reproducibility. To solve the issue of sidewall roughness, which is often encountered where deep etching is involved, a number of techniques are under investigation.

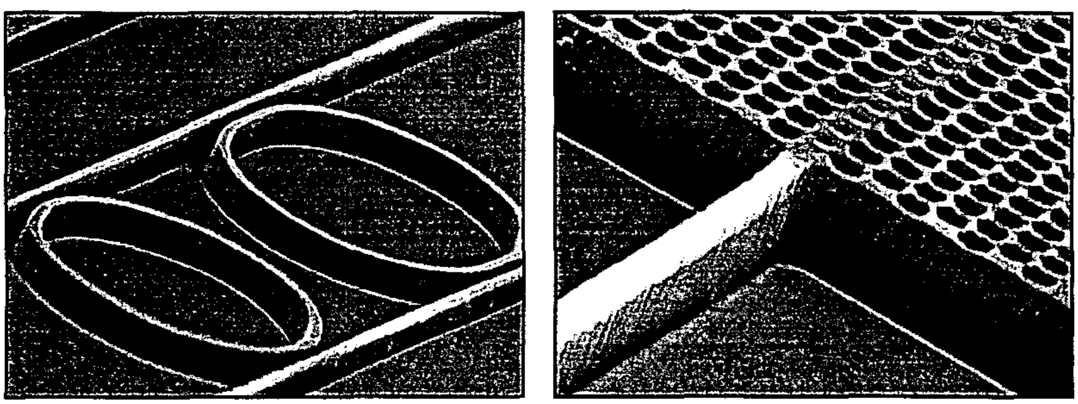

Fig. 3: Photonic nanostructures fabricated in SOI using deep UV lithography and deep RIE etching. Left: A double ring resonator; right: A photonic crystal waveguide.

REFERENCES

more information: http://photonics.intec.rug.ac.be.