An out-of-plane grating coupler for efficient butt-coupling between compact planar waveguides and single-mode fibres

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We have designed and fabricated an out-of-plane coupler for butt-coupling from fibre to compact planar waveguides. The main part of the coupler is a short second order grating or photonic crystal. The coupler is optimized using mode expansion based simulations. Simulations show that up to 74% coupling efficiency between single-mode fibre and a 240nm thick GaAs/Alox waveguide is possible. We have measured 19% coupling efficiency on first test structures.

Introduction

Ultra compact waveguides such as photonic crystal waveguides [1][2] or photonic wires are an interesting research topic because they may allow to make photonic IC's more compact and achieve a higher level of integration than today's PIC's. One of the problems to be solved is the interface between these compact waveguides and the outside world. Coupling to a standard single mode fibre using edge-coupling is a daunting task, because of the small dimensions of the waveguides, which are typically an order of magnitude smaller than conventional integrated optical waveguides. We propose the use of a grating coupler to butt-couple light from a single mode fibre, perpendicular to the surface, into planar waveguides, as shown in figure 1.

This coupling scheme allows dense integration and wafer scale testing because there is no need to cleave the devices to couple light in or out. For this coupling scheme to work two problems have to be solved. The light has to make a 90° turn from the fibre to the waveguide and a broad (approximately 10µm wide) waveguide has to be tapered into a small waveguide, preferably over a short distance. An adiabatic taper can be used as a horizontal spot-size convertor, but a more compact solution is preferred. In this work we have only considered the 90° bending issue.

Several grating couplers have been demonstrated that couple light out of or into [3][4][5] waveguides. These couplers achieve high efficiencies (>50%) but have a very narrow bandwidth and they use relatively long (>100µm), shallow gratings. In our design the grating is much shorter (approximately 10µm long) to be able to butt-couple to fibre. Therefore the grating has to provide strong coupling and has to be etched relatively deeply. This also means a rigorous electromagnetic method instead of perturbation theory is used to design these structures. To optimize the design, we used eigenmode expansion with perfectly matched layer boundaries [6]. The coupler is based on a so-called second order grating [7], where the first order diffraction is useful to couple out-of-plane. Simulation results show that 20% coupling efficiency can be achieved with a short second order grating. By adding a first order grating reflector behind the coupler grating this can be improved to 37%. With the addition of a DBR under the waveguide, the theoretical efficiency can be as high as 74%. The coupling efficiency to fibre versus wavelength for these structures is shown in fig. 2. Figure 3 is a schematic cross-section of the structure. All results are for TE polarisation. Details of the grating design are described elsewhere [8].

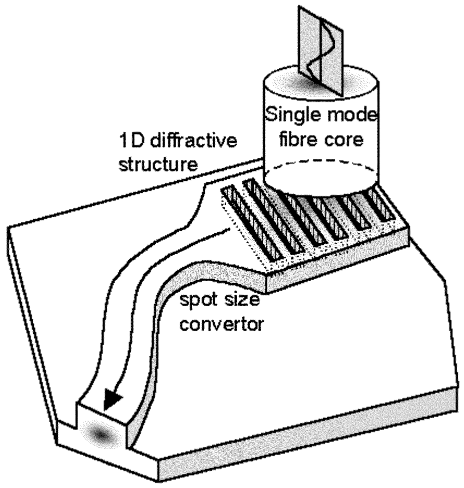


Figure 1: fibre coupler principle

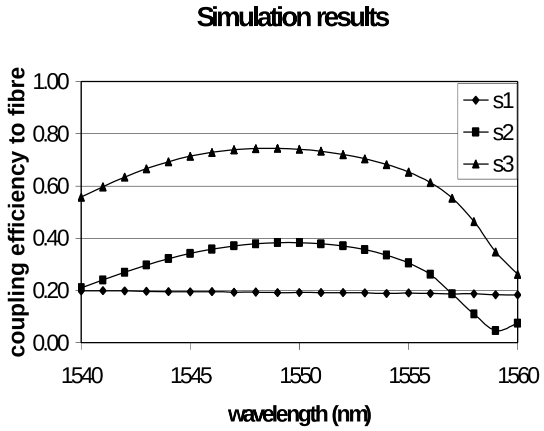


Figure 2 : simulation results

Experimental results

Devices were fabricated in AlGaAs-GaAs material grown by MOVPE on GaAs substrate. The waveguide layer structure consisted of a 240nm thick GaAs core with $\mathrm{Al_{0.94}Ga_{0.06}As}$ cladding and a 2 pair DBR under the waveguide (240nm GaAs core/290nm $\mathrm{Al_{0.94}Ga_{0.06}As}$ cladding/115nm GaAs/240nm $\mathrm{Al_{0.94}Ga_{0.06}As}$/ 115nm GaAs/240nm $\mathrm{Al_{0.94}Ga_{0.06}As}$). The gratings were fabricated using electron-beam lithography and reactive ion etching. Afterwards ridge waveguides were defined using optical lithography and etching. A last step was the etching of oxidation trenches and wet thermal oxidation of the AlGaAs layers to obtain an oxide cladding. We use GaAs/Alox because it has a similar refractive index contrast as silicon on insulator. SOI is a promising candidate for large-scale photonic IC's. A cross-section of the grating is shown in fig. 4.

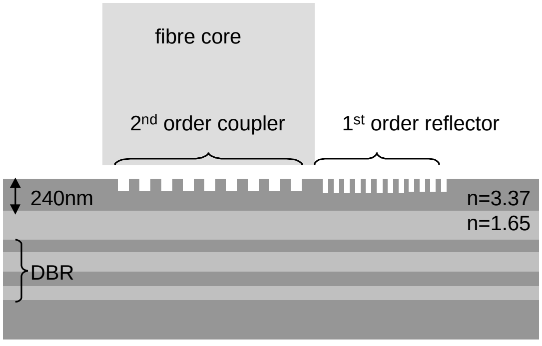


Figure 3: cross-section of the structure

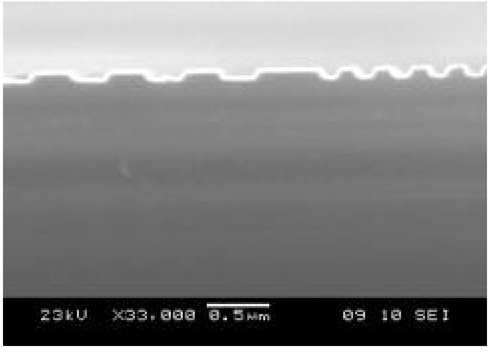
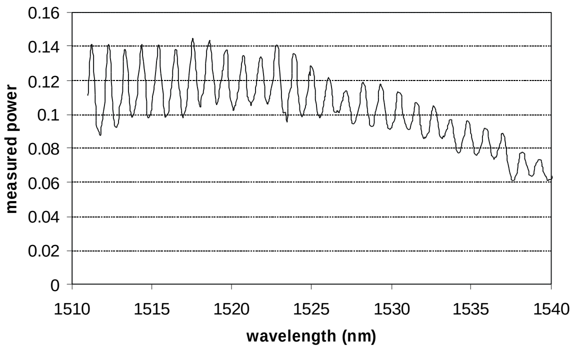


Figure 4 : SEM-picture of the grating

For the measurements we use a widely tunable laser source with 1mW output power and polarisation maintaining output fibre. The light is coupled from the pmf-fibre via the grating into the waveguides. The output light from a cleaved waveguide facet is imaged onto a detector or power meter. During inital alignment we use an IR-camera to monitor the waveguide spot. The output power, divided by input power, as a function of wavelength for a 10µm wide ridge waveguide is shown in fig. 5.



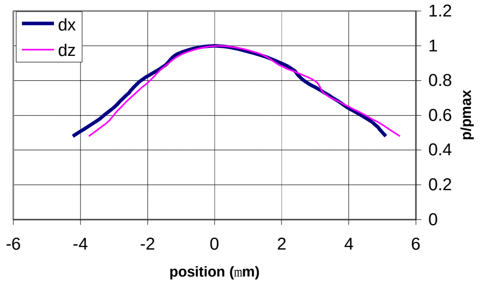


Figure 5: measurement result : P_{out}/P_{in} vs. wavelength

Figure 6 : alignment tolerances

We measure maximum efficiency in the 1510-1525nm range. (Unfortunately we are not able to meausure at shorter wavelengths because of the limitation of the tuning range of our laser). The peaks in the measurements are similar to Fabry-Perot fringes and are caused by a cavity formed by the grating and a cleaved facet. The spacing between the peaks depends on the cavity length (300µm in this case). To estimate the actual coupling efficiency from fibre to waveguide, we must take into account these cavity effects. When neglecting the waveguide propagation losses, the two parameters that determine the cavity are the facet reflection and the grating reflection. We have calculated the normalized transmission $P_{out}/(P_{in} * \text{efficiency})$ for a facet reflection of 0.36 and different grating reflections (fig. 7). The grating reflection can be estimated from P_{max}/P_{min} and the solid line from figure 7 fits to the measurements. With these values the FP-peaks are 75% of the power that would be measured without any reflection at the cleaved facet. Therefore we estimate the actual coupling efficiency to be 19% (=0.14/0.75).

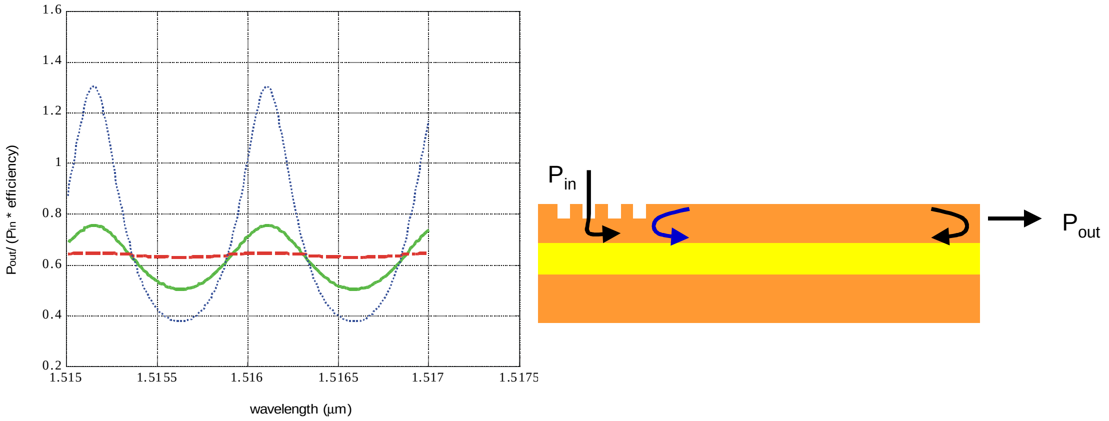


Figure 7: calculation of normalized cavity transmission for different grating reflections

The lateral alignment tolerances are shown in figure 7. For this measurement, we first aligned the fibre for maximum coupling efficiency and scanned the position of the fibre afterwards. The two curves are for fibre misalignment in one direction (dx for z=0 and dz for x=0, y is the fibre axis, x is parallel to the grating grooves).

Conclusion

We have demonstrated 19% coupling efficiency from a vertical single-mode fibre to a 240nm thick GaAs/Alox waveguide. This fibre coupler is a promising approach to solve the coupling problem to ultra-compact waveguides.

Acknowledgment

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