

A Compact Fiber-to-Waveguide Coupler Based on Angled Slots.

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Abstract We present a compact grating coupler, consisting of slanted air slots, for coupling from single-mode fiber to InP-based waveguides. The theoretical coupling efficiency is better than 50% and first fabrication experiments are promising.

Introduction

For optical communication, efficient and compact coupling between fiber (the outside world) and chip is very important. However, the large deviation in dimensions between a fiber mode (typical diameter around $10\ \mu\text{m}$) and an optical waveguide mode (submicron dimensions), causes large coupling losses and high packaging cost. Several taper-based solutions have been proposed for this problem [1,2]. Coupling losses of the order of 1.5 dB have been reported, but these solutions typically need long tapers (more than $500\ \mu\text{m}$). Here, we propose to make use of grating couplers to couple vertically from fiber to waveguide. This approach has some advantages as compared to edge coupling. Devices can be tested at wafer level and no AR-coatings are needed on the chip facets. Recently, Taillaert demonstrated compact and efficient rectangular grating couplers, but they work only for high vertical index-contrast waveguides (e.g. SOI) [3]. In [4] the use of a compact slanted grating coupler for coupling to SiON waveguides was proposed and theoretically investigated. In that case, the grating is etched through the cladding and filled with a higher index material. In this paper, we describe the design and fabrication of compact ($10\ \mu\text{m}$ long) slanted grating couplers for coupling from fiber to low vertical index-contrast InP-based waveguides.

Principle

The principle of the slanted coupler is sketched in Fig. 1. In a waveguide, narrow air slots are etched at an angle of 45 degrees, completely through the core. The incident light reflects upwards at the interface with air. If the slots are narrow enough, some light can tunnel through the slot and reach a second slot, where again it gets partly reflected and partly transmitted, A fiber is positioned vertically above the grating. The better the outcoupled field profile matches the fiber mode, the higher the coupling efficiency.

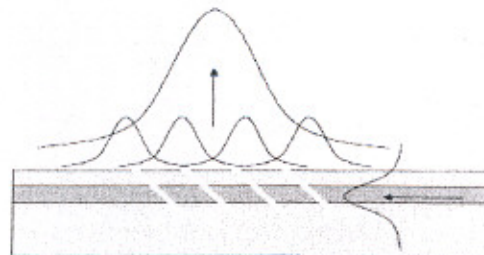


Fig. 1. Principle of the slanted grating coupler.

Design of a slanted grating coupler

An important parameter in the design is the width of the air slots. This choice also depends on the number of slots. When the slots are too wide, there will be little transmission, and almost all the light will be coupled out by the first slot, resulting in a poor overlap with the fiber mode. When the slots are too narrow, most of the light will tunnel through the slot, and little light will be reflected upwards. A 2D-simulation of the influence of the width of a single slot on the transmitted power and the power coupled upwards is shown in Fig. 2. The slab waveguide has a 522 nm thick InGaAsP ($\lambda_g=1.22\ \mu\text{m}$) core and InP-claddings. All calculations are done in CAMFR (an eigenmode expansion tool) for TE-polarisation. The wavelength was $\lambda=1550\ \text{nm}$.

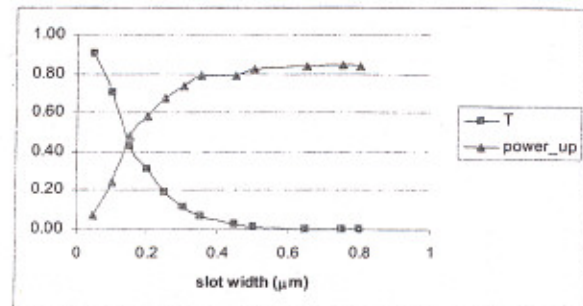


Fig. 2. Influence of the slot width (air) on transmission and outcoupled power (power_up) for a single slot.

Third order slanted grating coupler

In a first design we use 5 slots, which do not overlap. The first 4 slots are 100 nm wide. To couple all the remaining light upwards, the last slot is 700 nm wide. The period is 1.51 μm and has been optimised to obtain a phase front propagating in vertical direction. An AR-coating is needed to avoid reflection at the InP-air interface. The field distribution calculated for this structure is shown in Fig. 3. The fiber coupling efficiency is calculated by multiplying the outcoupled power with the overlap integral between de outcoupled field distribution and the fiber mode (beam-diameter of 10.4 μm). The calculated coupling efficiency to a (SM)-fiber positioned at 1 μm above the grating is 50%. This coupling efficiency can be further increased by individually optimising the width of each slot and the spacing in between them. In this way we can correct for phase mismatches and the upwards coupled field distribution can better approximate the Gaussian profile of the fiber mode, resulting in a better overlap [5].

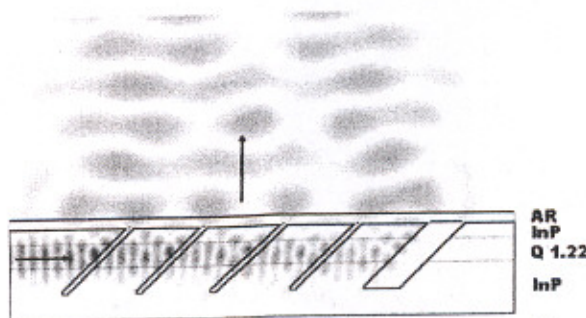


Fig. 3. Field distribution of a slanted grating coupler.

First order slanted grating coupler

We can also design a slanted grating coupler with overlapping air slots. In this case, the period is smaller and more periods are needed to match the dimensions of the fiber core. This implies that the slots should be narrower than the design with only five periods. Narrow angled slots are difficult to fabricate, so we choose 50 nm slots as a lower bound. The optimised structure has 20 periods (period = 0.49 μm), resulting in a coupling efficiency to fiber of 53%. The field distribution of this structure is shown in Fig. 4.

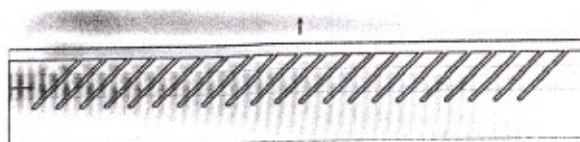


Fig. 4. Field distribution of a first order slanted grating coupler.

Fabrication

We have done first experiments on fabricating slanted grating couplers. The used layer structure is a 522 nm thick InGaAsP ($\lambda_g = 1.22 \mu\text{m}$) waveguide core and a

300 nm InP-topcladding on an InP-substrate. A 300 nm PECVD-deposited SiO_2 layer was used as a hard mask. The structures were defined by e-beam lithography and transferred to the SiO_2 hard mask. Finally the structure was etched at an angle into the epistructure by means of CAIBE (Chemically Assisted Ion Beam Etching). Fig. 5 shows a SEM picture of a fabricated structure.

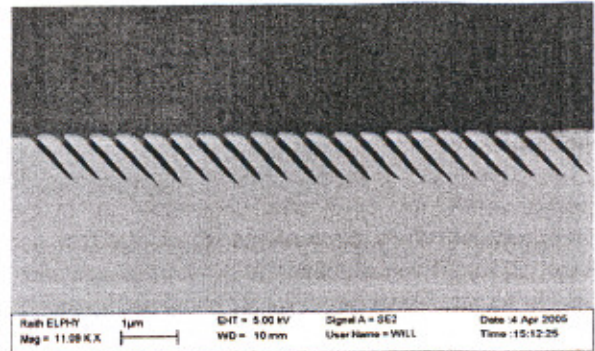


Fig. 5. Cross-section of a first order slanted coupler.

Conclusions

We have presented the design of a compact coupler for coupling to low vertical index-contrast InP-waveguides. We use narrow air slots etched at an angle of 45 degrees. The theoretical coupling efficiency to fiber is about 50% (with an AR-coating), and can be increased by further optimisation of the individual slot widths and position. First experiments on fabricating slanted grating couplers showed to be very promising. We plan to have measurement results on coupling efficiencies in the near future.

Acknowledgements

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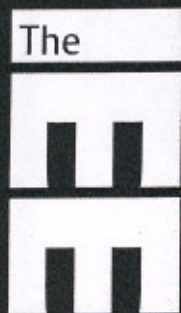
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