Compact and Highly Efficient Grating Couplers Between Optical Fiber and Nanophotonic Waveguides in Bonded InP-membranes

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Abstract We present compact and highly efficient grating couplers in bonded InP-membranes for coupling between single-mode optical fiber and nanophotonic waveguides. We have measured 56% coupling efficiency on grating couplers extended with a gold bottom mirror.

Introduction

Nanophotonic waveguides and components are the route towards large scale integration of photonic circuits. However, coupling light between single-mode fiber and nanophotonic waveguides remains an important problem. Key features of an effective solution to this coupling problem are low insertion loss, broadband operation, relaxed tolerances to fabrication and alignment. These requirements can be met by using an inverse taper [1]. This approach however does not allow for wafer-scale testing. We use grating couplers for coupling light out-of-plane from standard single-mode fiber to thin-film waveguides. In this approach, there is no need for cleaved facets and light can be coupled in and out everywhere on the chip, opening the prospect of wafer-scale testing. The grating is followed by an in-plane taper to couple to single-mode nanophotonic waveguides. The principle is shown in Fig. 1.

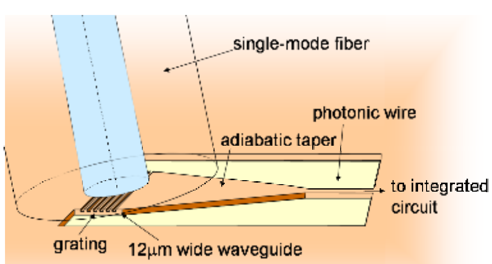

Fig. 1. Coupling principle for out-of-plane coupling between single-mode fiber and photonic wires.

When using a high refractive index contrast, these gratings can be very compact and relatively broadband. A coupling efficiency of 33% from fiber to waveguide was measured for 10x10 μm^2 grating couplers in SOI [2]. The 1 dB bandwidth is 40 nm and the alignment tolerances are relaxed (2 μm for 1 dB excess loss). A 2D-grating version can be used for getting polarization independence through polarization diversity [3]. The coupling efficiency to fiber is limited by radiation towards the substrate however. In [4], we avoid this by adding a bottom mirror to existing SOI-grating couplers and the measured coupling efficiency increases to 69%. However, SOI is not very well suited for implementing active functionality. Therefore, we have transferred the principle to InP-based material. We apply wafer bonding for achieving high vertical index contrast membranes, which are important for ultra compact photonic circuits (e.g. high-Q microcavities). In [5], we have demonstrated 30% coupling efficiency between single-mode fiber and waveguides in BCB-bonded InP-membranes using grating couplers. In this paper, we report on the improvement of these InP-membrane grating couplers by adding a bottom mirror. The measured coupling efficiency increases to 56%.

High vertical index contrast by wafer bonding

We focus on adhesive bonding, using an intermediate low-index BenzoCycloButene (BCB)-layer (a spin-on polymer). The bonding procedure is shown in Fig. 2.

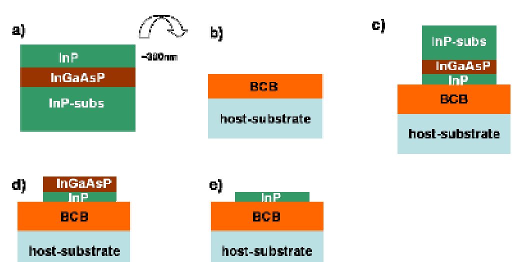

Fig.2. BCB-bonding procedure.

We start from an InP-based layer structure with an InP-substrate, an InGaAsP etch-stop layer and an InP-membrane layer. This structure is bonded by means of BCB onto a host-substrate. Afterwards, the original InP-substrate is removed, and finally the etch-stop layer is removed.

Design

The couplers are designed with CAMFR [6] for TE-polarization. The design method is described in detail in [7]. We use near vertical coupling at 10 degrees in order to avoid second order reflection. A gold bottom mirror is added to the structure to avoid radiation towards the substrate. The period of the optimised grating is 660 nm, the etch depth is 70 nm and the duty cycle 50%. The thickness of the BCB bonding layer is optimised in order to achieve constructive interference between the directly upwards radiated wave and the reflected wave at the bottom mirror. The reflected wave also interacts with the grating and the BCB-layer thickness influences the coupling length of the grating. The maximum coupling efficiency as a function of BCB-thickness is shown in Fig. 3. The optimal thickness is 1.23 μm and the maximum coupling efficiency is 78%. A field plot of the optimal structure is shown in Fig 4.

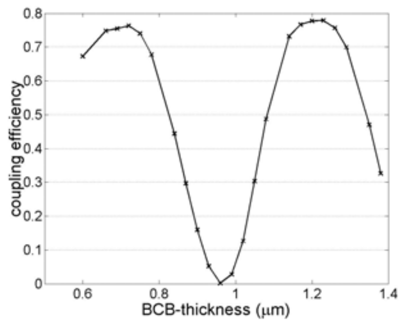

Fig. 3. Maximum coupling efficiency as a function of BCB-thickness.

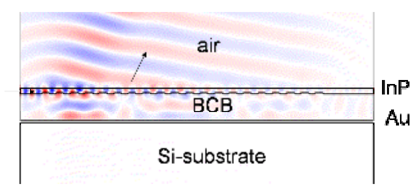

Fig. 4. Field plot of the optimal structure.

Fabrication

The layer structure consists of an InP-substrate, a Q1.22 etch-stop layer and a 300 nm InP-membrane layer. First, the gratings and waveguides are defined by e-beam lithography using PMMA, and transferred to a SiO_2 hard-mask by Reactive Ion Etching (RIE). The structures are etched to a targeted depth of 70 nm into the InP-heterostructure by Inductive Coupled Plasma (ICP) etching. This structure is then bonded using BCB onto a gold coated Si-substrate, with the grating at the bottom side. The BCB-layer thickness is targeted to 1.23 μm. The BCB is cured for 1 hour at 250 degrees in a nitrogen environment. Afterwards, the substrate is removed using lapping and wet etching. Finally the etch-stop layer is removed by wet etching.

Measurements

The coupling efficiency is determined from a fiber-to-fiber transmission measurement for TE-polarization. The structure consists of an input coupler, a 12 μm wide waveguide and an output coupler. We assume that input and output coupler are the same. By characterizing losses in our setup, we calculate the coupling efficiency to fiber from the transmission efficiency. The measurement result is shown in Fig. 5, together with the simulated curve. The measured coupling efficiency is 56% and the 1dB bandwidth is around 45 nm. The deviation between theory and experiment is caused by a deviation in theoretical and fabricated structure (etch depth, filling factor, BCB-thickness).

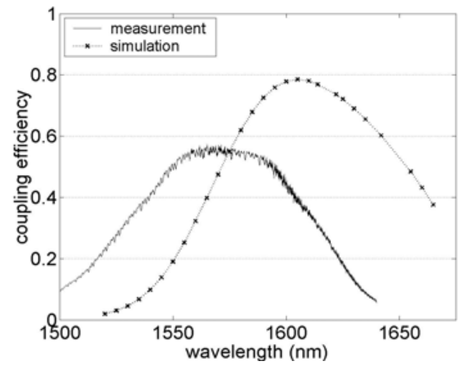

Fig.5. Measured and simulated coupling efficiency.

Conclusions

We have designed and fabricated compact and highly efficient grating couplers between single mode fiber and waveguides in BCB-bonded InP-membranes. A gold bottom mirror is used to increase the coupling efficiency to a measured value of 56%. Apodising the grating can increase the coupling efficiency further to a theoretical value over 90% [6].

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