Fabrication and characterization of a wet-etched InP-based vertical coupling mirror

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In this work we describe the fabrication and characterization of couplers realized with a wet etching process that is compatible with the standard COBRA active-passive process. The implementation of this broadband structure allows for wafer-scale waveguide-loss and absolute-wavelength measurements.

Introduction

Recent developments in large-scale production of photonic integrated circuits (PICs) require the use of process control modules (PCMs) that allow the foundries to monitor and guarantee the quality of their fabrication process and increase the production yield [1]. One particularly interesting component is a vertical input/output coupler for optical signals. The realization of this type of structure would allow on-wafer characterization of the properties of individual building blocks, before cleaving and separating each individual PIC from the wafer. In particular it would allow the study of the spectral performance of the devices. One approach to achieve vertical coupling is through grating couplers which are widely used in Si membrane technologies [2]. However, in standard InP technology, this approach cannot be used because the transversal index contrast is not large enough for making efficient couplers. In previous works, efficient vertical couplers have been successfully realized by us in a standard InP layer stack using a Focused Ion Beam milling technique. However, this method has the drawback of not being well-suited for large-scale wafer processing [3].

In this work we report on the fabrication and characterization of a new type of vertical coupler. To realize this coupler, a wet-etching process alongside with etched-facet waveguides was developed. This process is compatible with the full-wafer standard active-passive integration that is used by COBRA. However, fabrication of the structures may be compatible with other processes, such as the ones of Oclaro and the Heinrich-Hertz institute.

Device fabrication

Typically, waveguide endings in InP technology are at the cleaved facets of a chip. Here we take a different approach, where the end of the waveguides is etched with a vertical etch. This has a number of advantages. Firstly it is now possible to end the waveguide at an angle to reduce the backreflections, while at the same time this ending can be designed such that the light exits the chip perpendicular to the edge of the chip, thus enabling coupling, for example, to a fiber array. The second advantage is that the waveguide end is on the wafer and thus accessible for characterization before cleaving or dicing out the individual chips. To improve the (vertical) in and out-coupling, these waveguides were fabricated in a spot-size converter layer-stack for achieving larger alignment tolerance and better mode profile matching between the waveguide and the optical fiber. The fundamental mode in such a waveguide has a diameter around 3µm. InP has a crystallographic plane at an angle of 55^o with respect to the (001) surface [4]. By anisotropic etching the InP in this plane a mirror will be formed that allows the light coming from a waveguide to be reflected into the vertical direction. This mirror should be positioned in front of the waveguide. The reflectivity of this mirror is calculated to be around 32% for TE and 21 % for TM polarization. That is sufficient for accurate on-wafer measurements. A high-reflection coating can be applied to the angled mirror, should a higher reflectivity be required.

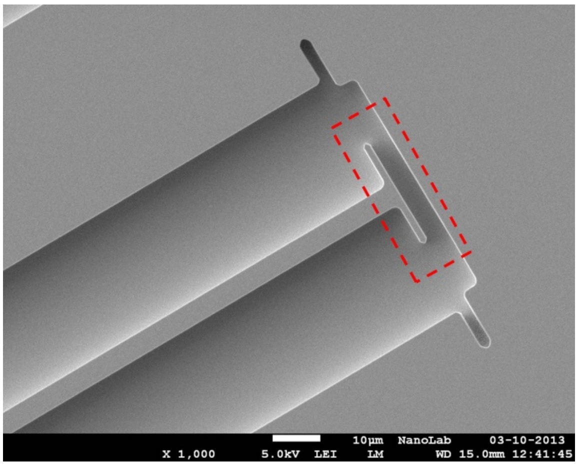


Fig. 1 – SEM picture showing the etched facet indicating the special structure for preventing diffraction rounding.

The fabrication process has two main steps, the first one is the etching of both the waveguides and the waveguide endings ("etched facets") and second, the processing of the angled mirrors for vertical out-coupling. It is important to have a very high quality of the etched facet, to prevent scattering and to ensure a proper beam shape. For this reason the end of the waveguide was widened over a short distance, in order to avoid rounding of the waveguide due to diffraction effects during the lithography of the waveguides. The widened waveguide end consists of a 2 µm long, 25 µm wide bar is included at the end of the waveguide so that possible rounding of the corners of this structure do not affect the central part of the waveguide where the light exits (Fig. 1). These waveguides and facets were processed using a chlorine-based ICP etching.

A resume of the process flow for the fabrication of the angled mirrors is schematized in Fig. 2. First, SiN_x is deposited using PECVD over the SSC waveguides with etched facets (Fig 2 (a)). The thin SiN_x is used as hard mask for the wet-etching process (Fig 2 (b)). Then, after the lithography using AZ-4533 photoresist due to the profile of the device, the SiN_x hard-mask is opened. Once the hard mask is opened, the realization of the mirrors was done by wet-etching using Br_2:methanol (Fig 2 (c)). This wet-etching process forms a V-groove shape at the edge of the facet. When the chips are cleaved out of the wafer, these V-grooves will also allow for precision cleaving of the PIC devices, leaving the etched facets as the normal out-coupling waveguides.

After fabrication of the waveguides and the angled mirrors, a scanning electron microscopy inspection was made of the coupler structure (Fig. 3).

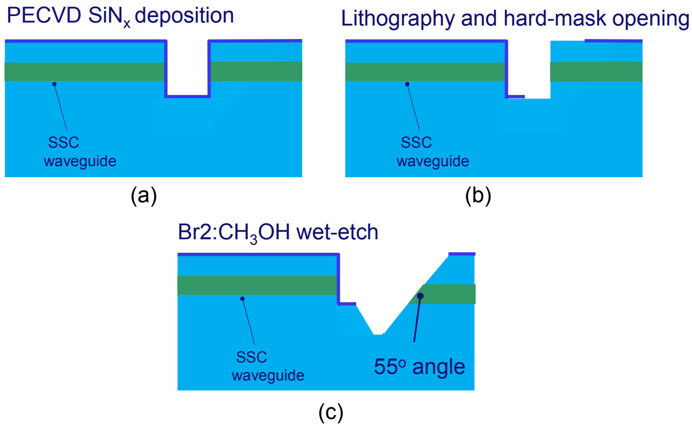


Fig. 2 Schematic of the process flow used to fabricate the vertical couplers: (a) PECVD depositions of SiN$_x$; (b) Lithography and hard-mask opening and (c) wet-etch for the mirror processing.

As can be seen in this figure, the surface of the mirror is smooth. For this particular device, the waveguides have a separation pitch of 25 μm and the mirror is separated 10 μm from the etched facets.

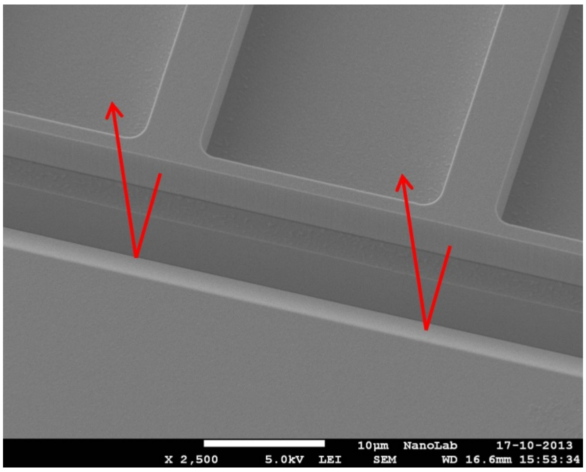


Fig. 3 – SEM picture of the vertical out coupling mirrors. The arrows indicate the light path out of the device.

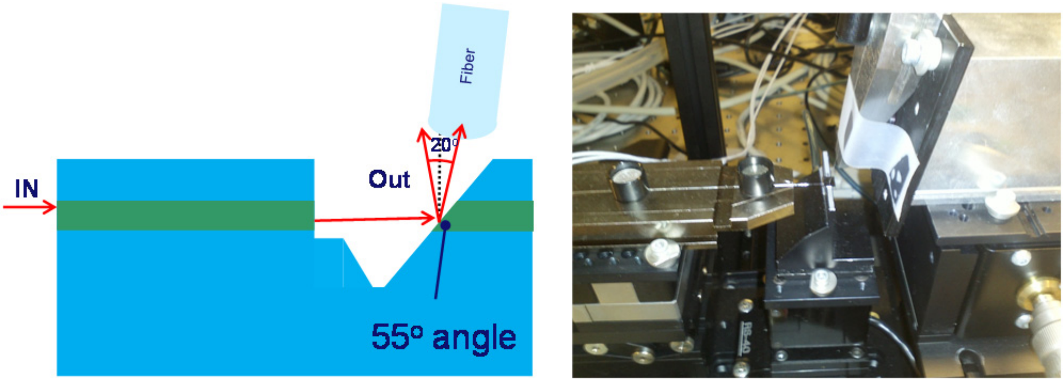
Experimental characterization

To characterize the performance of vertical coupler, first we measured the propagation losses of the waveguides. For that we used the Fabry-Perot method which has the advantage to be independent from the input and output coupling to the waveguide [4]. The losses can be determined with the following expression:

$$\alpha = -\frac{1}{L}\ln\left[\frac{1}{\sqrt{R_1 R_2}}\frac{\sqrt{C_R}-1}{\sqrt{C_R}+1}\right] \quad (1)$$

Where L is the length of the waveguides, R_1 and R_2 are the reflectivities for each one of the facets and C_R is the amplitude of the measured fringes. The facet reflectivity for this waveguide geometry is calculated to be 0.25. From the measurement over a set of 1.1 cm long waveguides, the losses were found to be 2.0 dB/cm.

To measure the coupling loss between the fiber and the vertical structure, the setup scheme described in figure 4 was used. The input light enters thru the etched facet and the output is collected by a fiber positioned vertically. As shown in Fig. 4 (a), the angle at which the fiber is positioned has not been optimized yet, due to experimental setup constrains, and could deviate by as much as 20°. Under these conditions, the coupling efficiency was measured to be approximately -20 dB. However, this non-optimized coupling, still allowed us to determine the reflectivity of the etched facets. By using the same method as described by equation (1) and using the measured propagation loss of the waveguides, the reflectivity of the etched facet was measured to be 0.25, equal to the calculated value for a perfect mirror. This indicates that the etched facets were smooth and vertical.



(a) (b)

Fig. 4 – (a) Schematic of the measurement setup used to characterize the vertical coupler and (b) photograph of the setup.

Conclusions

In this work, we report on the successful fabrication and characterization of a vertical outcoupling structure. The structure was realized by wet-etching an angled mirror in front of an expanded-beam waveguide with etched facets. From the measurements we were able to determine the reflectivity of the etched facets using the vertical coupler structure.

Acknowledgments

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