Fabrication and characterization of etched facets in InP for advanced packaging of Photonic Integrated circuits

Fabrication and characterization of etched facets in InP for advanced packaging of Photonic Integrated circuits

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In this work we describe the fabrication and characterization of straight and angled etched facets compatible with the standard COBRA active-passive process. The implementation of these structures enables advanced packaging of photonic integrated circuits with multiple optical inputs and outputs.

Introduction

The increasing complexity of photonic integrated circuits (PIC) in terms of functionality, number optical inputs and outputs and electrical contacts imposes a challenge in terms of their packaging [1]. In particular, for a PIC with multiple optical inputs/outputs with cleaved angled facets that needs to be coupled to a fiber array unit there is no practical solution available at the moment.

Angled facets are required as optical inputs/outputs when the PICs are sensitive to the back-reflections that occur in the interface between InP and air. This can be the case for on-chip lasers such as DBR lasers or ring-lasers, where a small reflection at the semiconductor air interface may degrade their performance significantly. Additionally, in these facets, an anti-reflection coating can be applied to further decrease the reflections.

Typically, the facets of a PIC are obtained by cleaving the wafer through the InP crystallographic planes. This process produces atomically flat facets. To have angled facets, the waveguides are designed and fabricated with an angle with respect to the cleaving planes. This angle is chosen such that, for the mode refractive index of the specific waveguide, the reflection coefficient is minimized [2]. In the COBRA active-passive process this angle is 7°. Due to refraction, the light exits the waveguide into air with an angle of 23°, as shown in figure 1a.

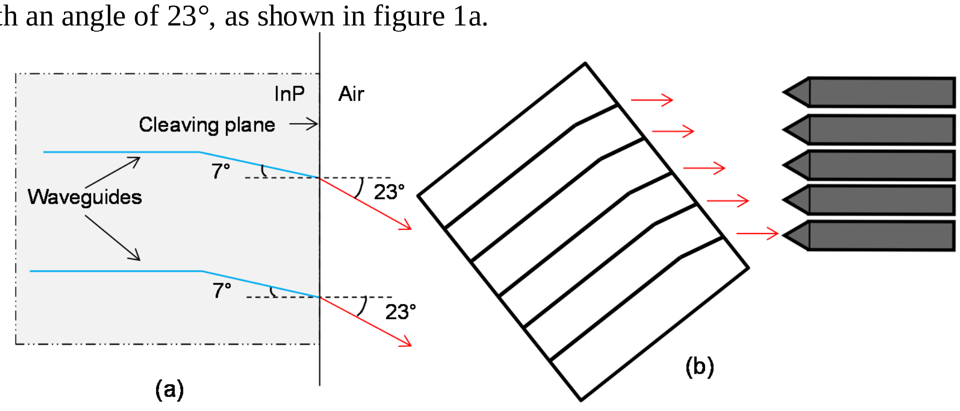

Fig. 1 – (a) Schematic of the output of the light from angled facets; and (b) the relative angle between the PIC and a fiber array.

Having a PIC with multiple angled-facet inputs and outputs presents a major challenge for coupling to a standard Fiber Array Unit (FAU). As shown in Fig 1b, the PIC and the FAU must be rotated with respect to each other so that both optical axes are aligned. But, this implies an increasing variation in the distance between the two devices which would significantly degrade the coupling efficiency.
In this work we present the fabrication and characterization of etched facets which allow perpendicular emission with respect to the cleaving plane which enables the packaging of PICs with multiple angled or straight waveguides with fiber array units.

Design and fabrication

To obtain an output with an angled facet that is perpendicular to the cleaving plane (Fig.1a), a new structure has been designed. The schematic of this structure is shown in Fig. 2a. The output waveguides were rotated by 16° and at the end of of these waveguides, the facet was positioned with an angle of 83° with respect to the optical propagation axis. The result is a waveguide angled at 7° with the etched facet and angled at 23° with the cleaving plane. In Fig. 2b a detail of the mask design used to fabricate the etched facets is shown. The waveguides are positioned at an angle of 16° and were fabricated in a spot-size converter layer-stack for achieving larger alignment tolerance and better mode profile matching between the waveguide and the FAU. The fundamental mode in such a waveguide has a diameter around 3µm.
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, at the end of the waveguide a T-bar was added, in order to avoid rounding of the waveguide due to diffraction effects during the lithography of the waveguides.

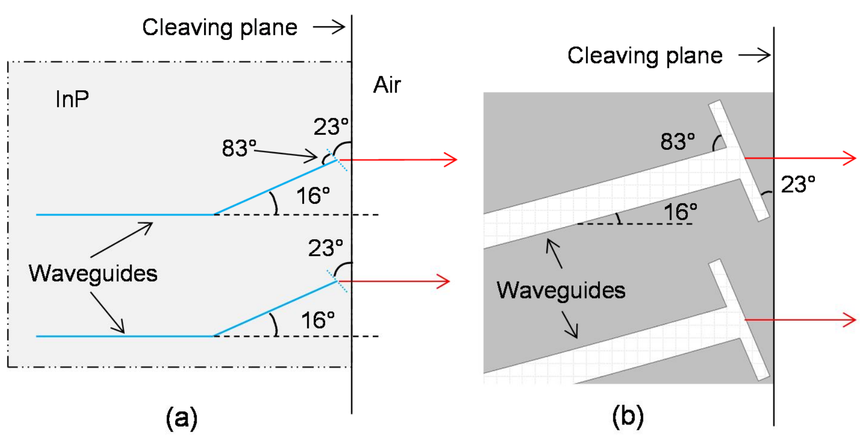

Fig. 2 – (a) Schematic of the position of the waveguides and facets for perpendicular emission respect to the cleave plane and (b) detail of the mask design of the etched angled facets.

The T-bar end consists of a 2 εm long, 15 εm wide section, Fig. 2b. Also very important is the verticality of the etching process. The waveguides and facets were fabricated simultaneously using a chlorine-based ICP etching [3] that was optimized for smooth etching of vertical waveguides.
In Fig. 3, a SEM photograph of the fabricated structures is shown. The surface of the facet is smooth and the walls are vertical. The etch depth of the waveguides and facets

is approximately 5 µm. After the etching of the waveguides, the next step in the process was to fabricate a V-groove in front of the facets that allows precision cleaving of the InP chip [4]. This aspect is fundamental for the packaging of the PICs since the facet needs to be as close as possible to the edge of the chip to allow for optimum coupling between the FAU and the PIC.

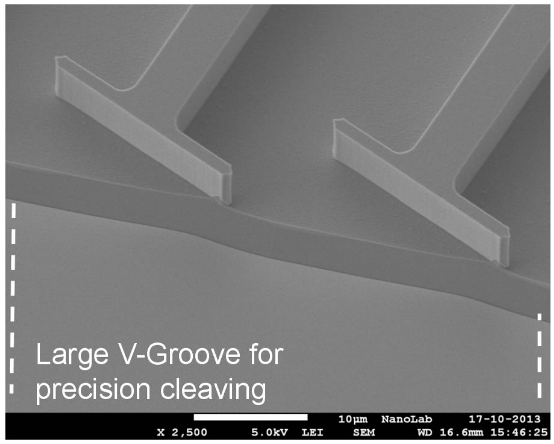

Fig. 3 – SEM photograph of the fabricated angled etched facets with a wet-etched V-groove for precision cleaving.

Experimental characterization

In order to characterize the verticality and smoothness of the etched facets, a set of test structures with straight etched facets were also fabricated in the same chip. The test structures consisted of a set of waveguides with cleaved facets on one side and either etched or cleaved facets on the other. With a Fabry-Perot method [5], we evaluated the quality of the etching from the contrast of interference fringes obtained from the transmission spectra of cleaved/etched waveguides and by comparing them to the results obtained from cleaved/cleaved waveguides.

In Fig. 4a we show the transmission spectrum of two waveguides. The solid line trace refers to the etched/cleaved facet waveguide and the dashed one to the waveguide with both cleaved facets. As we can see, the contrast of both curves is almost the same indicating that the reflectivity of the etched facet is the same for etched and cleaved facets. This shows a good quality in the etching process both in terms of the verticality and smoothness.

The other key aspect in the characterization is the angle of emission of the angled etched facet waveguides with respect to the cleaving plane. To measure it, the far field of the etched angled facet waveguide was measured and compared to that of a reference waveguide with a cleaved facet. These measurements are shown in Fig. 4b. As can be observed, both facets show the same divergence angle but a small deviation in the emission angle of about 2° between them. This deviation is of the same magnitude as the estimated measurement accuracy.

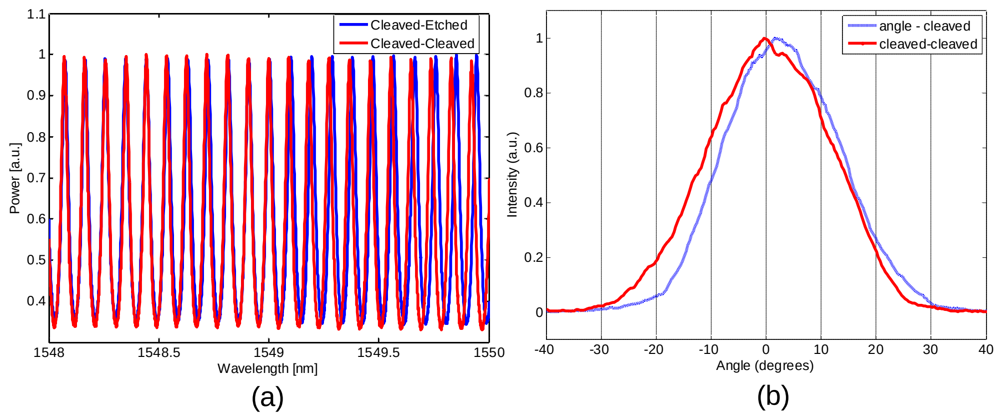

Fig. 4 – (a) Transmission spectrum of cleaved/cleaved (dashed) and cleaved/etched (solid) waveguides and (b) far field profile of cleaved/cleaved (red) and waveguides

Conclusions

In this work, we report on the successful fabrication and characterization of etched facet waveguides. These structures were realized by ICP etching in a single etch step. With this technique we are able to fabricate angled facet waveguides that emit light perpendicular to the cleaved plane of InP chips. The experimental characterization shows smooth and vertical waveguide facets with comparable performance for the etched-facet waveguides and the cleaved-facet waveguides.

Acknowledgments

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