Fabrication and characterization of an InP-based vertical coupling mirror

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In this work the fabrication and characterization of a vertical coupler is described. Such a vertical coupler can be used in a process control module for assessing the quality of the fabrication process of photonic integrated circuits early in the process. In addition, they can be employed for on-wafer probing of optical signals, which enables characterization of optical devices before cleaving or dicing of the wafer.

Introduction

The development of process control modules (PCMs) is important in large-scale production of photonic integrated circuits (PICs) [1]. They allow the foundries to monitor and guarantee the quality of the fabrication process and increase the production yield. With these PCMs the foundries can ensure proper operation of each of the building blocks with which the PICs are designed, regardless of the application. This type of structure should be realized early in the fabrication process for evaluation of the process quality. One particularly interesting component is a vertical input/output coupler for optical signals. The development of this type of structure would allow on-wafer characterization, before cleaving and separating each individual PIC, and accurately characterize the properties of individual building blocks. In particular it would allow the study of their spectral performance.

In this work the fabrication and characterization of such a coupler is described. In this work the vertical coupler was fabricated with a focused ion beam (FIB) at the output of an extended cavity laser. This way, a horizontal cavity surface emitting laser (HCSEL) is realized. The analysis of the HCSEL laser properties allows the characterization of the performance of the coupler.

Device Fabrication

The vertical mirror was realized in an extended cavity laser (ECL). The total length of the device is 4 mm and the gain section is 800 µm as can be seen in the top part of Fig. 1. The laser is then formed by a short deeply etched waveguide connected to a shallow-deep transition, a shallow-etched gain section, another shallow deep transition and a large deep waveguide. The cavity is achieved by the reflection given by the cleaved facets.

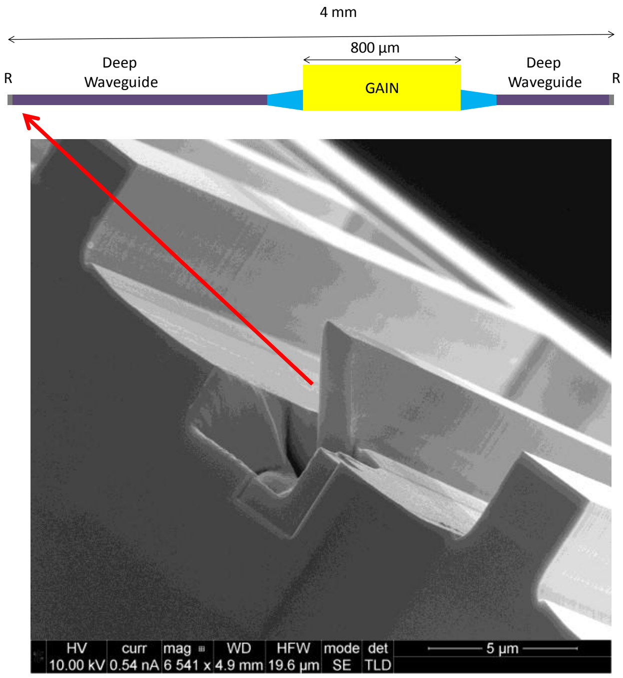

Fig. 1 – Schematic of the extended cavity laser (top) and SEM picture of the 45° mirror fabricated.

In this work, the fabrication of the 45° mirror was done by milling one of the outputs of the ECL with a Focused Ion Beam (FIB) (Fig. 1- bottom). To optimize the quality of the mirror, the milling was done in two steps. For the first etching step a current of 0.28 nA was used, then to smooth the mirror's surface the ion beam current was set to 28 pA and a line scan performed. The depth of the etching was set to be 7 µm, to guarantee total internal reflection. The total time to perform this etching was around 30 min. For wafer scale processing, the FIB etching technique is not the most suitable since only one vertical coupler can be processed at the time. In a wafer scale production, this structure can be realized with chemical assisted ion beam etching (CAIBE) and in [2].

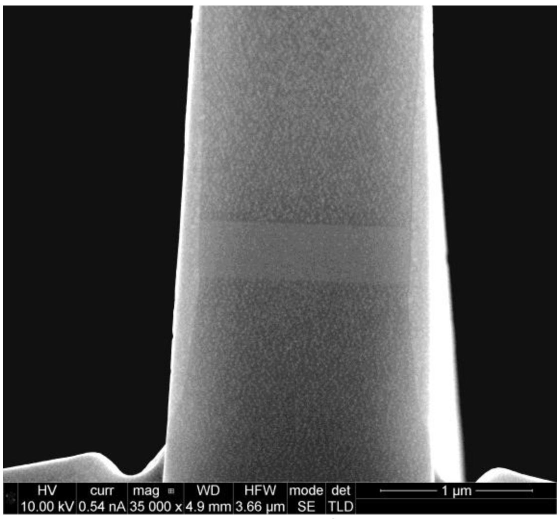

Fig. 2 – Detail of the 45° mirror facet.

From the SEM picture, the quality of the etching is analysed and, as can be seen in Fig. 2, the surface presents negligible roughness.
The new cavity of the laser is now formed by the reflection of the top section of the waveguide (Fig.3). The overall efficiency of the 45^{o} mirror is highly dependent on the misalignment during the FIB etching process. Also in Fig. 3, it can be seen that a deviation α from the 45^{o} angle, has big effect on the efficiency of the coupler since the misalignment angle β is multiplied by 4 times when the light couples back into the waveguide. Following this, the characterization made in the next section takes into account this effect and the efficiency is defined as the effective reflectivity.

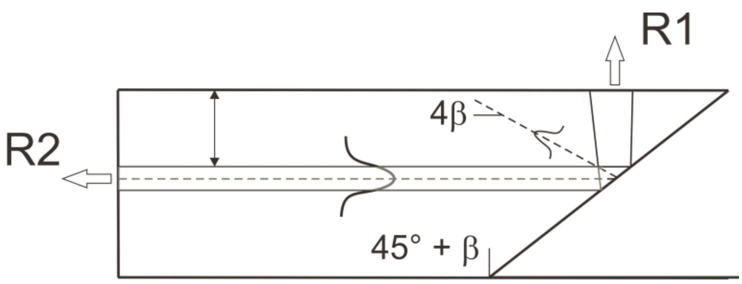

Fig. 3 – Schematic of the vertical coupler output.

Experimental characterization

To characterize the efficiency of vertical coupler, an analysis of the laser with vertical coupler was made and compared with the characteristics of an extended cavity laser (ECL) laser with the same dimensions and gain characteristics but where the cavity is formed by cleaved facet mirrors. In Fig. 4 the obtained I-P characteristics of each one of the devices is presented. These curves were obtained at the same temperature conditions (18 ^{o}C). The ECL device has a threshold current of 22.40 mA while the HCSEL has a higher threshold current of 33.75 mA.

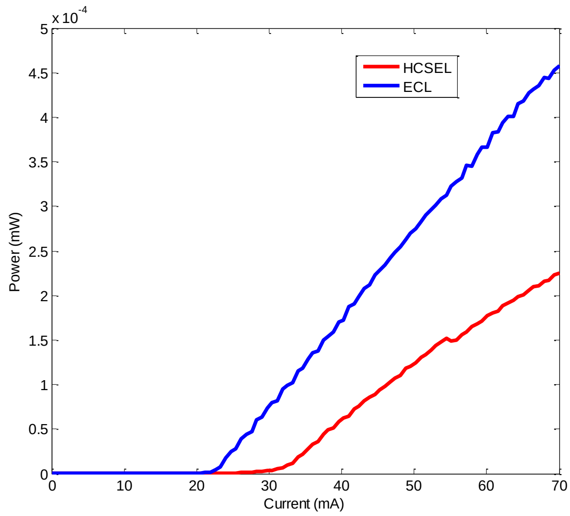

Fig. 4 – I-P characteristics of HCSEL and ECL devices.

Following the analysis performed in [3], the relative threshold current increase of the HCSEL with respect to the reference ECL can be obtained by the expression:

$$\Delta I_{th} / I_{th} = \exp\left[\left(g_{HCSEL} - g_{ECL}\right) / g_0\right] - 1 \quad (1.1)$$

where the modal gain g_0 = 12 cm^{-1}. The gain of the HCSEL can be expressed as:

$$g_{HCSEL} = \alpha_l + (2L)^{-1} \ln(R_2 R_{eff}) \quad (1.2)$$

where α_l = 6 dB/cm is the measured waveguide loss obtained from a straight waveguide test structure, L = 4 mm is the total laser length, R_2 = 0.32 is the modal reflectivity of the 90^o cleaved facet and R_{eff} is the effective reflectivity of the vertical coupler taking into account the misalignment of the 45^o mirror (see Fig. 3). In a similar way, the gain of the ECL device can be expressed and

$$g_{ECL} = \alpha_l + L^{-1} \ln(R_2)^{-1} \quad (1.3)$$

Solving equations 1.1-1.3 we obtain the effective reflectivity R_{eff} = 0.14. The reduction in the reflectivity, when compared with the one given by a cleaved facet, is mainly due to the efficiency in the coupling from the light reflected in the top of the cladding back to the waveguide core. This value is consistent with the one reported in Reference [3].

Conclusions

In this work, the fabrication and characterization of a vertical coupler is described. The structure was realized with a FIB etching technique at the output of an extended cavity laser. The effective reflectivity of the mirror was calculated by analysing the threshold current variation of HCSEL laser and was estimated to be 0.14. This structure can be made after finalizing the fabrication process and has the advantage that is can be realized in an specific section of the PIC without cleaving the wafer.

References

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