Compact Grating Coupled MMI on DVS-BCB Bonded InP-Membrane

F. Bordas[1], F. Van Laere[2], G. Roelkens[2], E. J. Geluk[1], F. Karouta[1], P.J. van Veldhoven[1], R. Nötzel[1], D. Van Thourhout[2], R. Baets[2] and M.K. Smit[1]

[1]TU Eindhoven, Eindhoven, the Netherlands
F.Bordas@tue.nl
[2]Ghent University-IMEC, Ghent, Belgium

Abstract. *Compact passive components have been successfully fabricated on 200 nm thick InP membrane BCB-bonded on a GaAs wafer. The characterization reveals that 400 nm wide wires show a loss <10dB/cm, S-bends have a loss of 2dB and a very compact MMI coupler (<20μm^2) show a loss of 0.6 dB.*

Introduction

In this paper, we demonstrate compact passive devices (single-mode wires, compact bends and MMI's) in DVS-BCB bonded InP-membrane. Light is coupled into and extracted from the chip using compact grating couplers [1, 2]. The wires are completely etched through the membrane, whereas the grating couplers are shallowly etched, to avoid excessive reflection. Moreover, this shallow etch make them more tolerant to fabrication deviations from the designed gratings.

Fabrication

The layer structure consists of a 200 nm InP-membrane layer on top of 3 etch-stop layers (InGaAs-InP-InGaAs) grown on a semi-insulating InP-substrate. The first step is the pattern definition. E-beam lithography is used on a positive resist over a 50 nm SiN_x hard mask, deposited by PECVD. After development and post-bake of the resist, the hard mask is etched with a CHF_3-based RIE. The resist post-bake allows reducing the sidewall roughness, as illustrated in Fig.1-a and 1-b. Then optical lithography is performed to cover the gratings and open the remaining part of the layout. A CH_4/H_2 based ICP etching step follows, to etch the deep part through the whole InP membrane. After removal of the resist, a second etch step is performed, for the gratings to be 70 nm deep. Finally we remove the SiN_x hard mask with a HF solution. The shallow-deep transition is shown at Fig.1-c.

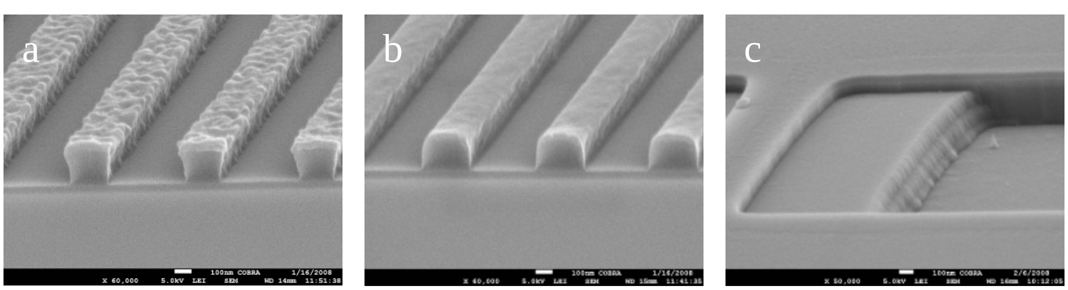

Fig 1: a – Resist pattern of a grating without post-bake;
b – Same pattern after a 150°C post-bake for 2';
c – Shallow-deep transition morphology.

After pattern definition, a BCB layer of 780 nm was spin-coated onto the InP-die, and cured for 1 hour at 250°C in a nitrogen environment. Then, the InP-sample was bonded onto a GaAs host-substrate with a 1µm thick BCB-layer [3]. This BCB-layer was also cured for 1 hour at 250°C in a nitrogen environment. The InP-substrate was removed using lapping and wet-etching in HCl until the InGaAs etch stop layer was reached. Finally, the InGaAs-InP-InGaAs etch-stop layer stack was removed using selective wet-etching.

Results and discussion

Grating couplers

The gratings are designed for an optimal coupling at 1.55µm at an angle of 10°. To avoid excessive reflections, the depth is 70nm, and two different periods are used: 730nm and 760nm for grating A and B respectively, with a filling factor of around 50%. The optimal simulated BCB thickness is 780nm + p*λ/2n, where λ is the wavelength in vacuum, p an integer, and n is the refractive index of the BCB layer. In our case p=1.

Transmission measurements are performed with a tunable laser as a source. The gratings are 10x10µm^2, and the device consists in a 50µm long 400nm wide wire and 600µm long tapers on each side. Figure 2-a shows the transmission of such a device with grating A (black) and grating B (red) as input and output couplers. The measured fiber-to-fiber loss at peak wavelength is 6.8dB for the device with grating B. For grating A, the tunable laser could not reach the peak wavelength. As the wire is very short, we assume losses only arise from the two grating couplers, which will be confirmed in the next paragraph. We can deduce a coupling efficiency of 47% at the optimal wavelength from these values, which is represented at Fig.2-b. Some measurements with a SLED as a source (not shown here) showed the same coupling efficiency for grating A at lower wavelength.

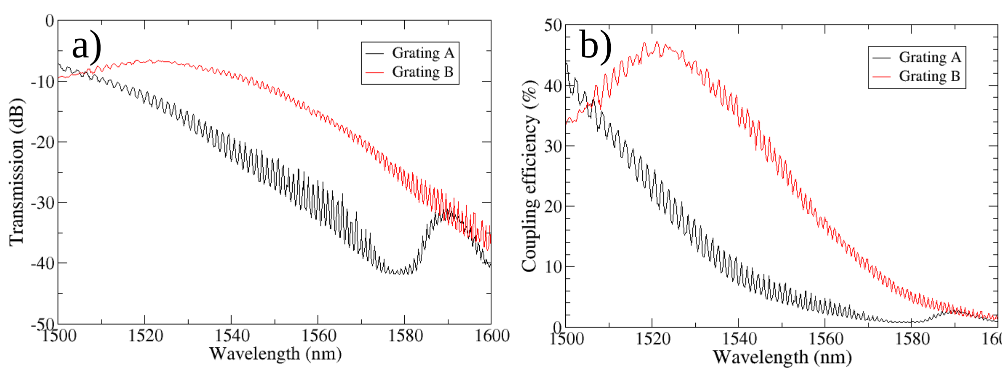

Fig. 2: a – Transmission through a 50 µm wire with two grating couplers, for two different grating;. b – Corresponding coupling efficiency.

Now the grating couplers are characterized, we can focus on the different fabricated devices, which are wires of different length, S-bends of different radii, and MMI's. For wires and MMI, the grating coupler used is grating B, whereas grating A is used for the bends.

Wires

We fabricated 400nm wide wires of four different lengths, in order to determine the losses. Fig.3 shows the transmission through 500µm (black), 300µm (red), 100µm (green) and 50µm (blue) long wires. As can be seen, it is very difficult to deduce from these measurements the loss per cm length, but we can access to a maximal value of these losses around 10dB/cm. This confirms the assumption made in the preceding paragraph. However this quite low loss value will be confirmed by fabricating wires in the mm range in the near future.

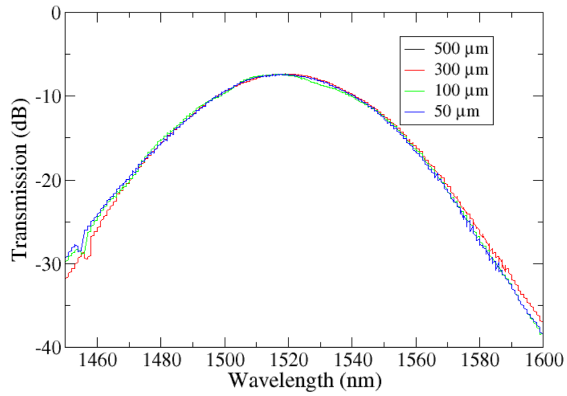

Fig. 3 : Transmission through 400nm wide wires of different lengths : 500 µm (black), 300µm (red), 100µm(green), and 50µm (blue).

Bends

The reference here is a 50µm long wire. Three different S-bends are measured, with radii of 40µm, 20µm, and 5µm. The losses are shown in Fig.4. Assuming the coupling efficiency of the gratings is the same for all devices, we can measure 2dB losses for the bends as compared to the reference, but could not measure any difference between bends of different radius.

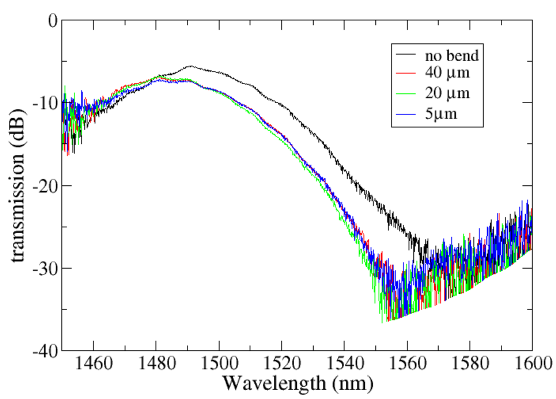

Fig.4 : Transmission through a simple wire (black) and S-bends of 40mm, 20mm, and 5mm (red, green, and blue respectively).

This suggests that very compact integrated optical circuits can be fabricated using sharp bends (5µm radius bend). Moreover the 2dB measured losses can be improved by inserting offsets between wires and bends.

MMI's

The fabricated MMI's are meant to be 1x2 couplers. Fig.5-a shows a SEM image of the resist pattern after development. The dimensions of the MMI are 6.64 x 2.75 x 0.2 μm^3. Transmission measurements on this device are shown in Fig.5-b. The reference (in black) is a 50µm long wire without MMI. Transmission through the upper and the lower branch (red and green respectively) are very comparable, and 3.6dB lower than the reference.

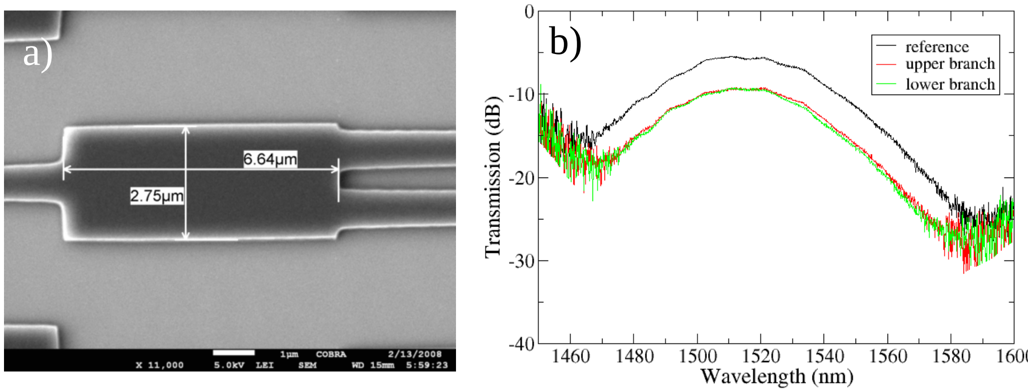

Fig.5 : a – SEM image of a fabricated MMI ;
b – transmission through both output branches, together with the reference.

Hence the fabricated MMI coupler operating as a 3dB splitter shows a loss of only 0.6dB.

Conclusion

In this paper we showed very compact and efficient devices fabricated on InP membranes bonded on GaAs with BCB. The light was coupled in and out through shallowly etched grating couplers, with an efficiency of 47%. Losses through the wires could not be accurately measured, indicating an upper limit of 10dB/cm for losses; the S-bends (radii of 5µm up to 40µm) had all 2dB losses. The most exciting result is the very compact 3dB-splitter, with a 0.6dB loss.

References

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