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K. Wörhoff, L. Agazzi,
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Low-loss waveguides and passive devices in BCB-bonded InP membranes on Silicon

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The high vertical index contrast and the small thickness of thin InP membranes (200nm) bonded with BCB allow the achievement of very small devices. In this paper we will present some performances of such photonic integrated circuit building blocks (wires, sharp bends and 3dB splitters). Some preliminary results about passive cavities (ring resonators) will also be presented.

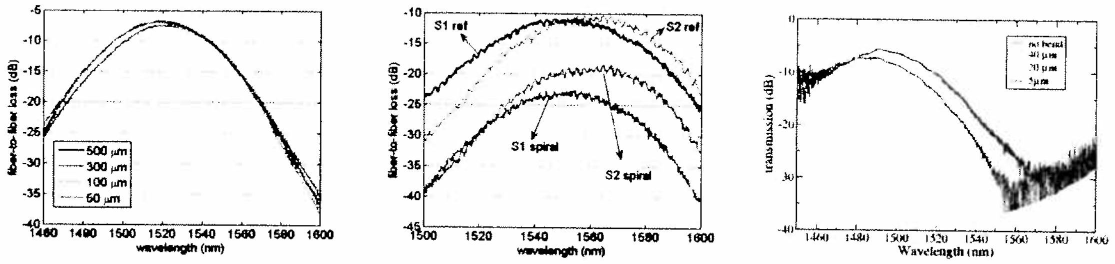
Introduction

The complexity of photonic integrated circuits (PICs) has raised these last years, following Moore's law. But to satisfy the need for even further complexity, devices and waveguides have to be made smaller and less power consuming. One of the solutions for this is to use membranes, so the waveguide layer has a high vertical index contrast. Suspended membranes have the highest vertical index contrast, as they are surrounded with air. However this solution is hard to handle for a complete PIC. Lot of work has been reported about bonded membranes, mainly Silicon On Insulator (SOI). Silicon is an ideal candidate for passive devices, but this material does not allow the achievement of integrated active devices. III-V semiconductors can handle both passive and active functionnalities, which make them good candidates for non-heterogeneous active-passive integration. Our work concerns thin InP membranes bonded with BCB on Si. We will first present the performances of basic circuitry building blocks, such as wires and 3dB-splitters. Then preliminary results about ring resonator notch filters will be presented.
The chip is first processed on an epitaxial InP and quaternary layer structure. Then, the sample is bonded with BCB [1] and the substrate and sacrificial layers are removed so that only the 200nm thick patterned InP membrane is left. The whole fabrication process is described elsewhere [2]. Light is coupled into and extracted from the chip using compact grating couplers [3, 4].

Devices

The fabricated wires are 400nm wide. In a first set of experiments the different lengths were 50, 100, 300 and 500 μm. Fiber-to-fiber losses are reported on figure 1(a). The difference between the various curves is less than 0.5 dB, which gives an upper value for propagation losses of 10 dB/cm. Some longer wires (5.6 mm) were later fabricated, in a spiral configuration. Transmission results are reported figure 1(b) with the reference

50 μm long wire transmission. The measured propagation losses are estimated to be 15 dB/cm, but include the losses due to the 40 bends of the spiral, which are not yet quantified. This loss value is higher than the one reported for similar wires in SOI [5], but can still be improved. Moreover, they are comparable to losses achieved in wide deeply etched III-V waveguides [6]. Similar performances have been achieved in [7] for InP wires in the same configuration.



(a) Wires losses : measurement 1 (b) Wires losses : measurement 2 (c) Bends losses

Figure 1: Characterization of the wires : fiber-to-fiber transmission measurements

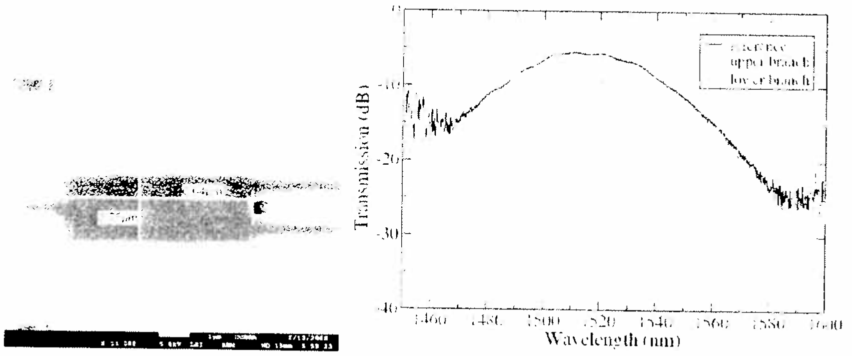
We also fabricated S-bends with different radii, to estimate the bend-losses. The transmission results are reported in figure 1(c). The difference between reference and S-bends transmission is 2 dB, which means a loss as high as 1 dB/90°. This high loss value is rather attributed to a difference in the grating couplers, as it is incompatible with the spiral measurements as the spiral has 40 bends. The conclusion we can draw is that the losses are as low for a 5 μm radius bend and for a 40 μm radius bend.

3dB-splitters are common building block of circuitry in PICs. We fabricated an ultra-small 1$\times$2-MMI splitter (less than 20 μm^2) and measured the transmission through each output branch while using the same input for both. As a reference a 50 μm long wire is used. A SEM image of the device is shown in figure 2(a) while the transmission measurements are reported in figure 2(b). The transmissions through each branch are the same, and are 3.6 dB lower than for the reference. This device is to our knowledge the smallest 3dB-splitter ever reported in InP with an excess loss of only 0.6 dB.

Ring resonators

We also fabricated ring resonator notch filters as shown in figure 3(a). The measured transmission spectrum for a ring resonator with a radius of 4 μm and a separation gap of 150 nm is shown in figure 3(b), revealing a free spectral range (FSR) of 28.2 nm. One resonance is at λ=1603.5 nm and it has an extinction ratio of 16 dB. The loaded Q-factor, defined as f_0/FWHM with f_0 the central frequency while FWHM is the full width half maximum, is then 5830.

The asymmetric form of the curve indicates non-linear effects, similar to the behavior of SOI ring resonators [8]. Therefore, we have measured the transmission spectrum of the ring resonator structure for increasing input power of the tunable laser. The result is shown in figure 3(c). For the lowest input powers, the resonance wavelength is slightly

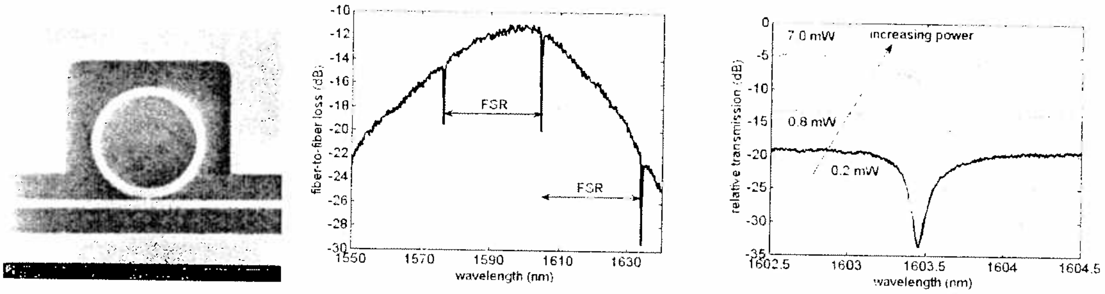


(a) SEM image of the fabricated MMI splitter

(b) MMI splitter transmission measurement

Figure 2: MMI splitter characterization

blue shifted as the input power is increased. For higher input powers, a wavelength red shift and bistability occur. This can be explained as follows ; due to two photon absorption free carriers are generated, resulting in additional absorption (free carrier absorption) and an associated negative refractive index change due to free carrier dispersion. Recombination of these carriers results in heating and a positive thermal refractive index change. For the lower input powers, the free carrier dispersion effect is dominant, resulting in a blue shift of the resonance while for higher input powers, the thermal effects take over, resulting in a wavelength red shift and eventually bistability.



(a) SEM image of the fabricated ring resonator

(b) Fibre-to-fibre transmission through the bus waveguide at low input power

(c) Resonance at λ=1603.5 nm for increasing input powers, resulting in bistability.

Figure 3: Ring resonator notch filter.

For the SOI ring resonators in [8], thermal effects are dominant for all input powers and only a red shift of the resonance is observed. In [9], where III-V material is bonded onto SOI racetrack resonators, the blue shift due to free carrier dispersion is also observed.

Conclusion

We fabricated and characterized very compact and low-loss straight and bended wires, together with an ultra-compact 3dB-splitter in thin InP membranes bonded with BCB on silicon. The measured losses are below 15 dB/cm for the wires and the 3dB-splitter has only 0.6 dB excess loss. The fabricated ring resonators showed a free spectral range of 28 nm and a loaded Q-factor ¿ 5000. This value is high enough to ensure lasing action with active material. We could also observe a non-linear behavior of these rings for an increasing input power, leading to bistability.

We believe that this IMOS (InP Membrane On Silicon) strategy is particularly attractive for very complex PICs working at telecom wavelengths as it supports the integration of active and passive devices at the same level.

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