InGaAsP/InP based Flattened Ring Resonators with Etched Beam Splitters

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Abstract: A novel flattened ring resonator design utilizing Etched Beam Splitters (EBS) in InGaAsP/InP is proposed and demonstrated. A multiple-thickness hard mask that compensates for RIE-lag realizes waveguides and EBS gaps in a single etch step.

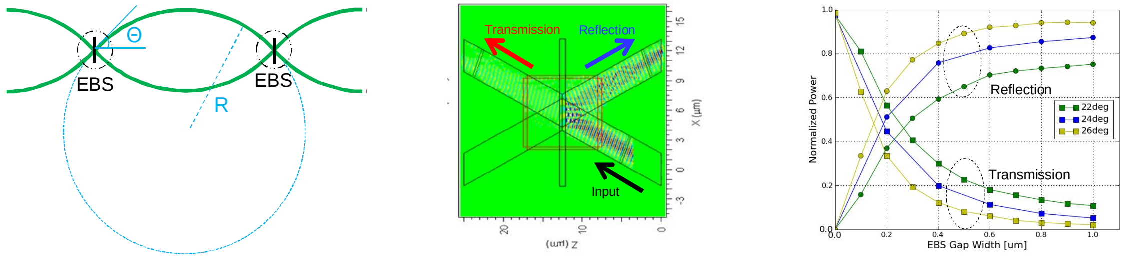
OCIS codes: 230.5750 Resonators, 250.5300 Photonic integrated circuits

1. Introduction

Ring resonators are a basic building block in filters needed for DWM applications and analog signal processing, resonators should ideally have small footprint and be easily integrateable with other PIC structures. The problem when scaling down resonators lies with the coupler since the length of the coupler ultimately limits the total ring length. Directional couplers are most often used when the resonator sizes are reduced; however when the ring size shrinks, the coupler region and amount of cross coupling reduces accordingly. In order to have enough cross coupling the inter waveguide distance must be made extremely small. For lateral directional couplers this implies the use of electron-beam lithography and more difficult fabrication; and even when using sub-micron features the directional couplers have cross-coupling limited to only a few percent. A solution to this problem is the Etched Beam Splitter (EBS)[1,2], an extremely compact coupler that allow the full range of cross/bar coupling ratios. Byungchae et al. have previously demonstrated an EBS in the AlGaAs/GaAs system with passive micro-ring resonators [3]. In order to achieve integration with conventional InP PIC technology, we have extended to the InGaAsP material system and report in this work for the first time on active ring resonator devices with EBS used for input/output coupling.

2. Flattened Ring Resonator Design and Simulations

Ring resonators are most often based on bent waveguides, when reducing the size of the resonator the bend radius decreases accordingly, whence a need for higher confinement is crucial to avoid radiation losses. In our design we therefore use a deeply etched waveguide to highly confine the mode laterally. But to obtain smaller ring circumferences without extremely small bend radii, we propose a novel flattened ring design, figure 1a). This design is a natural extension of the EBS coupler into a ring resonator, where the length of the ring is defined by the incident angle at the EBS coupler together with the bend radius of the waveguides, $L = \Theta R\pi / 45$. It has the major advantage of a reduced bend radius as compared to circular or racetrack type resonators that utilize directional couplers, the reduced bend radius translates into less optical scattering loss.



a) *b)* *c)*

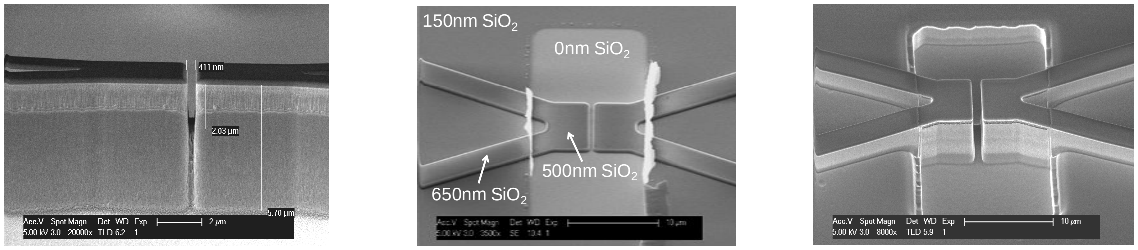
Fig 1. a) Schematic illustration of flattened ring resonator design. b) EBS design and 2D-FDTD simulation. c) Simulated power splitting as a function of incident angle and gap width.

The EBS design proposed in this work is the first based on high confinement waveguides, previous work have investigated EBS in weak guides [1,2]. Utilizing an EBS gap of air offers the smallest critical angle (18º), and thus the largest bend radius for a fixed resonator length. The EBS design is shown in figure 1b), varying the gap width and incident angle adjusts the amount of power reflected or transmitted through the process of Frustrated Total-Internal Reflection (FTIR) [4]; simulation results from 2D-FDTD is shown in figure 1c), the complete range of power splitting is evident. For the EBS design, a given incident angle has an optimal shift between input and output waveguides, as expected due to the Goos-Hanchen shift [5].

3. Fabrication of EBS in InGaAsP/InP

There have been a few papers that investigated ICP etching of InGaAsP using Cl_2:H_2:Ar chemistry [6,7]. We have previously optimized the conditions of this etch to yield smooth and straight sidewalls for deeply etched waveguides, for which low passive loss was demonstrated [8]. In this work we have further developed the etch to yield higher aspect ratio for the EBS gaps; we found Cl_2:H_2:Ar = 7.6:11.4:2, 800W ICP, 125W RIE and 8mT to be the optimal conditions. Surprisingly, better results was achieved with 8mT rather then lower pressures(~1.5mT), this is attributed to a Si-passivation layer being responsible for the anisotropy [7], and not a low etch pressure as in the case of many other RIE etch chemistries.

The FDTD simulations show that the loss in the EBS is very sensitive to rotational misalignment of the EBS gap with respect to the waveguides, for this reason we simultaneously define the EBS gaps and the waveguides. using standard photolithography. In the process of high-aspect-ratio deep etching, an aspect dependent etch rate (RIE-lag) is present, this is a well documented effect [9], and very hard to avoid by only varying etch parameters. This limits the EBS gap depth that can be achieved while keeping the waveguides in other areas at reasonable heights (< 6µm); the etch depth of the EBS gap might be less than half of that in planar areas, figure 2a). We address the RIE-lag problem by using a novel multiple-thickness hard mask. First, both EBS and waveguides are patterned into a 500nm SiO_2 mask using standard photolithography, secondly, using a lift off technique with low temp SiO_2 deposition a second layer of SiO_2 is added everywhere except around the EBS, figure 2b). When the ICP deep etch takes place, the EBS region effectively etches for a longer time then the waveguides and hence the RIE-lag effect is compensated as illustrated in figure 2c). With the conditions given above the selectively is 1:20 for SiO_2:InP, thus a second deposition of 150nm SiO_2 translates into an extra 3µm of etch depth in the EBS region; for a 0.4µm wide EBS gap the depth is increased from 2µm to 3µm, a critical improvement in order for the optical mode to see the TIR mirror as the waveguide layer is located at a depth of 1.8µm from the top.



a) *b)* *c)*

Fig 2. a) RIE-lag limits the EBS gap depth. b) Multiple-thickness SiO_2 mask effectively delays the waveguide deep etch. c) RIE-lag is reduced yielding higher aspect ratio EBS gaps

After the simultaneous deep etch of the EBS and the waveguides, only a single non-critical extra lithography step is needed in order to fully integrate the EBS couplers with our standard active PIC fabrication process; this is the removal of SiN on the EBS mirrors, figure 3.

4. Active Flattened Ring Resonators

In this work we used an InGaAsP Active/Passive Offset Quantum Well (OQW) platform with a 300nm 1.3Q waveguide layer and 7 OQWs with a total confinement factor of 7.1% [10]. The resonator design utilized 3µm wide waveguides with a bend radius of 500µm and EBS with an incident angle of 24º; this yields a total resonator length of 838µm. The resonator has a 375µm long gain region and two passive metal contacts for current injected phase tuning, figure 3.

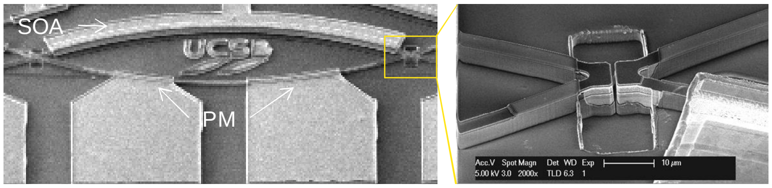
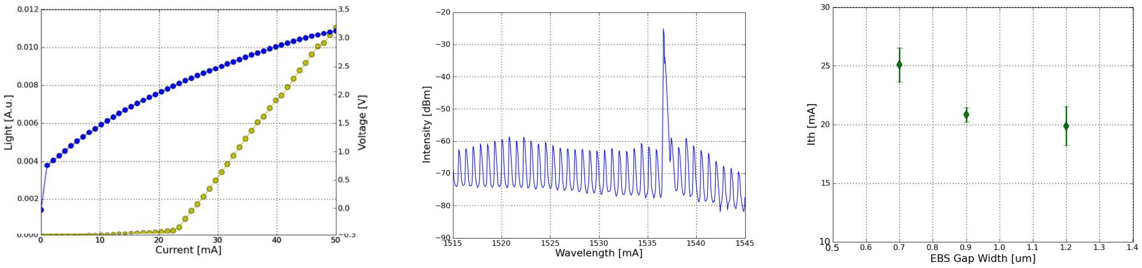


Fig.3 Fabricated active flattened ring resonator with an SOA, two Phase Modulators (PM) and EBS for in/out coupling

All measurement was done in room temperature CW, for *LIV* measurements an on chip passive pad outside the ring was used as photodetector, the quantum efficiency of this is very low, thus the optical power indicated in figure 4a) is arbitrary. The lasing spectra were captured using a lensed fiber to an Optical Spectrum Analyzer (OSA), it shows single mode lasing with a SMSR up to ~35dB, figure 4b). The threshold currents decreases as a function of EBS gap width as less output coupling is provided, the data is based on 22 devices with three different gap widths.



a) *b)* *c)*

Fig.4 a) LIV characteristic for an EBS ring resonator. b) Lasing spectra for same device at 65mA. c) Threshold currents as a function of EBS gap width, mean values and standard deviations indicated.

These proof of concept results verify that the material structure, etching technology, and device designs are capable of providing state-of-the-art ring-resonator results with nearly arbitrary input/output coupling levels. From the low CW threshold current densities and de-embedded losses observed in these and other experiments, we can project that much smaller circumference rings should operate cw at room temperature, and results on such rings as well as more details on the EBS couplers will be presented in the oral presentation.

5. Conclusions

In this paper we have proposed a new micro-ring resonator design based on deeply etched flattened rings; the EBS design has been optimized using 2D-FDTD simulation. A novel hard masking process was demonstrated, which produced high aspect ratio EBS gaps together with deeply etched waveguides in a single etch step. The EBS fabrication is fully compatible with other InGaAsP-based PIC structures; active EBS-coupled flattened-ring resonators are demonstrated for the first time.

Acknowledgements

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