Low loss waveguides for standardized InP integration processes

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InP generic processes allow monolithic integration of sources, passive elements and detectors on a common p-n doped layerstack. The passive loss can be greatly reduced by formation of local p-n junctions by means of Zn-Diffusion or regrowth. The attainable loss is experimentally derived from spiral ring resonators, coupled to a waveguide via multimode interference. By folding the ring into a spiral we obtain circumferences up to 73 mm, with a footprint of 2.4 mm x 3.6 mm. We measure a quality factor of 1.2 million and extinction ratio of 9.7 dB, implying a loss below 0.4 dB/cm.

Introduction

The InP generic foundry approach allows for the realization of complex Photonic Integrated Circuits (PICs) [1]. Complete integrated systems consisting of active light sources, high speed detectors, and a variety of passive optical elements can be integrated fully monolithically [2,3]. Consequently, cost-efficient Application Specific PICs (ASPICs) can be designed by exploiting the existing infrastructure provided by the InP foundries.

Integrated optical sensing is feasible by integration of a source, a ring as sensing element and an optical read out. The sensitivity of this system is closely related to the quality factor (Q) of the ring. The latter requires low propagation loss and extended optical path lengths, which are typically provided by dielectric platforms [4] or silica on silicon [5]. InP loss is usually reported for waveguides compatible with active and passive components. The essential doping profile to form a PIN structure introduces inherit and significant loss. An improved loss figure can be achieved by separating the active and passive regions by formation of localized p-doped regions.

This paper experimentally quantifies the achievable loss by characterization of spiral ring resonators with a circumference up to 73 mm, fabricated in n-doped waveguides with an n.i.d. top cladding. The propagation loss is deduced by measurement of extinction ratio and Q. The longest device has a Q of 1.2 million and an extinction of 9.7 dB, which yields a loss below 0.4 dB/cm for TE polarized light. This result enables the fabrication of novel angular velocity sensors for military and aerospace [6] within a generic foundry process.

Waveguide fabrication

One of the most important parameters of a PIC is the propagation loss α of waveguide. In order to understand the contributions to the loss, it is essential to mention fabrication process, employed materials and doping levels.

A simplified process for an InP ridge waveguide, as fabricated in the COBRA process, is depicted in Fig. 1(a). The starting point is a substrate which is common for all waveguides. An InGaAsP layer is epitaxial grown between two doped InP cladding

layers, forming a PIN Diode. Patterning the hard mask and ICP dry etching with CH_4-H_2, allows for the fabrication of waveguides which can be contacted by planarization with polyamide and additional metal evaporation. Passive waveguides therefore experience an unnecessary loss due to the presence of dopant. The p-doped cladding is the major contribution due to intervalence band absorption [7]. The minor n-type absorption, can be modelled by accounting for scattering introduced through electron-phonon and electron-ionized impurity interaction [8].
Alternatively, the removal of the p-cladding in regions where no electrical contacts are required is feasible. This can be achieved prior to the waveguide fabrication by adding a few non critical fabrication steps. The first approach is depicted in Fig. 1 (b) and is based on an additional regrowth. Here, the p-cladding is selectively removed and replaced by n.i.d. InP via epitaxy. The second approach is shown in Fig. 1(c). Initially a hardmask is patterned to define the active and passive regions on a substrate with n.i.d. cladding. By means of local Zn-Diffusion, the cladding is doped positively where an electrical contact is desired.

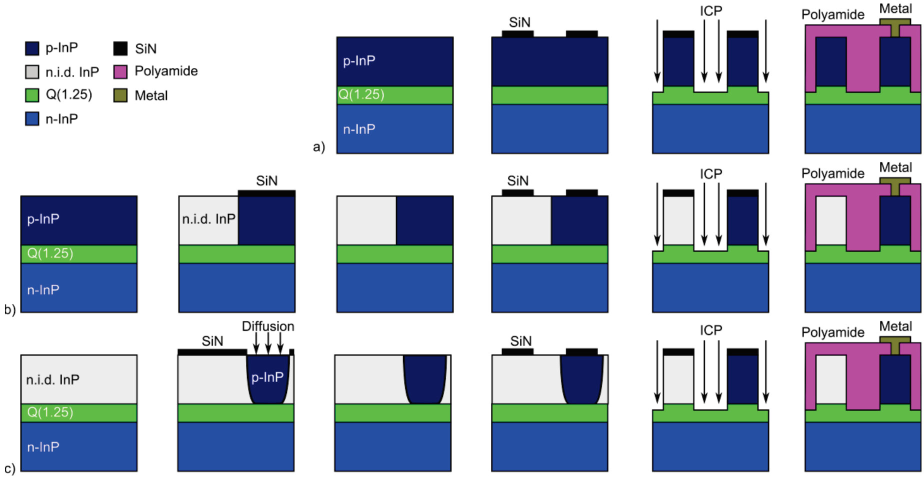

Figure 1: Schematic of waveguide fabrication using: (a) PIN substrate, (b) PIN substrate with regrown n.i.d. top cladding, (c) n.i.d. substrate with doped cladding formed by local Zn-Diffusion.

Circuit Layout

The circuit, designed for the COBRA generic process [1], is shown in Fig. 2 (a) and based on waveguides containing an n.i.d. top cladding, an n-doped 600 nm Q(1.25) guiding layer and an n-doped substrate. For reduced reflections, the optical ports are formed by angled waveguide terminations located at the input and output of the PIC. The optical ports are connected to spatial mode filters, suppressing the excitation of higher order modes due to imperfect fiber chip coupling. The ring resonator is formed by a shallowly etched spiral delay line, coupled to a waveguide via a MMI with unequal power splitting ratio. A deeply etched MMI-coupler as shown in Fig. 2(b), with power coupling coefficients of 0.72 for the bar and 0.28 for the cross port [9], is used for coupling.
For optimal Q of the ring resonator it is crucial to minimize the ring loss and simultaneously increase the path length [10]. The ring transmission is determined by the waveguide loss, radiation loss due to bends, reflections caused at waveguide junctions

and imaging loss of the MMI. The radiation loss is reduced by employing shallowly etched waveguides with bending radii larger than 1 mm and two non-critical bends of 0.5 mm in the center of the spiral. The number of junctions is minimized by gradual reduction of the radius towards the center. The remaining junctions are optimized, with a cumulative loss of roughly 0.1 dB. An additional spatial mode filter is placed inside the ring to further suppress higher order modes. With a pitch of 25 µm between waveguides, the longest resonator has a footprint of 2.4 mm x3.6 mm.

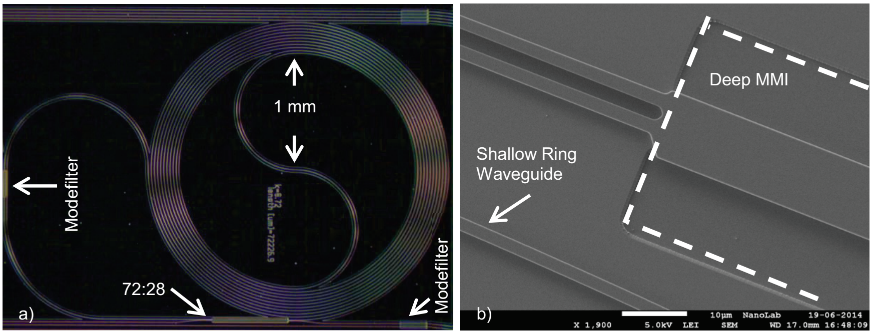

Figure 2: (a) Microscope picture of a MMI coupled spiral ring resonator with 73 mm circumference. (b) SEM image of 72:28 MMI used for coupling.

Ring Resonator Performance

The resonator is characterized using the setup depicted in Fig. 3. A tuneable laser is coupled via a collimating lense to free space. After passing through the polarizer, the collimated beam is coupled to the device via a microscope objective. A fiberized polarization controller is used to maximize the transmission through the polarizer set to TE or TM. The tuning of the laser is continuous with a speed of 500 pm/s. We record the transmission with a photo diode, connected to real time oscilloscope with a frequency of 100 kHz. The non-uniform sweep of the laser introduces an error in the Q estimation, which is reduced by averaging over several tens of periods.

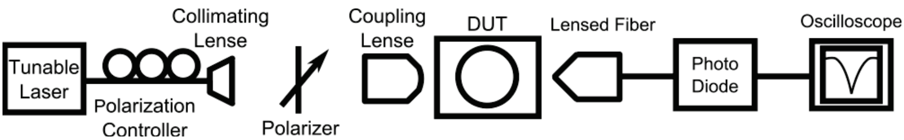

Figure 3: Schematic of the experimental setup to measure the ring transmission.

The measured Q and extinction for various ring circumferences are given in Fig. 4. We fit an analytical model [10] to the measurements using the least square method with the propagation loss as parameter. An insertion loss of 0.2 dB was considered for the MMI coupler, based on measurements of dedicated test-structures. An additional loss of 0.2 dB was determined for the mode filter. The extinction is fit with 0.39 dB/cm for TE and 0.49 dB/cm for TM. An excellent fit is achieved for the Q with 0.33 dB/cm for TE and 0.43 dB/cm for TM. The extinction for the longest circumference in TE is 9.7 dB, with a Q of 1.2 Million. These values enable the fabrication of high performance angular velocity sensors within InP generic foundry processes [6].

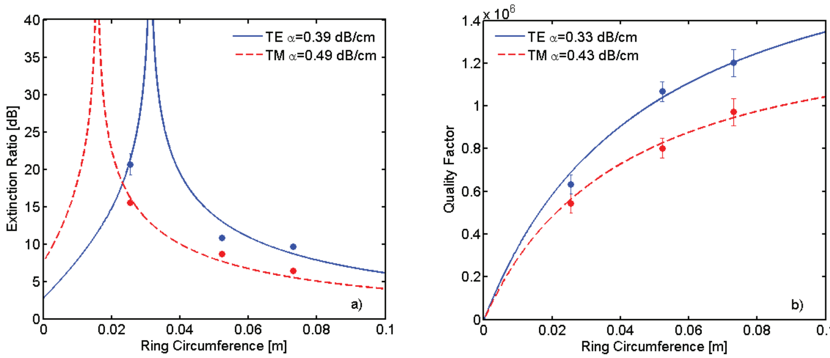

Figure 4: Measured ring resonators with different circumferences: (a) Extinction Ratio, (b) Quality Factor.

Conclusion

We fabricated ring resonators with tens of millimeter circumference to determine the attainable waveguide loss for passive InP waveguides within a generic foundry process. The resonators consist of a spiral delay line up to 73 mm path length coupled via a MMI to a waveguide. Based on measured quality factors of 1.2 million and extinction of 9.7 dB, we deduce a propagation loss below 0.4 dB/cm for TE polarized light.

Acknowledgments

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