Fabrication and characterization of compact photonic wire 90° bends in InP

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Waveguide bends—key components in integrated optics circuits—have a strong impact on functional density. Indeed, in order to prevent radiations, the radii of conventional ridge waveguides are much larger than the wavelength. Additionally, substantial mode conversion is observed in the case of multi-mode waveguides. Several propositions were made for reducing the radiation and enhance the transmission of sharp 90° bends such as corner mirrors and waveguide resonators. To our knowledge, single mode operation is assumed and this leads to very narrow, deeply etched waveguides that are hard to fabricate. For wider waveguides, multimode operation poses the additional problem of mode conversion. The waveguide bend must then be designed so that radiation *and* mode conversion are avoided.

Recently, Photonic Crystal (PhC) waveguides attracted much attention because sharp bends with zero reflection and radiation are theoretically possible for certain frequencies. The main problems of integrating such PhC waveguide bends in conventional integrated optics waveguides are the coupling of the shallow-etched rib or deeply-etched trench waveguides with PhC waveguides and the high impact of fabrication imperfections such as sidewall roughness.

In addition to the optimization of mirror- and resonator-based sharp bend structures, we introduce an ultra-small local pillar-like PhC in the bend area. We show that this local PhC suppresses radiation and reduces problems caused by fabrication imperfections at the same time.

The structures were fabricated in an InP/InGaAsP/InP vertical slab waveguide using a combination of electron-beam lithography for the bends patterning and of inductively-coupled plasma reactive ion etching of the InP and InGaAsP layers. The designs included two identical 90° bends for co-linear in- and out-coupling separated by a 30µm straight waveguide piece. The waveguide width in the bending region and in-between was designed such as to be 400nm after fabrication. Addtionally, 1.5mm-long and 1µm-wide access waveguides coupled the light in and out of the device by means of 15µm-long tapering sections. Fig. 1 shows a close-up view of a 90° bend incorporating a small PhC.

The optical measurements were performed with the end-fire technique. Two tunable lasers, covering a wavelength range from 1470 to 1630 nm and 19 mW output power were combined using a 2×2 coupler. One output was used for reference power measurements. The second was coupled to the device under test (DUT) via a tapered lensed fiber. The input set-up is polarization-maintaining and all measurements were done with transversal electric (TM) polarization. Signal collection was done over a microscope objective to measure the DUT power throughput.

2D frequency-domain MMP simulations using the effective-index model predict transmissions of 2.3%, 93%, and 99.6% for the abrupt, 45° and PhC bends, respectively. Fig. 2 shows the measured transmission for TM-polarized light of the three double-bend structures after deembedding the access-waveguide losses. As expected from the simulations, the measured transmission of the abrupt bend is the lowest (<-15dB), the sum of losses and reflections amounting to ca. 8dB/bend. On the other hand the bends with 45° mirror and PhC mirror show losses and reflections of ca. 4 dB/bend and 2.5dB/bend, respectively. An improvement larger than predicted by the simulations indicates the lower sensitivity of the bend with PhC mirror on nm-scale sidewall roughness, unavoidable in the deeply-etched InP material system.

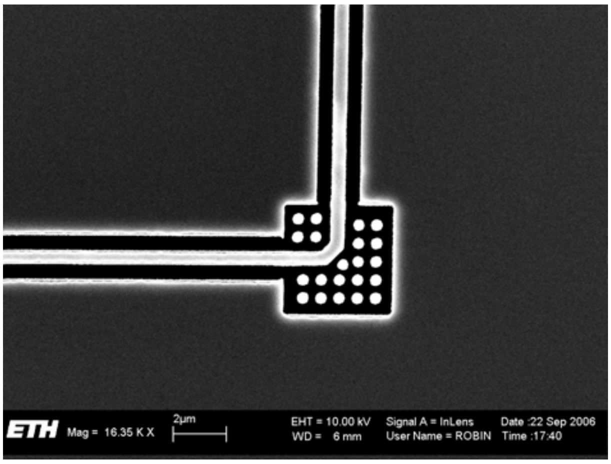

Fig. 1: SEM micrograph of 90° sharp bend incorporating a small photonic crystal in the InP/InGaAsP material system.

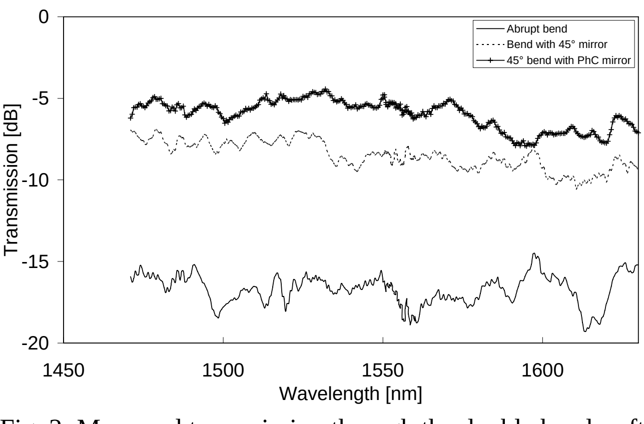

Fig. 2: Measured transmission through the double bends, after deembedding of the access waveguides. The bend with 45° mirror is identical to the structure shown in Fig. 1, without the pillars. The abrupt bend does not include the 45° facet.