Low Polarisation Conversion in Whispering Gallery Mode Micro-Bends

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Abstract—**A new fabrication tolerant micro-bend design is proposed exploiting the unique properties of whispering gallery modes. Low polarisation conversion (<25dB/90°) is predicted for low bend radii (~20 μm). The design removes fabrication critical design parameters to provide a low variability solution for high density integrated photonics.**

Keywords-micro-bend; whispering gallery modes; polarisation conversion

INTRODUCTION

Increasing photonic integration densities require ever-smaller bends between waveguides with uncompromised waveguide modal properties. However higher order mode excitation and polarisation conversion are critically dependent on absolute waveguide dimensions for micro- and nano-photonic devices. Current lithographic processes lead to feature size deviation of order hundreds of nanometers. Total internal reflecting mirrors are heavily sensitive to such critical dimension variation through the mirror facet placement and tilt[1]. Photonic band-gap devices require high resolution fabrication[2]. Hard mask erosion during etching of waveguides can induce sidewall tilt, leading to a hybridization of guided modes and undesirable polarisation rotation. This is a particular problem for curved waveguides, where polarisation conversion is predicted to increase rapidly for reducing bend radii, even for modest radius (~50 μm) curves[3]. To this end, design focus for curved waveguide has so far been placed on enhancing polarisation rotation[4]. There is therefore little quantitative understanding of the mode of operation of optimised ultra-compact micro-bends.

In this work, a new class of deep-etched micro-bend designs is proposed, which exploits whispering gallery mode operation in disc-like micro-bends. By moving the inner sidewall beyond the caustic radius, the guided bend-modes are defined by only the outer sidewalls. The inner sidewall no longer plays a role in waveguiding and scattering loss, and so bend waveguide width is no longer sensitive to fabrication variation[5]. Critical waveguide offsetting required for optimum mode-coupling is defined in the mask and thus is similarly unaffected by feature size variations. In this work, we identify fabrication tolerant optima for radius and sidewall tilt for low polarisation conversion in such micro-bends.

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MICRO-BEND DESIGN

The simulated structures are shown schematically in Fig. 1. Straight, deep-etched, single-mode input and output waveguides are connected via a deep-etched micro-bend.

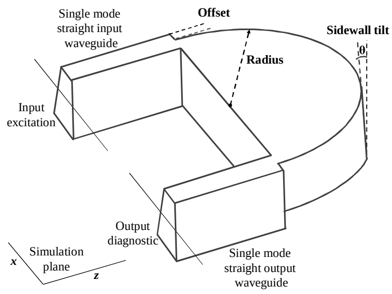

Figure 1. Schematic of the simulated waveguide core.

Assessment is performed by placing numerical 'probes' in the straight waveguides. 2D and 3D finite difference time domain (FDTD) simulations are performed with the Omnisim commercial solver[6] for 90° and 180° micro-bends. The scanned variables, shown schematically in Fig. 1, are as follows:

- Straight waveguide to micro-disc mode offset: optimizing the mode-matching at the junctions[7];
- Outer bending radius: exploring sensitivity of loss to physical size;
- Sidewall tilt angle: exploring polarisation conversion and its tolerances to fabrication parameters.

A vertical effective refractive index of 3.28 is calculated for the InGaAsP/InP waveguide using an effective index mode solver. The input and output deep etched rib waveguide widths are fixed at 1.5 μm to support a single transverse mode. Optimal offsetting between straight waveguide and micro-disc is determined iteratively for each bend radius. Vertical confinement is defined by InP cladding layers while horizontal confinement is defined by air. A screen capture from the 2D simulation tool is shown in Fig. 2. The input fundamental mode produces an excitation that propagates from the straight waveguide, around a 20 μm radius 180° disc, into a second straight waveguide. A pulse of duration 1.4 ps propagates completely through the circuit within the calculation period. The plot shows the amplitude of the *x*-component of the electric field. After the offset, less than 3% of the input mode power is scattered at the straight-to-bend junctions. The remaining power is coupled into disc whispering gallery modes. Only a negligible amount (<1%) of input power is radiated out from the waveguide. The power coupled to the fundamental mode of the output waveguide is calculated once the light has propagated around the complete circuit. The cross-section of the device is shown as an inset in Fig. 2.

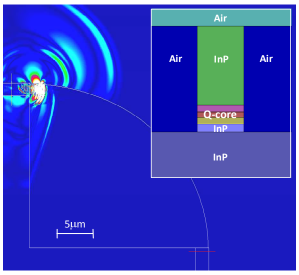

Figure 2. 2D model screen capture showing key loss mechanisms. Inset: cross section of the designed layer stacks.

LOSS MECHANISMS

Radiation and coupling losses are calculated for micro-bends with radii from 3 µm to 40 µm (Fig. 3). Total losses remain low (~0.3 dB) for radii in the range from 15 to 30 µm when waveguide offset is optimised, showing a relaxed fabrication tolerance. At radii exceeding 30 µm there is evidence of higher order disc mode excitation which leads to reduced coupling into an output fundamental mode. This can however be reduced by defining an inner radius close to the caustic radius limit. At radial values below 15 µm, losses increase with decreasing radius as a result of imperfect coupling into the micro-bend, despite the optimised mode offsetting.

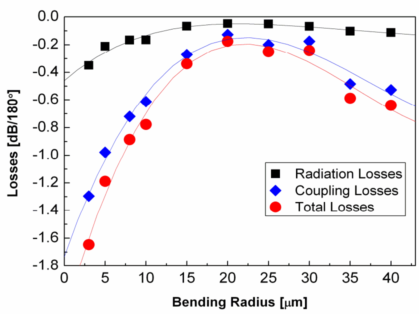

Figure 3. Total losses in 180° micro bends for varied micro-bend radius. Waveguide offsets are optimised for each radius.

SIDEWALL TILT AND POLARISATION CONVERSION

Polarisation conversion results from waveguide asymmetry, which can be incurred through an off-vertical sidewall tilt in real fabricated circuits. TE-to-TM coupling is calculated for the optimum 20 µm radius micro-bends. The sidewall angle is scanned from the vertical condition at 0° to 10°, which is readily achieved with reactive ion etching. Simulations are performed for both 90° and 180° micro-bends, showing a cumulative build up in the coupling from TE-to-TM field at the output (Fig. 4). It is less straightforward to simulate intermediate angles, but there is no physical constraint.

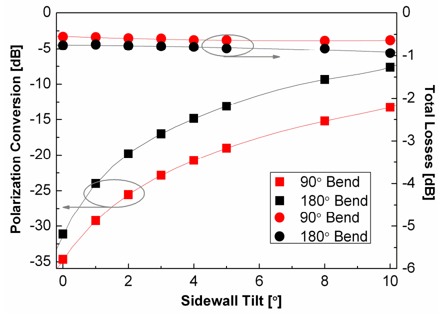

Figure 4. Polarisation conversion and loss as a function of the sidewall angle for 20 µm radius micro-bends.

A low polarisation conversion (<25dB/90°) is feasible for sidewall tilts of less than 3°. This is expected to be feasible with carefully optimised etching and masking. The increased deviation of sidewall tilt from the vertical also shows a moderate increase in the total losses (Fig. 4). The small mismatch in the losses reported in Fig. 2 (2D FDTD simulation) and Fig. 4 (3D-FDTD simulations) reflects the different description of vertical confinement.

CONCLUSIONS

A new class of micro-bend design exploiting whispering gallery modes is proposed. Relaxed fabrication tolerances and low losses, critical for high density photonic interconnection, are predicted. 20 µm radius micro-bends offer minimized total losses of ~0.5 dB/90°. Polarisation conversion is reduced to below 25 dB/90° for sidewall tilts of less than 3°, and is thus achievable with suitably optimised plasma etching.

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