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Euler bends and TIR mirrors for ultra-dense PIC integration on SOI

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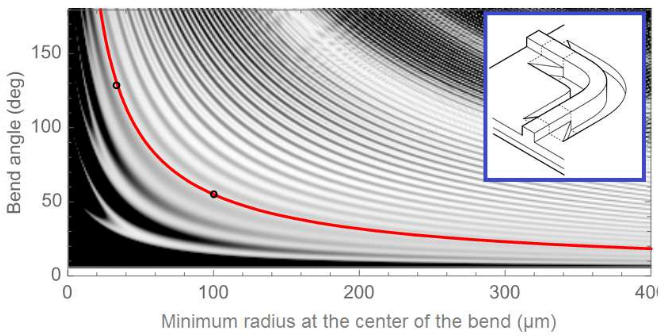
Photonic integrated circuits (PICs) can be realized on multiple technology platforms that all have their own strengths and limitations. In this paper we describe some of the latest results in the ultra-dense integration of PICs using 3 µm thick silicon-on-insulator (SOI) waveguides. In particular we describe the design, fabrication and testing of Euler bends and total internal reflection (TIR) mirrors that both allow to turn light e.g. 90° with an effective bending radius of a few micrometers and ~0.1 dB/90° or smaller loss. For the Euler bends we also introduce a concept that allows designers to draw bends without the need to perform numerical simulations for each bend angle, wavelength and polarization that they want to use in the PIC.

Figure 1 illustrates an Euler bend and the new concept to design it. The bend is realized in a multi-moded (MM) strip waveguide that is adiabatically coupled to singe mode (SM) rib waveguides [1] using rib-strip converters. This way the PIC can be single-moded even if some parts are multi-moded. In 3 µm thick SOI waveguides the light is extremely well confined into the Si core, which eliminates radiation losses in the bend and enables down to 1 µm bending radius with <0.1 dB/90° loss [2]. Figure 1 shows the simulated transmission of TE-polarized light through the Euler bend at 1550 nm wavelength as a function of bend angle and minimum radius. The red line and the two dots show a fitted curve that represents bends that have high transmission and low transmission ripple. One should note that the colour scale is from 99.5% (black) to 100% (white) transmission, so that the ripple around the curve is very small. By using the analytical formula of the curve one can design a bend with arbitrary angle without numerical simulations. Different curves can be defined for different polarizations and wavelengths, although the same design typically works well for both polarizations over a very wide wavelength range.



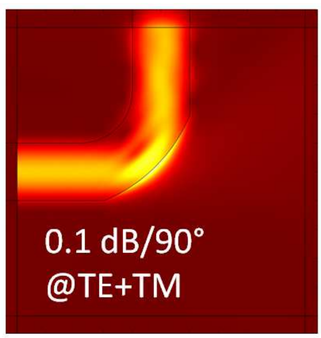
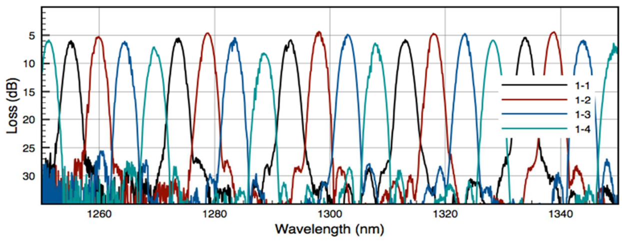


Fig. 23. Left: Simulated light transmission in an Euler bend (schematic in inset). Right: Simulation of a TIR mirror with curved facet (loss result is experimental).

Figure 1 also shows the simulation result for a TIR mirror that has a curved facet. The experimentally measured loss for such a TIR mirror in a strip waveguide is 0.1 dB/90° at both polarizations. Conventional TIR mirrors with straight facet have approximately 0.3 dB/90° loss. The advantage of the TIR mirrors is that they can be integrated directly into SM rib waveguides. However, the Euler bends are a natural choice when strip waveguides are anyway needed to realize e.g. ultra-small multi-mode-interference (MMI) couplers that require very high confinement between the input/output waveguides. The Euler bends can also be used to turn light by an arbitrary angle, unlike the TIR mirrors.

Despite the micron-scale core dimensions the 3 µm SOI waveguides also support the realization of many other densely integrated components, such as arrayed waveguide gratings (AWGs), Echelle gratings and asymmetric Mach-Zehnder interferometers (AMZIs). Examples of such devices have been illustrated in Fig. 2. The benefits of the large core dimensions also include low propagation loss (~0.1 dB/cm), small polarization dependency (dual polarization operation, even for DWDM), tolerance to high optical power and insensitivity to small fabrication errors.



Parameter	Value
Insertion loss	5 dB
Extinction ratio	>20 dB
Pass-band (FWHM)	2.0 nm

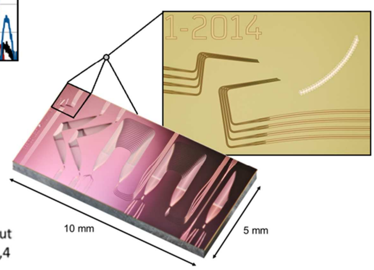


Fig. 2. Bottom right: 3 µm SOI chip with various wavelength multiplexers having 50 GHz (DWDM) to 5 nm (CWDM) channel spacing. The Echelle grating is magnified. Top: Transmission spectra from four AWG outputs with 5 nm channel spacing and tabulated performance. Bottom: Cascaded AMZIs for compact and low-loss multiplexing (here 1x4).

References

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[2] M. Cherchi, S. Ylinen, M. Harjanne, M. Kapulainen, and T. Aalto, "Dramatic size reduction of waveguide bends on a micron-scale silicon photonic platform," Optics Express, vol 21, pp. 17814-17823, 2013