Computational modeling of serpentine low loss trapezoidal silica waveguides on silicon

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Background
Optical waveguides operate on the principle of total internal reflection. If the core of the waveguide has a higher refractive index than the cladding, then light propagating in the core down the length of the waveguide will be totally internally reflected into a guided mode. There are many sources for loss in a waveguide, including insertion loss, propagation loss and bending loss. When a waveguide undergoes a bend, part of the guided mode may be leaked into a radiating mode, which results in the loss of optical power guided by the waveguide. The loss depends on the geometry of the waveguide as well as the index contrast between the core and the cladding. An analytical formula for the bending loss, $a_B$, is shown to the right, where $R$ is the bend radius, $\beta_g$ is the propagation constant of the waveguide, $V$ is proportional to the refractive index contrast between the core and the cladding, $\kappa$ is proportional to the refractive index of the waveguide, the free space propagation constant and $\gamma$ is proportional to the refractive index of the cladding layer, the free space propagation constant and $\beta_g$.

Fabrication
The devices are fabricated using a 3-step process. The steps, briefly, are as follows: 1) Double photolithography and Buffered HF etching (a,b,d), 2) XeF$_2$ etching to undercut the silica (c,e), 3) cleaving the end using a diamond scribe to create clean input and output facets (f).

Simulations
Simulations were performed using COMSOL multiphysics and Lumerical FDTD software. The bend loss simulations were performed using 3D models in the FDTD software.

Data and Results
Overview of $R = 50 \mu$m FDTD simulation showing optical power in the waveguide. Power clearly leaks out of the waveguide and into the silica membrane while travelling through the inner bend, however, the outer bend contains the light without leaking it to a radiating mode.

Calculated bending loss from simulations compared to the measured bending loss. The simulation loss is slightly lower because we did not model the silicon pillar.

Conclusions and Future Work
We developed a computational model for our silica suspended waveguides in order to characterize the bending losses of these devices. The simulations did not include the silicon pillar due to memory constraints of our computer system. Our developed model corroborated our experimental measurements, and confirmed our theory for the loss mechanism. We believe the primary loss mechanism in the bent devices is leakage of the optical field into the silica membrane followed by loss into the higher refractive index silicon pillar. From our results, we calculated the critical bending radius to be below 375 $\mu$m for all wavelengths tested. Loss in these devices could be reduced by limiting the optical signal to travelling through only outside bends, or by thinning the silica membrane.

Due to the current high performance and small bending radius of these devices, we believe they will find use in many applications in integrated photonics.

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