Ming Hsieh Department of Electrical Engineering

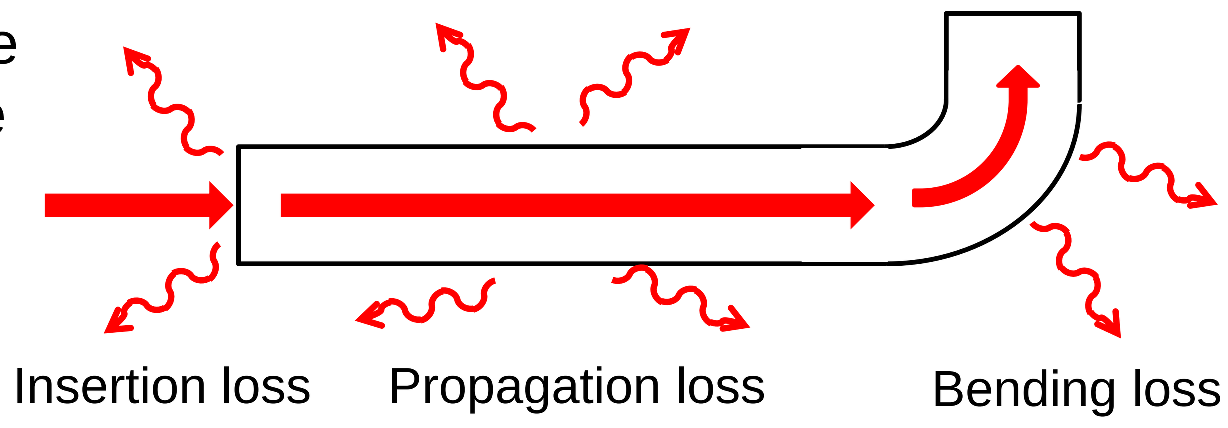
USC Viterbi School of Engineering

Computational modeling of serpentine low loss trapezoidal silica waveguides on silicon

Mark C. Harrison, Xiaomin Zhang, Audrey Harker, Andrea M. Armani

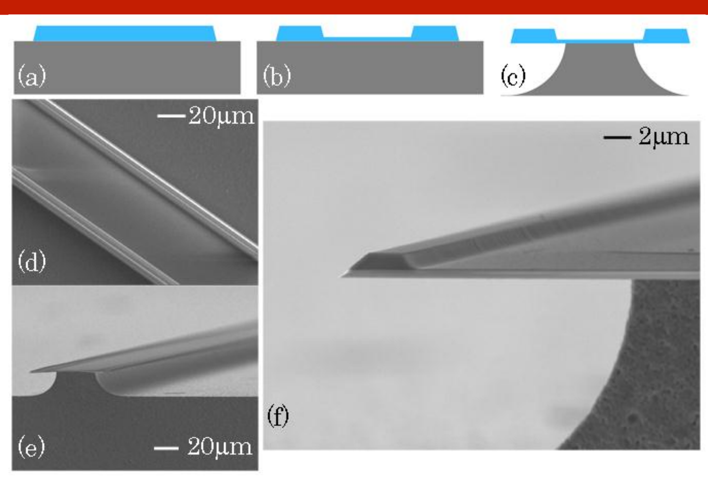
Background

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, α_B, is shown to the right, where R is the bend radius, β_g is the propagation constant of the waveguide, V is proportional to the refractive index contrast between the core and the cladding, κ is proportional to the refractive index of the waveguide, the free space propagation constant and β_g, and γ is proportional to the refractive index of the cladding layer, the free space propagation constant and β_g.



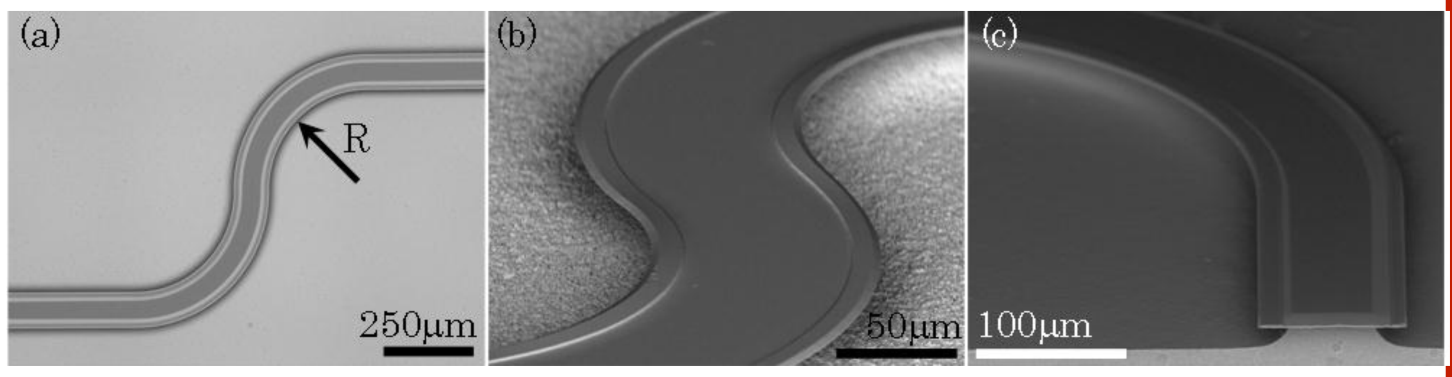
$$\alpha_B \propto \left(\frac{\pi}{\gamma^3 R}\right)^{1/2} \left(\frac{\kappa}{V}\right)^2 \exp\left(-\frac{2}{3}\left(\gamma^3/\beta_g^2\right)R\right)$$

Fabrication

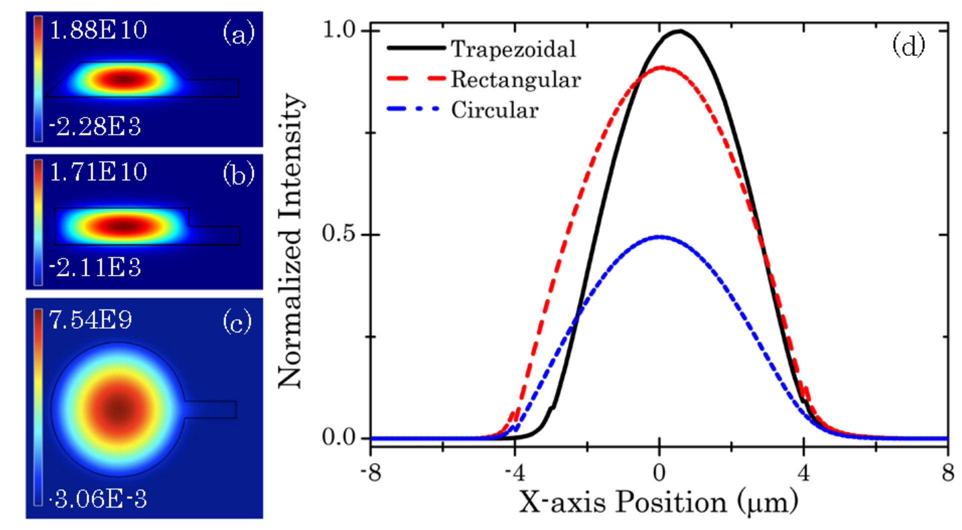


The devices are fabricated using a 3-step process. The steps, briefly, are as follows: 1) Double photolithography and Buffered HF etching (a,b,d), 2) XeF_2 etching to undercut the silica (c,e), 3) cleaving the end using a diamond scribe to create clean input and output facets (f).

SEM images of serpentine waveguides. a) Overhead view indicating internal radius, R. b) Tilted view of the s-shaped curve. c) Tilted view of end-facet of the waveguide.

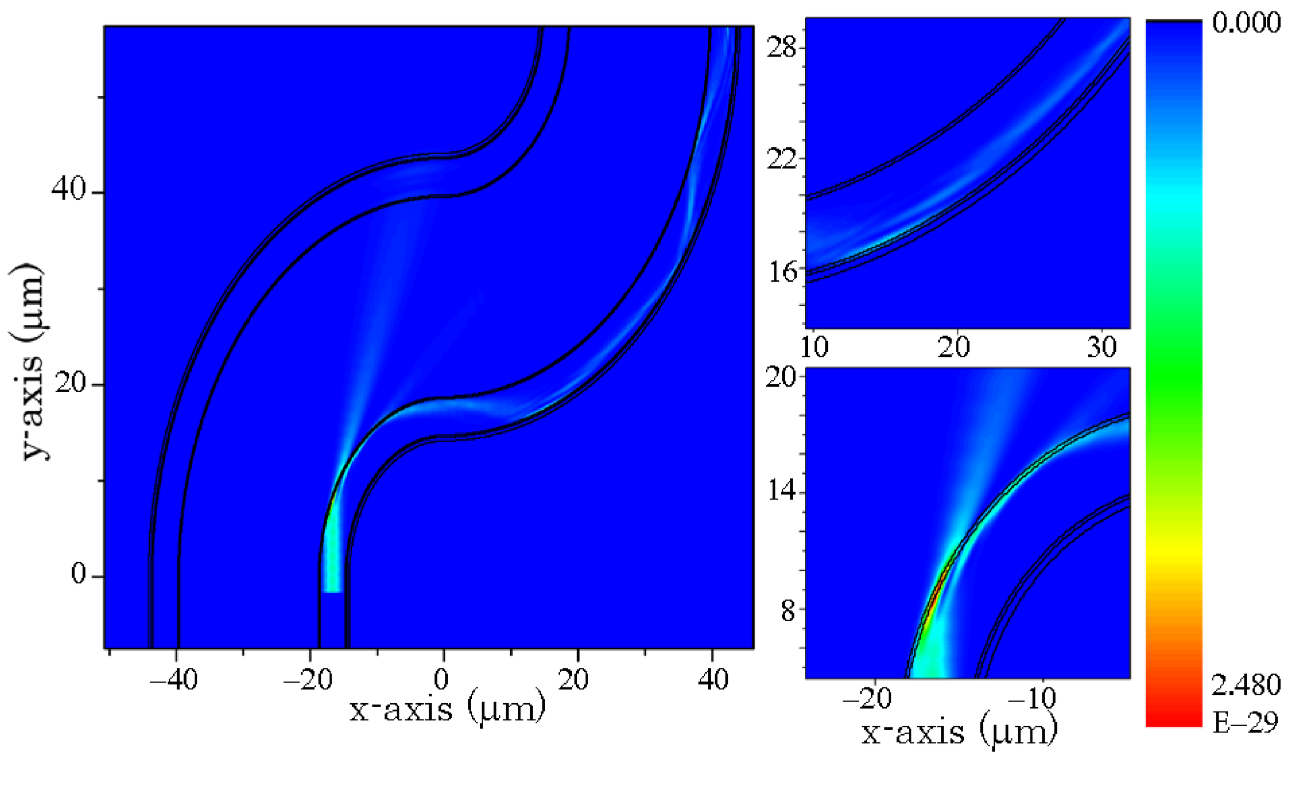


Simulations



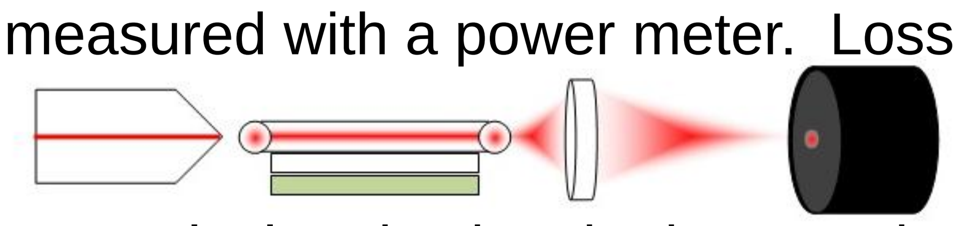
Simulations were performed using COMSOL multiphysics and Lumerical FDTD software. The bend loss simulations were performed using 3D models in the FDTD software.

Data and Results



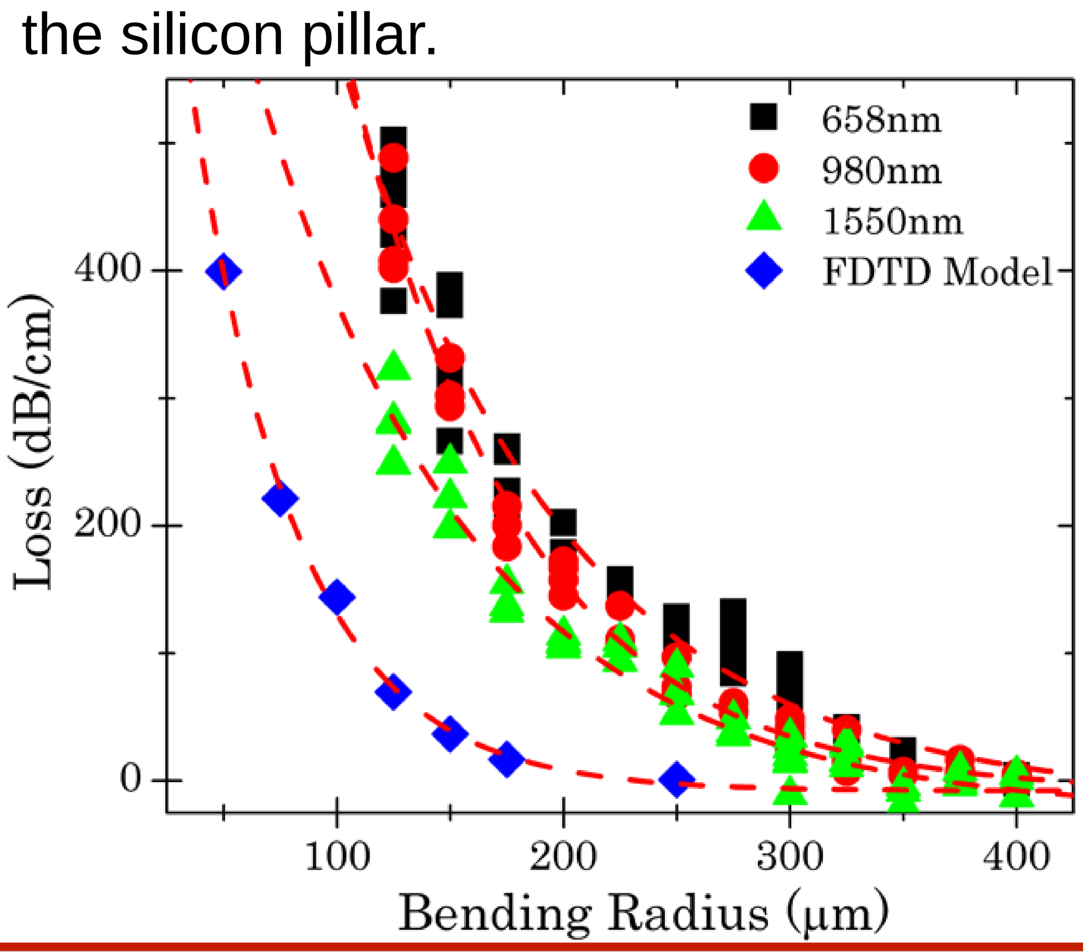
Overview of R = 50 μm FDTD simulation showing optical power in the waveguide. Power clearly leaks out of the waveguide and into the silica membrane while travelling through the inner bend, however, the outer bend contains the light without leaking it to a radiating mode.

Measurements were performed by coupling light into waveguides fabricated with two bends at various bending radii and wavelengths. Thus, the light travels through an inner and outer bend for every device tested. Output light was collected with an aspheric lens and measured with a power meter. Loss



was calculated using the input and output power of the waveguide, and by subtracting the propagation loss of the device using measured losses and the device length. Finally, the bending loss was normalized by the length of the curved region of the waveguide.

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 μm 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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More information is available at:
Armani Research Group: http://armani.usc.edu
Mark C. Harrison: http://www-scf.usc.edu/~markchar

Ming Hsieh Institute
Ming Hsieh Department of Electrical Engineering