The Glass Ceiling: *Limits of Silica*

**Loss:** amplifiers every 50–100km
...limited by Rayleigh scattering (molecular entropy)
...cannot use “exotic” wavelengths like 10.6µm

**Nonlinearities:** after ~100km, cause dispersion, crosstalk, power limits
(limited by mode area ~ single-mode, bending loss)
also cannot be made (very) large for compact nonlinear devices

**Radical modifications to dispersion, polarization effects?**
...tunability is limited by low index contrast

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**Breaking the Glass Ceiling:**
Hollow-core Bandgap Fibers

- Bragg fiber
- OmniGuide fibers
- PCF

**State-of-the-art air-guiding losses**

- 1.7dB/km
  BlazePhotonics
  over ~ 800m @1.57µm
State-of-the-art air-guiding losses
larger core = more surface states crossing guided mode
… but surface states can be removed by proper crystal termination

Hollow Metal Waveguides, Reborn
metal waveguide modes
OmniGuide fiber modes
wavenumber $\beta$

An Old Friend: the $\text{TE}_{01}$ mode
lowest-loss mode, just as in metal
(near) node at interface
= strong confinement
= low losses
non-degenerate mode
— cannot be split
= no birefringence or PMD

Suppressing Cladding Losses

[ Johnson, Opt. Express 9, 748 (2001) ]
Yes, but how do you make it?
[ figs courtesy Y. Fink et al., MIT ]

1. Find compatible materials (many new possibilities)
2. Make pre-form ("scale model")
3. Fiber drawing

Chalcogenide glass, $n \approx 2.8$
Polymer (or oxide), $n \approx 1.5$

A Drawn Bandgap Fiber
[ figs courtesy Y. Fink et al., MIT ]

- Photonic crystal structural uniformity, adhesion, physical durability through large temperature excursions

White/grey = chalco/polymer

High-Power Transmission
at 10.6µm (no previous dielectric waveguide)

Polymer losses @ 10.6µm ~ 50,000dB/m...

...waveguide losses < 1dB/m

Breaking the Glass Ceiling II:
Solid-core Holey Fibers

Solid core
Holey cladding forms effective low-index material

Can have much higher contrast than doped silica...
Strong confinement = enhanced nonlinearities, birefringence, ...

Mode in a Solid Core

small computation: only lowest-ω band!
(~ one minute, planewave)

Endlessly Single-Mode


at higher ω
(smaller λ),
the light is more
concentrated in silica

...so the effective
index contrast is less

...and the fiber can stay
single mode for all λ!

Band Diagram in “Metallic” Limit

Band Gaps from “Metallic” Limit

http://www.bath.ac.uk/physics/groups/opto
Nonlinear Holey Fibers:  

Supercontinuum Generation
(enhanced by strong confinement + unusual dispersion)

*e.g.* 400–1600nm “white” light:
from 850nm ~200 fs pulses (4 nJ)

Suppressing Cladding Nonlinearity

*Mode Nonlinearity* \( \div \) *Cladding Nonlinearity*

Will be dominated by nonlinearity of air

~10,000 times weaker than in silica fiber
(including factor of 10 in area)

* “nonlinearity” = \( \Delta \beta^{(1)}/P = \gamma \)

Holey Fiber PMF
(Polarization-Maintaining Fiber)

Birefringence \( B = \Delta \beta_c/\omega \) = 0.0014
(10 times \( B \) of silica PMF)

Loss = 1.3 dB/km @ 1.55\( \mu \)m over 1.5km

Can operate in a single polarization, \( \text{PMD} = 0 \)
(also, known polarization at output)