Subwavelength-diameter silica wires for microscale optical components
and also....

at Harvard:

Jonathan Aschom
Mengyan Shen
Iva Maxwell
James Carey
Brian Tull
Dr. Yuan Lu
Dr. Richard Schalek
Prof. Federico Capasso
Prof. Cynthia Friend

at Zhejiang University:

Dr. Sailing He
Dr. Jingyi Lou
Xuewen Chen
Liu Liu
Zhanghua Han

Dr. Ray Mariella (LLNL)
Outline

- waveguiding
- nanowire fabrication
- optical properties
single mode condition for 600-nm light:

\[ M = 2 \frac{d}{\lambda} (n_1^2 - n_2^2)^{1/2} \]

without cladding: \( d < 268 \text{ nm} \)

Add cladding with 0.4% index difference:

\( d < 5 \text{ \mu m} \)
### Waveguiding

**commercial single-mode fiber (Corning Titan®)**

<table>
<thead>
<tr>
<th></th>
<th>core</th>
<th>cladding</th>
</tr>
</thead>
<tbody>
<tr>
<td>index</td>
<td>( n_1 = 1.468 )</td>
<td>( n_2 = 1.462 )</td>
</tr>
<tr>
<td>diameter:</td>
<td>8.3 ( \mu \text{m} )</td>
<td>125.0 ( \pm 1.0 ) ( \mu \text{m} )</td>
</tr>
</tbody>
</table>

**operating wavelength:** \( \lambda = 1310 \, \text{nm} / 1550 \, \text{nm} \)
drawbacks of clad fibers:

- weak confinement
- no tight bending
- coupling requires splicing
Waveguiding
• waveguiding

• nanowire fabrication

• optical properties
Nanowire fabrication

two-step drawing process

standard fiber
Nanowire fabrication

two-step drawing process

standard fiber
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire

drawing
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire

sapphire taper
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire

drawing

sapphire taper

silica wire
Nanowire fabrication

two-step drawing process

standard fiber

1-µm silica wire

drawing

flame

sapphire taper

silica wire
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire

flame

sapphire taper

silica wire
Nanowire fabrication

two-step drawing process
Nanowire fabrication
Nanowire fabrication

Nanowire fabrication
Nanowire fabrication
Nanowire fabrication

500 µm
Nanowire fabrication
Nanowire fabrication
Nanowire fabrication
Nanowire fabrication

50 μm
Nanowire fabrication

20 µm
Nanowire fabrication

6 µm
Nanowire fabrication

2 µm

2 µm
Nanowire fabrication
Waveguiding

Specifications

diameter $D$: down to 20 nm

length $L$: up to 90 mm

aspect ratio $D/L$: up to $10^6$

diameter uniformity $\Delta D/L$: $2 \times 10^{-6}$
Nanowire fabrication

\[ d = 260 \text{ nm} \]

\[ L = 4 \text{ mm} \]
Nanowire fabrication

240-nm wire
Nanowire fabrication

RMS roughness < 0.5 nm
Nanowire fabrication
Nanowire fabrication

bend to breaking point

50 µm
Nanowire fabrication

bend to breaking point
Nanowire fabrication

bend to breaking point

50 µm
Nanowire fabrication
Outline

• waveguiding

• nanowire fabrication

• optical properties
Optical properties

coupling light into nanowires
Optical properties

coupling light into nanowires
Optical properties

coupling light into nanowires
Optical properties

280-nm nanowire

360 nm

450 nm
Optical properties
Optical properties

Poynting vector profile for 800-nm nanowire
Optical properties

Poynting vector profile for 800-nm nanowire
Optical properties

Poynting vector profile for 800-nm nanowire

evanescent wave
Optical properties

Poynting vector profile for 600-nm nanowire
Optical properties

Poynting vector profile for 500-nm nanowire
Optical properties

Poynting vector profile for 400-nm nanowire
Optical properties

Poynting vector profile for 300-nm nanowire
Optical properties

Poynting vector profile for 200-nm nanowire
Waveguiding

fraction of power carried in core

- 633 nm
- 1550 nm
Optical properties
Optical properties

coupling light between nanowires

Diagram showing a support, a nanowire, and a fiber taper.
Optical properties

coupling light between nanowires

- fiber taper
- support
- nanowire
Optical properties

coupling light between nanowires

- fiber taper
- light
- nanowire
- support
Optical properties

50 μm
Optical properties

50 µm
Optical properties

intensity distribution
Optical properties

loss measurement

Optical properties

loss measurement

Optical properties

loss measurement

Optical properties

Optical properties

Loss measurement

Optical properties

Loss measurement

Optical properties

loss at single-mode diameter < 0.1 dB/mm

Optical properties

100 µm
Optical properties

minimum bending radius: 5.6 µm
Optical properties

virtually no loss through 5 µm corner!
Summary

- strong confinement
- very tight bending
- large evanescent wave
Outlook

microphotonic components
Outlook
Outlook
Aerogel

density: 1.9 kg/m³

index of refraction: 1.03–1.08
Outlook
Outlook

loss measurement @ 633 nm

Nanoletters, in press (2005)
Outlook

530 nm

50 μm
Outlook

10 µm

530 nm
Outlook

bending loss @ 633 nm

Nanoletters, in press (2005)
Outlook

420 nm

aerogel

420 nm
Outlook

in

out

out
Outlook

5 µm
Funding:

Harvard Center for Imaging and Mesoscopic Structures
National Science Foundation
National Natural Science Foundation of China

for a copy of this presentation:

http://mazur-www.harvard.edu
Optical properties
Optical properties

self-phase modulation

![Graph showing self-phase modulation](image)
Optical properties

self-phase modulation

![Graph showing self-phase modulation](image)
Optical properties

self-phase modulation

![Graph showing optical properties and self-phase modulation](image-url)