Subwavelength-diameter silica wires for microscale optical components

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and also....

at Harvard:

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Dr. Ray Mariella (LLNL)
Outline

- waveguiding
- nanowire fabrication
- optical properties
Waveguiding

single mode condition for 600-nm light:

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

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®)

- **Core:**
  - Index: $n_1 = 1.468$
  - Diameter: $8.3 \, \mu m$

- **Cladding:**
  - Index: $n_2 = 1.462$
  - Diameter: $125.0 \pm 1.0 \, \mu m$

**Operating Wavelength:** $\lambda = 1310 \, \text{nm} / 1550 \, \text{nm}$
drawbacks of clad fibers:

- weak confinement
- no tight bending
- coupling requires splicing
Waveguiding
Outline

- waveguiding
- nanowire fabrication
- optical properties
Nanowire fabrication

two-step drawing process

standard fiber
Nanowire fabrication

two-step drawing process
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire
drawing

sapphire taper
Nanowire fabrication

two-step drawing process
Nanowire fabrication

two-step drawing process

standard fiber

1-μm silica wire

drawing

flame

sapphire taper

silica wire
Nanowire fabrication

two-step drawing process
Nanowire fabrication

two-step drawing process
Nanowire fabrication
Nanowire fabrication
Nanowire fabrication

1000 µm
Nanowire fabrication
Nanowire fabrication

200 µm
Nanowire fabrication
Nanowire fabrication
Nanowire fabrication

50 µm
Nanowire fabrication

20 µm
Nanowire fabrication
Nanowire fabrication

2 μm
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

200 nm
Nanowire fabrication

RMS roughness < 0.5 nm

20 nm
Nanowire fabrication

bend to breaking point

50 µm
Nanowire fabrication

bend to breaking point

50 µm
Nanowire fabrication

bend to breaking point

50 µm
Nanowire fabrication
Nanowire fabrication
Nanowire fabrication

20 µm
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
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

![Graph showing the fraction of power in the core vs. diameter for different wavelengths (633 nm and 1550 nm).]
Optical properties
Optical properties

coupling light between nanowires
Optical properties

coupling light between nanowires

- fiber taper
- support
- nanowire
Optical properties

coupling light between nanowires

- Fiber taper
- Light
- Support
- Nanowire
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

loss measurement

Optical properties

loss measurement

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

100 µm
Optical properties

minimum bending radius: 5.6 µm

100 µm
Optical properties

virtually no loss through 5 µm corner!

![Graph showing optical properties](image)
Summary

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

microphotonic components
Outlook

500 nm
Outlook
Outlook

5 µm
Outlook
Outlook

loss measurement @ 633 nm

Nanoletters, in press (2005)
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10 µm

530 nm

10 µm
Outlook

bending loss @ 633 nm

Nanoletters, in press (2005)
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420 nm

aerogel
Outlook

in

out

out
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