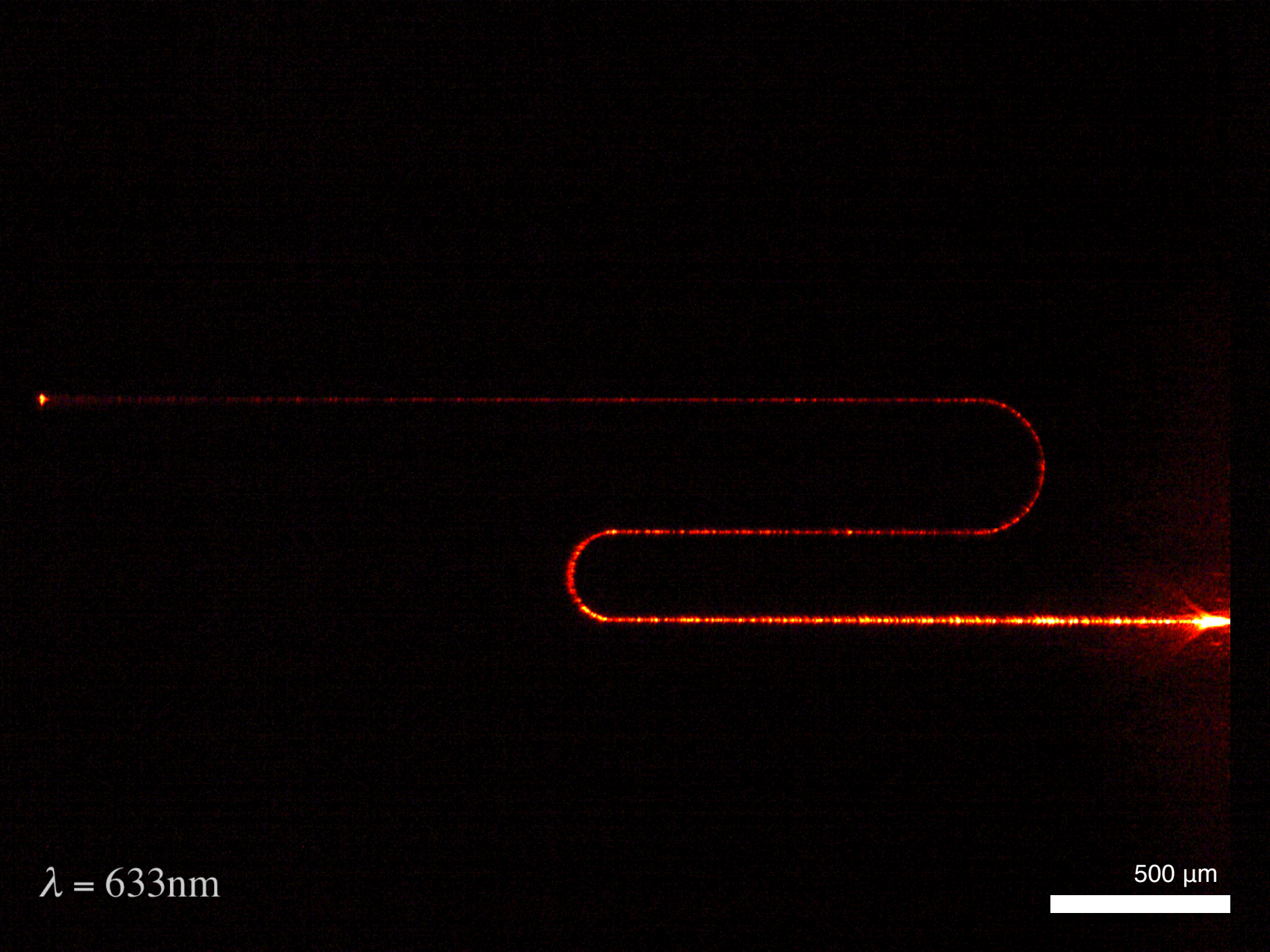
Titanium dioxide for nanophotonics

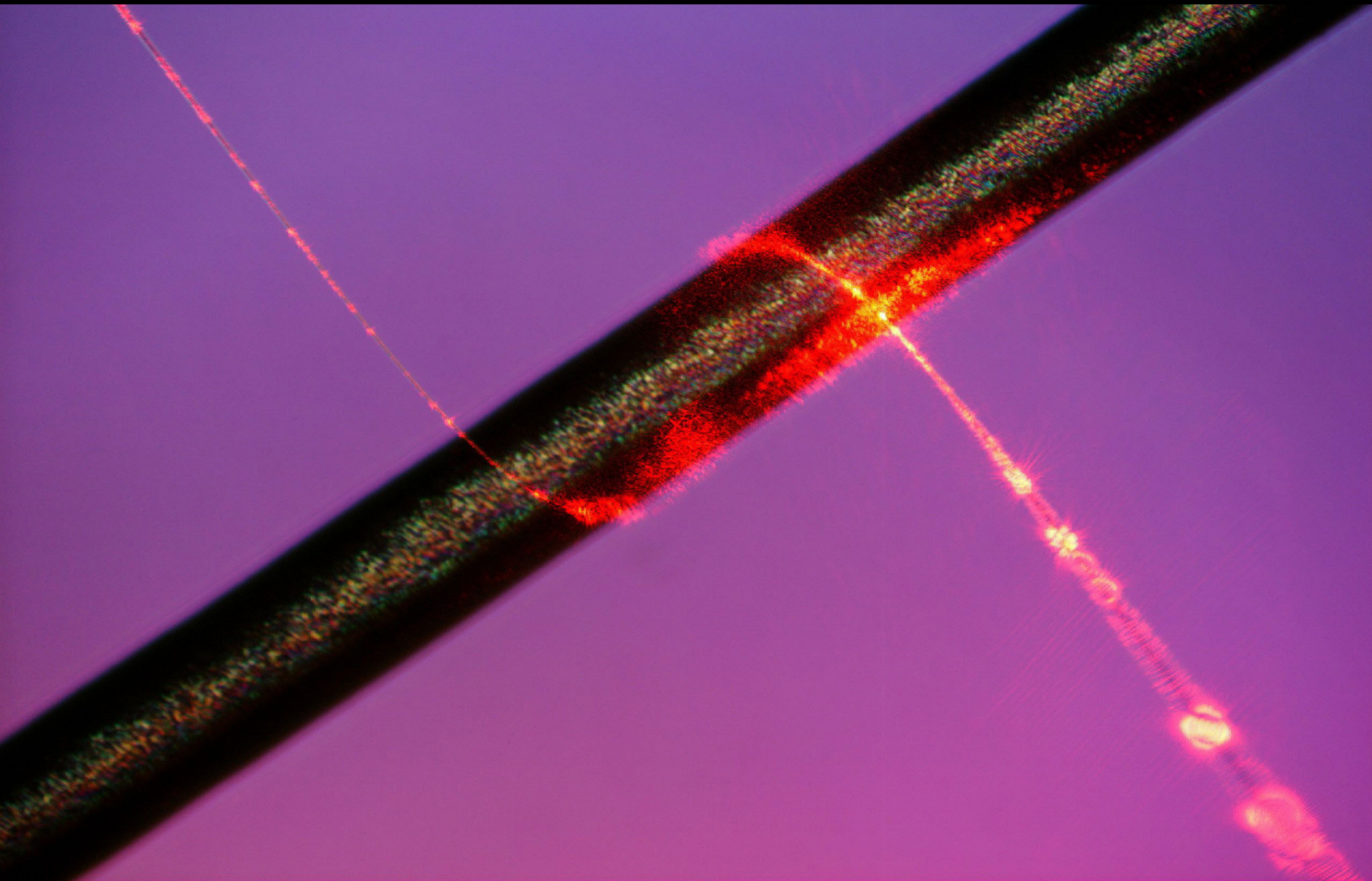
Orad Reshef

SPIE Optics and Photonics
San Diego, California
29 August, 2013

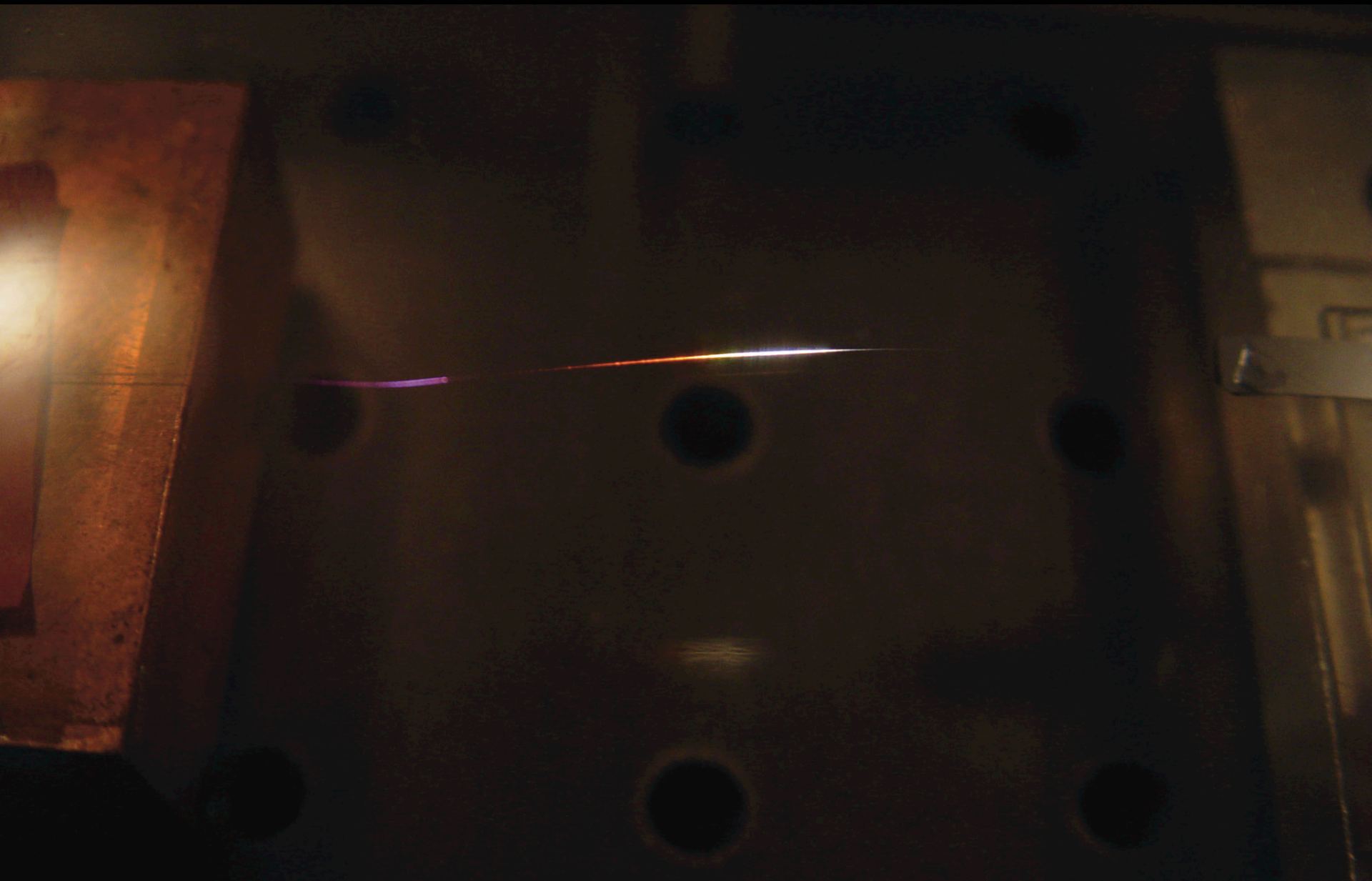
MAZUR GROUP


$\lambda = 633\text{nm}$
500 μm

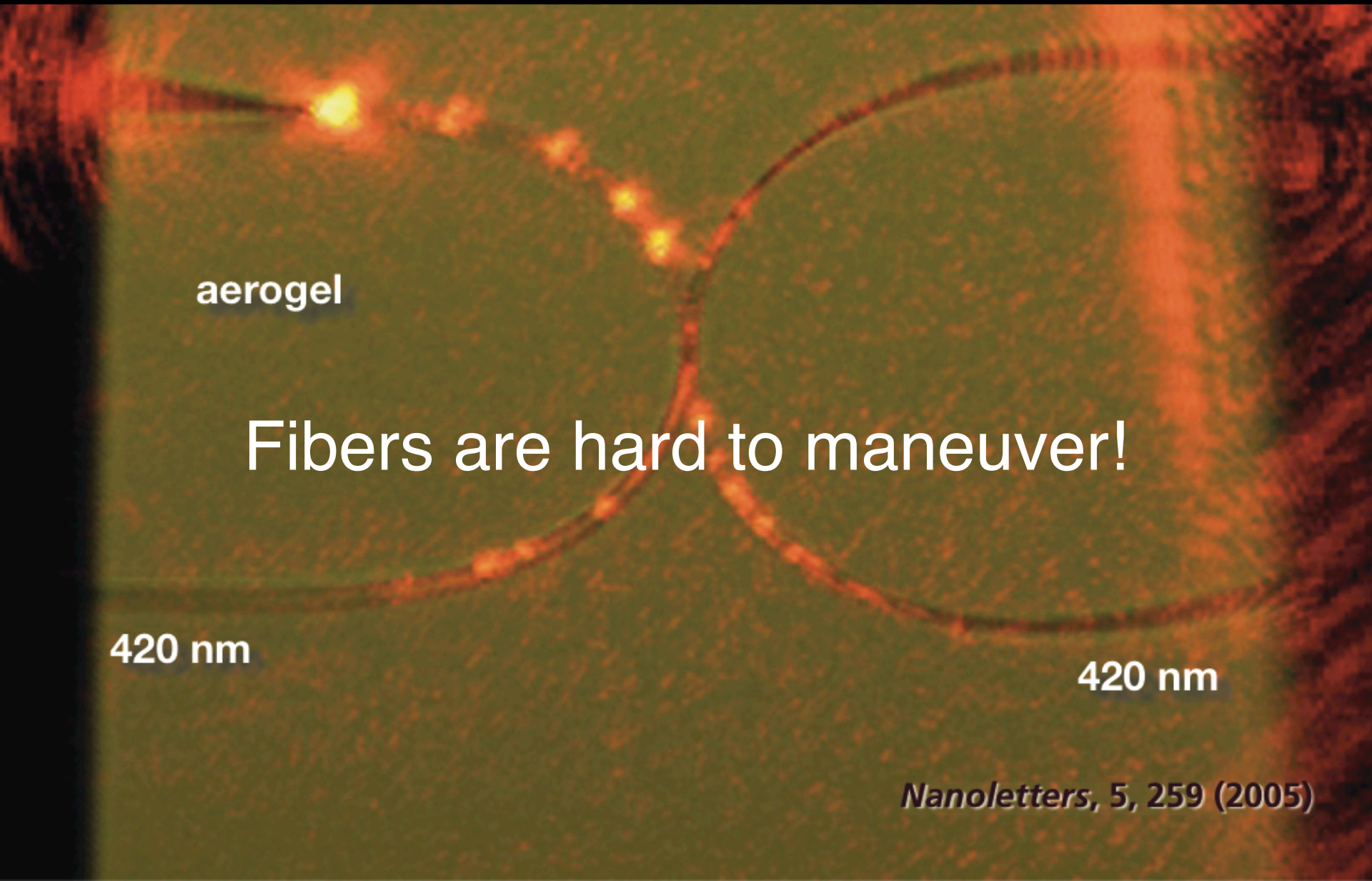
Silica nanowires



Silica nanowires



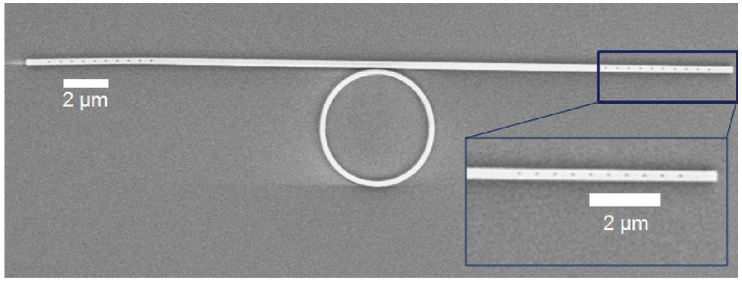
Silica nanowires



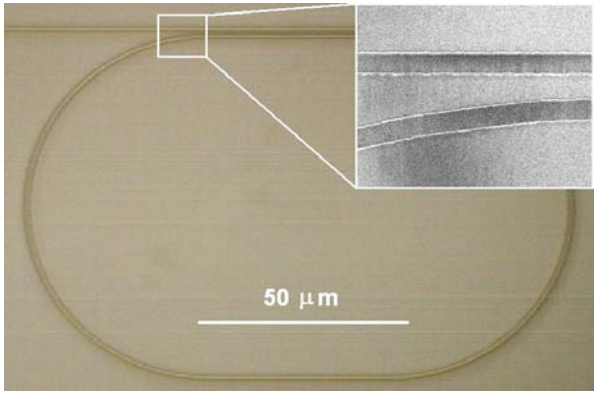
Fibers are hard to maneuver!

Nanoletters, 5, 259 (2005)

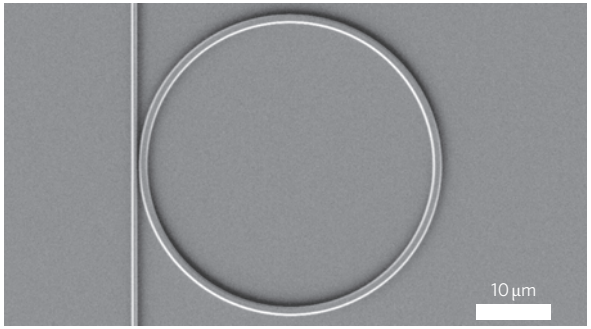
Photonic Integrated Circuits



Diamond



Chalcogenide
Glass



Silicon

M. Loncar et. al. *Nano Letters* (2012)
L. Kimerling et. al. *Optics Letters* (2008)
M. Lipson et. al. *Nature Photonics* (2009)

Material

What are we looking for in a material?

Convenience	Technical
Inexpensive	Large linear index n_0
Non-toxic	Large nonlinear index n_2
Abundant	Transparency at wavelengths of interest

Operation wavelength

telecommunication

1550 nm

Operation wavelength

...to the interconnect band at 850 nm

across the telecom octave

Titanium dioxide

Anatase

Brookite

Rutile

Wikipedia.org, “Titanium dioxide”

Titanium dioxide

Large refractive index

2.4

Large nonlinear index

9.7×10^{-19} m^2/W

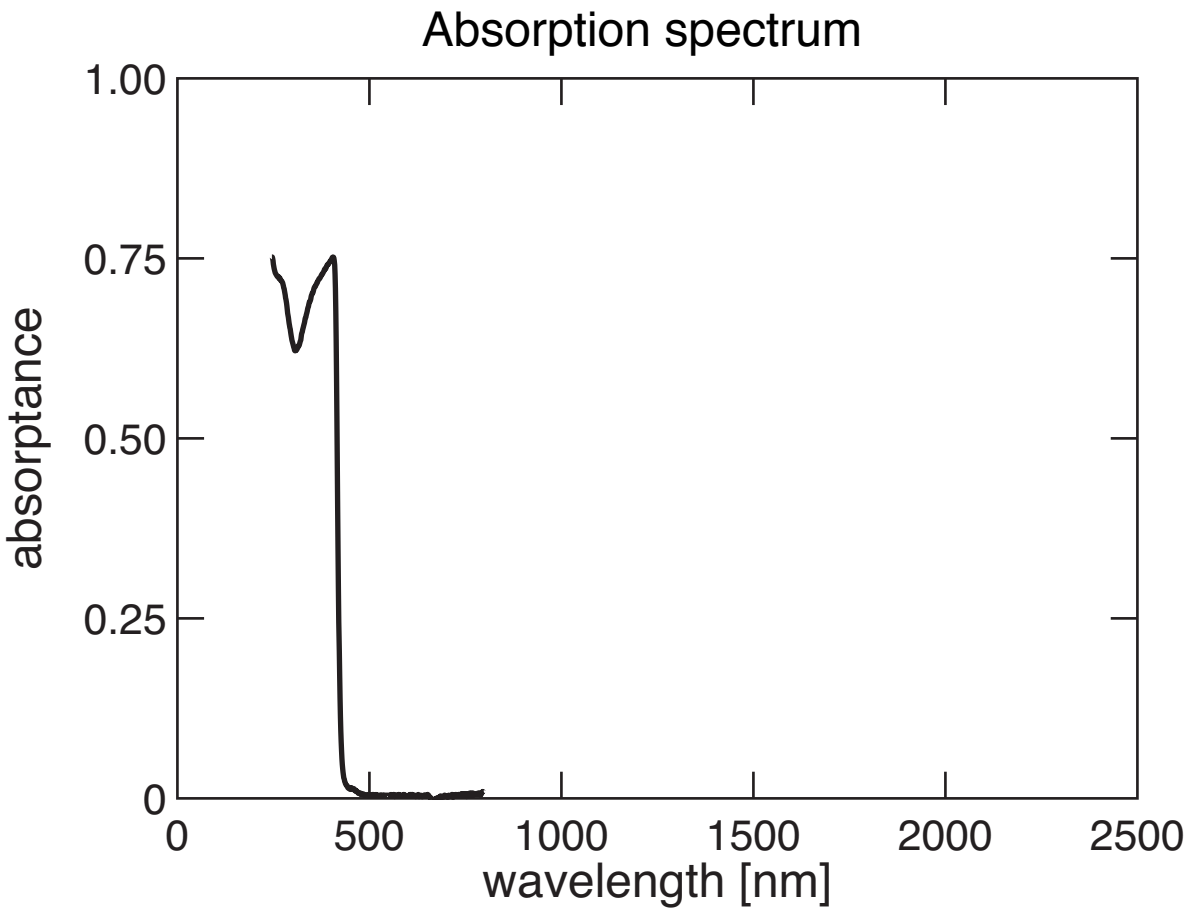
(40 x silica)

Large transparency

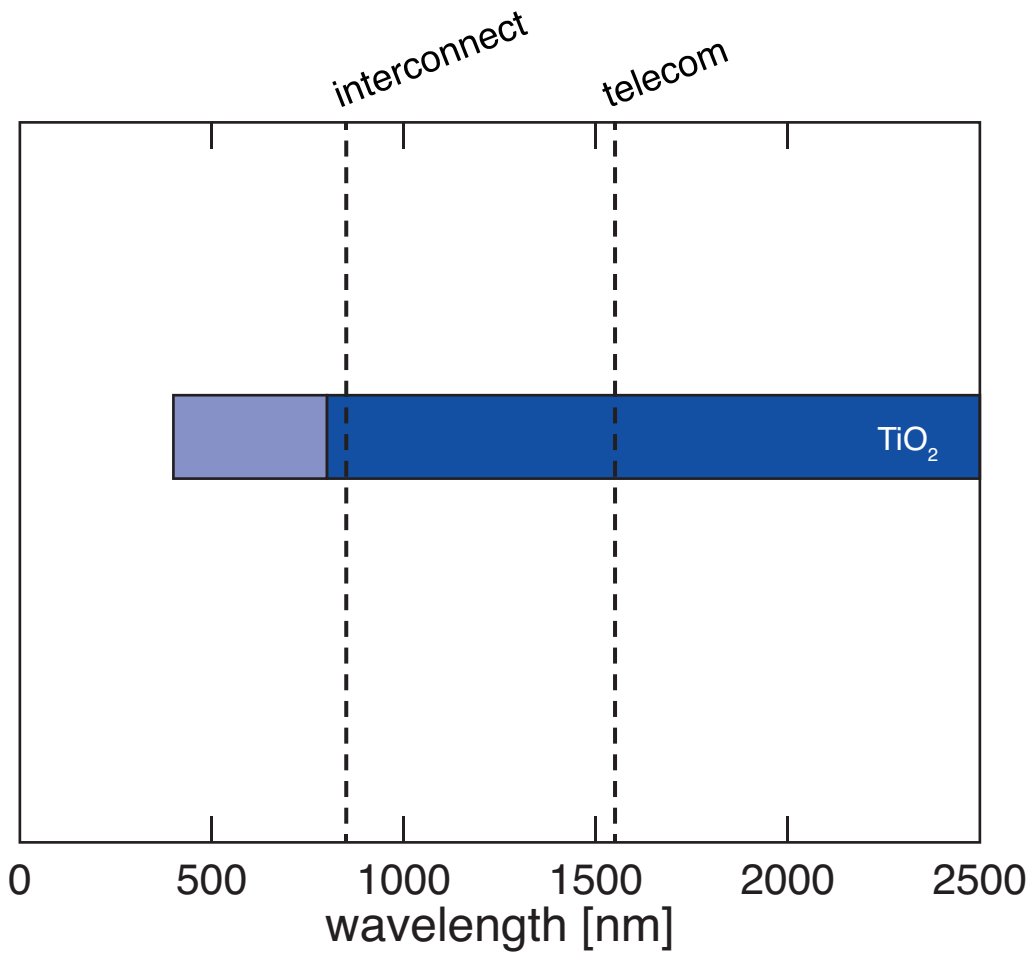
Absorption edge: 400 nm

Low two-photon absorption: > 800 nm

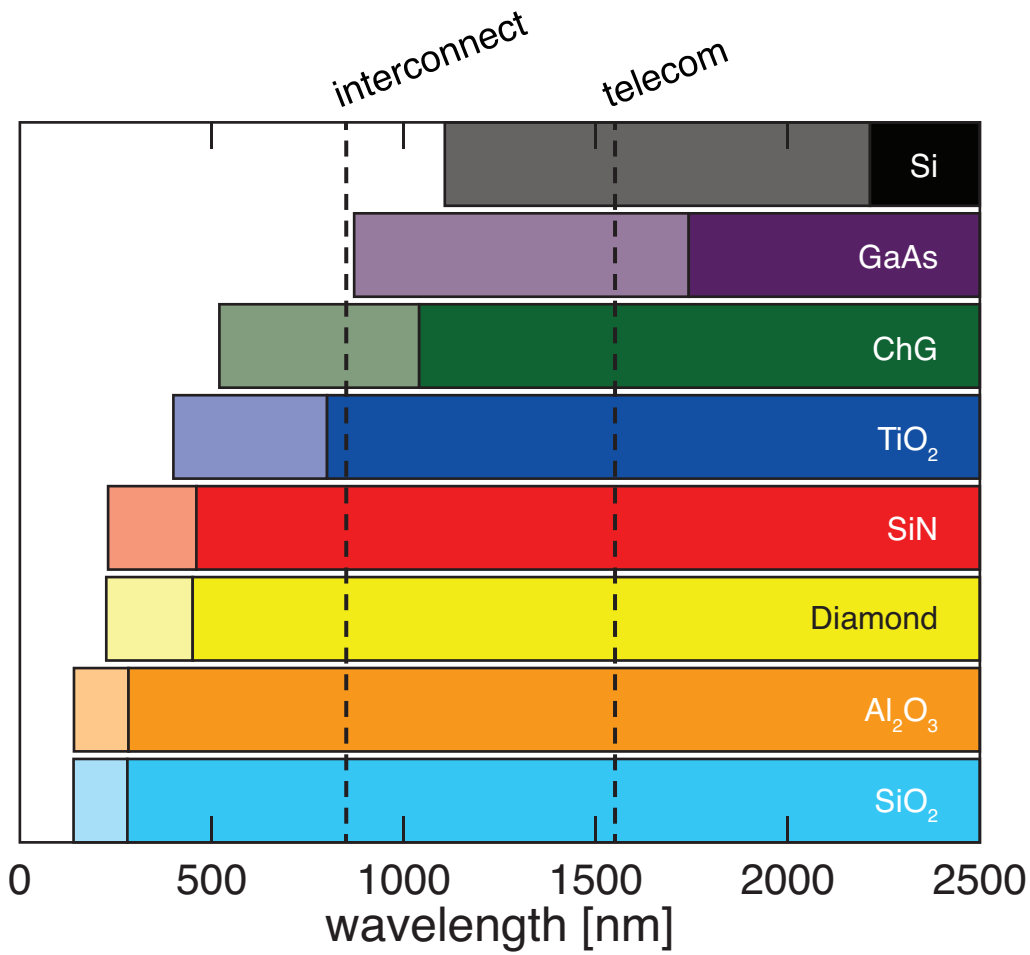
Titanium dioxide



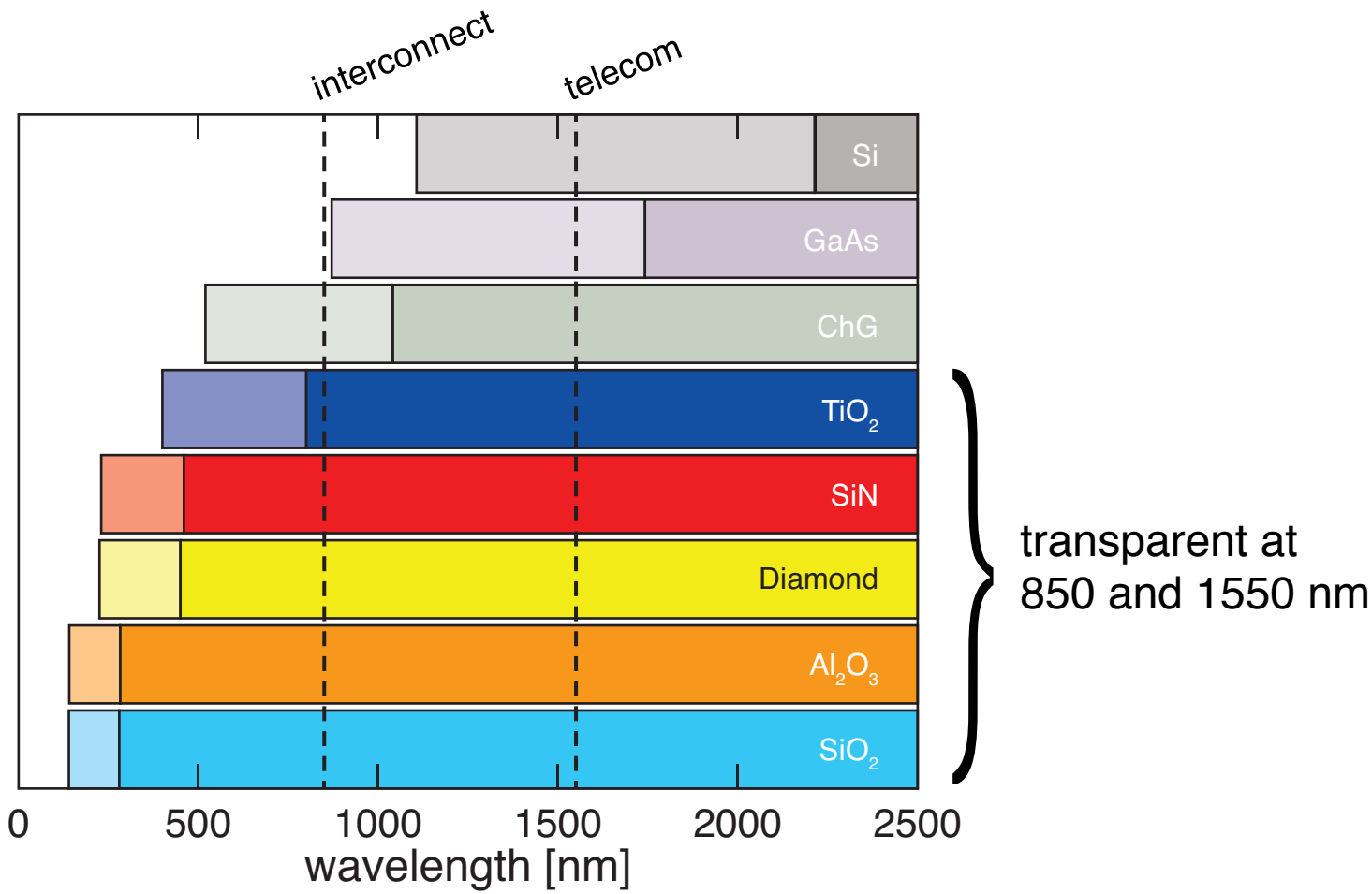
Titanium dioxide



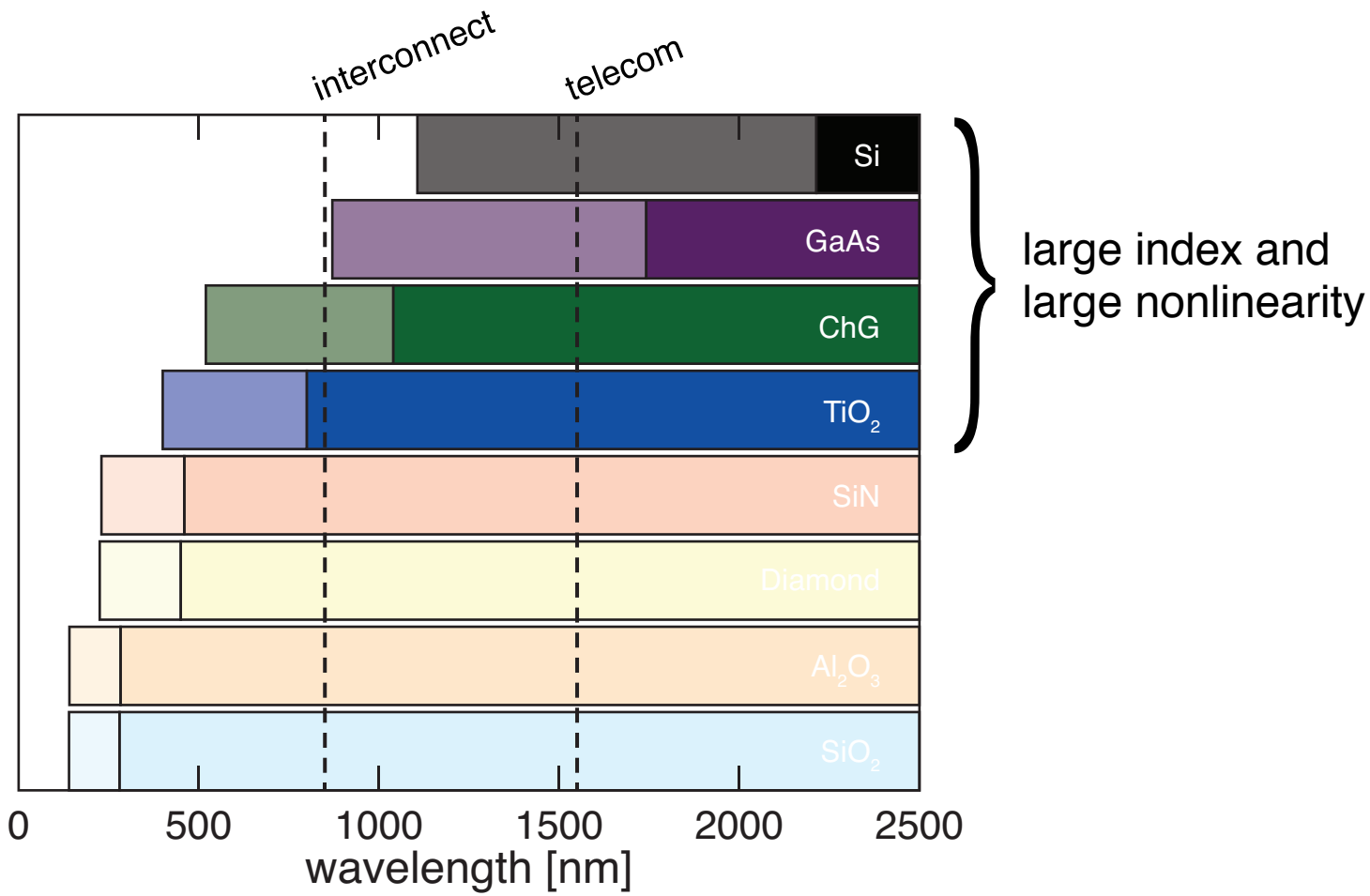
Titanium dioxide



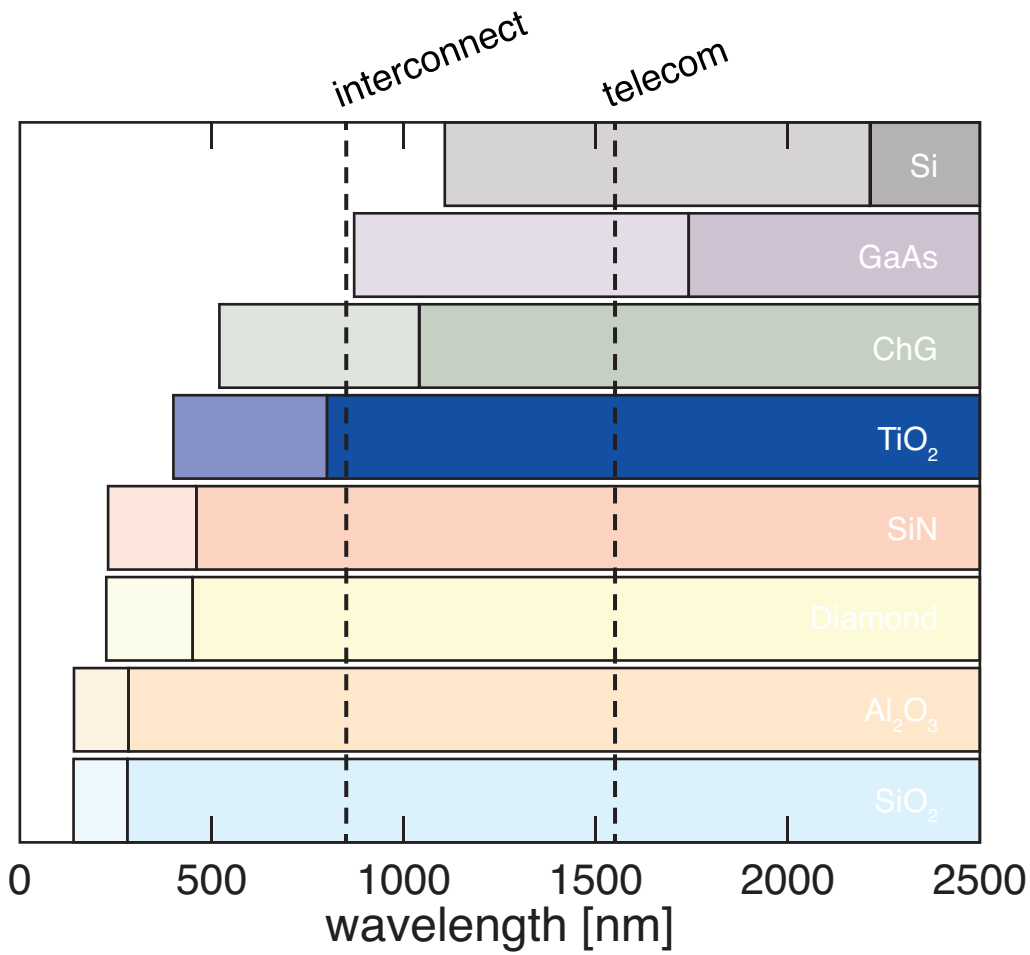
Titanium dioxide



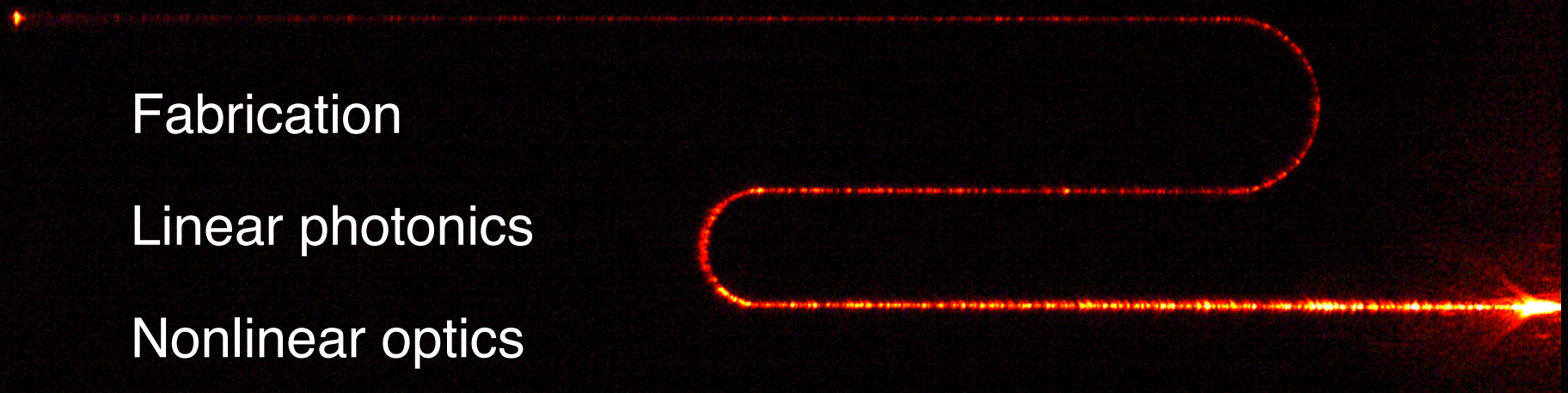
Titanium dioxide



Titanium dioxide



Titanium dioxide for nanophotonics



Fabrication

Linear photonics

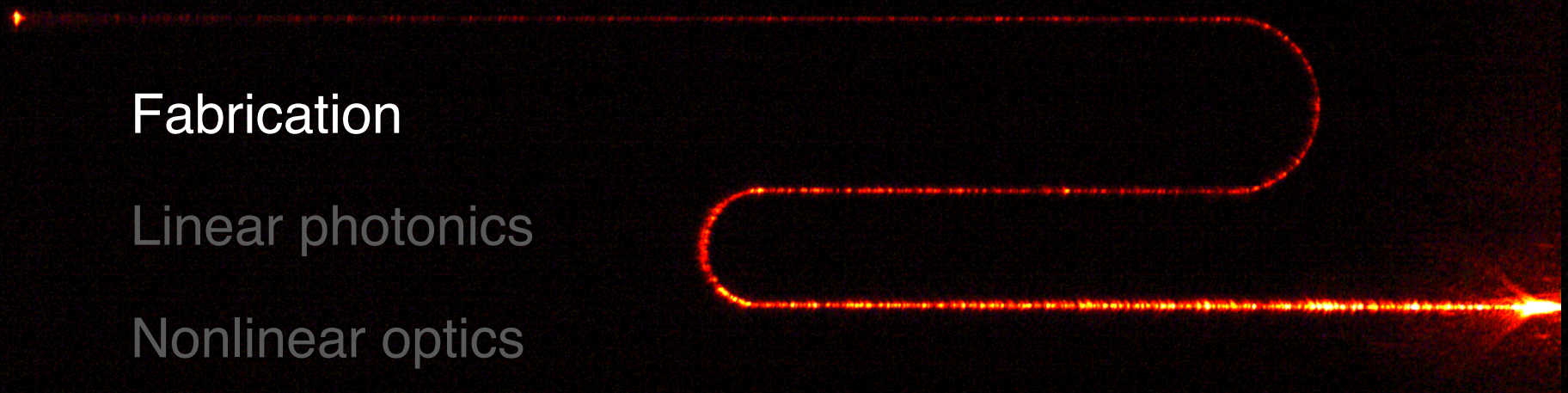
Nonlinear optics

Titanium dioxide for nanophotonics

Fabrication

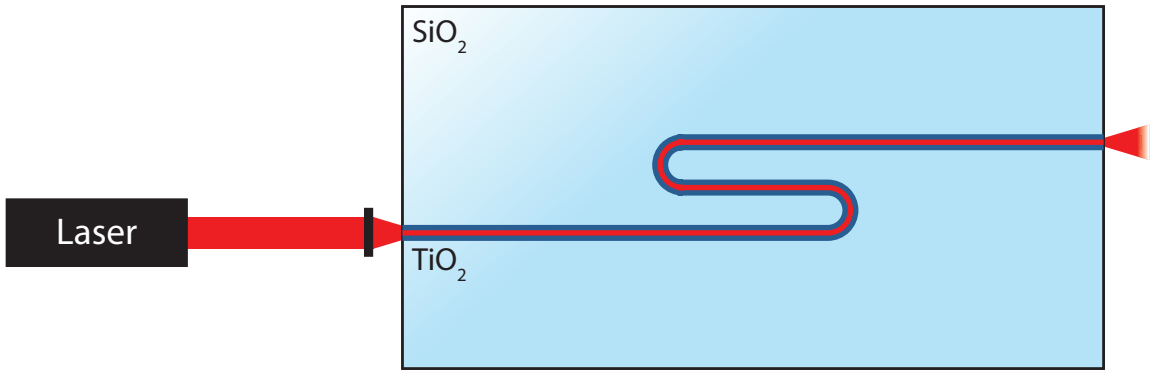
Linear photonics

Nonlinear optics

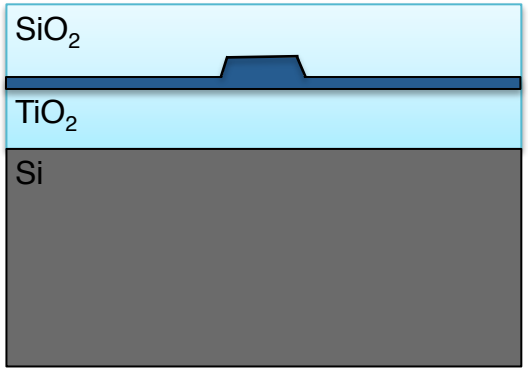


Fabrication

Top-down view

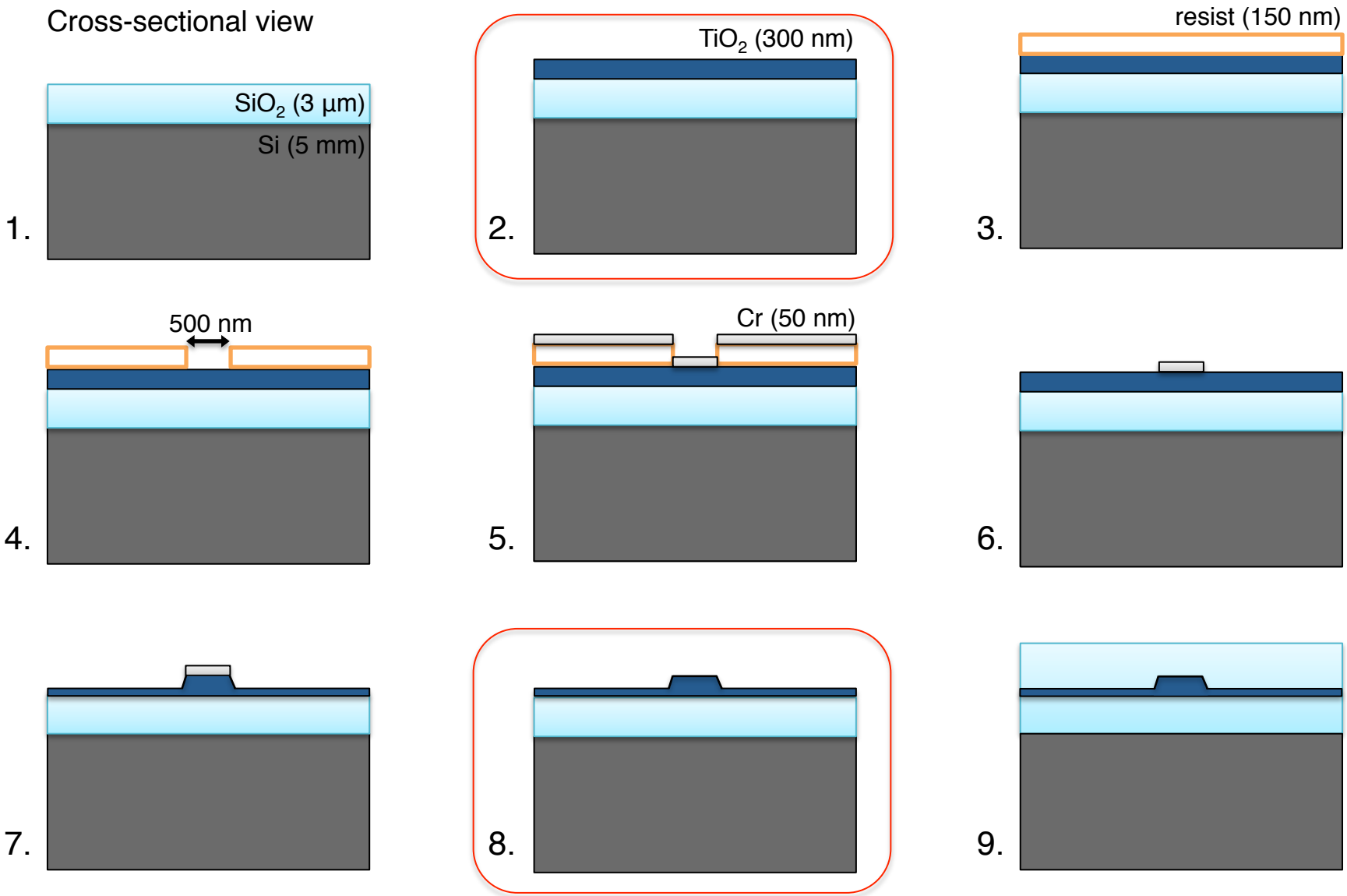


Cross-sectional view

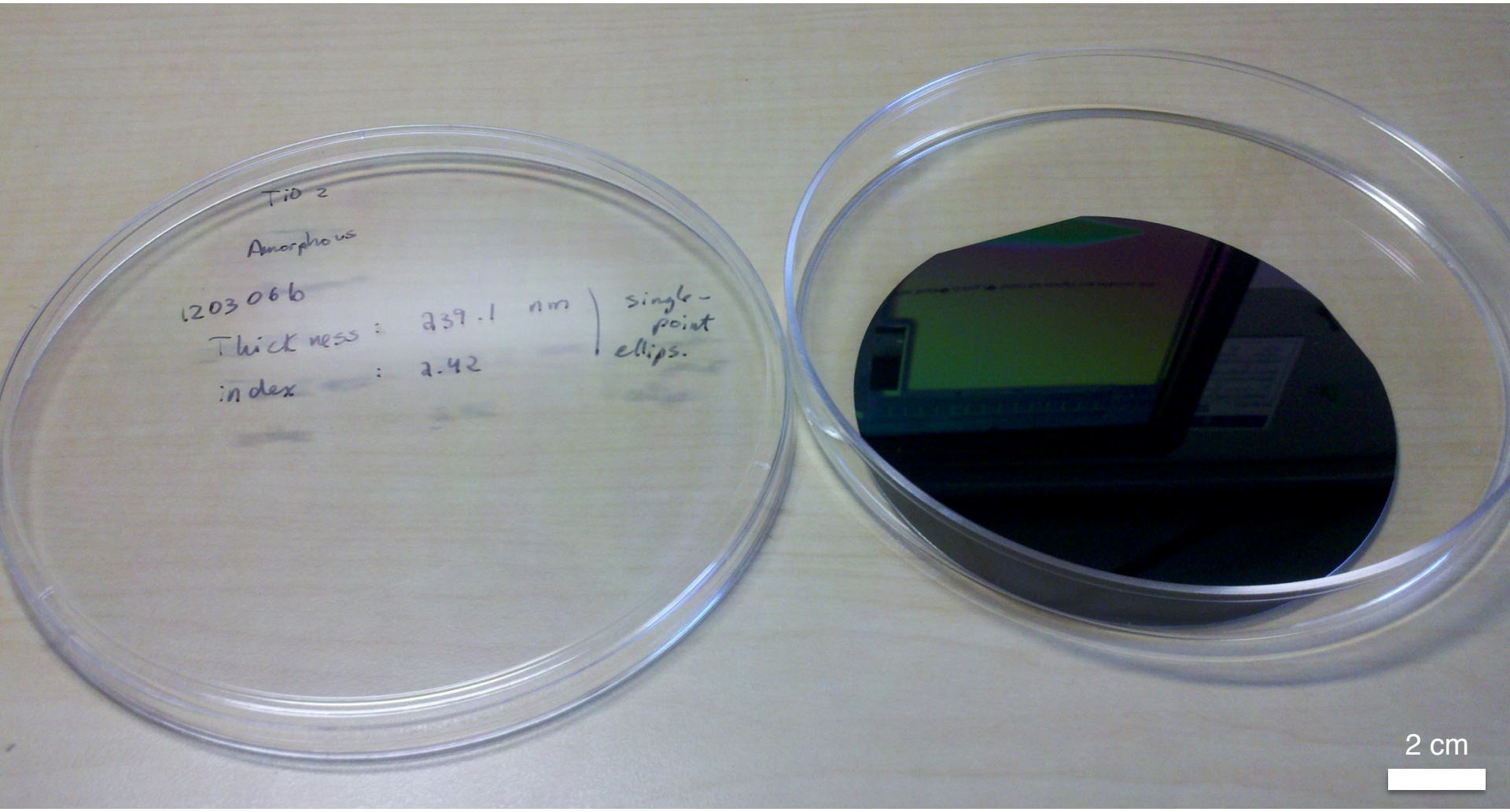


Fabrication

Cross-sectional view

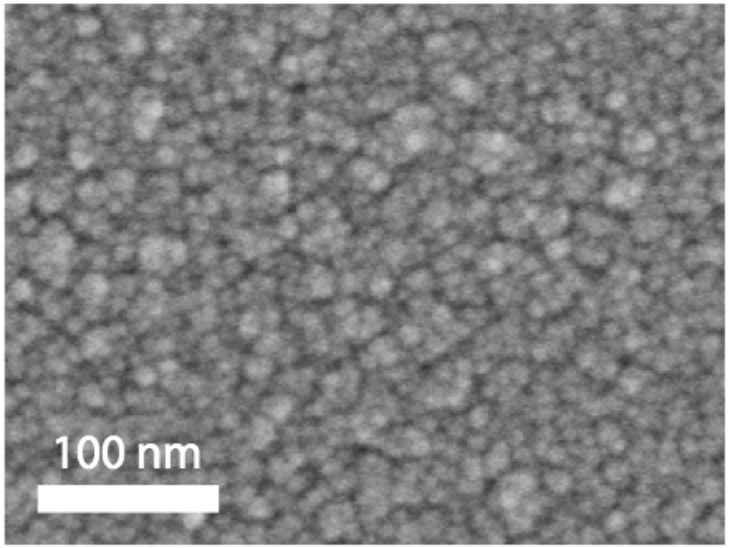


Thin films

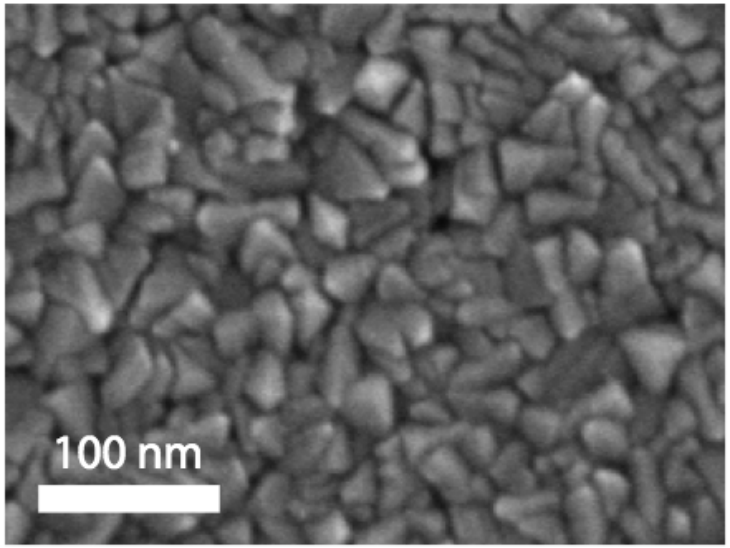

TiO 2
Amorphous
120306b
Thickness : 239.1 nm
index : 2.42
single-point ellips.
2 cm

Thin film characterization

Deposition temperature: 20°C



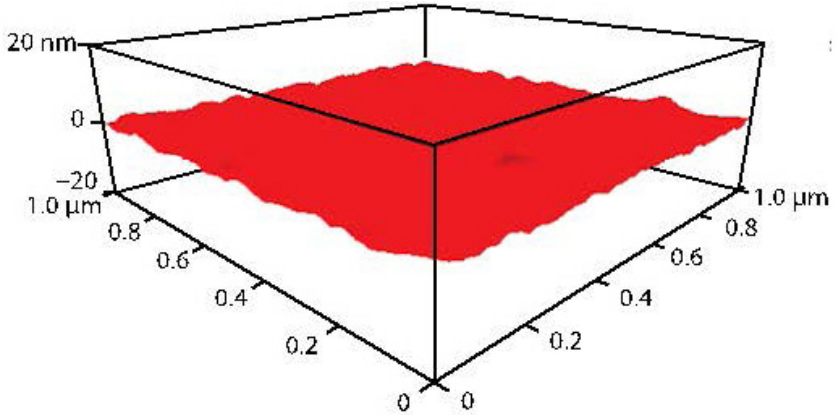
Deposition temperature: 350°C



Optics Express, 20, 23821 (2012)

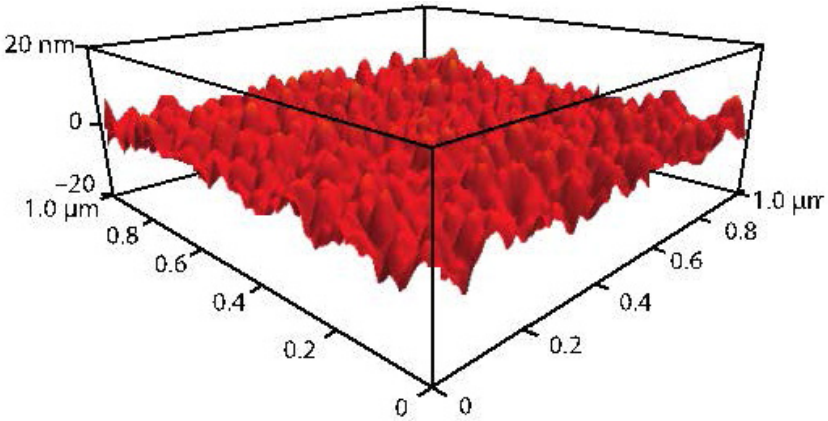
Thin film characterization

Deposition temperature: 20°C



RMS Roughness: 0.4 nm

Deposition temperature: 350°C

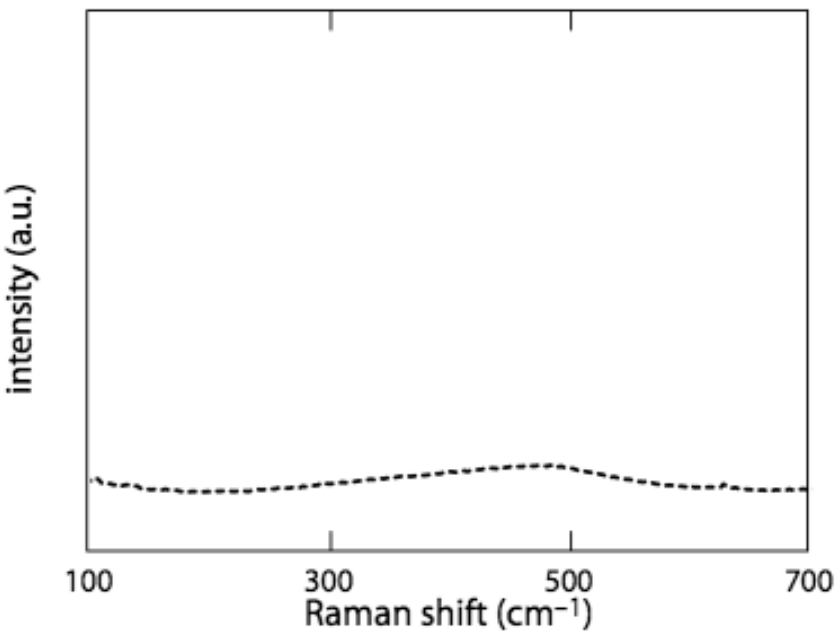


RMS Roughness: 2.7 nm

Optics Express, 20, 23821 (2012)

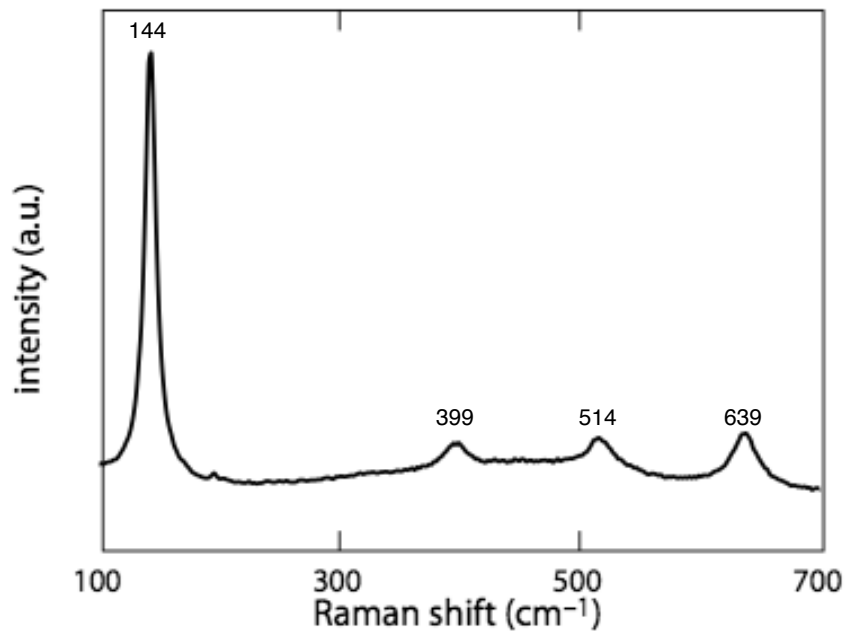
Raman spectroscopy

Deposition temperature: 20°C



Amorphous

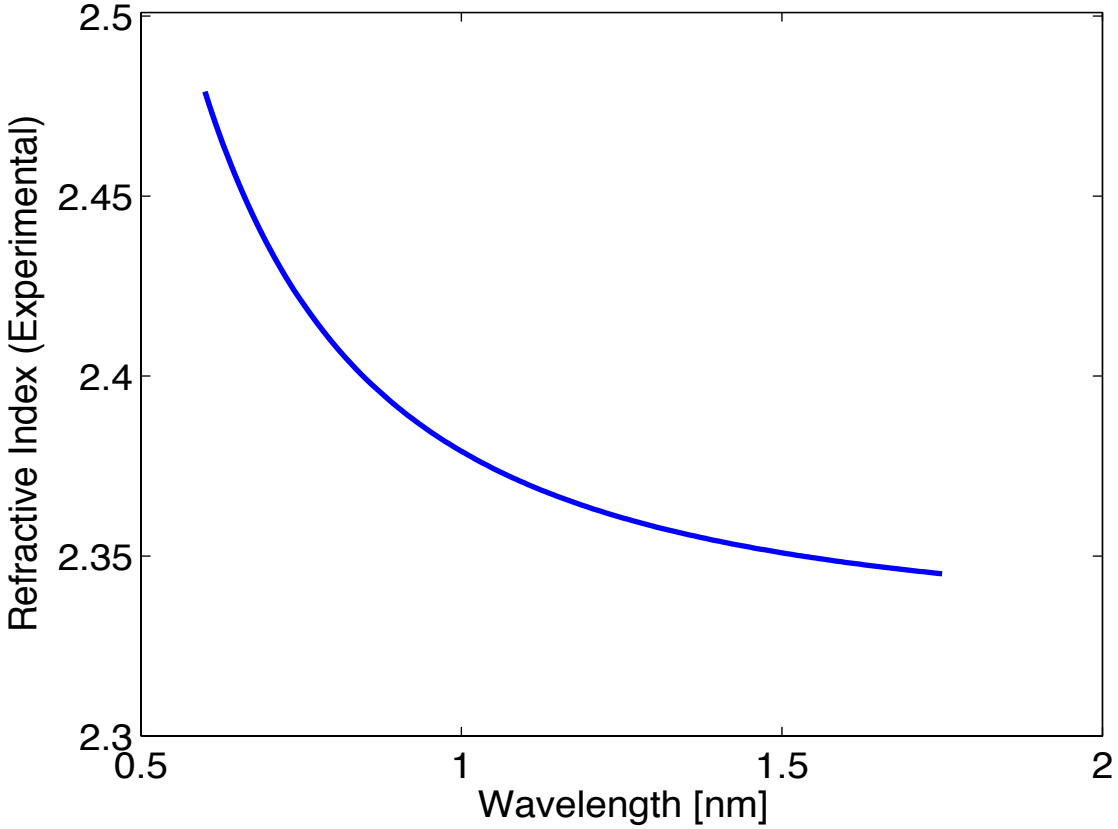
Deposition temperature: 350°C



Anatase

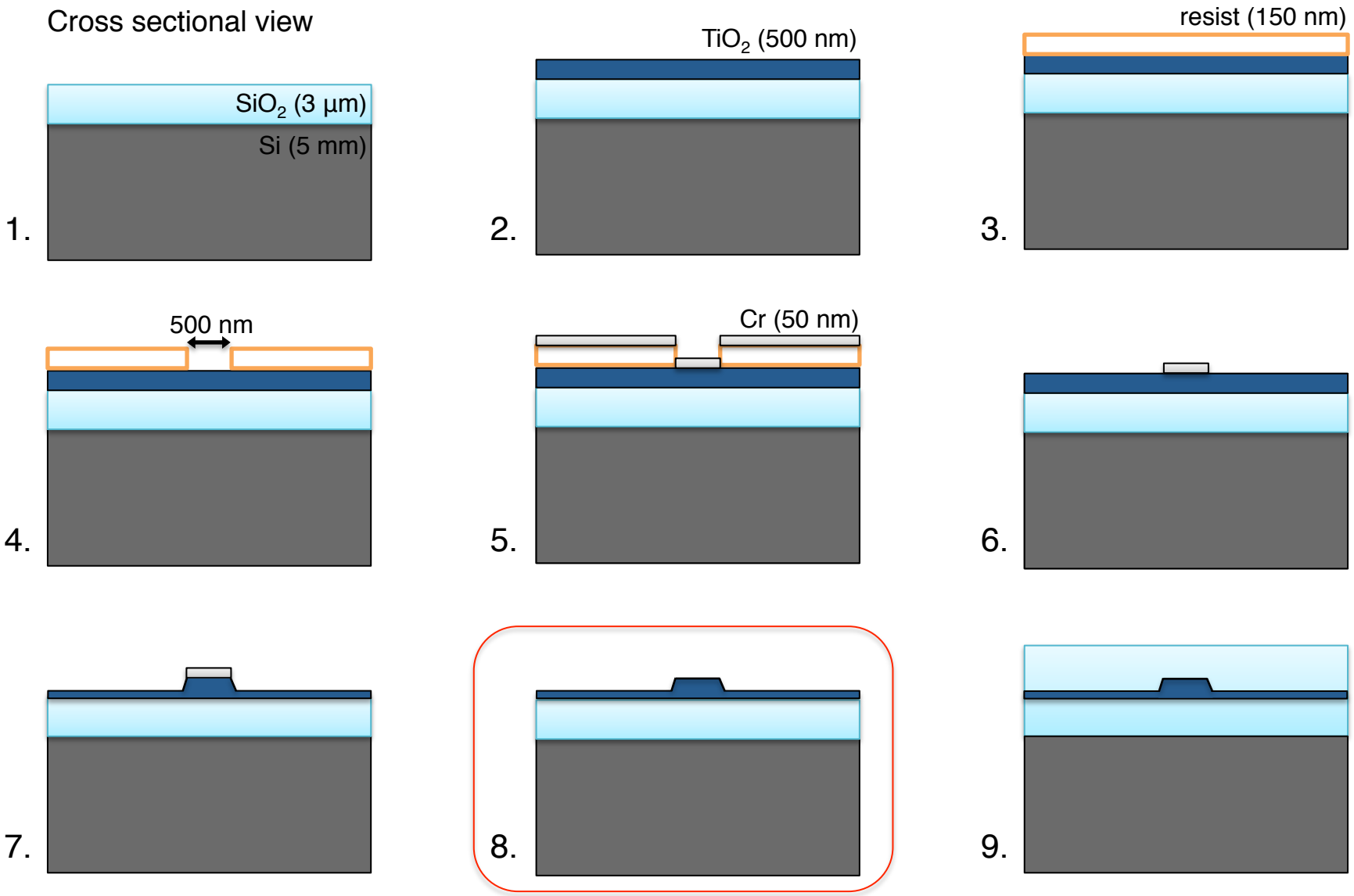
Optics Express, 20, 23821 (2012)

Ellipsometry



Fabrication

Cross sectional view



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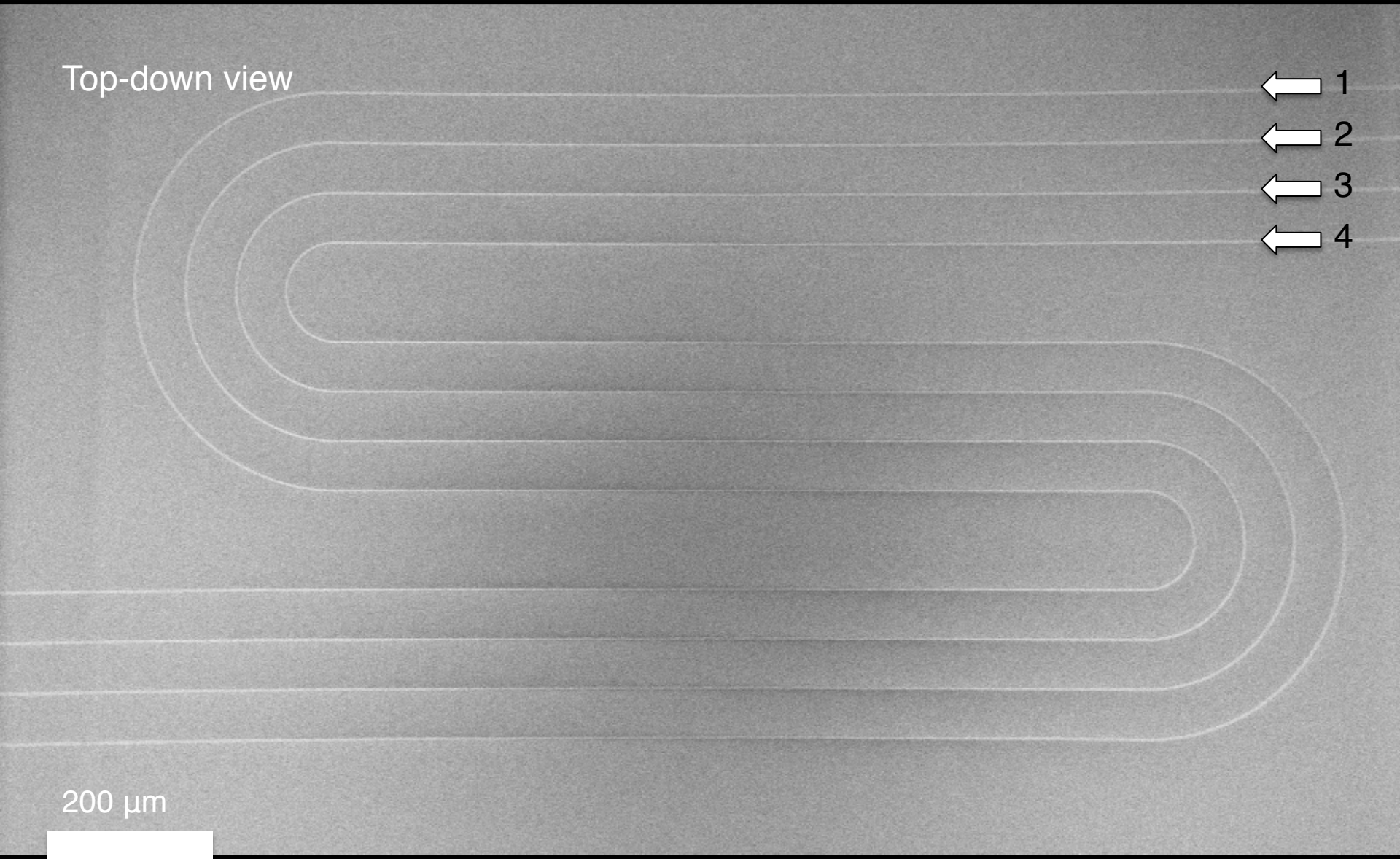
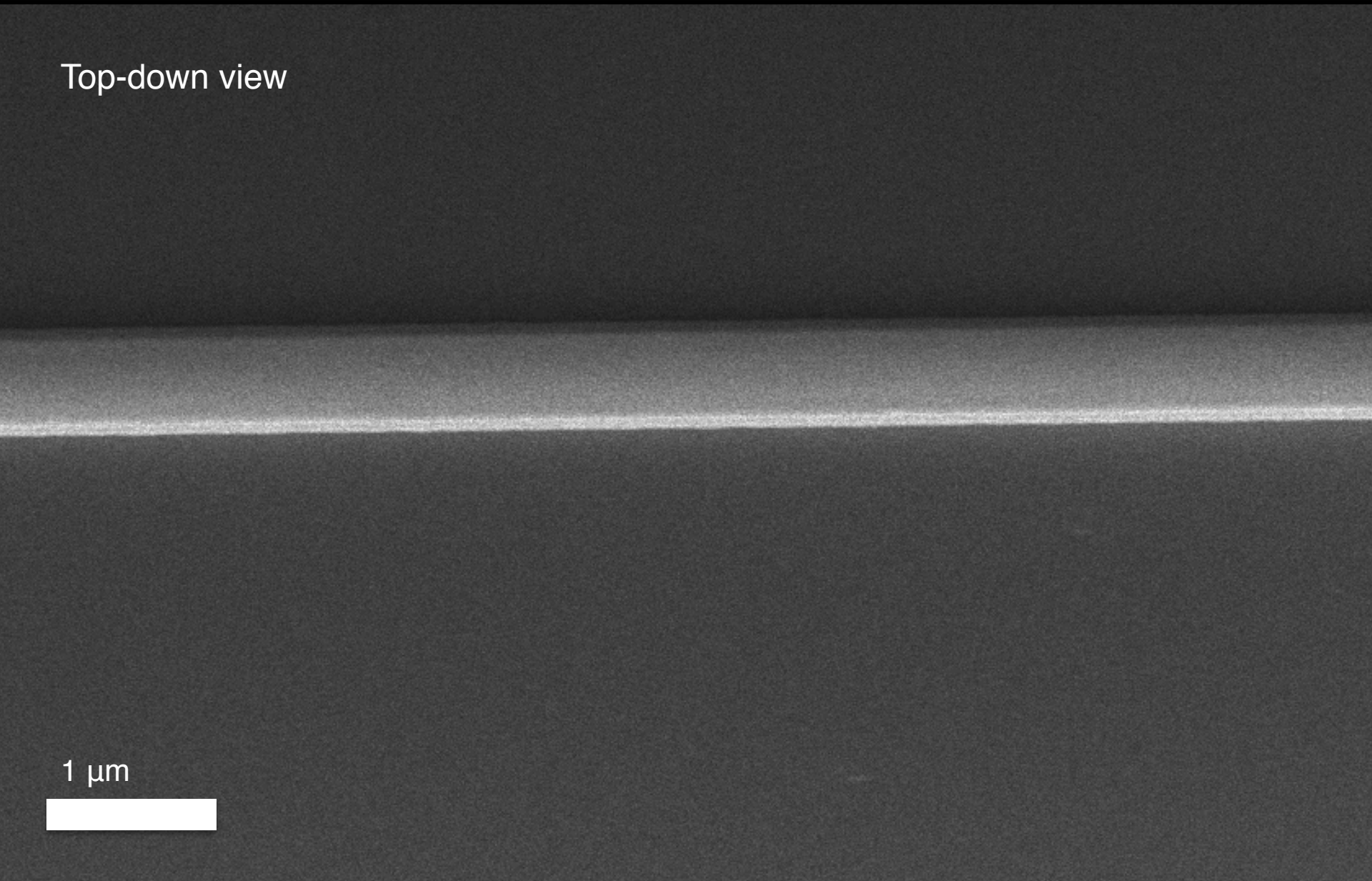
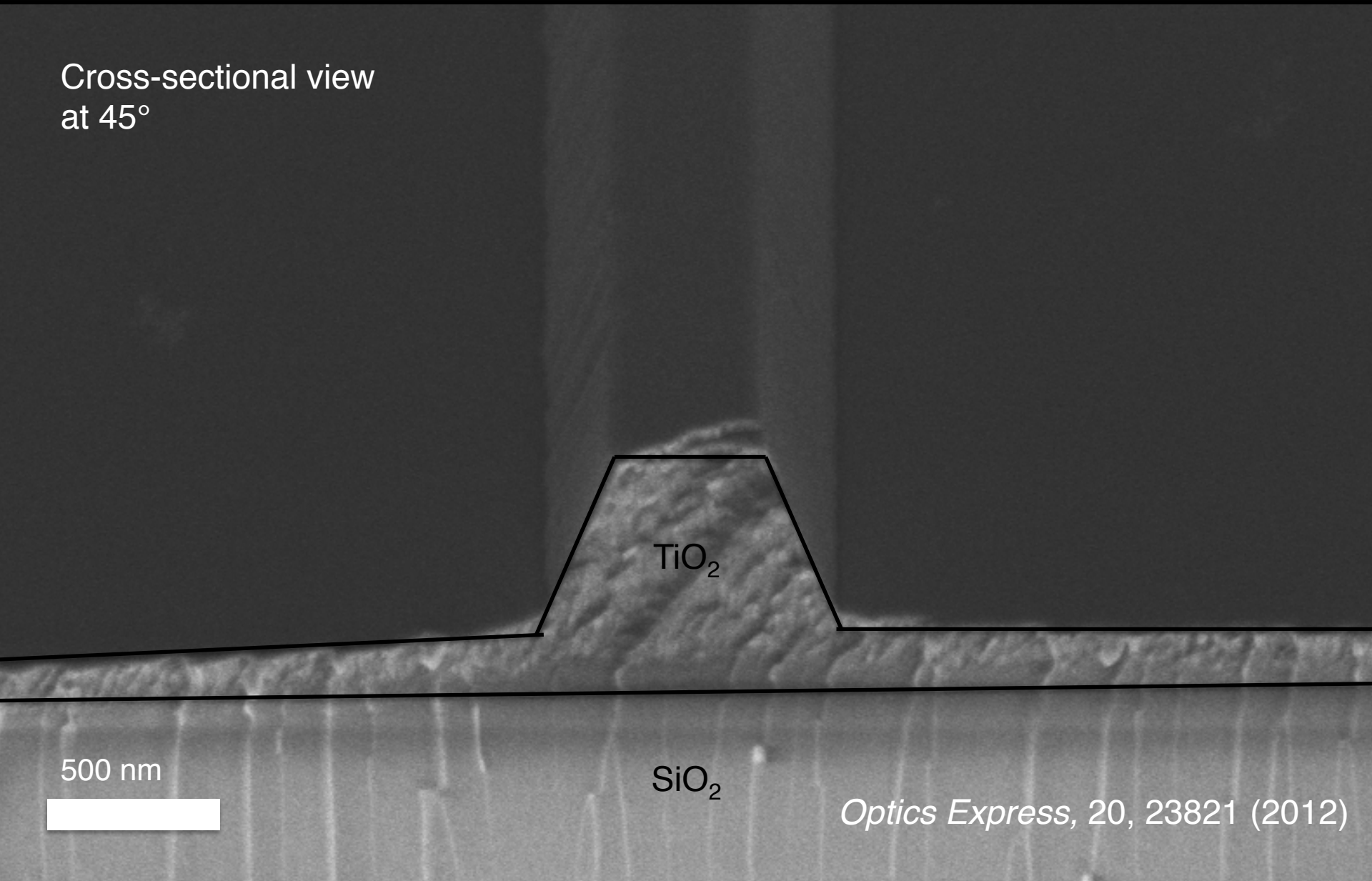


Fabrication

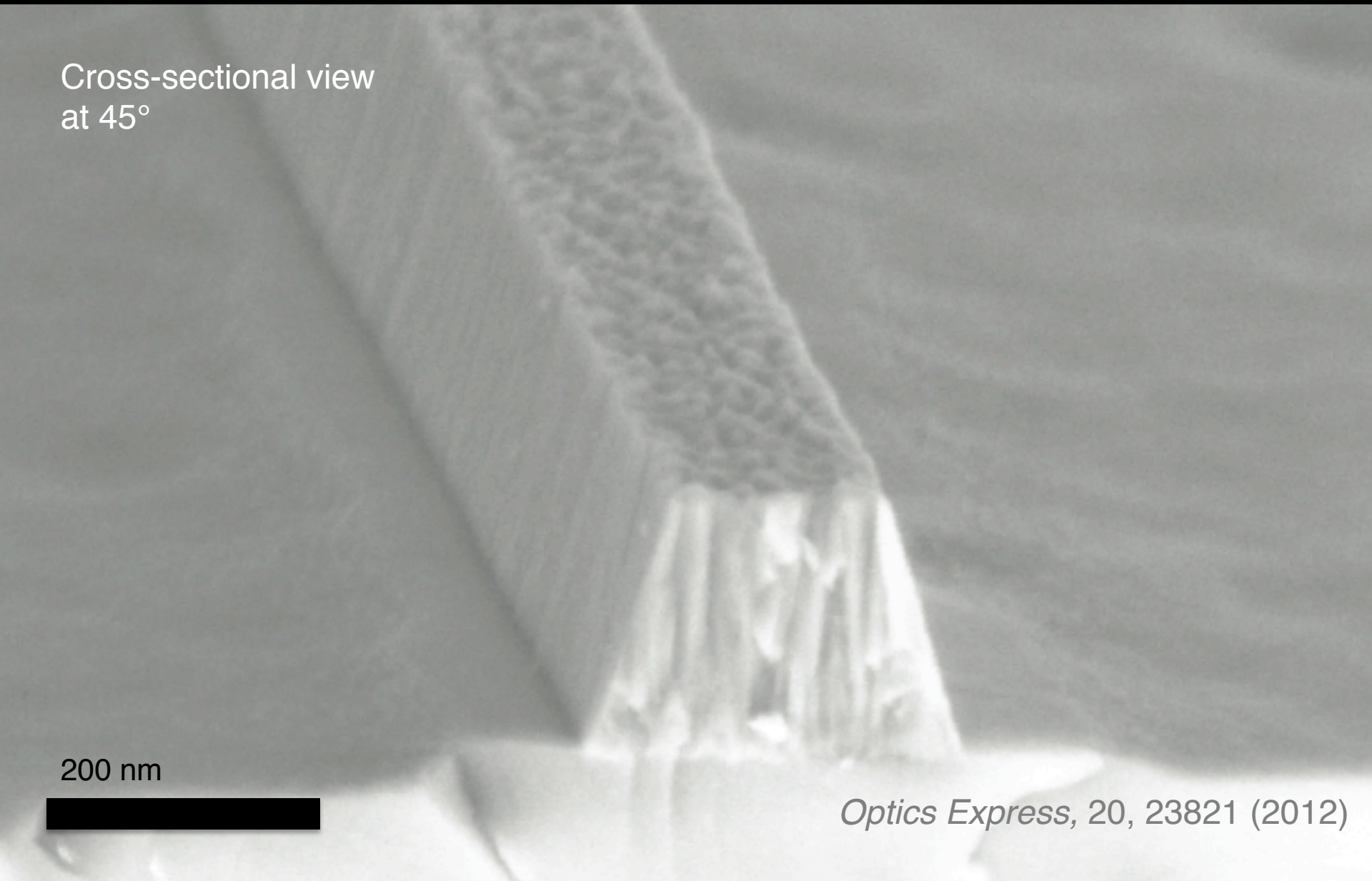


Fabrication



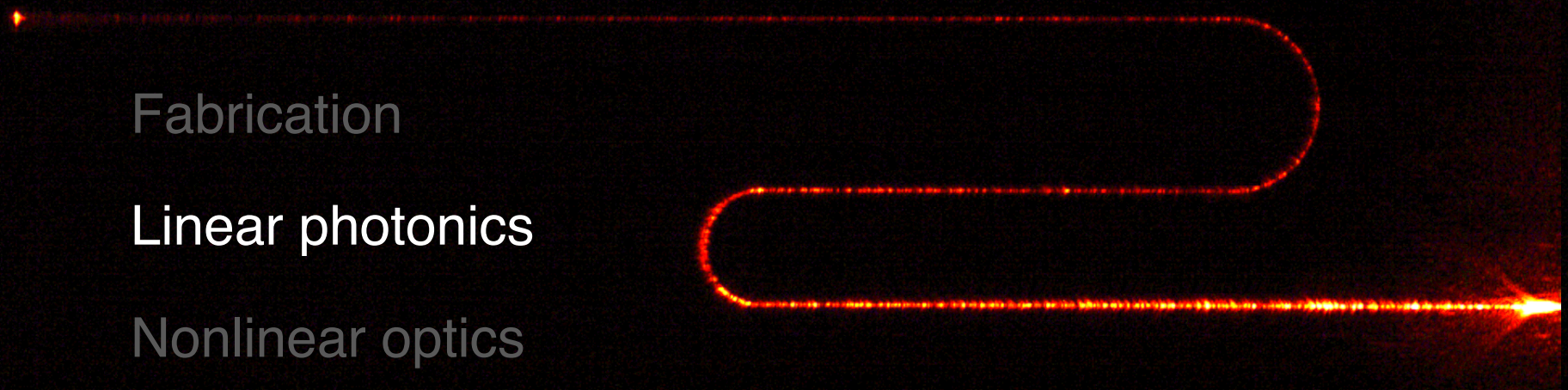
Optics Express, 20, 23821 (2012)

Fabrication



Optics Express, 20, 23821 (2012)

Titanium dioxide for nanophotonics

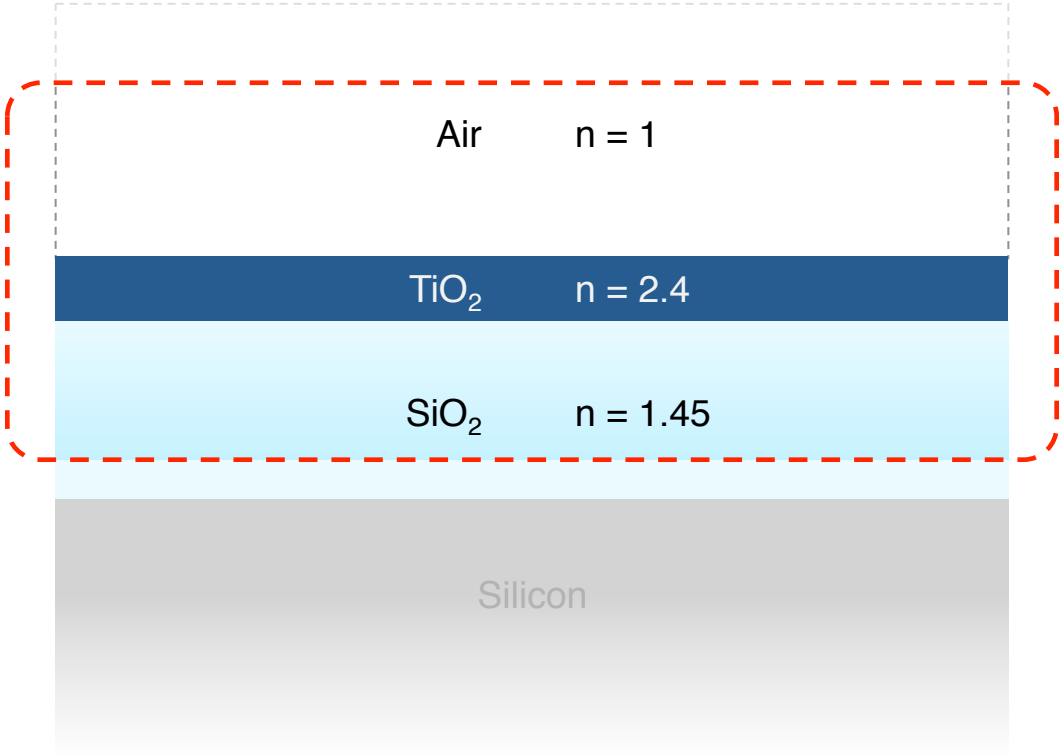


Fabrication

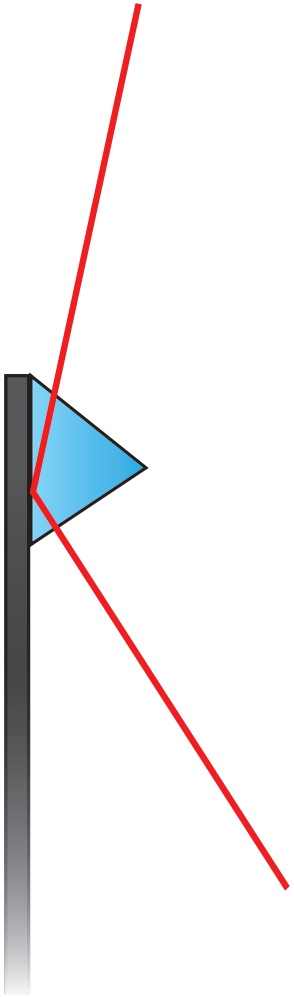
Linear photonics

Nonlinear optics

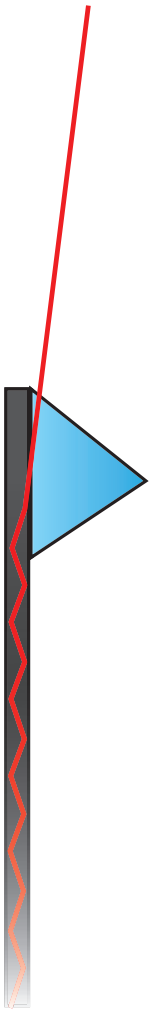
Prism coupling



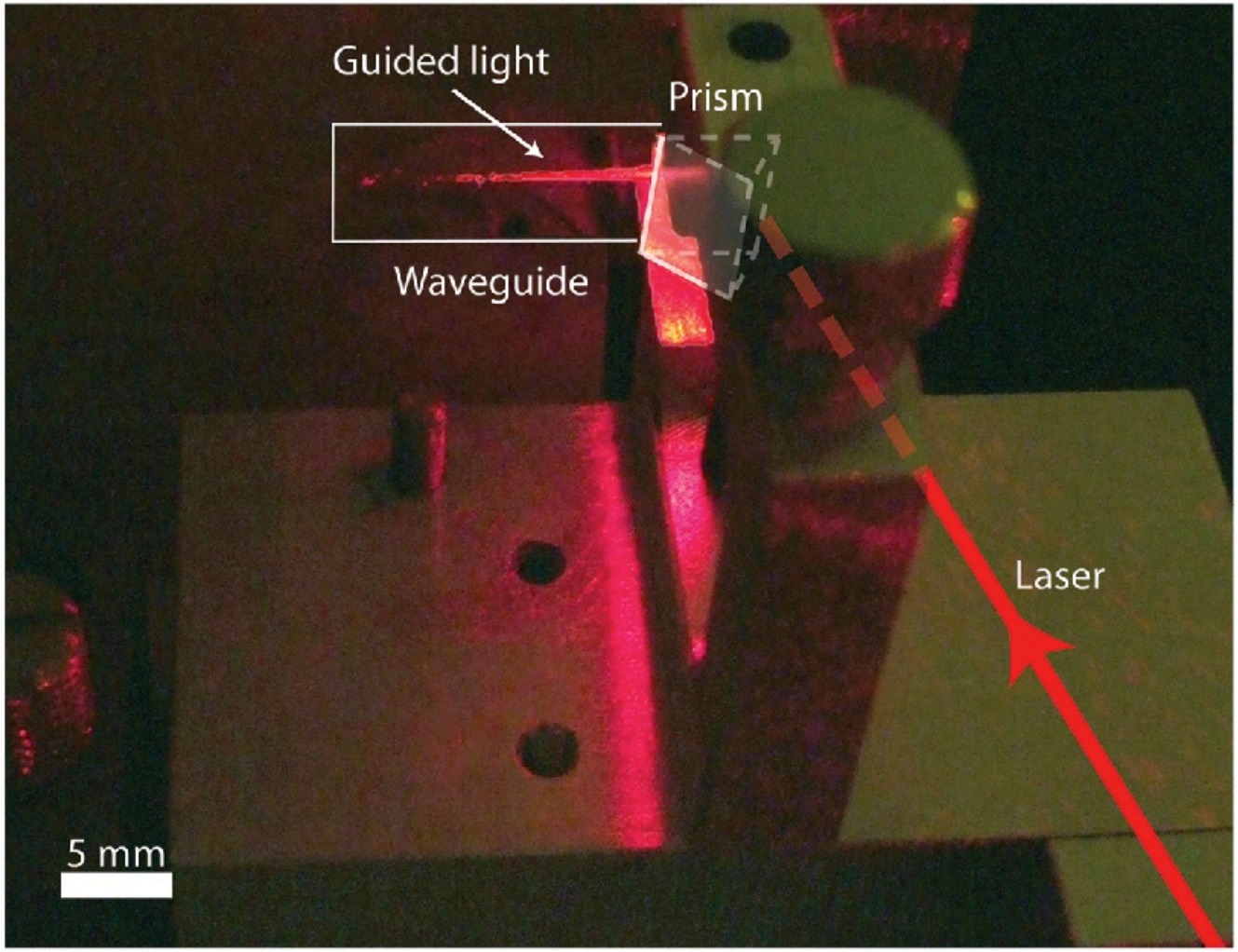
Prism coupling



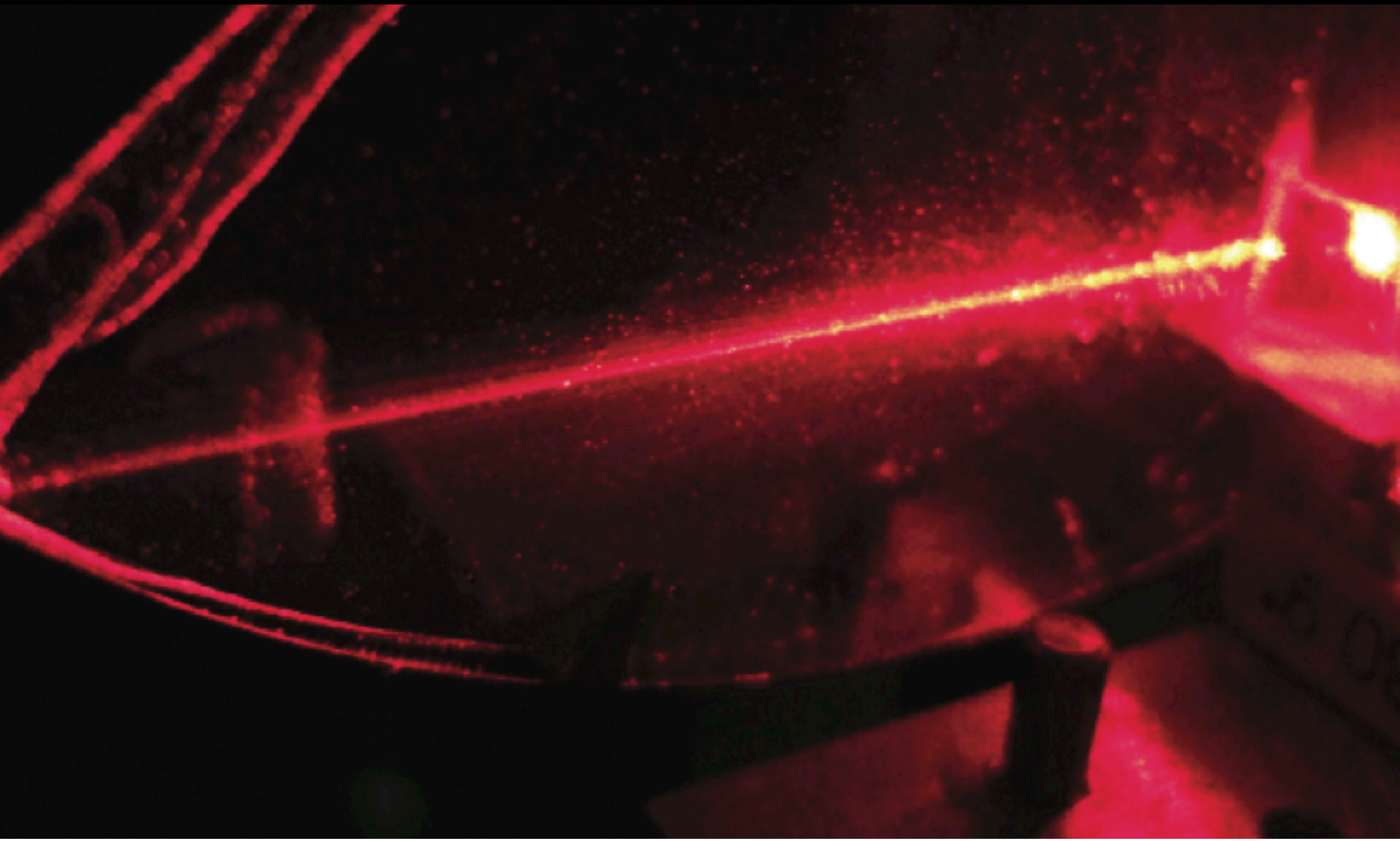
Prism coupling



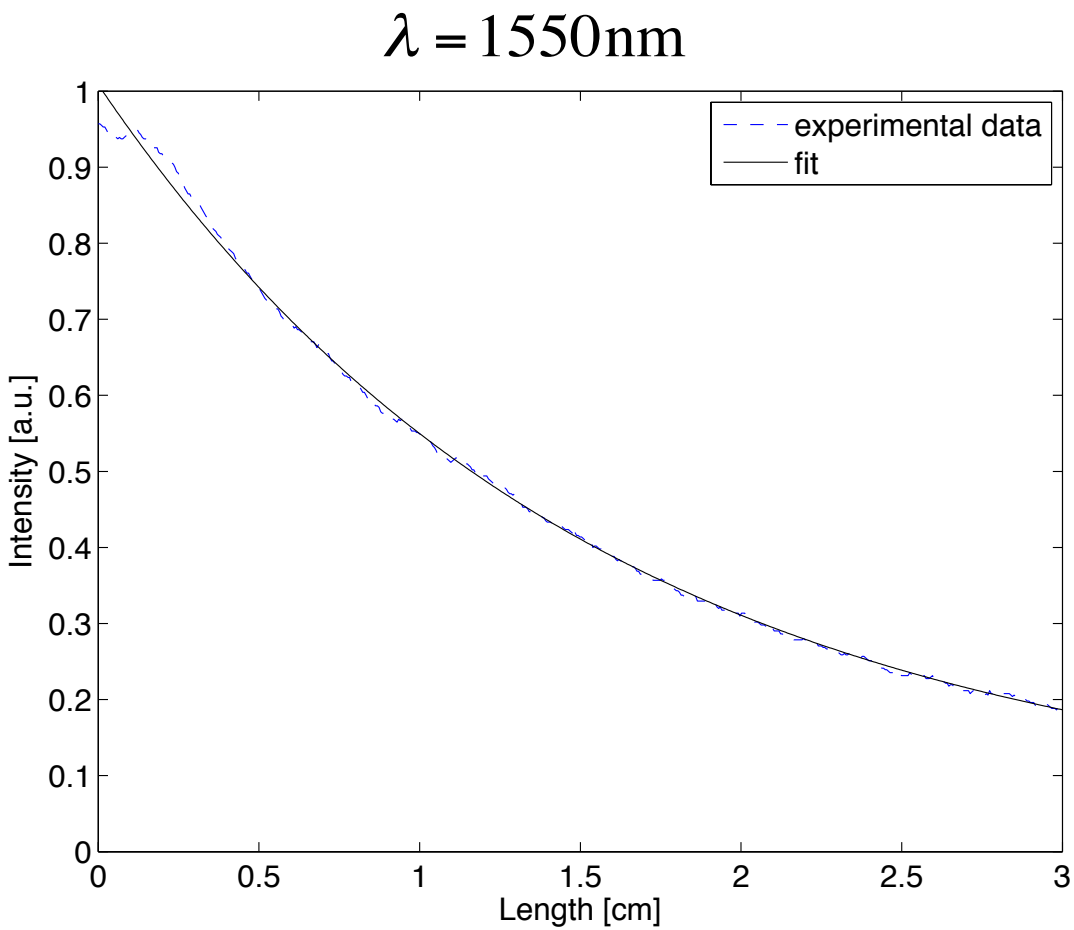
Prism coupling



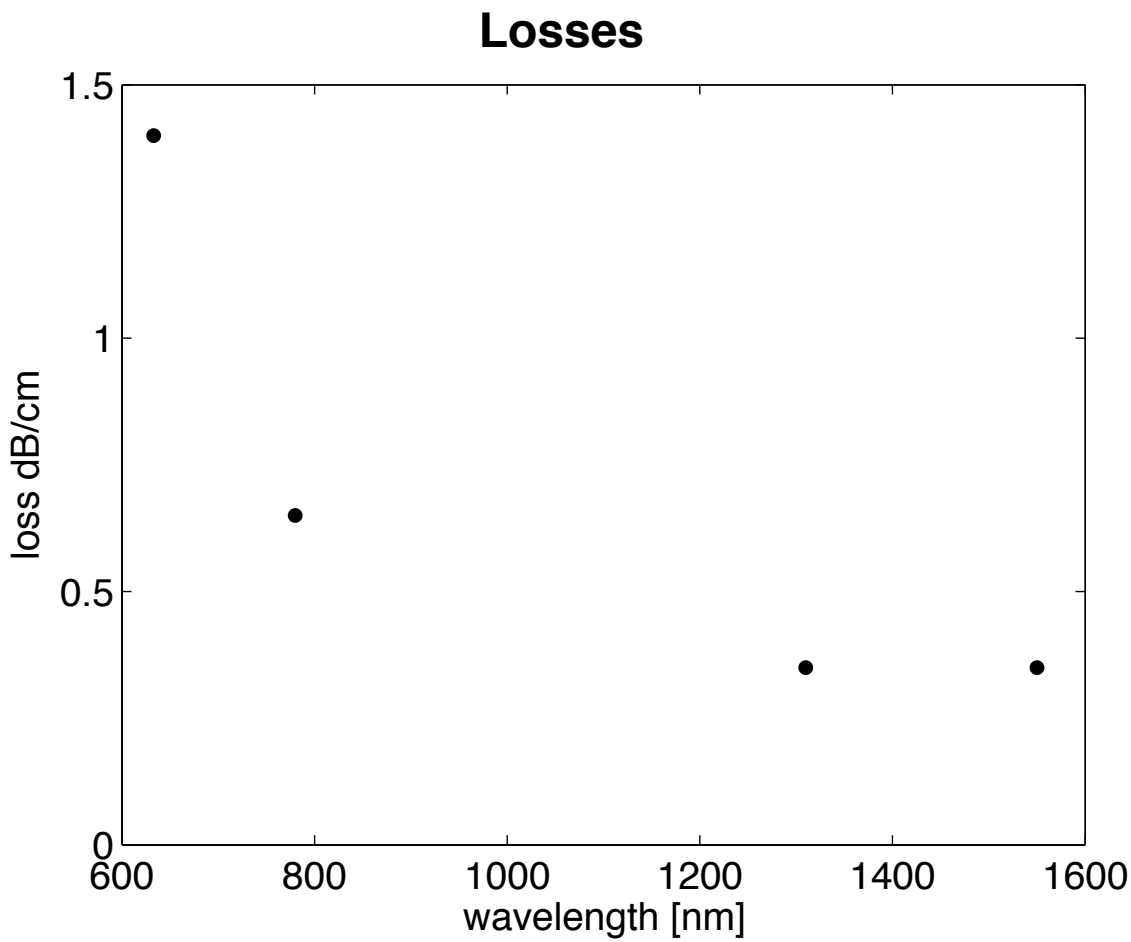
Prism coupling



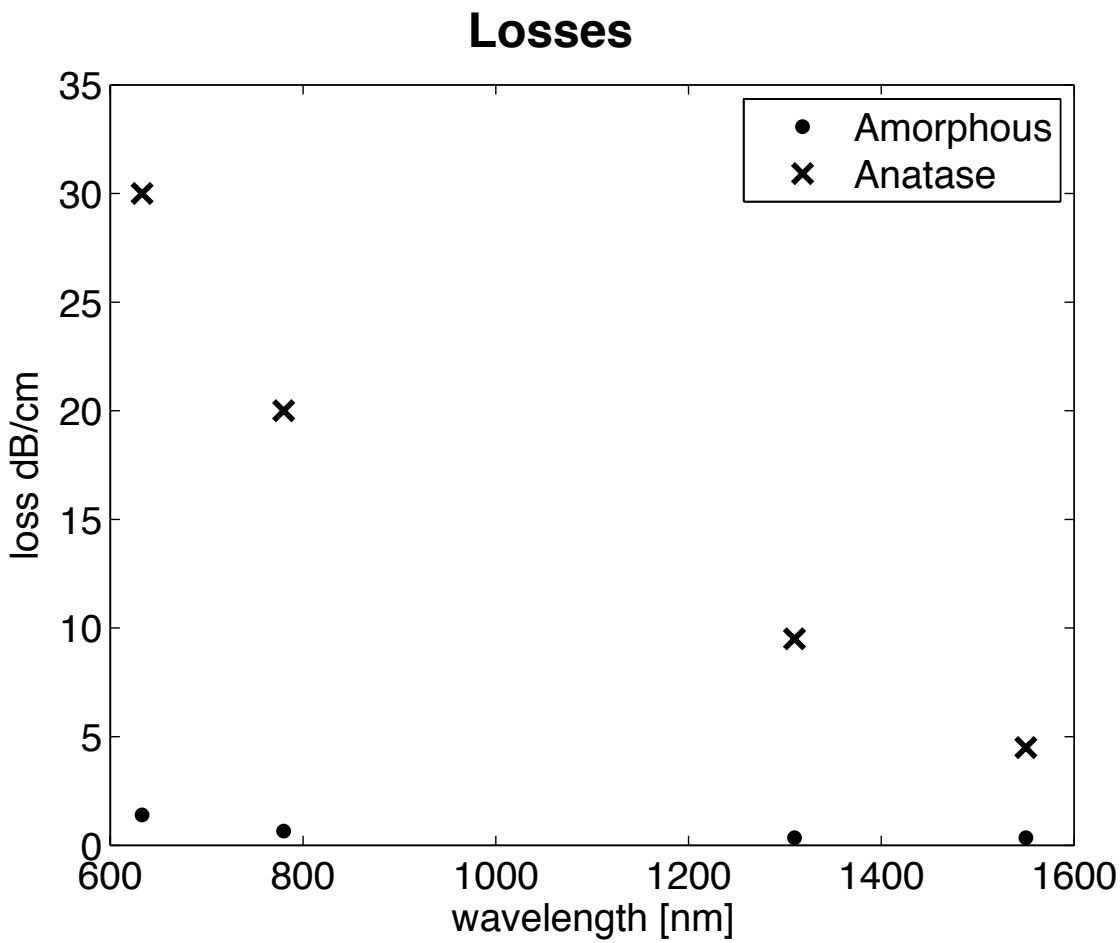
Prism coupling



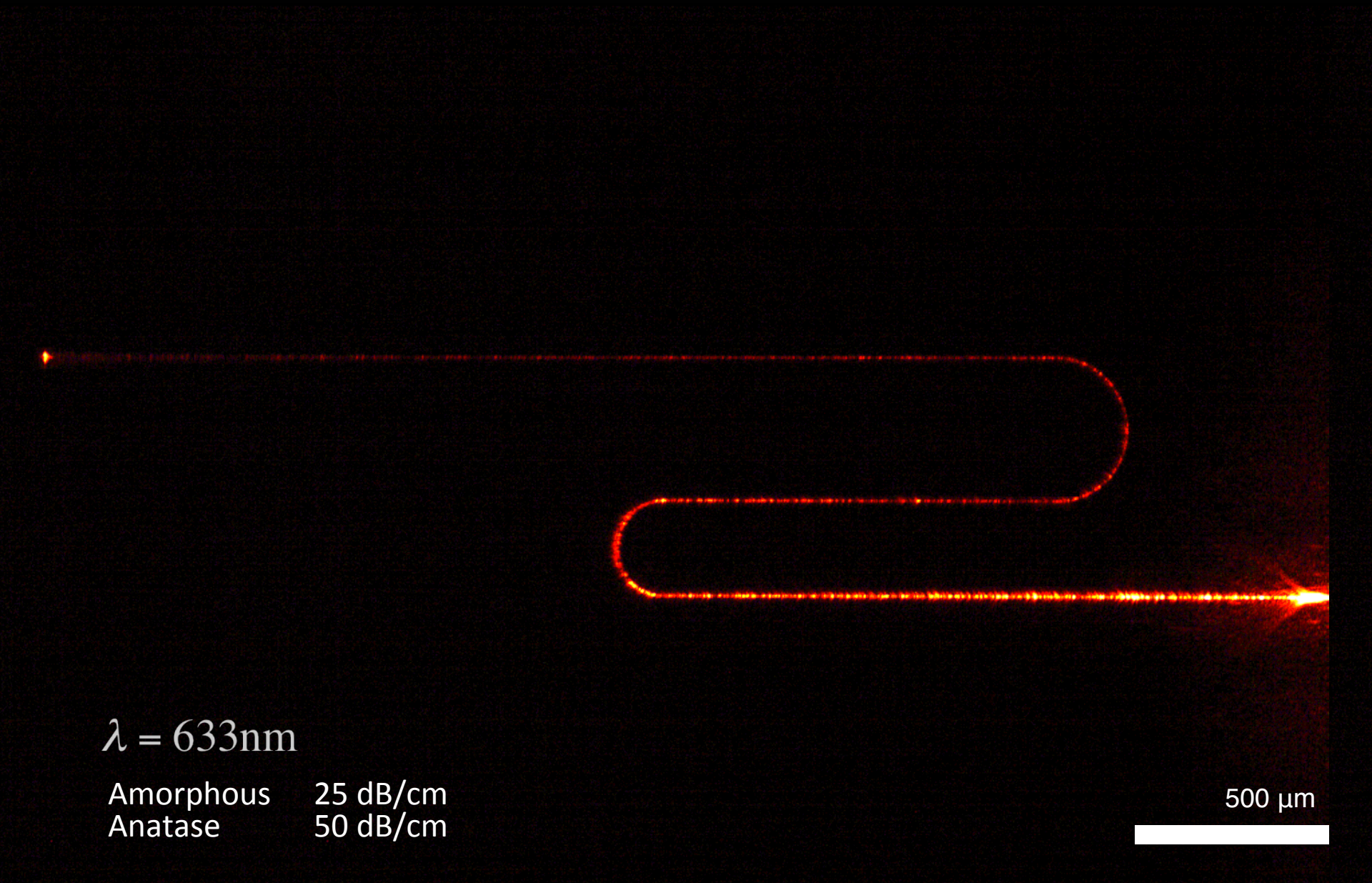
Prism coupling



Prism coupling



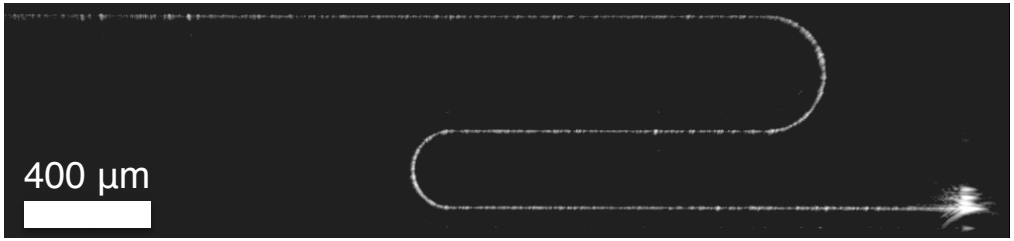
Linear photonics



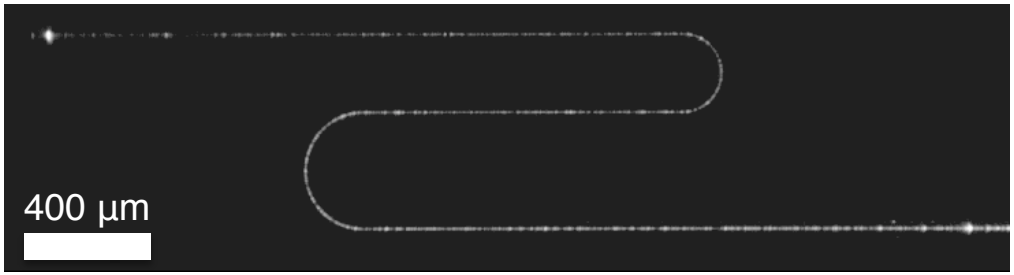
Linear photonics

$$\lambda = 780\text{nm}$$

Amorphous 10 dB/cm



Anatase 20 dB/cm

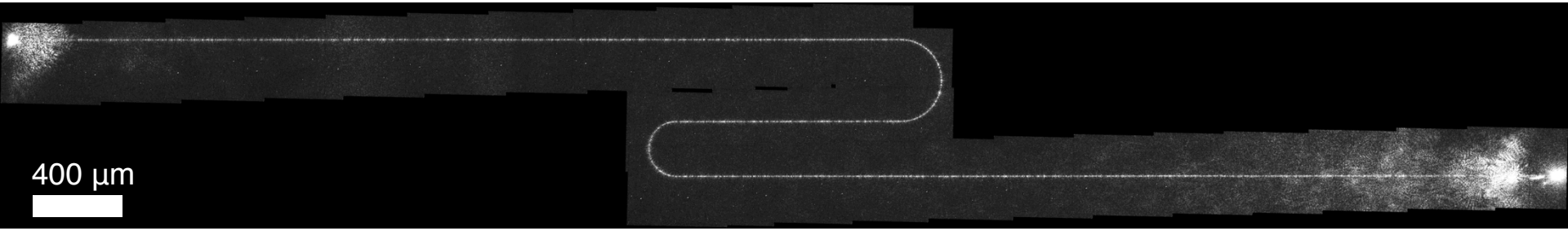


Optics Express, 20, 23821 (2012)

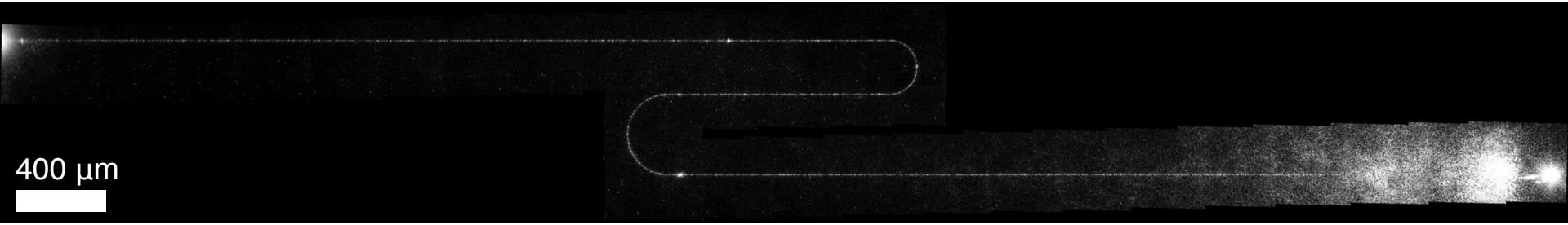
Linear photonics

$$\lambda = 1550\,\mathrm{nm}$$

Amorphous < 4 dB/cm



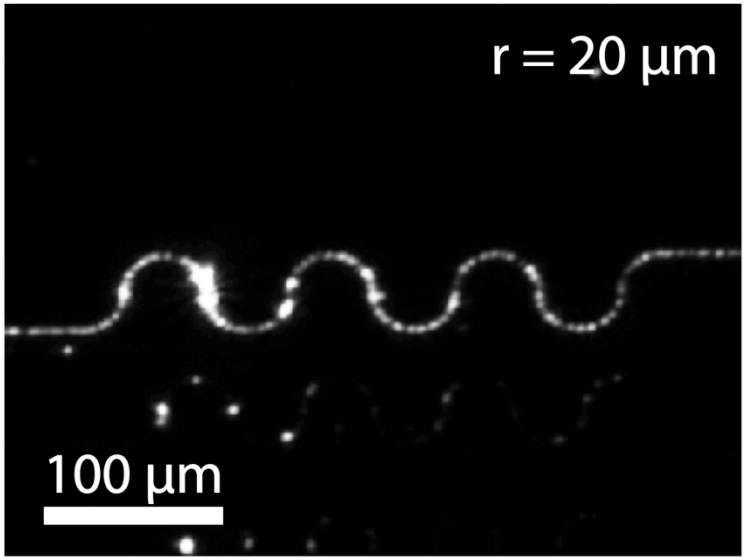
Anatase 4 dB/cm

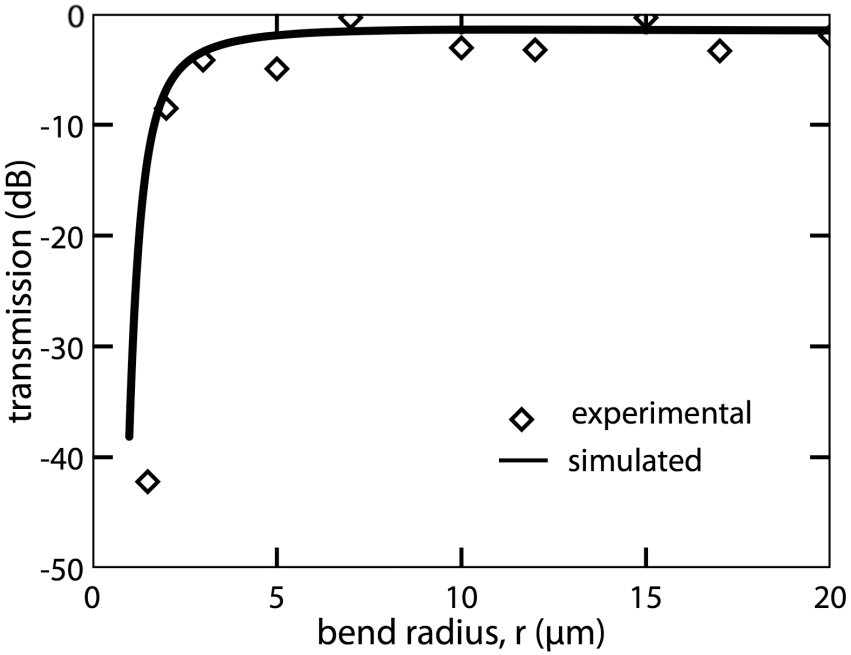


Optics Express, 20, 23821 (2012)

Linear photonics

Micro-scale bends

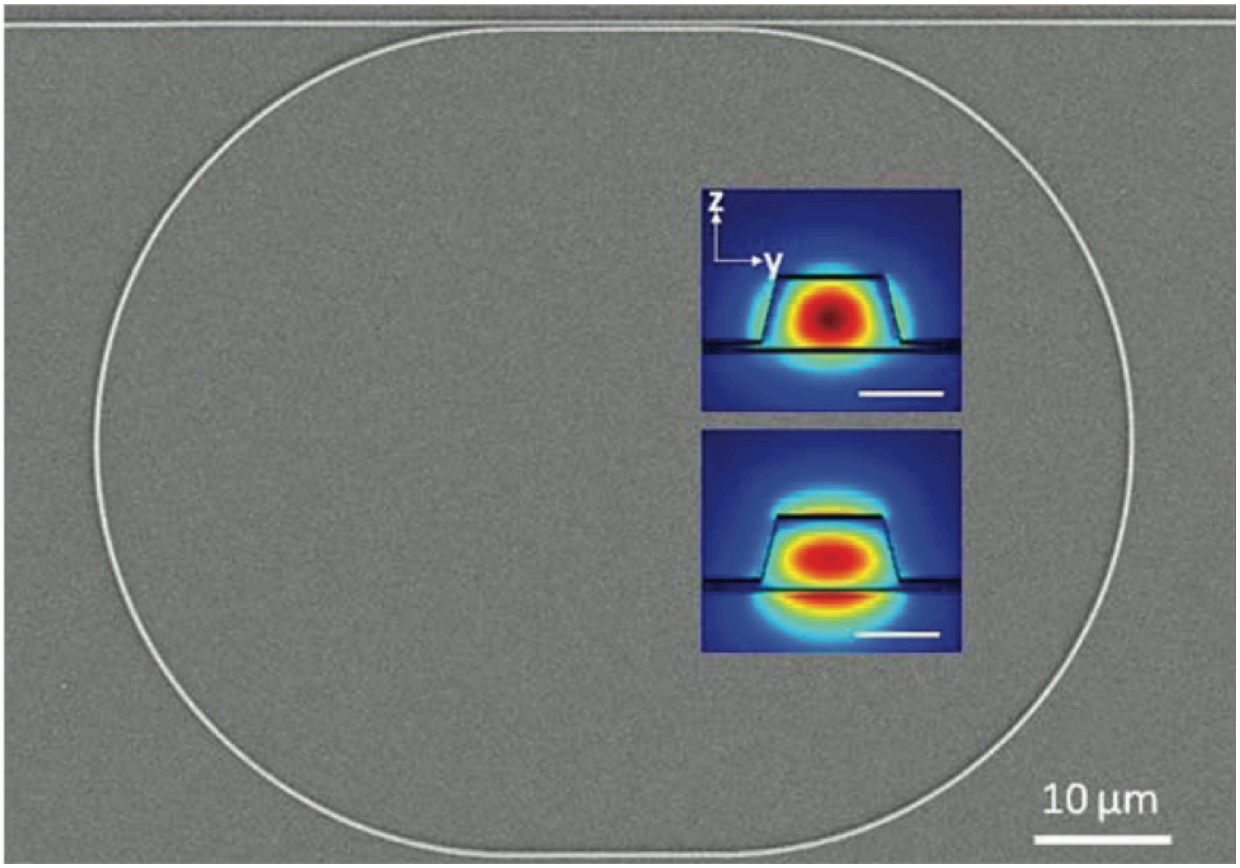




Optics Express, 20, 23821 (2012)

Linear photonics

Racetrack ring resonator

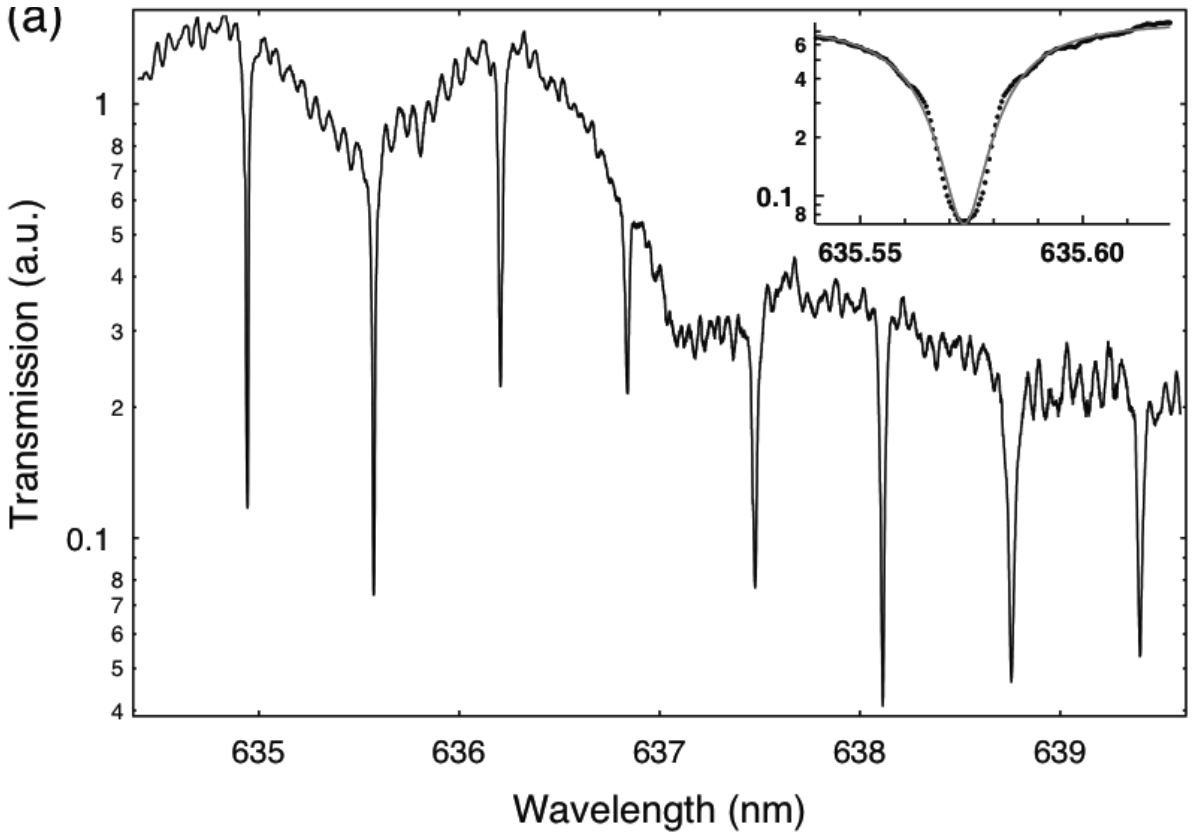


Optics Letters, 37, 539 (2012)

Linear photonics

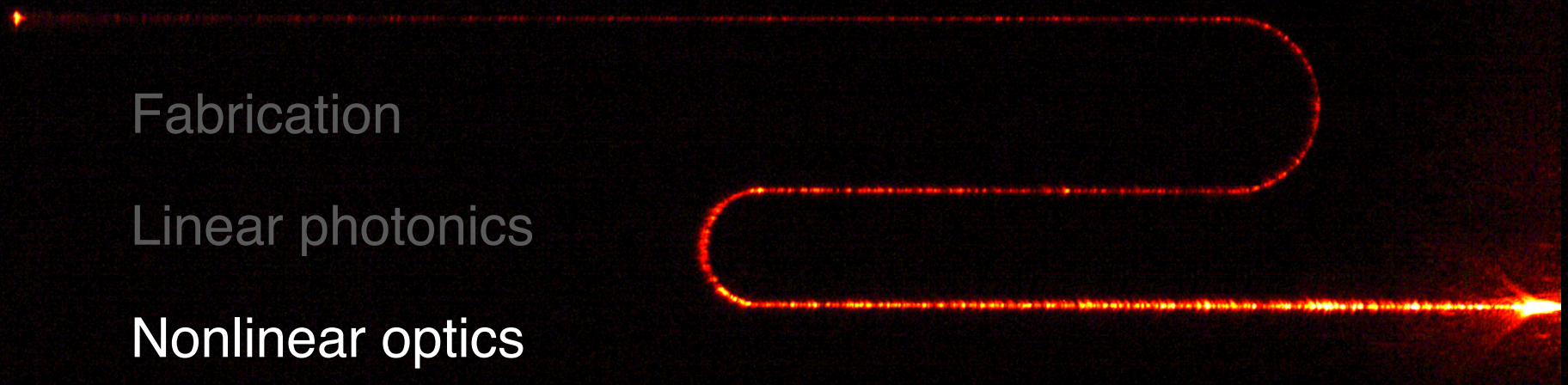
Racetrack ring resonator

Q = 2.2 x 10^4 at λ = 635 nm



Optics Letters, 37, 539 (2012)

Titanium dioxide for nanophotonics



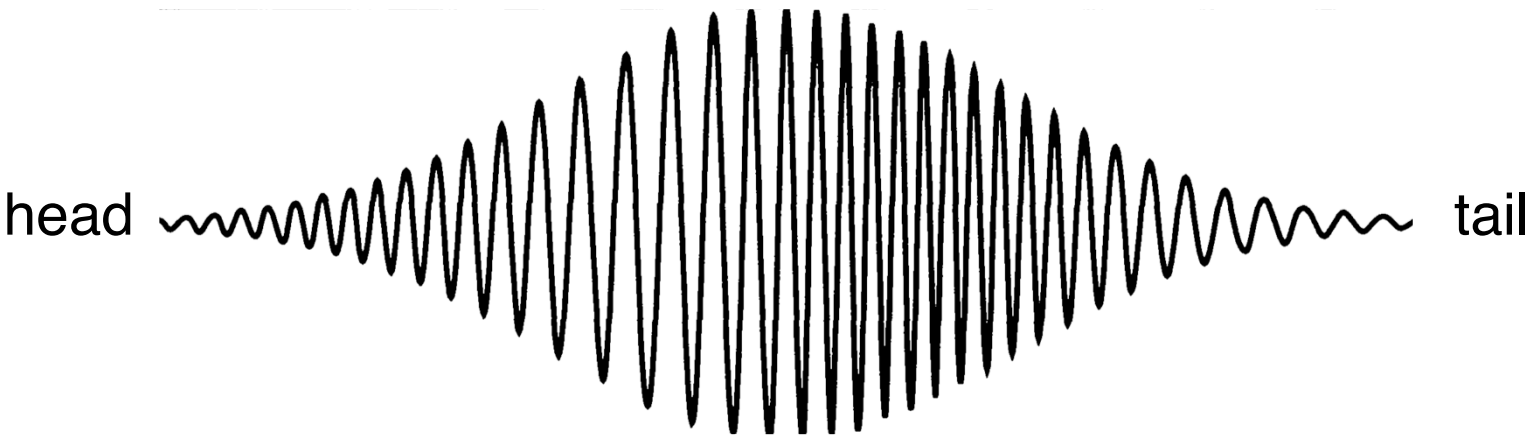
Fabrication

Linear photonics

Nonlinear optics

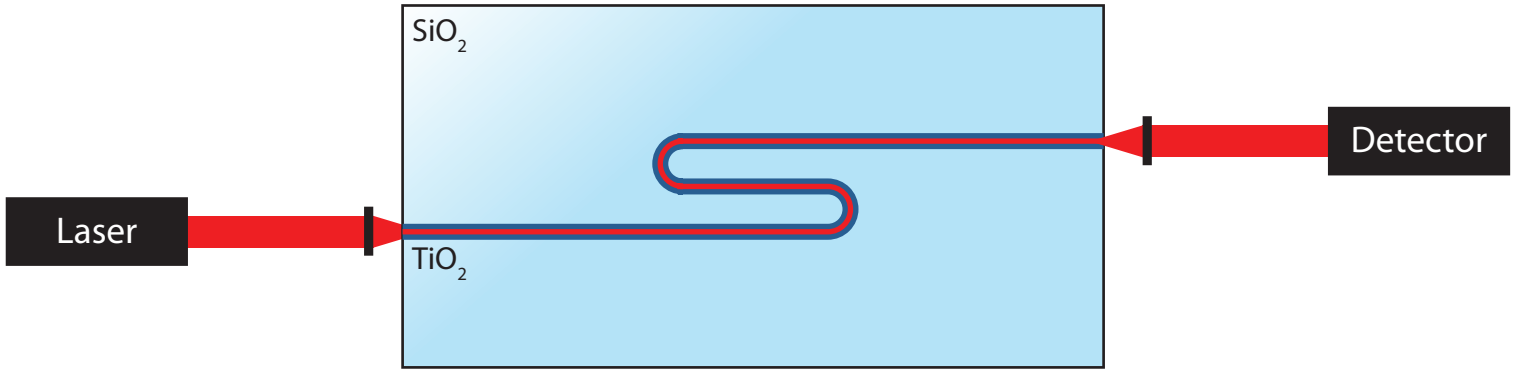
Nonlinear optics

Spectral broadening

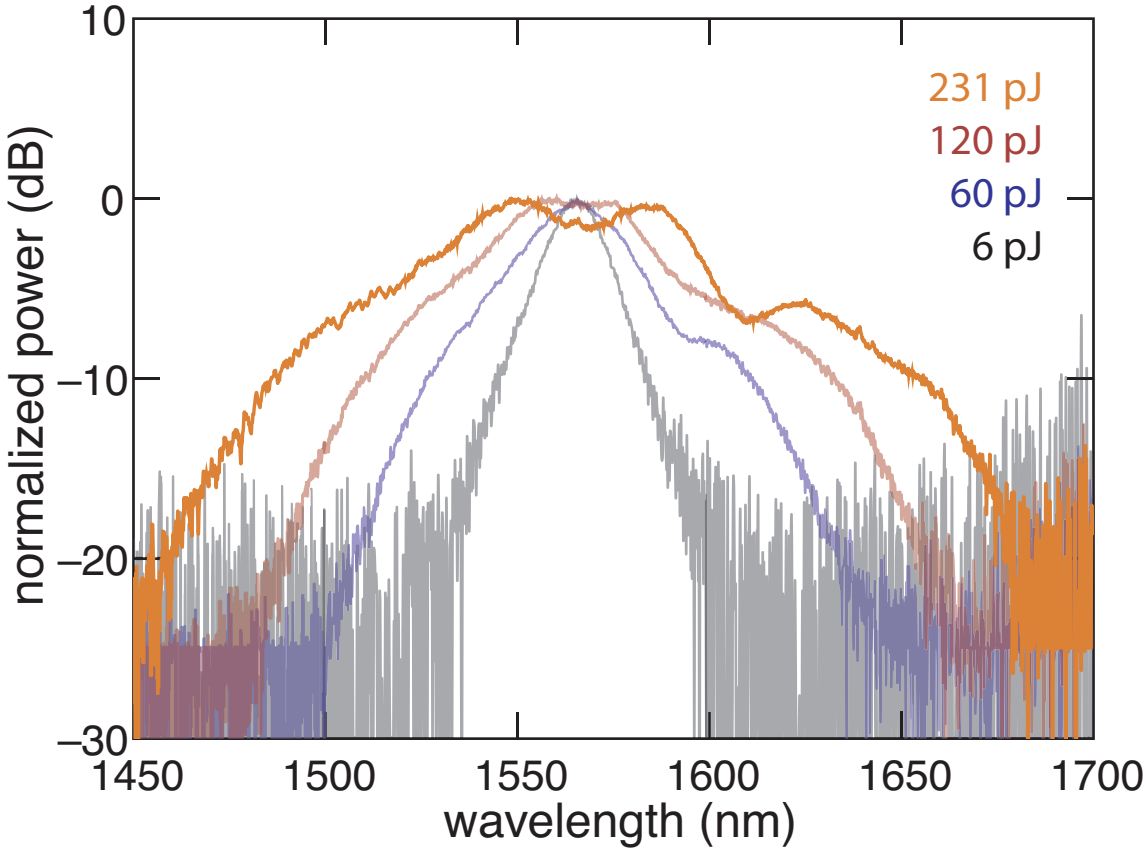


Pulse broadens spectrally

Spectral broadening

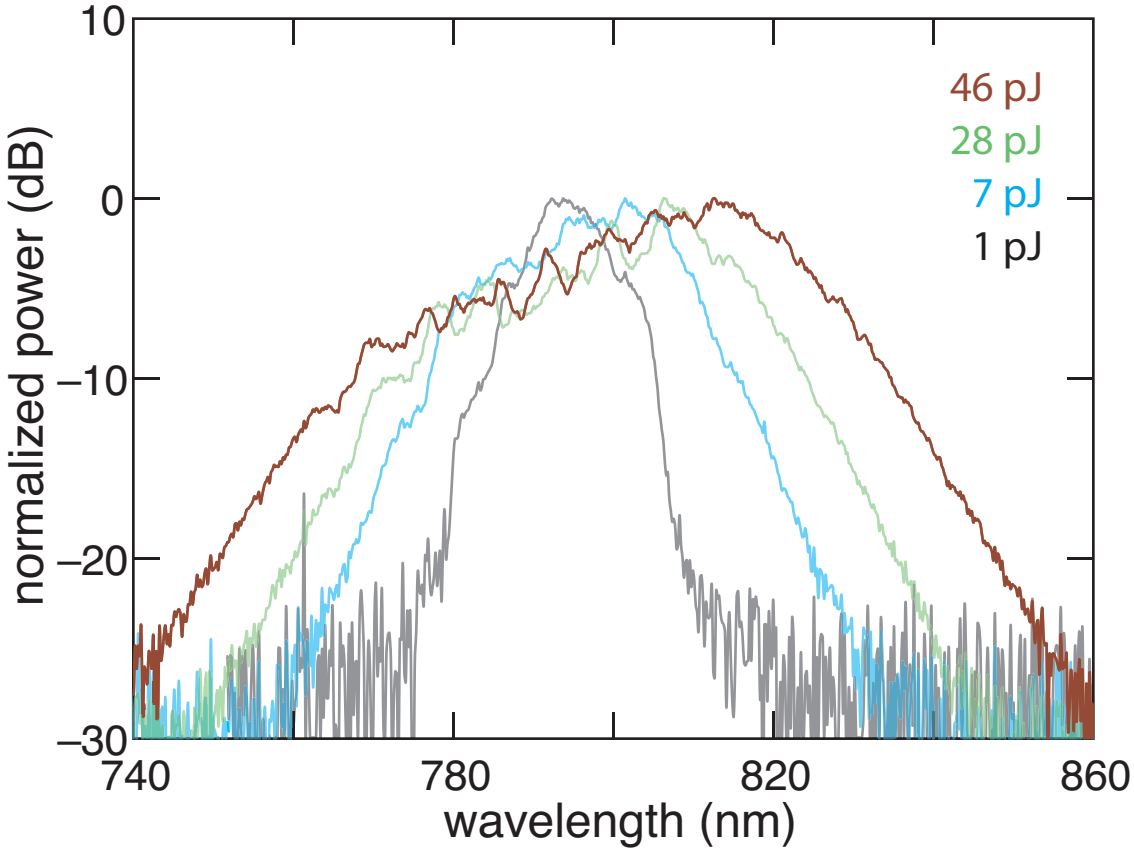


Spectral broadening



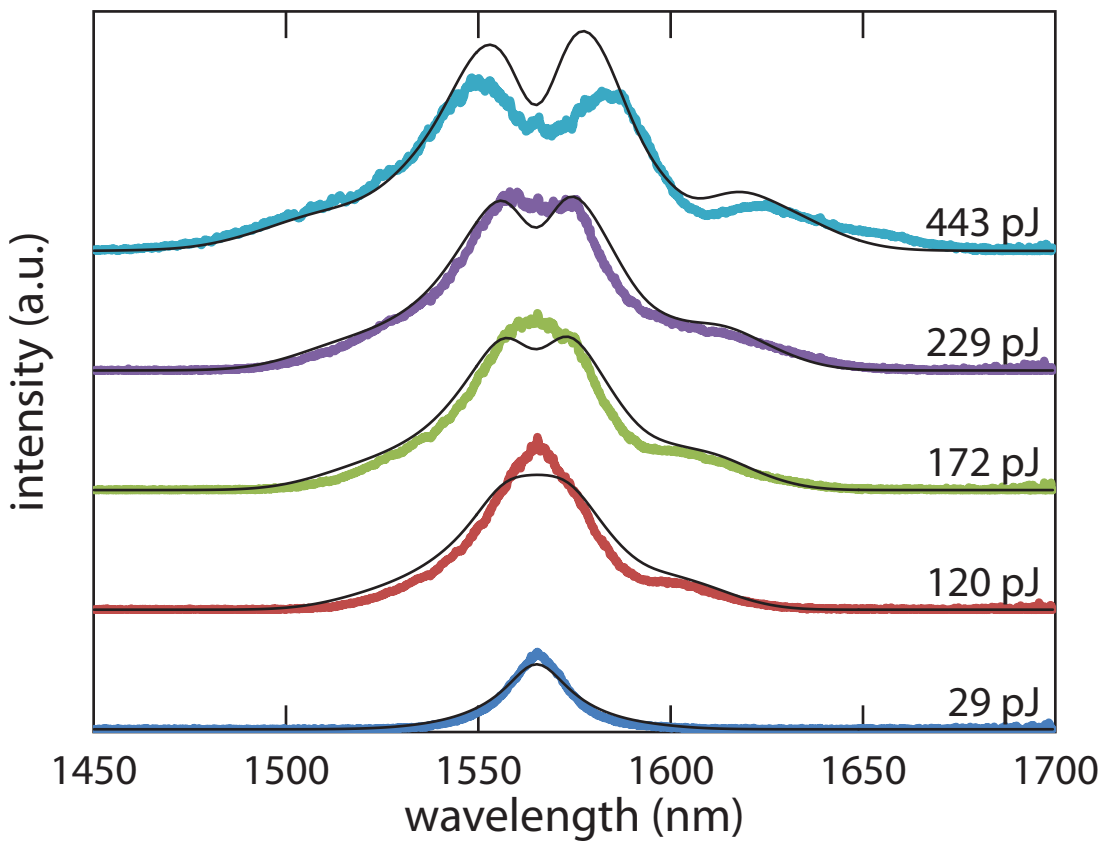
Optics Express, 21, 18582 (2013)

Spectral Broadening



Optics Express, 21, 18582 (2013)

Spectral Broadening



Optics Express, 21, 18582 (2013)

Spectral Broadening

Extracted nonlinear parameters

Kerr index

λ	n_2	equiv.
1565 nm	0.16×10^{-18} m^2/W	5 x silica
794 nm	1.6×10^{-18} m^2/W	50 x silica

Optics Express, 21, 18582 (2013)

Spectral Broadening

Extracted nonlinear parameters

Raman gain coefficient

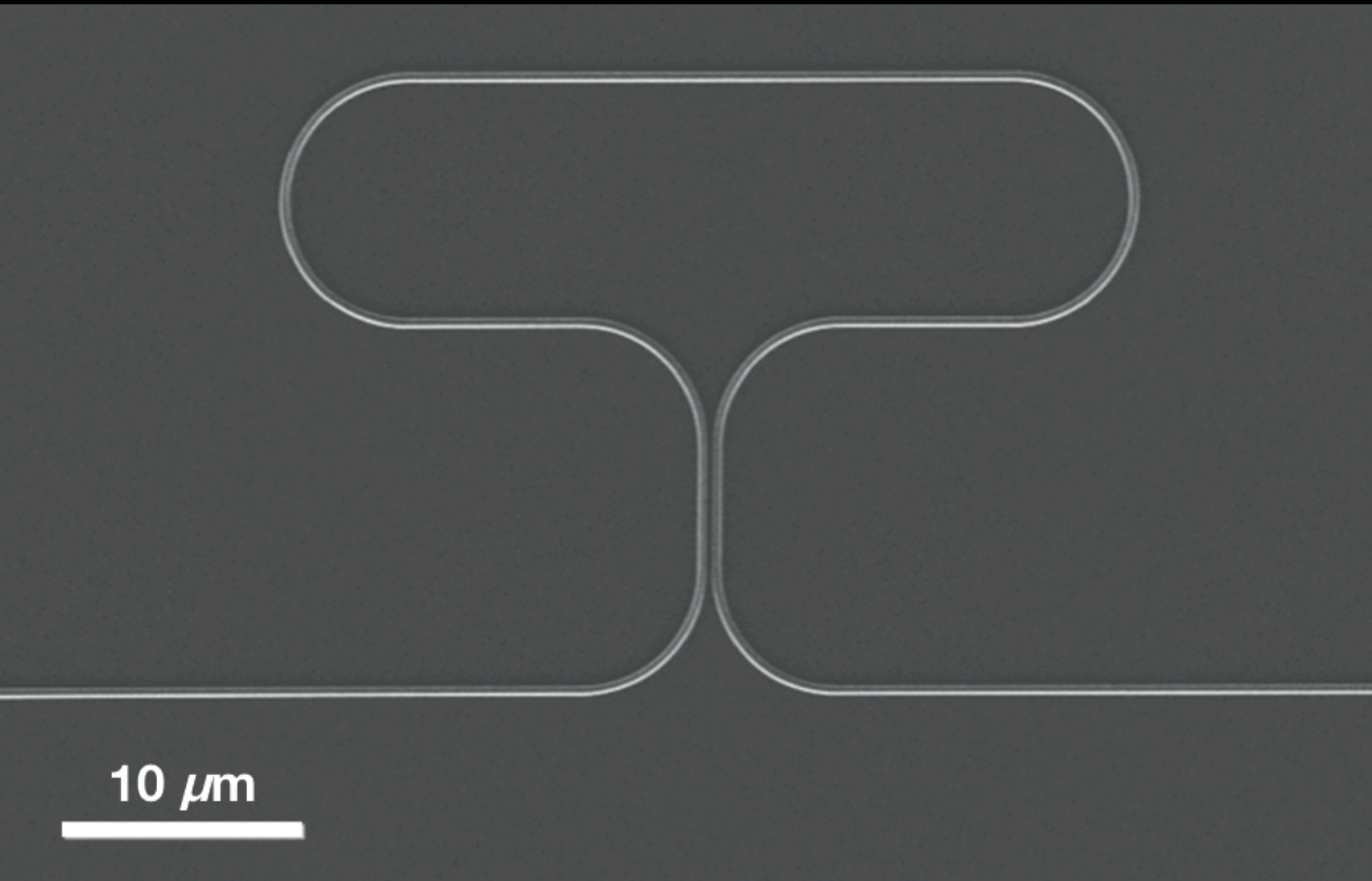
6.6×10^{-12} m/W	130 x silica

Optics Express, 21, 18582 (2013)

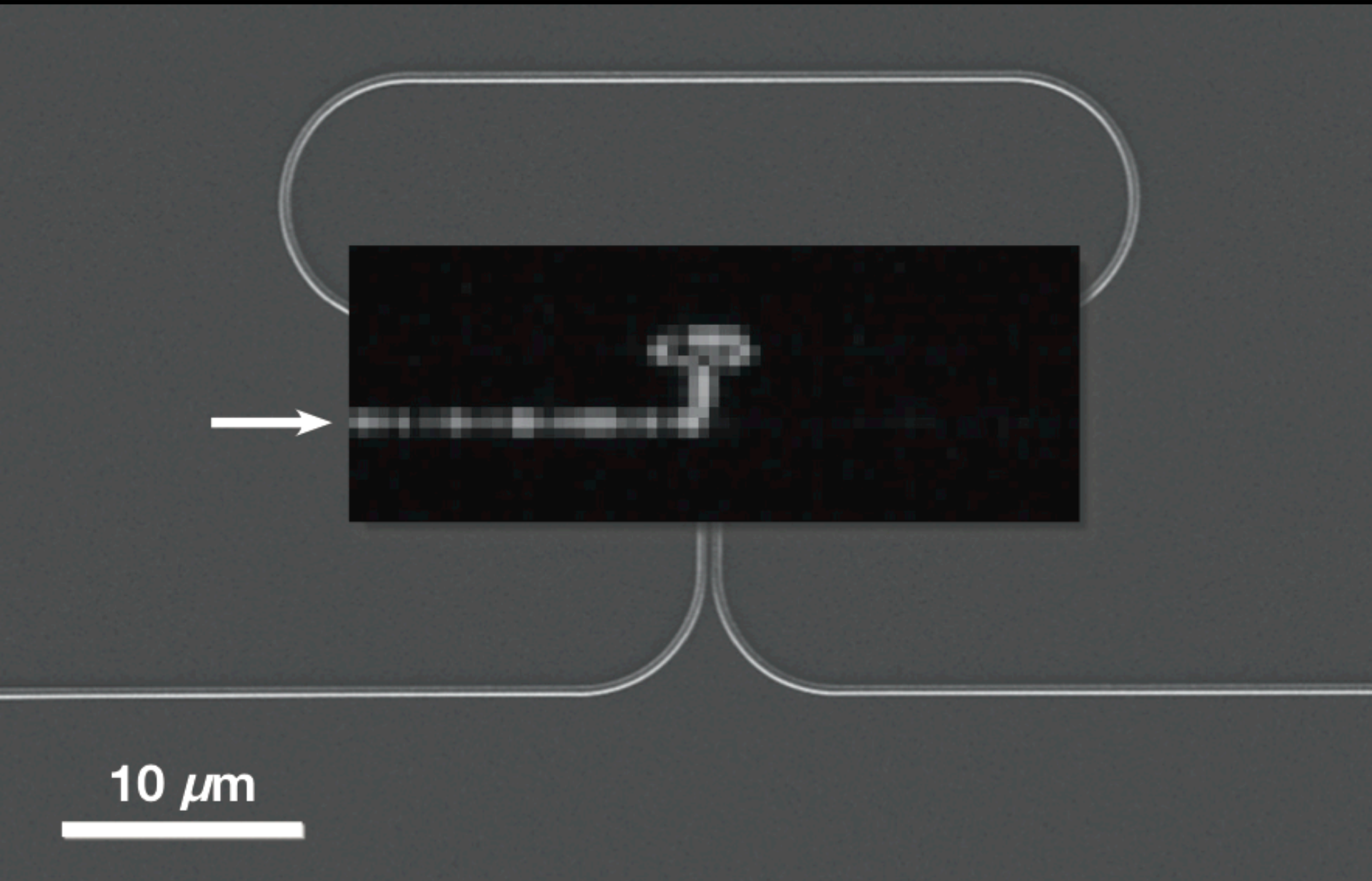
Green light generation

Manuscript in preparation

All-optical switching



All-optical switching



Future work

Raman gain

All-optical switch

Wavelength conversion

Summary

- Titanium dioxide is a cheap, abundant, non-toxic material with attractive properties.
- Promising platform for visible photonics.
- Nonlinear optics (spectral broadening, third harmonic generation) in the visible regime.

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Thank you

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