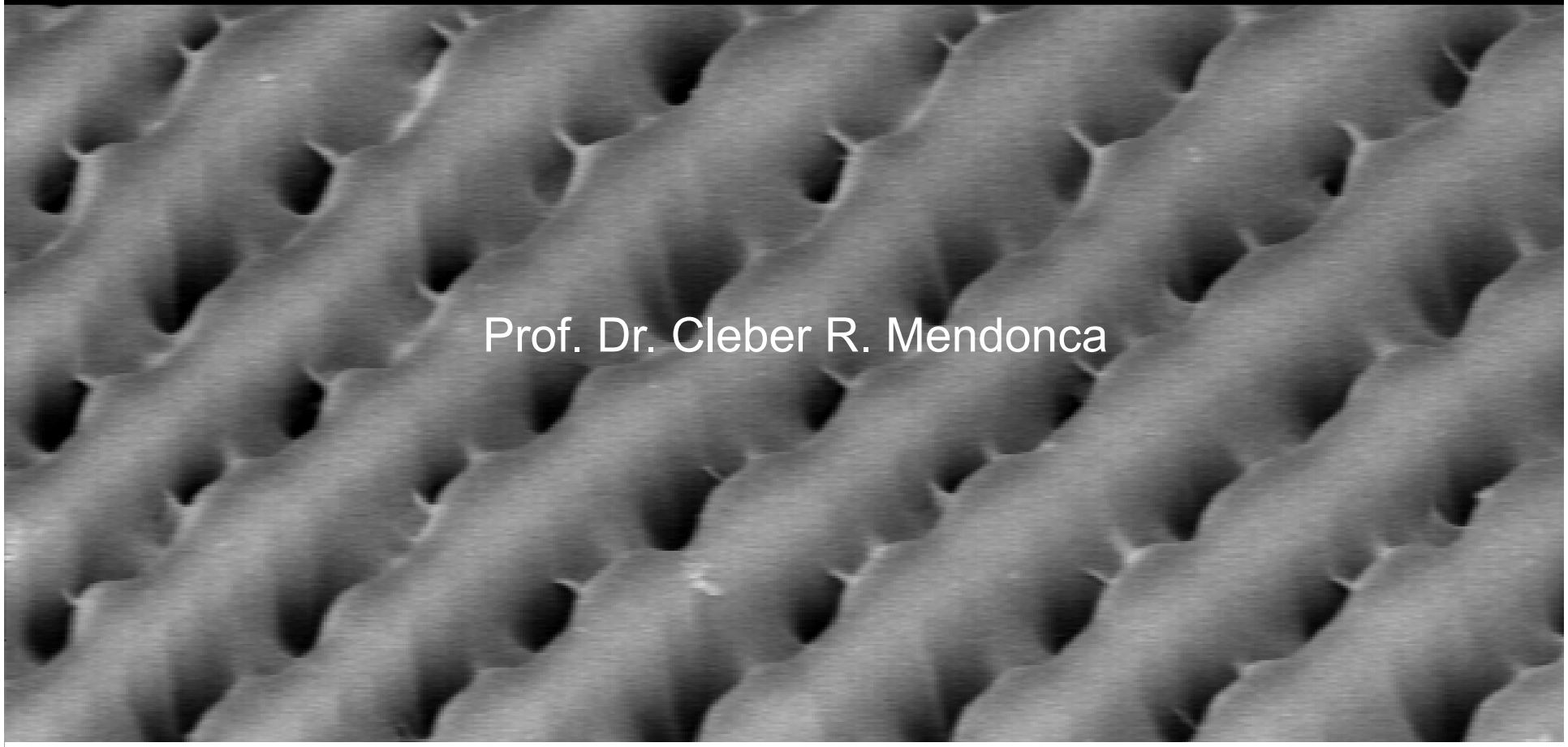
Sculpturing with light: micro/nanofabrication using fs-pulses



Prof. Dr. Cleber R. Mendonca

University of Sao Paulo - Brazil

students 77.000
52.000 undergrad.
25.000 grad.
employers 15.000
professors 6.000

- Sao Paulo
- Sao Carlos (9.000)
- Ribeirao Preto

University of Sao Paulo, Sao Carlos

Instituto de Física de São Carlos

Professors: 72

Employers: 173
(technical and administration)

Students: 600 (undergrad)
105 (master)
170 (phD)

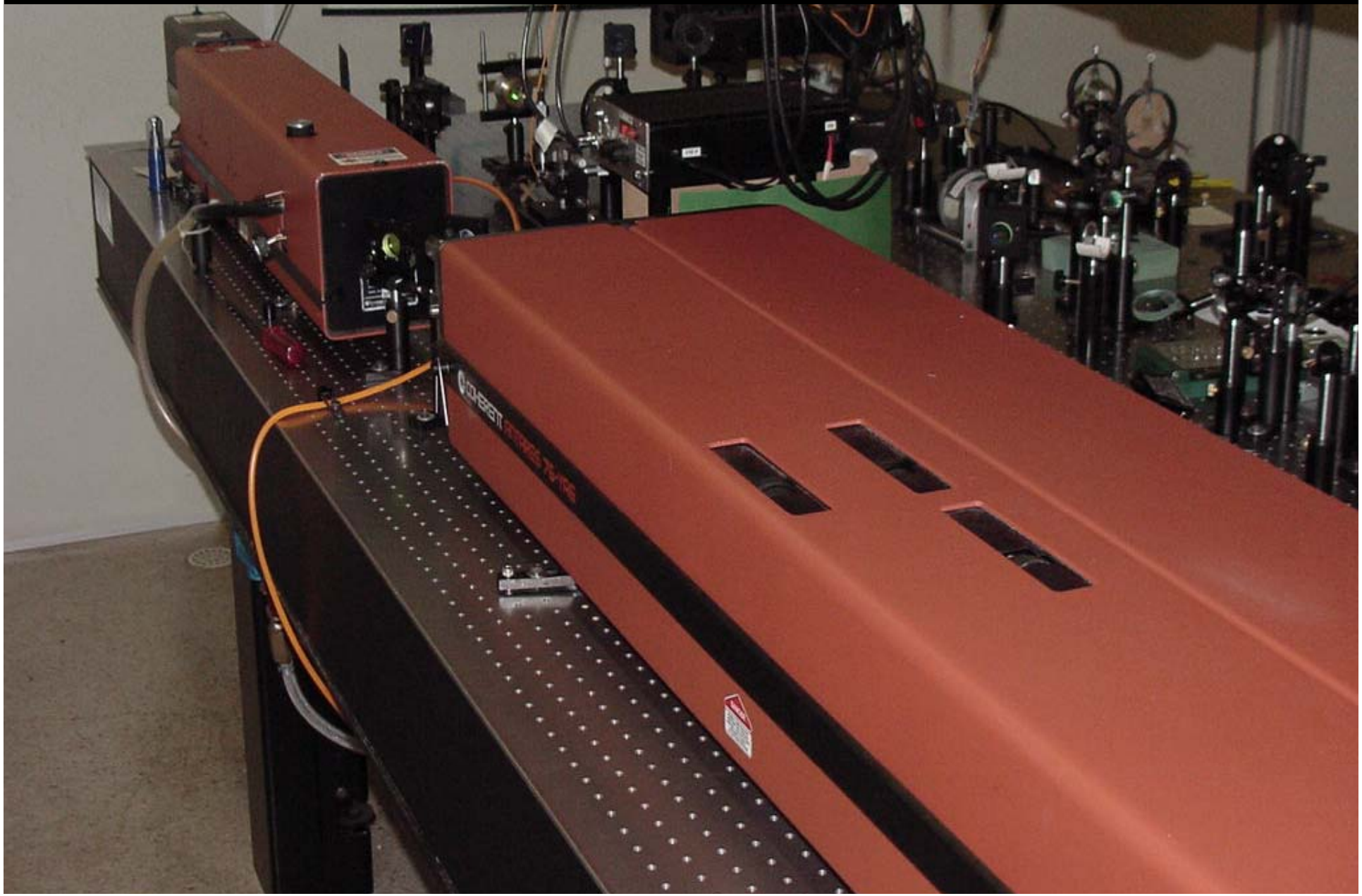
Several research areas in Physics and Material Sciences

Photonics Groups

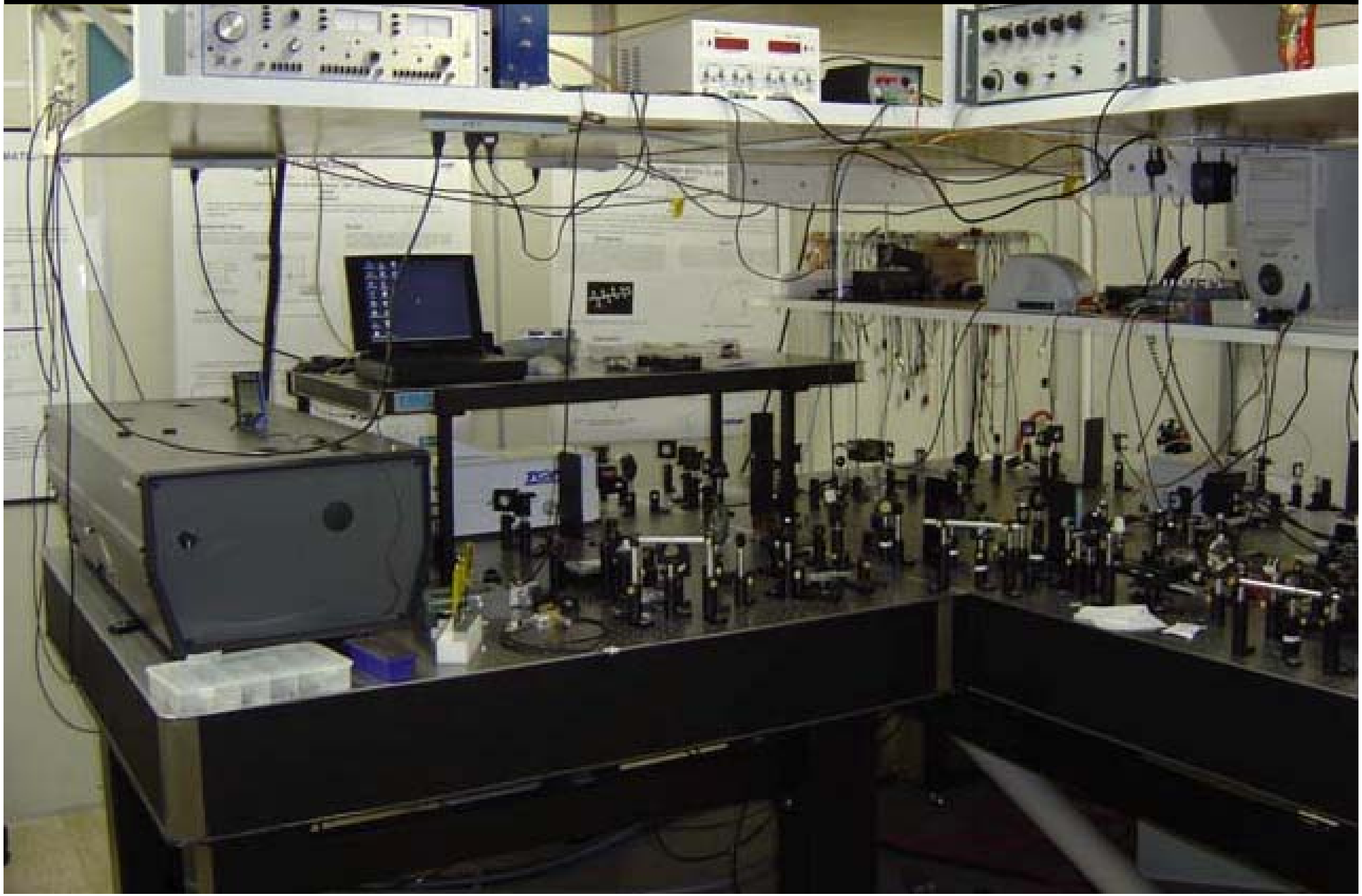
research areas

- study of optical nonlinearities in organic materials
- optical storage and surface relief gratings in azopolymers
- coherent control of light matter interaction
- fs-laser microfabrication

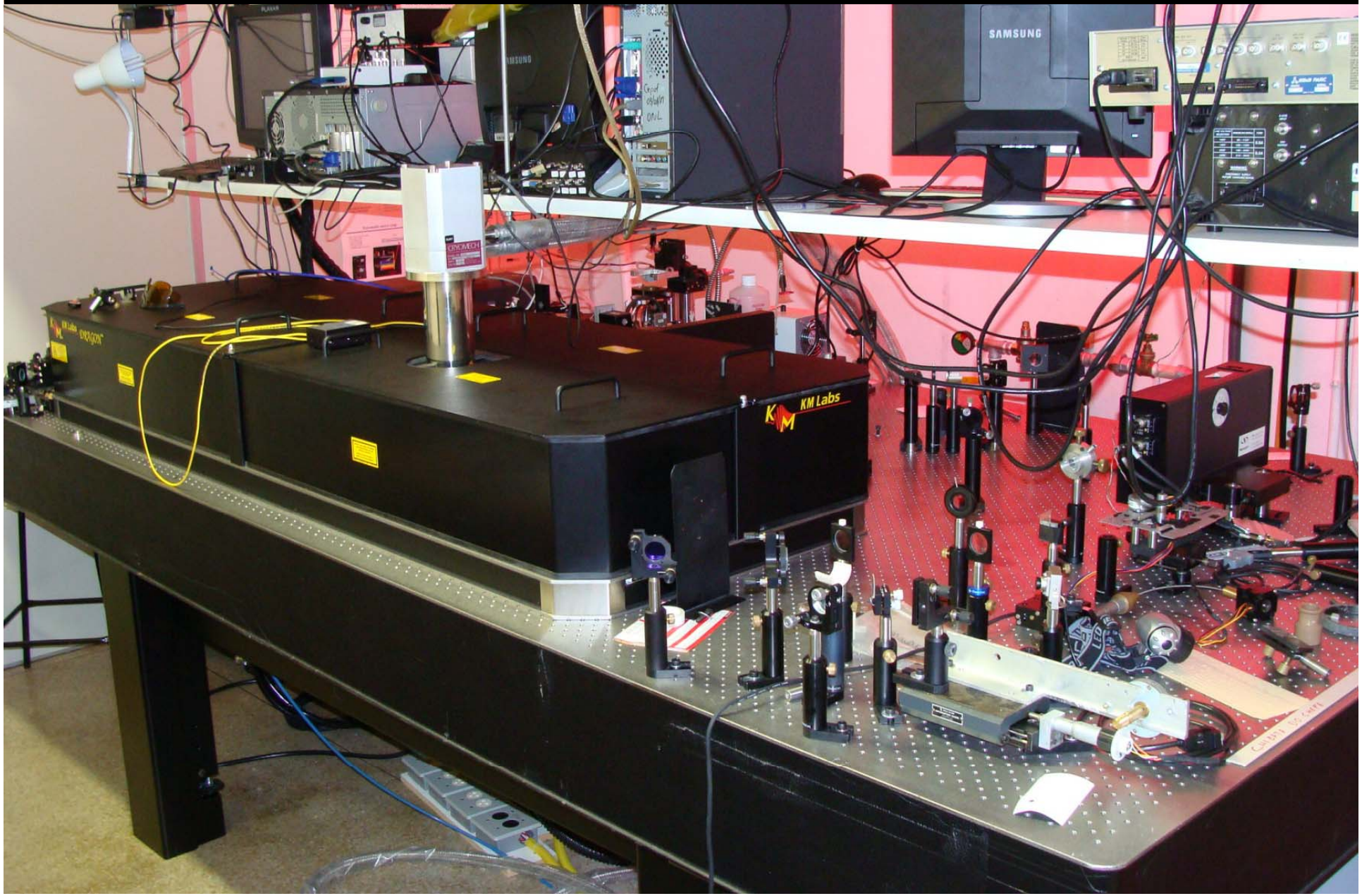
70 ps Q-switch/modelocked laser (532/1064 nm)



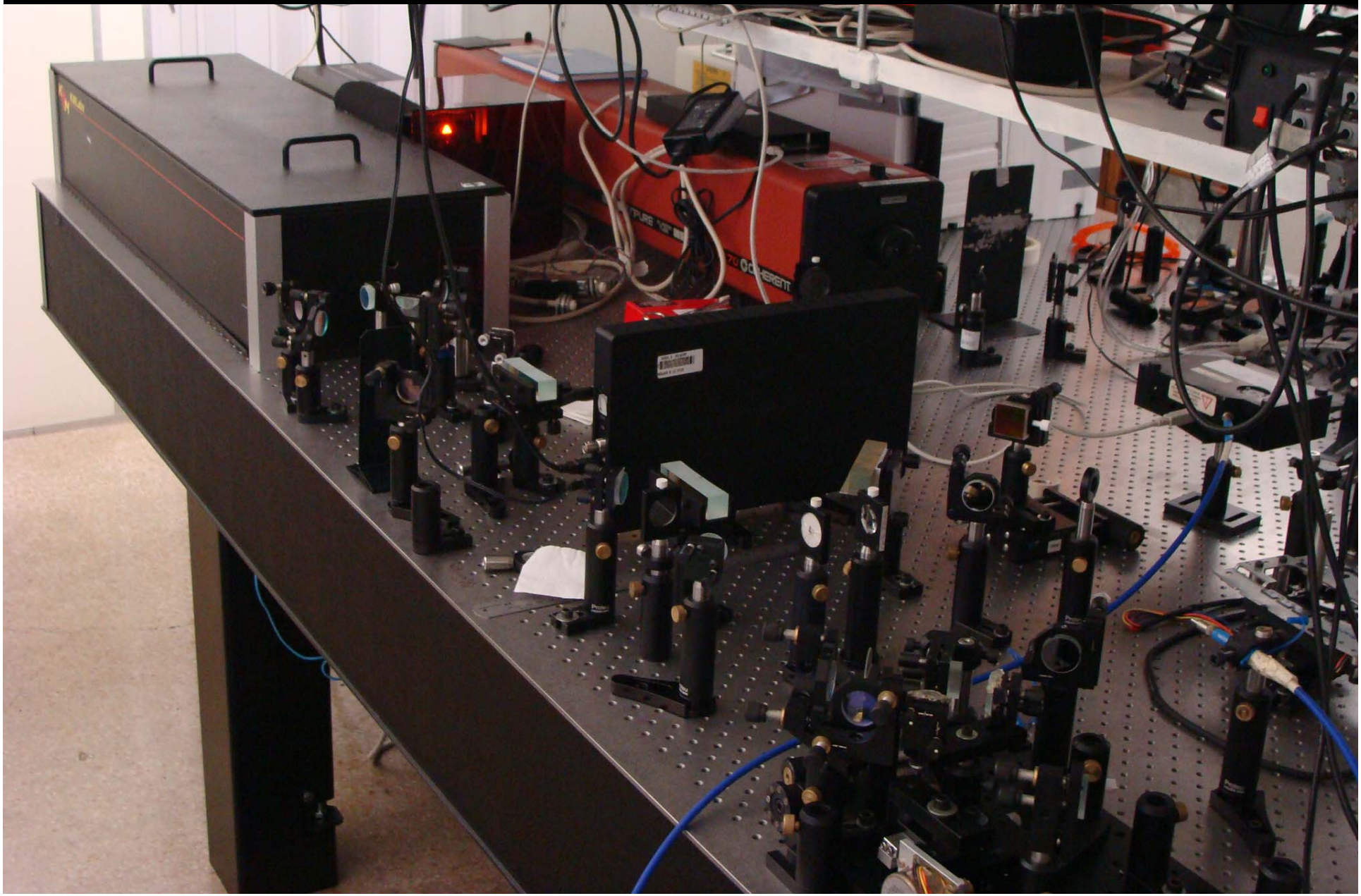
150 fs Ti:sapphire amplifier



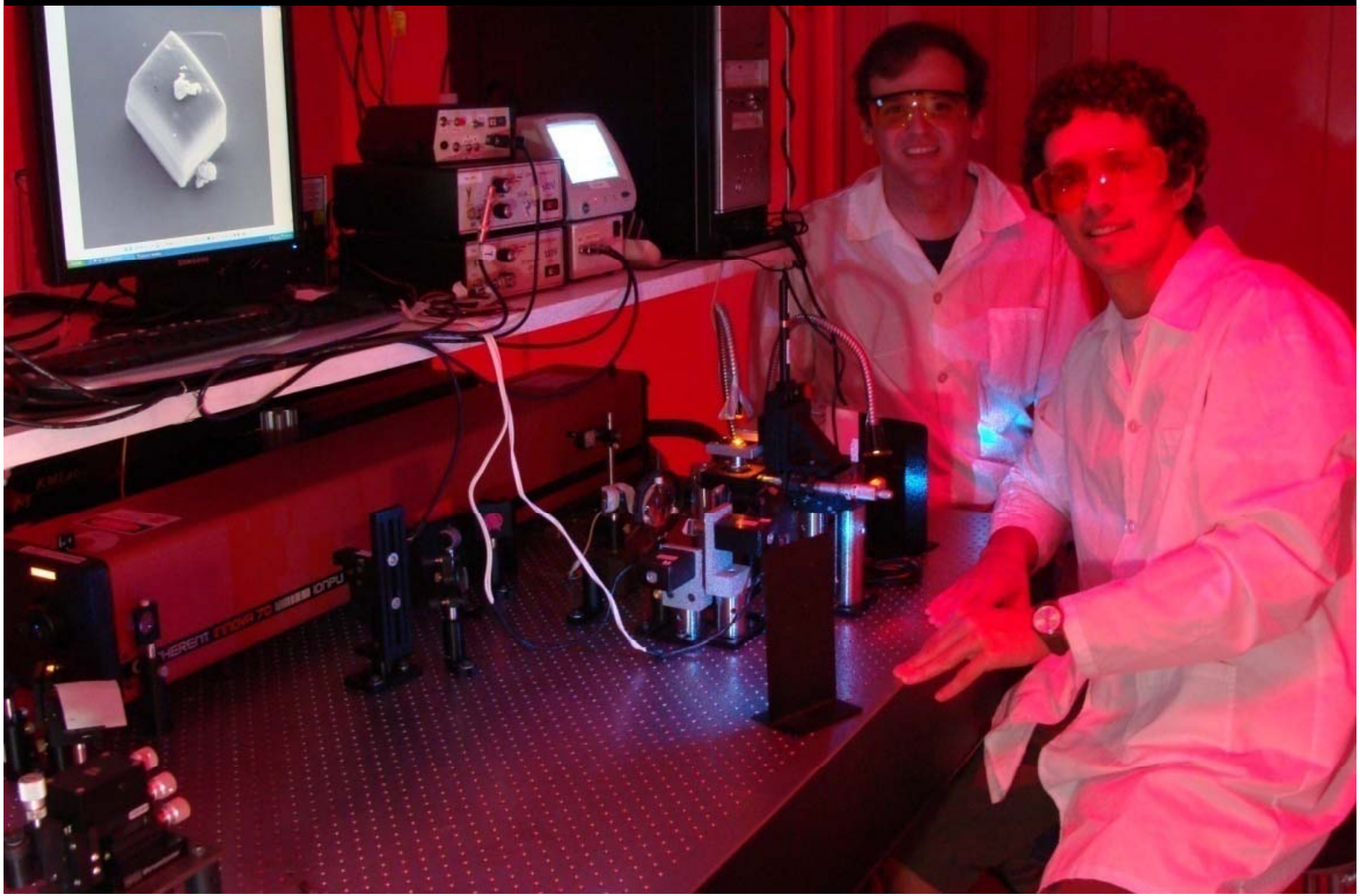
40 fs Ti:sapphire amplifier



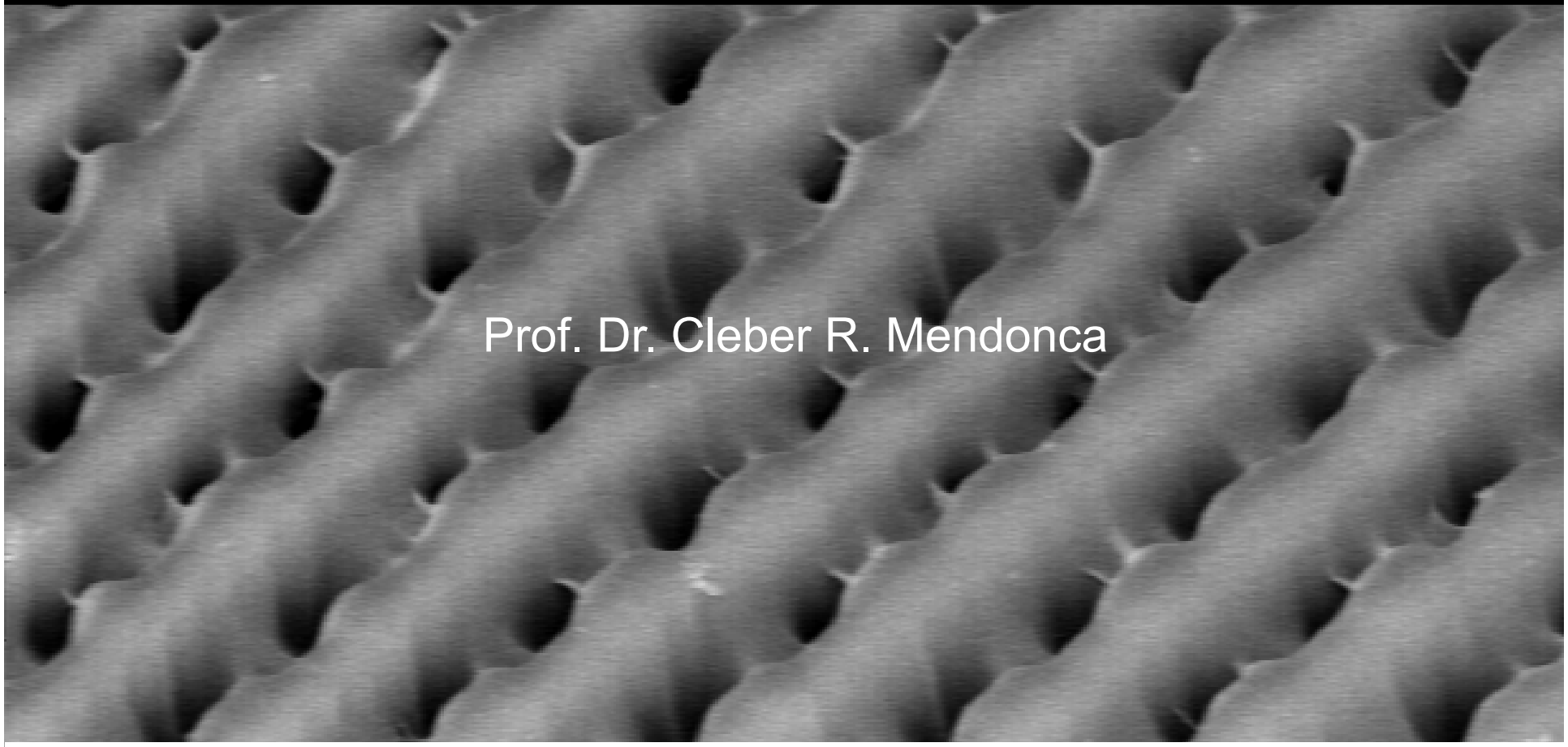
20 fs laser oscillator



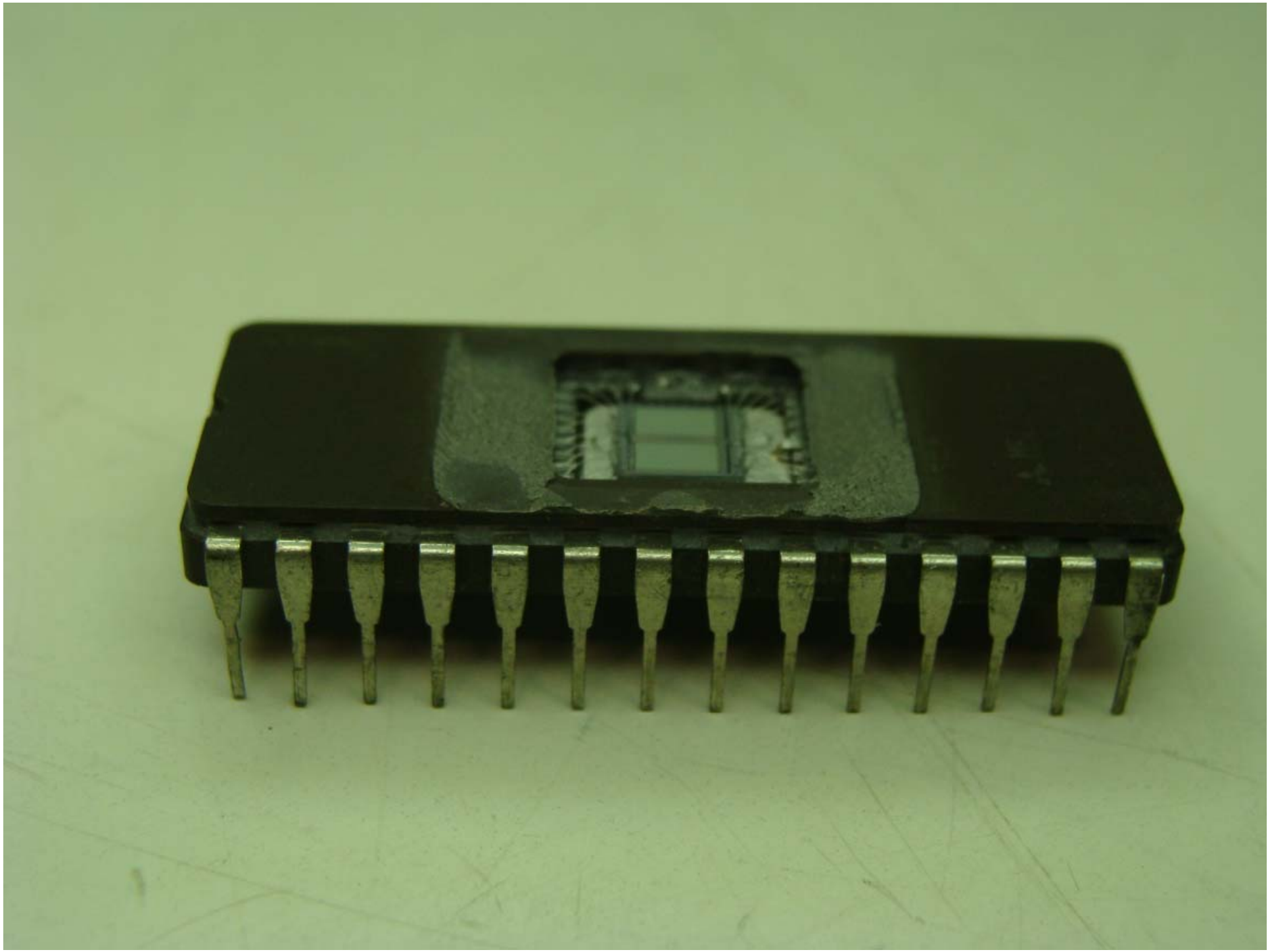
microfabrication laboratory

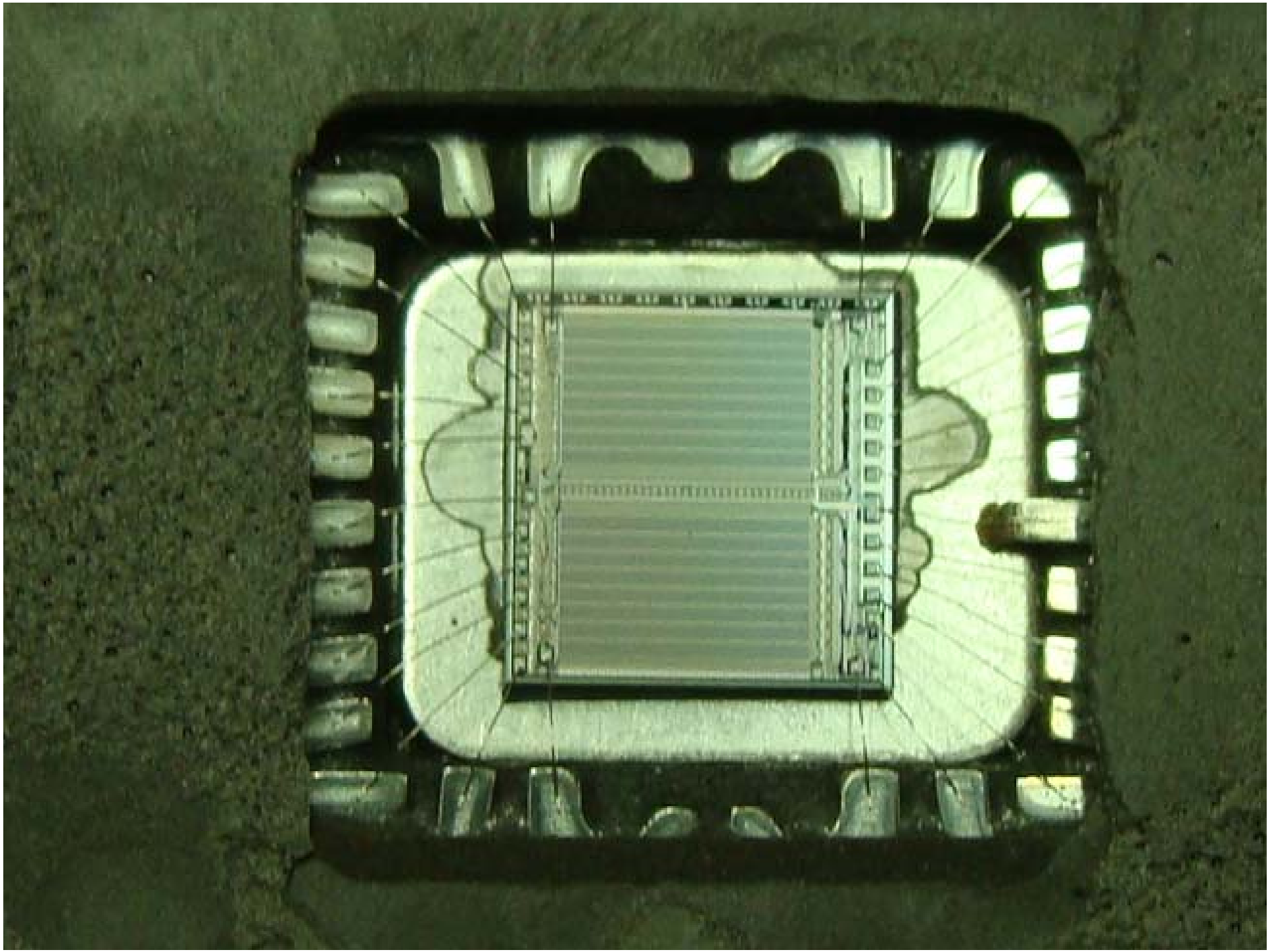


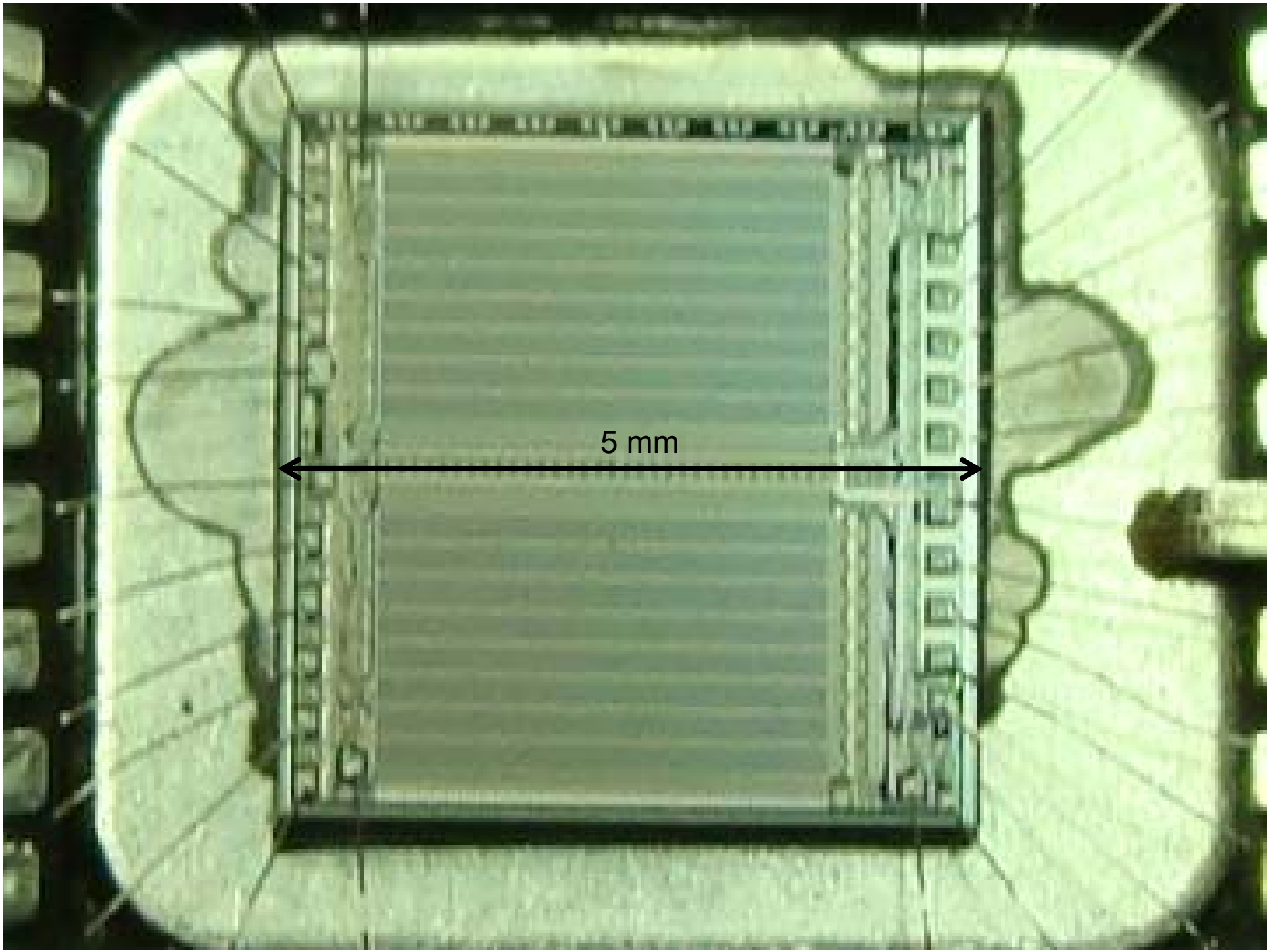
Sculpturing with light: micro/nanofabrication using fs-pulses



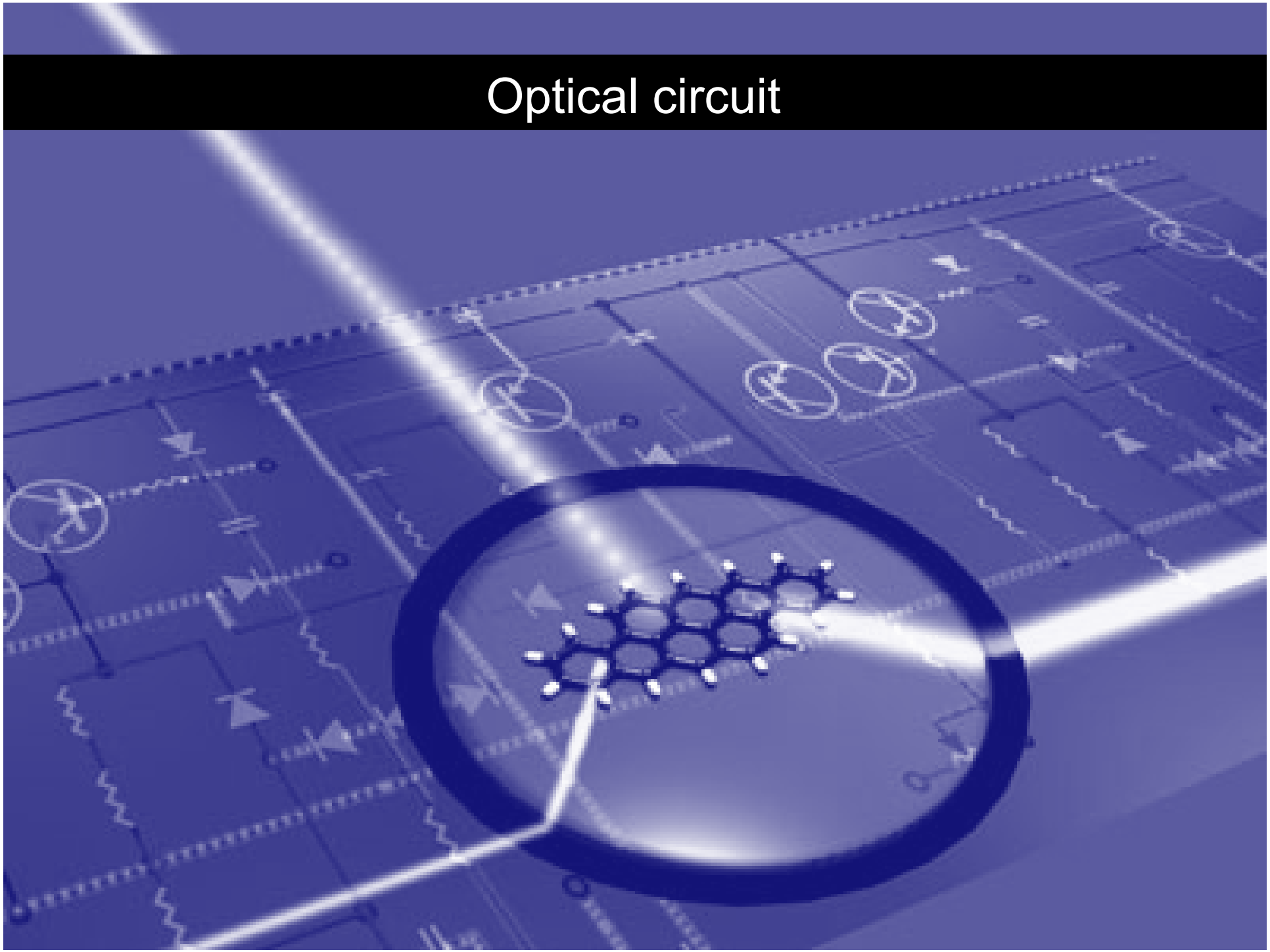
Prof. Dr. Cleber R. Mendonca



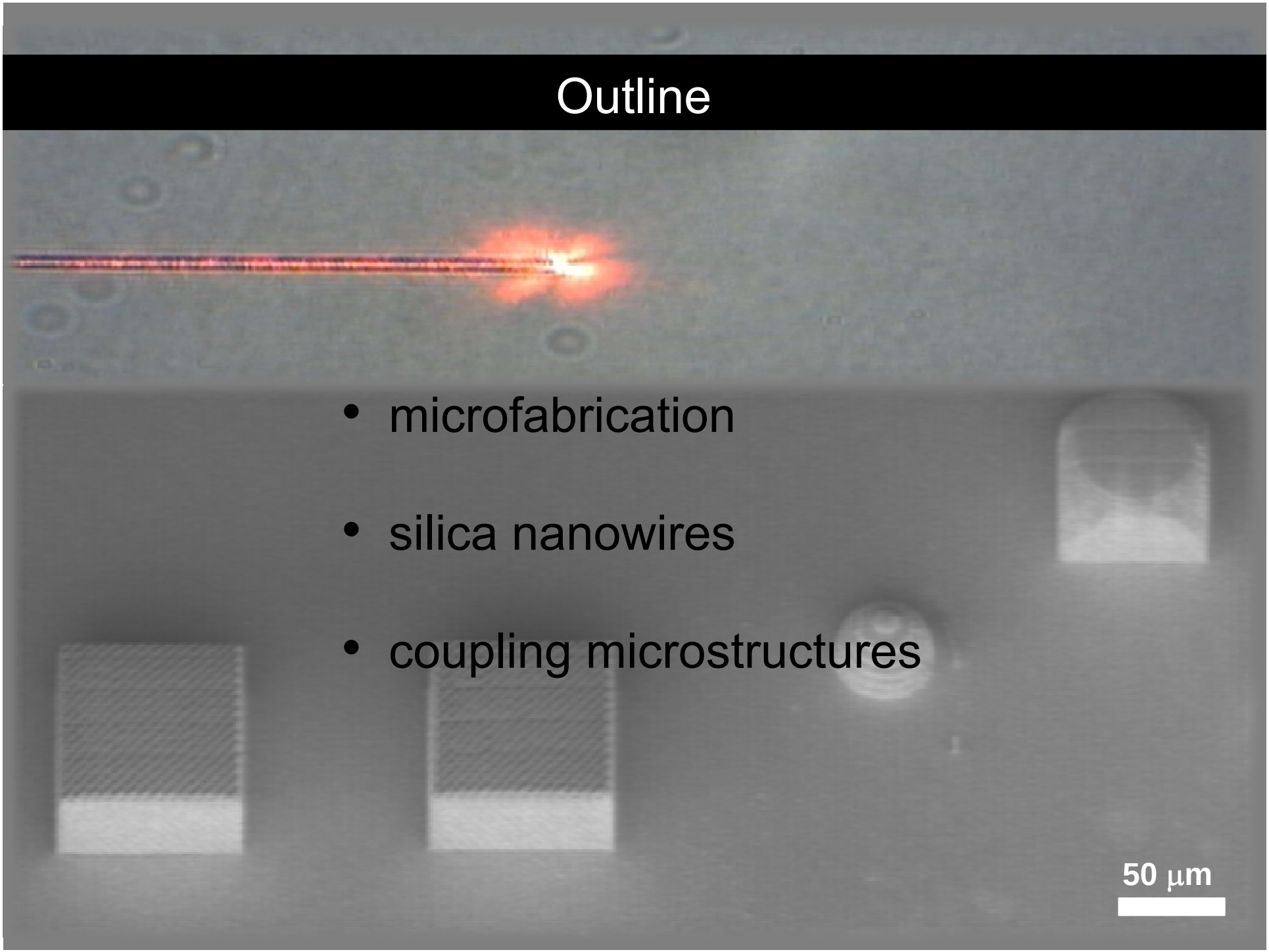



5 mm

Optical circuit



Outline



- microfabrication
- silica nanowires
- coupling microstructures

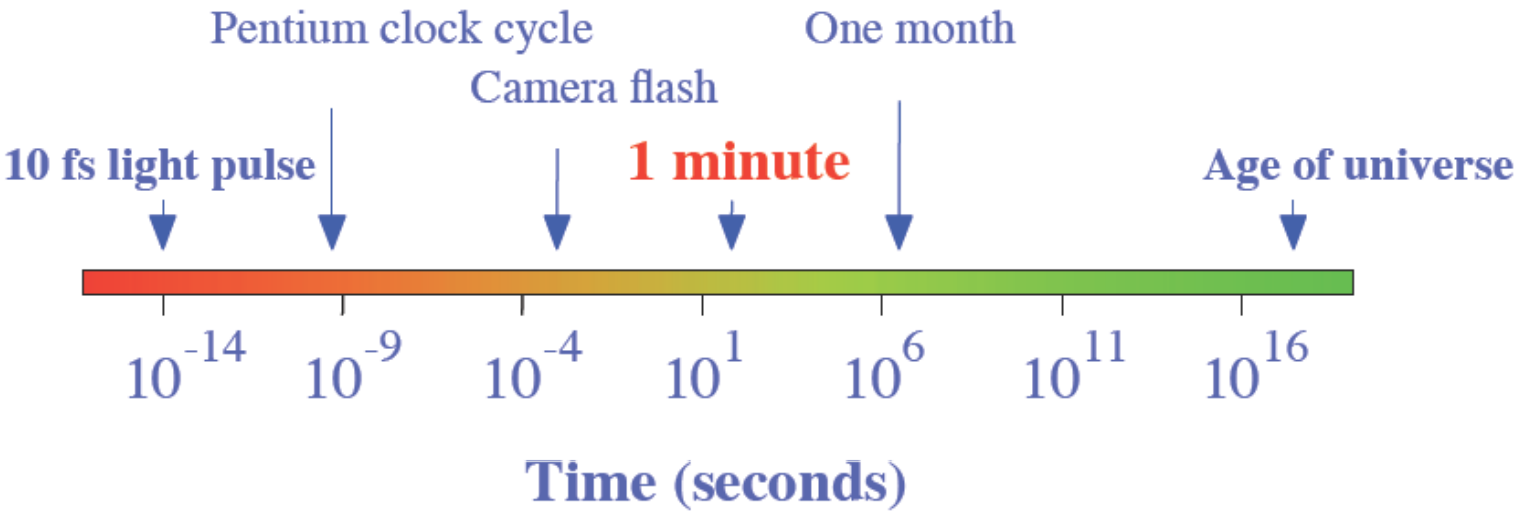
Microfabrication

Novel concept:

build a microstructure using fs-laser and nonlinear optical processes

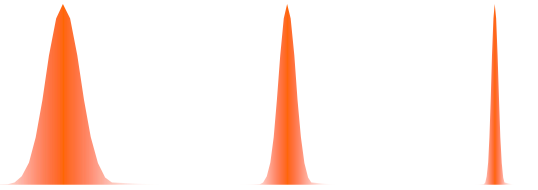
Microfabrication

1 fs = 10^{-15} s



Microfabrication

Ti:Sapphire lasers



100 fs 50 fs 20 fs

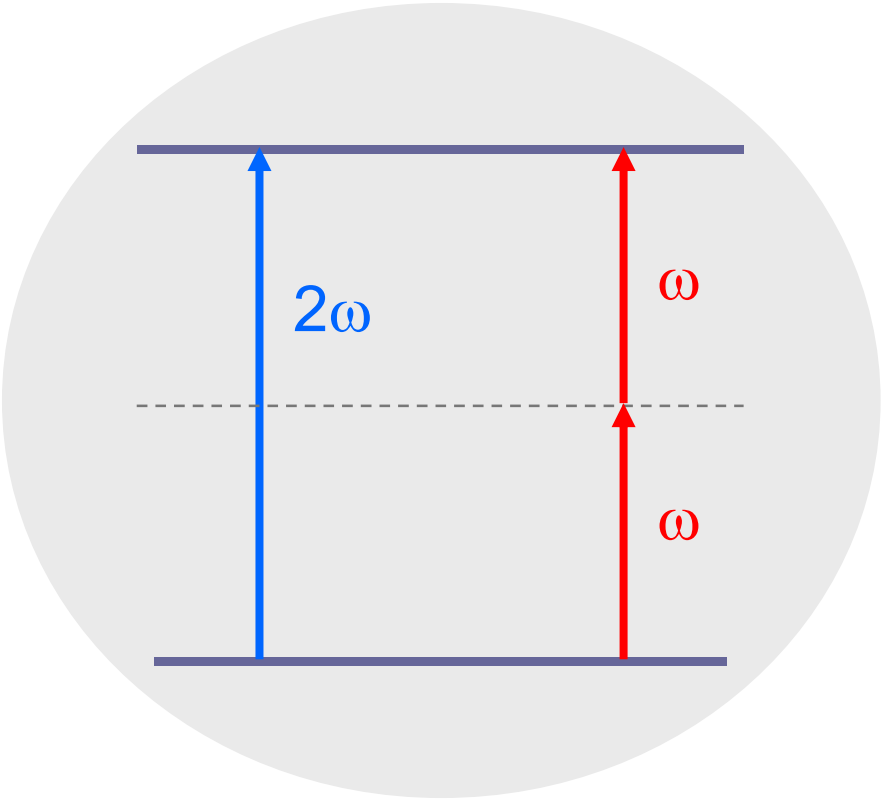
Very intense light

Laser intensities ~ *100 GW/cm²*

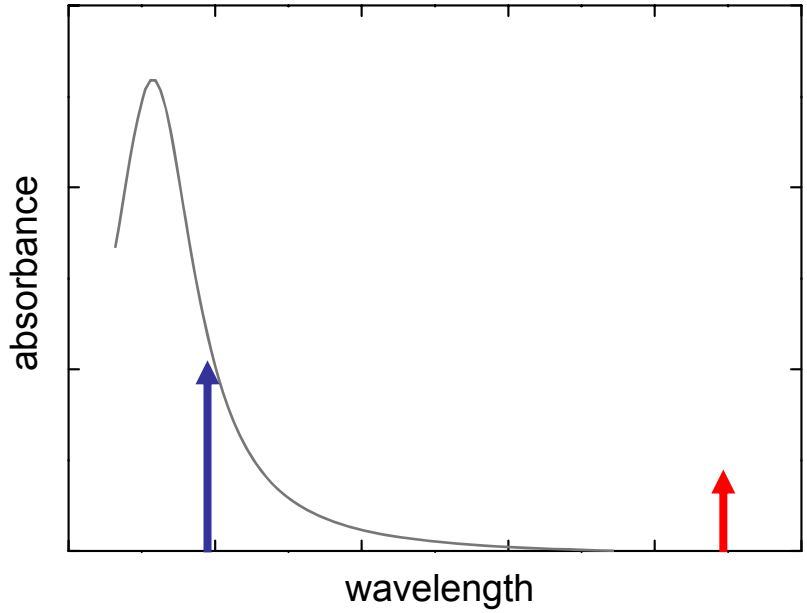
1 x 10^{11}W/cm²

Laser pointer: 1 mW/cm² (1 x10^{-3} W/ cm²)

Two-photon absorption

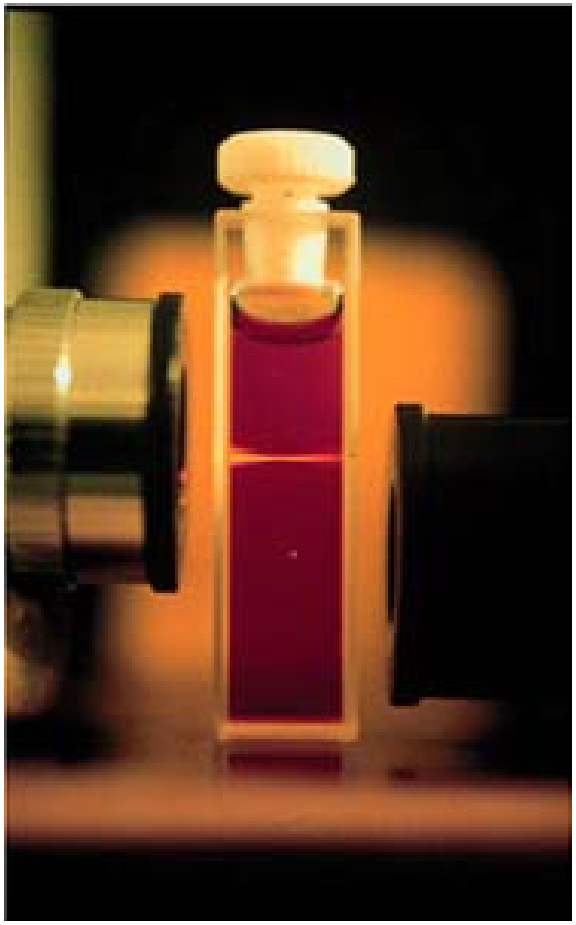


Third order processes $\chi^{(3)}$



$$\alpha = \alpha_0 + \beta I$$

Two-photon absorption



spatial confinement of excitation

Two-photon polymerization

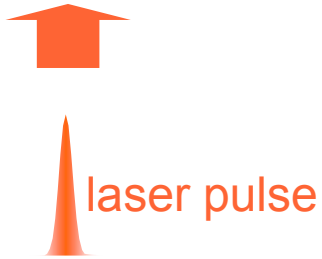
Photopolymerization

Monomer + Photoinitiator $\rightarrow$ *Polymer*

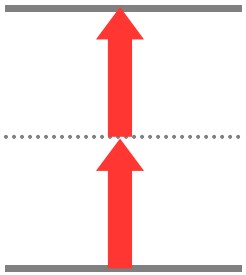
light

Two-photon polymerization

Monomer + Photoinitiator $\rightarrow$ *Polymer*



Photoinitiator is excited by ***two-photon absorption***

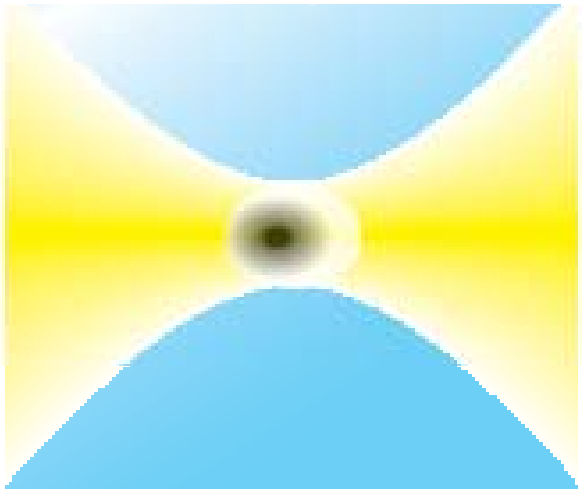


Appl. Phys. A, 90, 633–636 (2008)

Two-photon polymerization

Photoinitiator is excited by ***two-photon absorption***

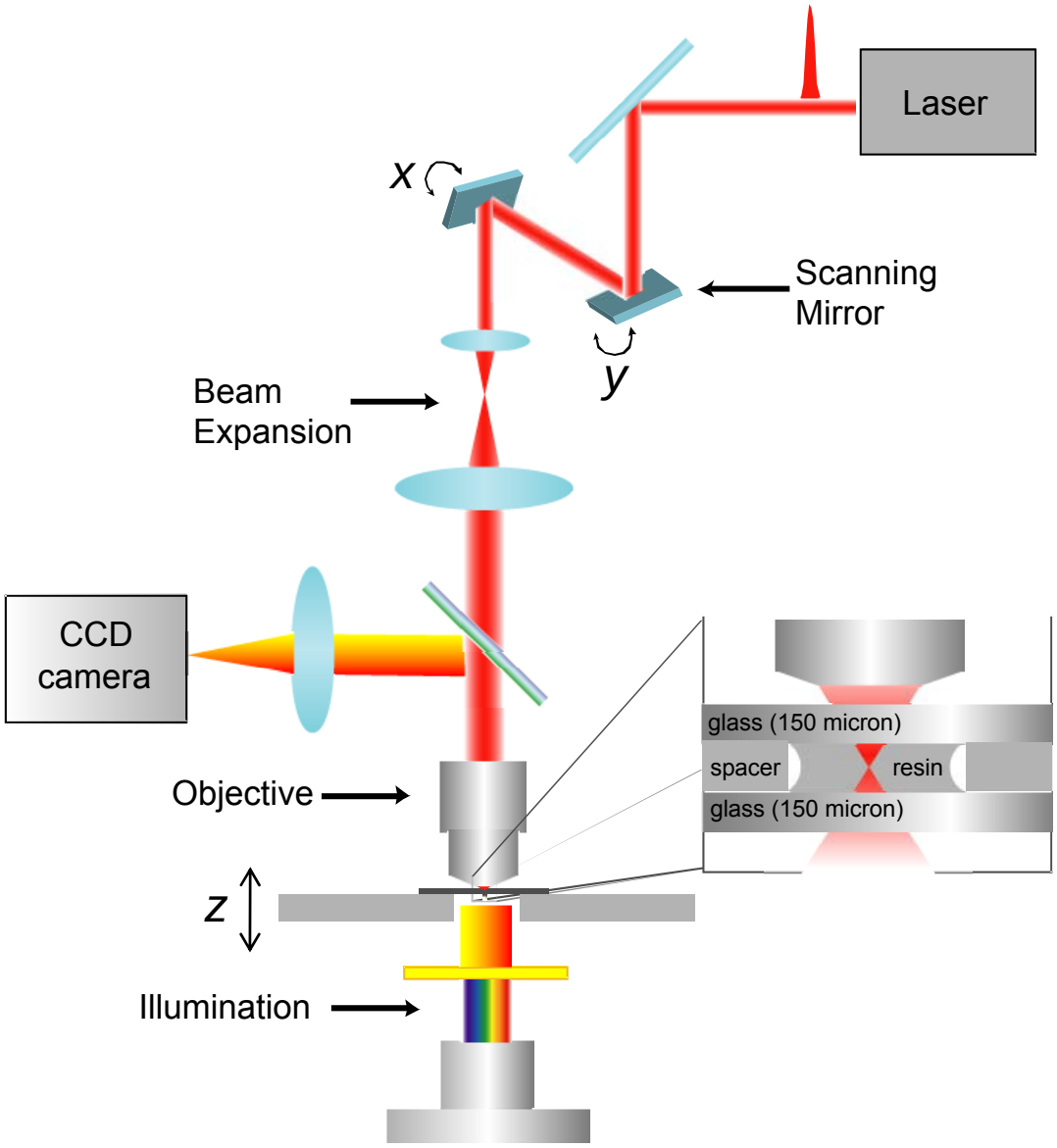
$$R_{2PA} \propto I^2$$



The polymerization is confined to the focal volume.

High spatial resolution

Two-photon polymerization setup



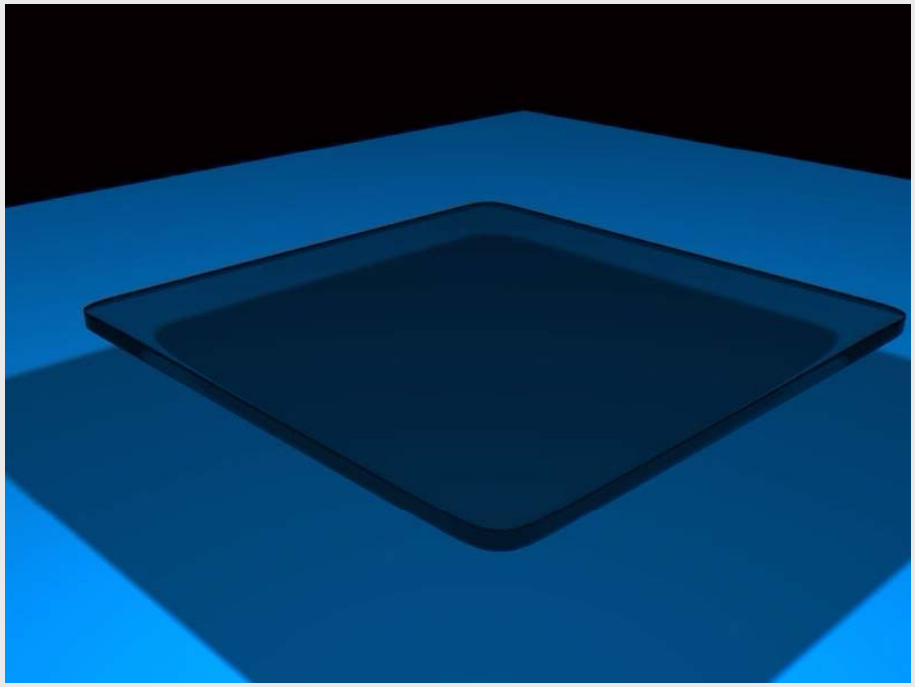
Ti:sapphire laser oscillator

- 100 fs
- 800 nm
- 76 MHz
- 20 mW

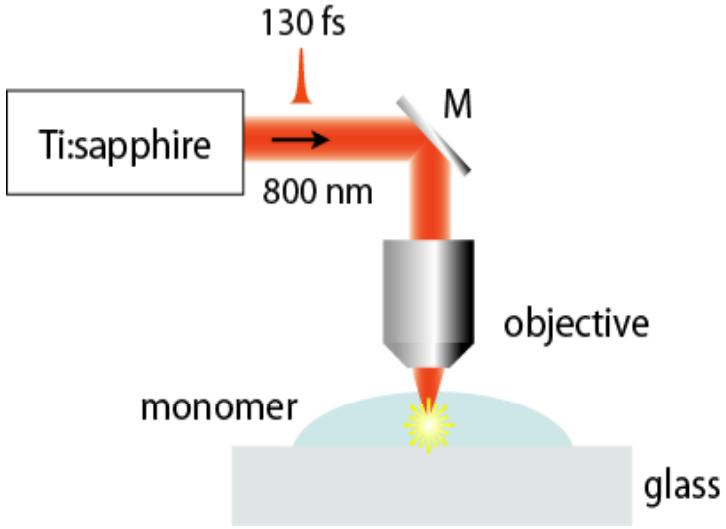
Objective

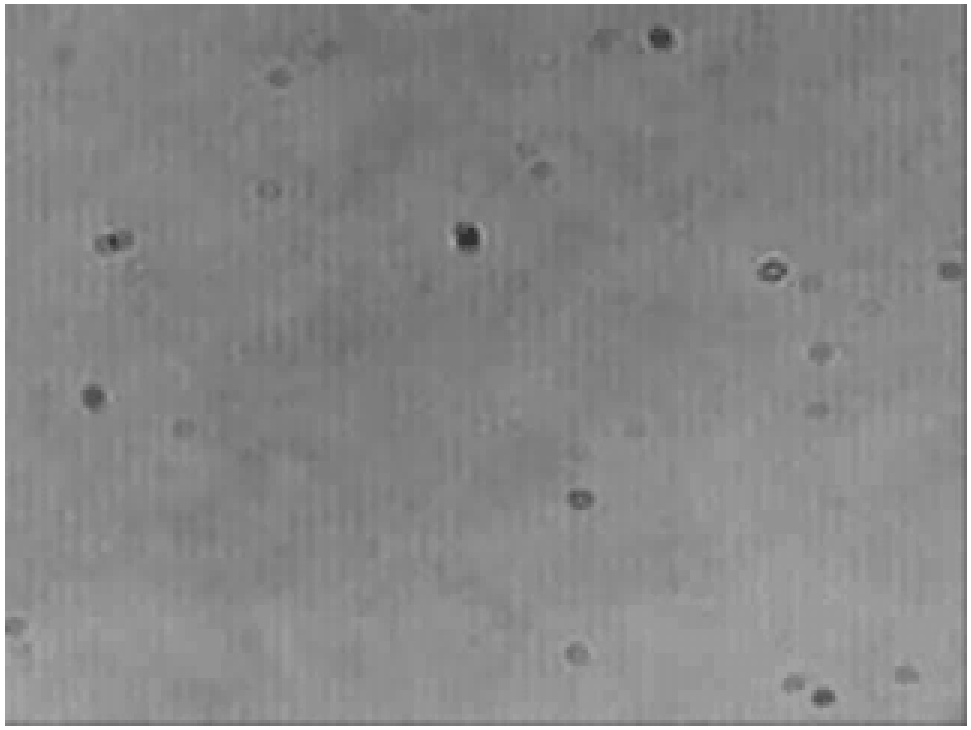
40 x
0.65 NA

Two-photon polymerization

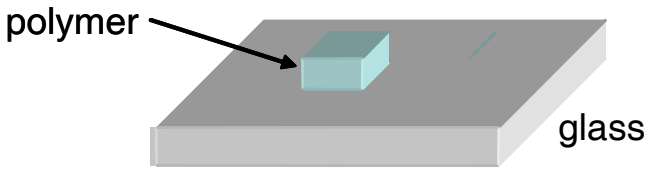


Two-photon polymerization

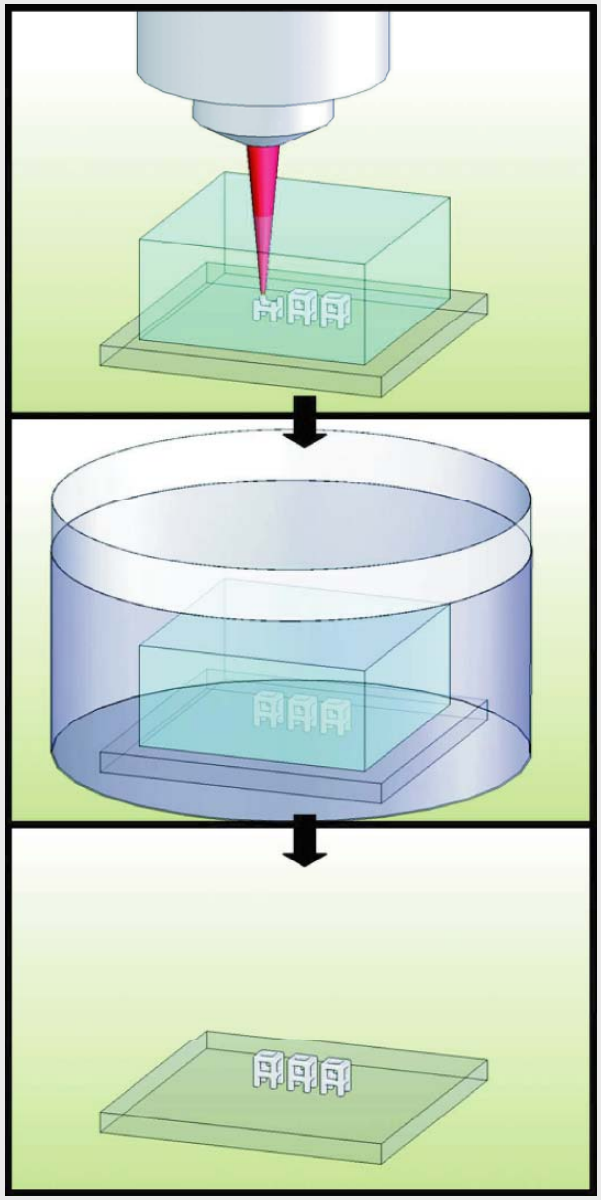




30 μm x 30 μm x 12 μm cube



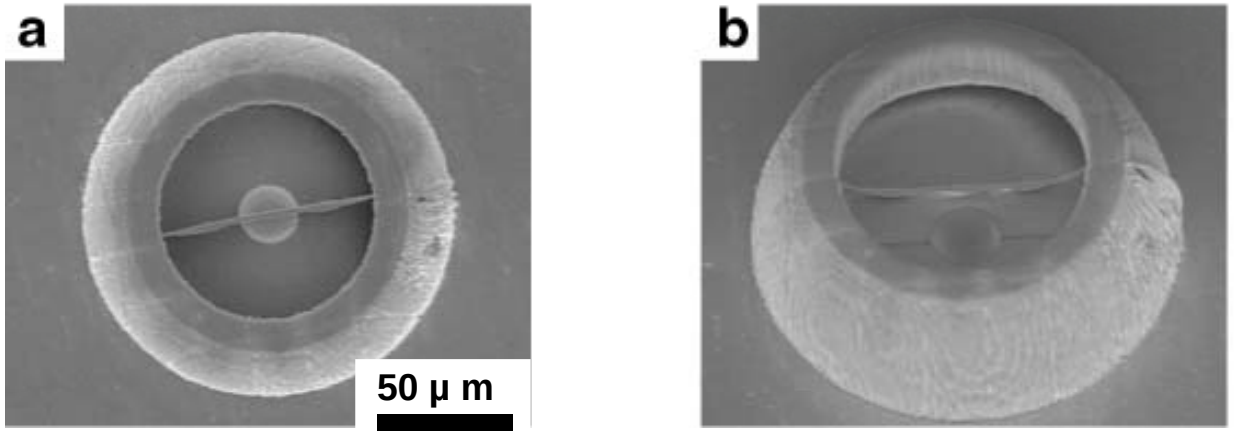
Two-photon polymerization



After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

Two-photon polymerization

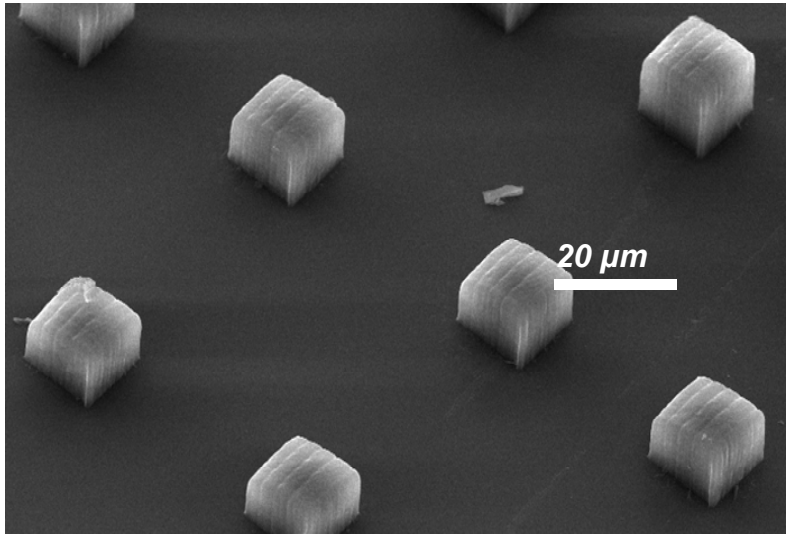
Microstructures fabricated by two-photon polymerization

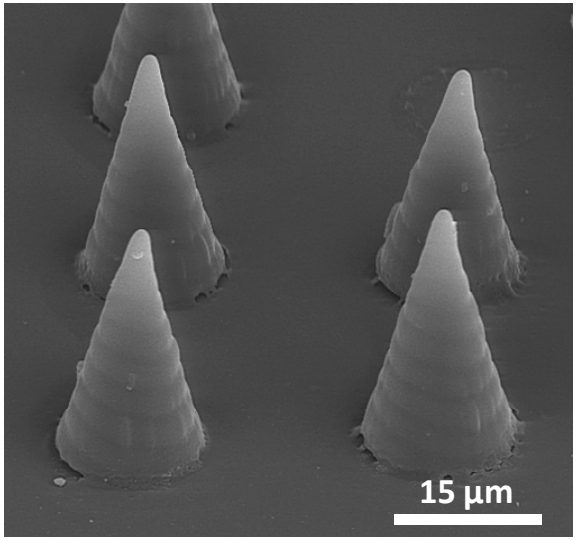


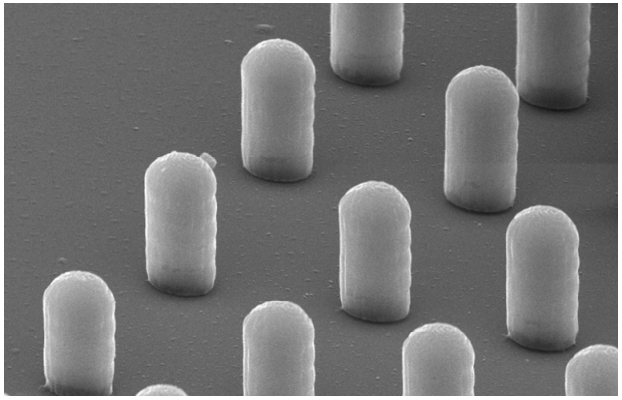
Appl. Phys. A, 90, 633–636 (2008)

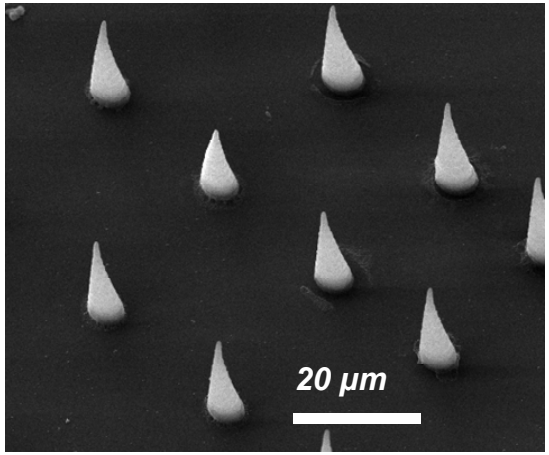
Two-photon polymerization

Microstructures fabricated by two-photon polymerization





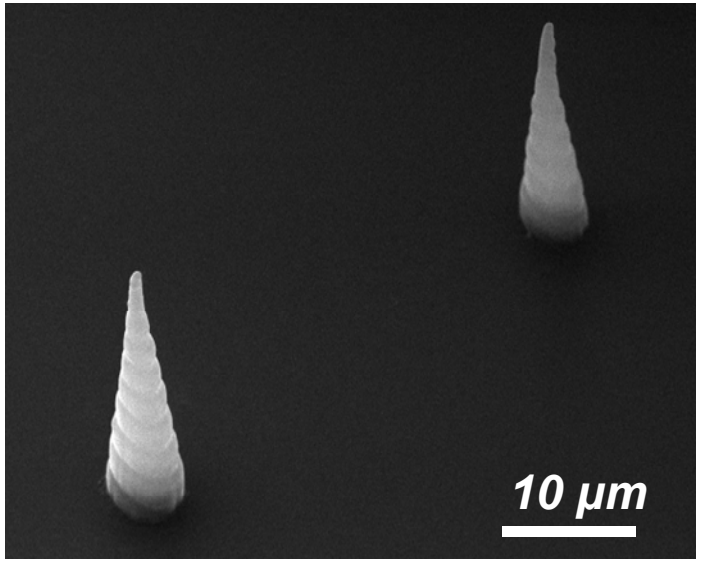




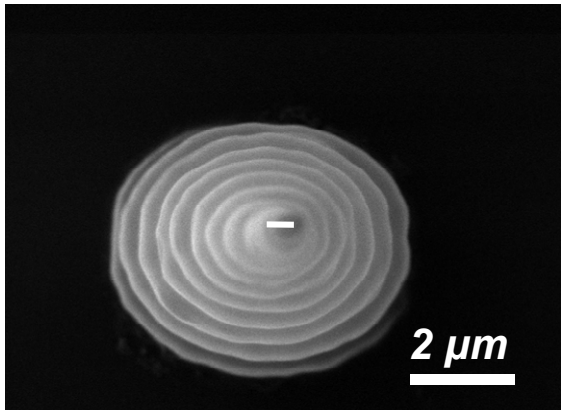
Two-photon polymerization

Feature size below the diffraction limit

side view



top view

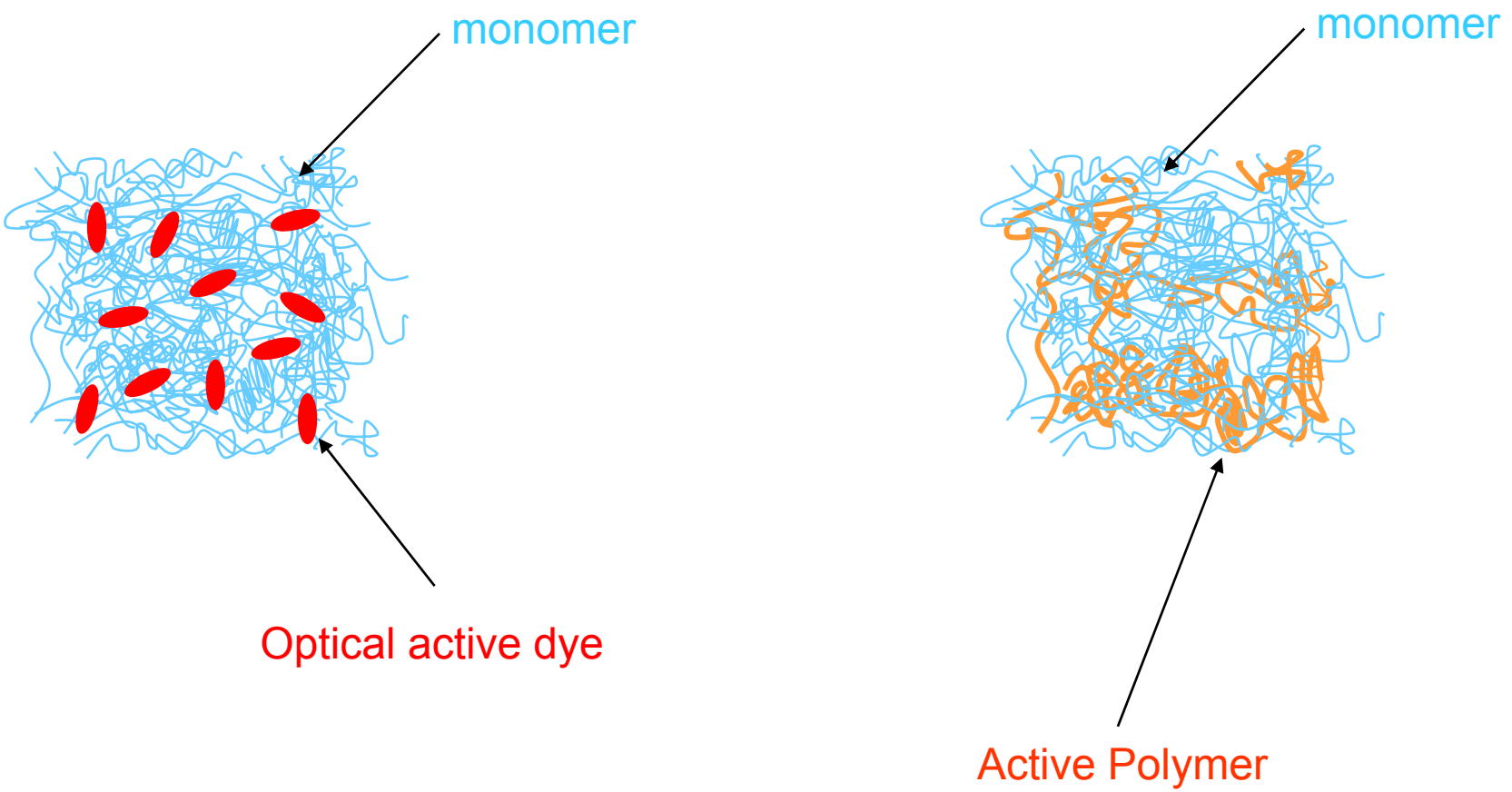


wavelength: **780 nm**
diffraction limited: **1100 nm**

Tip size of the conical microstructure: **600 nm**

Two-photon polymerization

Microstructures containing active compounds

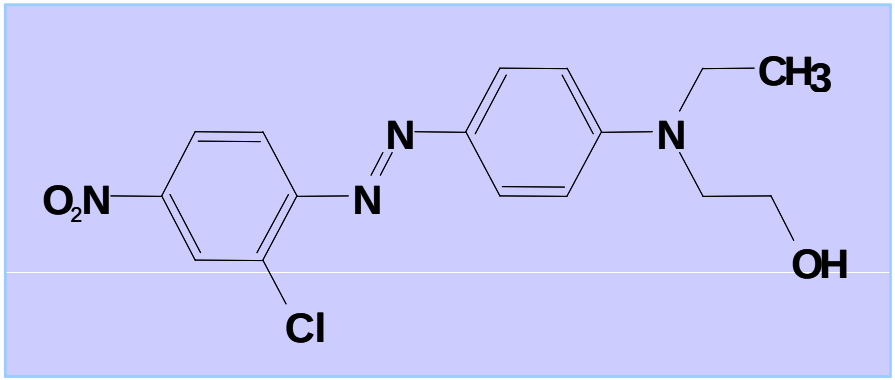


Microfabrication

- Micro-optical storage devices
- Micro-emitting devices

Micro-optical storage

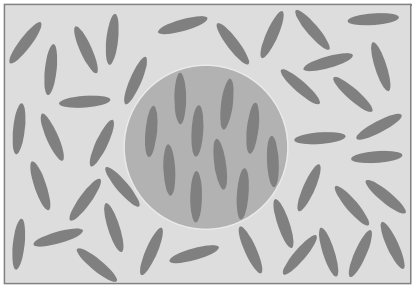
Incorporating the azodye DR13 into the microstructure



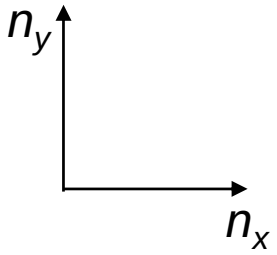
Micro-optical storage

Birefringent microstructures

After alignment

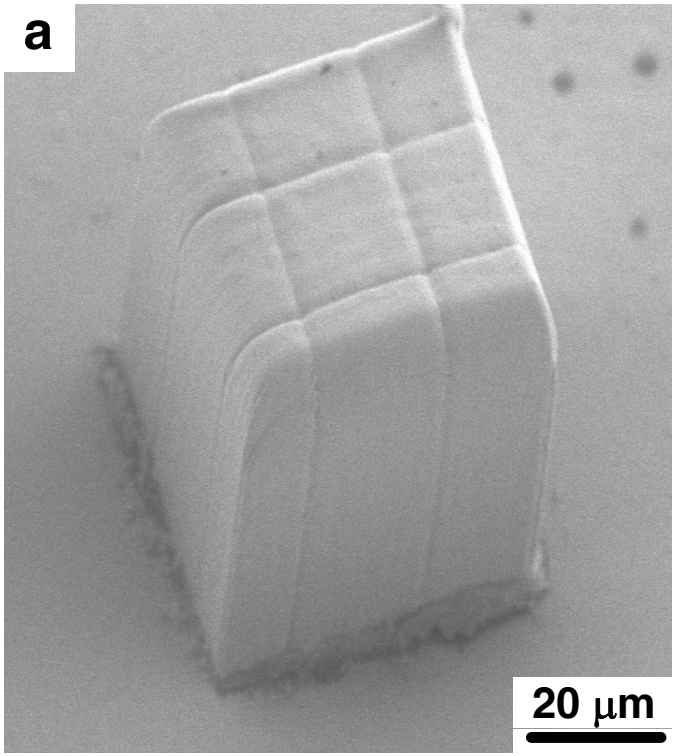


Optically Induced birefringence



$$n_y > n_x$$

Micro-optical storage



Birefringent microstructures

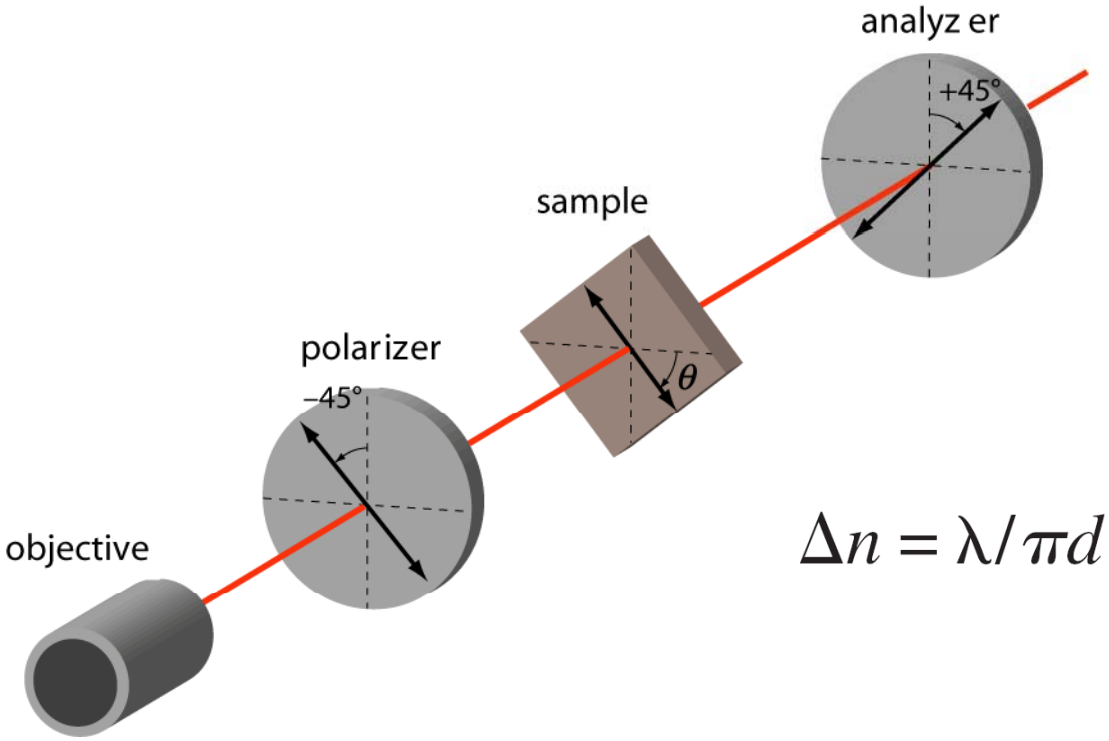
Ar+ ion laser irradiation

- 514.5 nm
- one minute
- intensity of 600 mW/cm^2

J. Appl. Phys., 102, 13109-1-13109-4 (2007)

Micro-optical storage

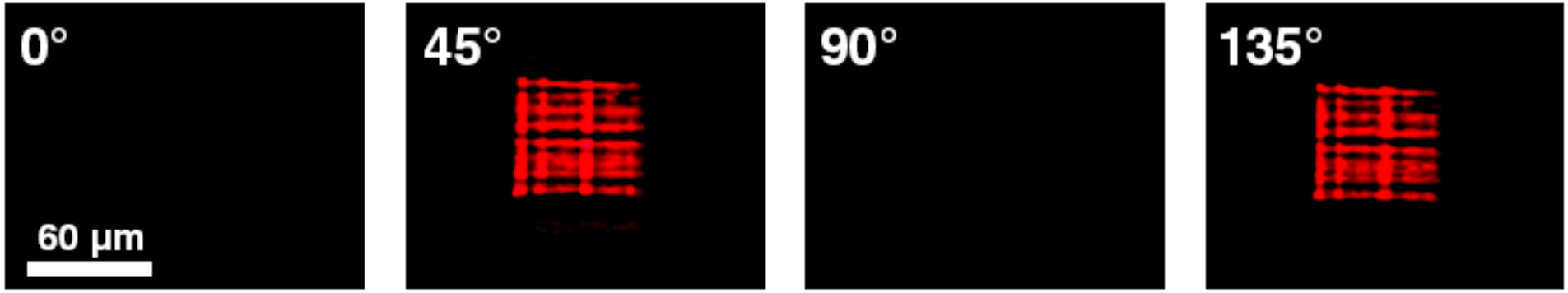
The sample was placed under an optical microscope between crossed polarizers and its angle was varied with respect to the polarizer angle



$$\Delta n = \lambda / \pi d \sin^{-1} \sqrt{T}$$

Micro-optical storage

The structure is visible when the angle between the birefringence axis and the polarizer is an odd multiple of 45°



$\Delta n = 5 \times 10^{-5}$

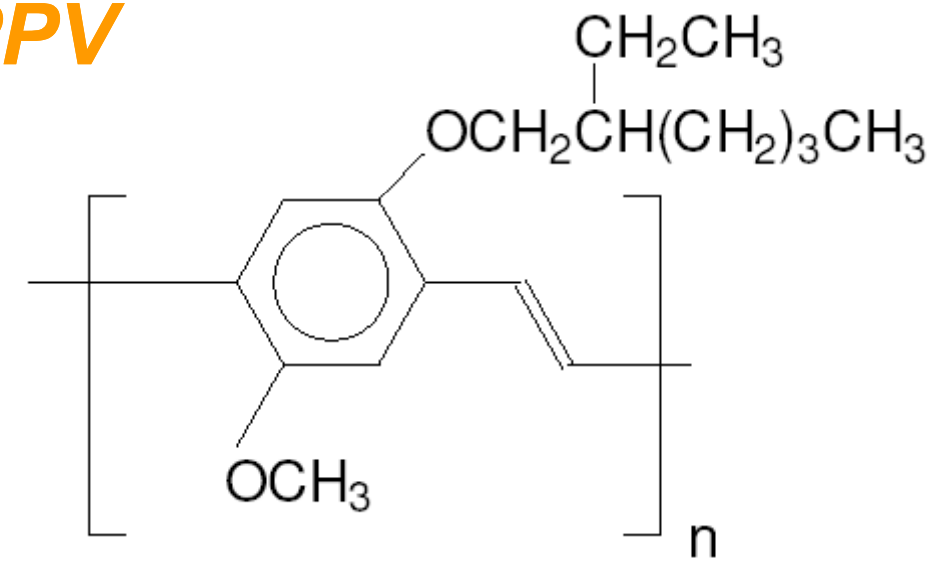
This birefringence can be completely erased by irradiating the sample with circularly polarized light.

Applications: micro-optical switch, micro-optical storage

J. Appl. Phys., 102, 13109-1-13109-4 (2007)

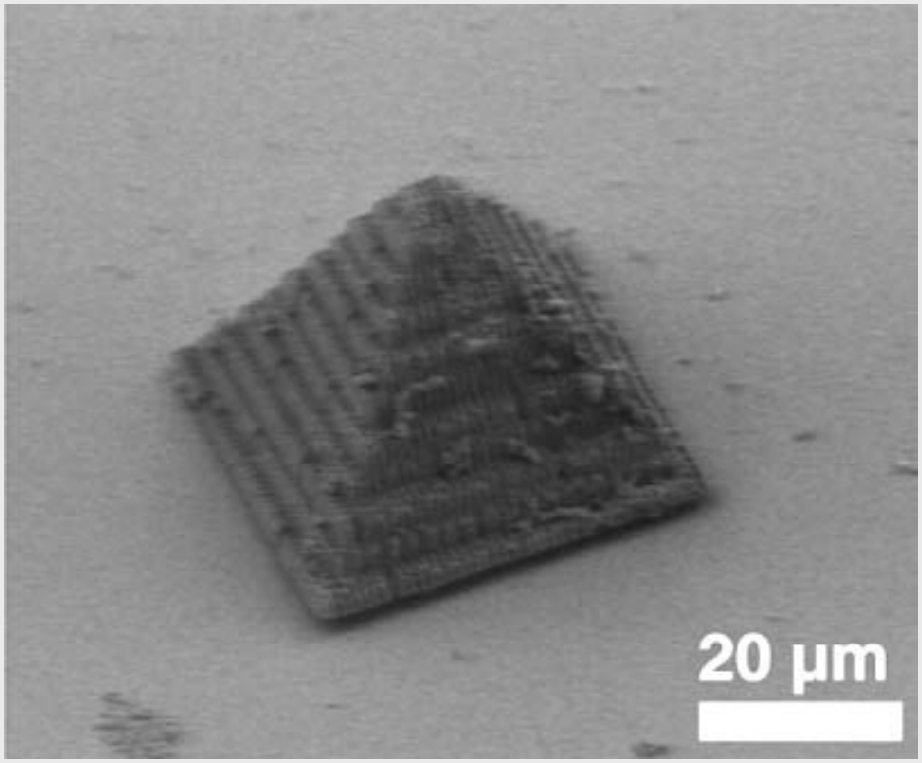
Microstructure containing MEH-PPV

MEH-PPV



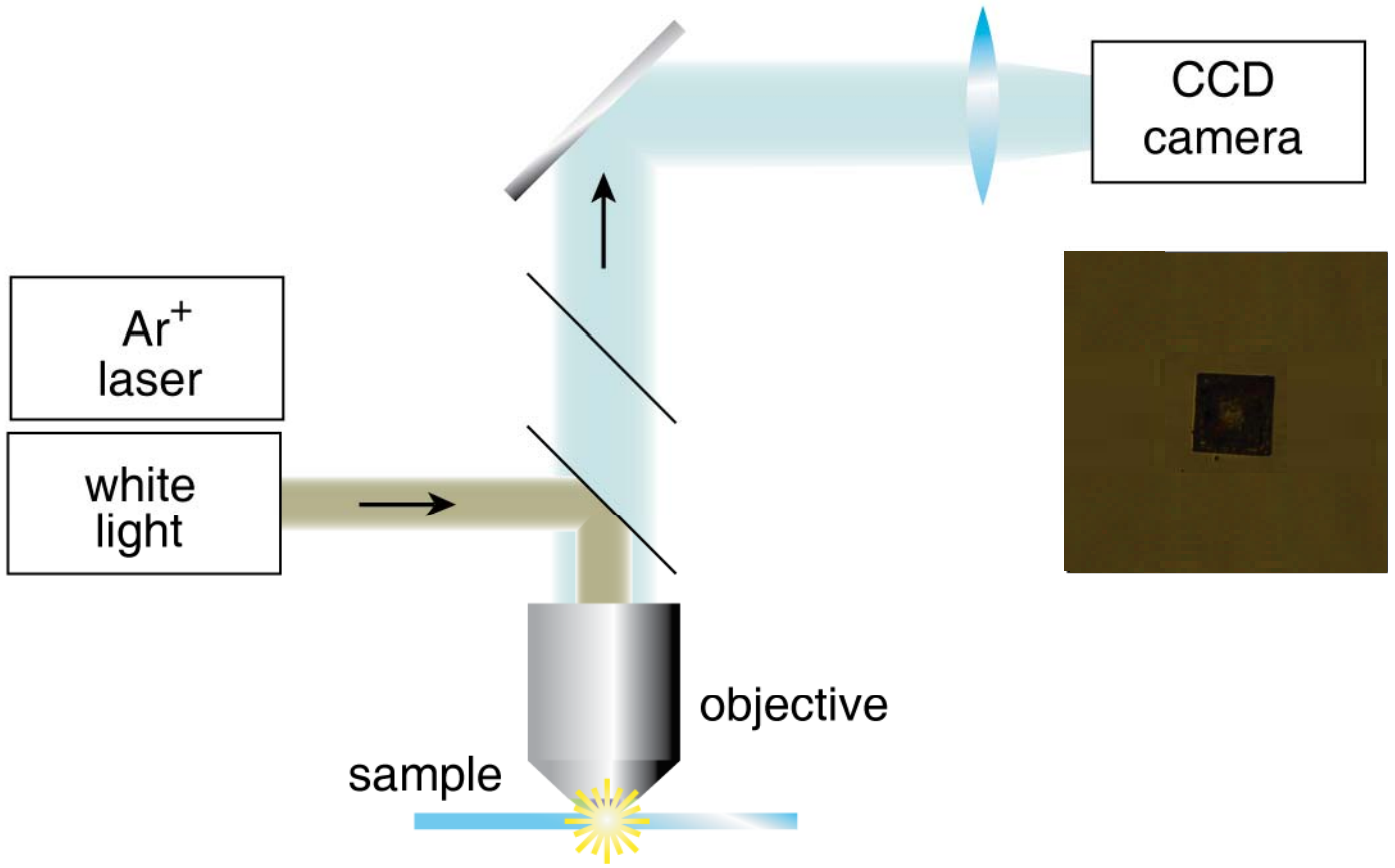
- Fluorescence
- Electro Luminescent
- Conductive

Microstructure containing MEH-PPV

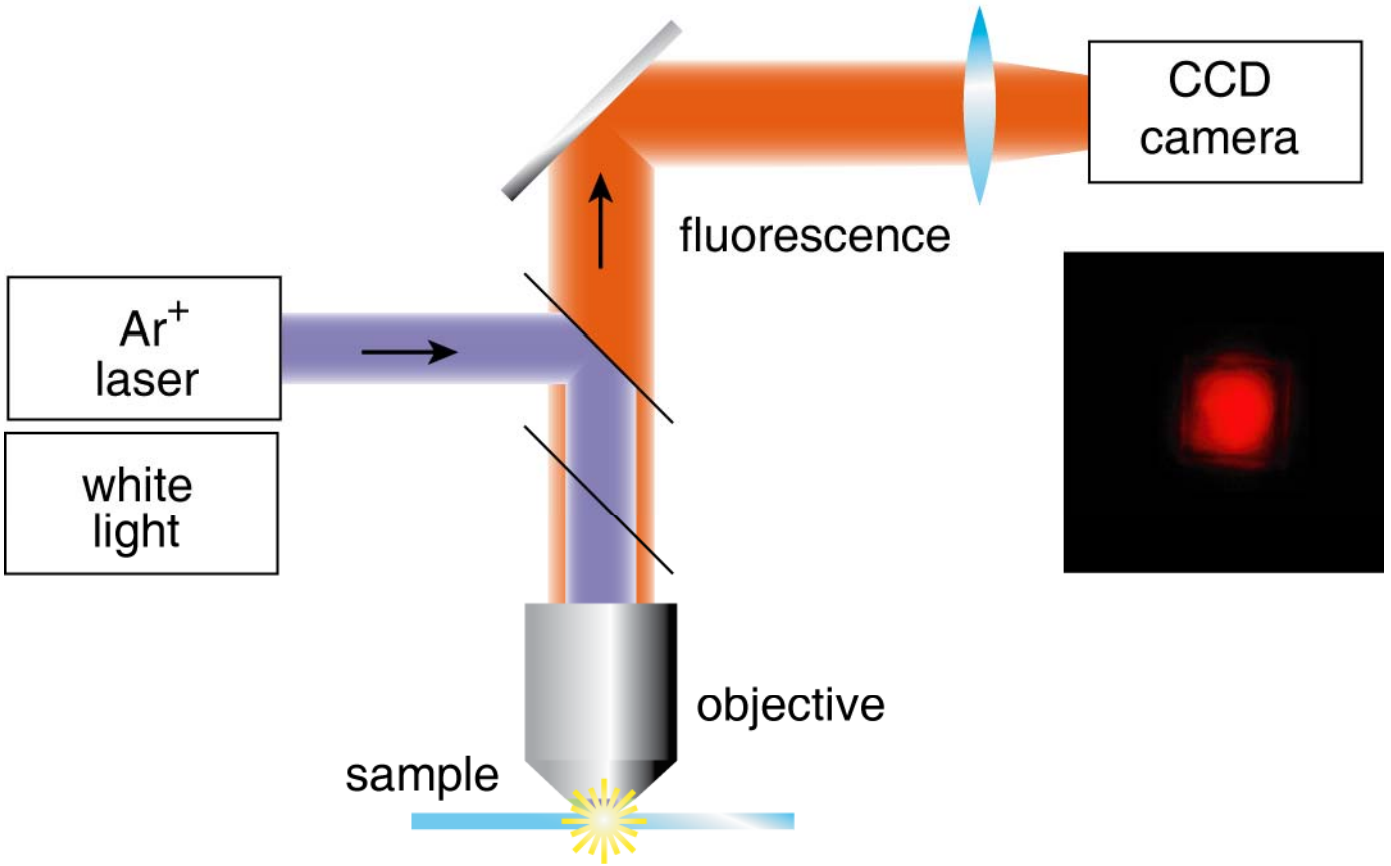


Appl. Phys. Lett., 95 1133091-3 (2009)

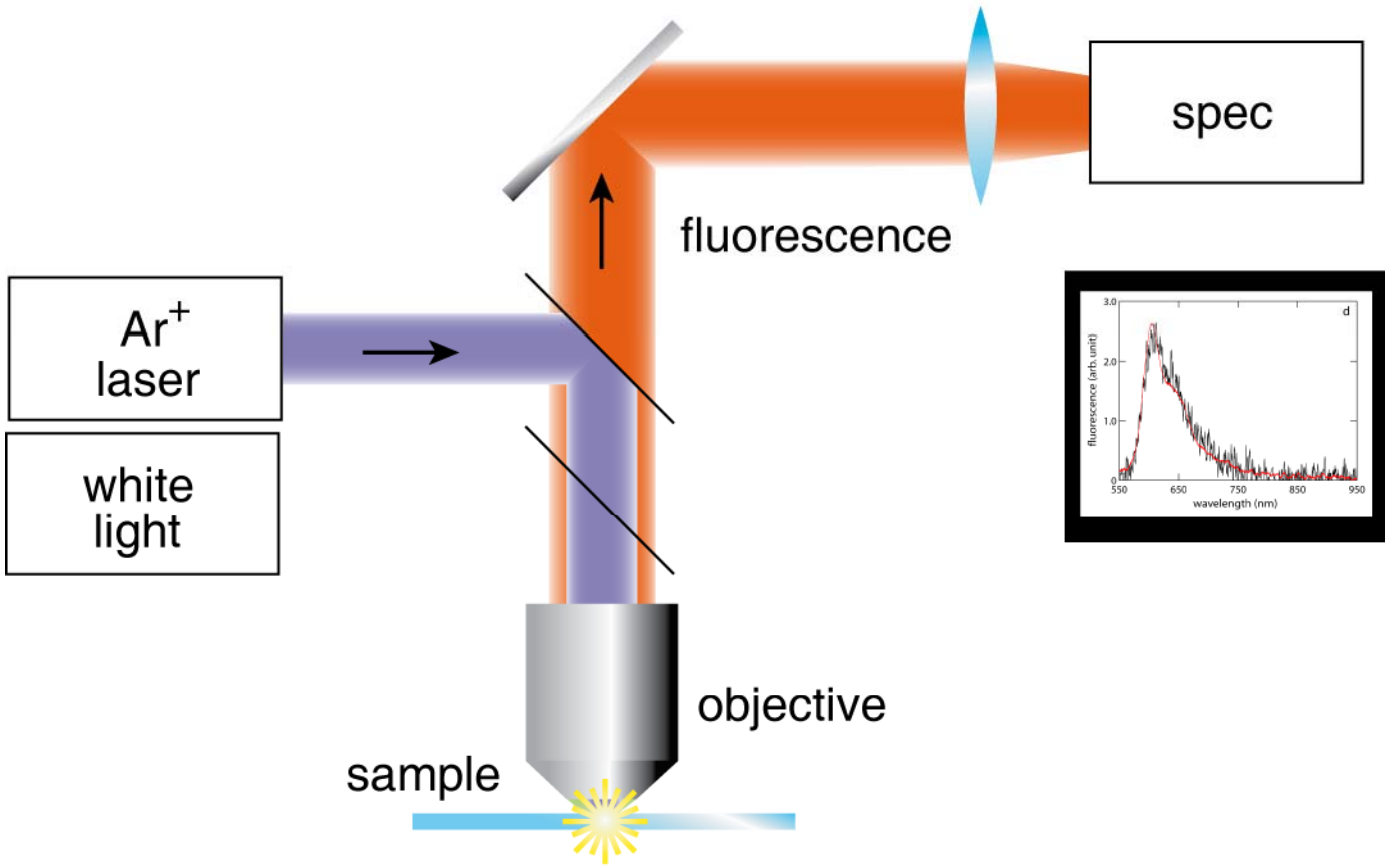
Microstructure containing MEH-PPV



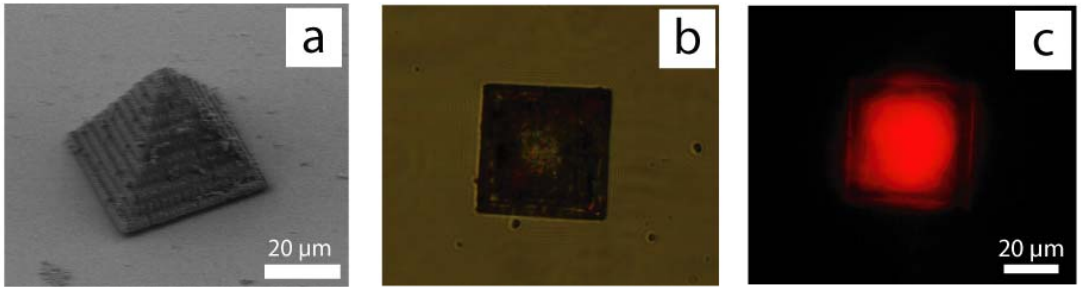
Microstructure containing MEH-PPV

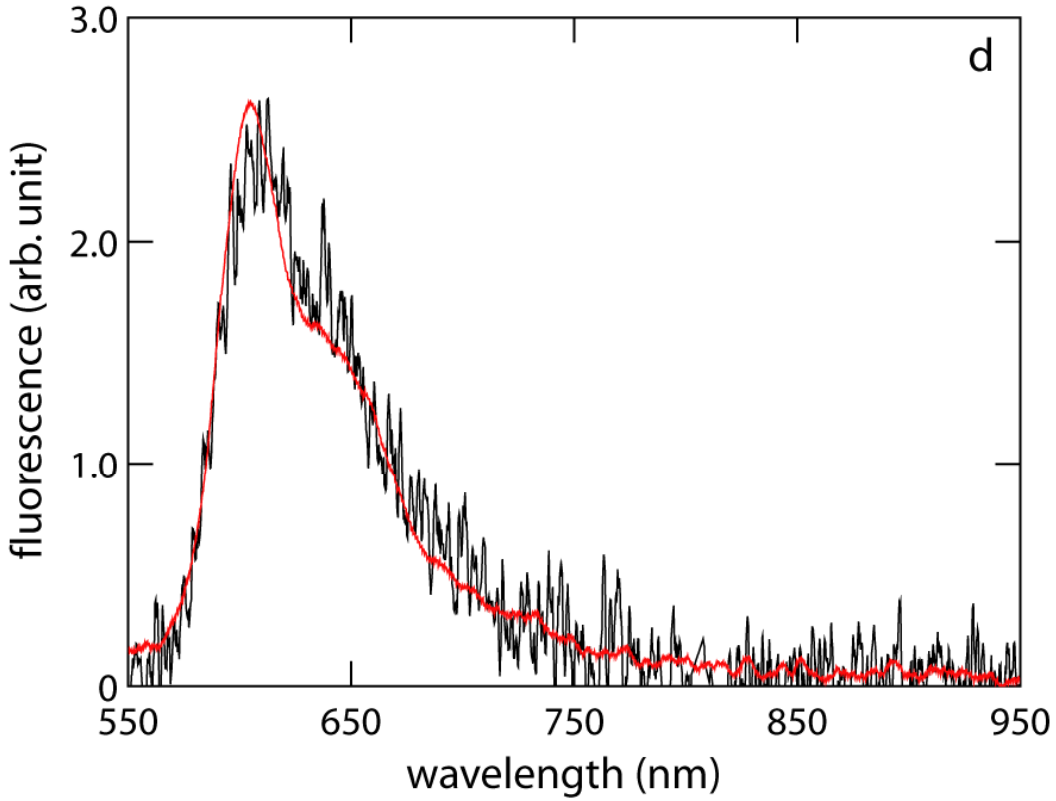


Microstructure containing MEH-PPV



Microstructure containing MEH-PPV





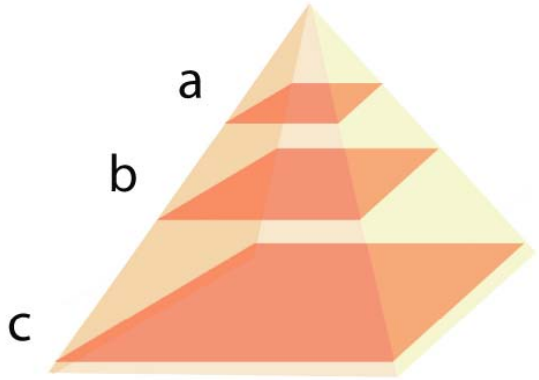
(a) Scanning electron microscopy

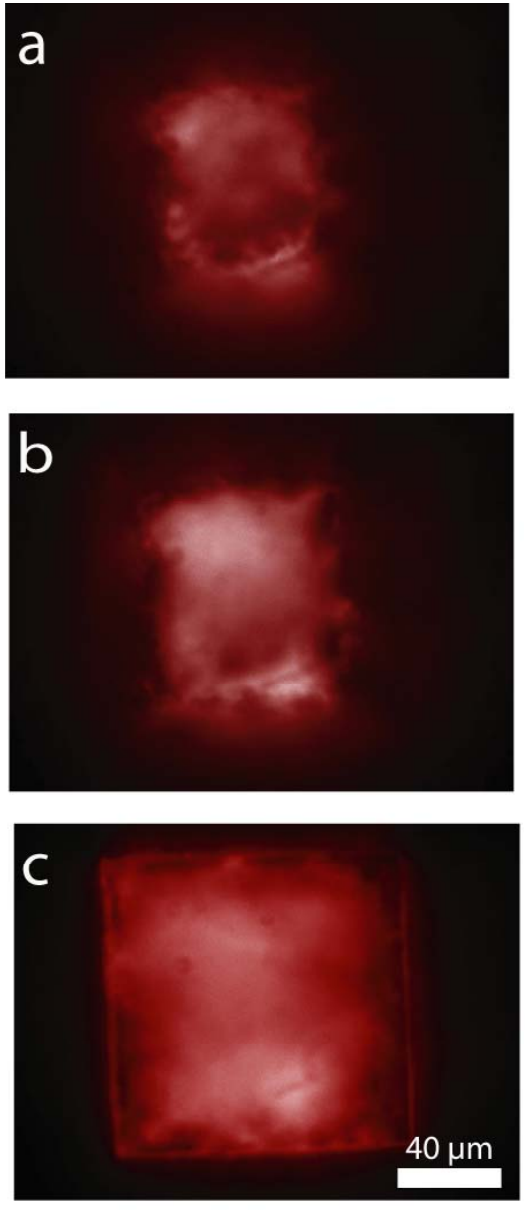
(b,c) Fluorescence microscopy of the microstructure with the excitation OFF (b) and ON (c)

(d) Emission of the microstructure (black line) and of a film with the same composition (red line)

Appl. Phys. Lett., 95 1133091-3 (2009)

Microstructure containing MEH-PPV

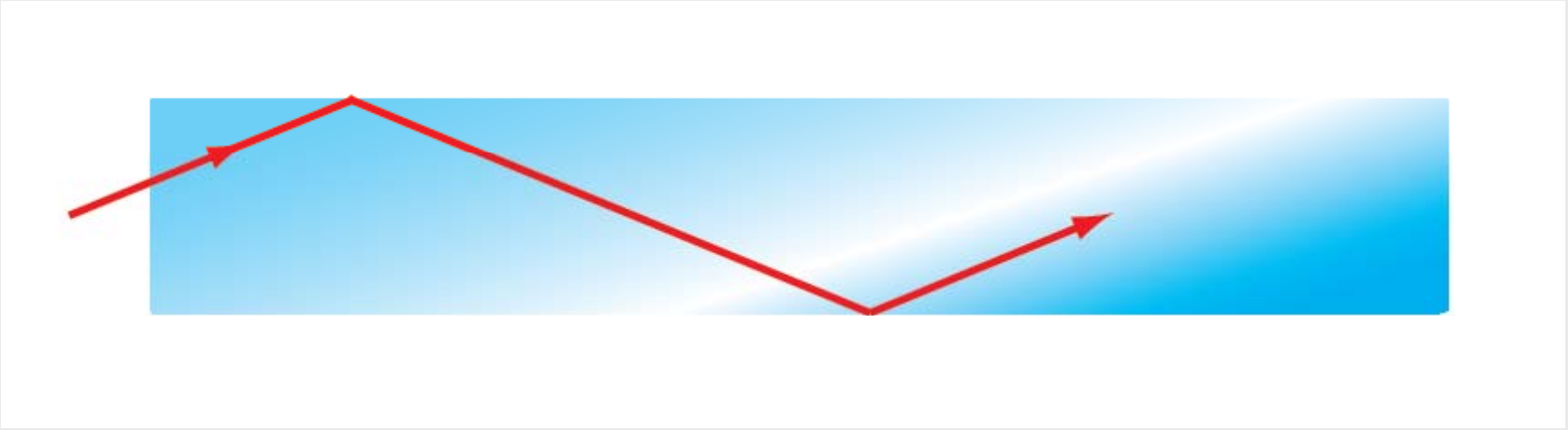




Fluorescent confocal microscopy images in planes separated by 16 μm in the pyramidal microstructure.

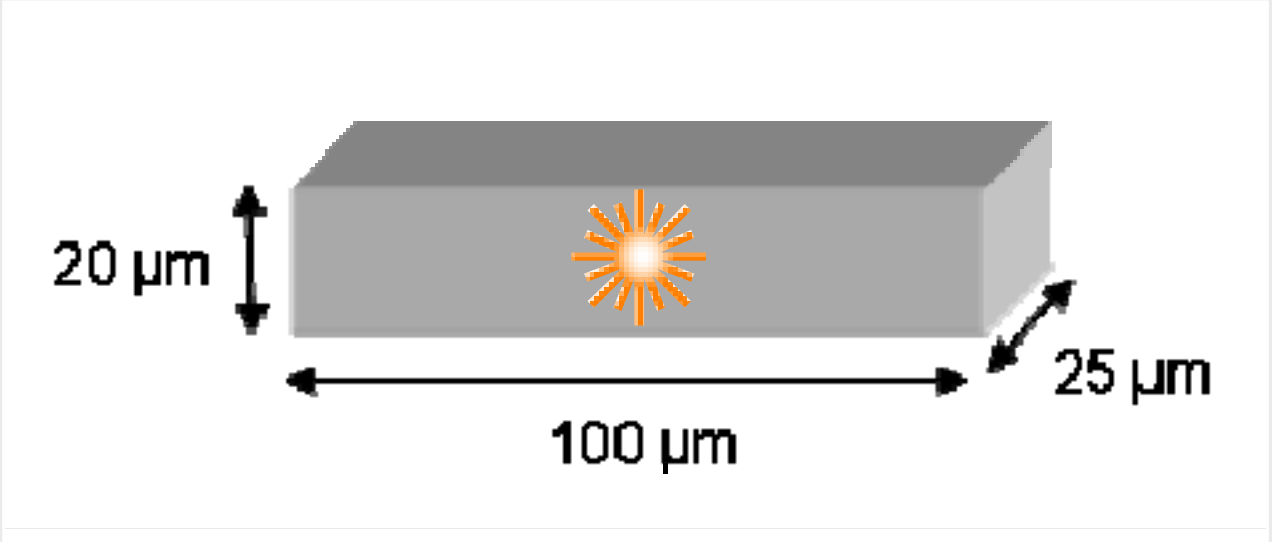
Microstructure containing MEH-PPV

Do we have waveguiding in the microstructure ?

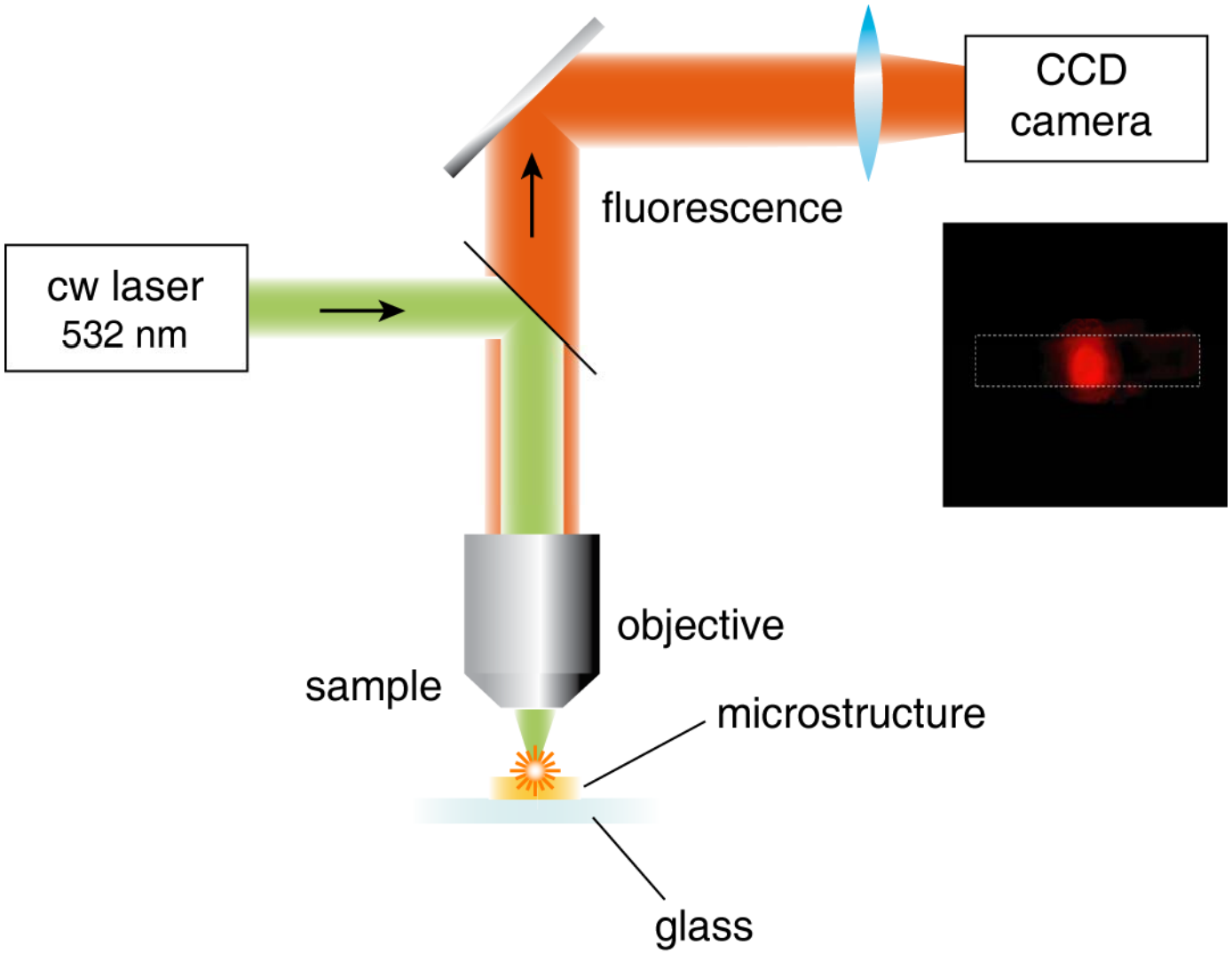


Microstructure containing MEH-PPV

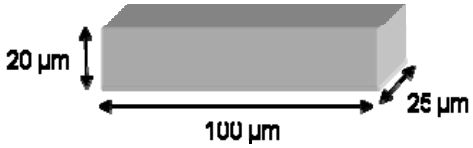
Do we have waveguiding in the microstructure ?

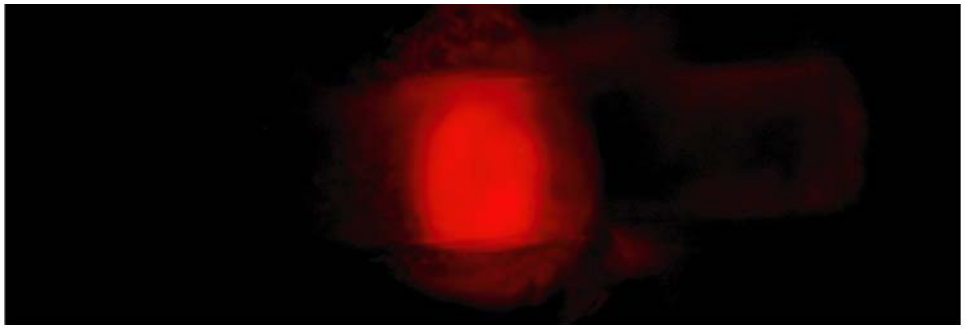


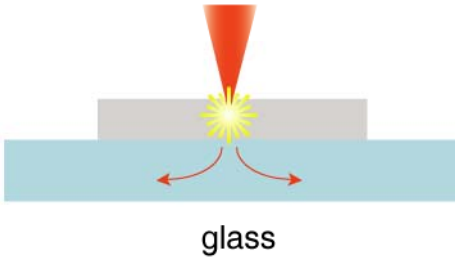
Microstructure containing MEH-PPV



Microstructure containing MEH-PPV

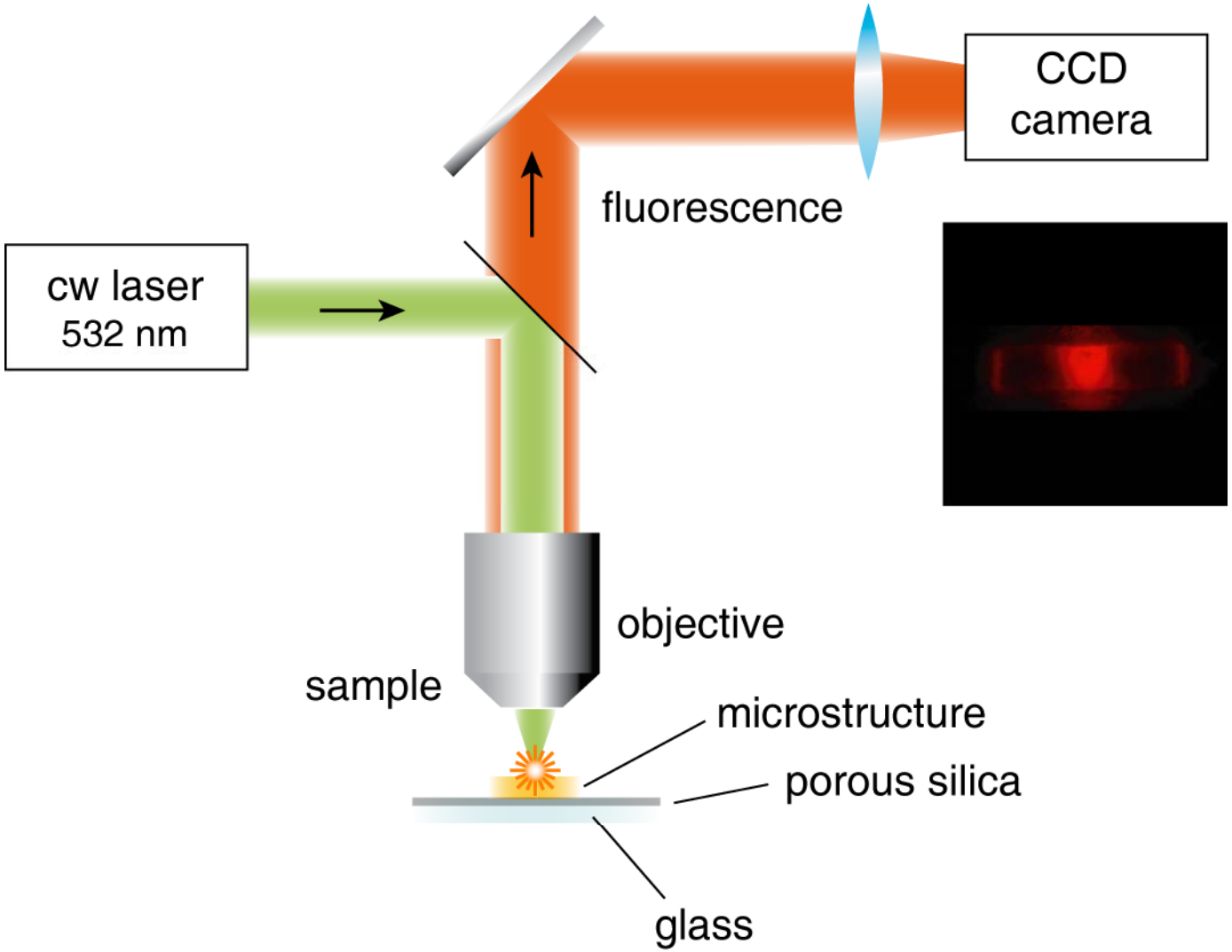




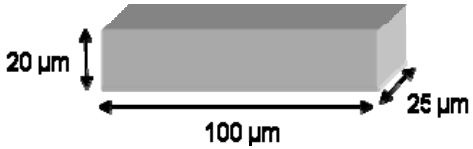


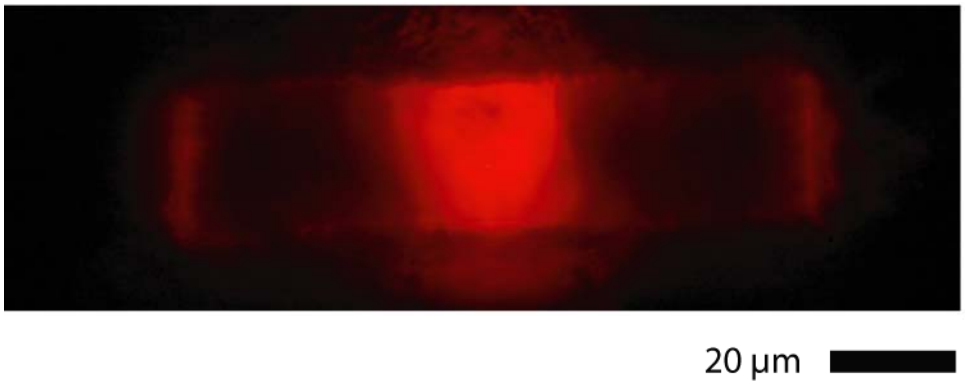
Appl. Phys. Lett., 95 1133091-3 (2009)

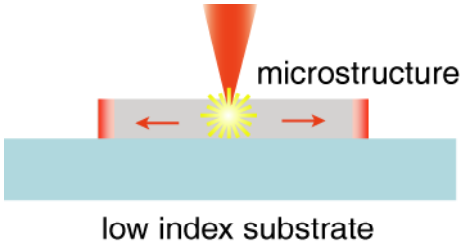
Microstructure containing MEH-PPV



Microstructure containing MEH-PPV





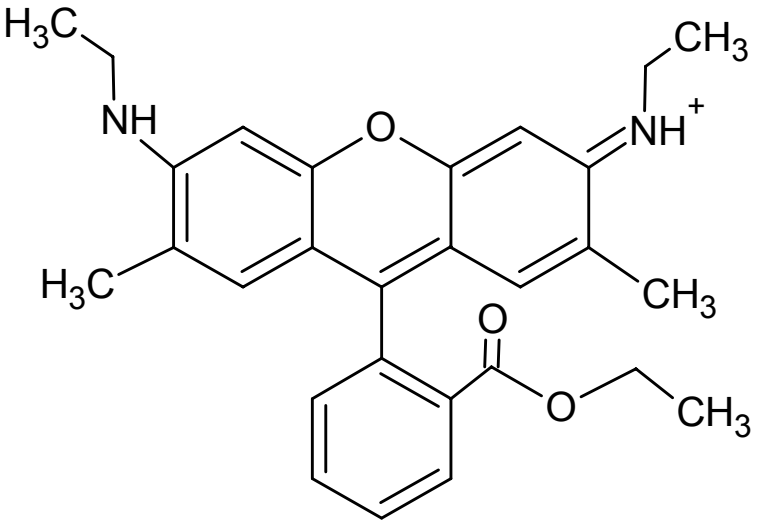


waveguiding of the microstructure fabricated on porous silica substrate (*n*= 1.185)

Applications: micro-laser; fluorescent microstructures; conductive microstructures

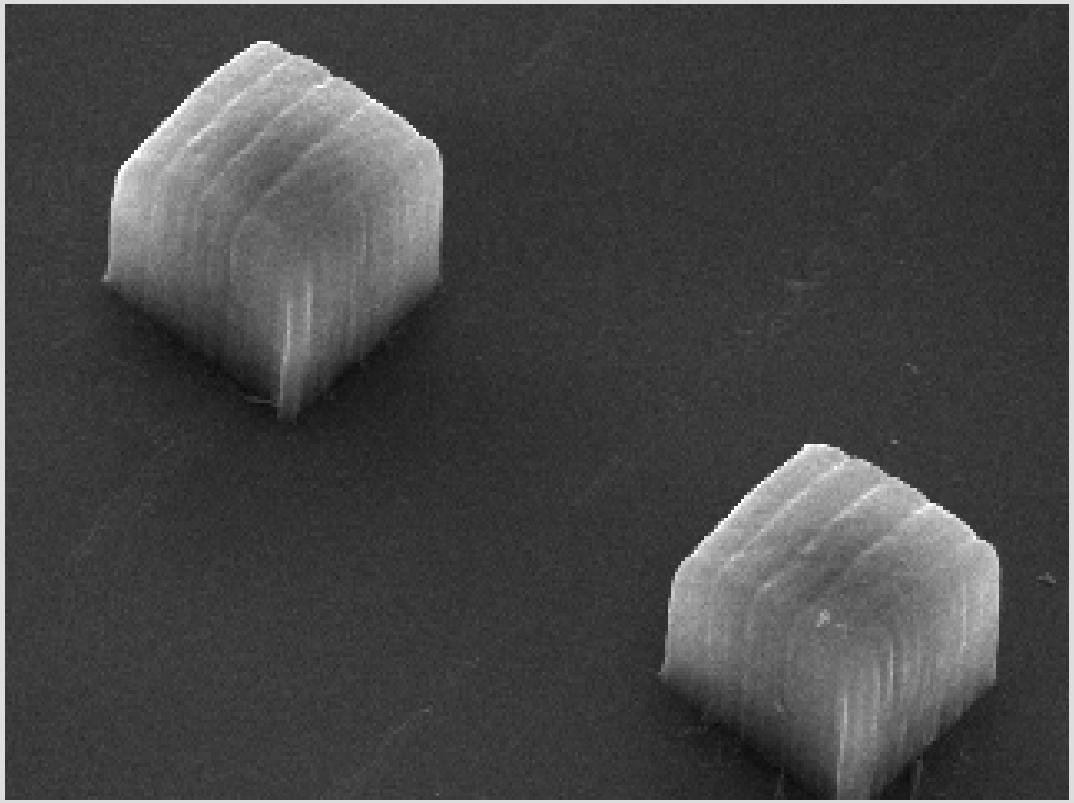
Microstructure containing Rhodamine

Rhodamine 6G



- *High luminescence*
- *Used as dye laser gain medium*

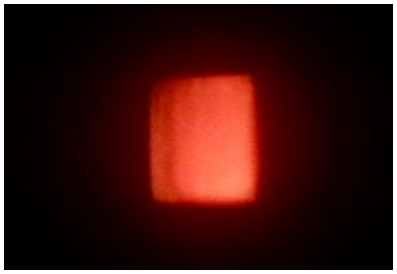
Microstructure containing Rhodamine

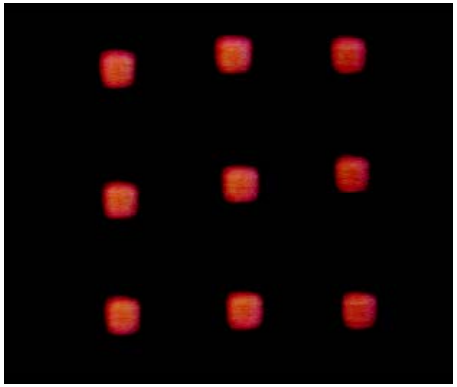


Microstructure containing Rhodamine

Microscopy fluorescence images of cubes and cylinders (top view)

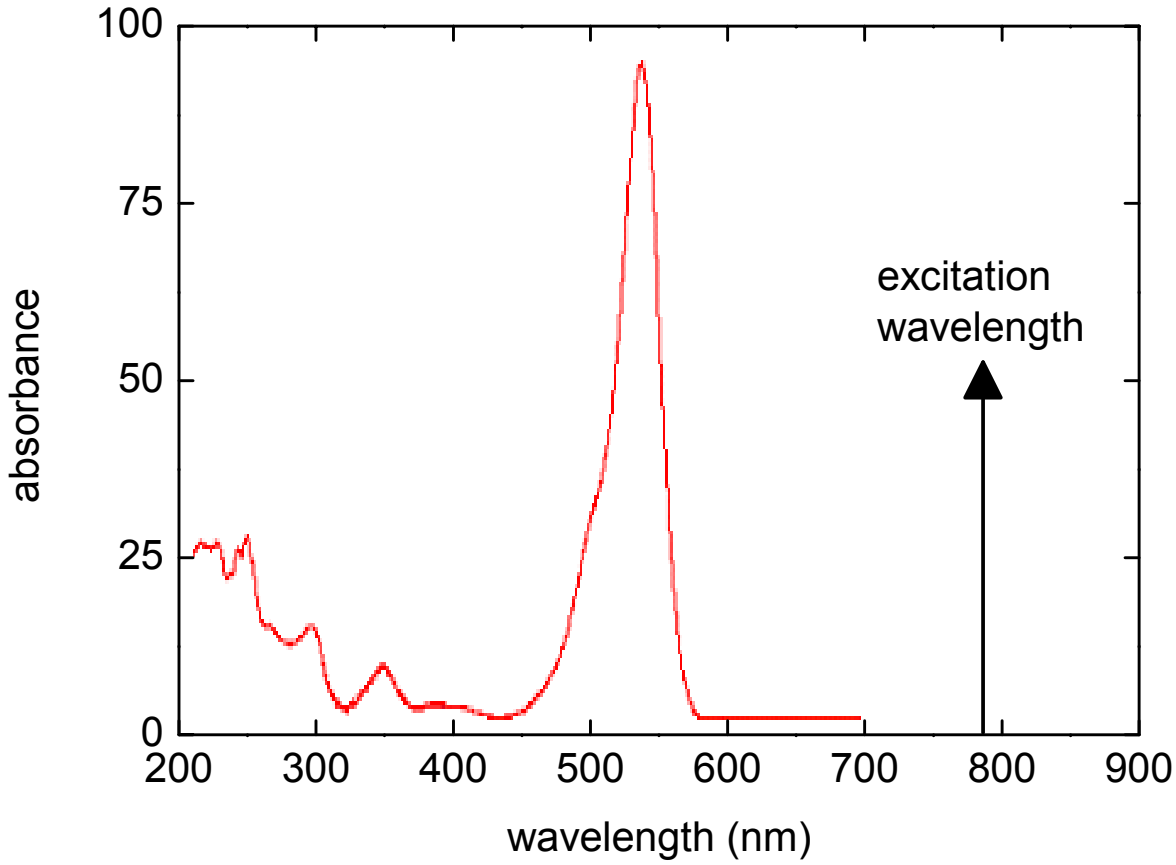
laser excitation at 480 nm

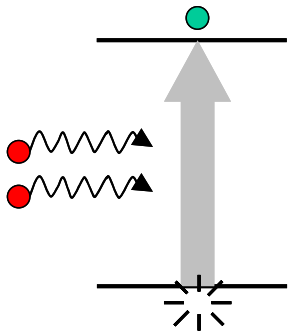




Microstructure containing Rhodamine

Two-photon excitation

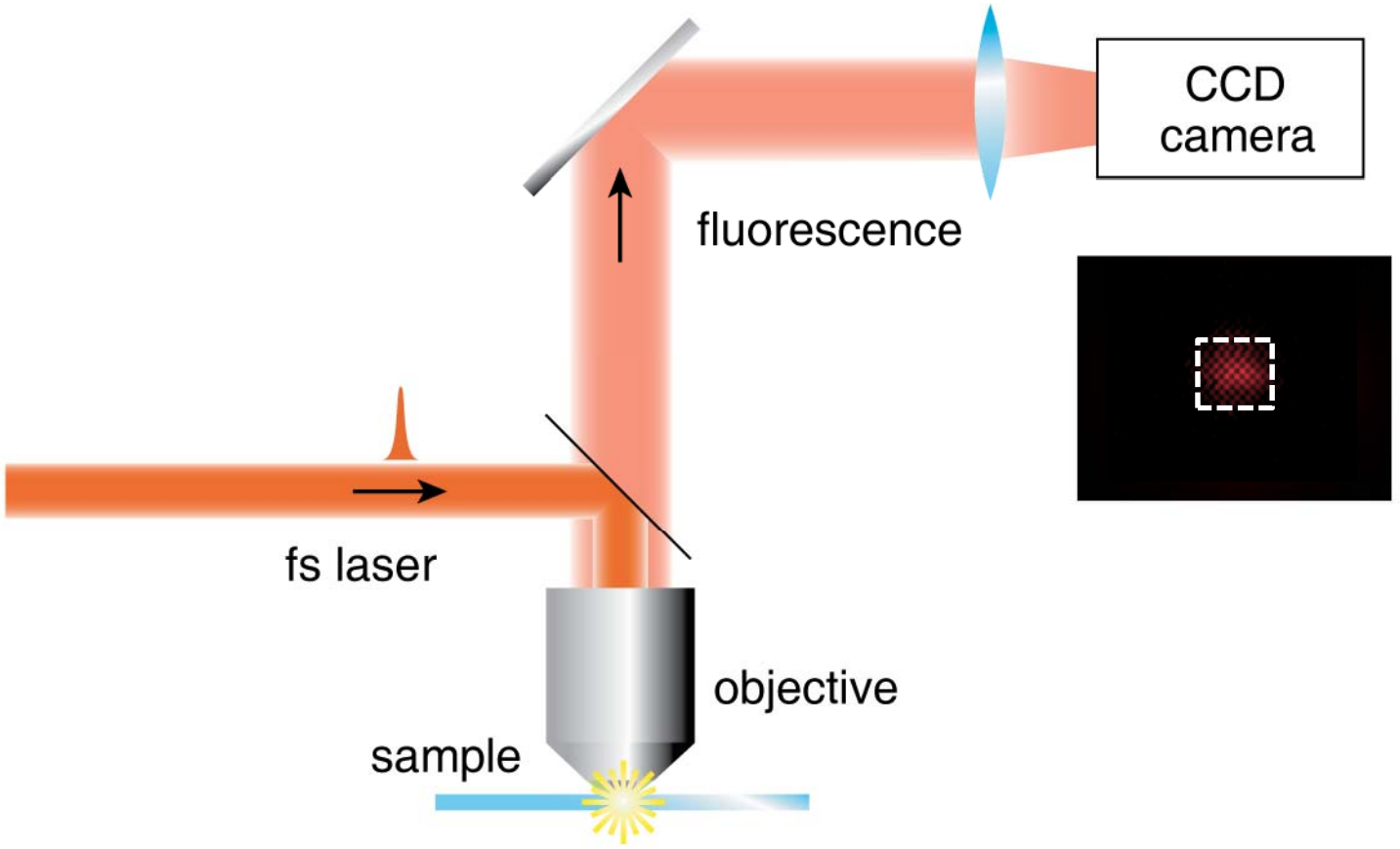




2-photon absorption
(nonlinear)

λ = 780 nm
absorption – only possible by 2PA

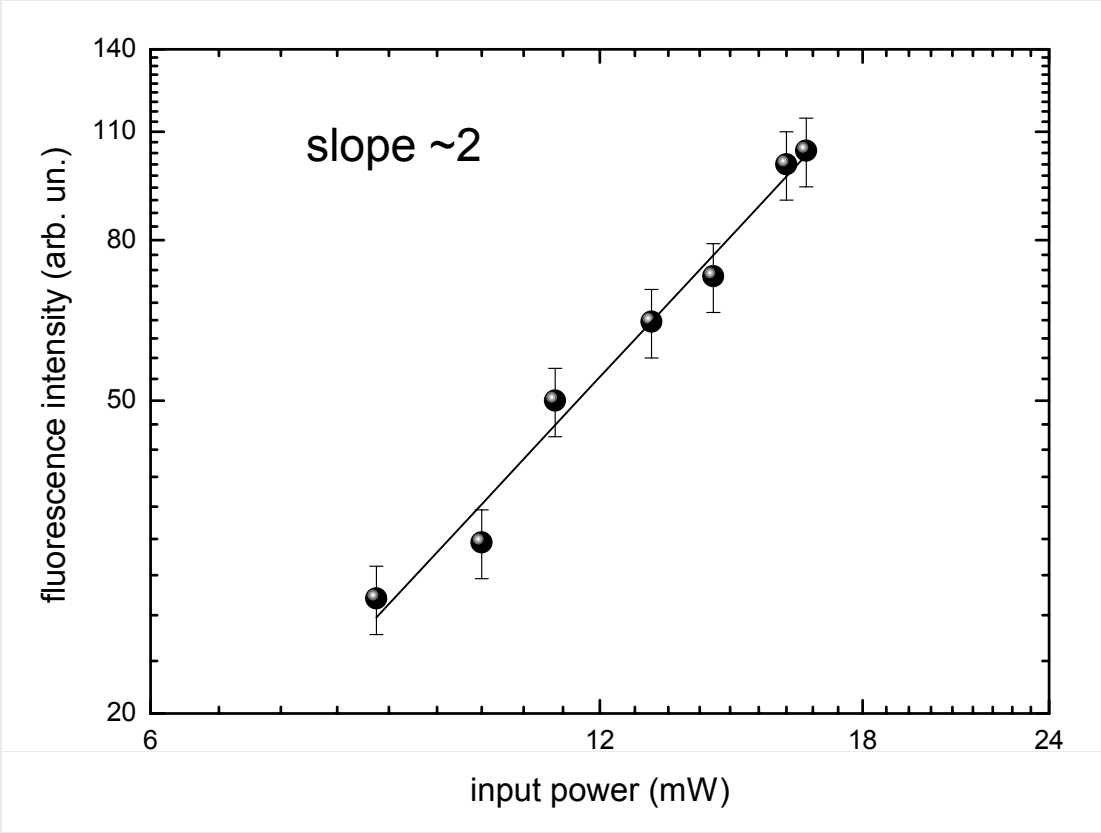
Microstructure containing Rhodamine



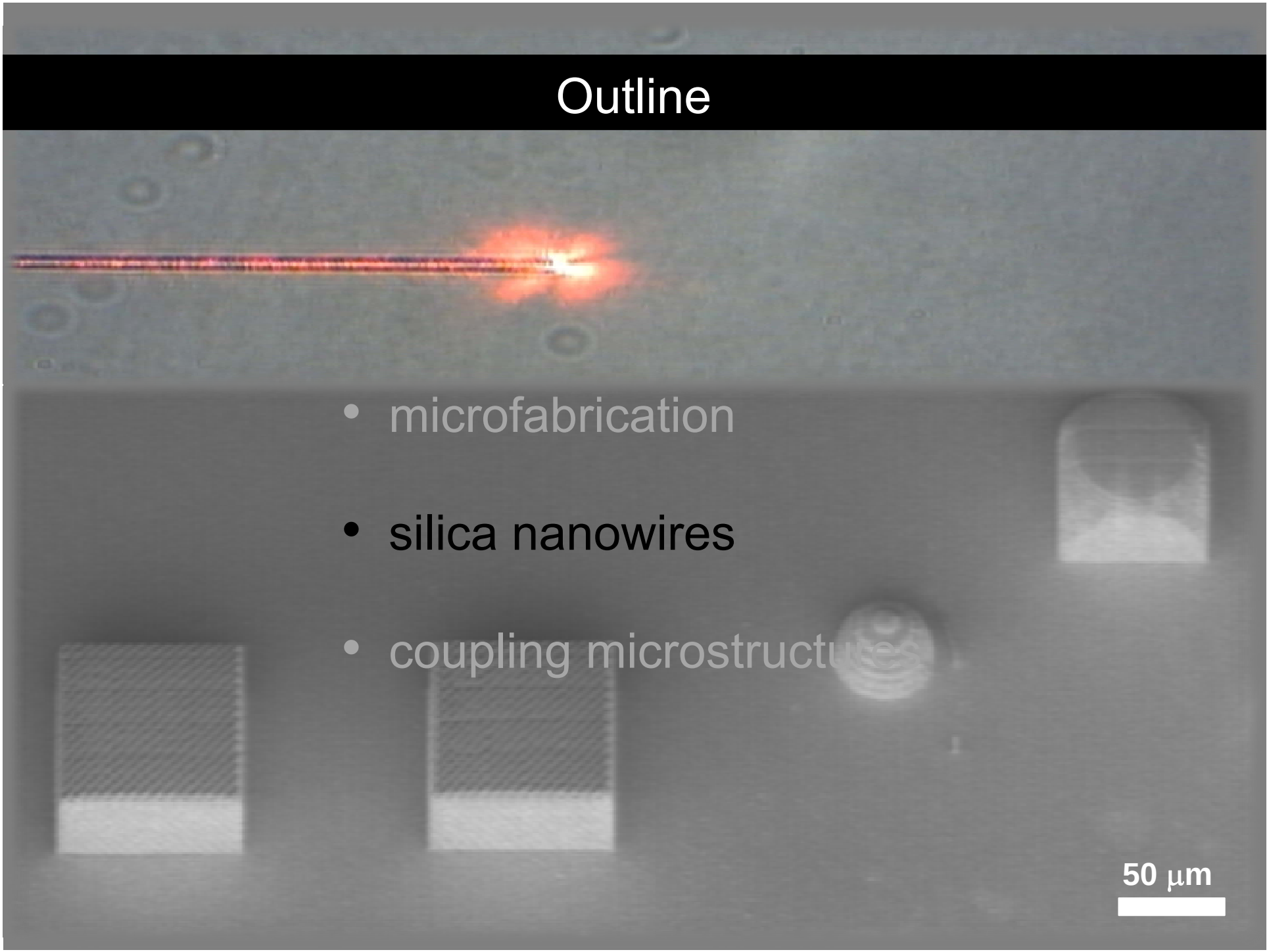
Microstructure containing Rhodamine

Two-photon excitation

$$\frac{dN}{dt} = \sigma_{2PA}\left(\frac{I}{h\nu}\right)^2$$



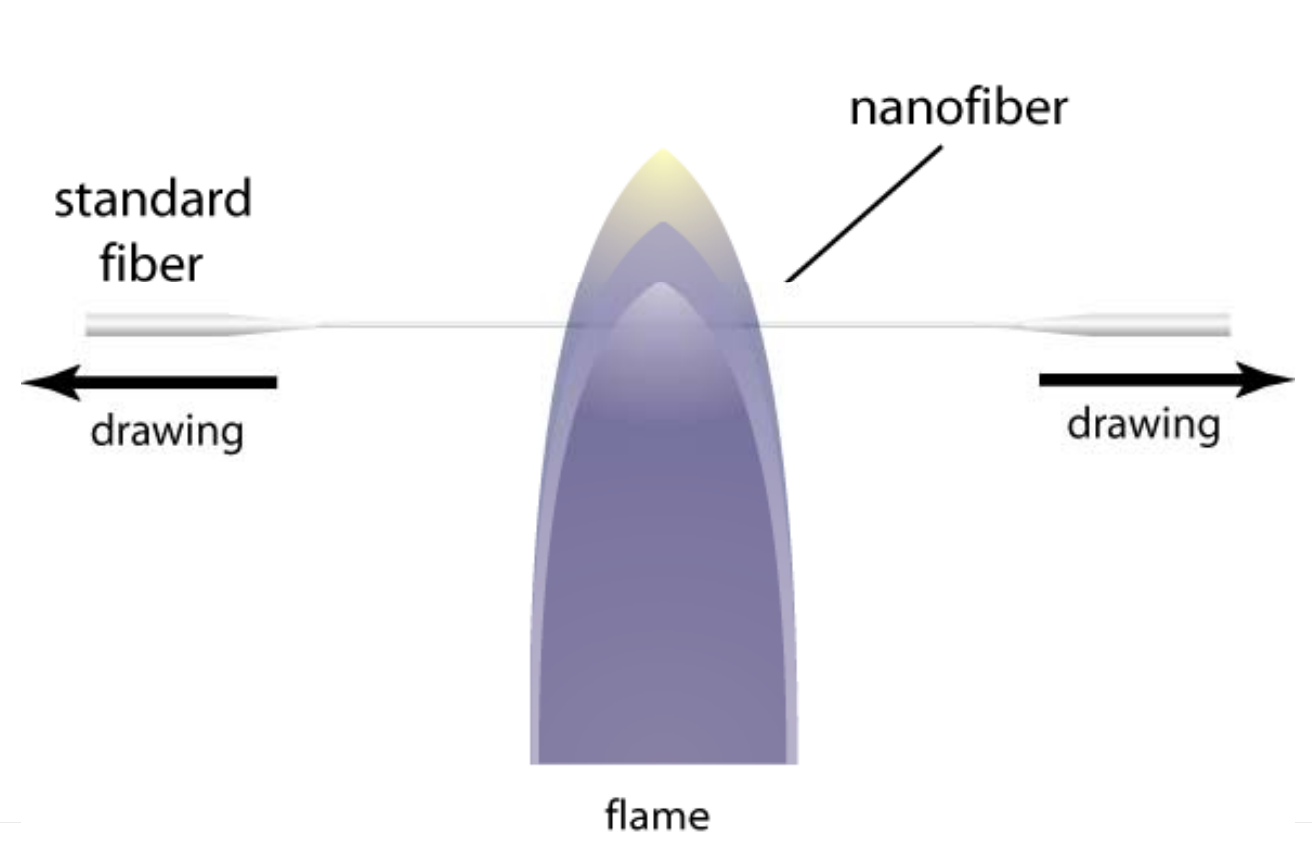
Outline



- microfabrication
- silica nanowires
- coupling microstructures

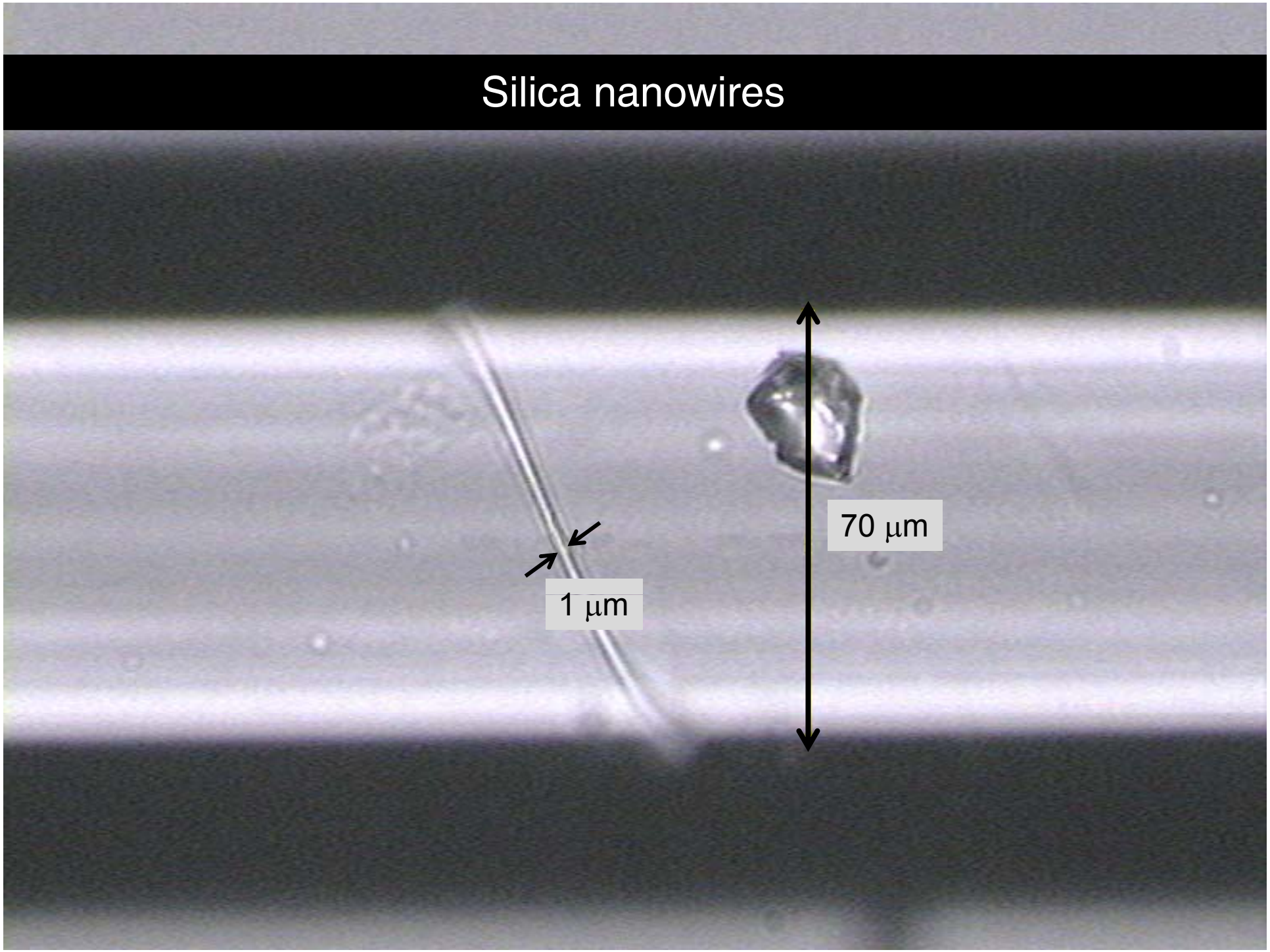
Silica nanowires

nanowires fabrication process

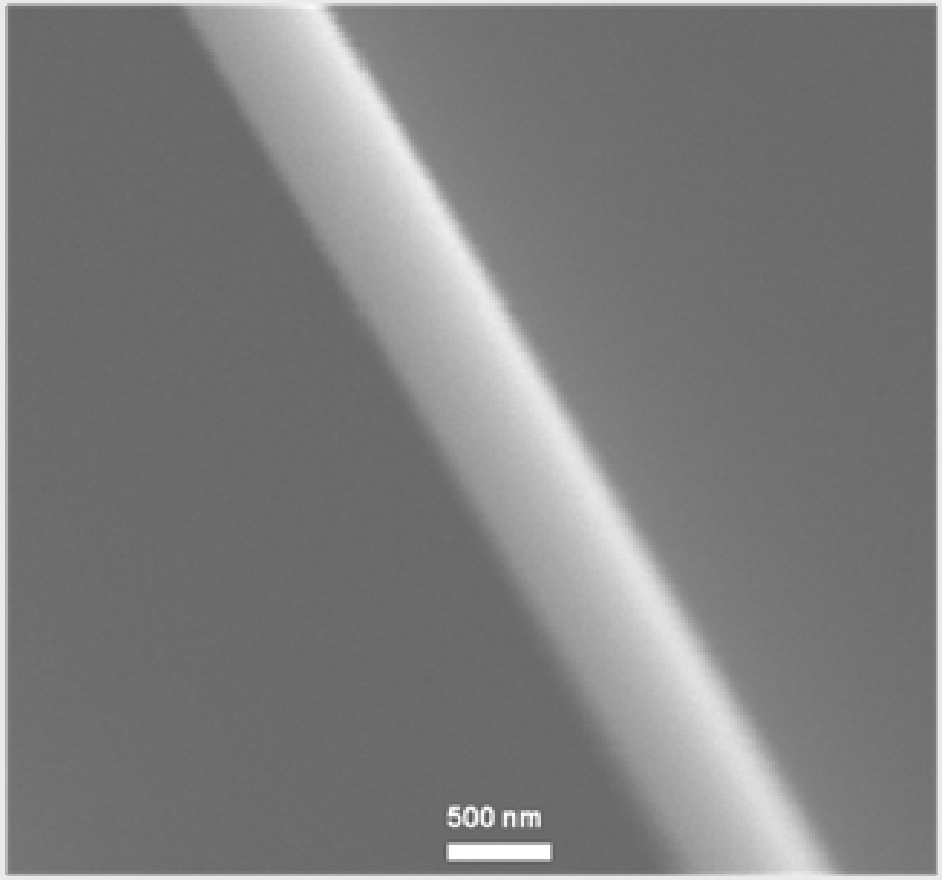


Silica nanowires

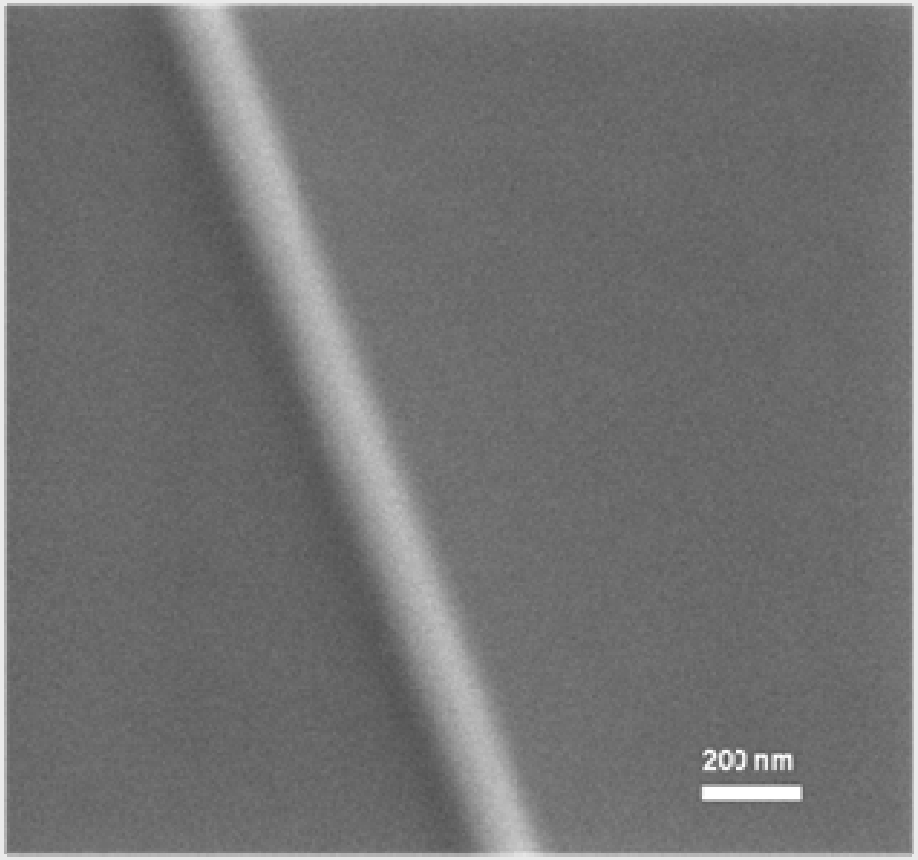
Silica nanowires



Silica nanowires

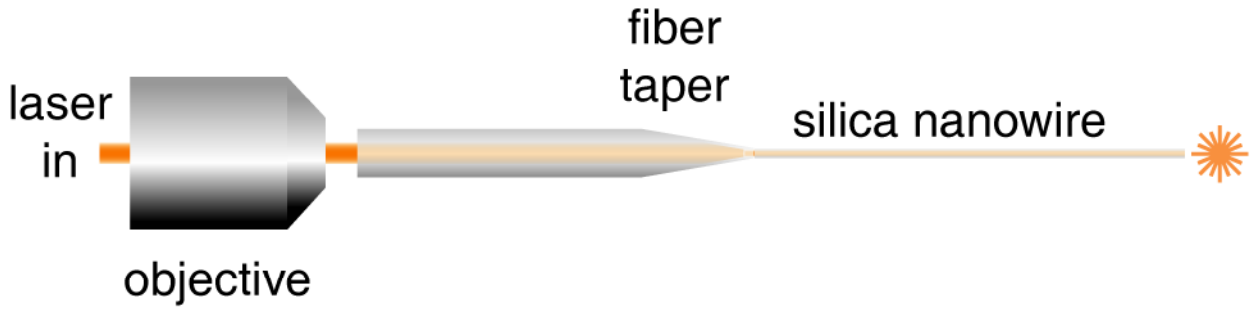


Silica nanowires



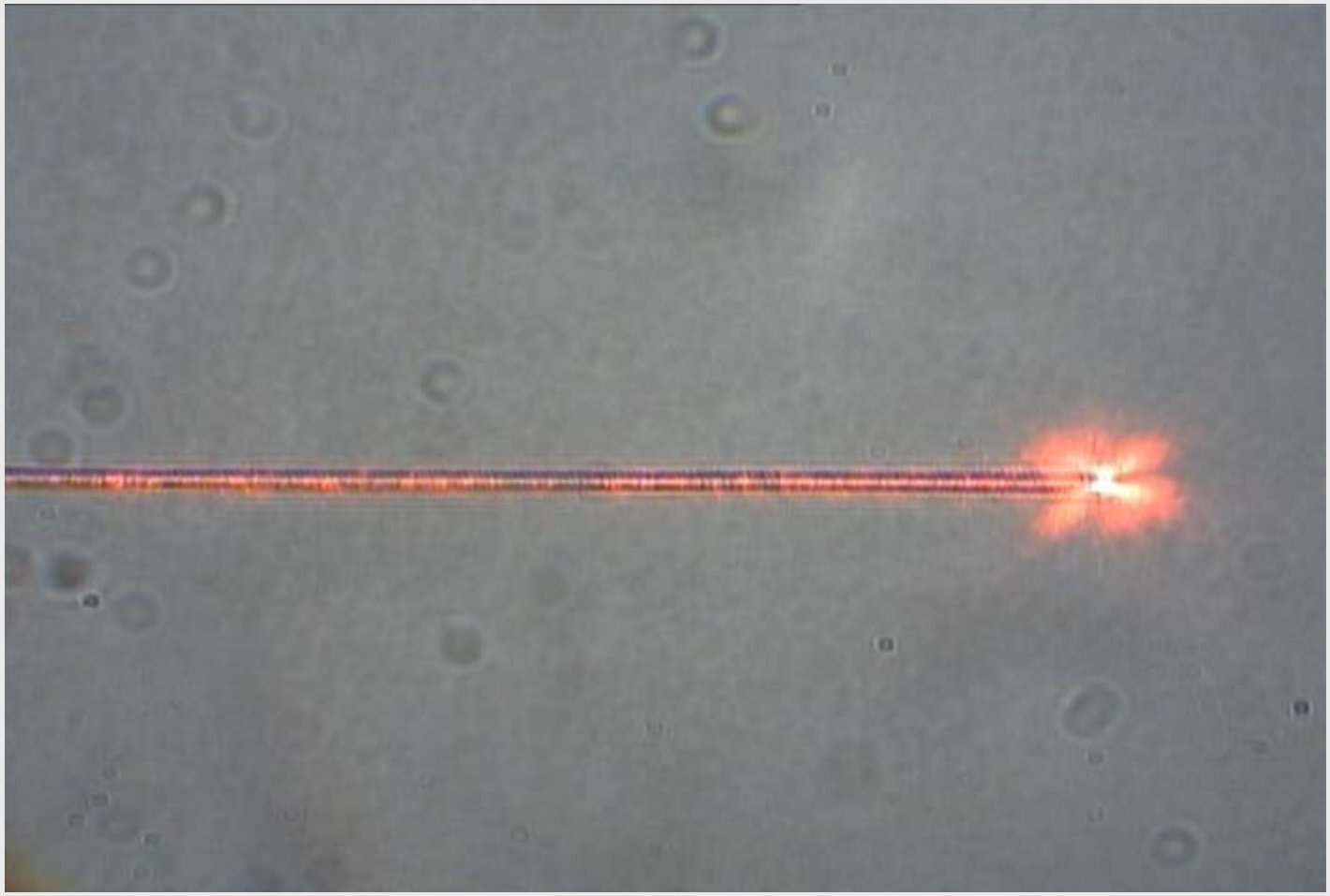
Silica nanowires

coupling light into nanowires

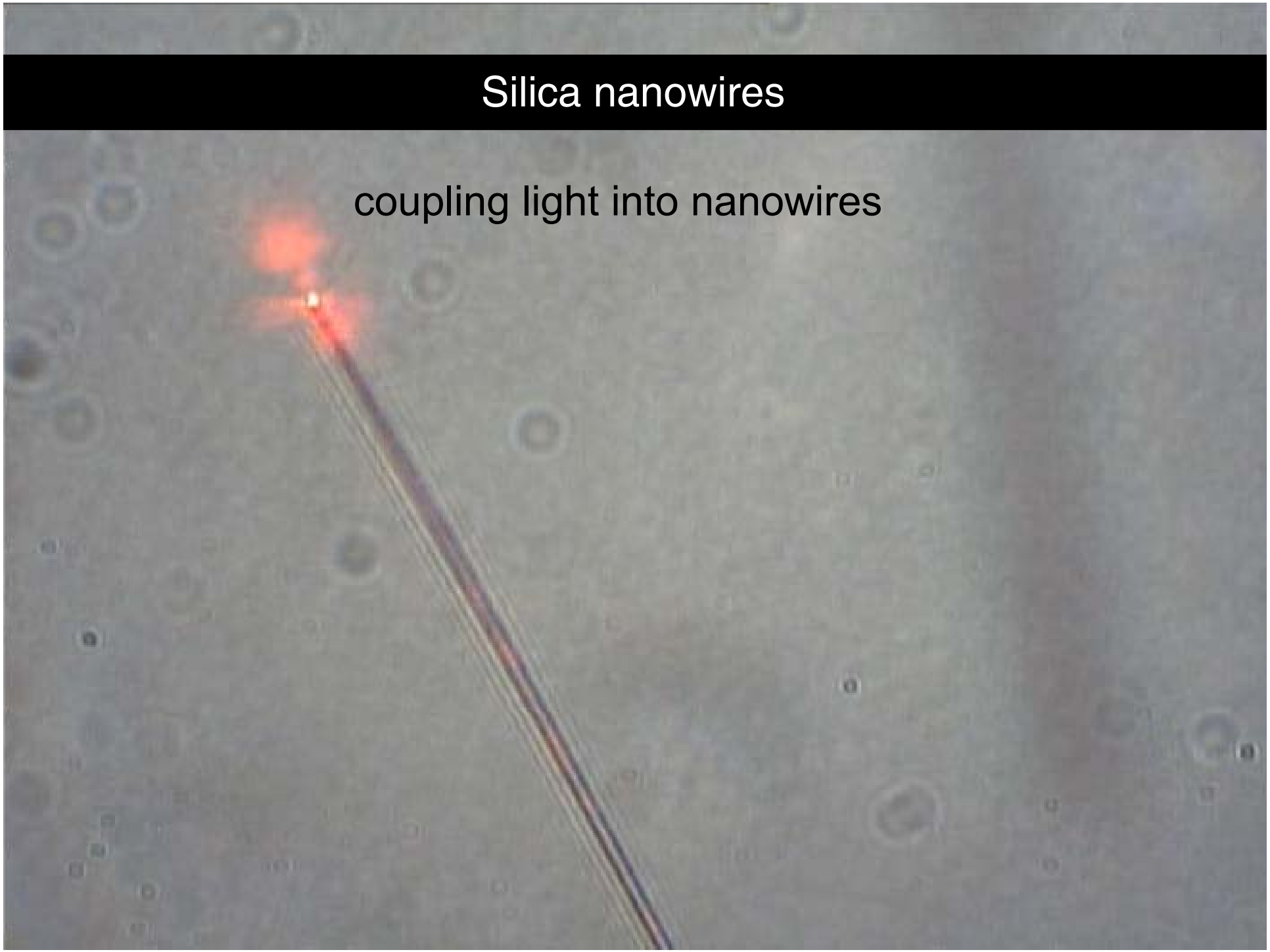


Silica nanowires

coupling light into nanowires

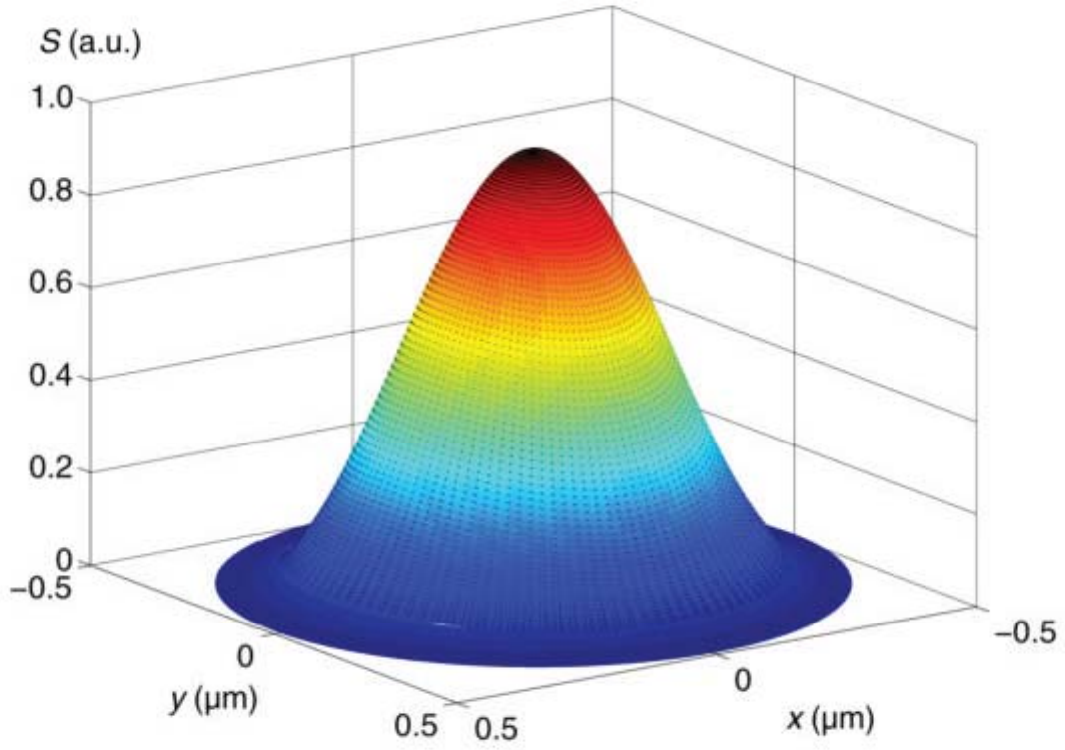


Silica nanowires



Silica nanowires

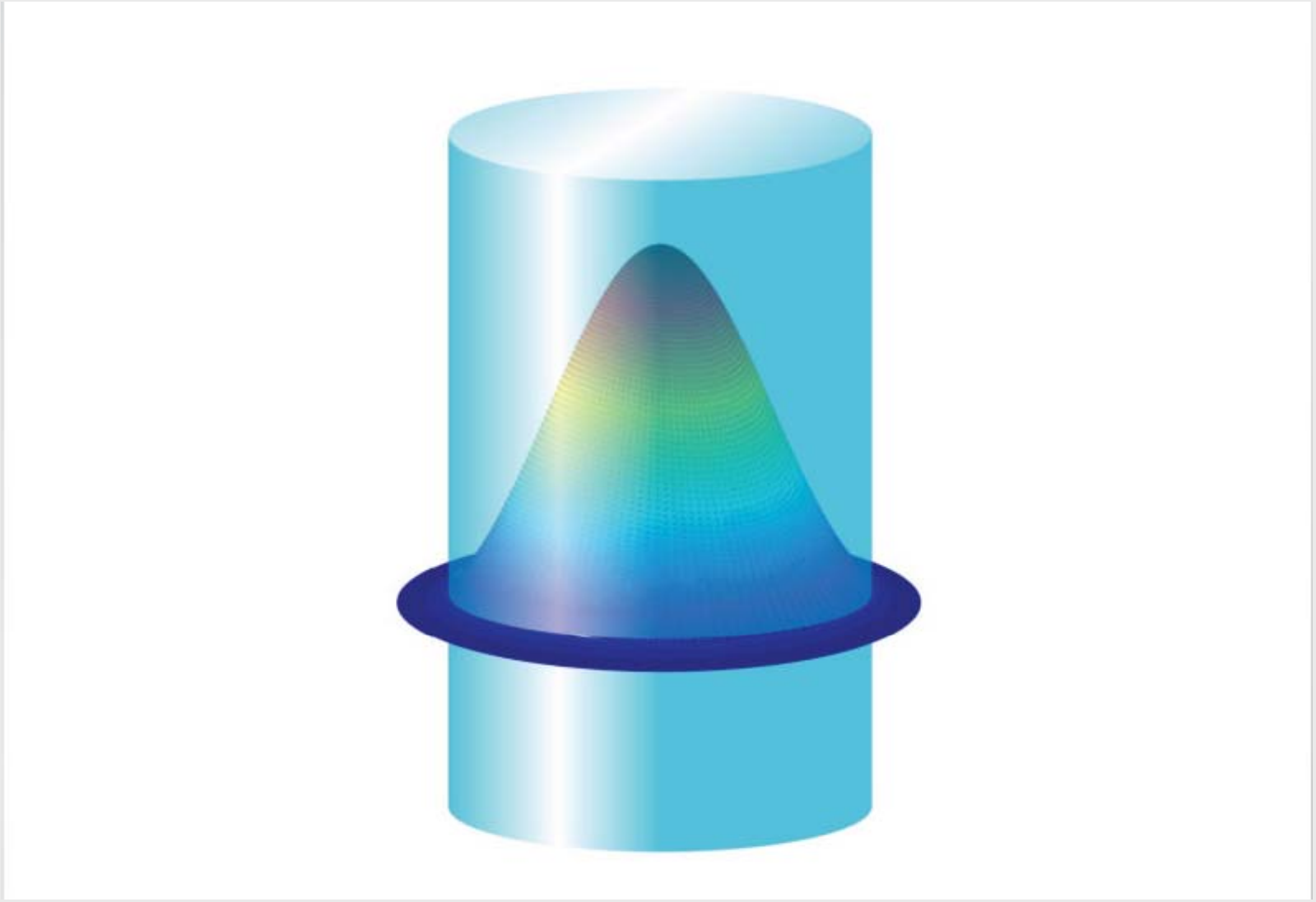
Poynting vector for 800 nm nanowires



Opt. Express 12, 1025-1035 (2004)

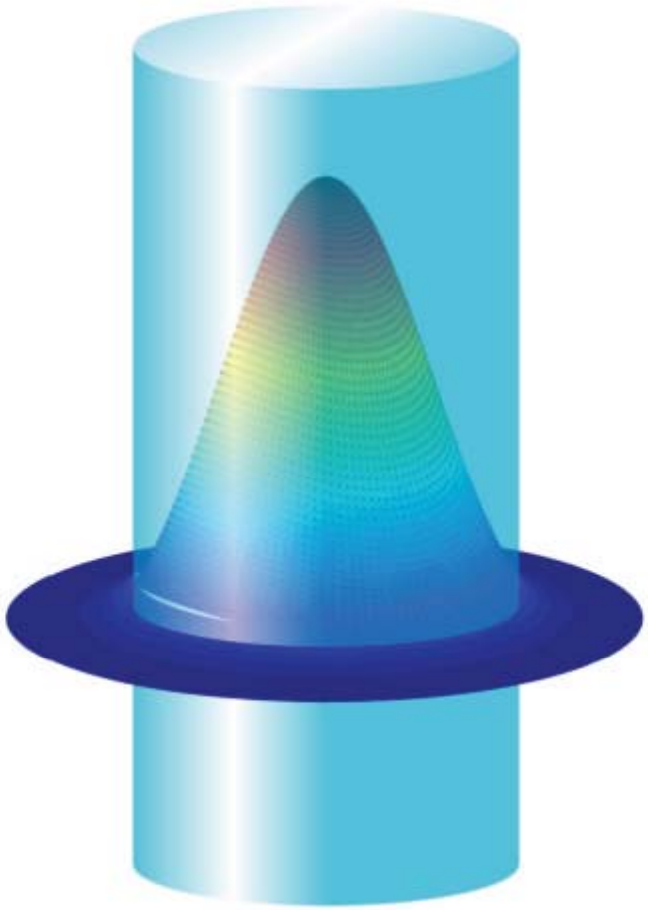
Silica nanowires

Poynting vector for 800 nm nanowires



Silica nanowires

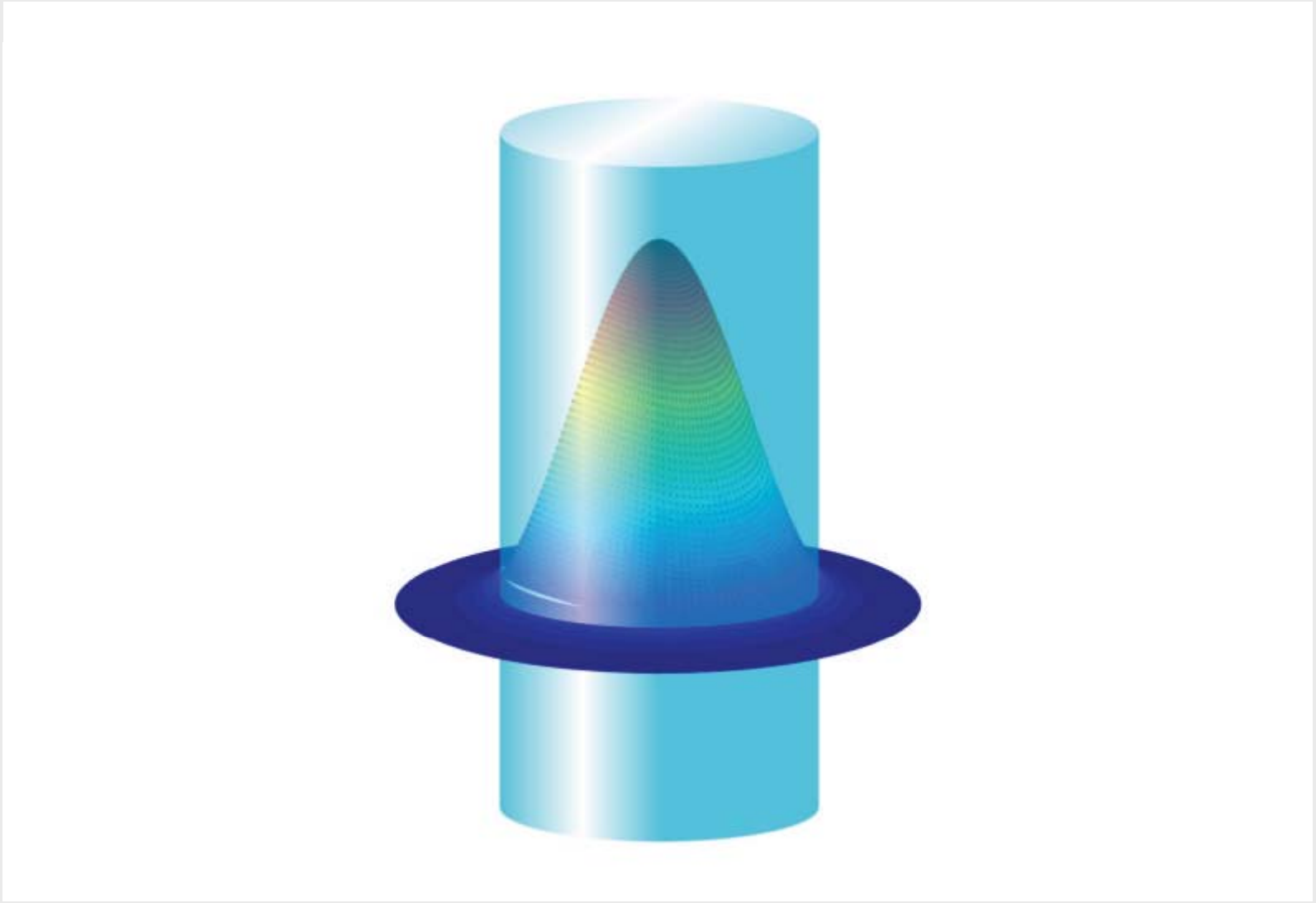
Poynting vector for 600 nm nanowires



Opt. Express 12, 1025-1035 (2004)

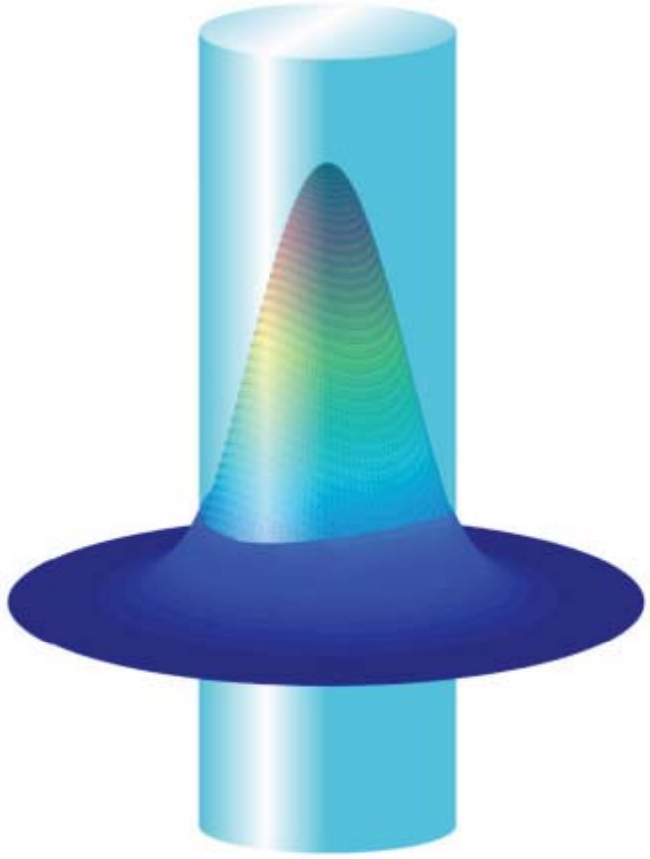
Silica nanowires

Poynting vector for 600 nm nanowires



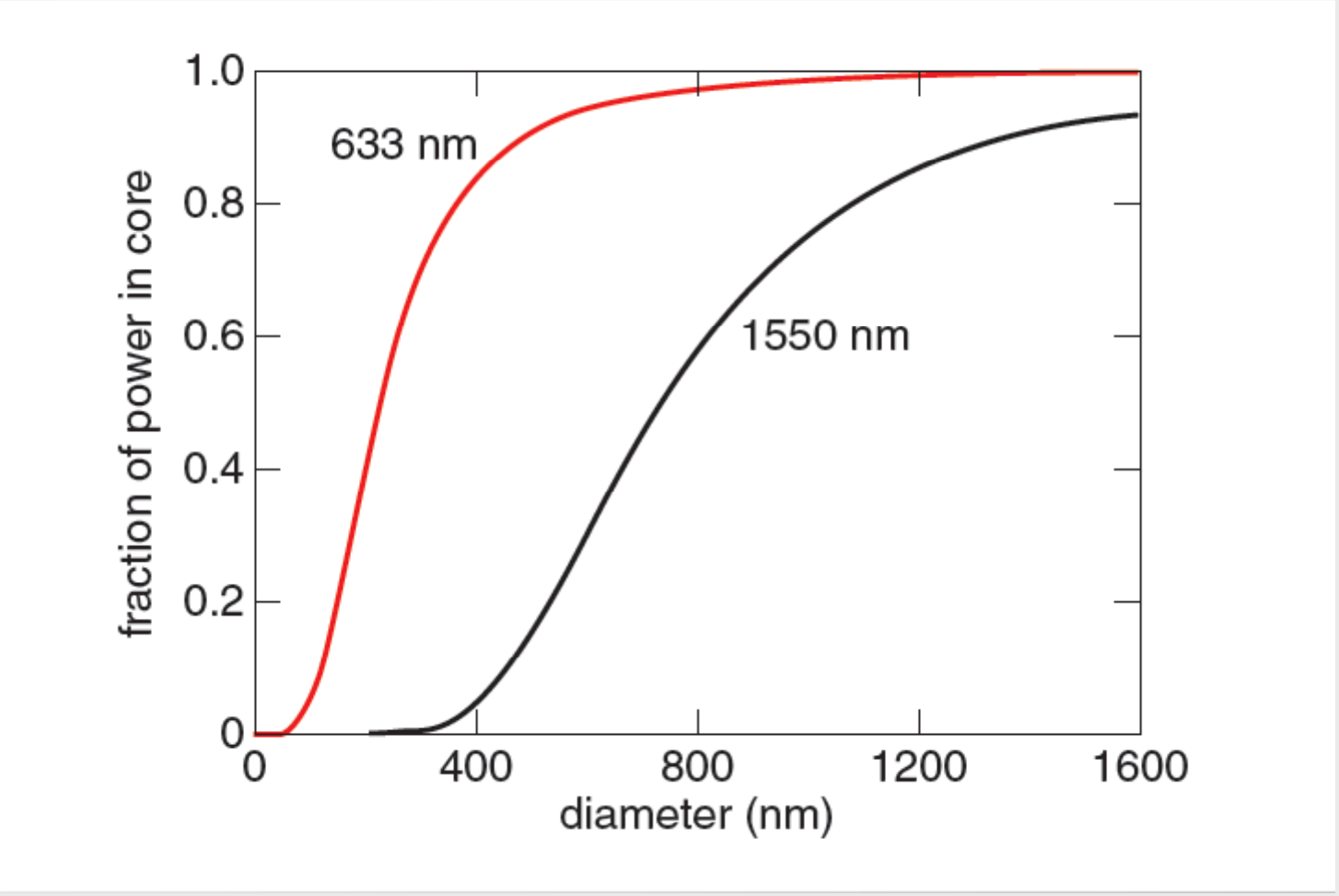
Silica nanowires

Poynting vector for 400 nm nanowires



Silica nanowires

Power fraction in the core of the nanowires



Opt. Express 12, 1025-1035 (2004)

Silica nanowires

Manipulating the nanowires

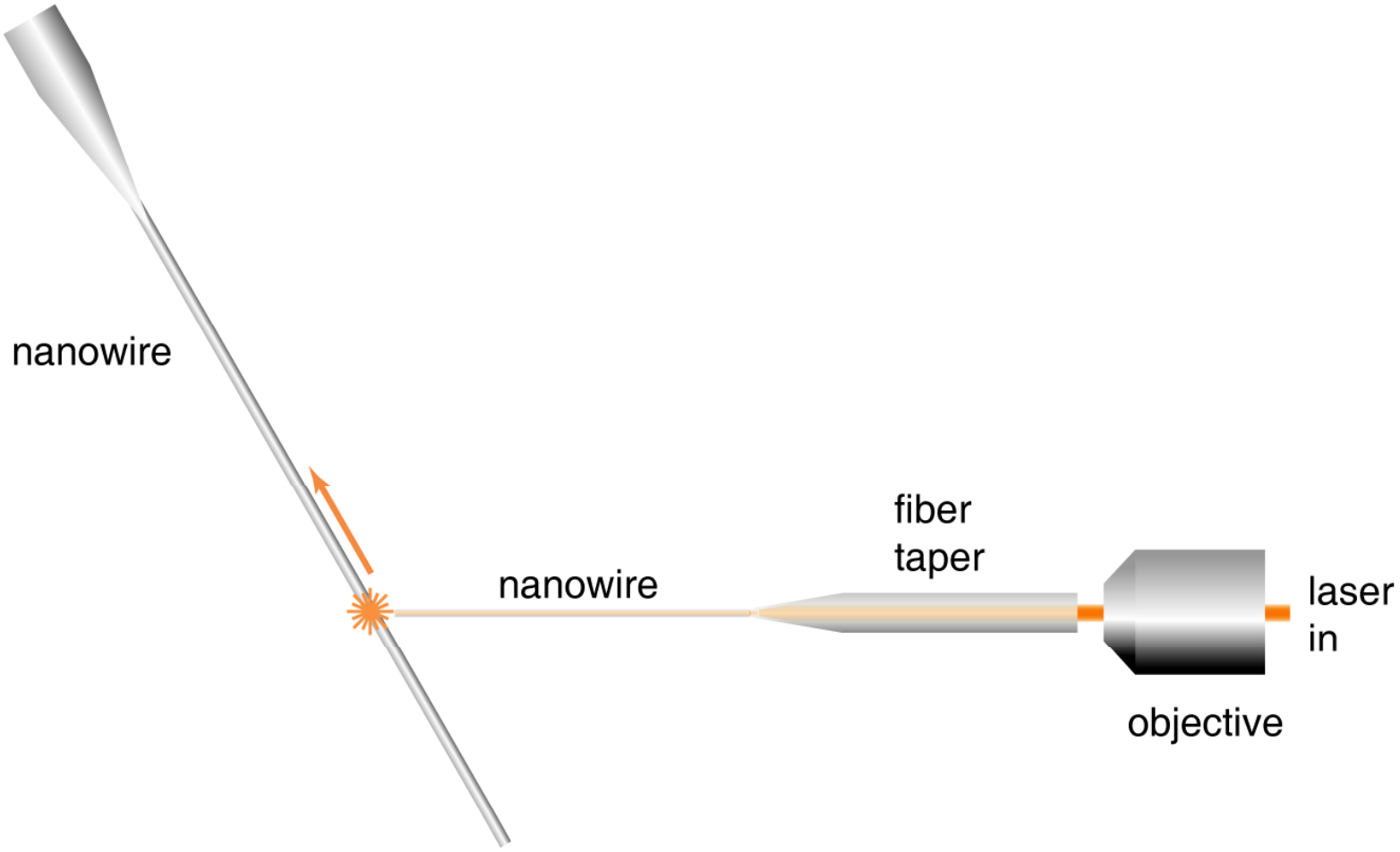
Silica nanowires

Silica nanowires

Silica nanowires

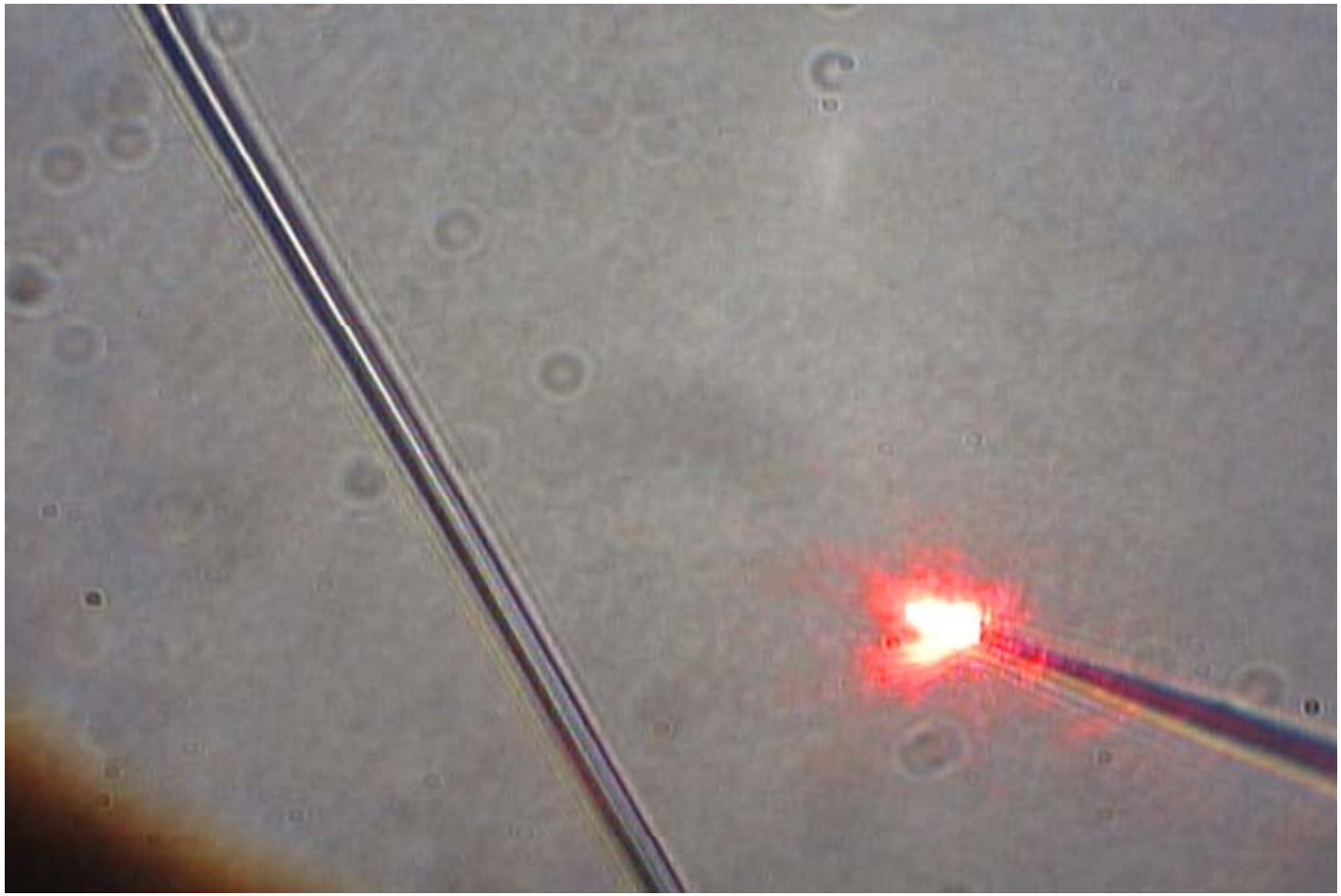
Silica nanowires

coupling light into nanowires



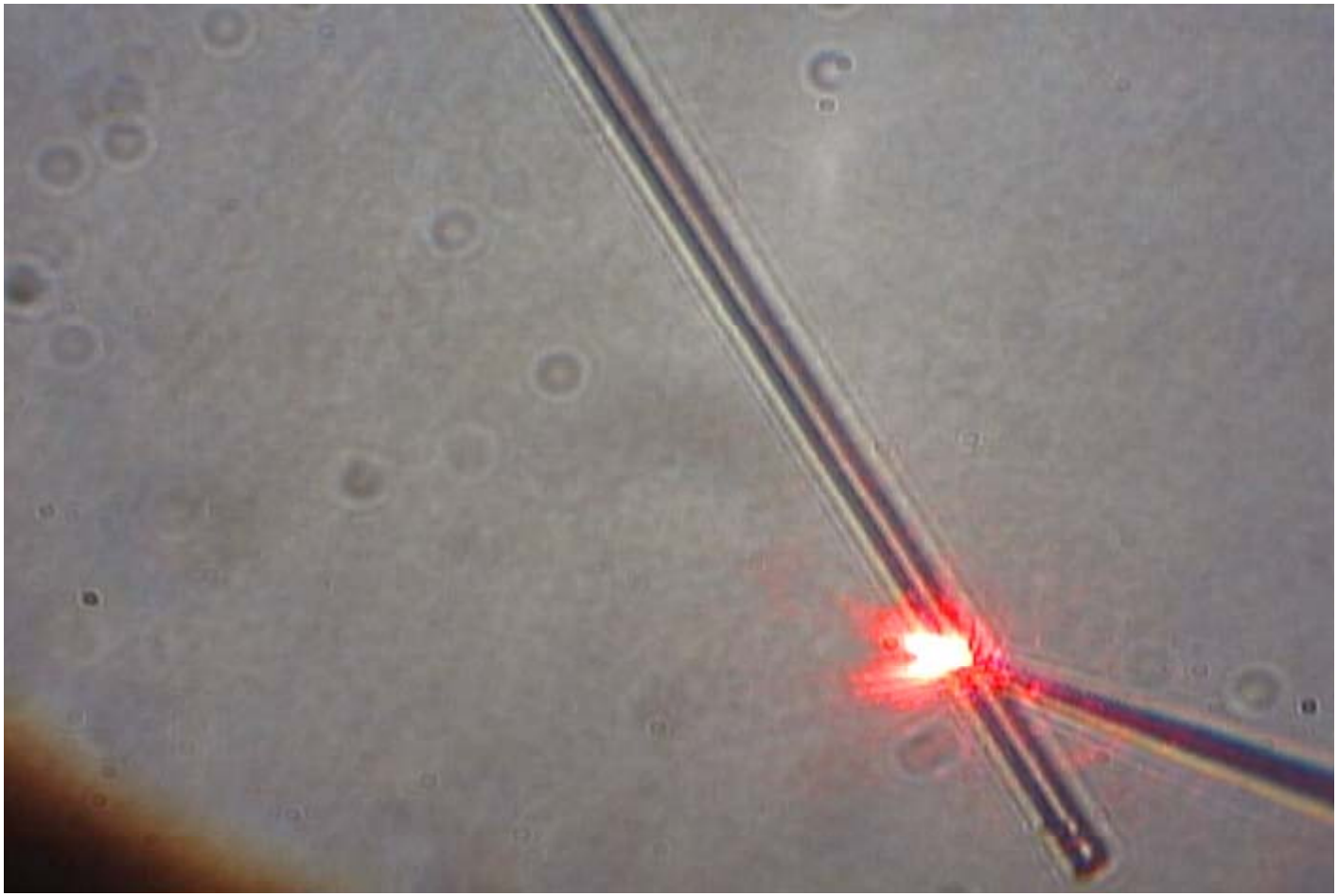
Silica nanowires

coupling light into nanowires

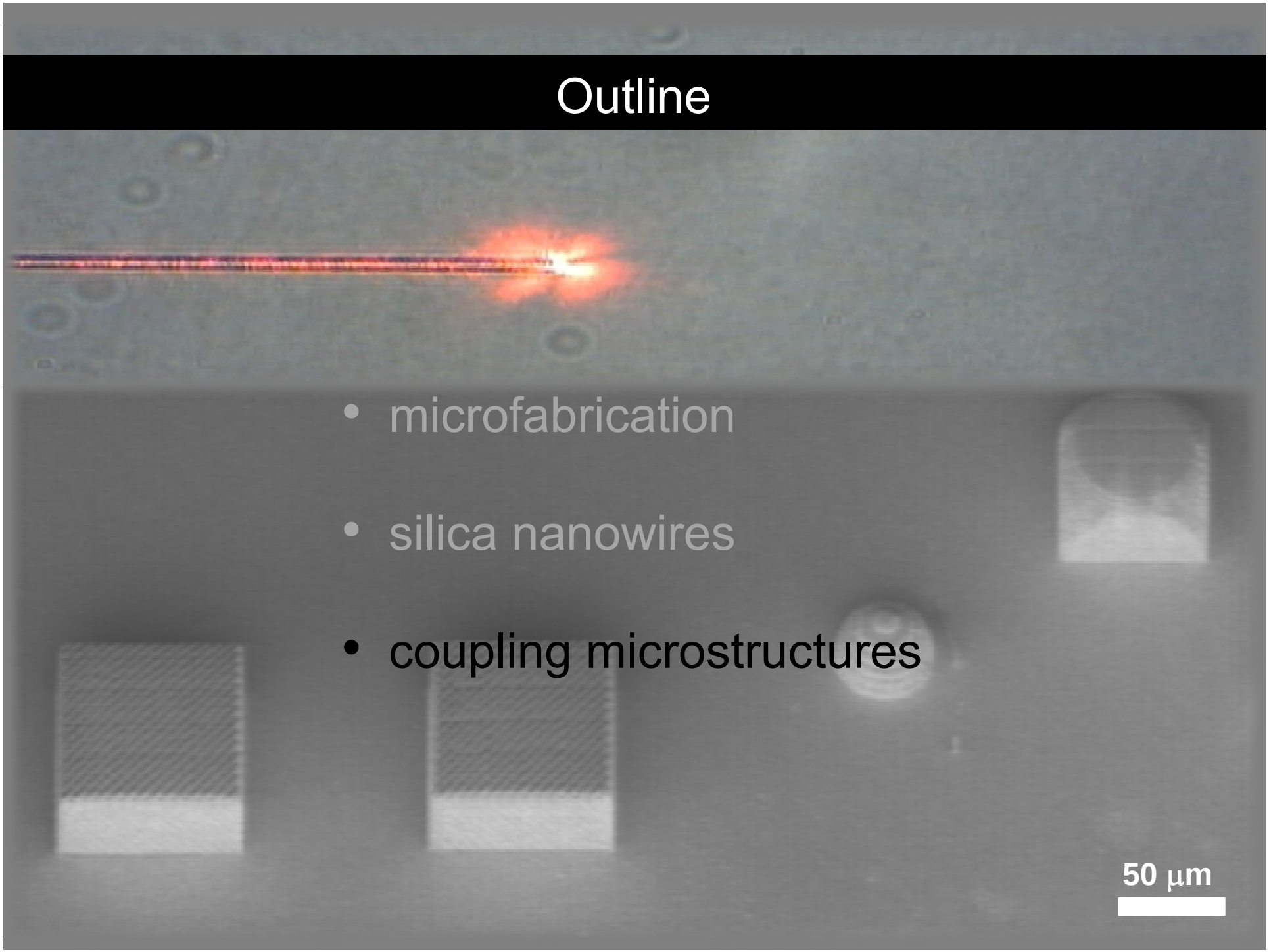


Silica nanowires

coupling light into nanowires

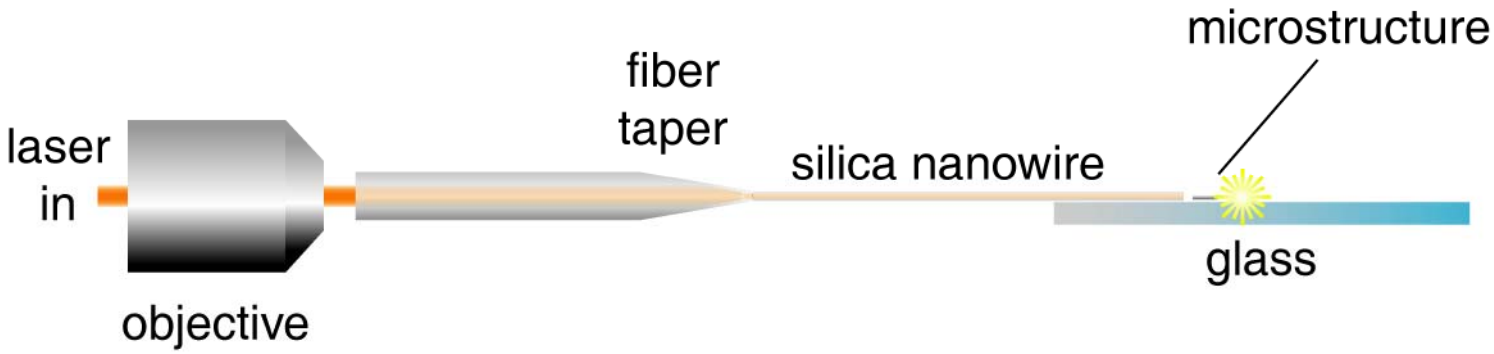


Outline

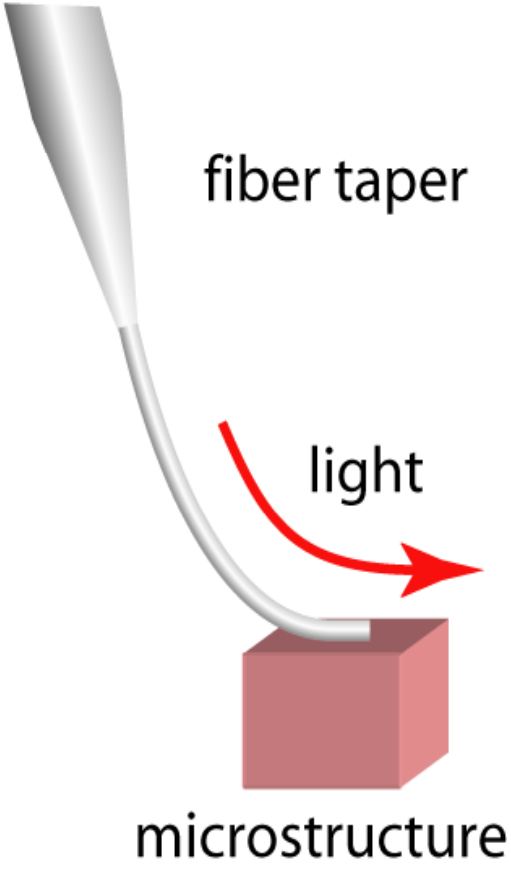


- microfabrication
- silica nanowires
- coupling microstructures

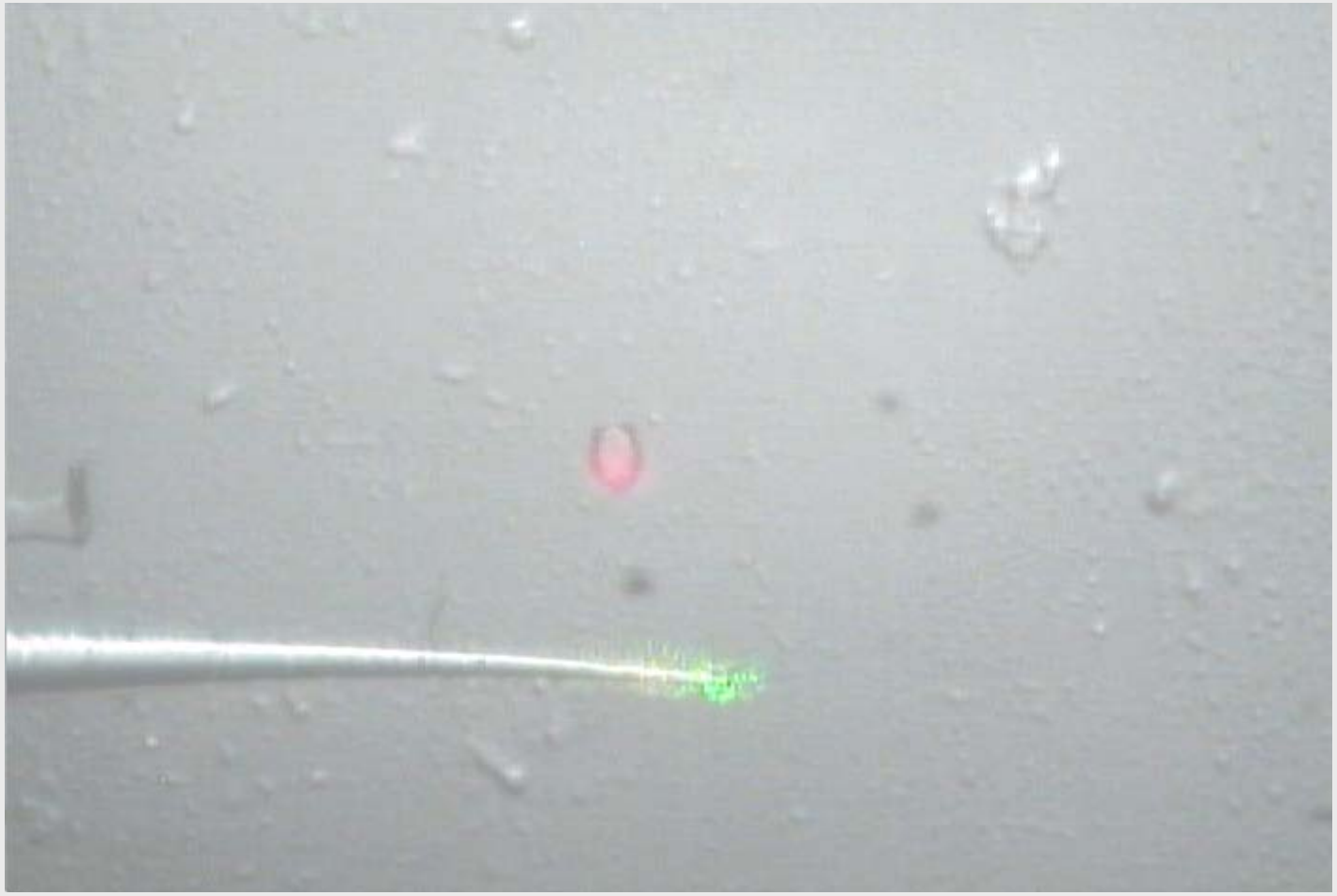
Coupling microstructures



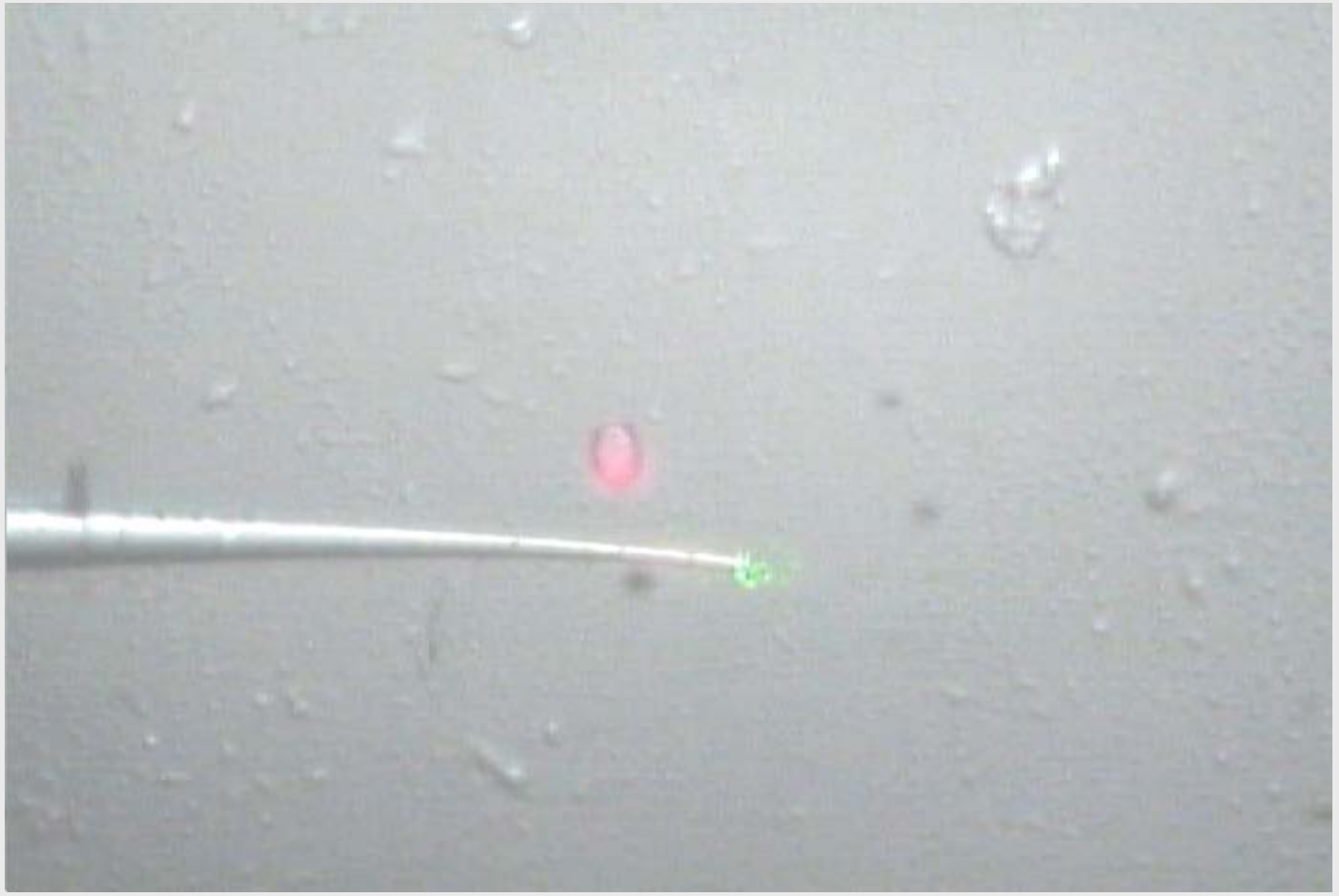
Coupling microstructures



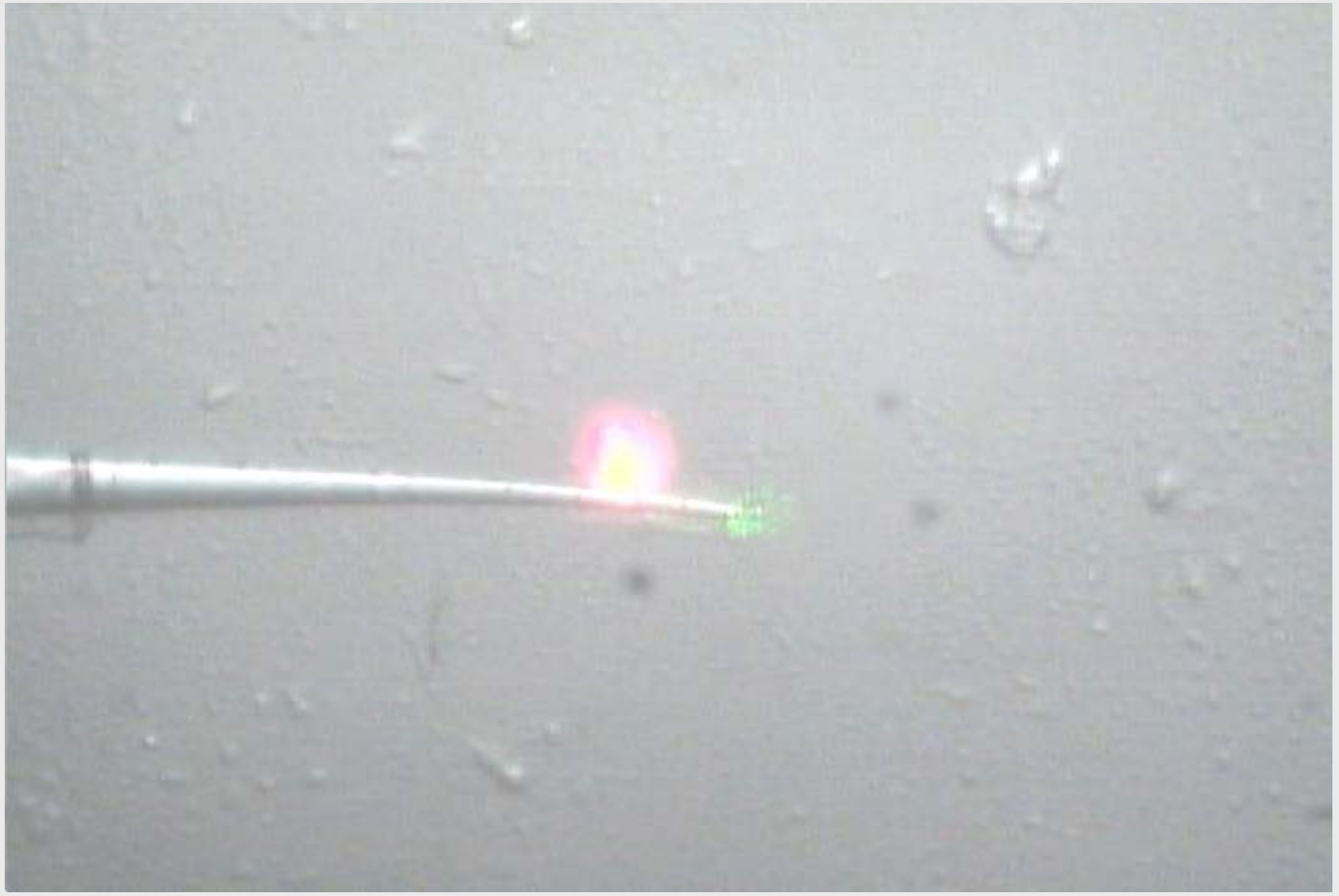
Coupling microstructures



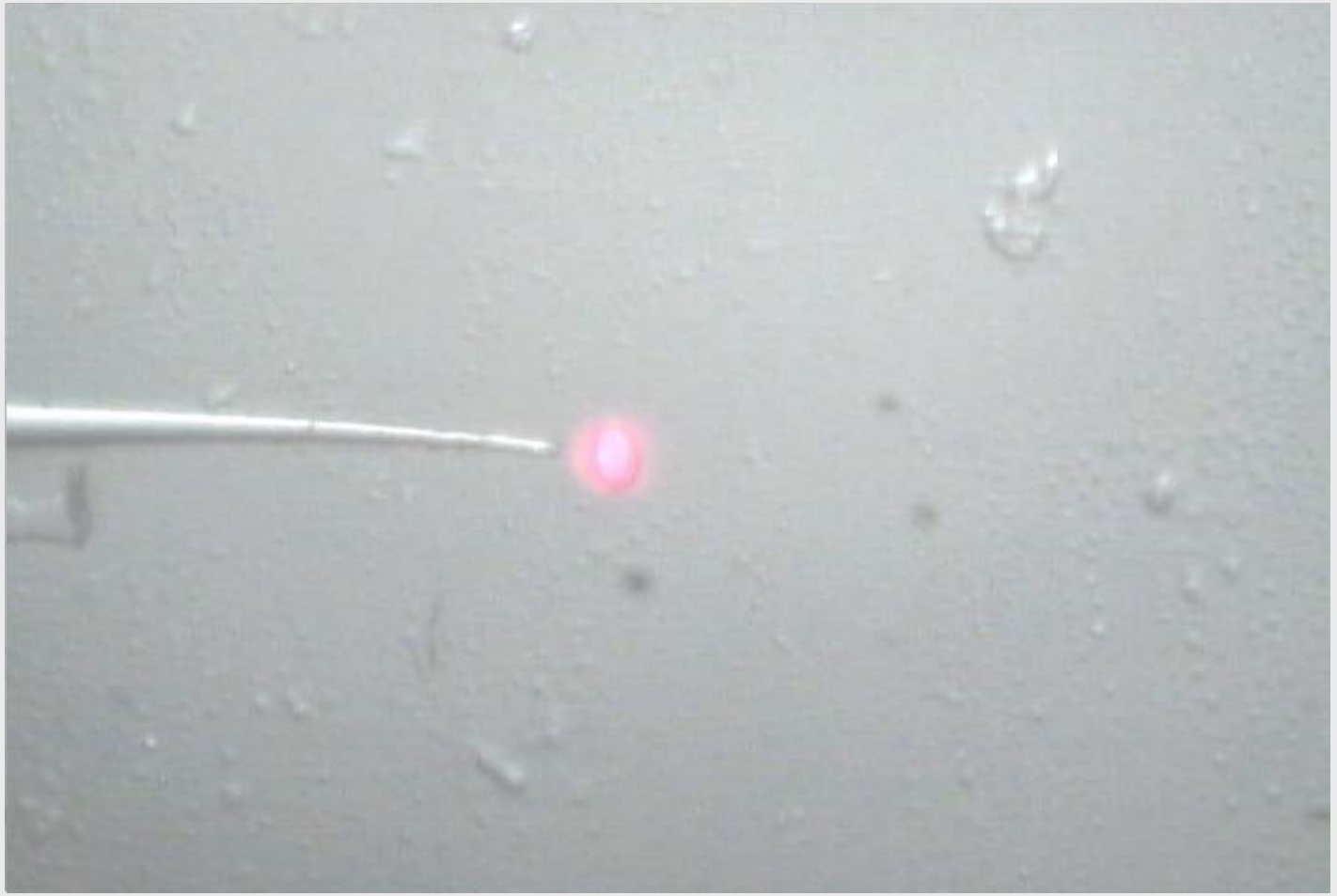
Coupling microstructures



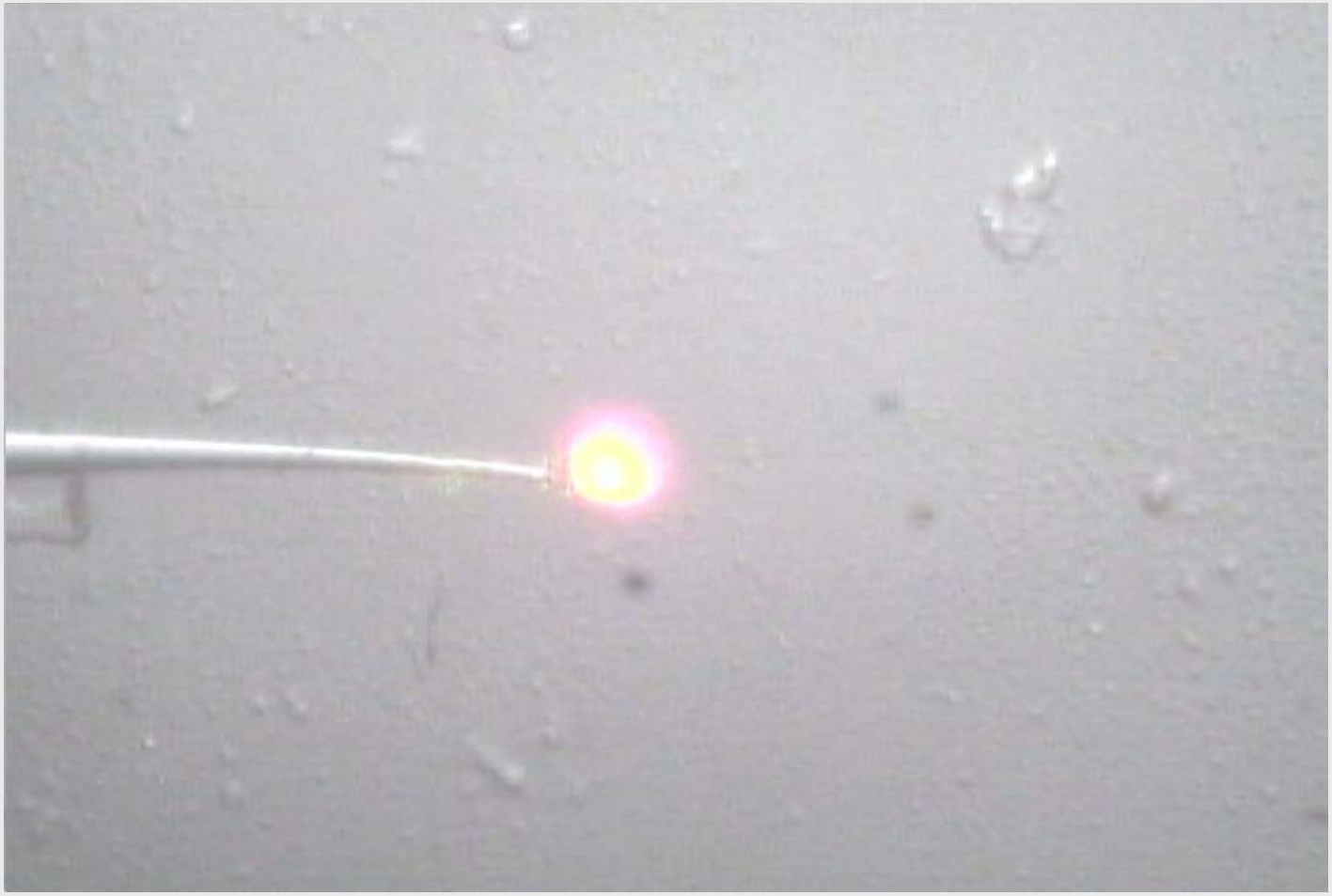
Coupling microstructures



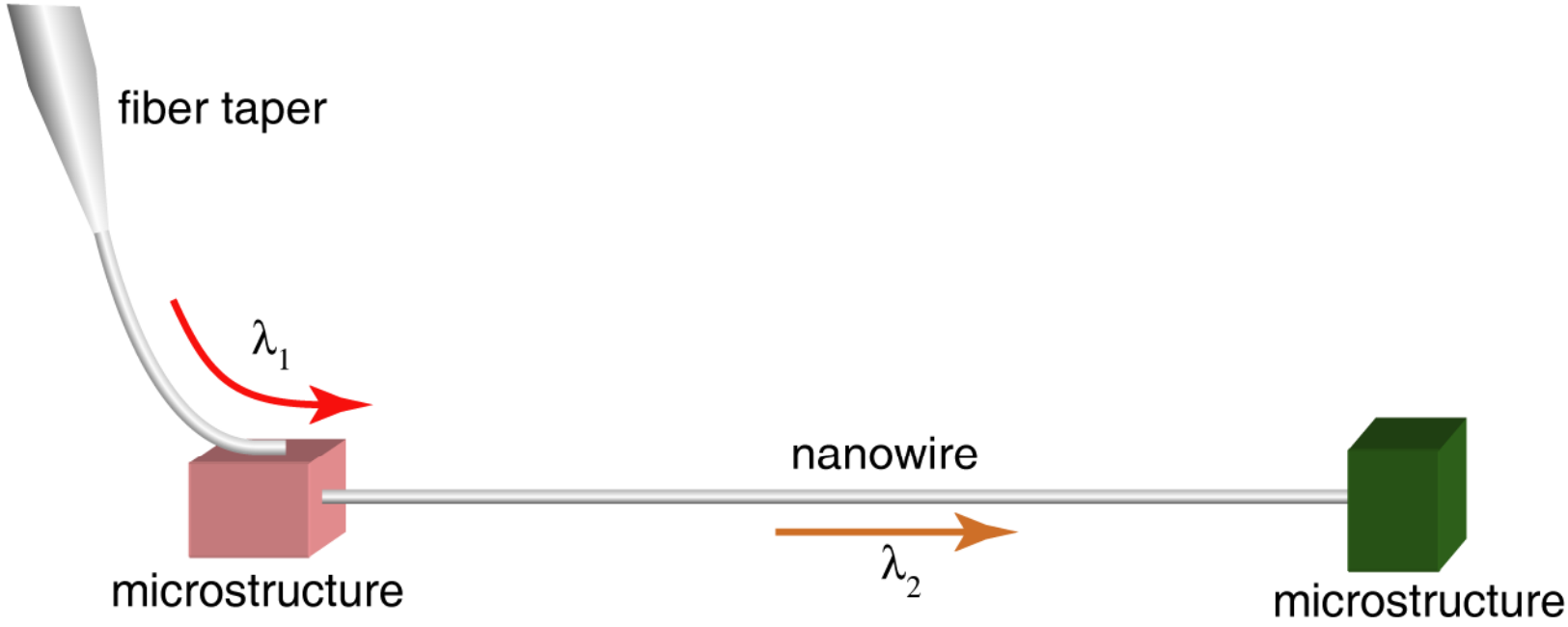
Coupling microstructures



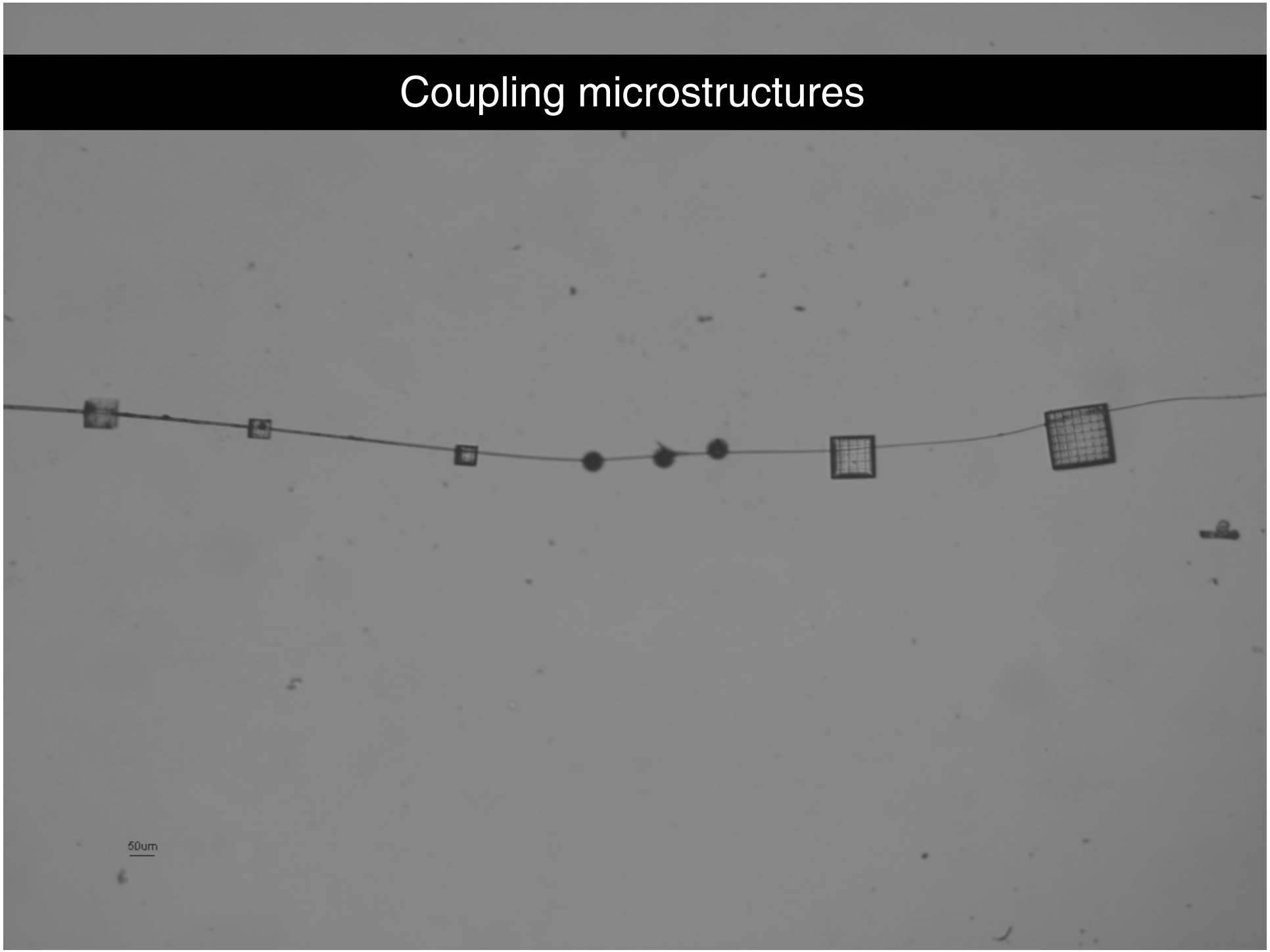
Coupling microstructures



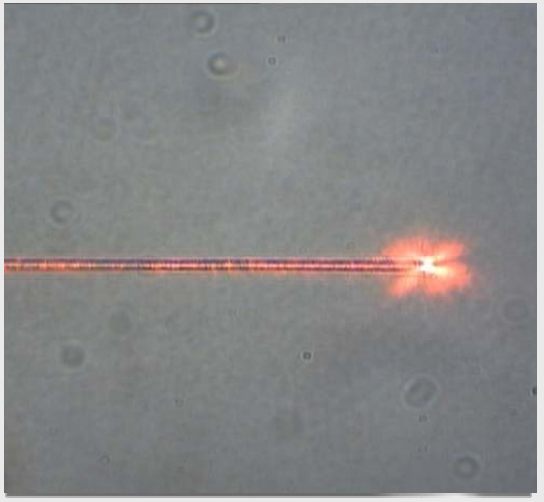
Coupling microstructures

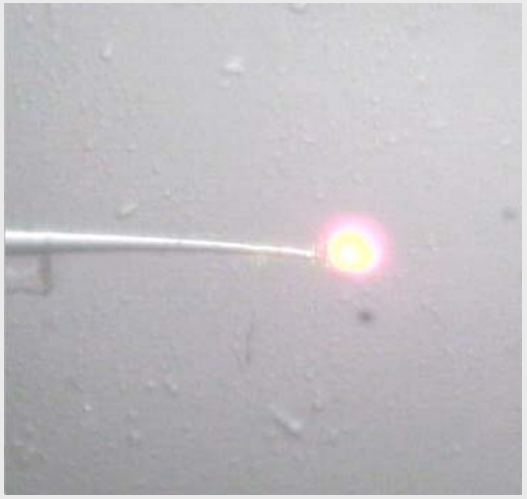


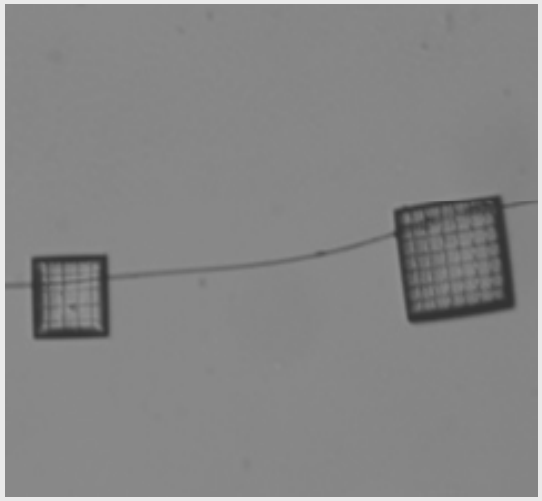
Coupling microstructures



Summary







Thank you !

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