Fabrication and optical connection of 3D microstructures

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outline

introduction

fs-micromachining

superhydrophobic surfaces
production of nanoparticles in glass
scaffolds for biological applications

fs-laser microfabrication

two-photon polymerization
birefringent microstructures
fluorescent microstructures
connection with silica nanowires
micro structres with ZnO nanowires
micro- environment for bacterial growth

introduction

short pulse duration $\rightarrow$ high intensity

(even at low energy)

fs-laser microfabrication

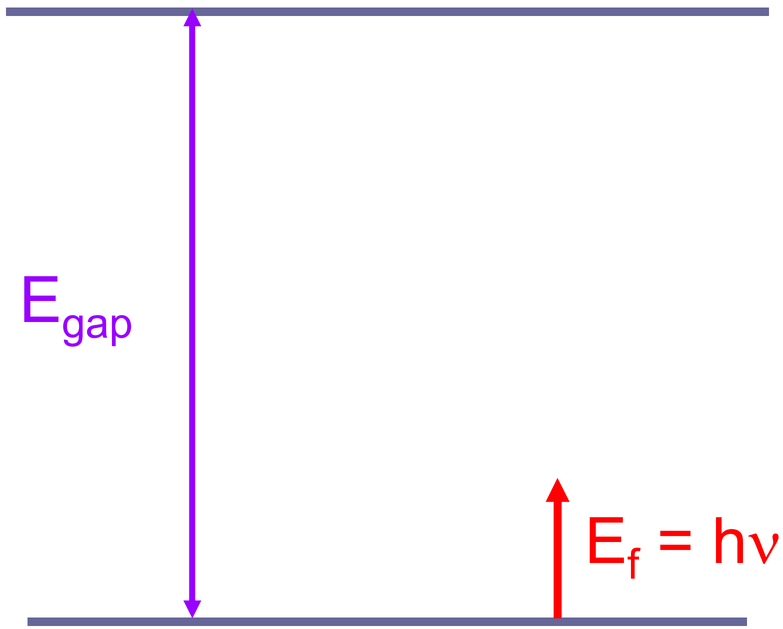
photon energy < bandgap

↓

nonlinear interaction

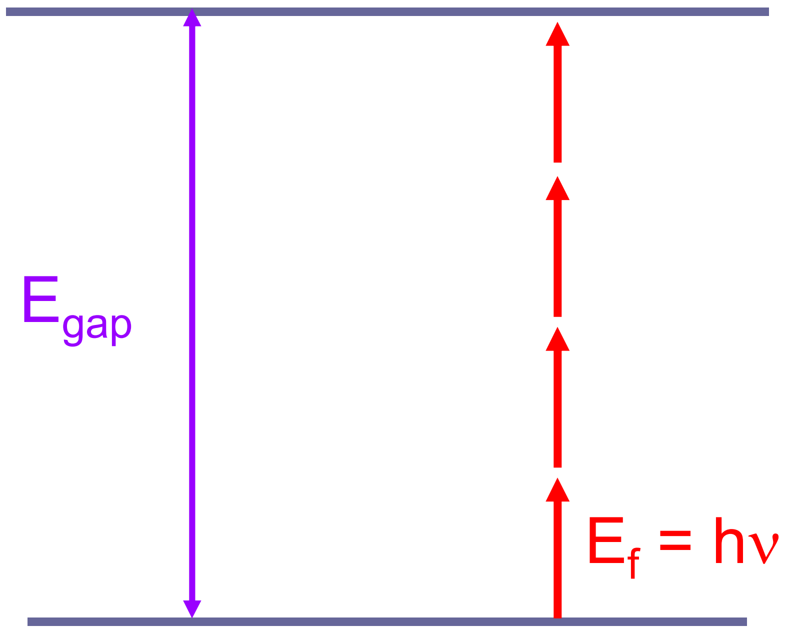
fs-laser microfabrication

nonlinear interaction



fs-laser microfabrication

nonlinear interaction

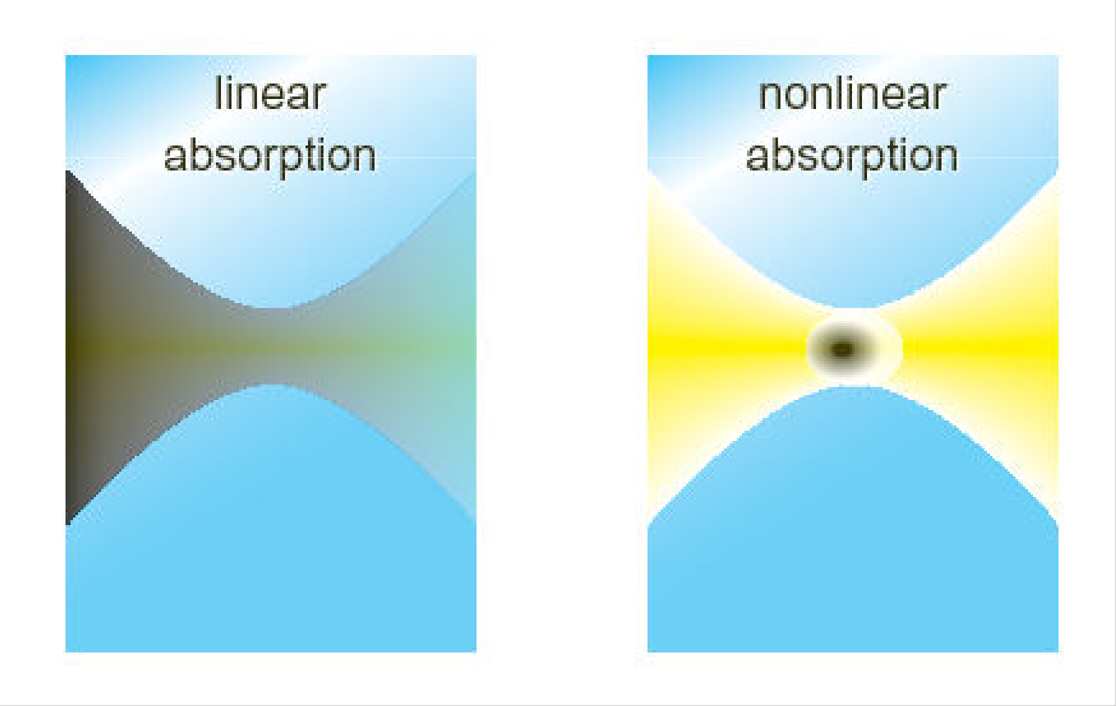


multiphoton absorption

Two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication

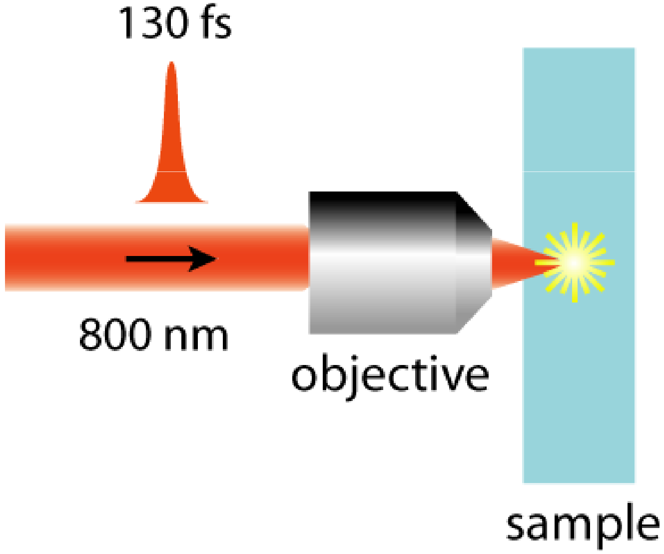


$$\alpha = \alpha_0$$

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

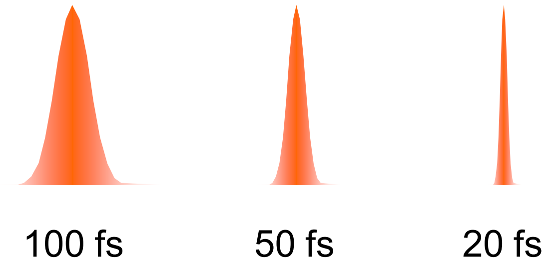
fs-laser microfabrication

focus laser beam inside material

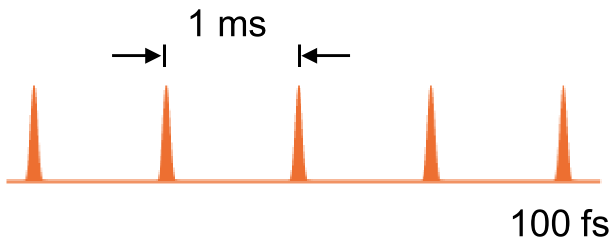
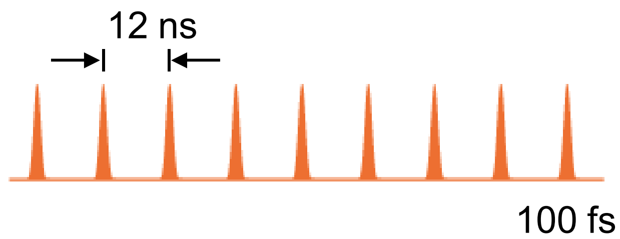


femtosecond pulses

Ti:Sapphire lasers

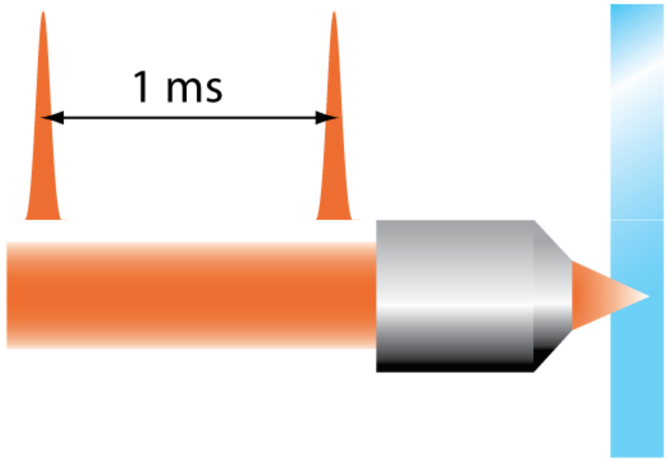


1 fs = 10^{-15} s

Repetition rate		Energy
1 KHz		mJ
86 MHz		nJ

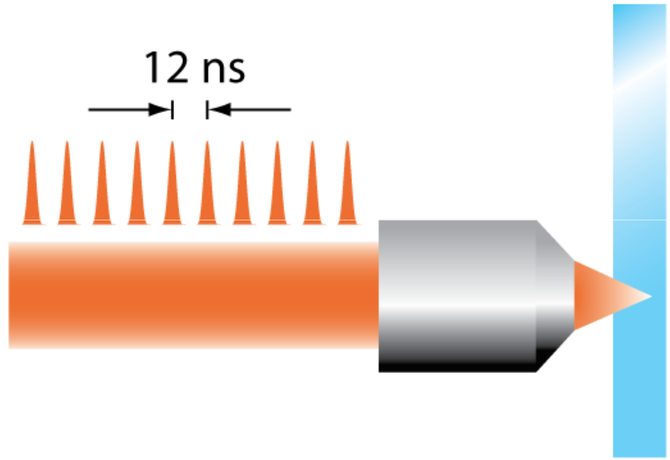
femtosecond pulses

amplified laser



repetitive

oscillator



cumulative

fs-micromachining

microfabrication can be controlled by

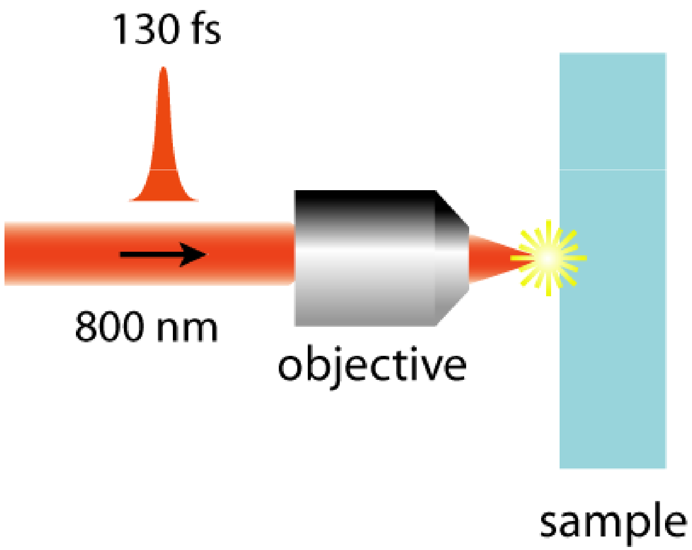
- objective NA
- number of pulses – scanning speed
- pulse energy

two main techniques

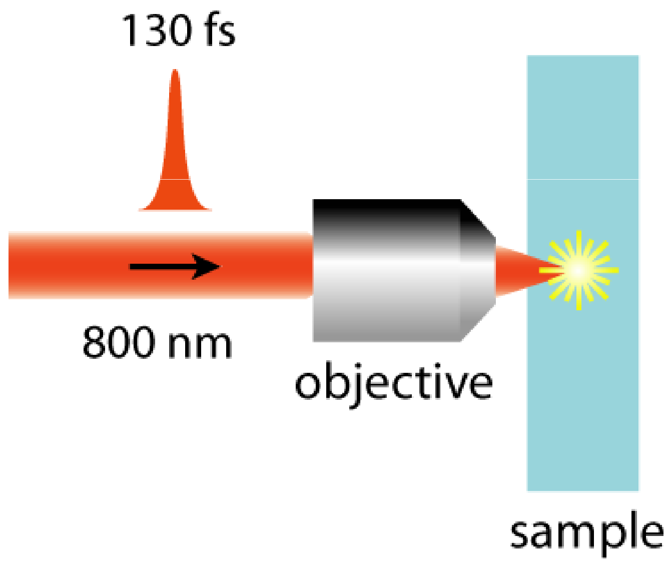
- fs-laser micromachining
- microfabrication via two-photon polymerization

fs-laser micromaching

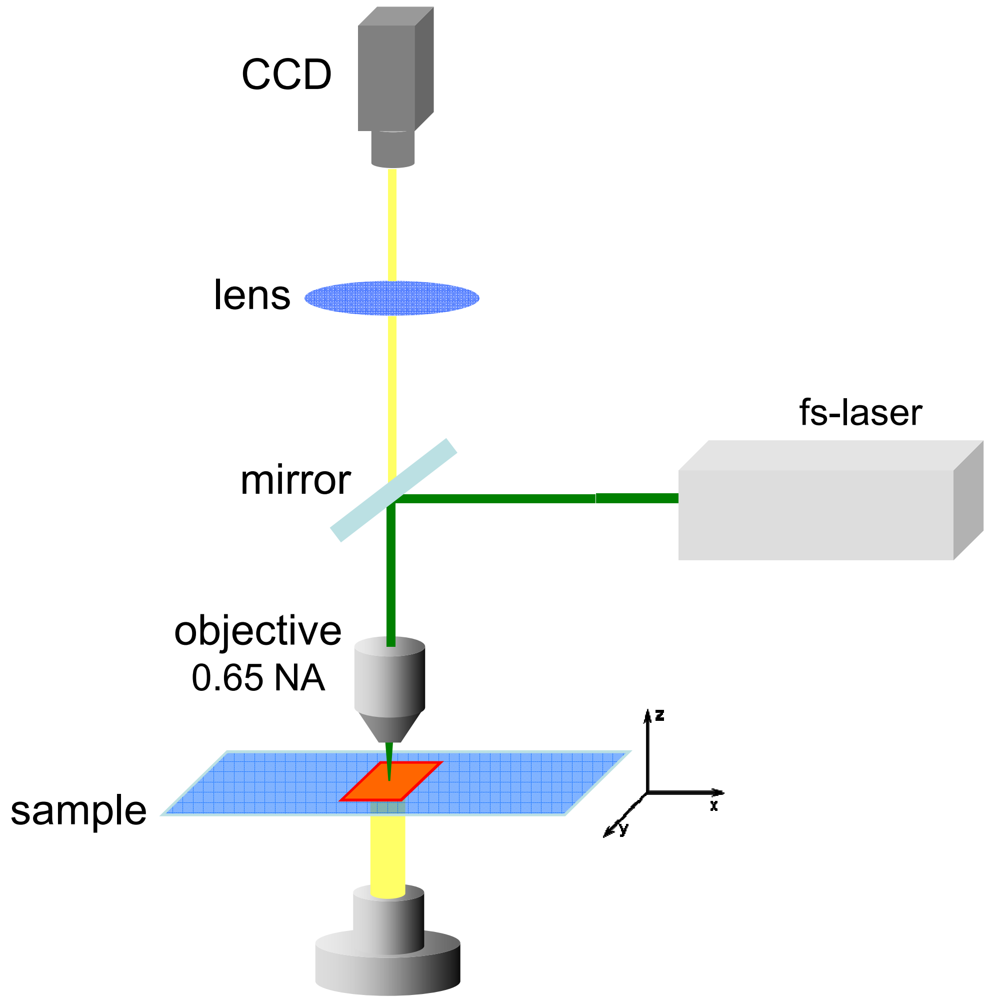
Surface



Volume

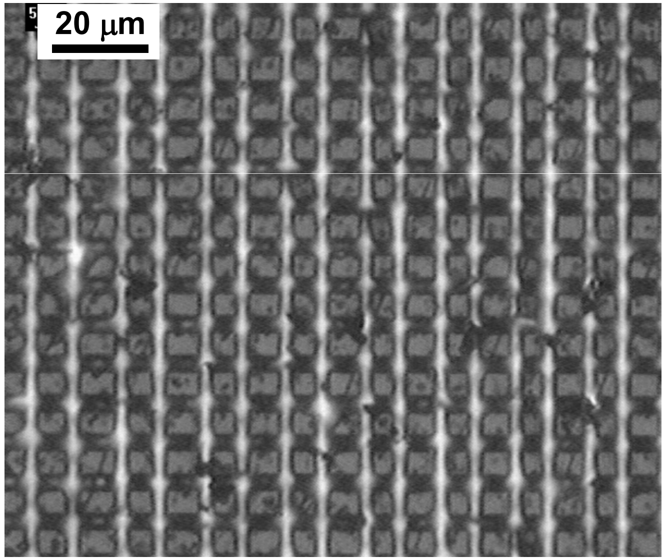


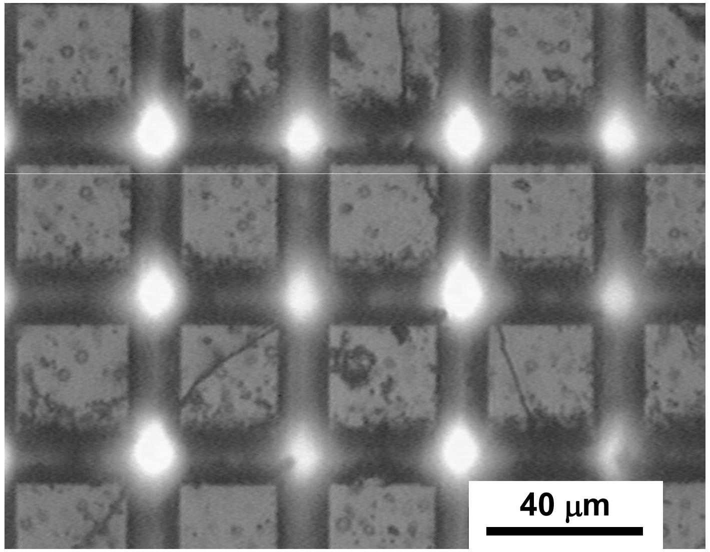
fs-laser microstructuring experimental setup



laser microfabrication: super hydrophobic surface

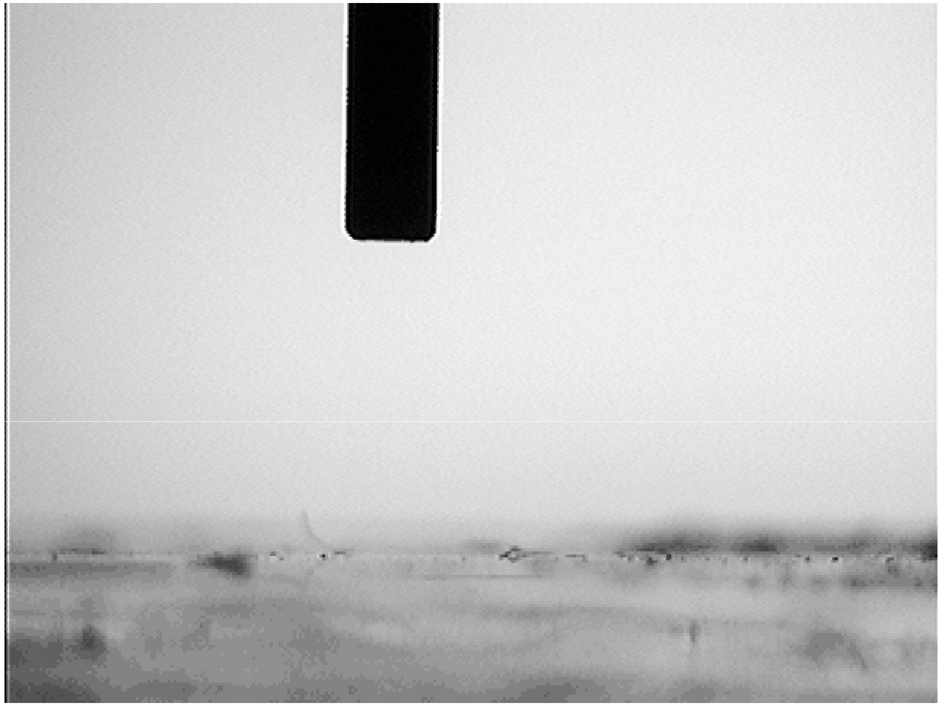
examples of fabricated surfaces



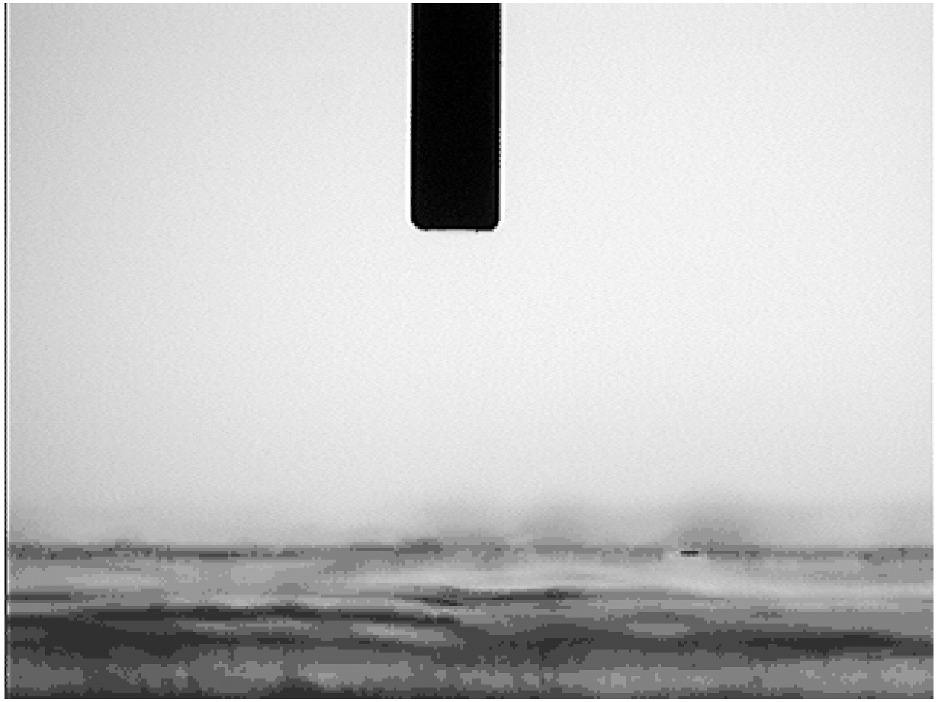


laser microfabrication: super hydrophobic surface

Superhydrophobic surfaces

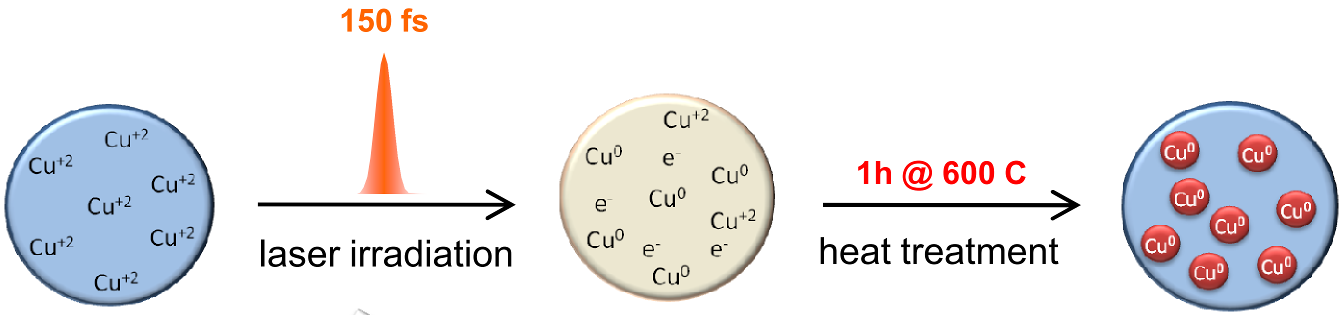


flat surface

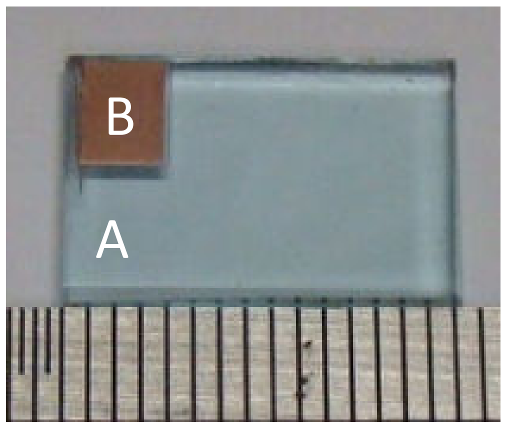


microstructured surface

Generation of Cu nanoparticles

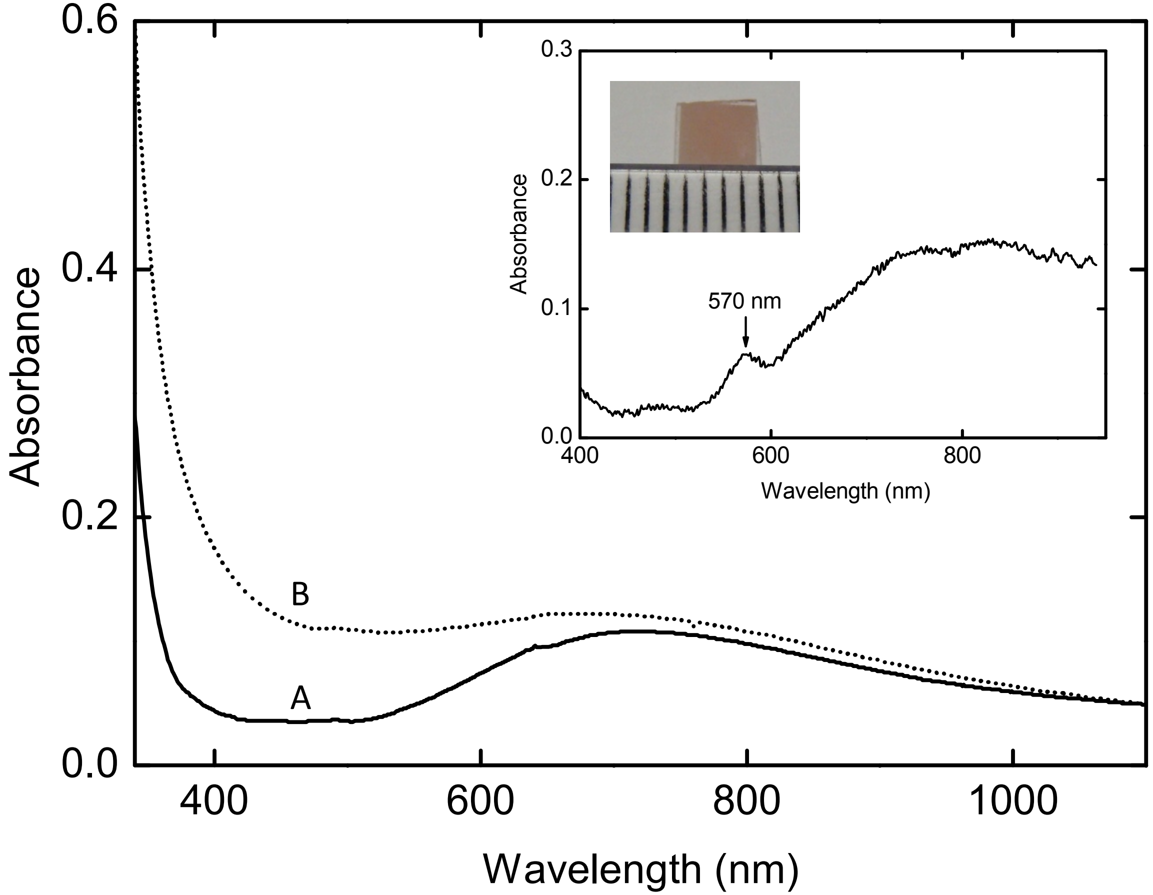


Cu nanoparticles are generated only in the irradiated area due to the **fs-laser induced photoreduction**



Generation of Cu nanoparticles

Absorption spectrum of the sample

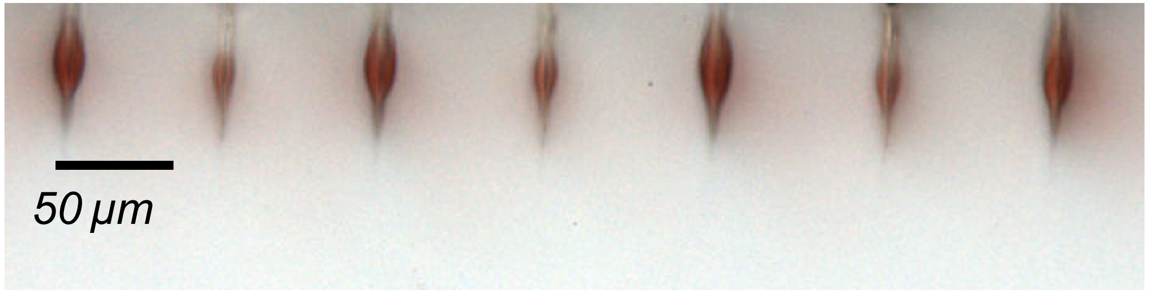


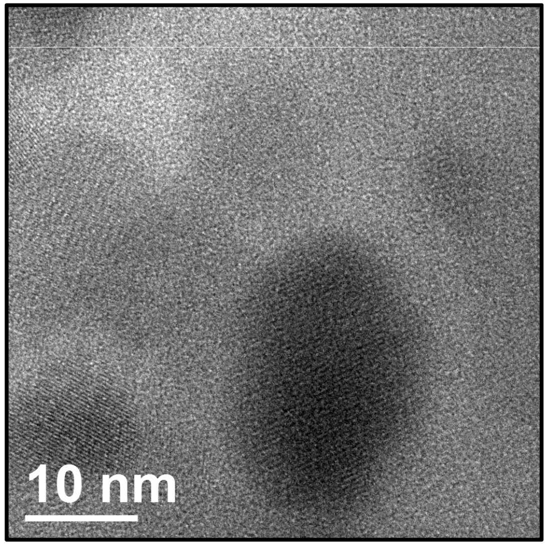
After heat treatment

A: as-prepared sample
B: sample after fs-laser irradiation

Generation of Cu nanoparticles

Optical microscopy showing the regions in the bulk where Cu nanoparticles were produced





TEM image of the nanoparticles

fs-laser microfabrication

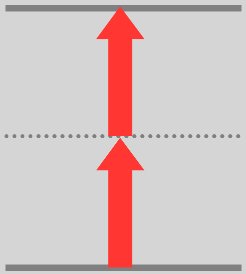
build a microstructure using fs-laser and nonlinear optical processes

Two-photon polymerization

Monomer + Photoinitiator $\rightarrow$ Polymer

light

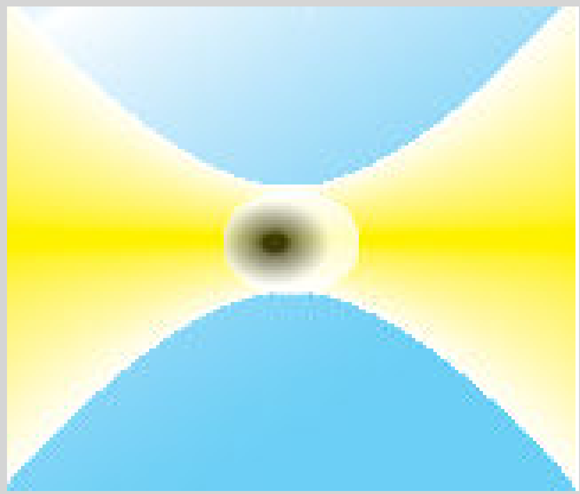
Photoinitiator is excited by ***two-photon absorption***



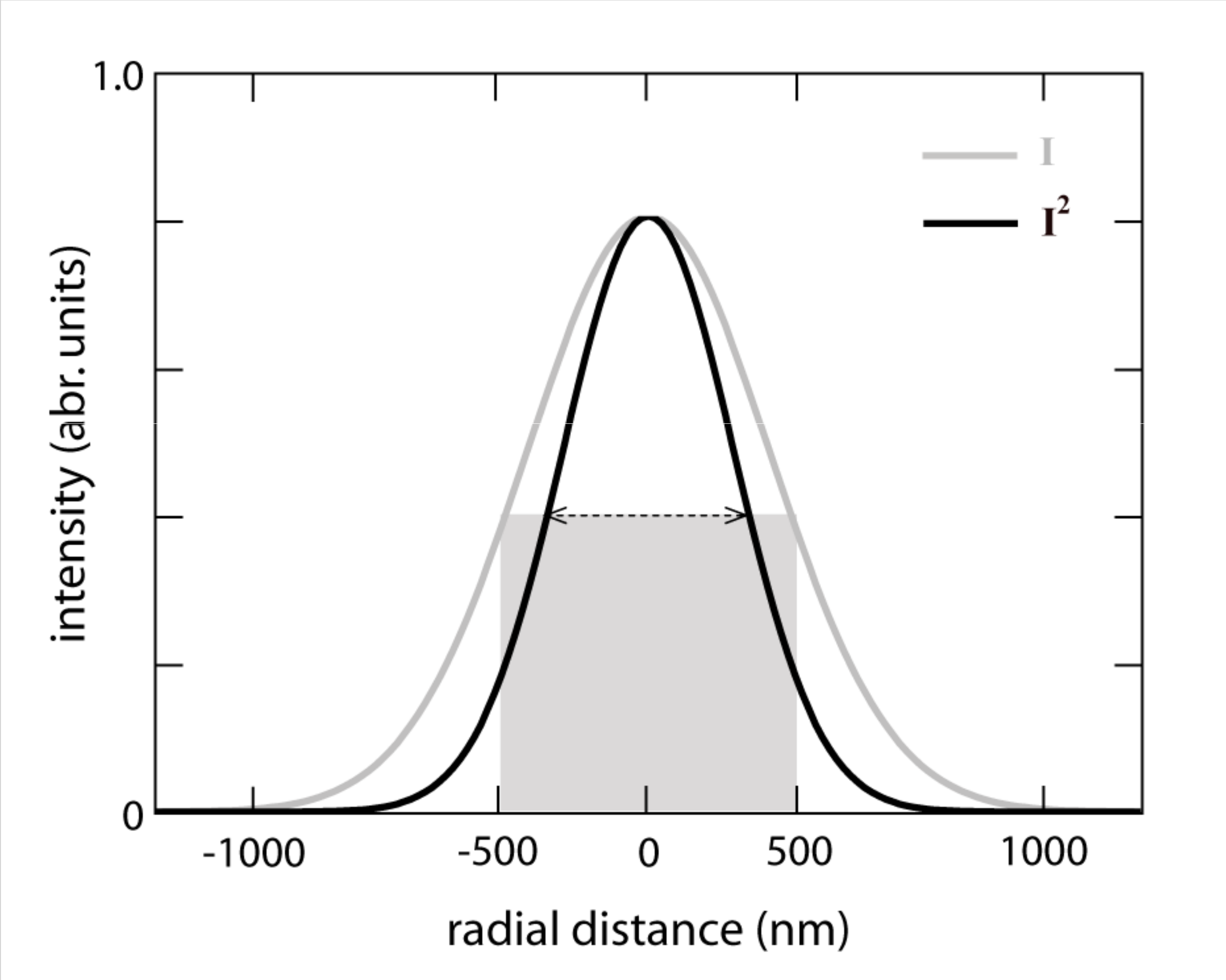
$$R_{2PA} \propto I^2$$

The polymerization is confined to the focal volume.

High spatial resolution

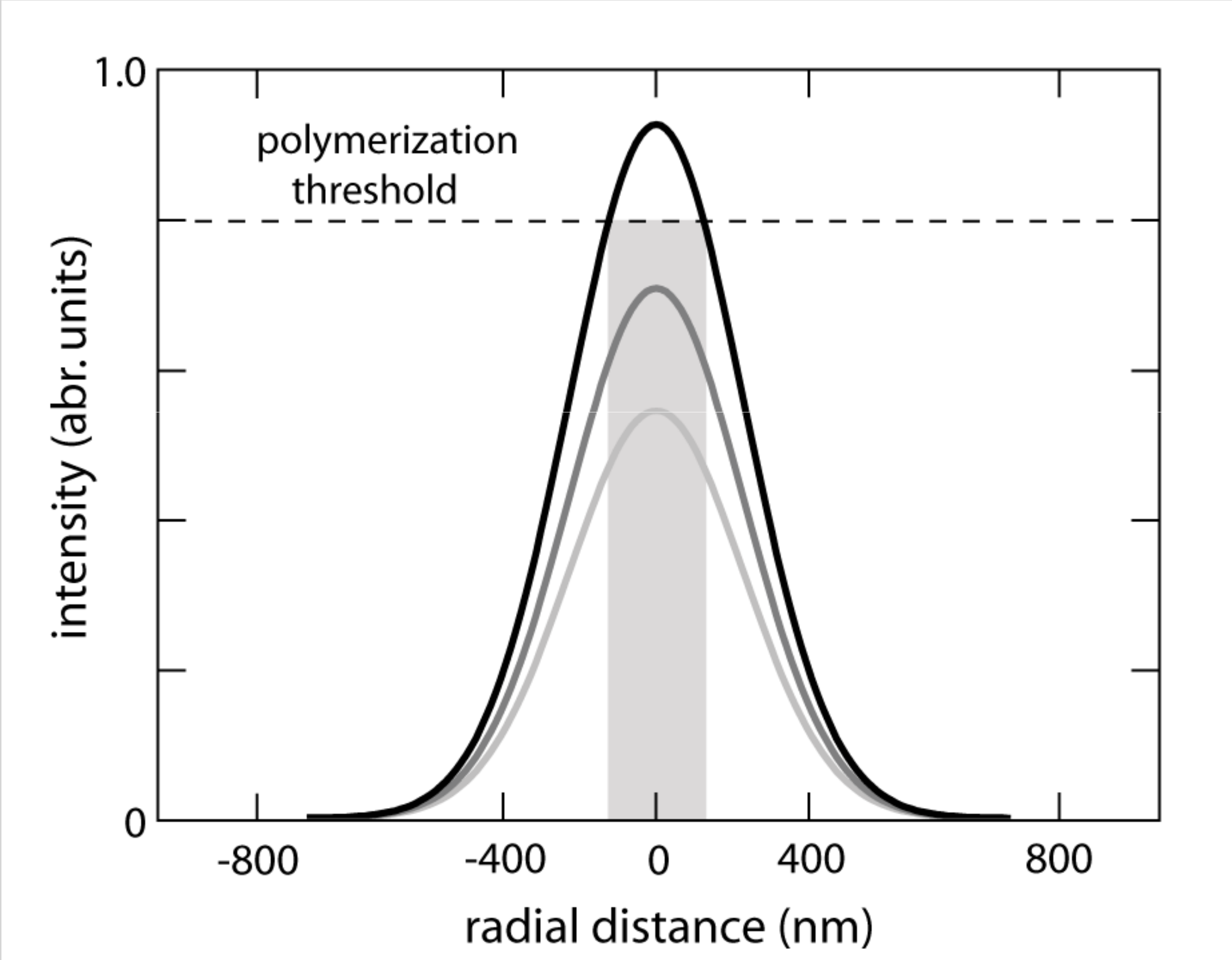


Two-photon polymerization



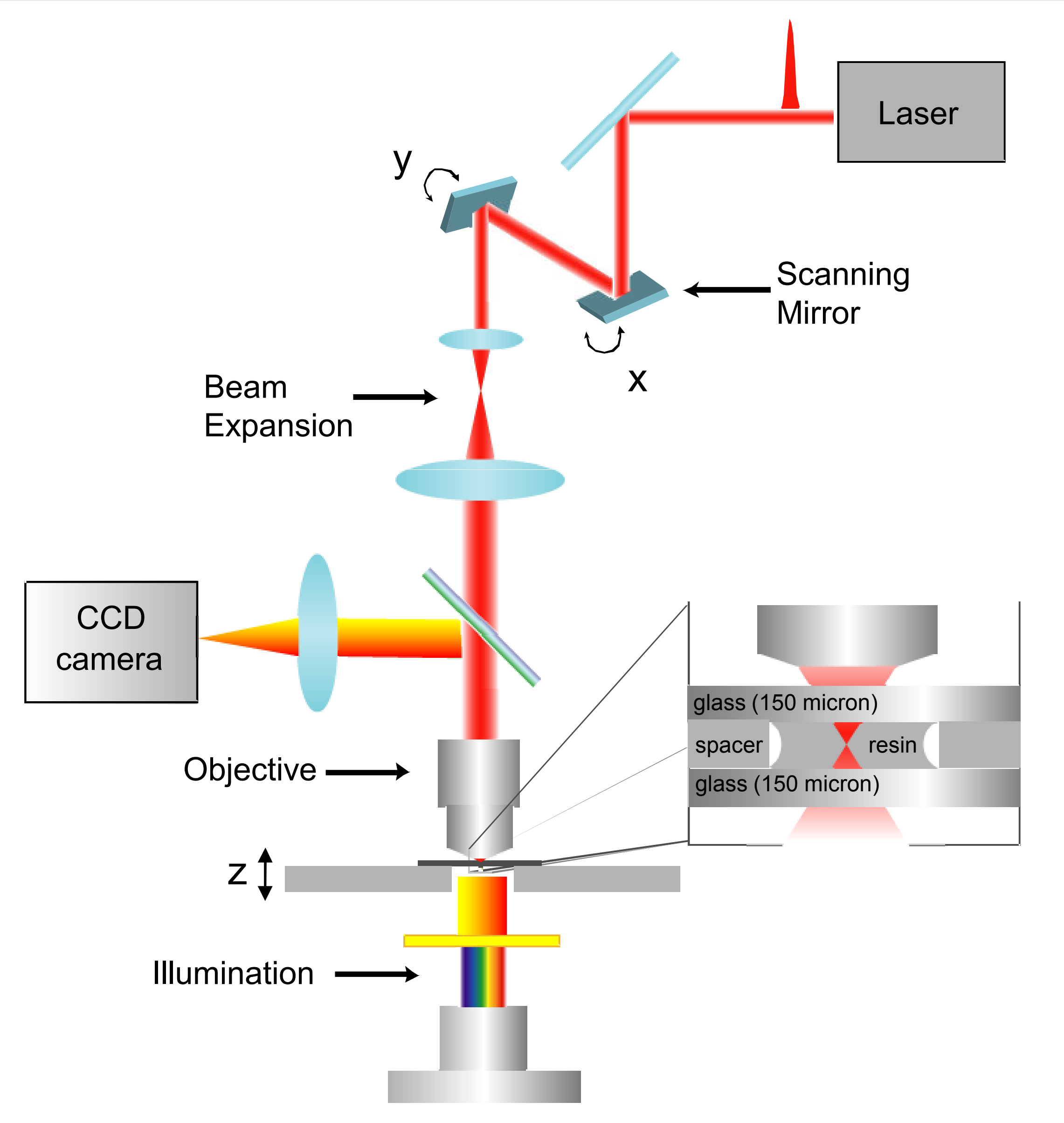
bellow the diffraction limit

Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



Ti:sapphire laser oscillator

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

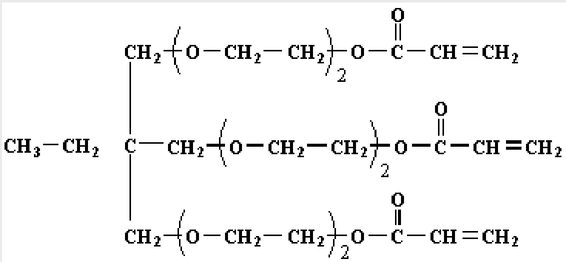
Objective

40 x
0.65 NA

Resin preparation

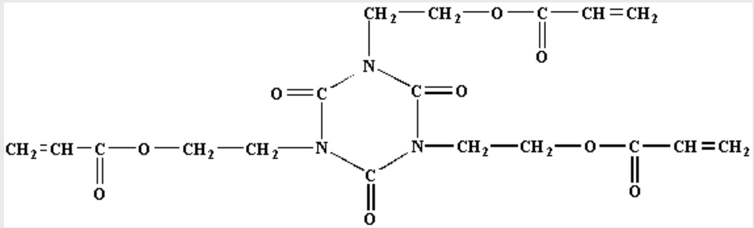
Monomers

Monomer A



reduces the shrinkage upon polymerization

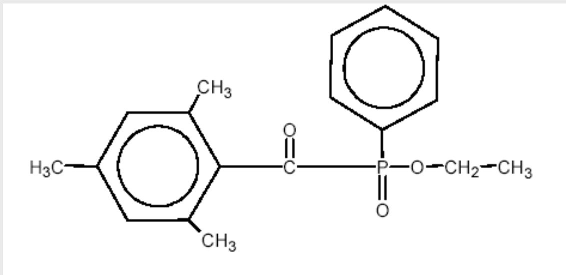
Monomer B



gives hardness to the polymeric structure

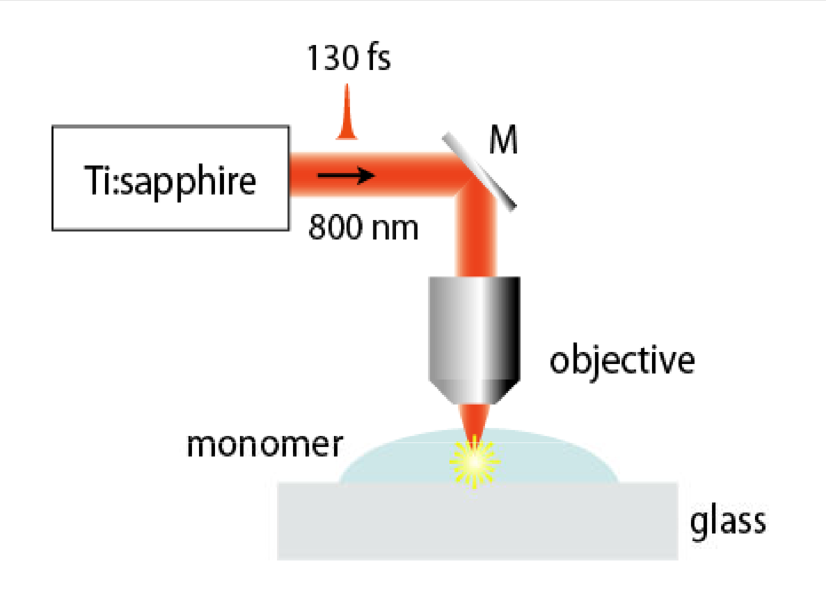
Photoinitiator

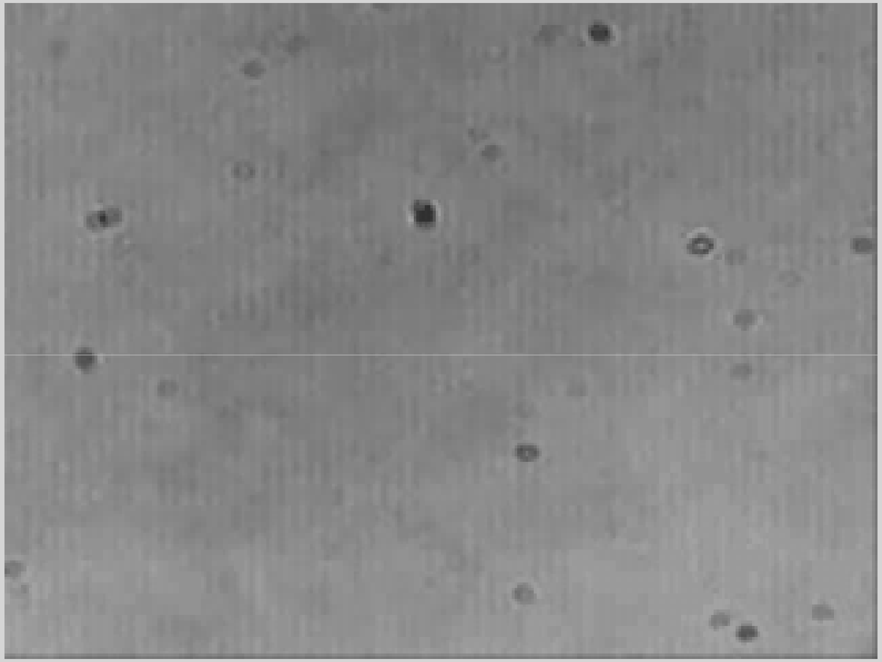
Lucirin TPO-L



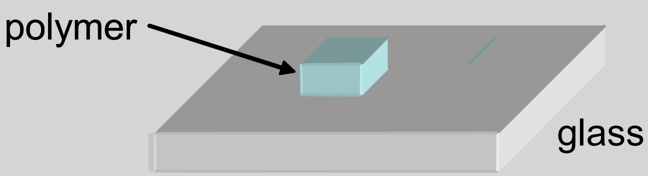
Appl. Phys. A, 90, 633–636 (2008)

Two-photon polymerization

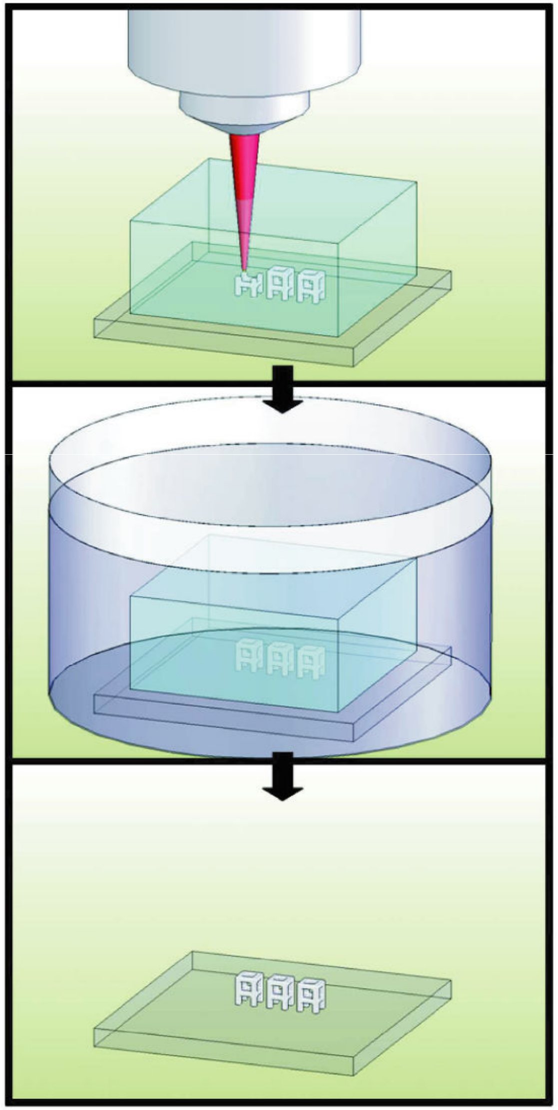




30 µm x 30 µm x 12 µm cube



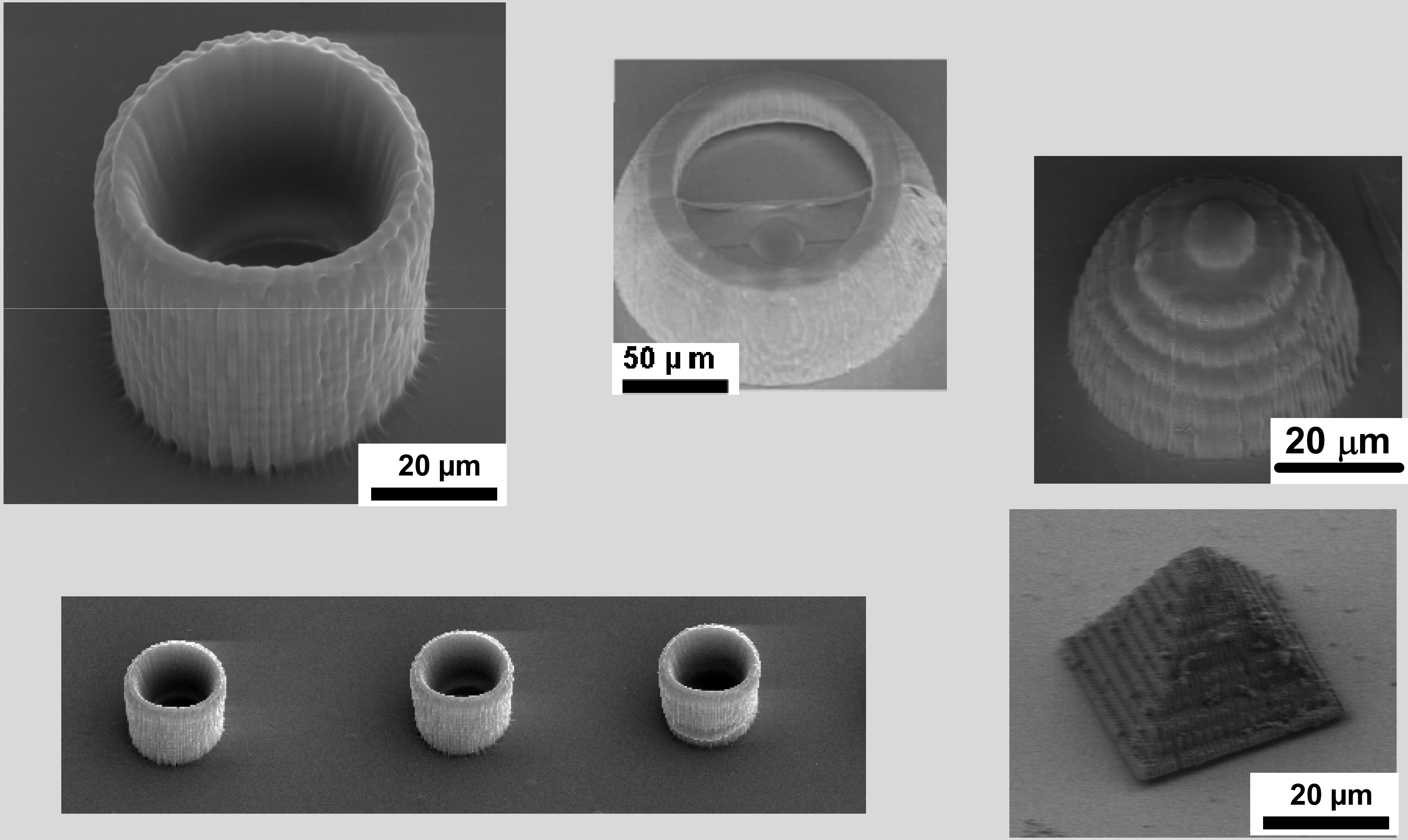
Two-photon polymerization



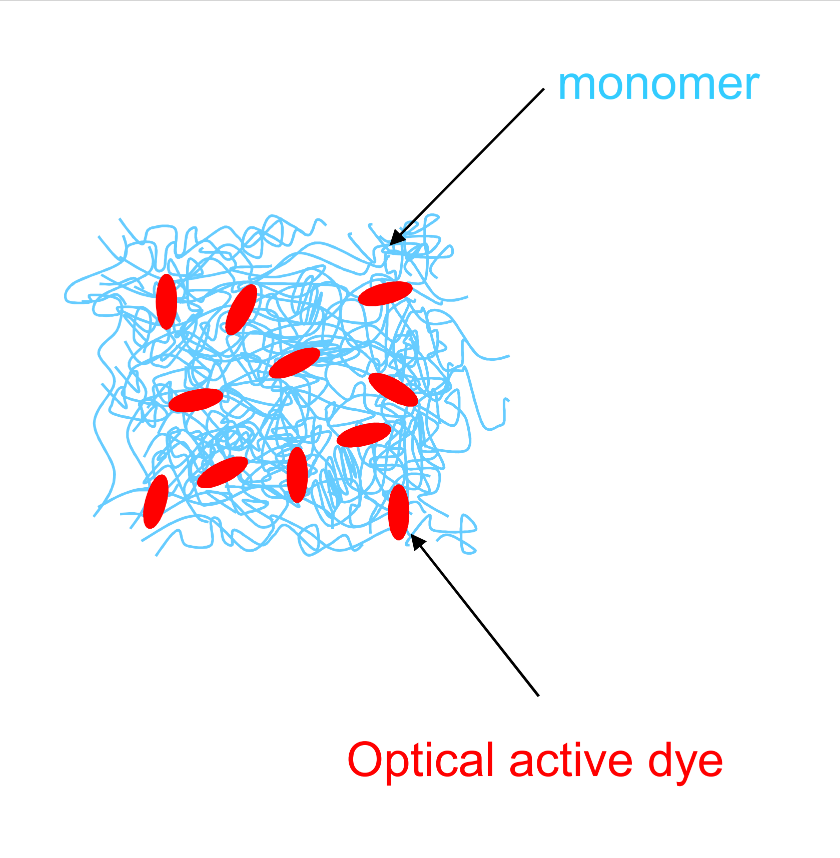
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

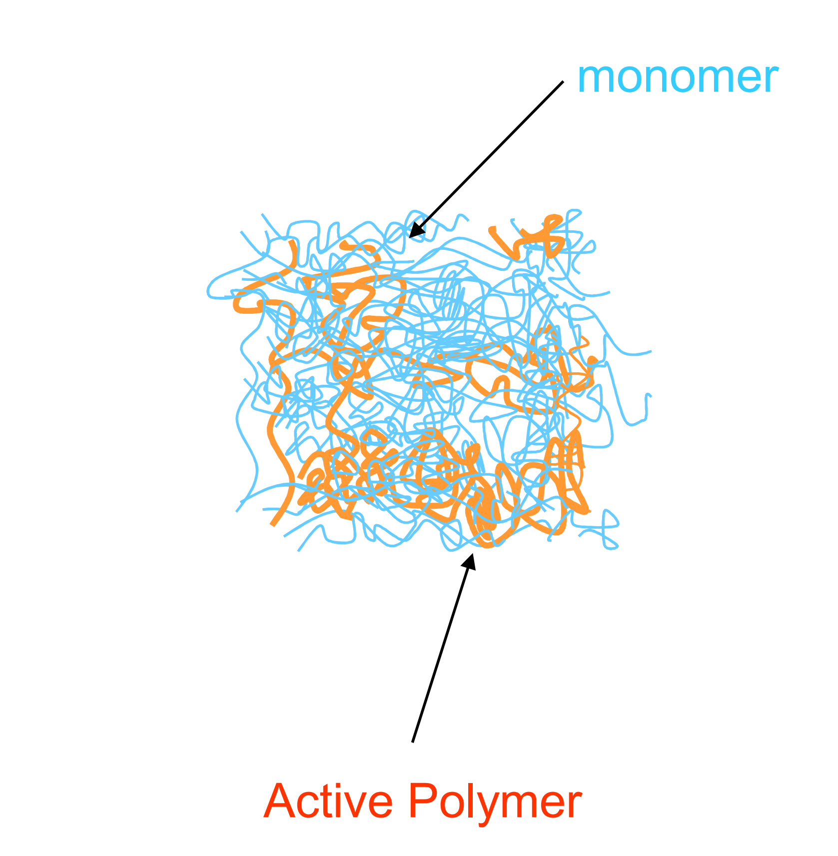
two-photon polymerization

Microstructures fabricated by two-photon polymerization



Microstructures containing active compounds





Applications of two-photon polymerization

Optics and Photonics

Doping microstructures with organic molecules and metals

- fluorescence
- birefringence
- conductivity

Bio-applications

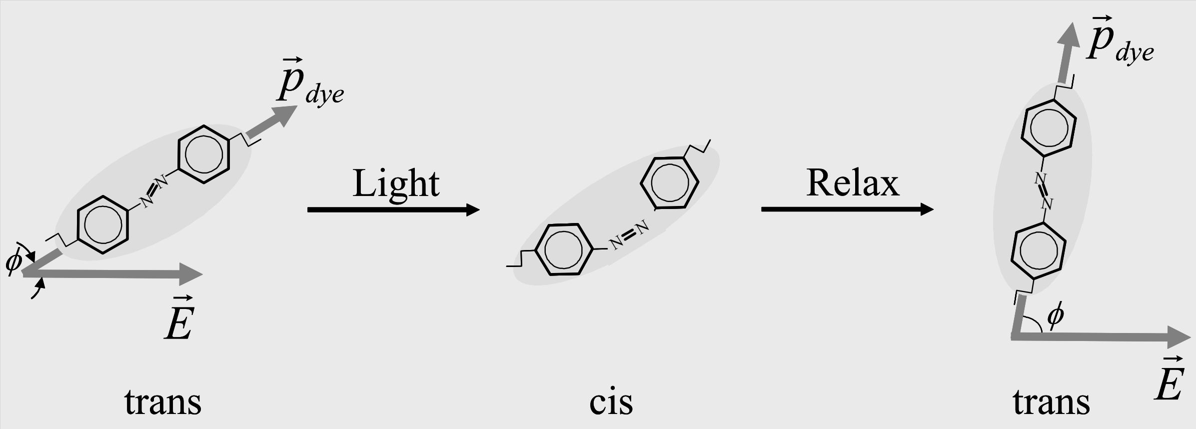
Fabrication using bio-compatible resins to biological applications

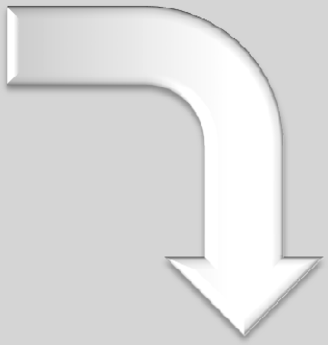
- tissue engineering scaffolds
- fabrication of microneedle
- cell study

Micro-optical storage

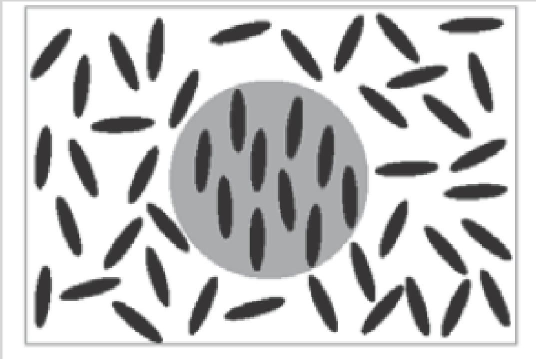
microstructures for optical storage

orientation mechanism in azochromophores





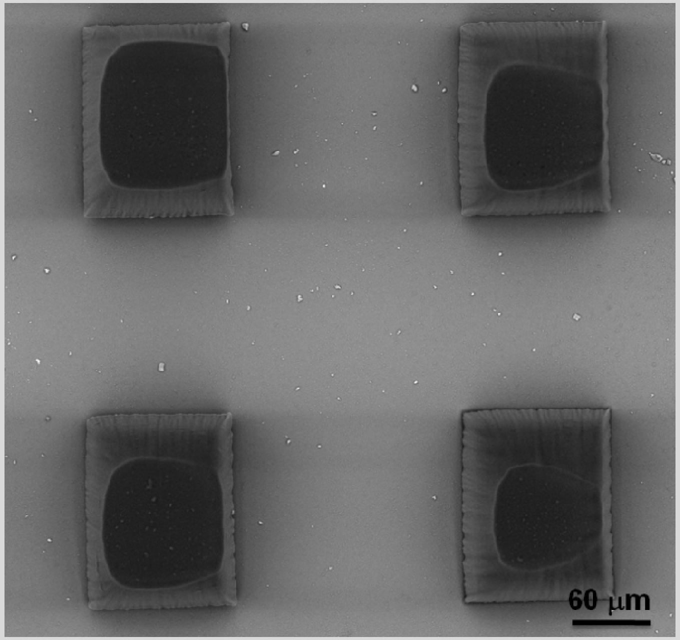
after writing



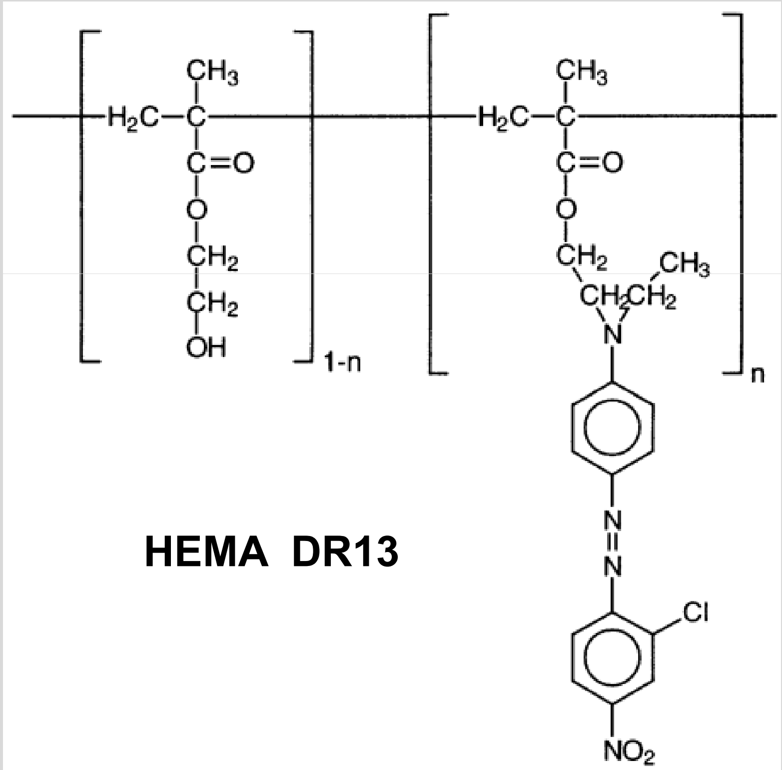
optically induced
birefringence

Micro-optical storage

Resin composition: **acrylate resin** + **HEMA DR13**

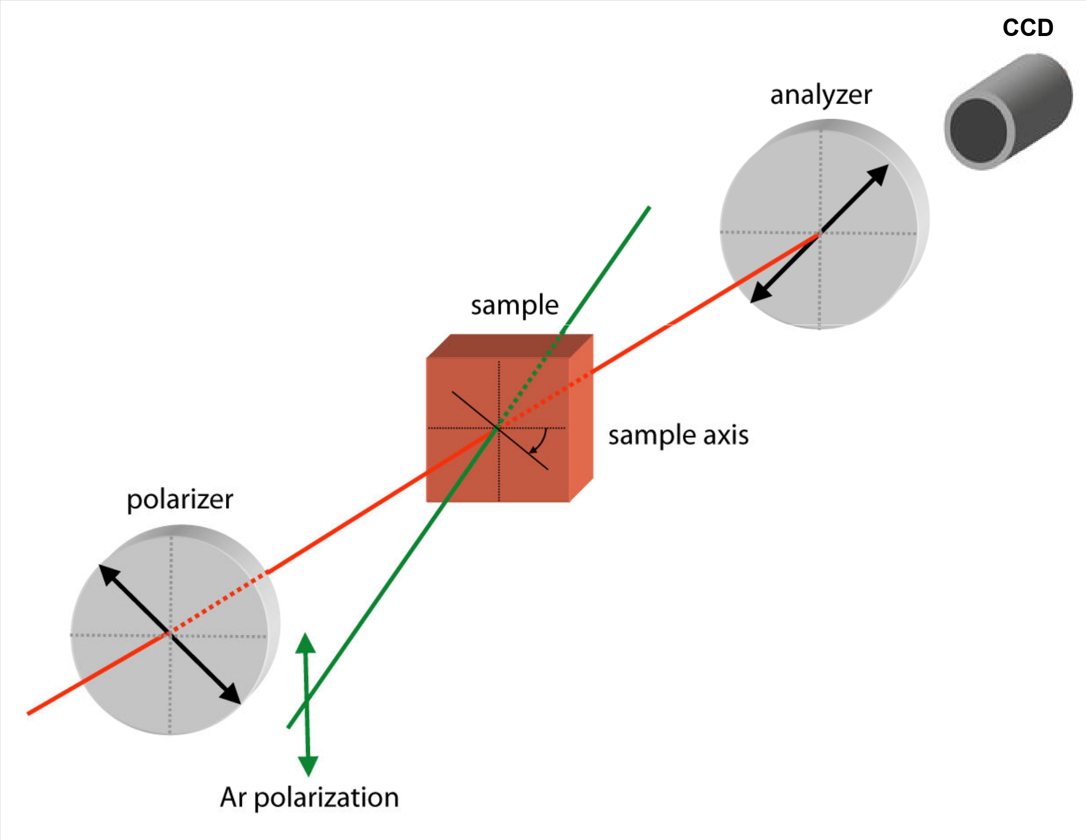


microstructure fabricated by two-photon polymerization containing HEMA DR13



Micro-optical storage

setup to measure the optically induced birefringence



WRITING

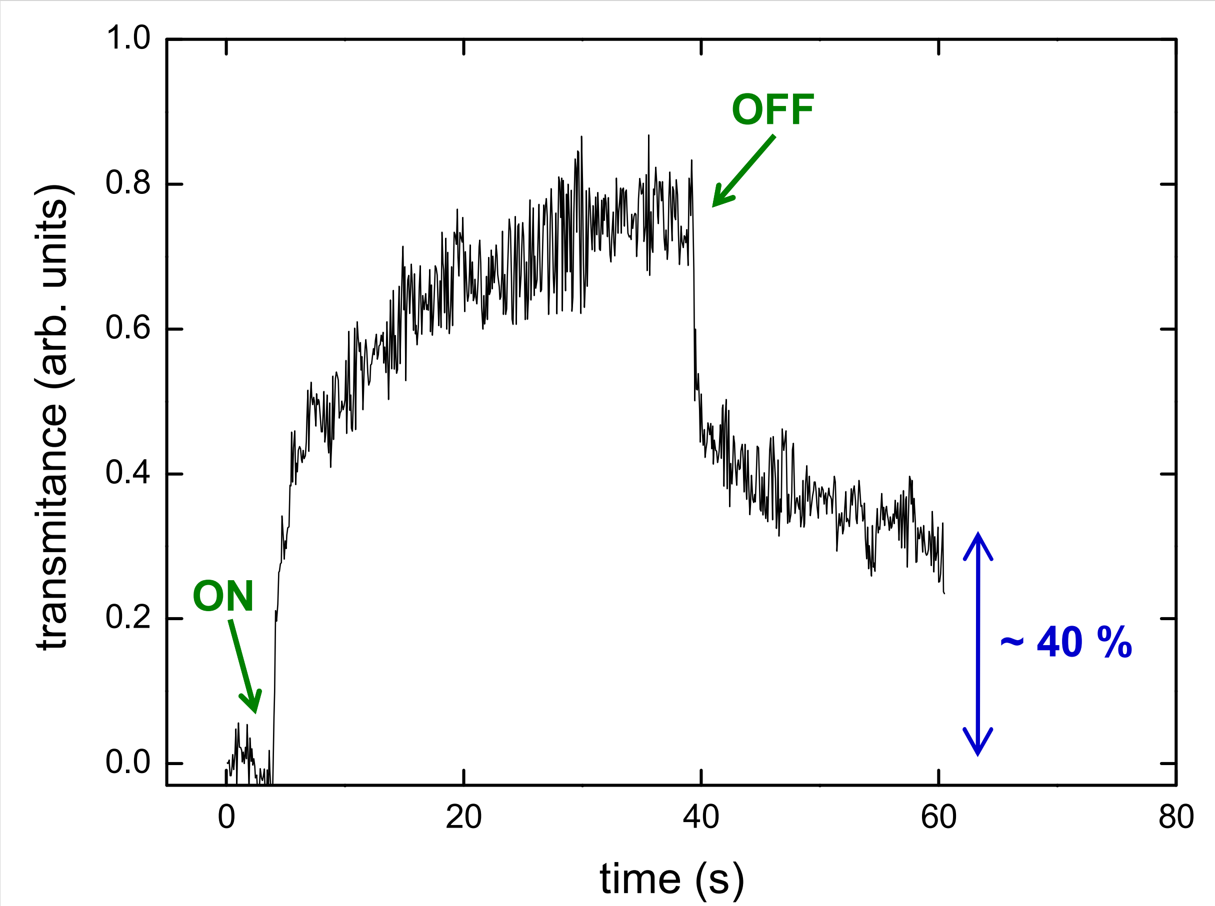
Pump beam:
Argon ion at 514 nm

READING

Probe beam:
HeNe at 632.8 nm

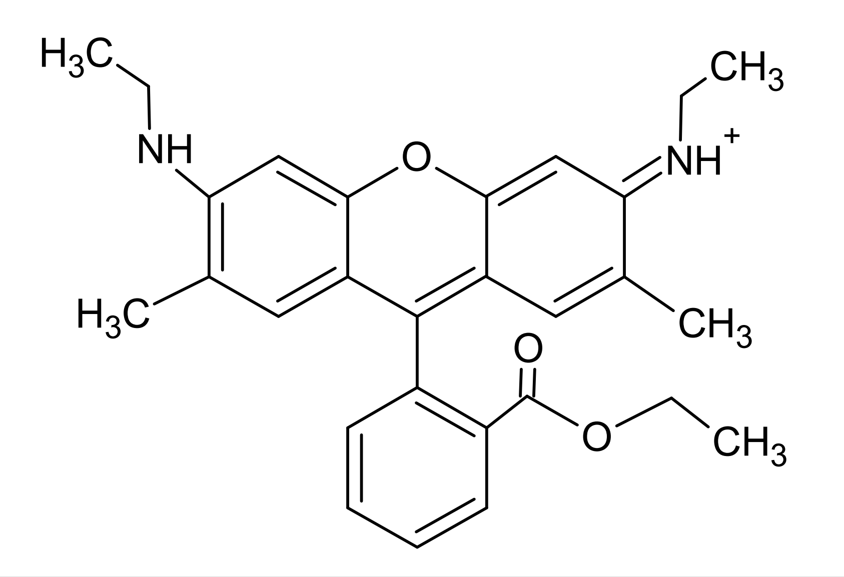
Micro-optical storage

Result demonstrating the induction of birefringence in the microstructure



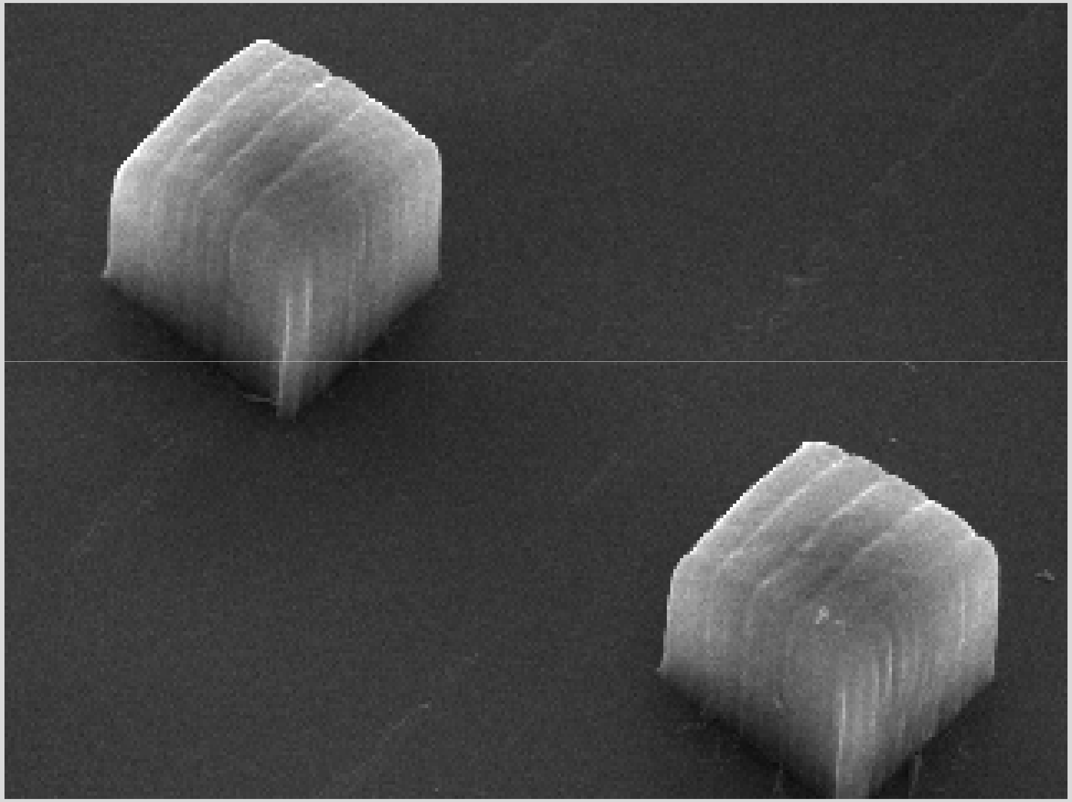
Microstructures containing Rhodamine

Rhodamine 6G

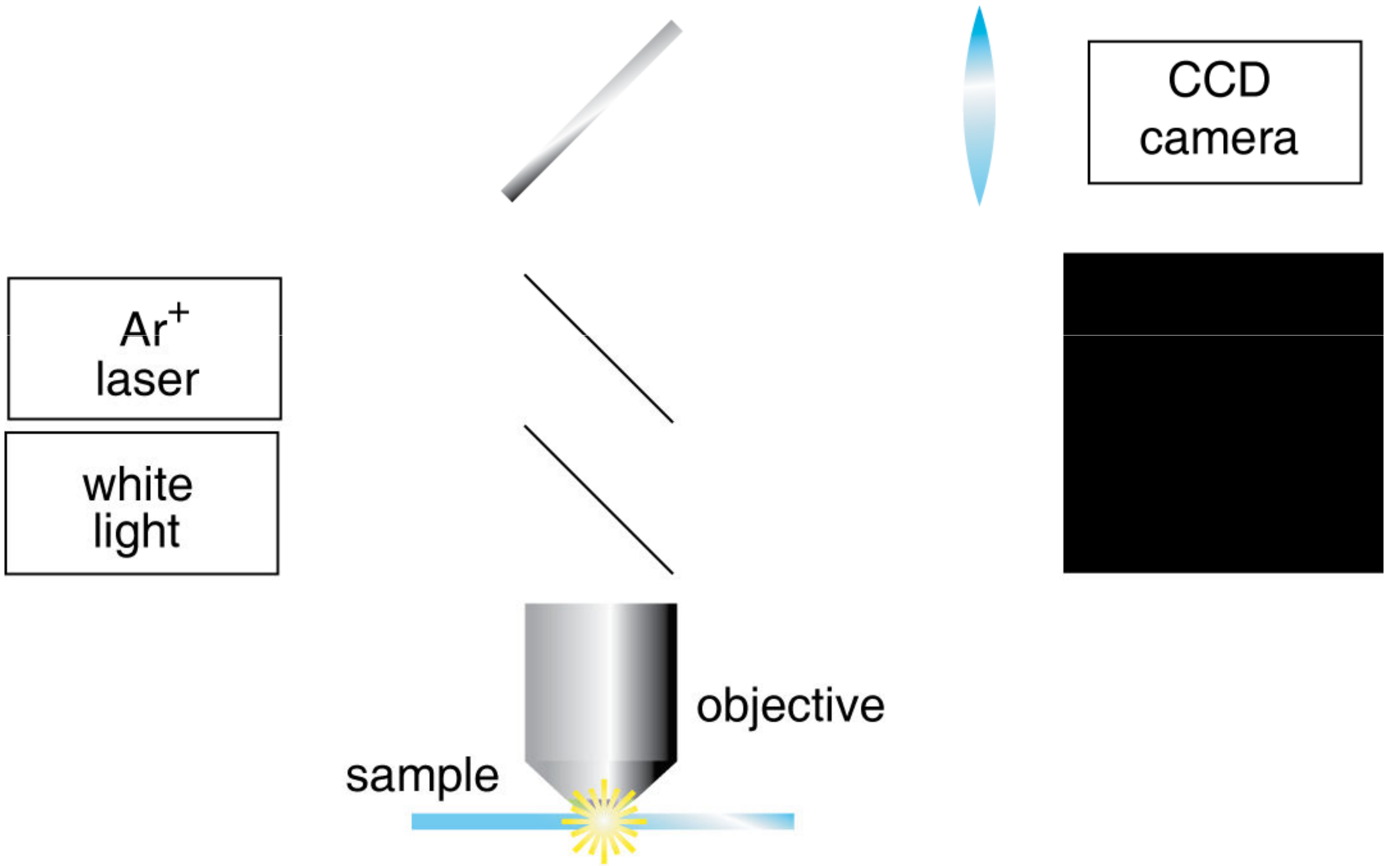


- *High luminescence*
- *Used as dye laser gain medium*

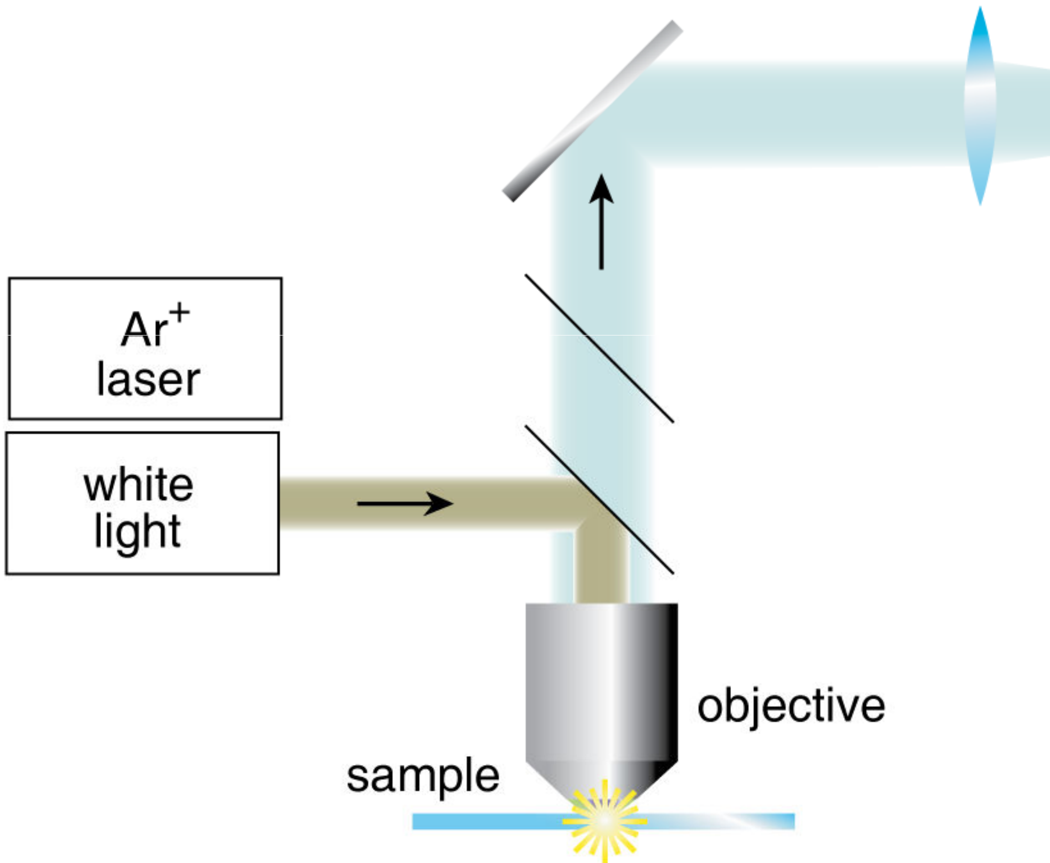
Microstructure containing Rhodamine



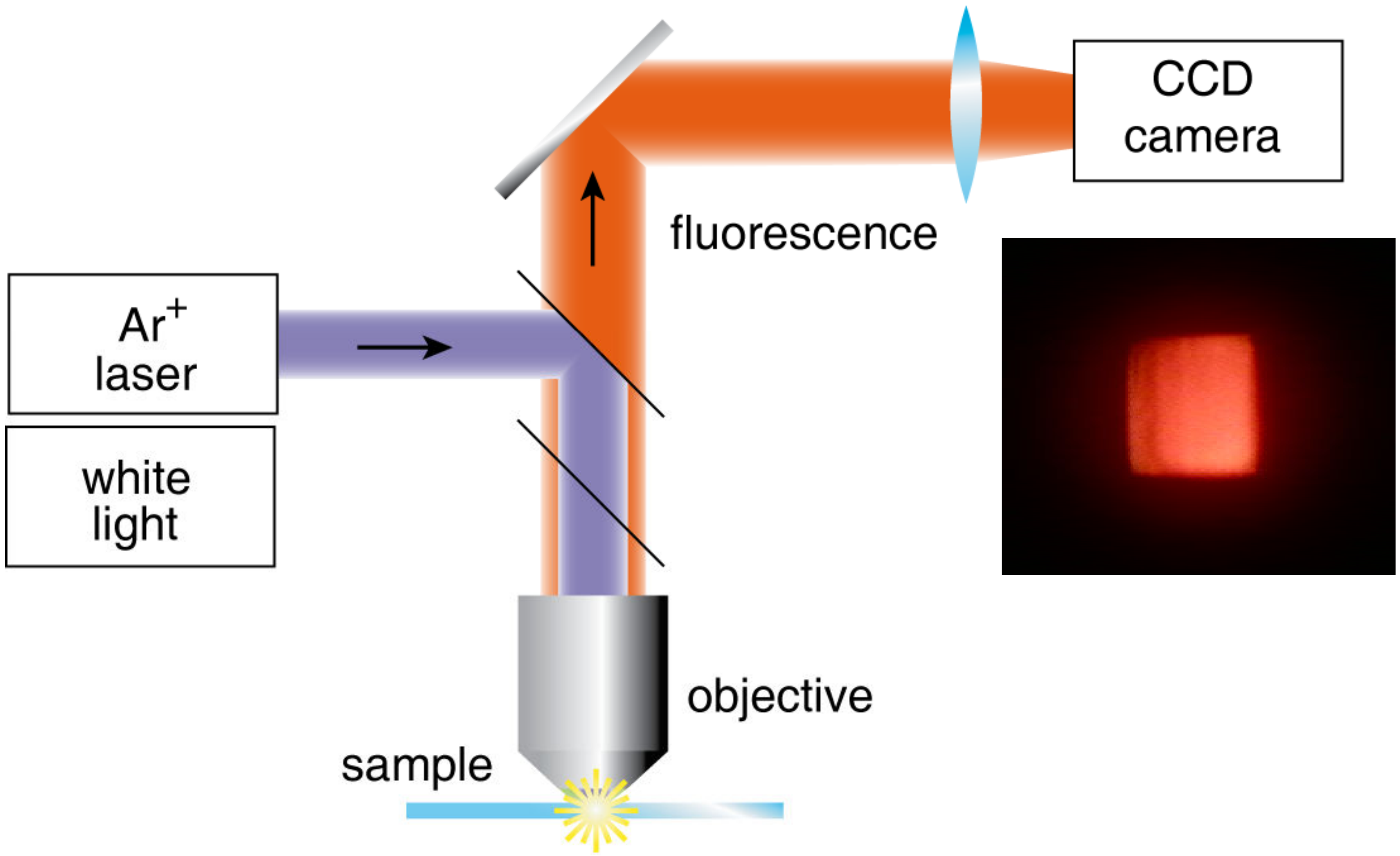
Microstructure containing Rhodamine



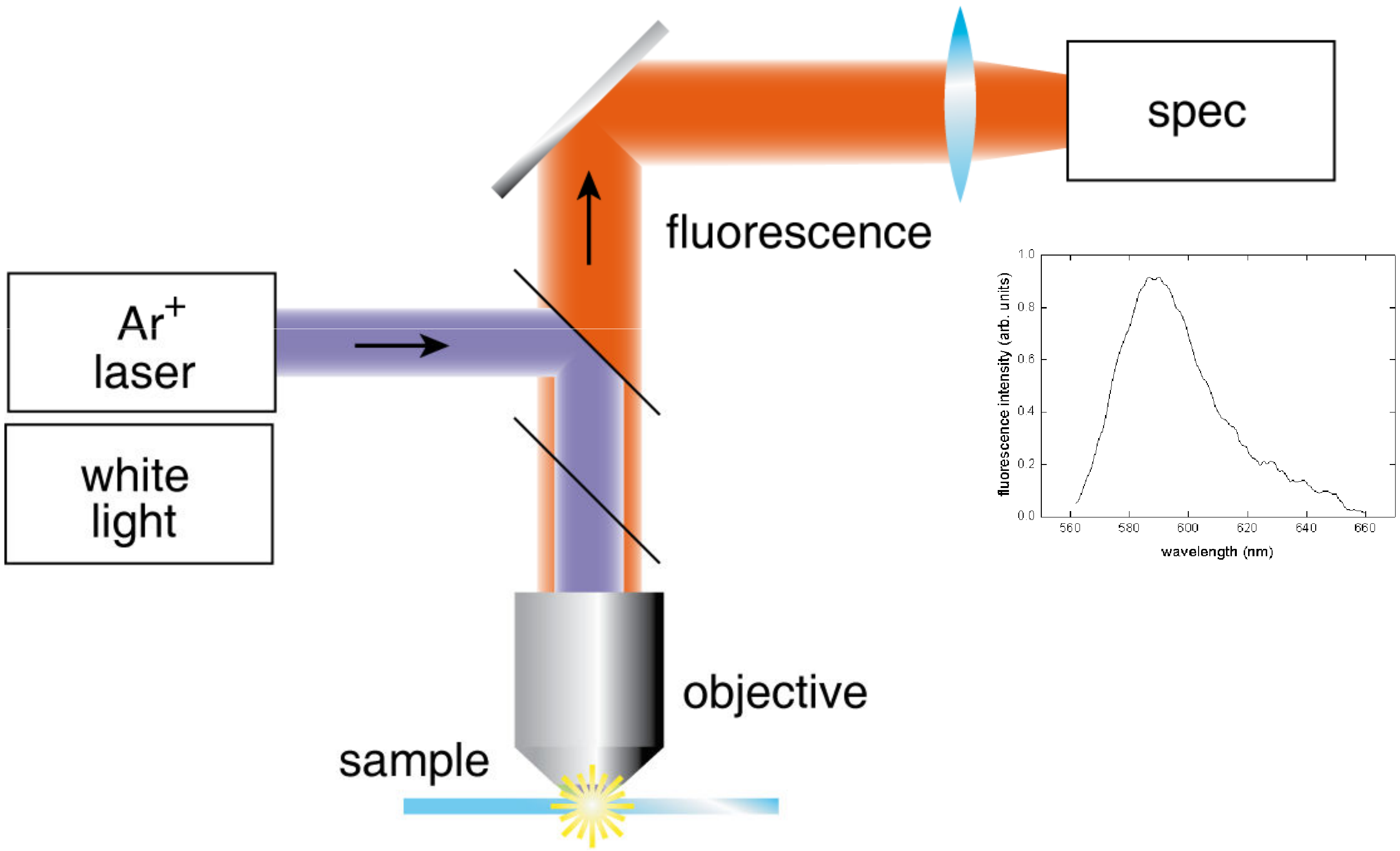
Microstructure containing Rhodamine



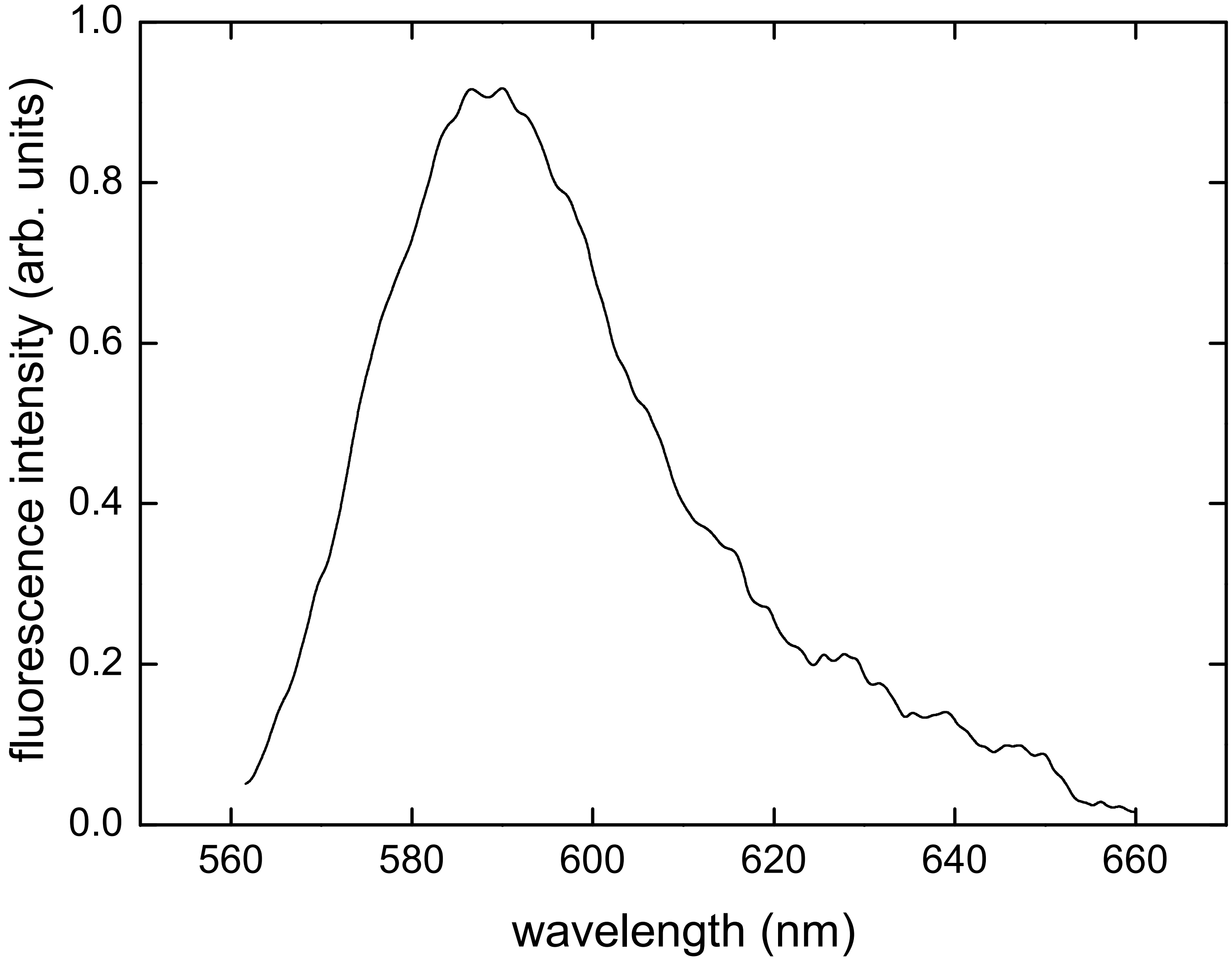
Microstructure containing Rhodamine



Microstructure containing Rhodamine

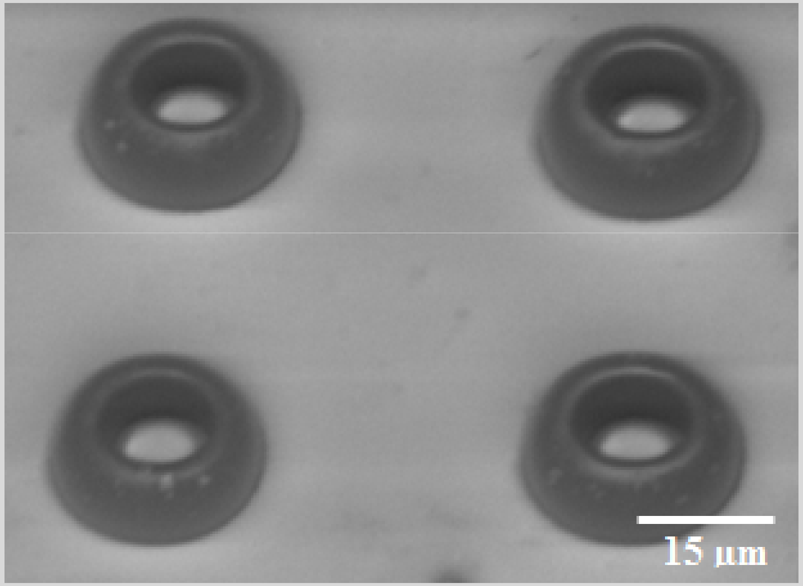


Microstructure containing Rhodamine

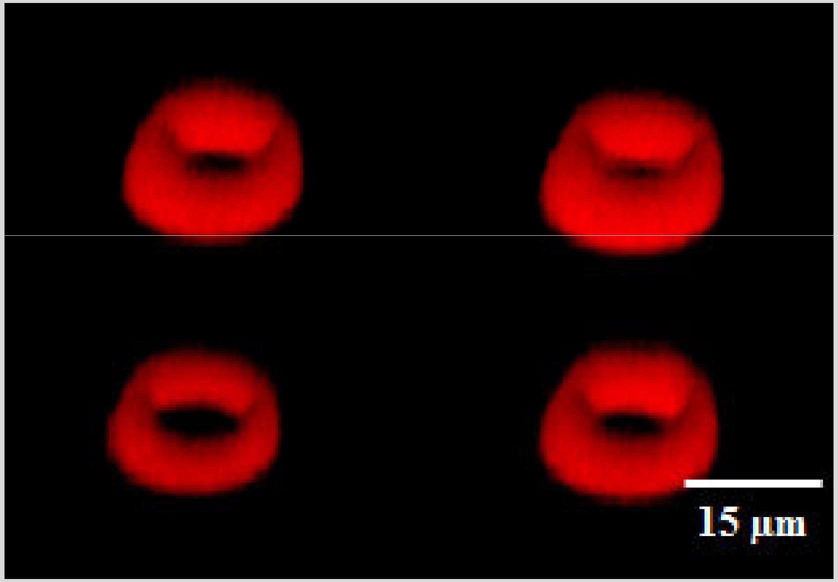


Microstructure containing Rhodamine

fabrication of array of doped microstructures

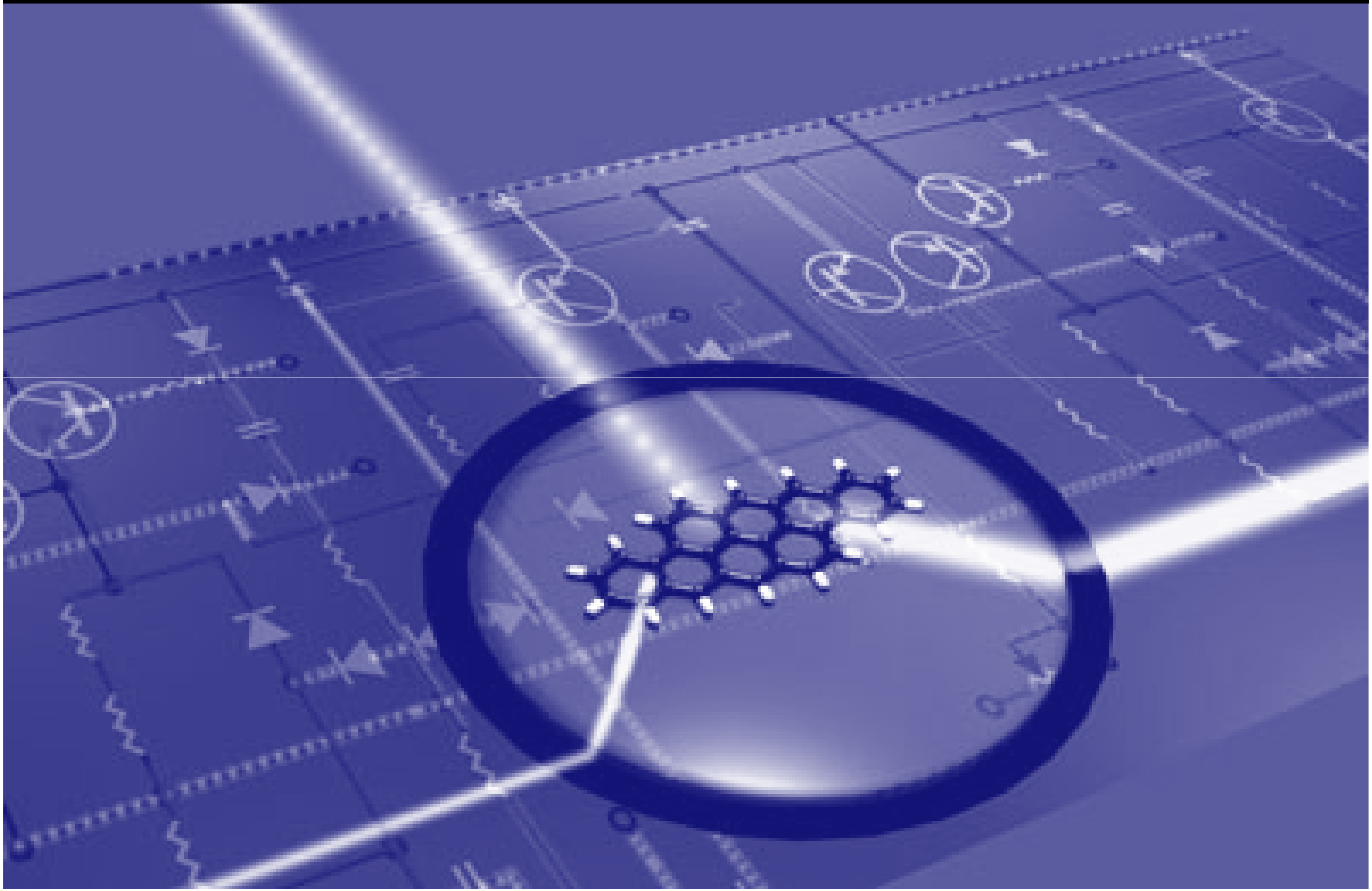


SEM

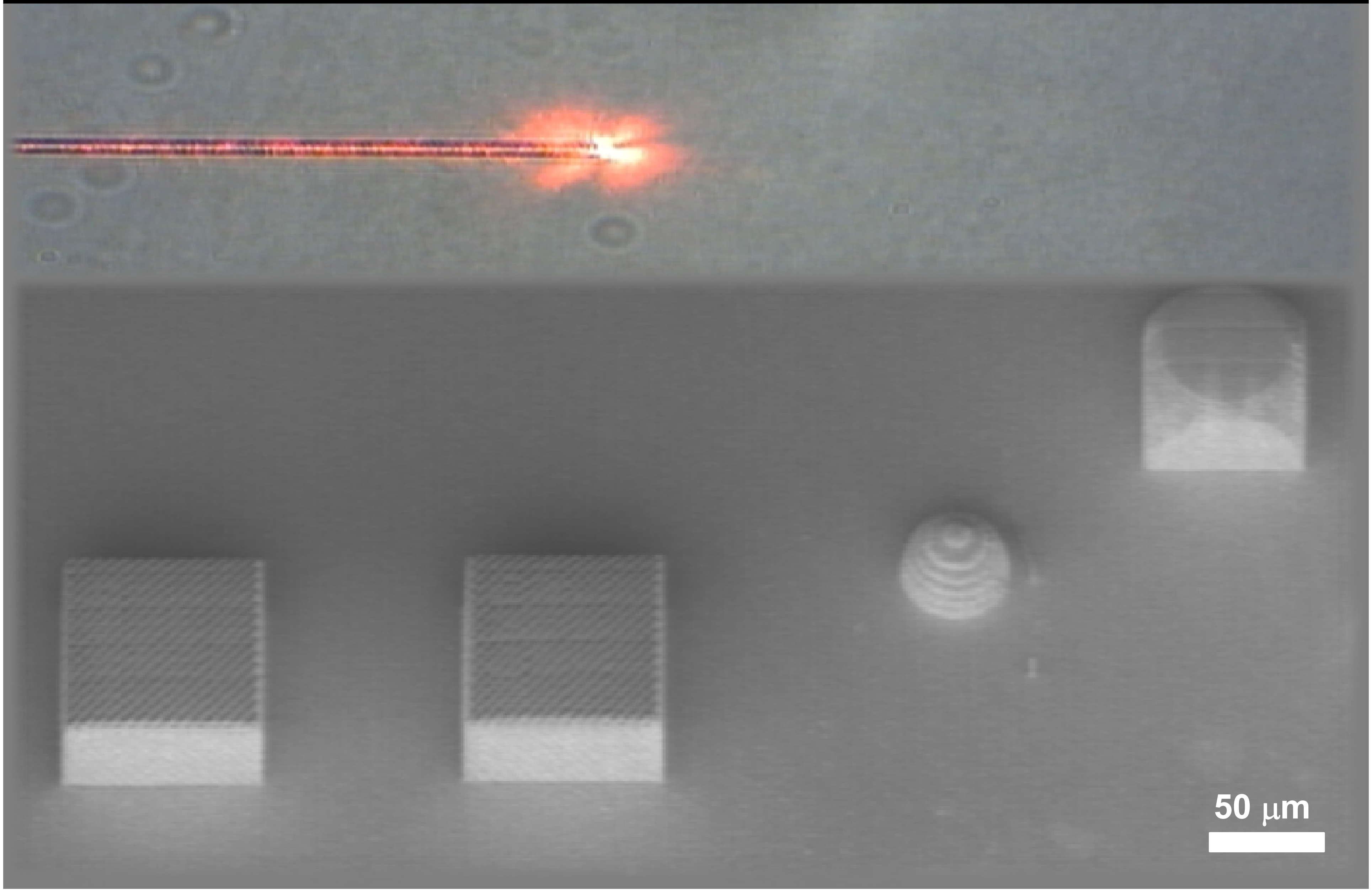


Confocal microscopy

Optical circuit



Optical circuit

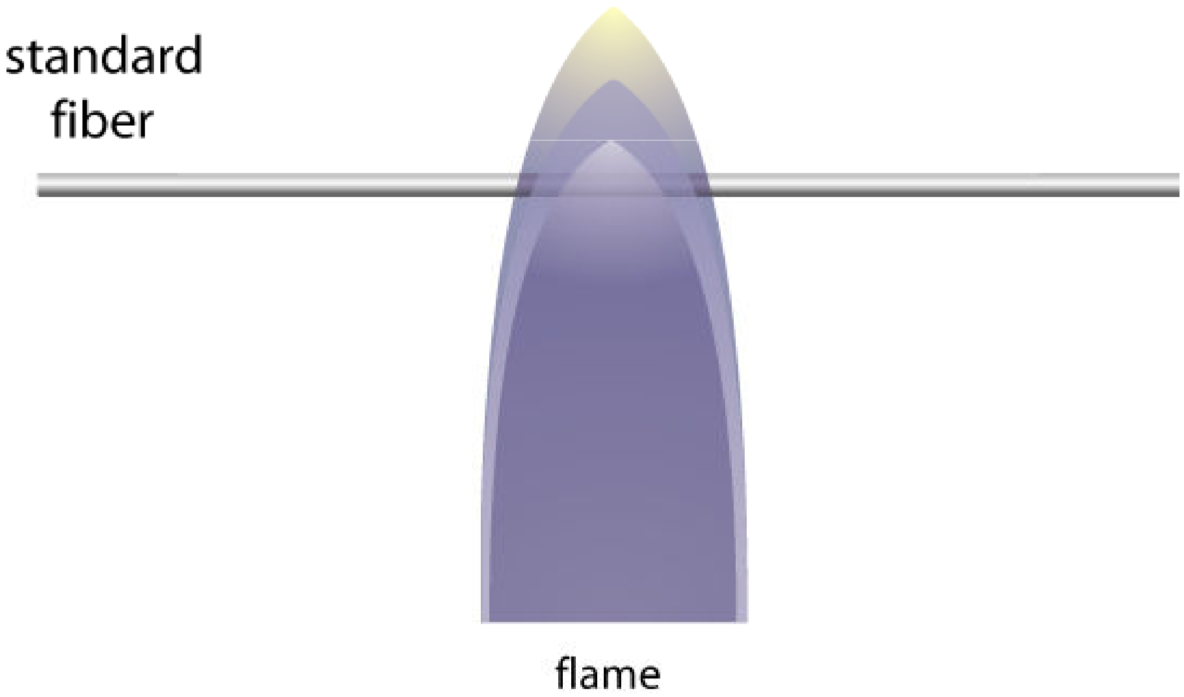


Silica nanowires

nanowires fabrication process

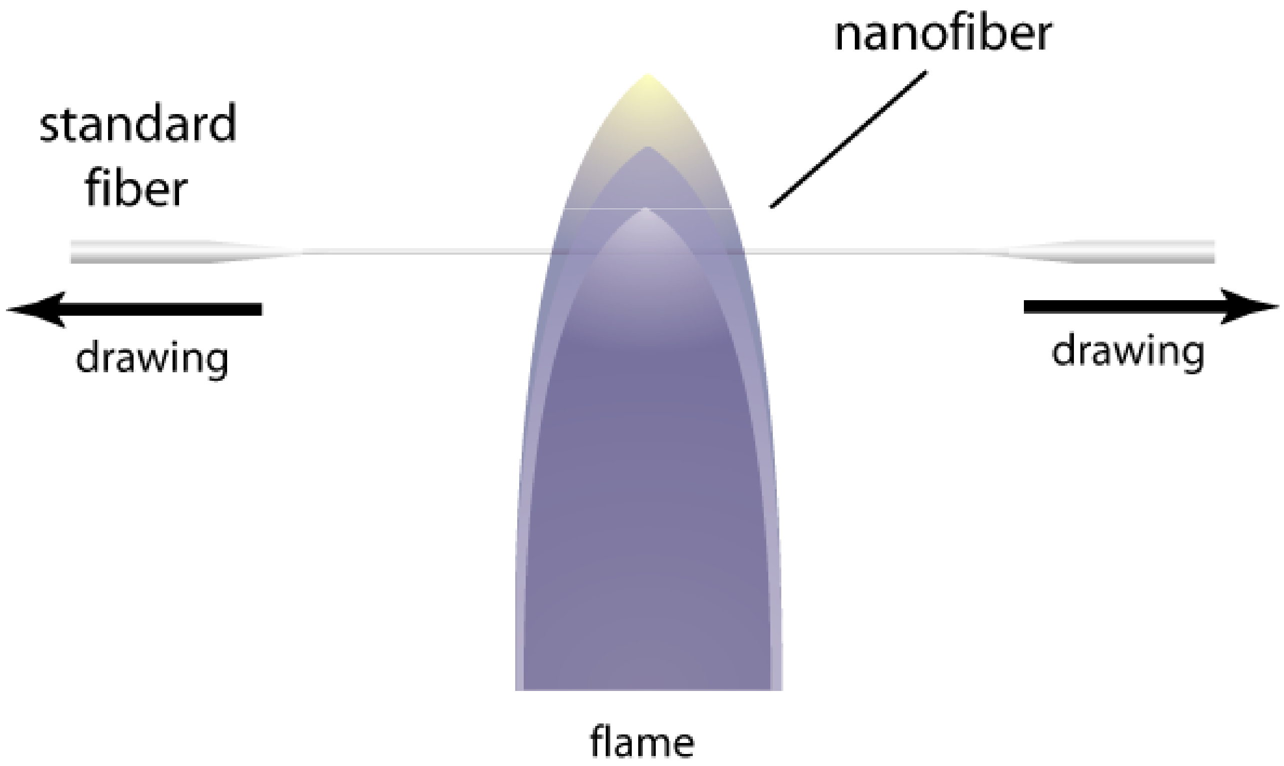
Silica nanowires

nanowires fabrication process



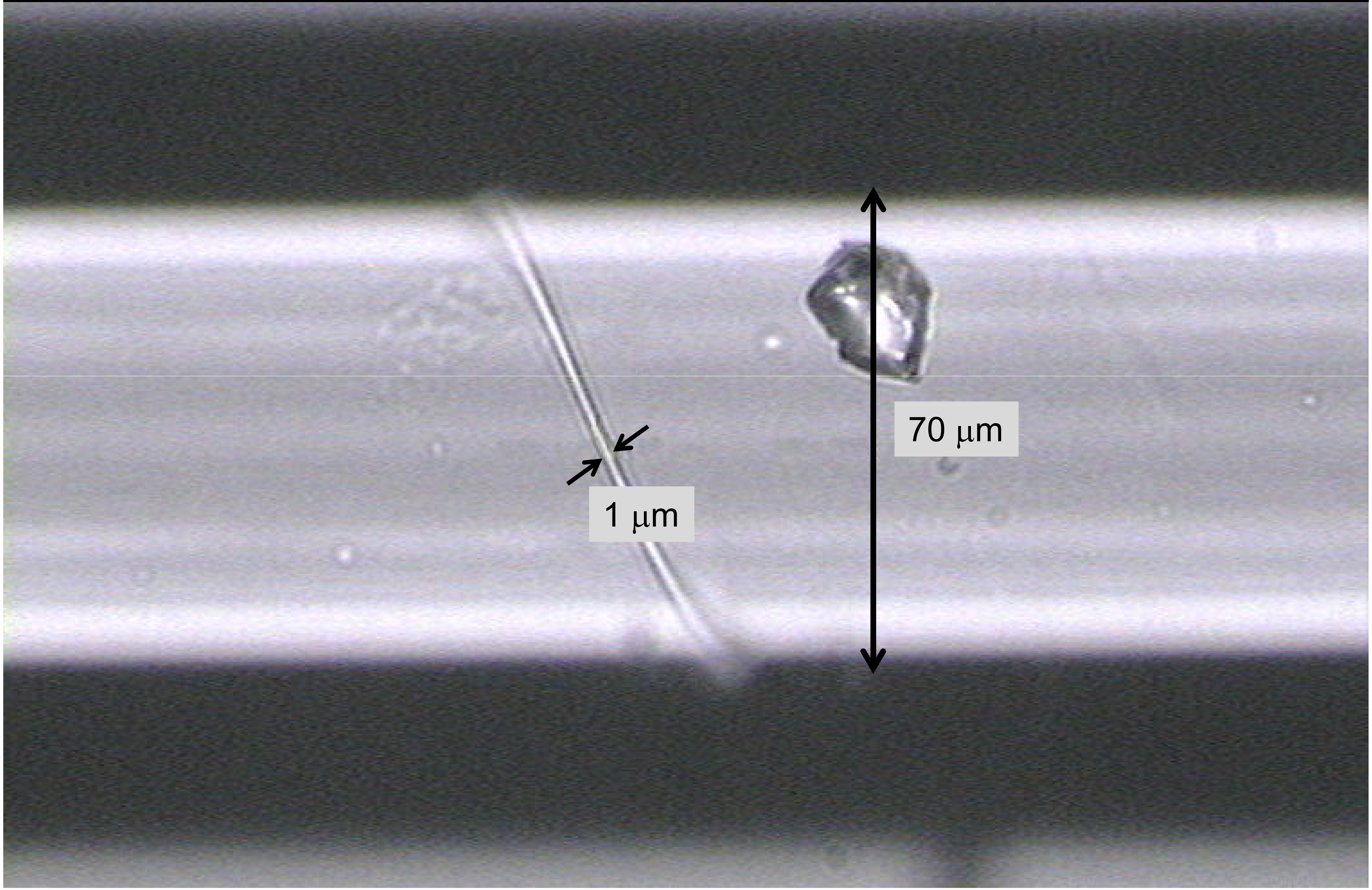
Silica nanowires

nanowires fabrication process

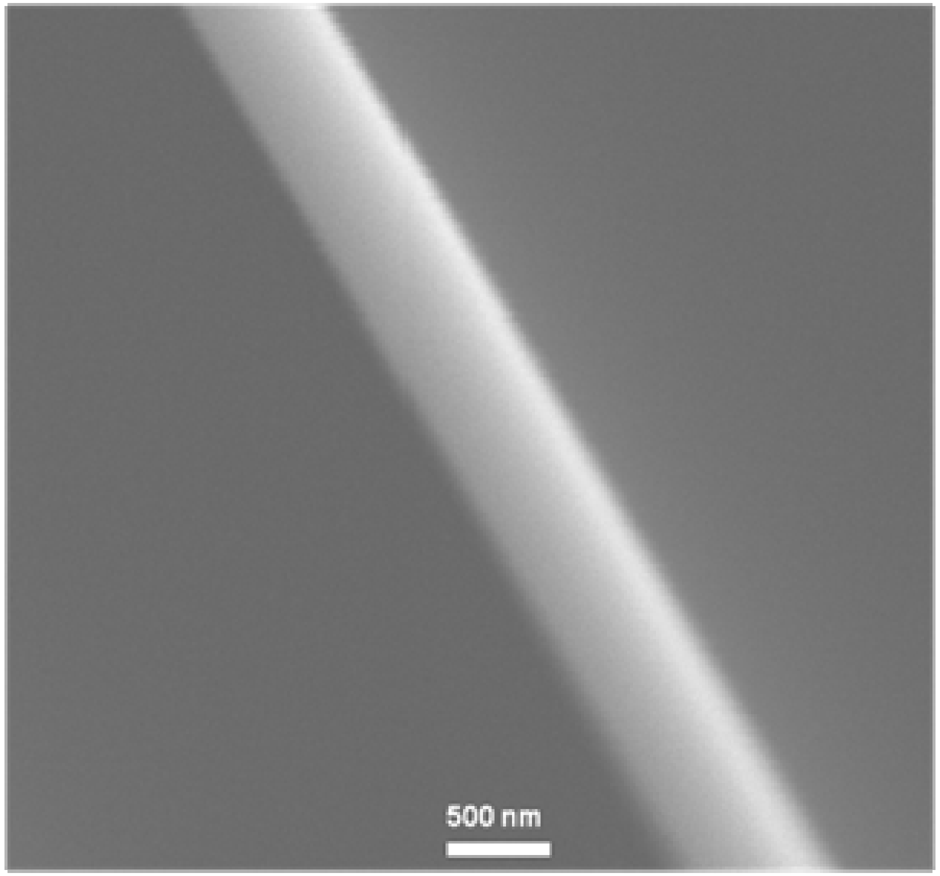


Silica nanowires

Silica nanowires



Silica nanowires

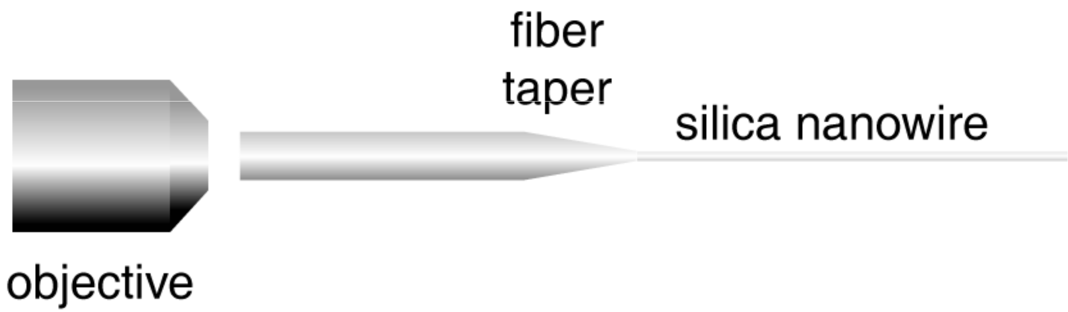


Silica nanowires

coupling light into nanowires

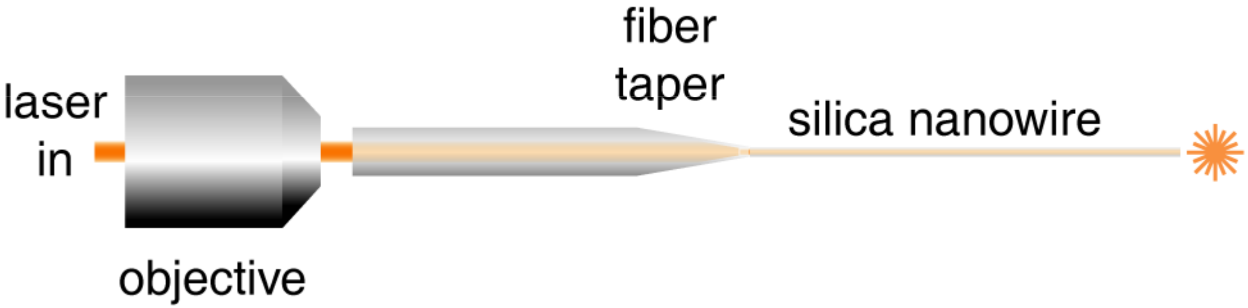
Silica nanowires

coupling light into nanowires



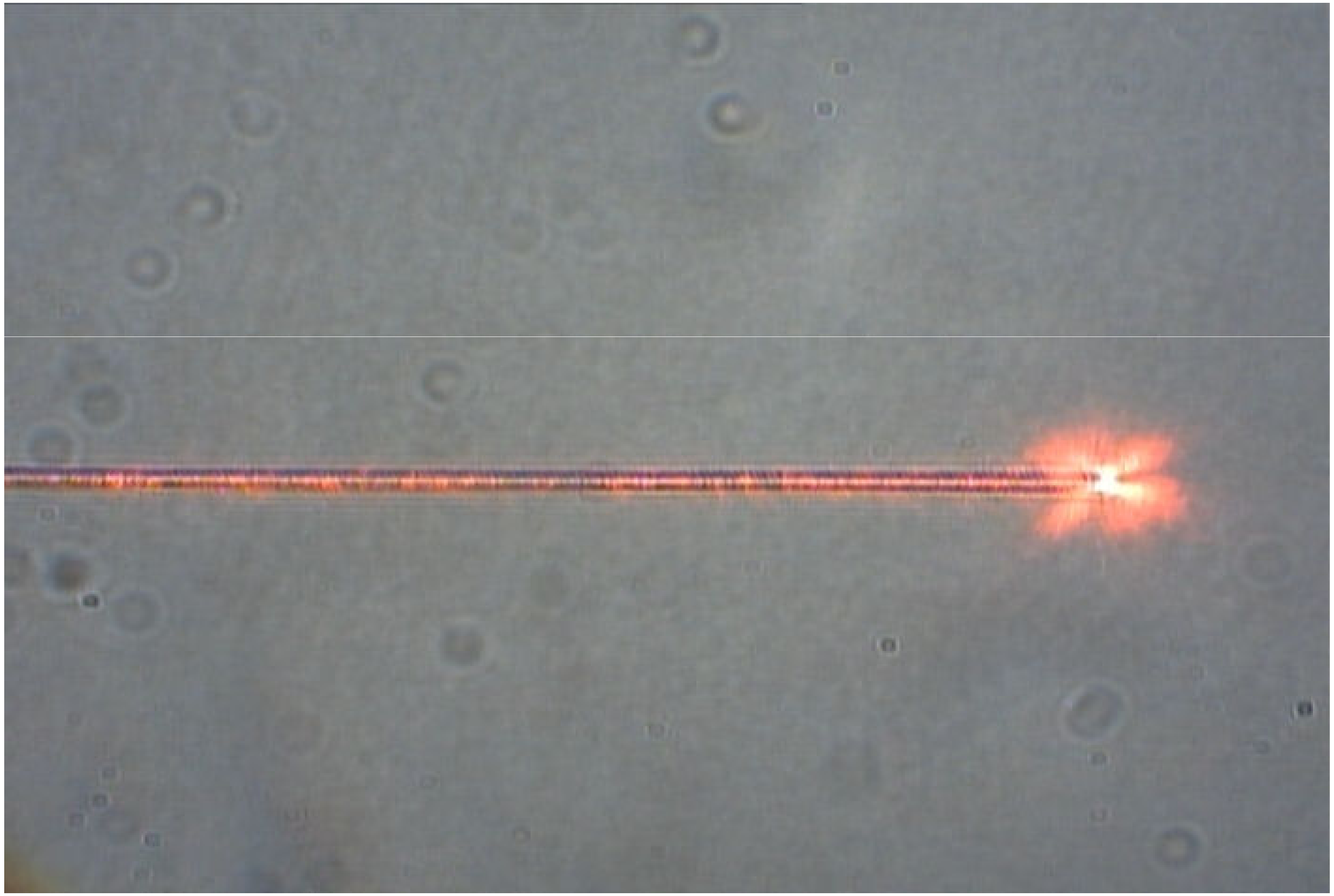
Silica nanowires

coupling light into nanowires

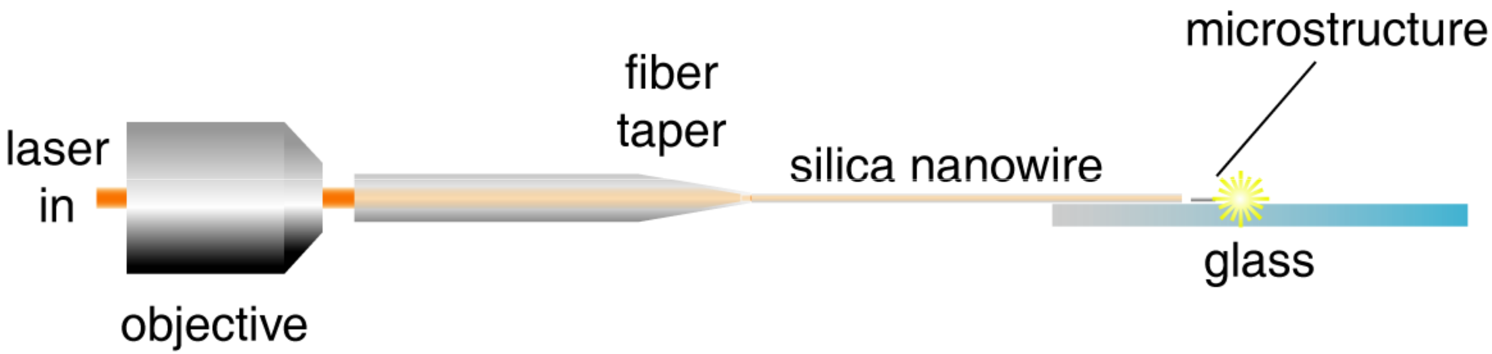


Silica nanowires

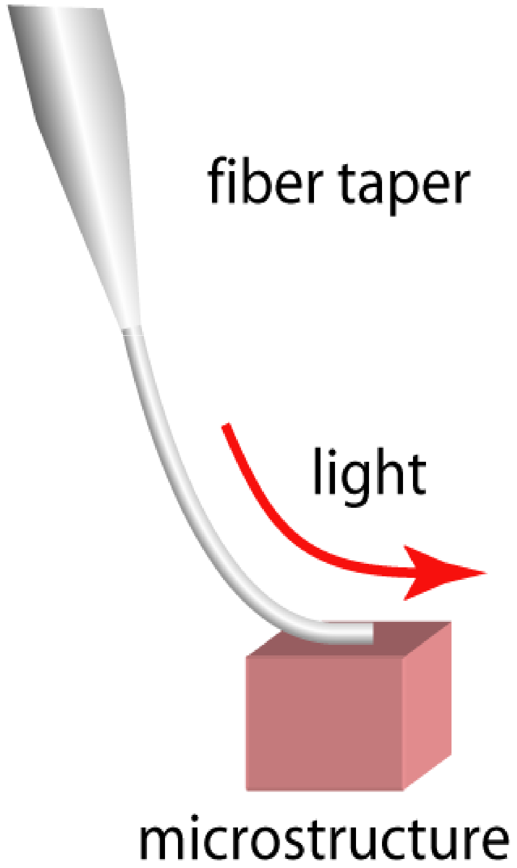
coupling light into nanowires



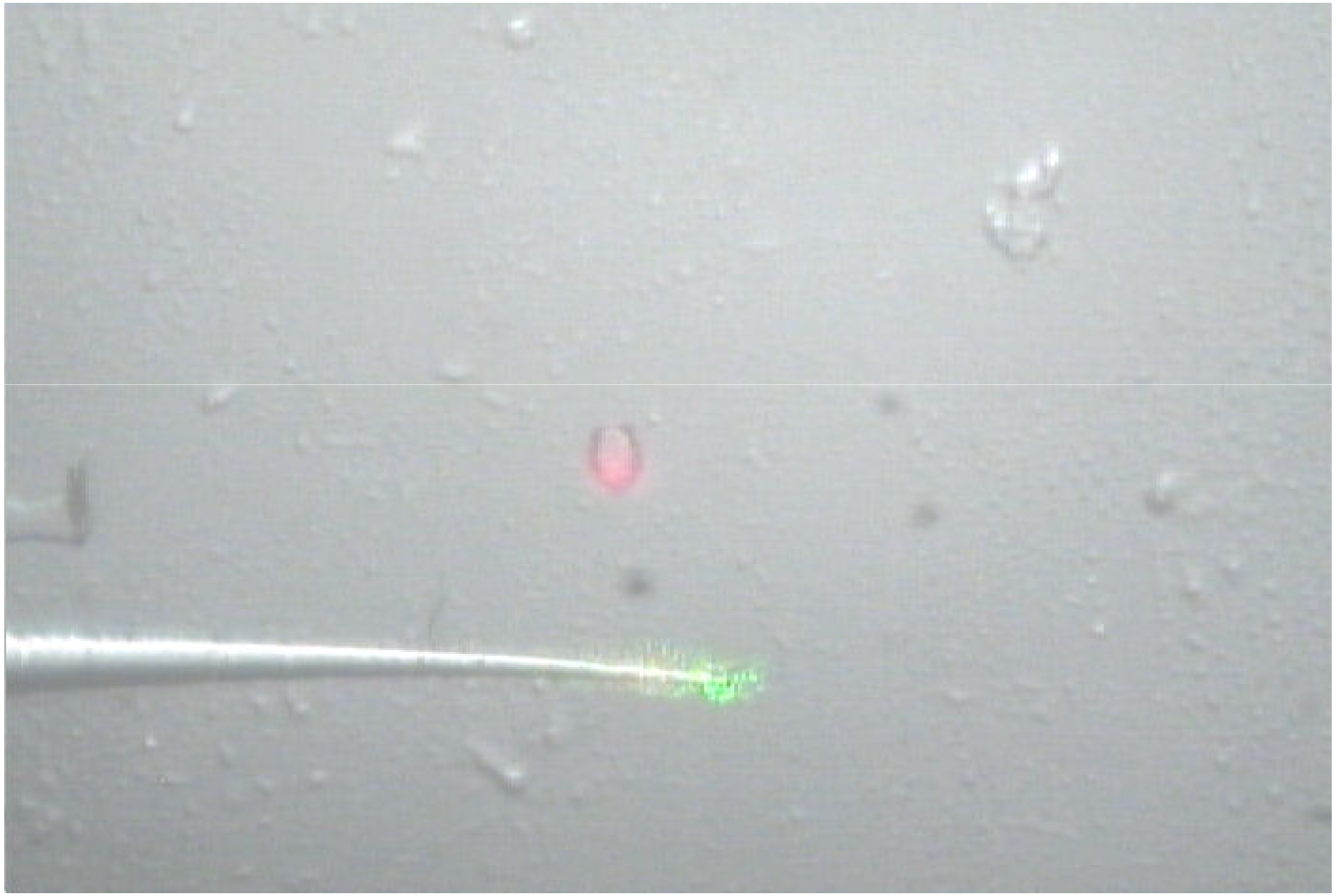
Coupling microstructures



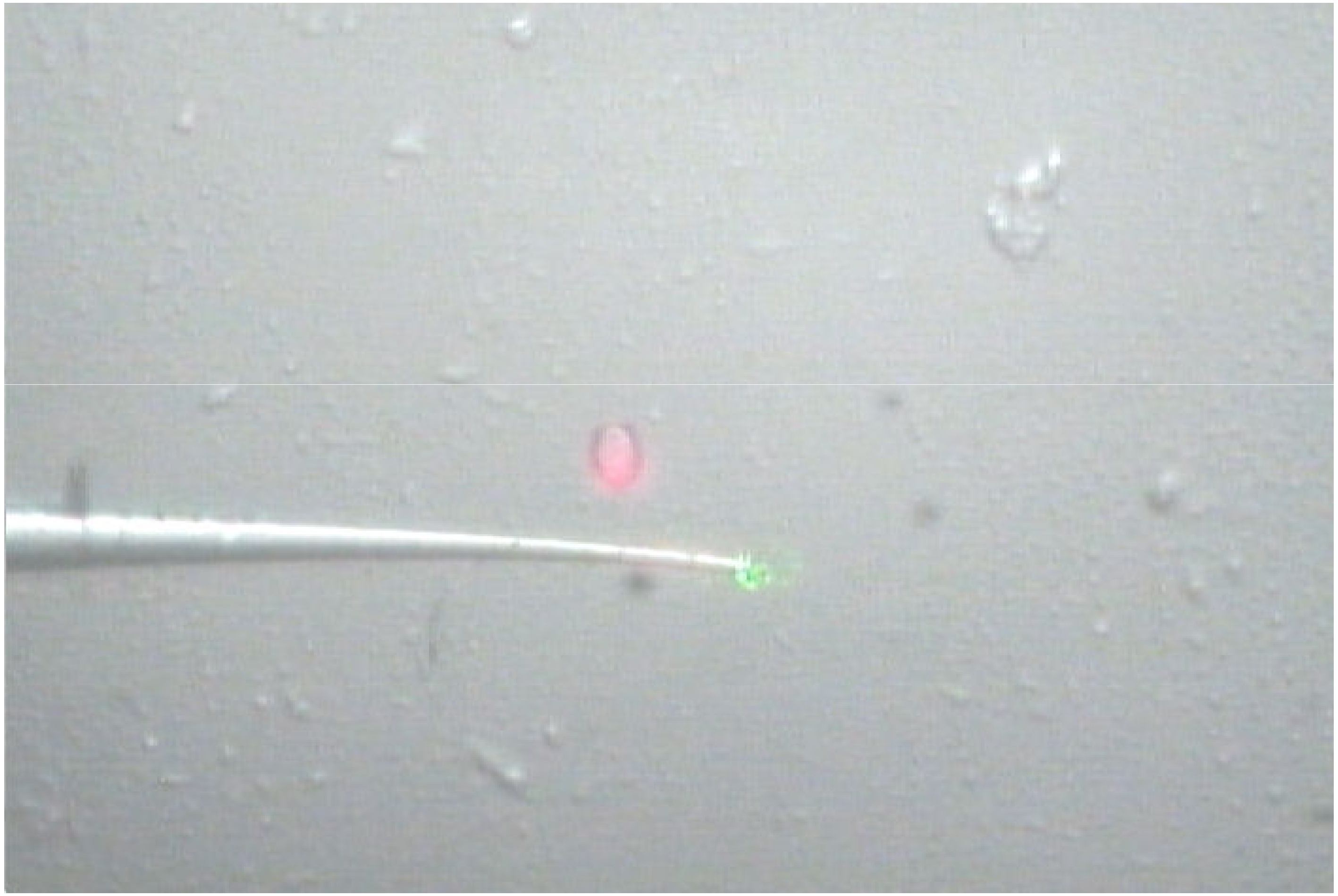
Coupling microstructures



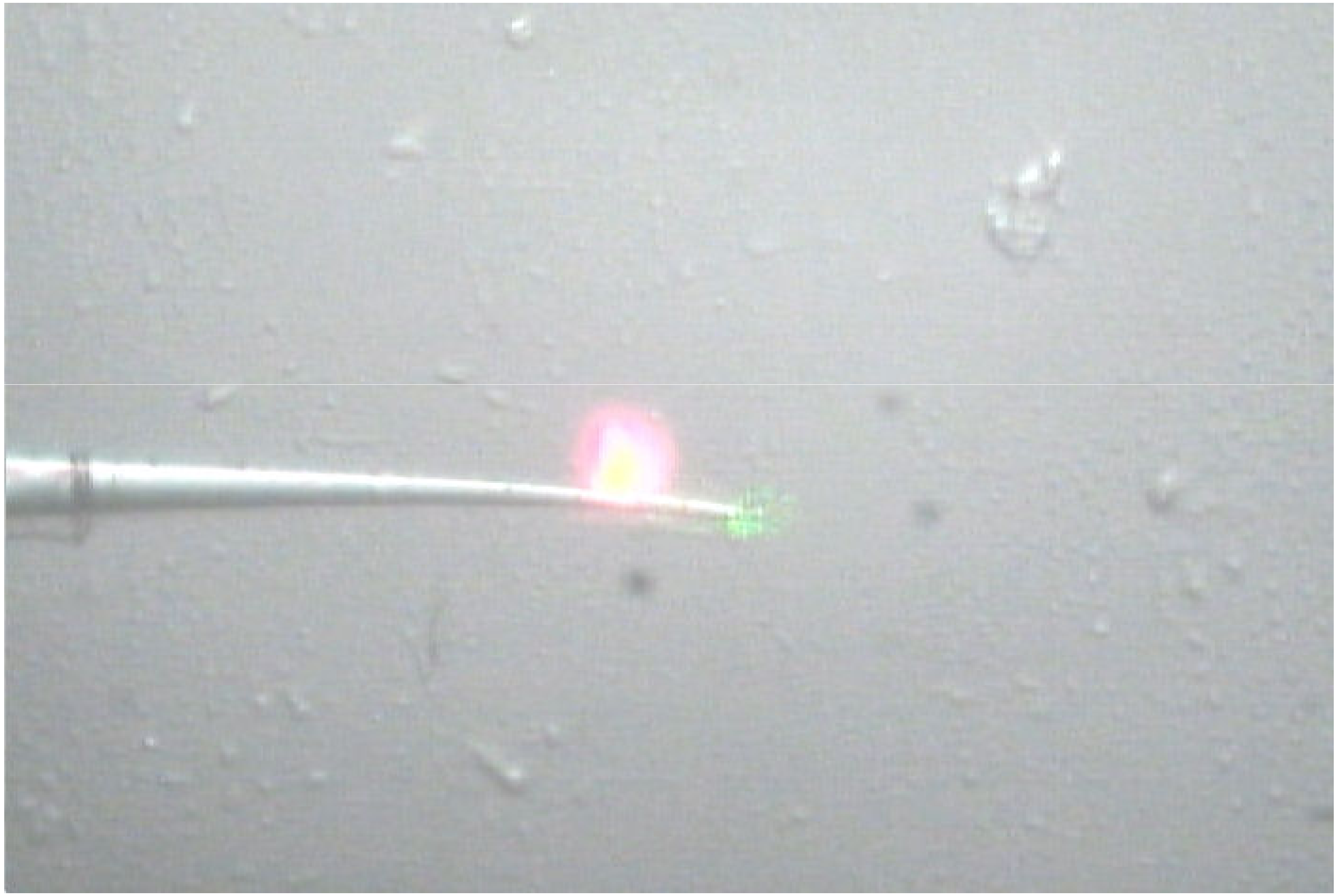
Coupling microstructures



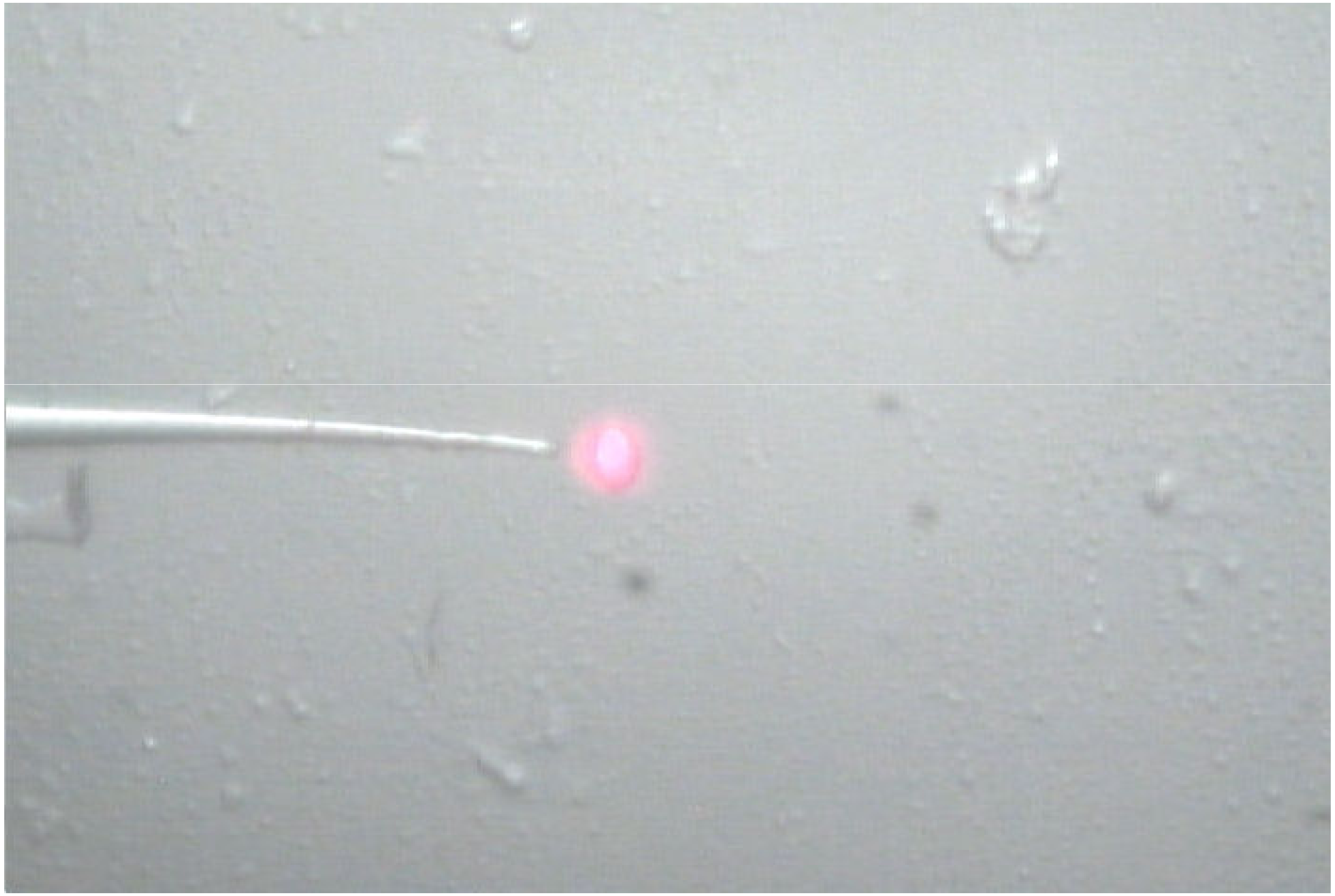
Coupling microstructures



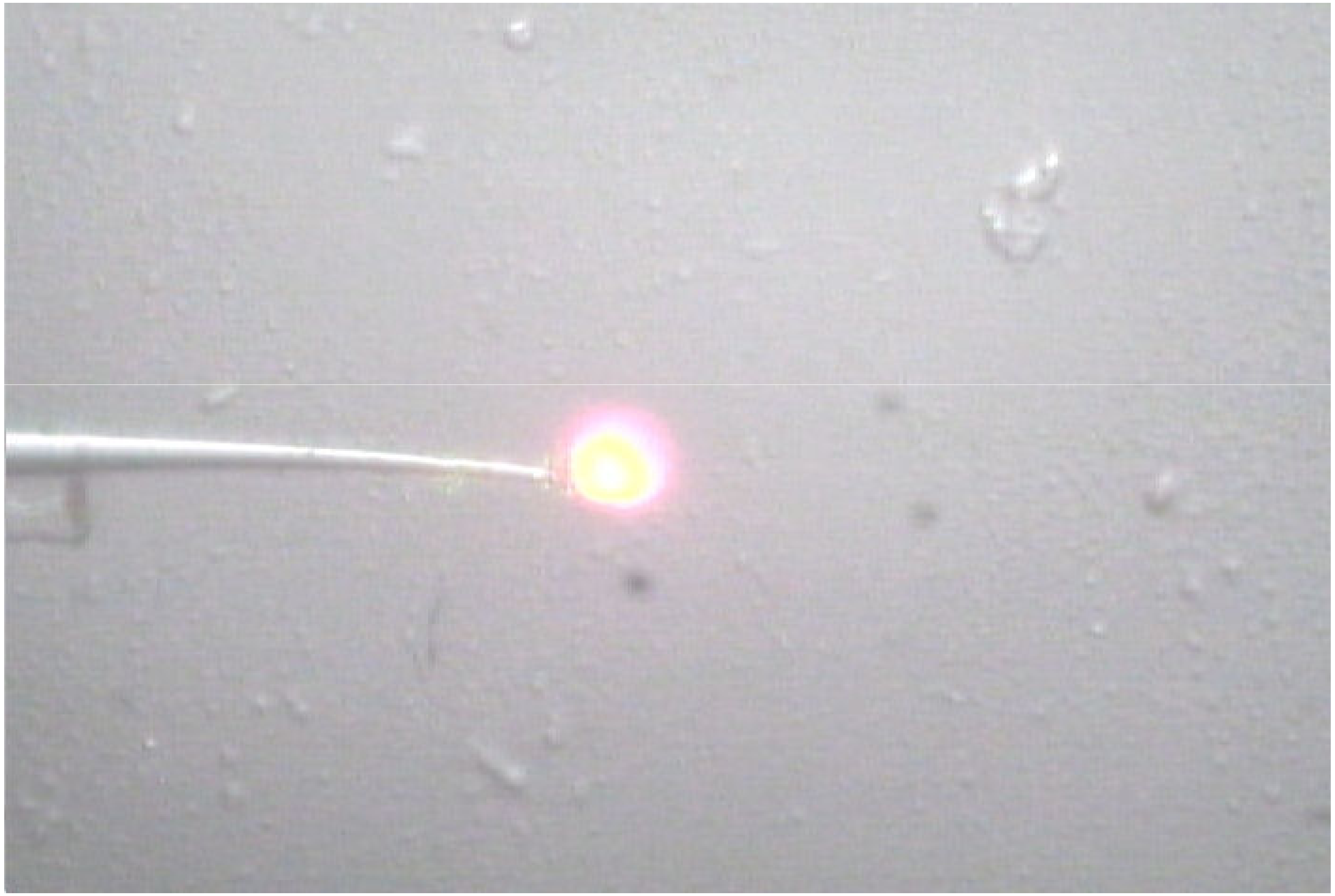
Coupling microstructures



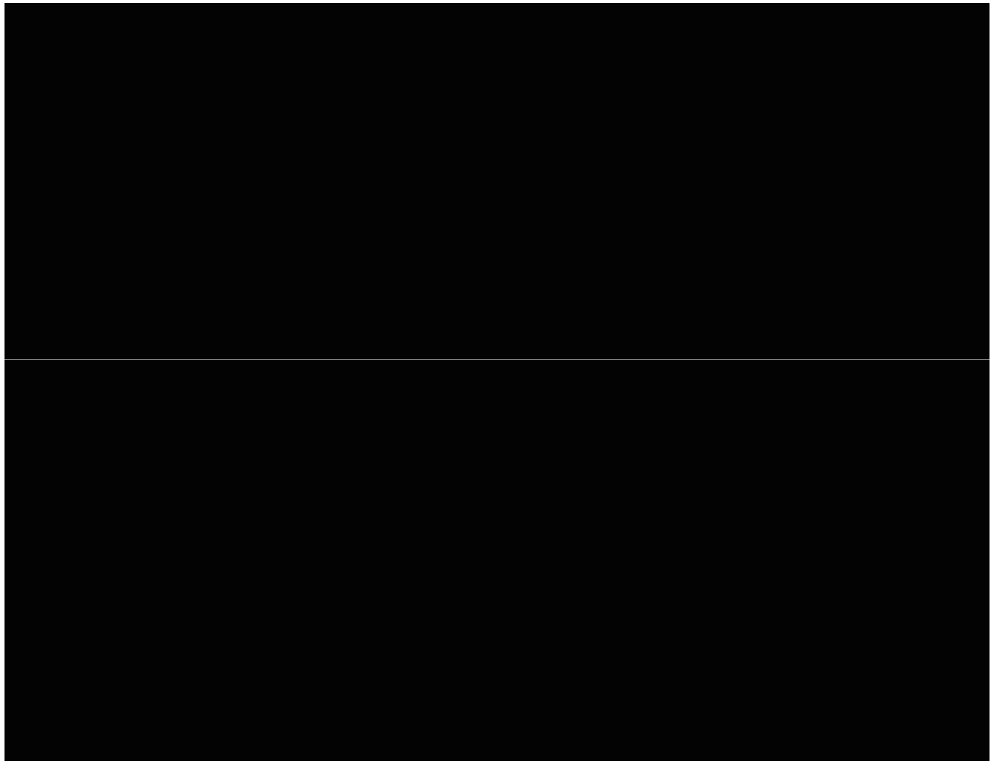
Coupling microstructures



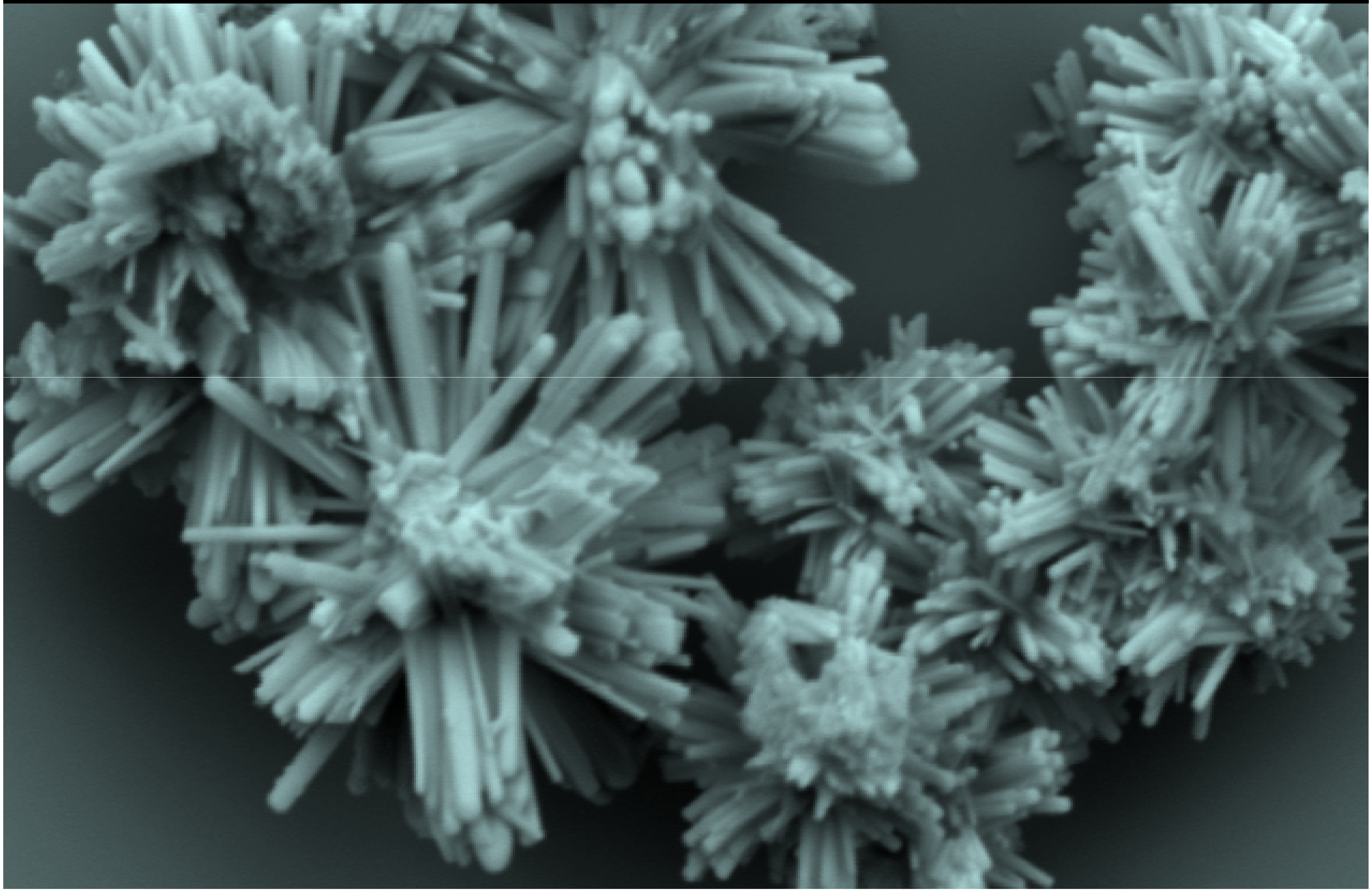
Coupling microstructures



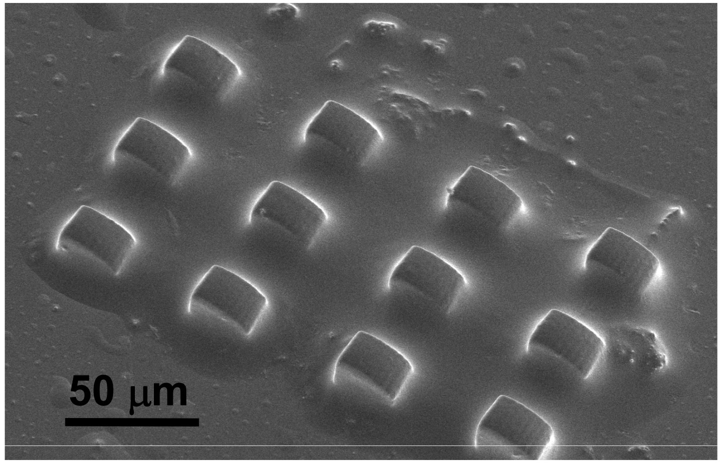
Silica nanowires

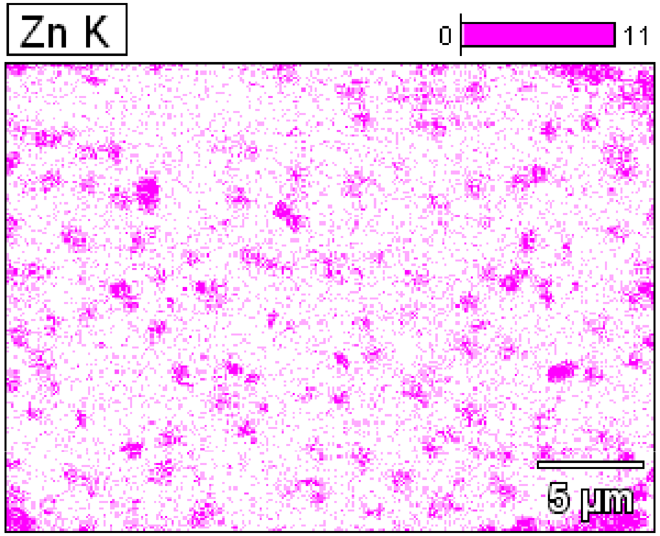


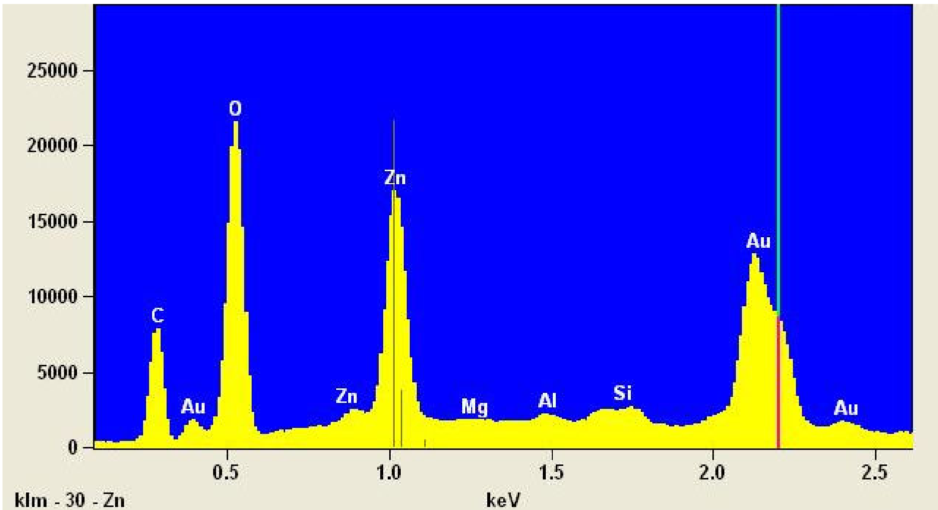
Microstructures with ZnO nanowires



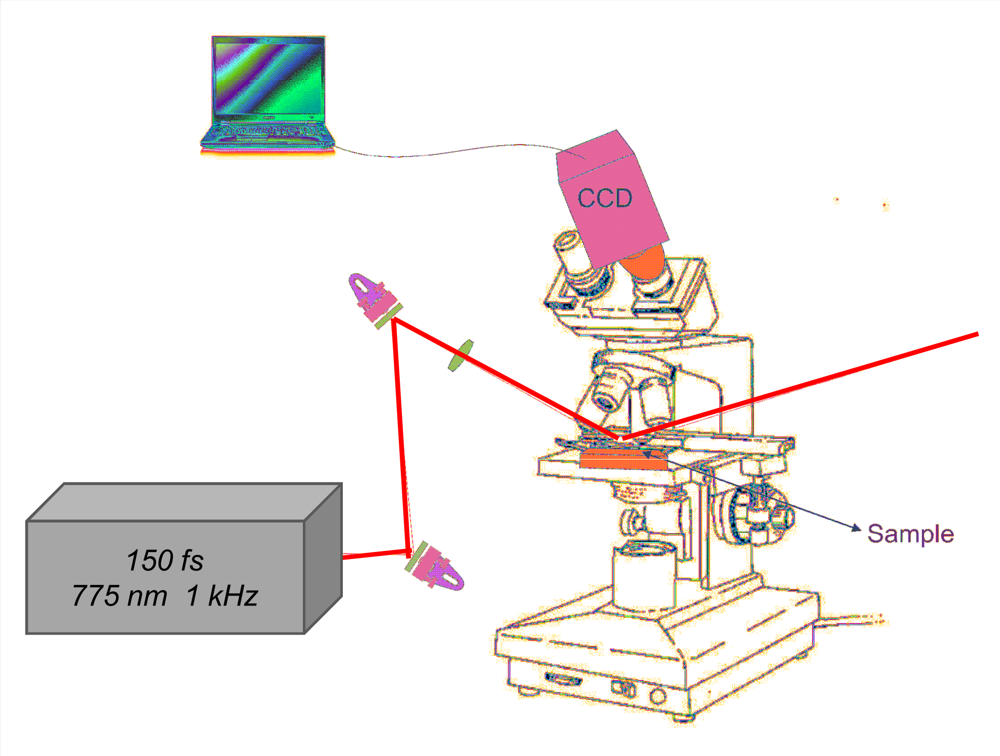
Microstructures with ZnO nanowires

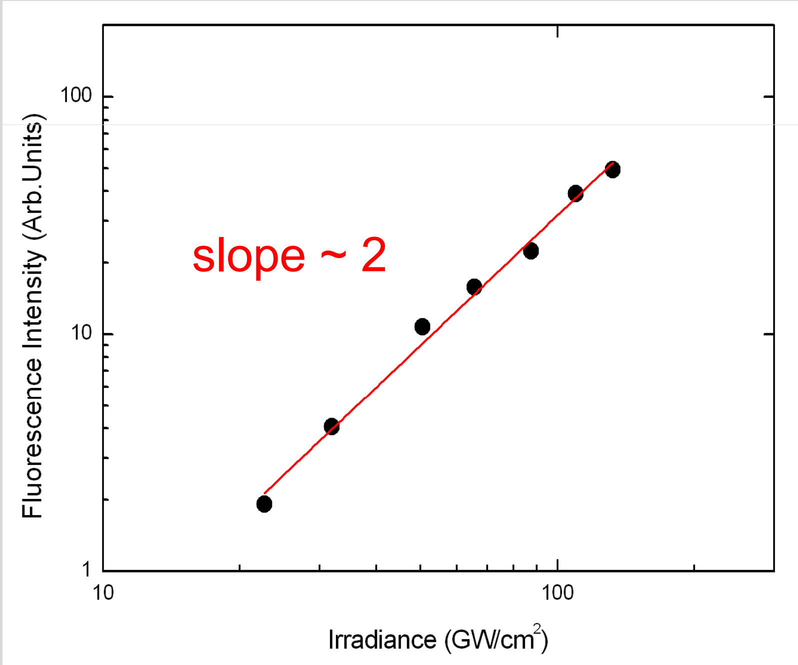




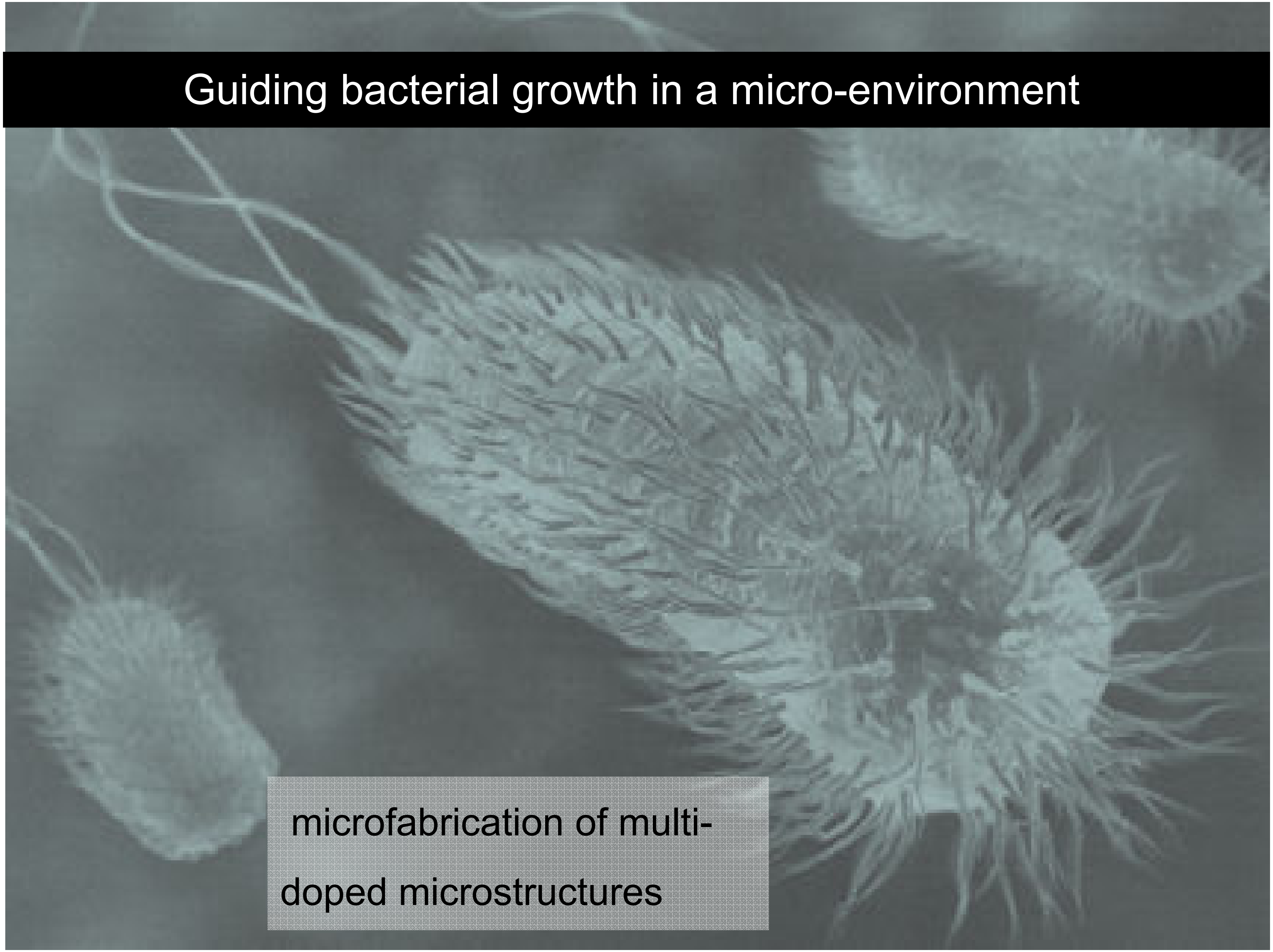


Microstructures with ZnO nanowires





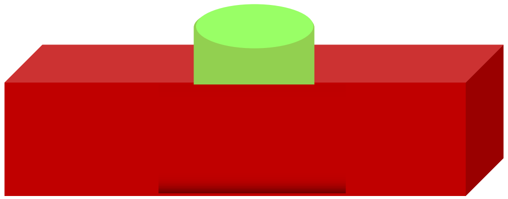
Guiding bacterial growth in a micro-environment



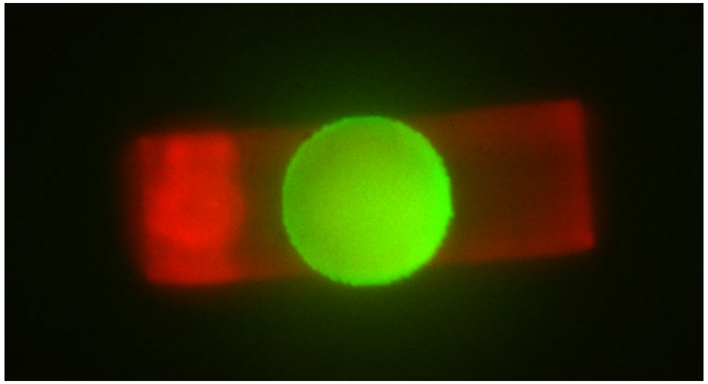
microfabrication of multi-doped microstructures

Guiding bacterial growth in a micro-environment

to study bacterial growth it was needed to develop
double doped microstructures

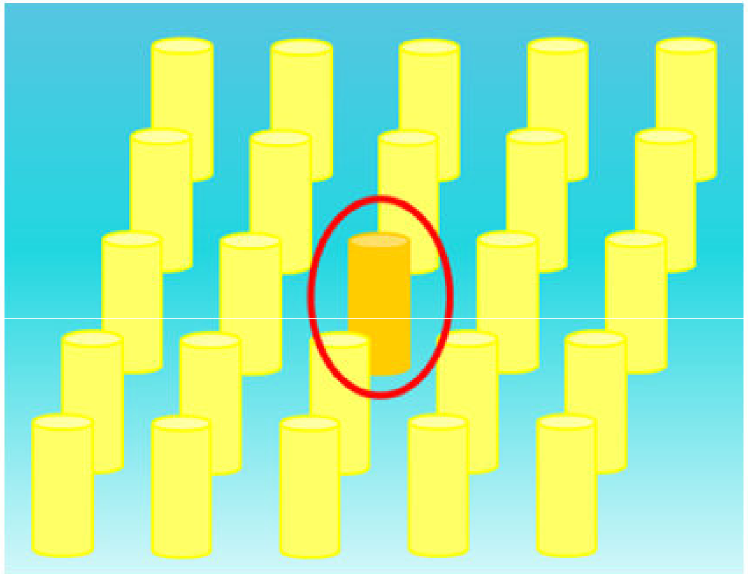


microstructure containing Fluorescein and Rhodamine

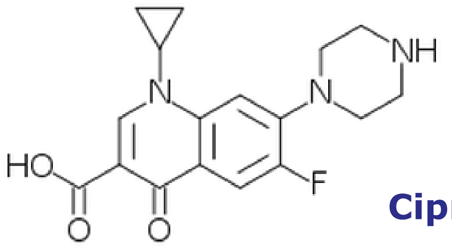


Guiding bacterial growth in a micro-environment

Study the development of E. coli in micro-environments:



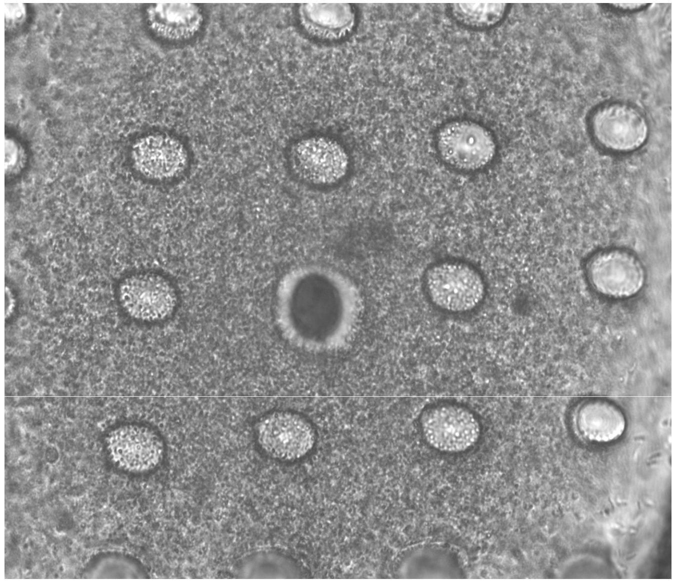
micro-environment in which the central structure contains antibiotic.



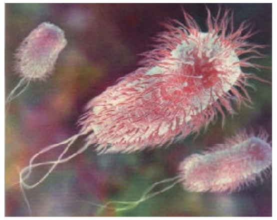
Ciprofloxacin

Guiding bacterial growth in a micro-environment

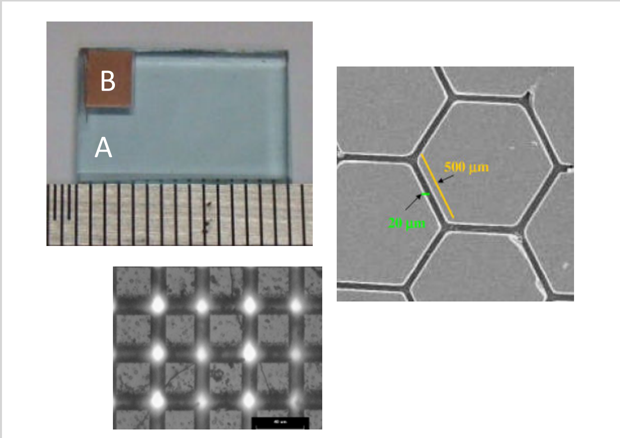
Study the development of E. coli in micro-environments:

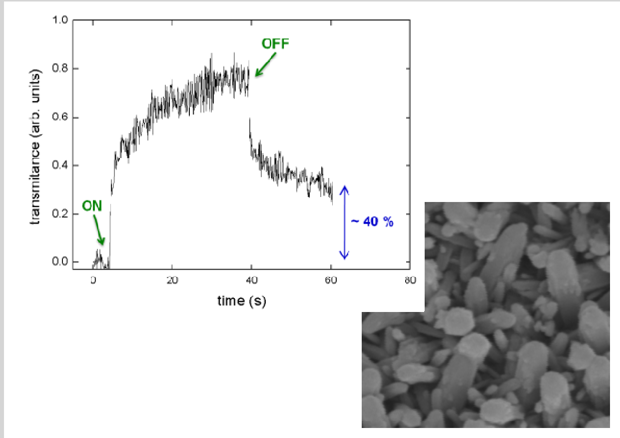


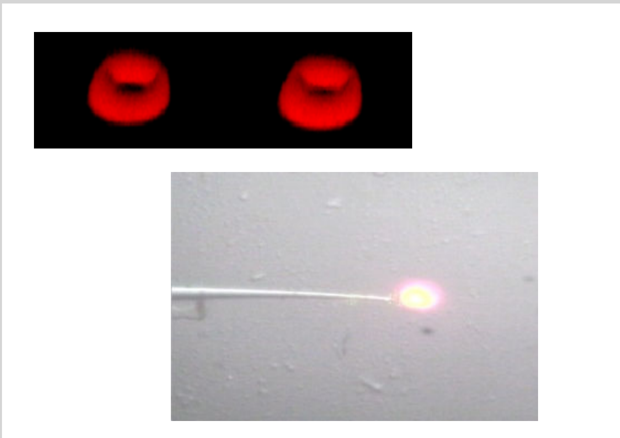
after 3 hours, we observed that a small region around the doped structure does not show bacterial growth.

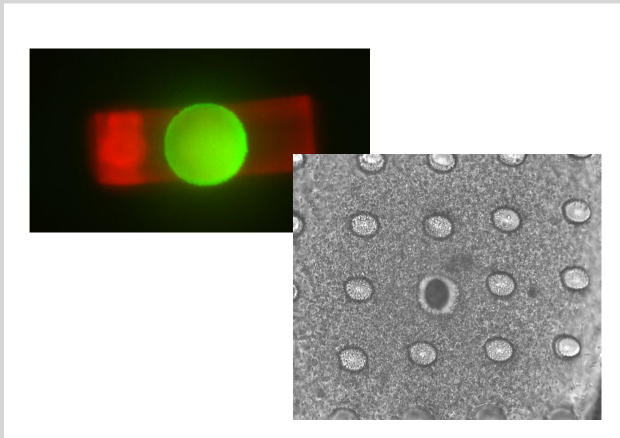


Summary


B
A
500 µm


1.0
0.8
0.6
0.4
0.2
0.0
transmittance (arb. units)
OFF
ON
~ 40 %
0
20
40
60
80
time (s)





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