Microfabricação em materiais poliméricos usando laser de femtossegundos

Prof. Cleber R. Mendonça

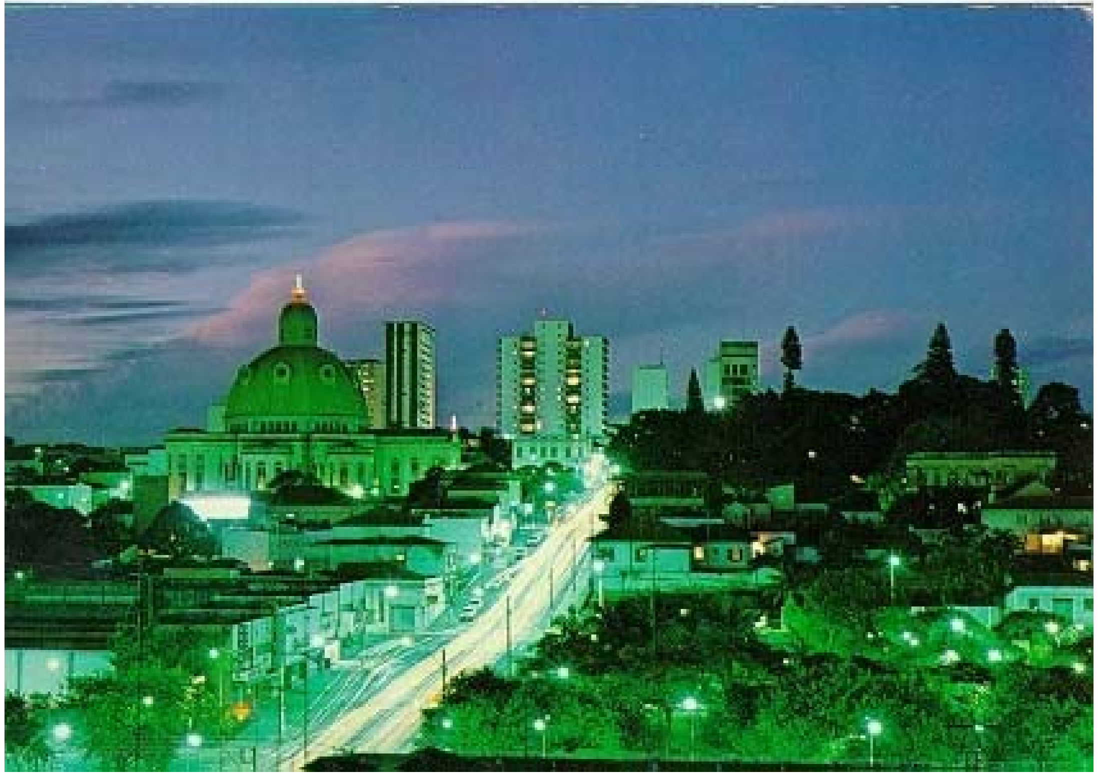
http://www.fotonica.ifsc.usp.br

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 – in Sao Carlos



University of Sao Paulo – in Sao Carlos

Instituto de Física de São Carlos

IFSC

Professors: 80

Employers: 180
(technical and administration)

Students: 450 (undergrad)
100 (master)
140 (phD)

Several research areas in Physics and Material Sciences

Photonics Groups

The purpose of the Photonics Group is to develop fundamental science and applied technology *in Optics and Photonics (founded in 2003)*

4 – Professor
2 – Researchers
1 – Technician
1 – Administrative

2 – Post docs
10 – PhD students
6 – Master students
5 – Undergrad students

Some of the research areas

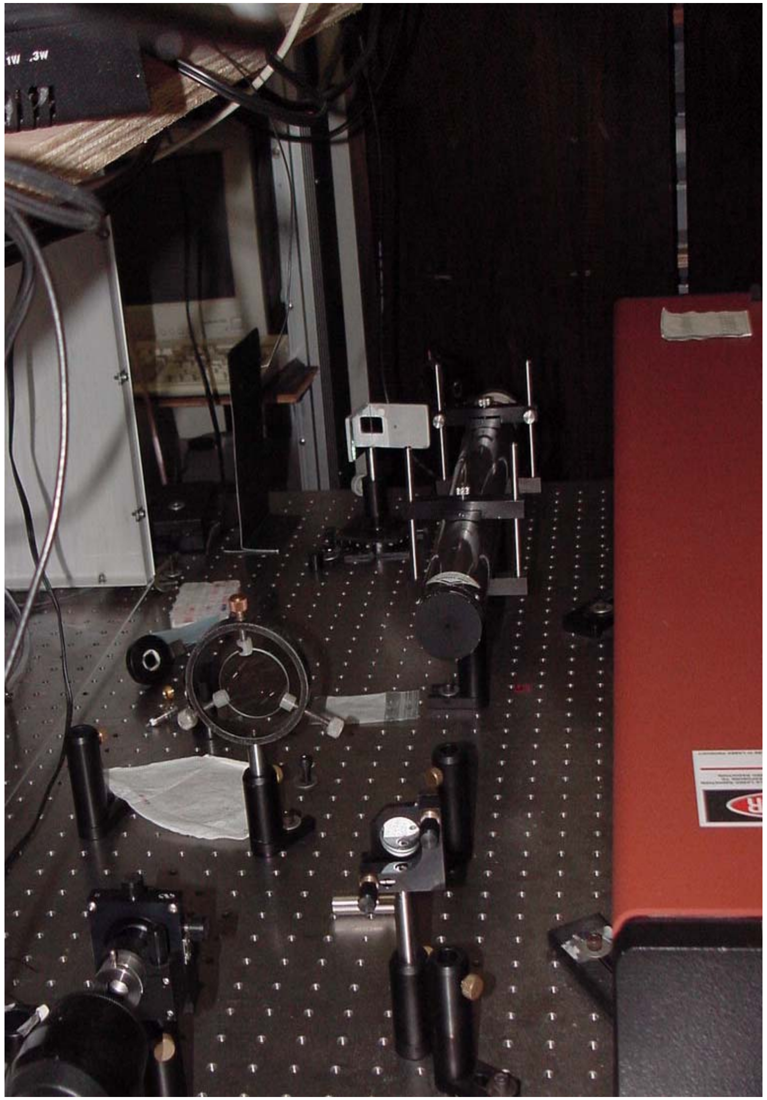
- Nonlinear optics
- Coherent control of light matter interaction
- fs-laser microfabrication and micromachining
- Optical spectroscopy
- Optical storage

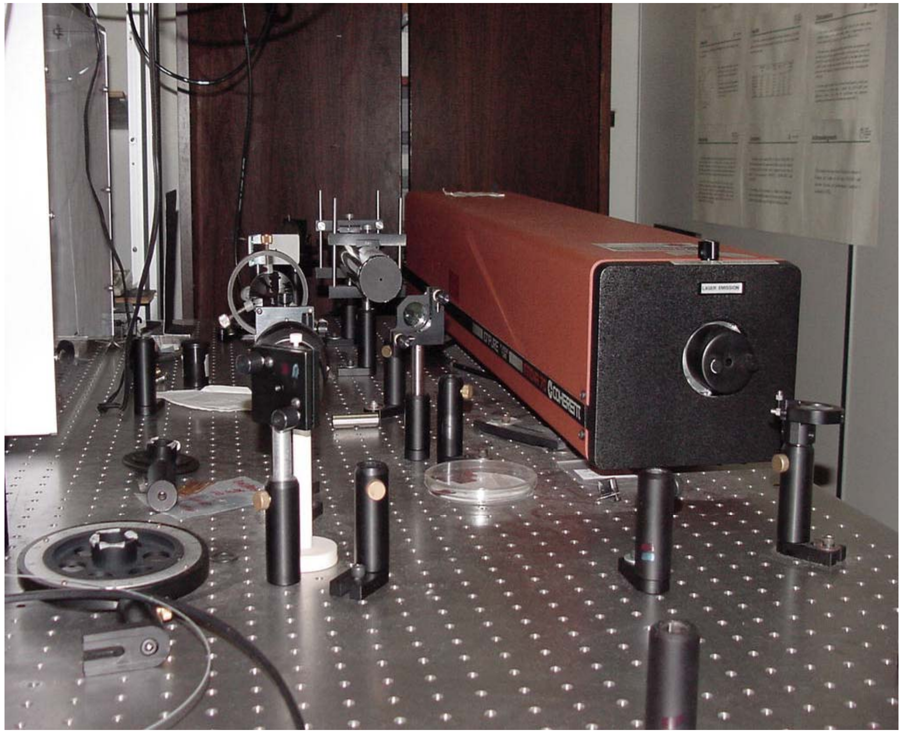
http://www.fotonica.ifsc.usp.br

research areas

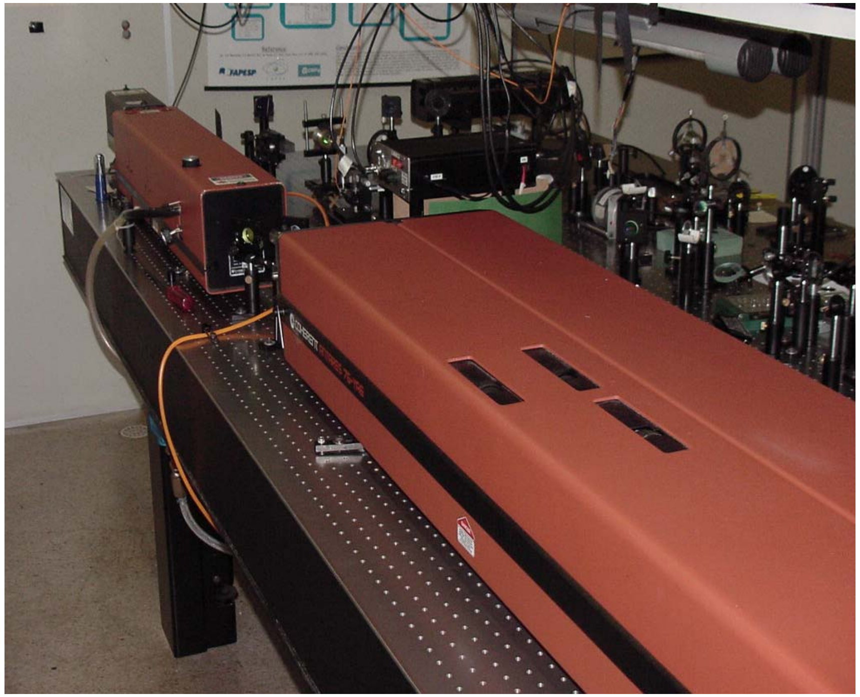
- study of optical nonlinearities in organic materials
- optical storage and surface relief gratings in azopolymers
- coherent control of light matter interaction
- fs-laser microfabrication

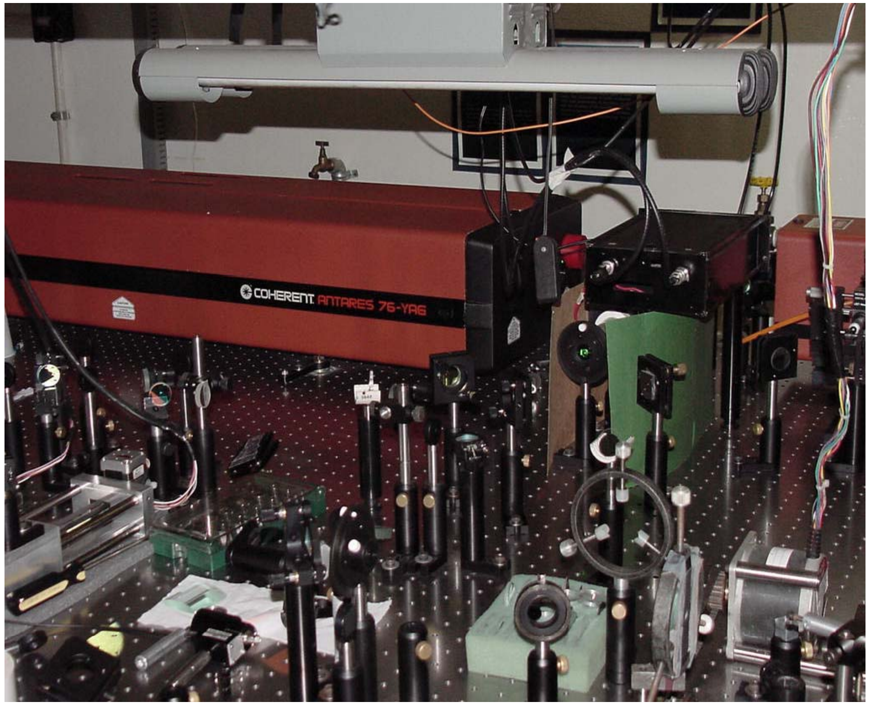
cw laser





Picosecond laser





- ✓ *Laser Nd:YAG Qswitched/modelocked*
  - ✓ *532nm and 1064 nm*
  - ✓ *100 ps*

150-fs amplified laser system

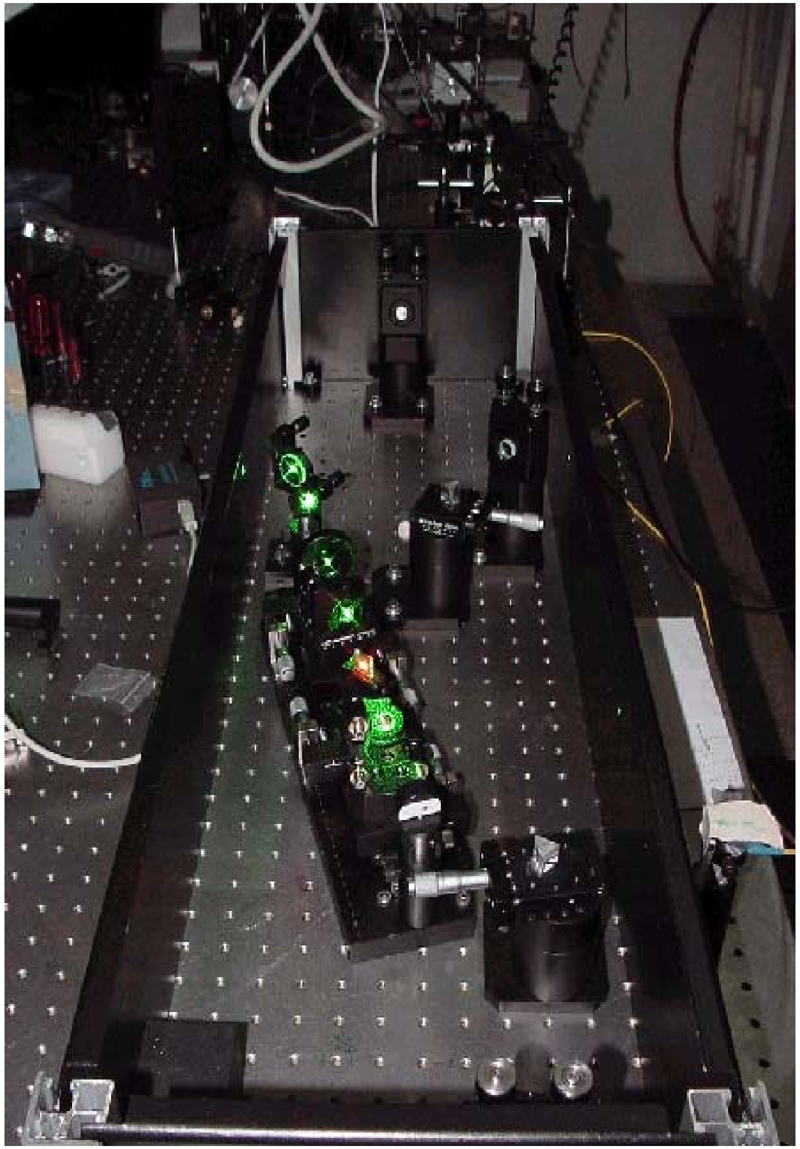
- ✓ *Amplifier Ti:safira*
  - ✓ *775 nm*
  - ✓ *150 fs*
  - ✓ *800 μJ*

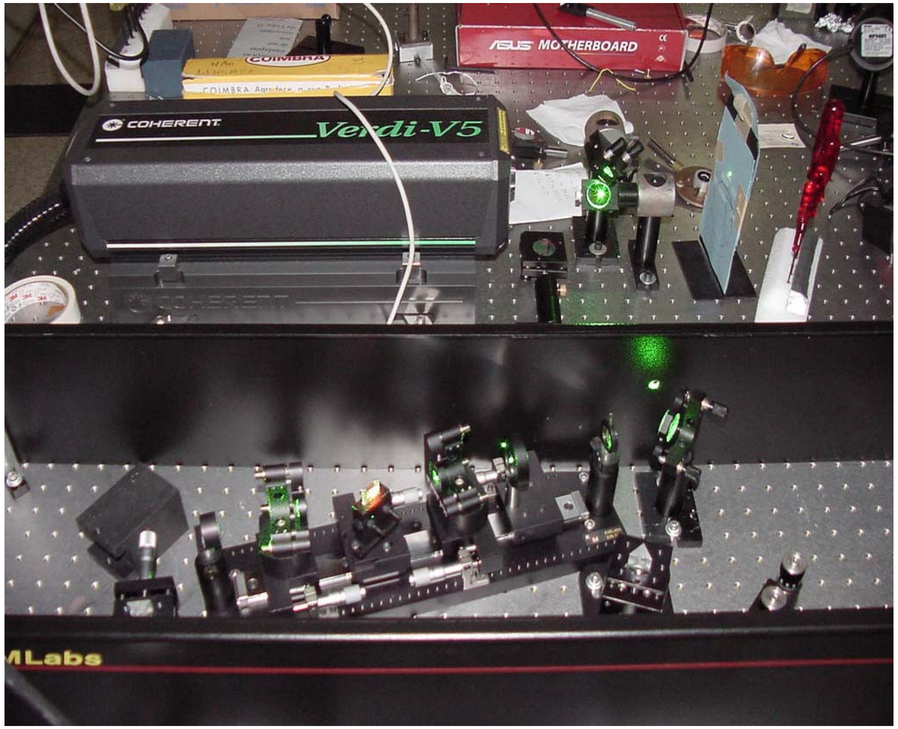
Optical Parametric Amplifier

TOPAS

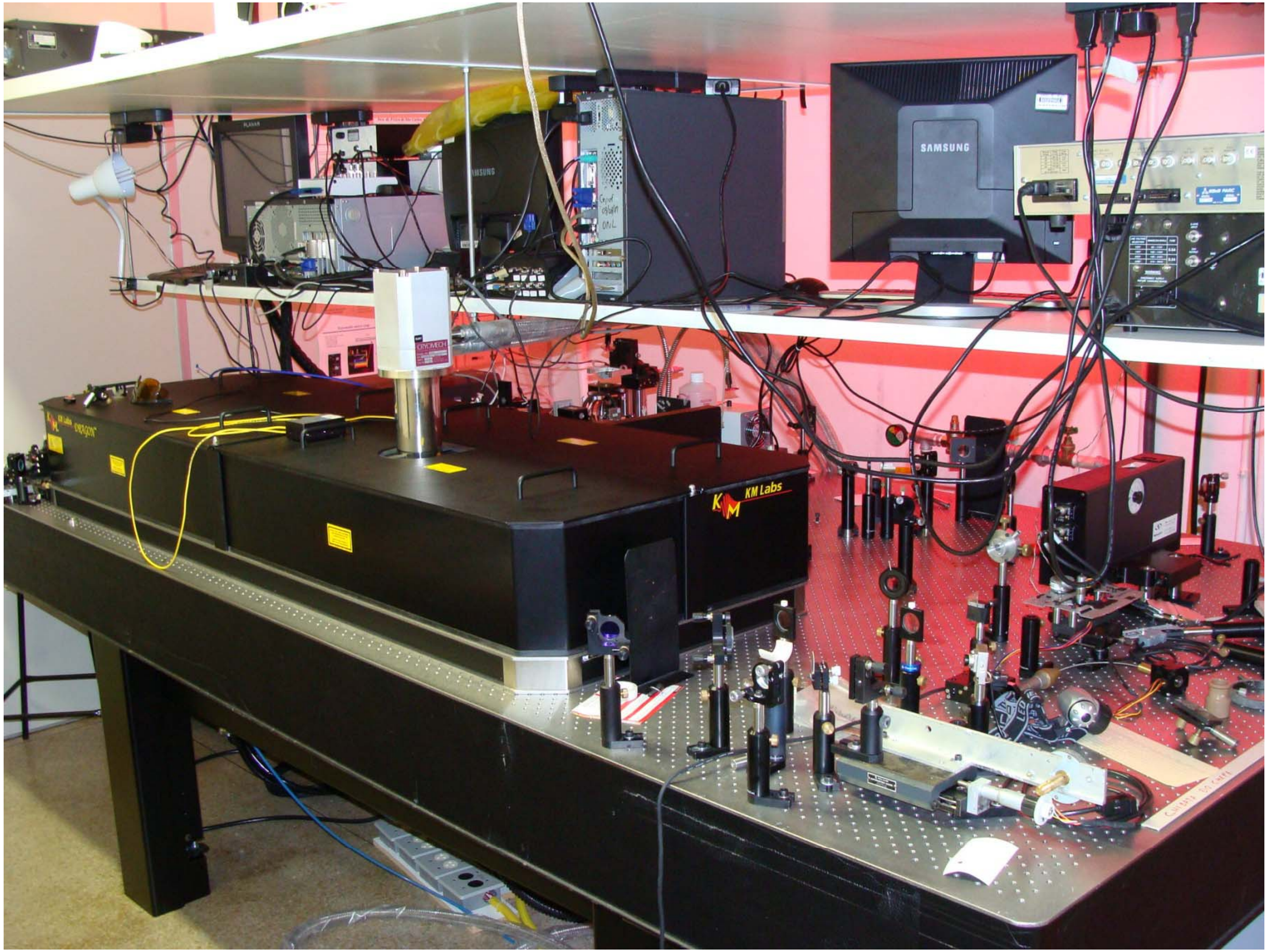
- ✓ *pumped - Laser Clark*
  - ✓ *460 - 2600 nm*
  - ✓ $\approx$ *120 fs*
  - ✓ *20-60 μJ*

15-fs laser

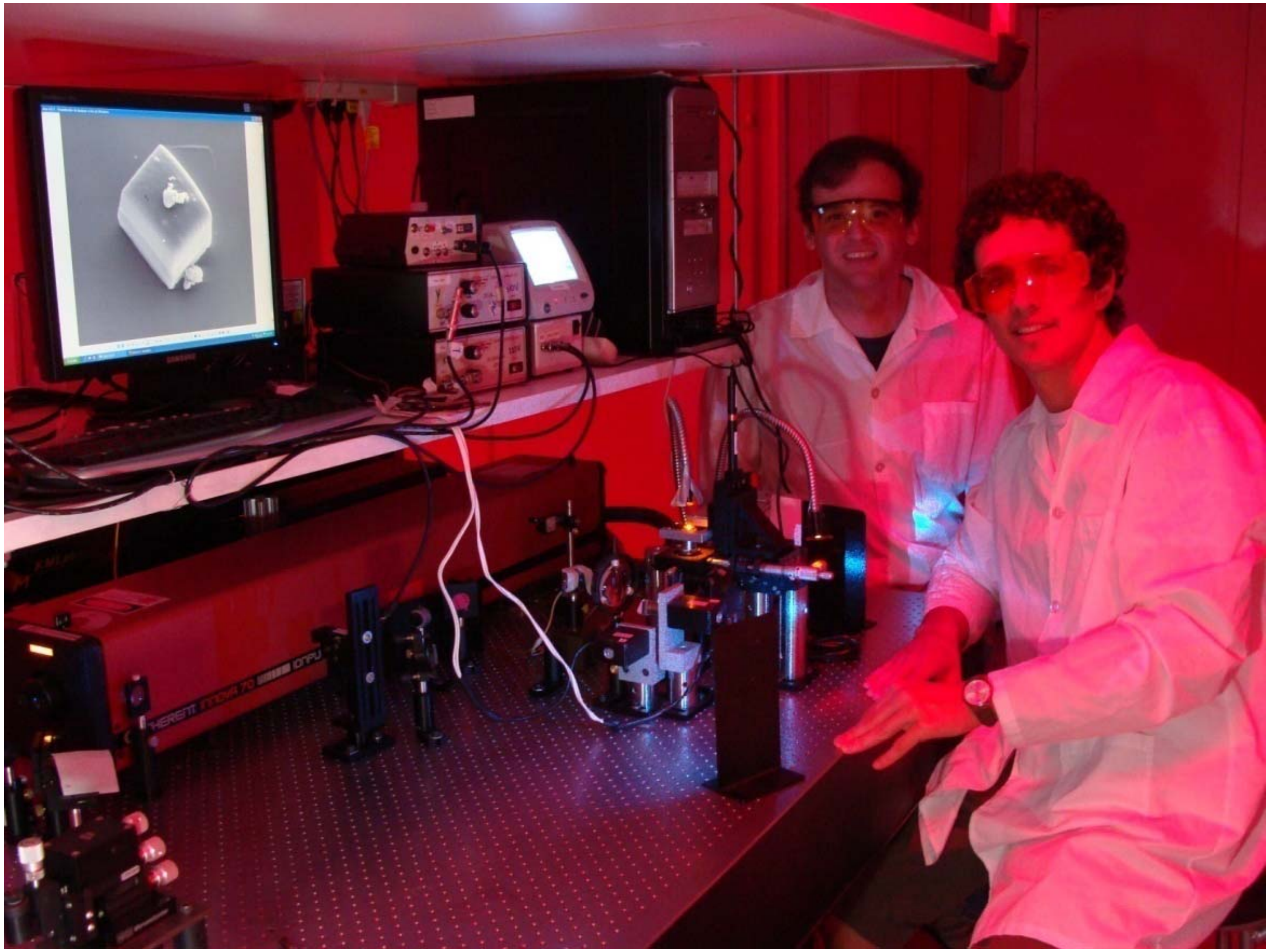




40-fs amplified laser system



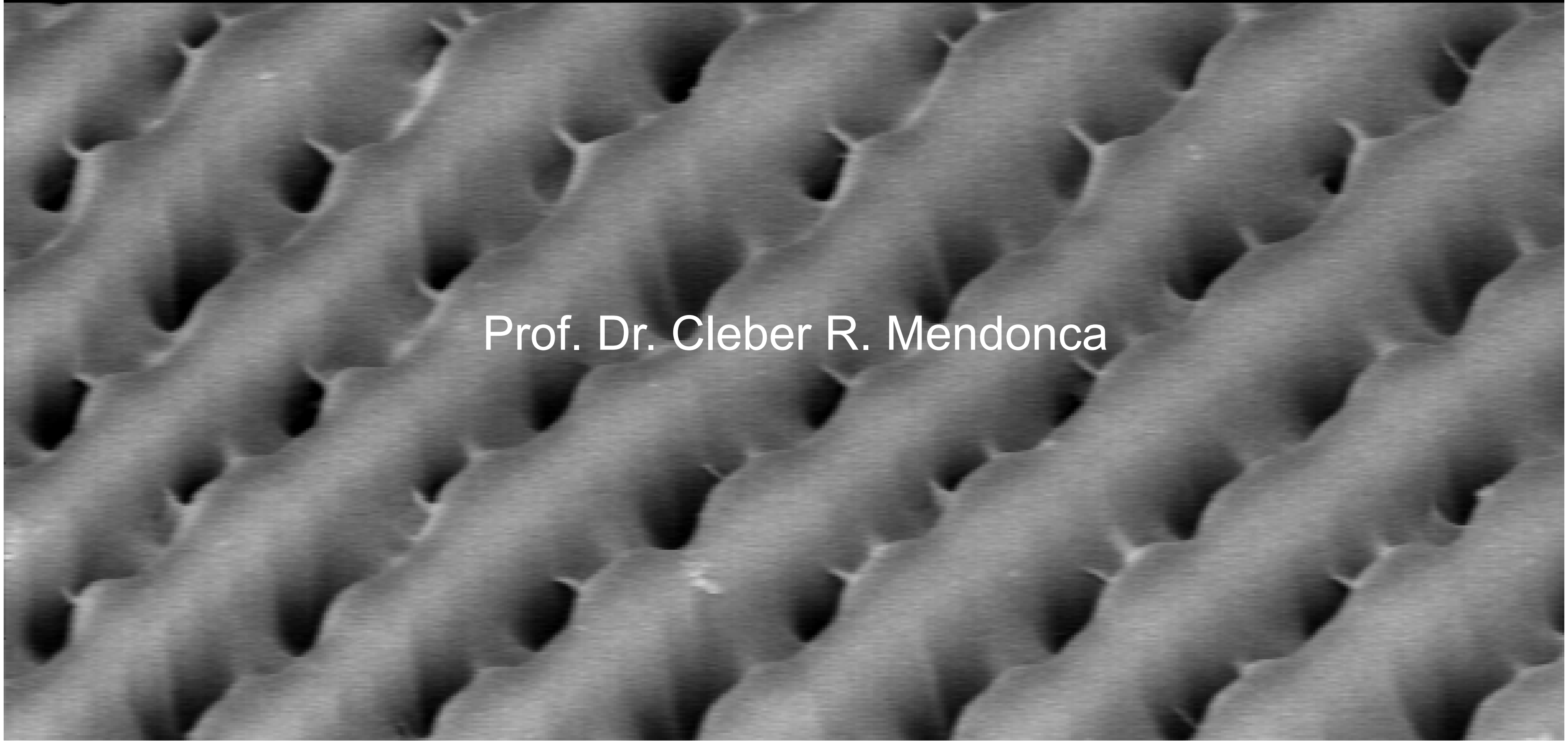
microfabrication lab



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

fs-laser microfabrication

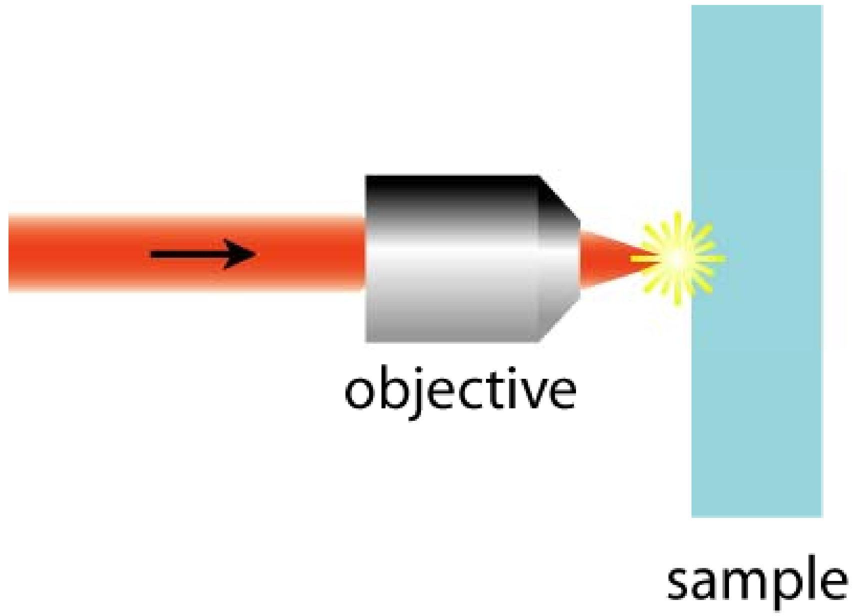


Prof. Dr. Cleber R. Mendonca

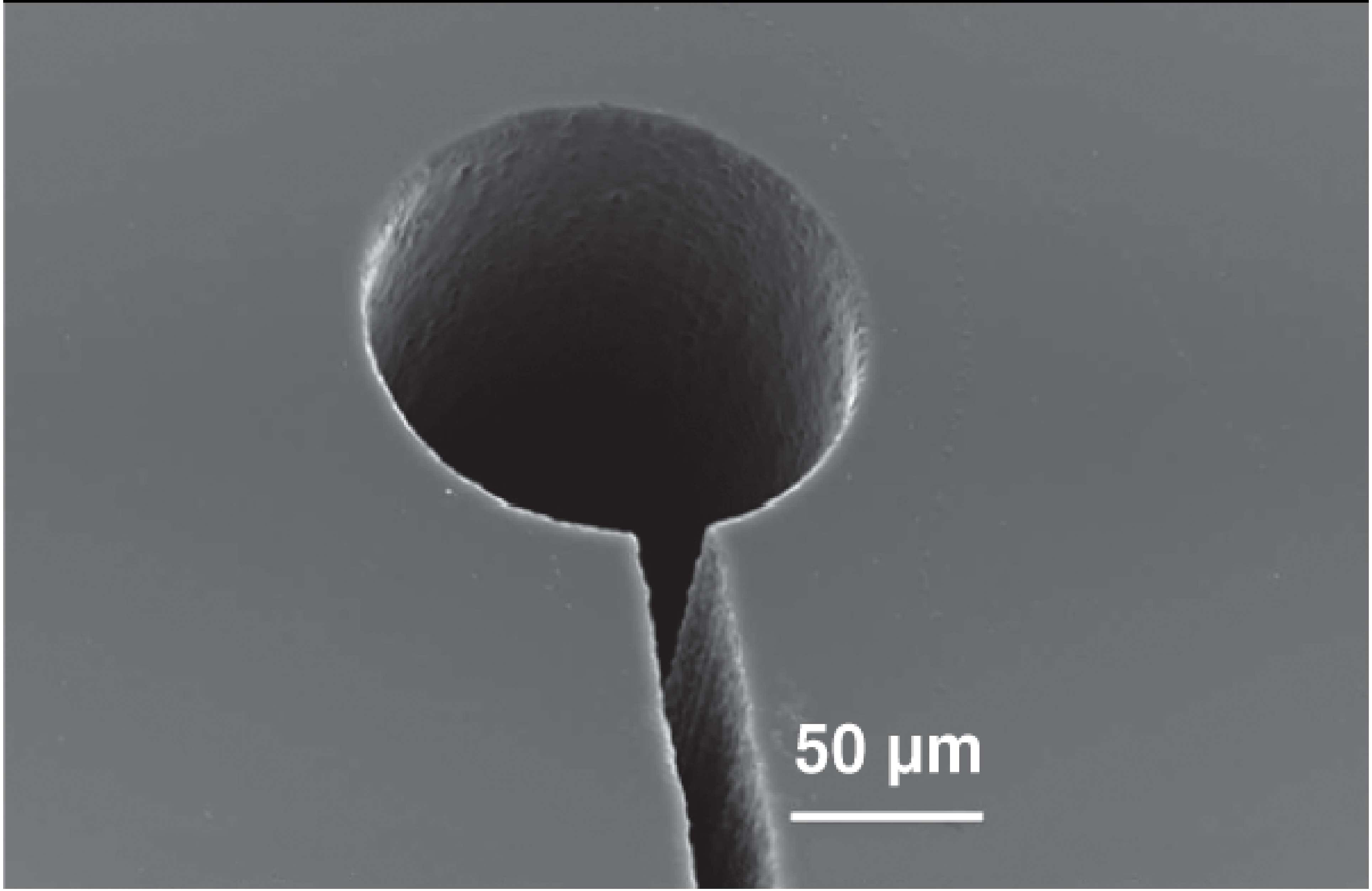
IFSC USP VE RI TAS HARVARD Fotônica

laser microfabrication

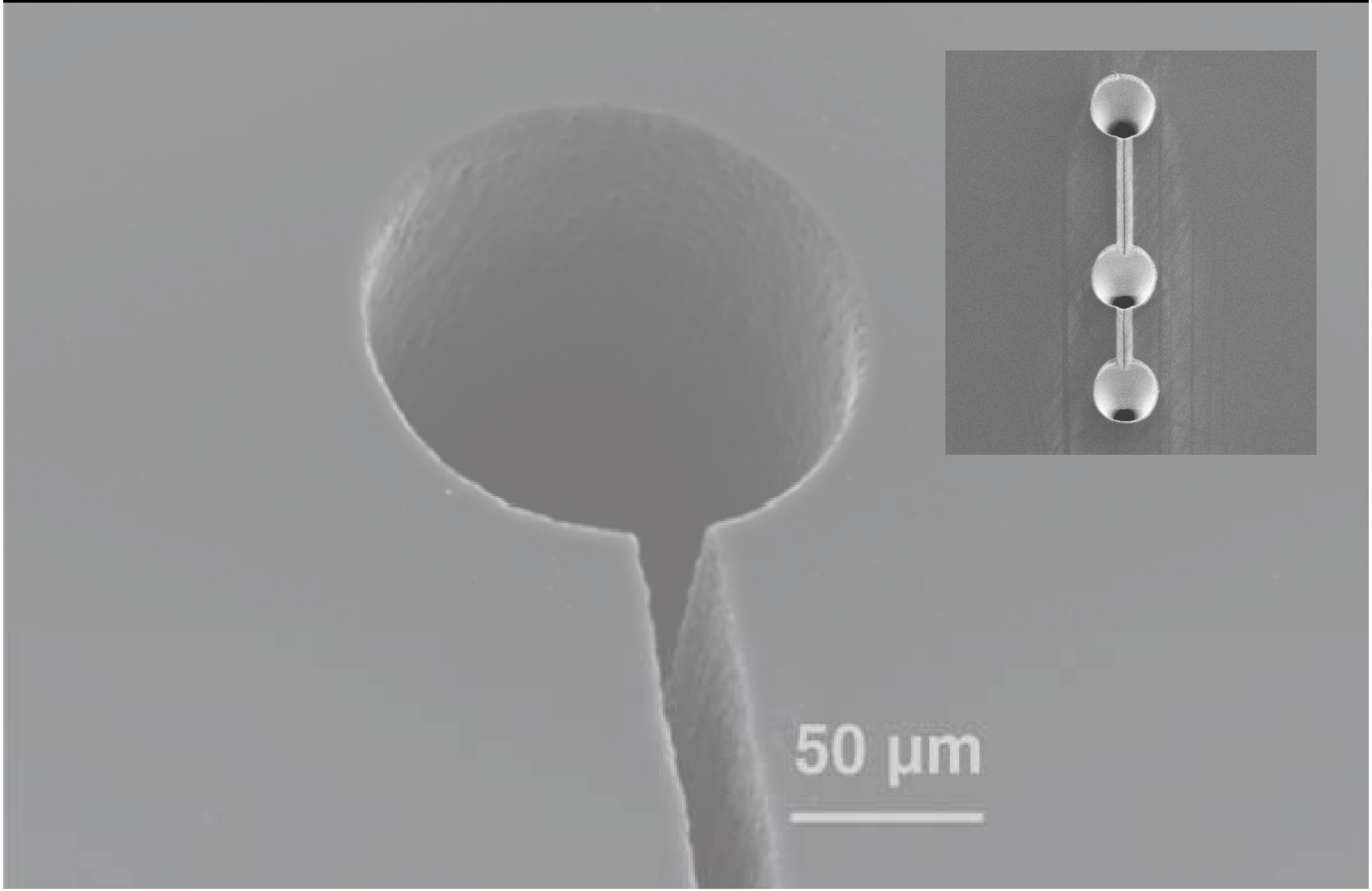
focus laser beam on material's surface



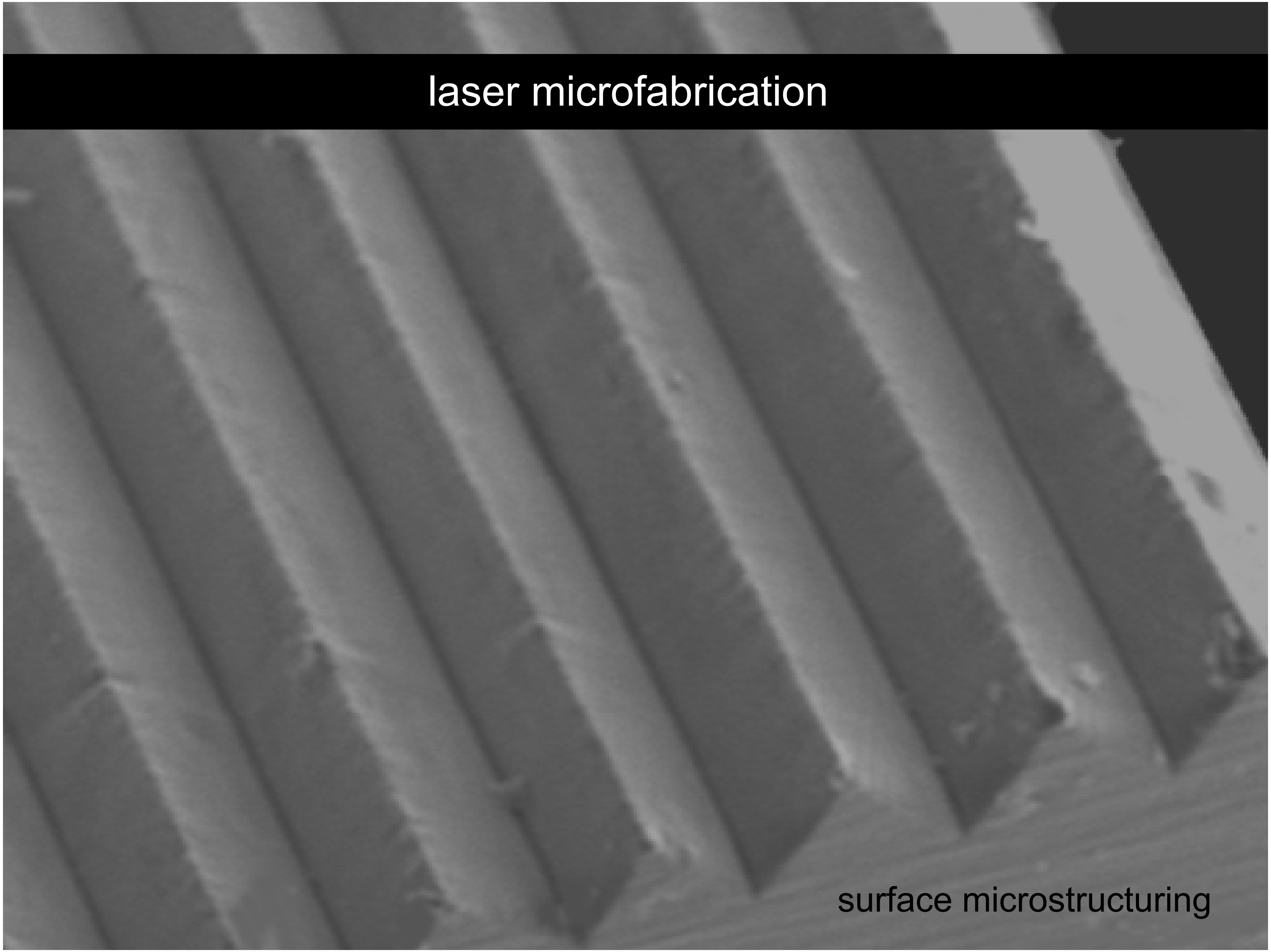
laser microfabrication



laser microfabrication



laser microfabrication



fs-micromachining

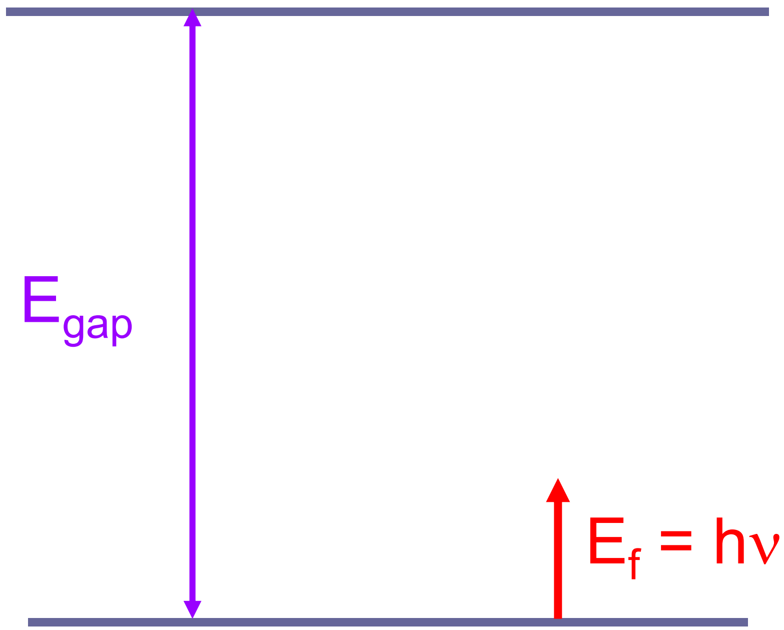
photon energy < bandgap

↓

nonlinear interaction

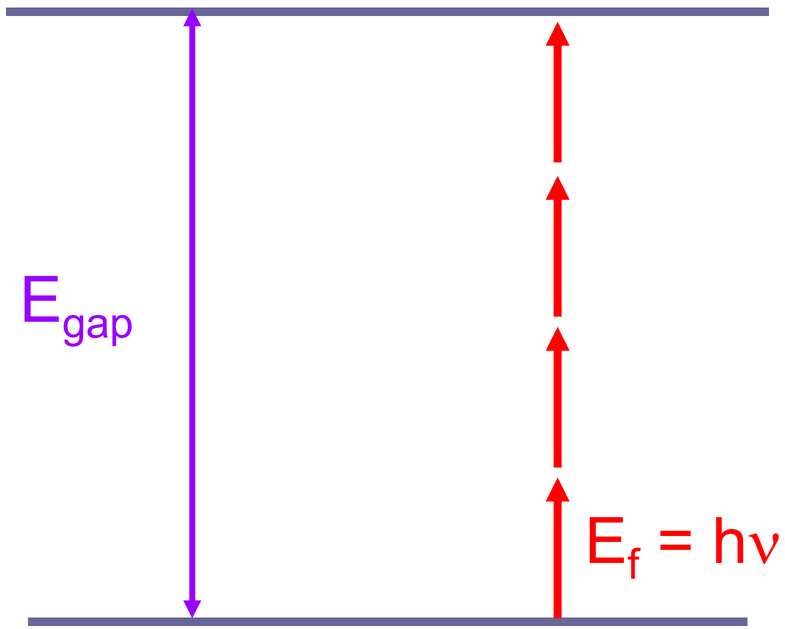
fs-micromachining

nonlinear interaction



fs-micromachining

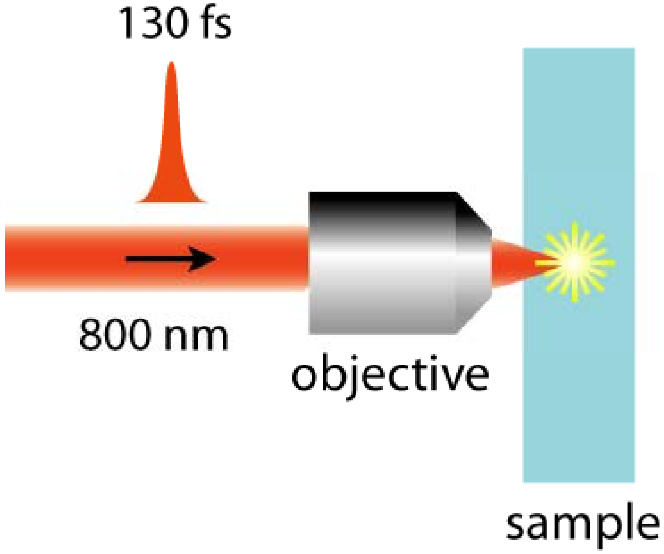
nonlinear interaction



multiphoton absorption

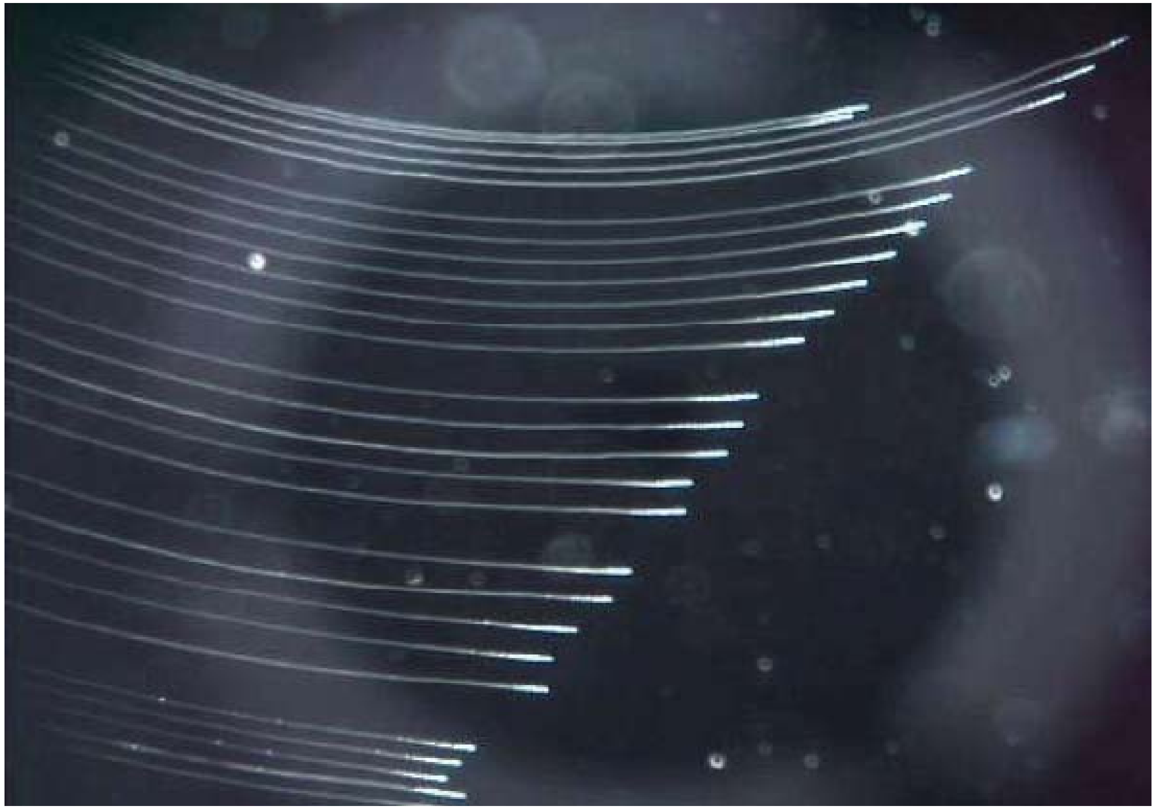
fs-laser microfabrication

focus laser beam inside material



fs-laser microfabrication

curved waveguides inside glass



fs-micromachining

it is important to understand the nonlinear interaction, as well as the nonlinear response of materials

Outline

Introduction to microfabrication/micromachining

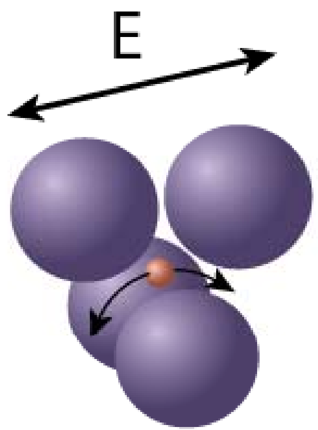
fs-micromachining

- microstructuring MEH-PPV
- waveguides in azopolymers
- superhydrophobic surfaces

two-photon polymerization

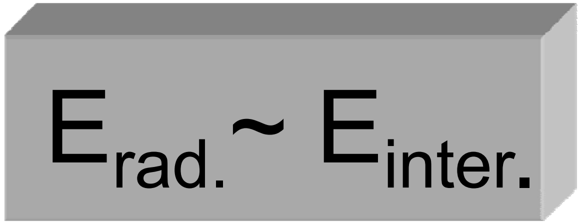
- birefringent microstructures
- fluorescent microstructures
- biocompatible microstructures

Nonlinear optics



anharmonic oscillator

high light intensity

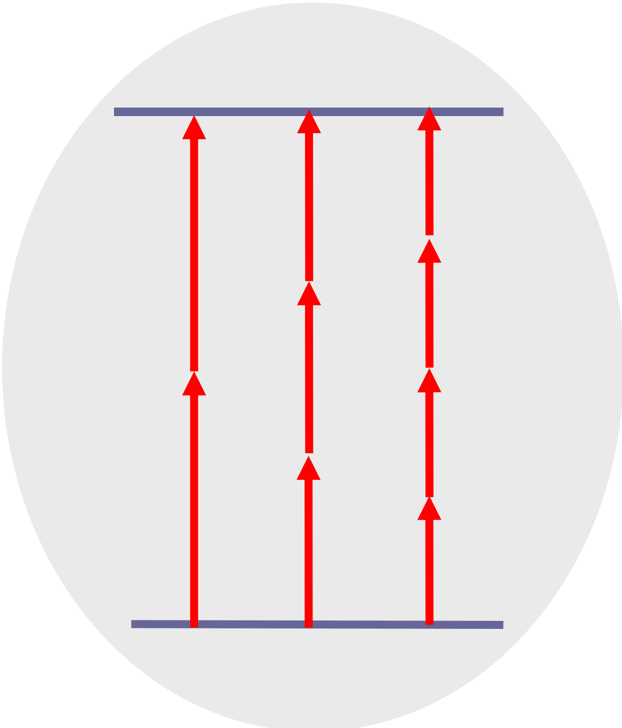


nonlinear polarization response

$$P = \chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \ldots$$

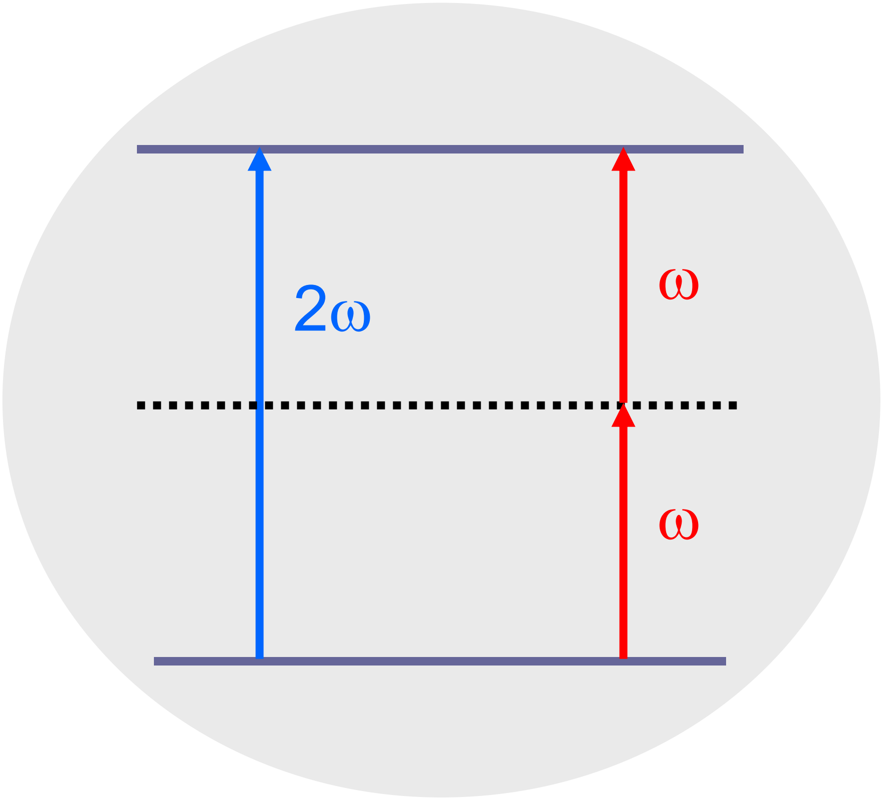
multi-photon absorption

$$\chi^{(3)}, \chi^{(5)}, \chi^{(7)}, \ldots$$



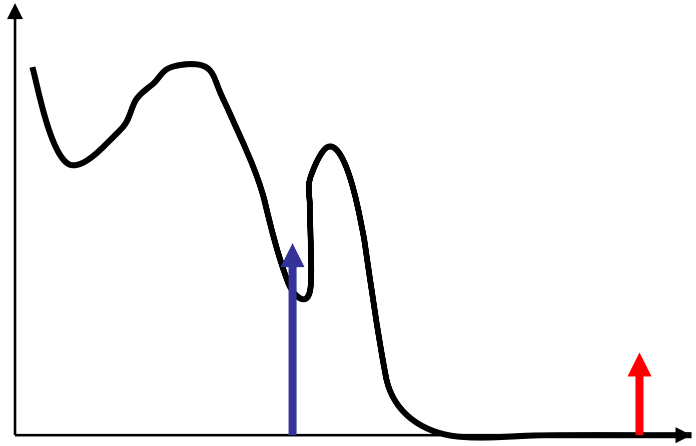
$$\alpha = \alpha_0 + \beta I + \alpha_3 I^2 + \alpha_4 I^3 + \alpha_5 I^4 + \ldots$$

two-photon absorption



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

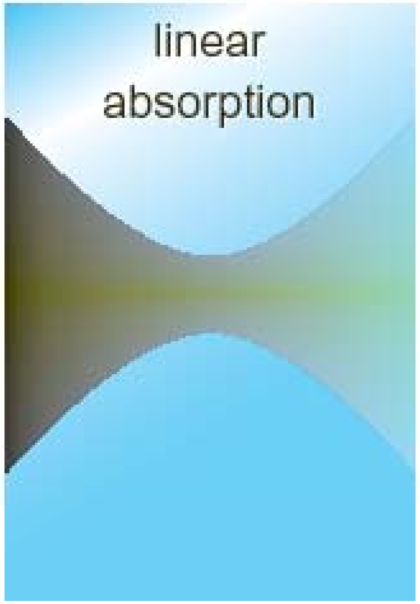
Third order processes $\chi^{(3)}$

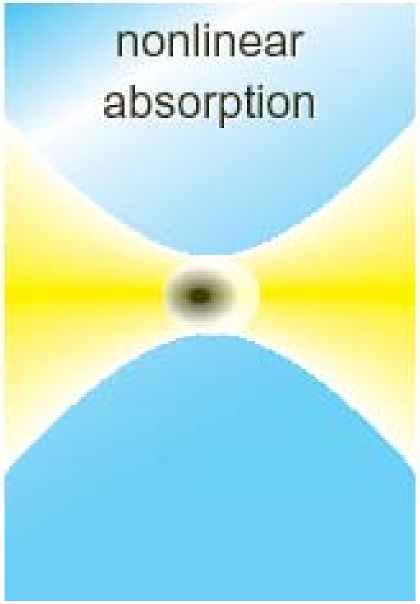


two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication



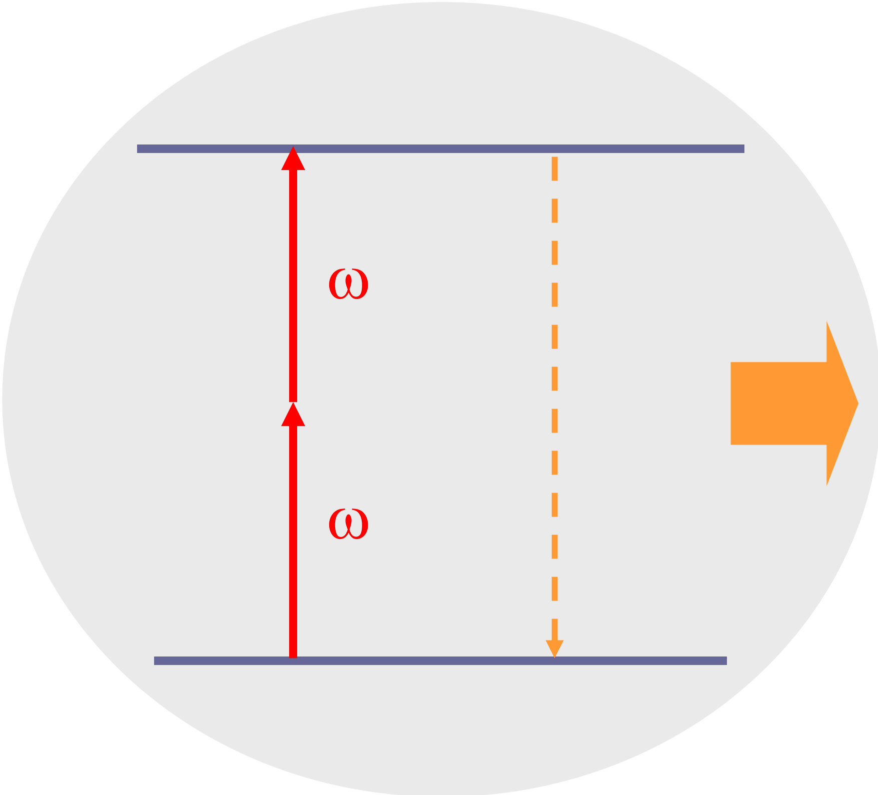


$$\alpha = \alpha_0$$

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

two-photon fluorescence

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

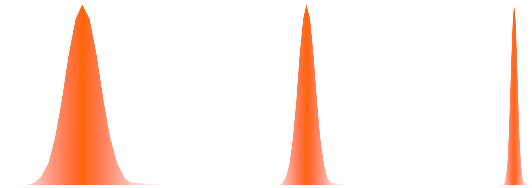


light emission
fluorescence

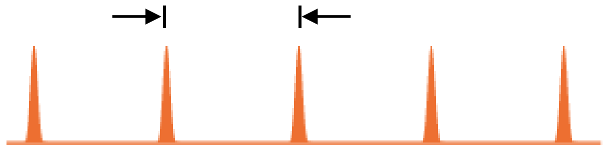
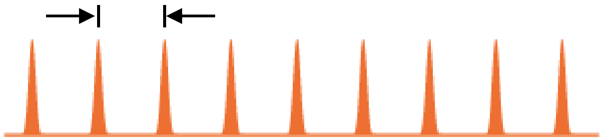
spatial confinement of excitation

femtosecond pulses

Ti:Sapphire lasers

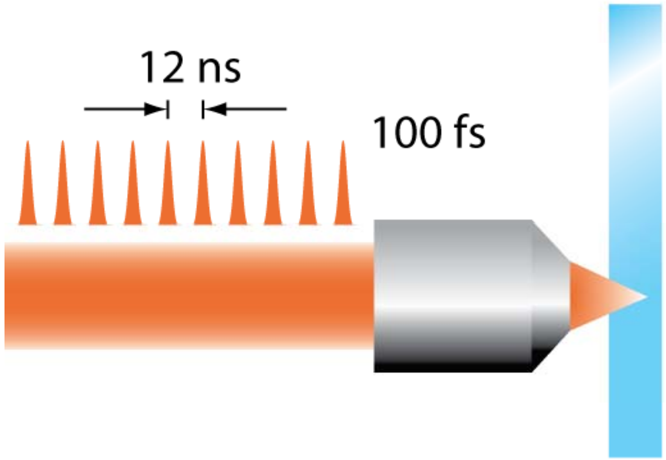


1 fs = 10^{-15} s

Repetition rate		Energy
1 KHz		mJ
86 MHz		nJ

fs-pulses for micromachining polymers

Oscillator: 80 MHz, 5 nJ

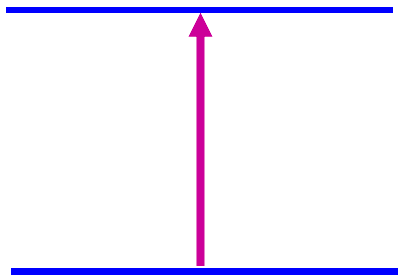


heat diffusion time: $t_{diff} \sim 1\ \mu s$

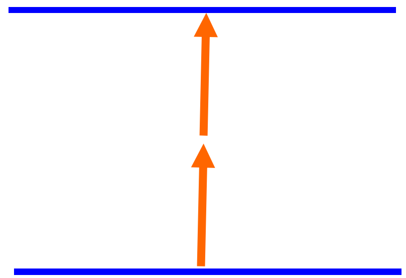
cumulative

fs-microfabrication

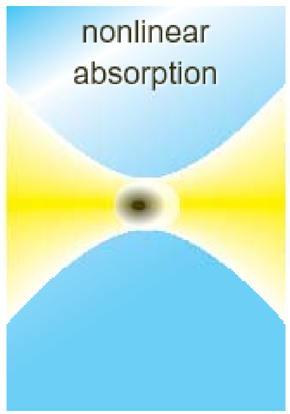
linear *versus* nonlinear absorption



$$\alpha = \alpha_0$$



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



two main techniques

1

fs-laser micromachining

ablation
structural modification

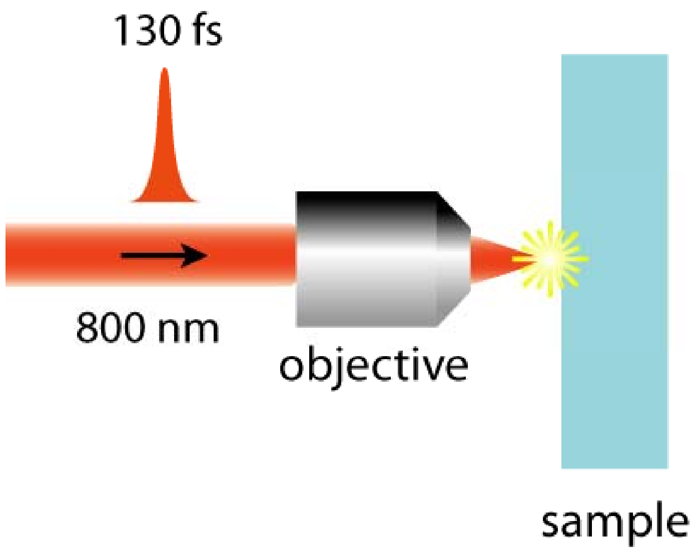
2

microfabrication via
two-photon polymerization

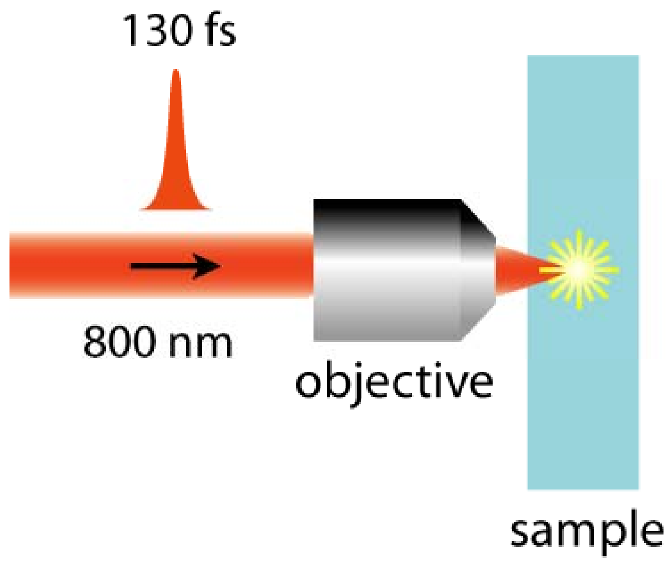
1

fs-laser micromaching

Surface

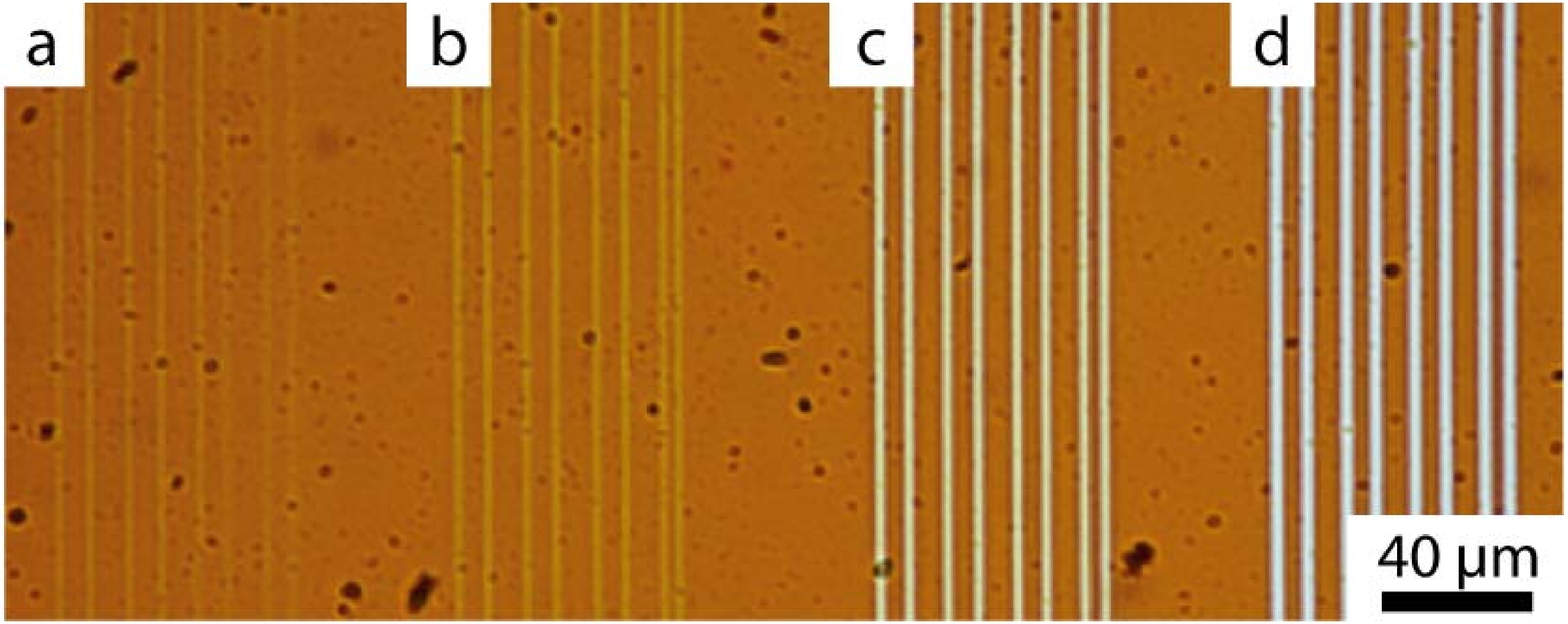


Volume



Micromachining the conductive polymer MEH-PPV

optical microscopy

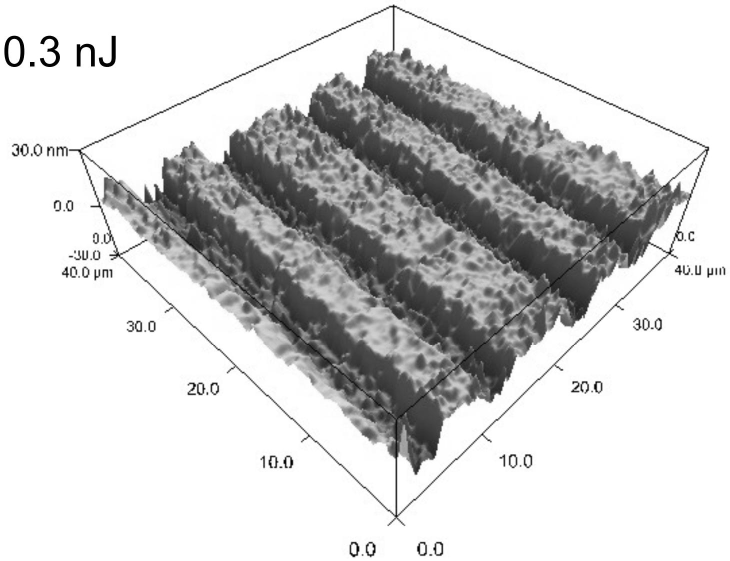


a: 0.07 nJ
b: 0.14 nJ
c: 0.34 nJ
d: 0.68 nJ

Applied Surface Science, 254, 1135–1139 (2007)

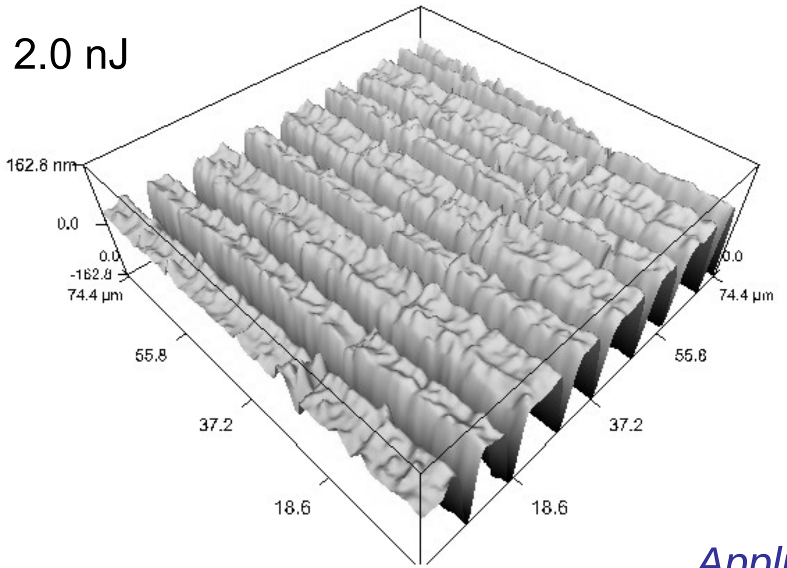
Micromachining the conductive polymer MEH-PPV

a 0.3 nJ



atomic force microscopy

b 2.0 nJ



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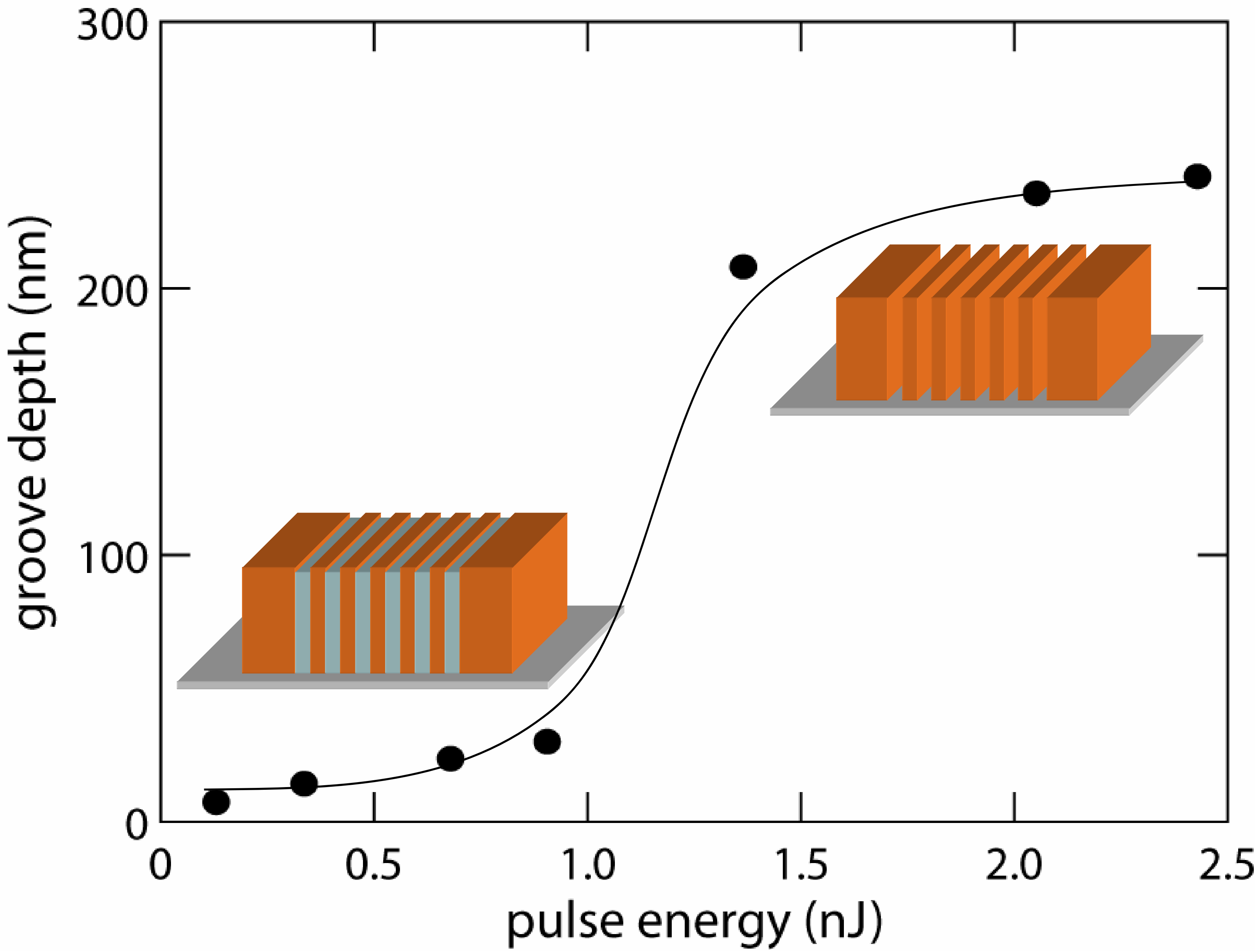
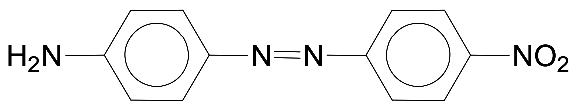
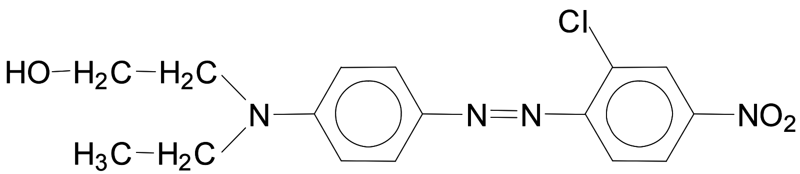
Micromachining the conductive polymer MEH-PPV



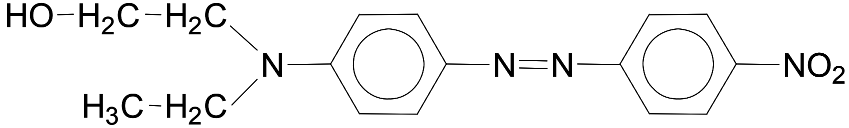
Waveguides in azo-polymers



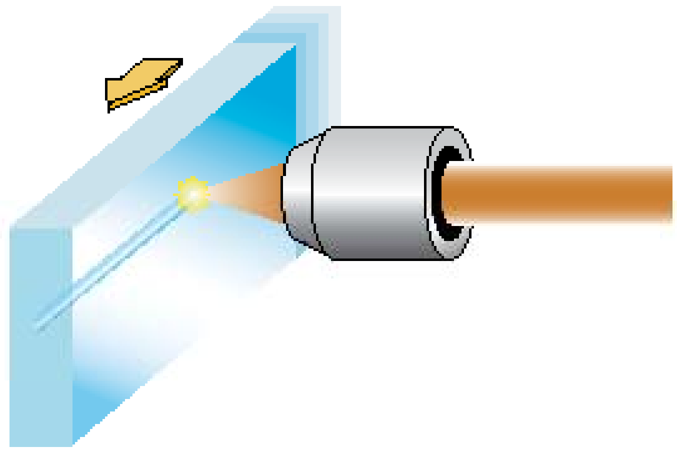
DO3



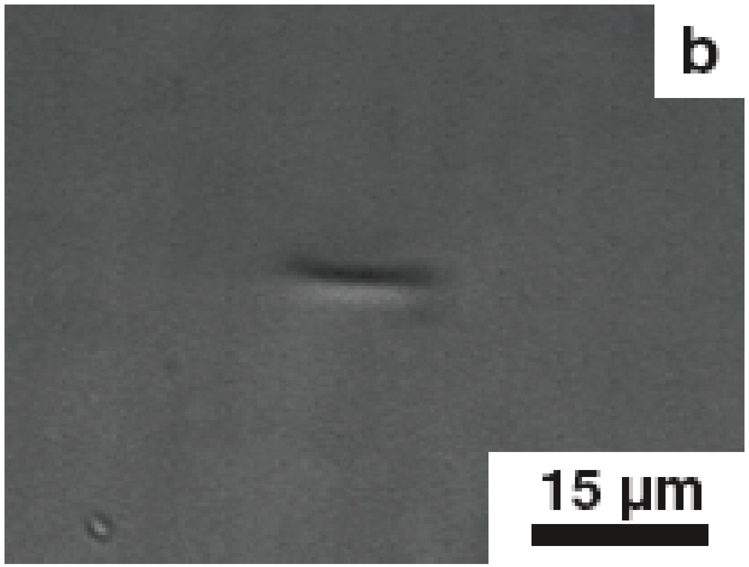
DR13



DR1



Waveguides in azo-polymers

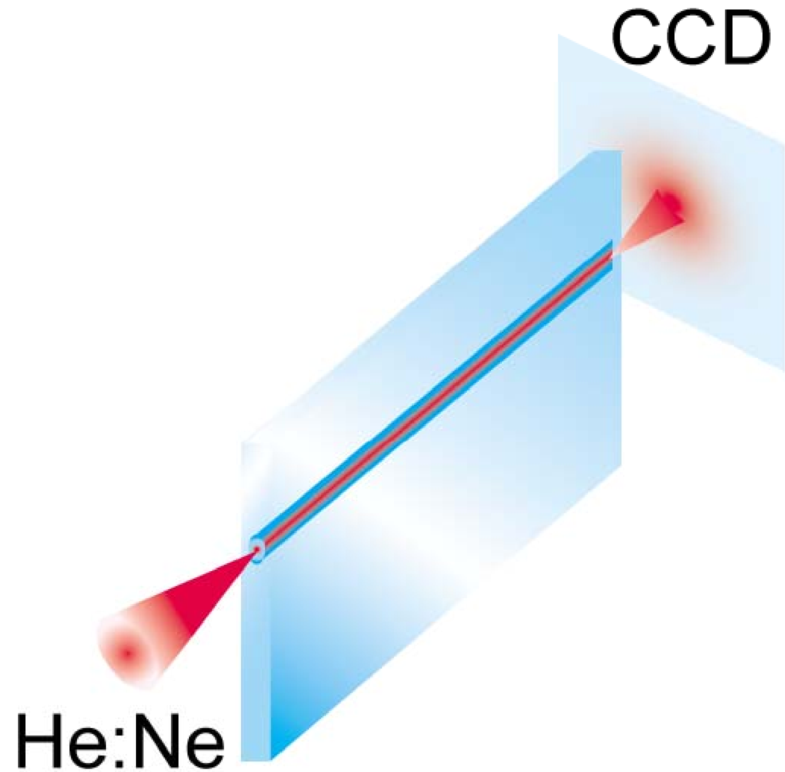


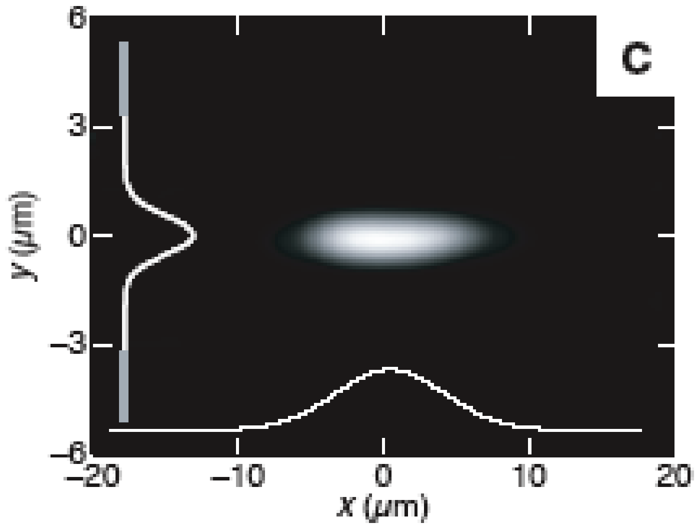
(a) Optical microscope image of the waveguides micromachined (PMMA/DR1)

(b) Cross-sectional view of the waveguides

Optics Express, 16, 200-205 (2008)

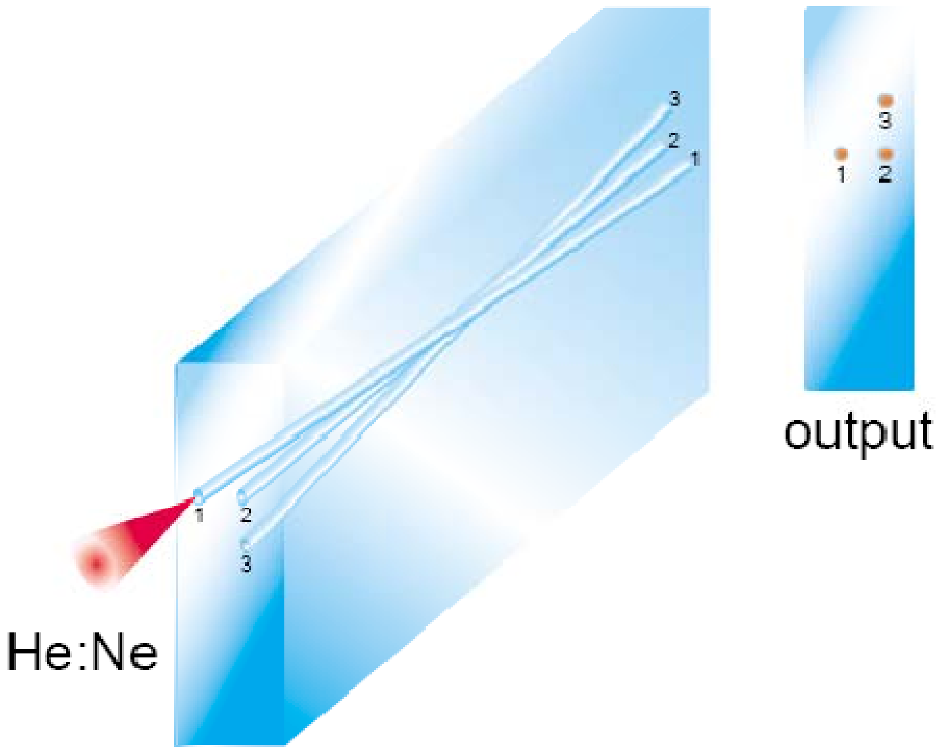
waveguides in azo-polymers



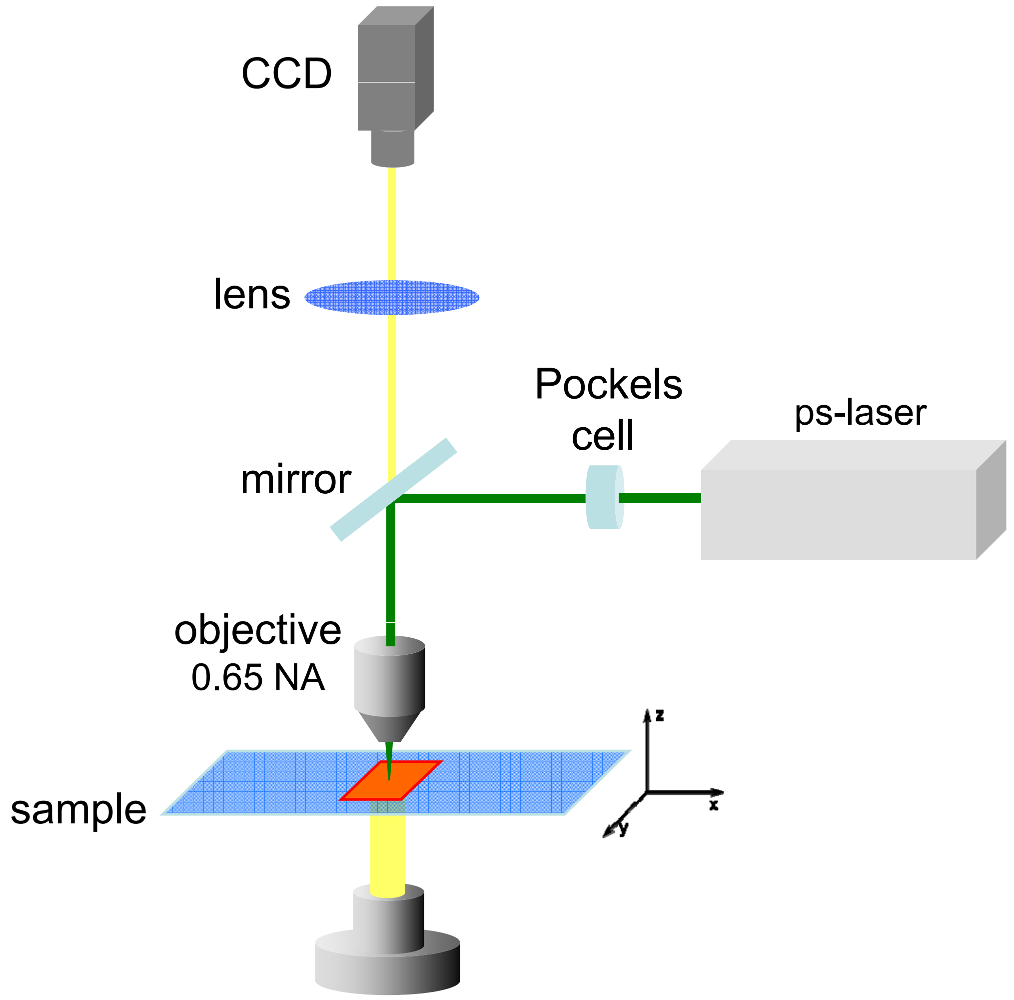


(c) Output image of the mode profile of 632.8-nm light coupled through the waveguide

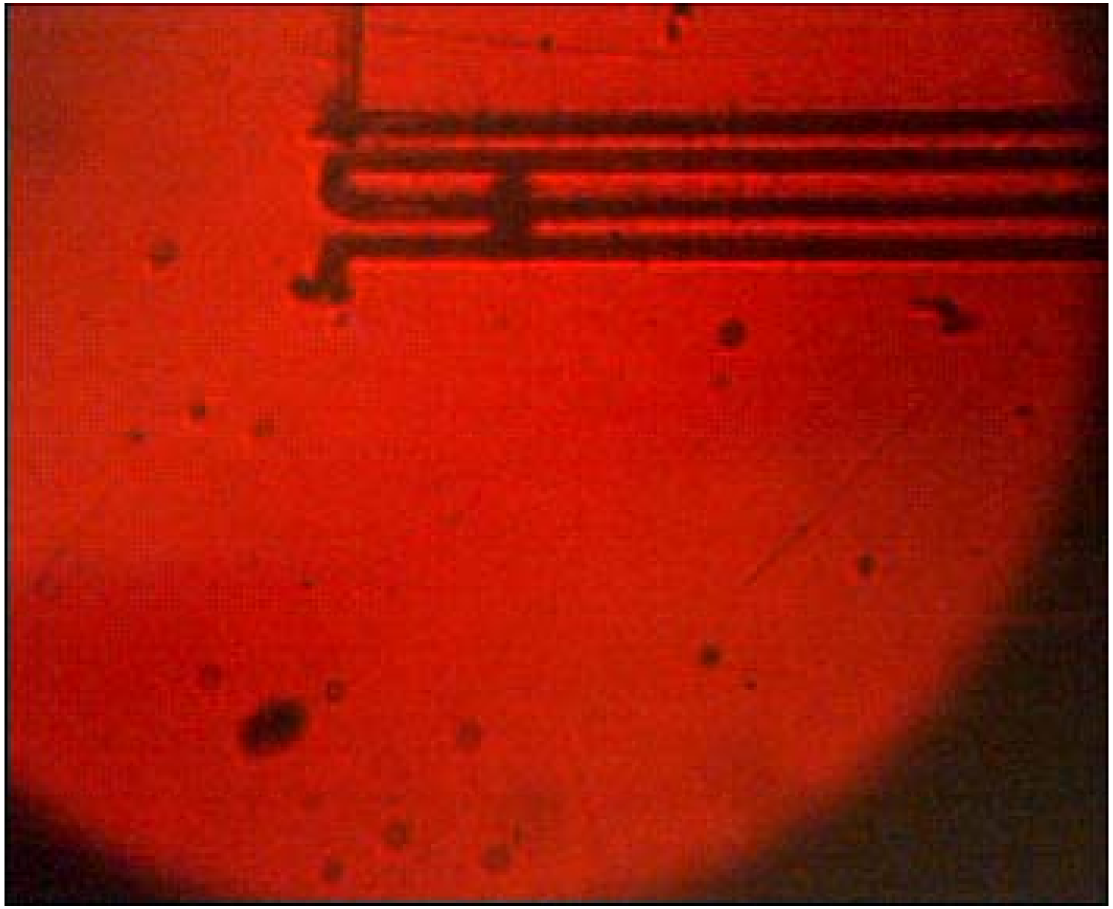
3D wave splitter



microstructuring polymer: super hydrophobic surface

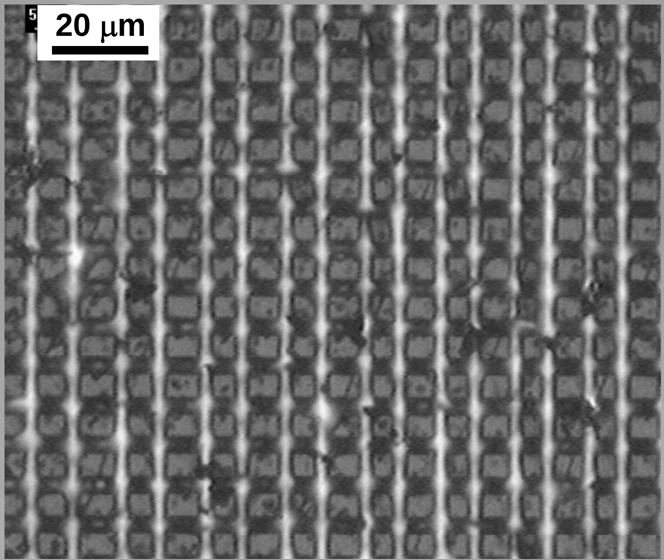


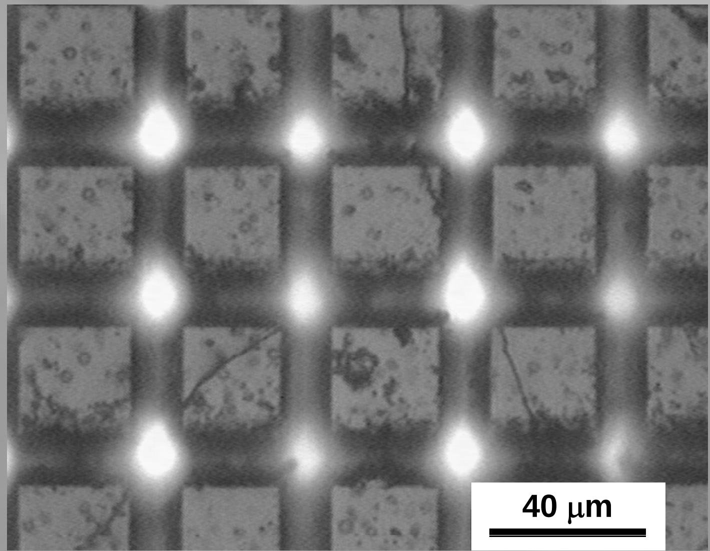
microstructuring polymer: super hydrophobic surface



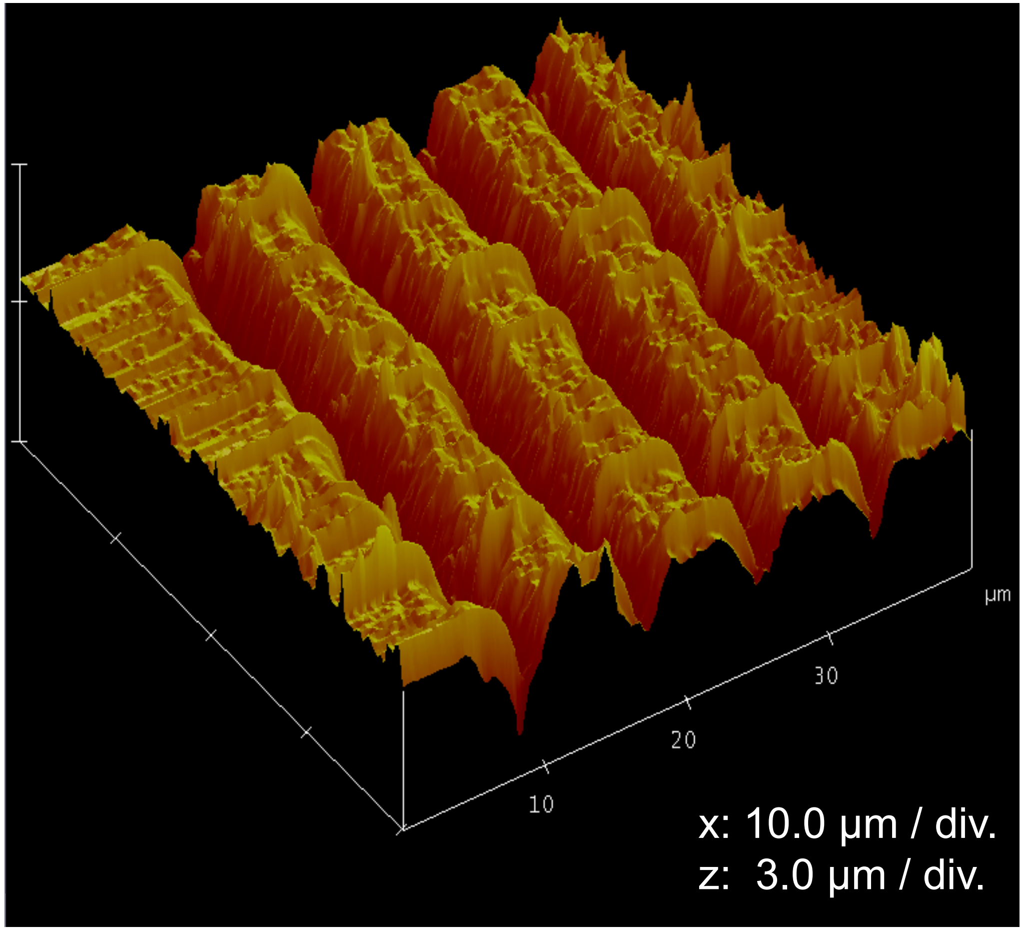
laser microfabrication

examples of fabricated surfaces





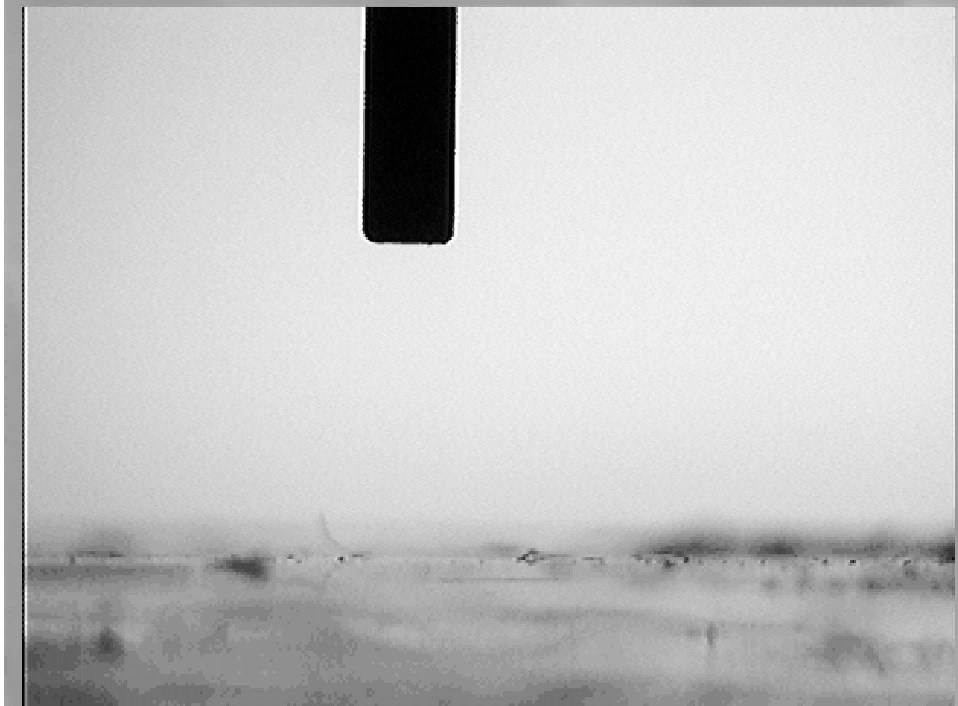
microstructuring polymer



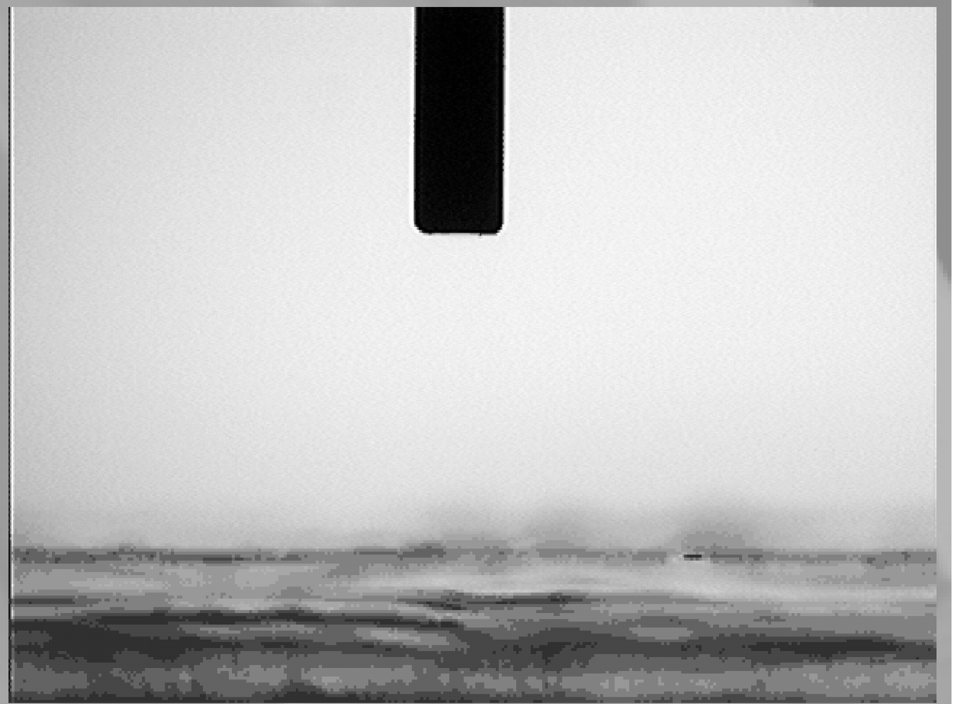
width and depth control

laser microfabrication

Superhydrophobic surfaces

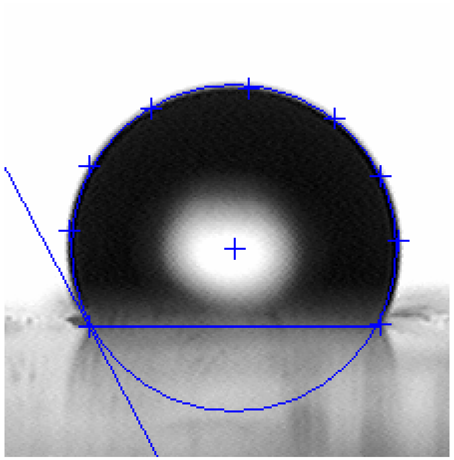


flat surface



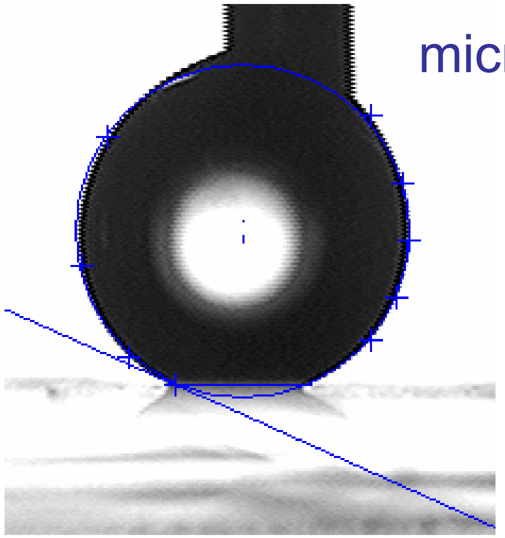
microstructured surface

microstructuring polymer



flat surface

θ = 118º



microstructured surface

θ = 160º

fs-laser microfabrication

Novel concept:

build a microstructure using fs-laser and nonlinear optical processes

two-photon polymerization

applications

- micromechanics
- waveguides
- microfluidics
- biology
- optical devices

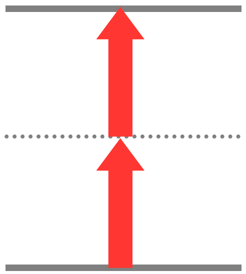
2

Two-photon polymerization

Monomer + Photoinitiator $\rightarrow$ Polymer

light

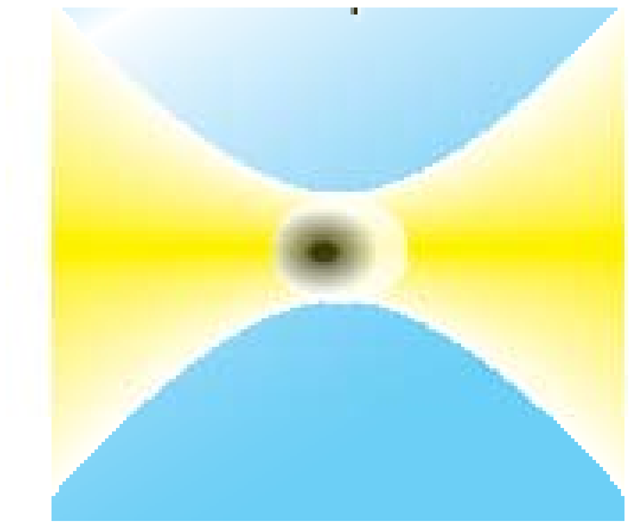
Photoinitiator is excited by ***two-photon absorption***



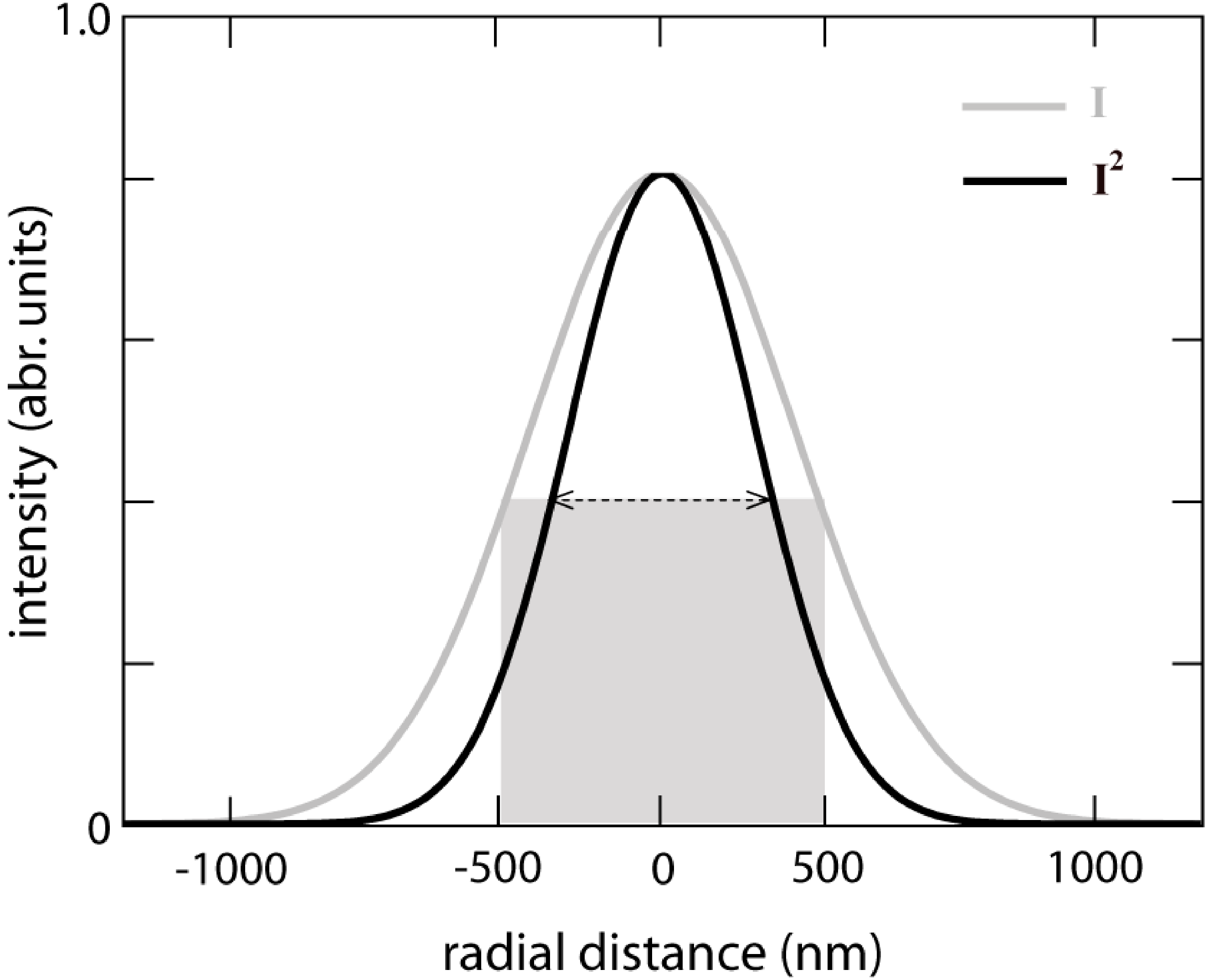
$$R_{2PA} \propto I^2$$

The polymerization is confined to the focal volume.

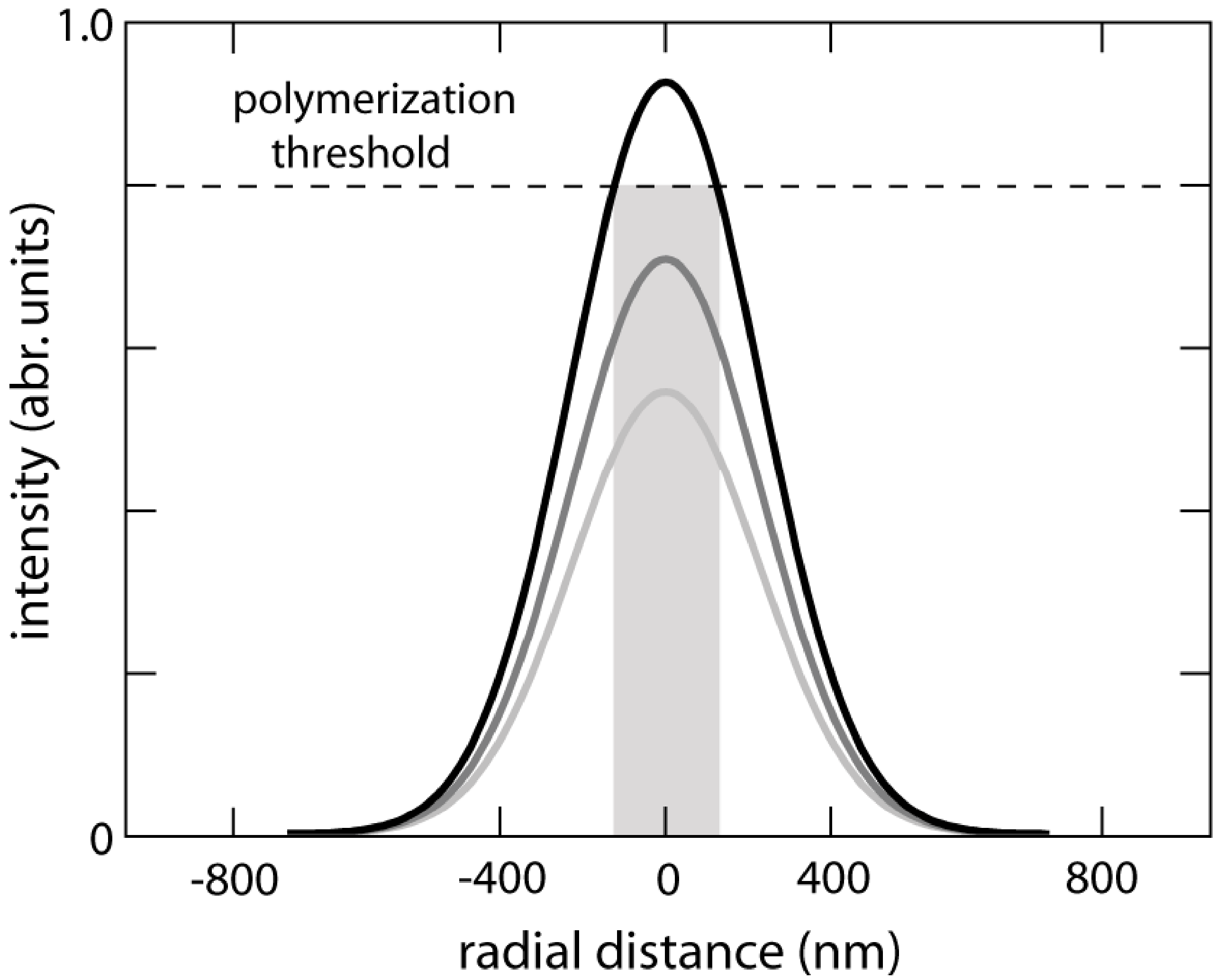
High spatial resolution



Two-photon polymerization

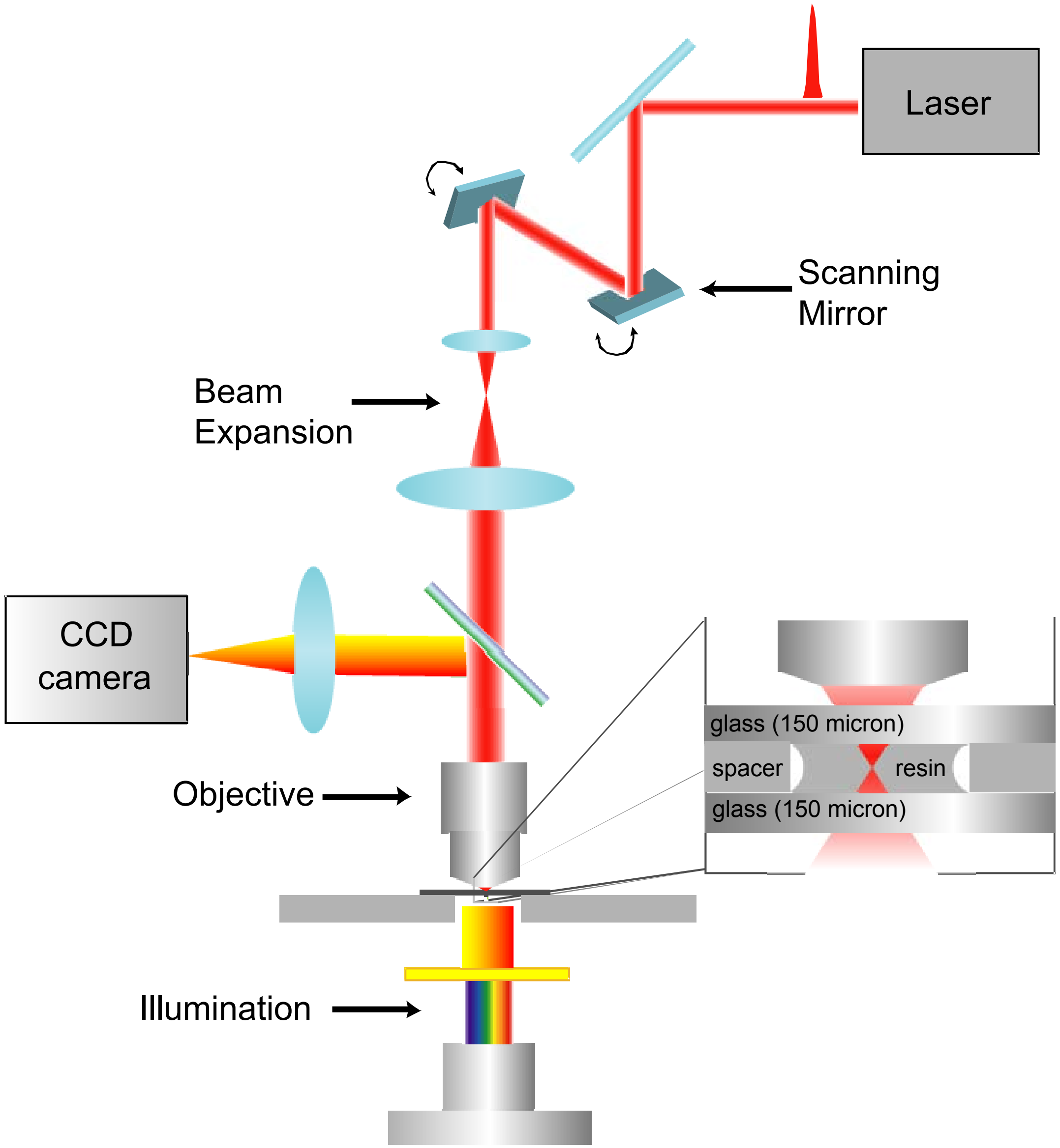


Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



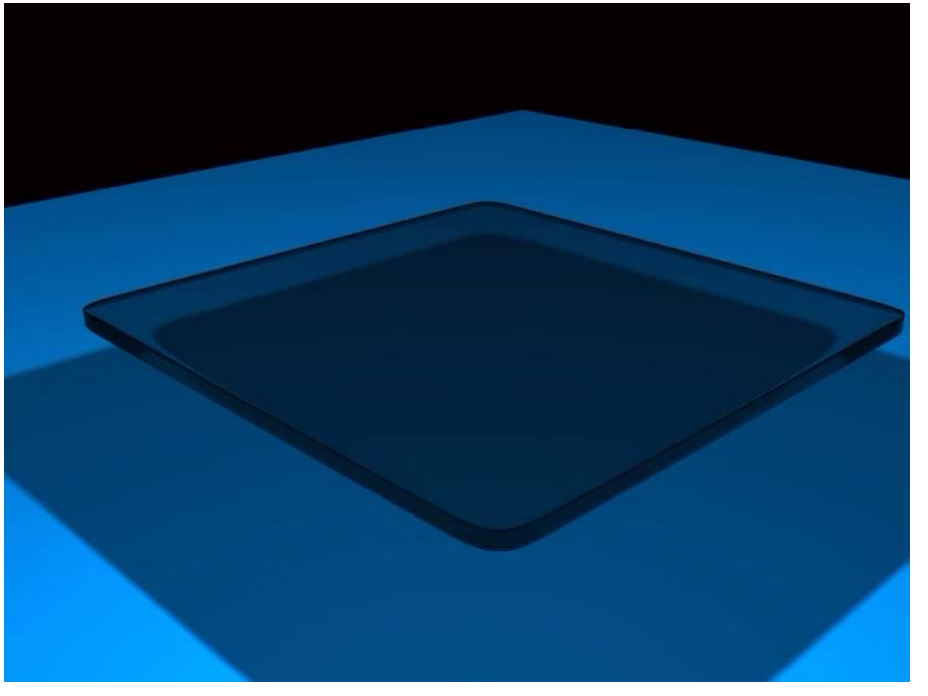
Ti:sapphire laser oscillator

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

Objective

40 x
0.65 NA

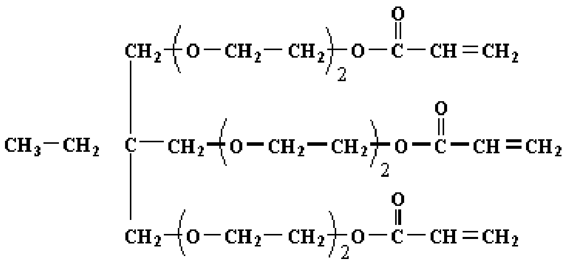
Two-photon polymerization



Resin Preparation

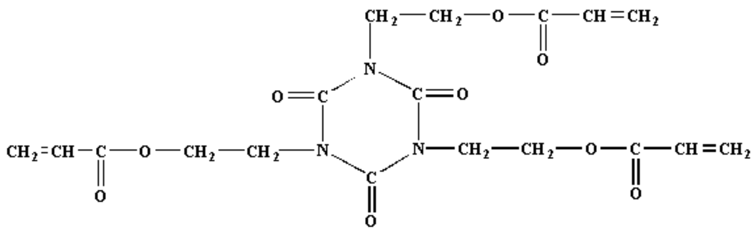
Monomers

Monomer A



reduces the shrinkage upon polymerization

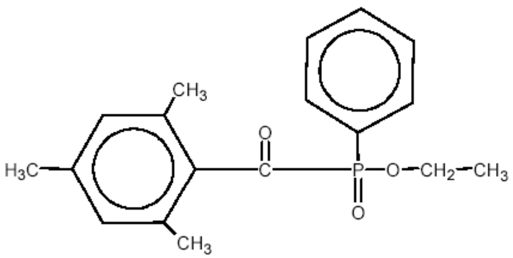
Monomer B



gives hardness to the polymeric structure

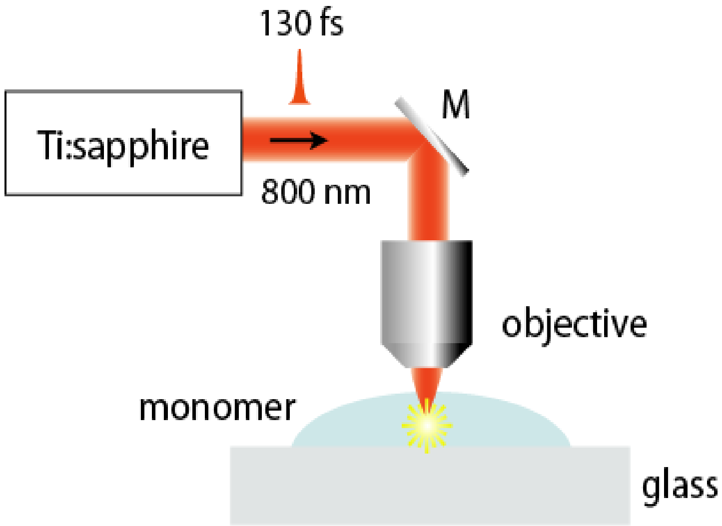
Photoinitiator

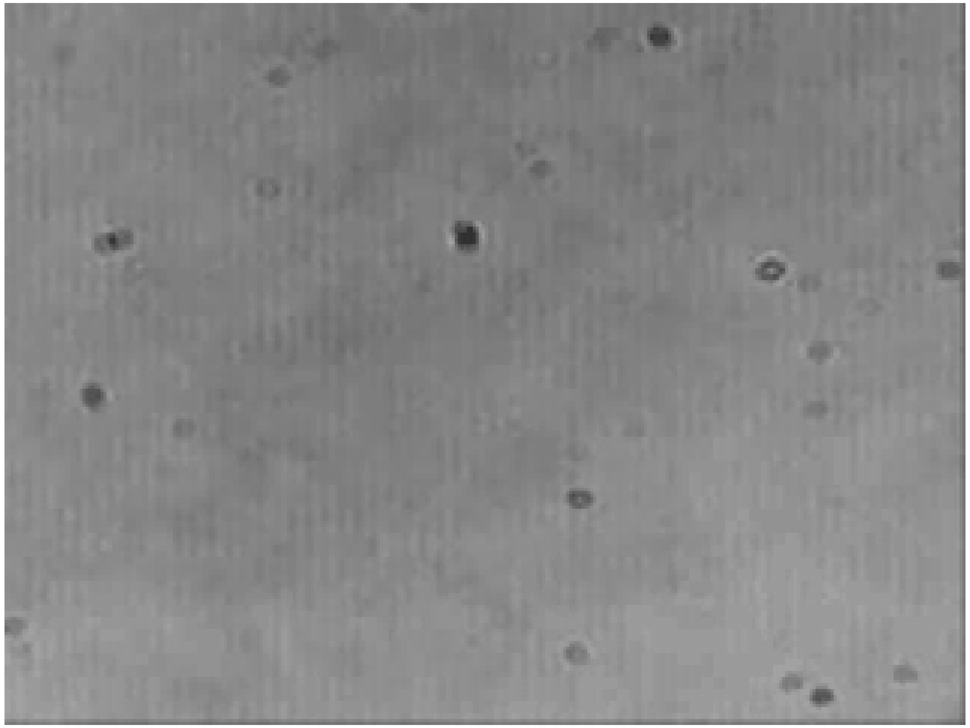
Lucirin



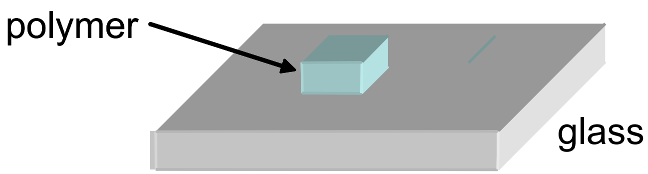
Appl. Phys. A, 90, 633–636 (2008)

Two-photon polymerization

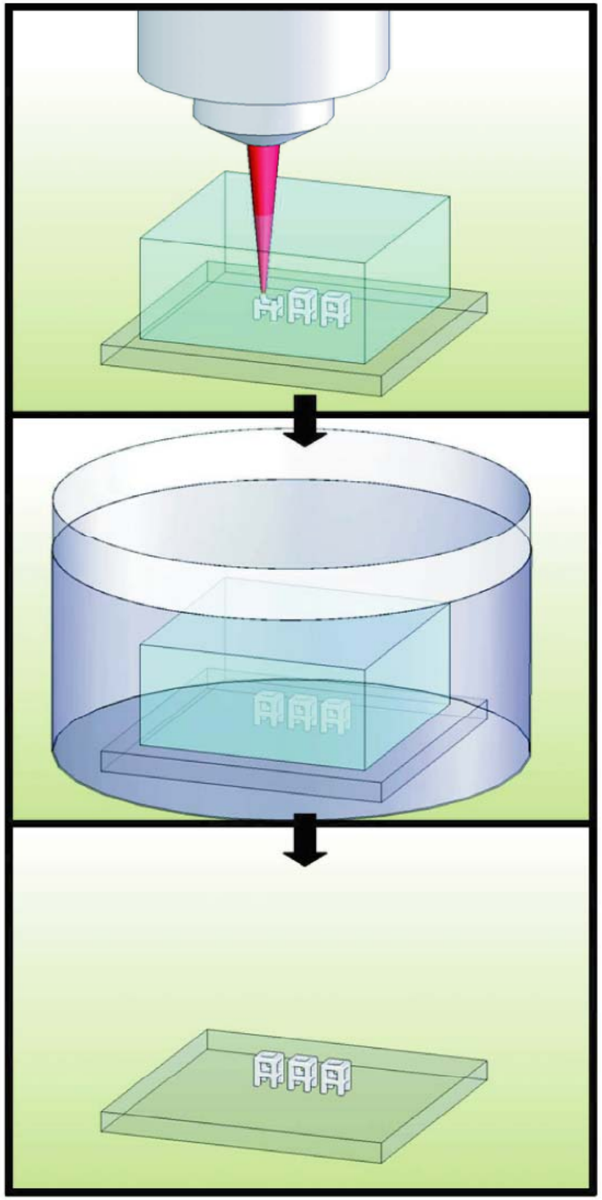




30 μm x 30 μm x 12 μm cube

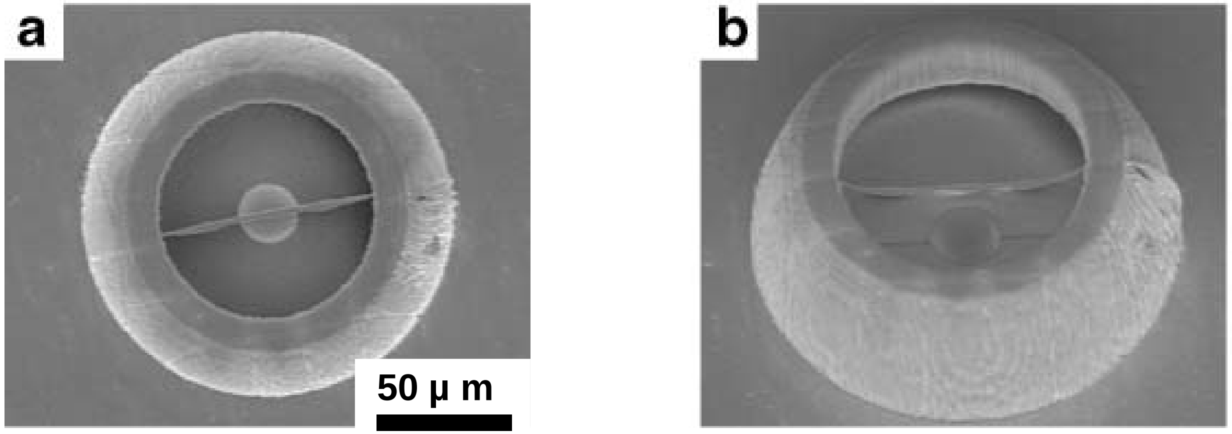


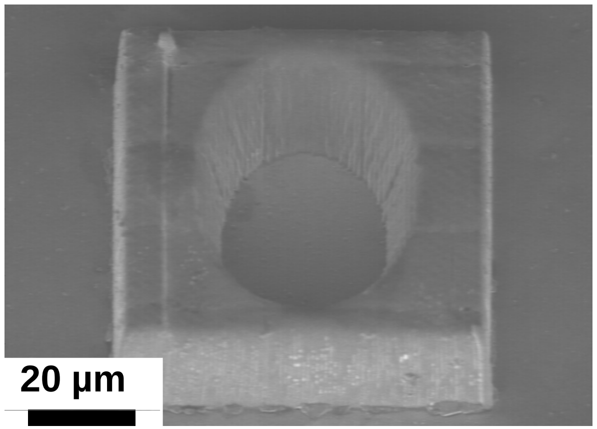
Two-photon polymerization

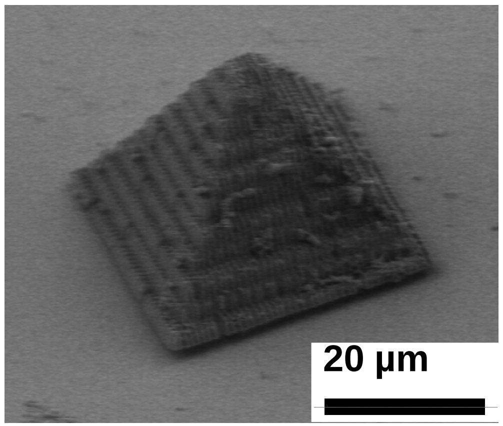


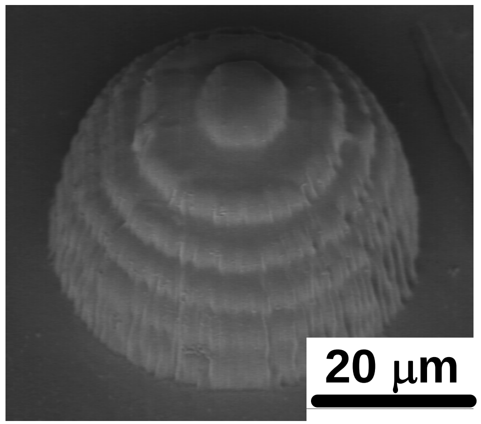
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

Microstructures fabricated by two-photon polymerization

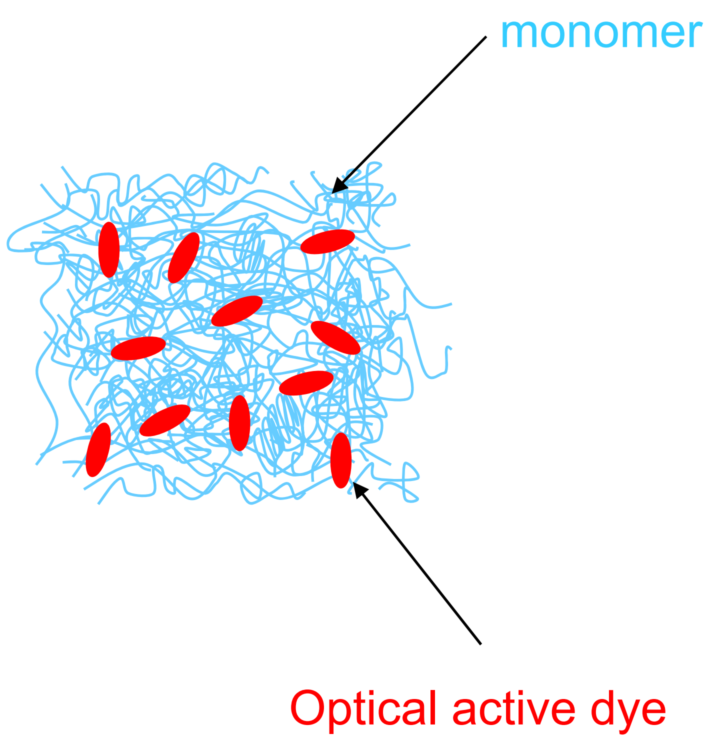


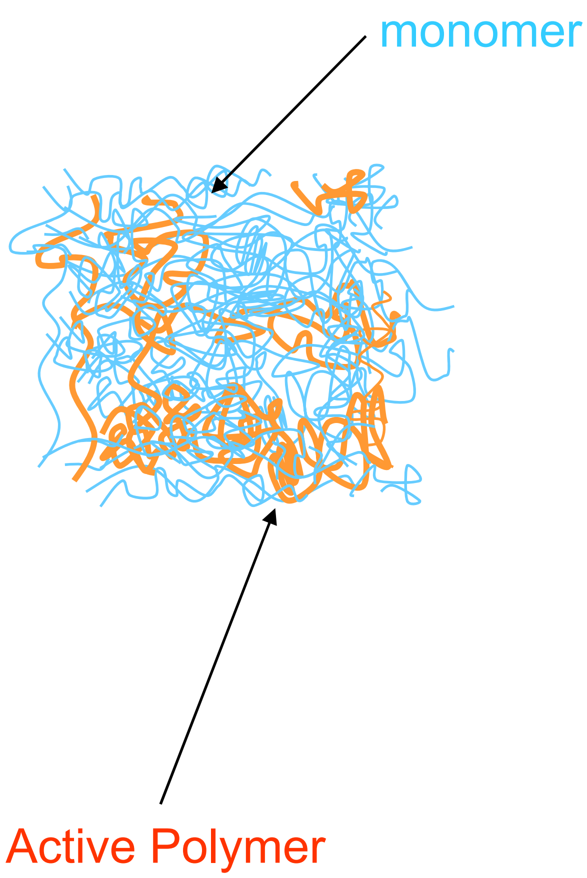






Microstructures containing active compounds





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

Applications

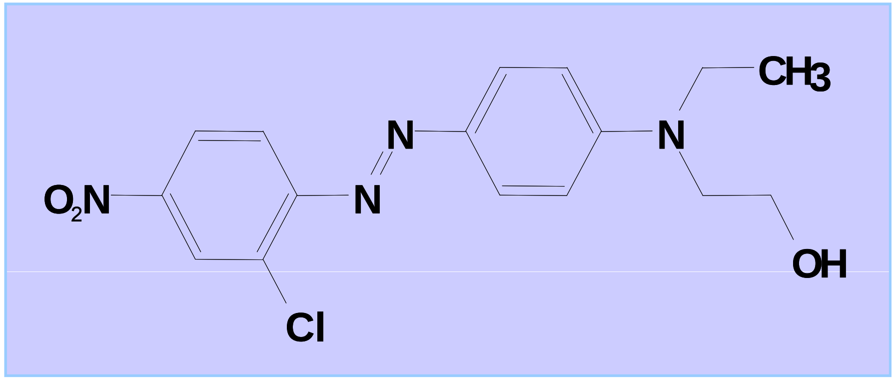
1) Optically induced birefringence

2) Emission and conduction

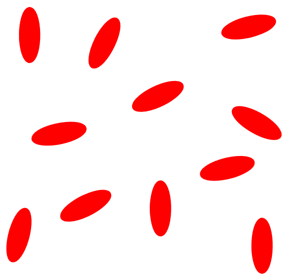
3) Biocompatible microstructure

Birefringent microstructures

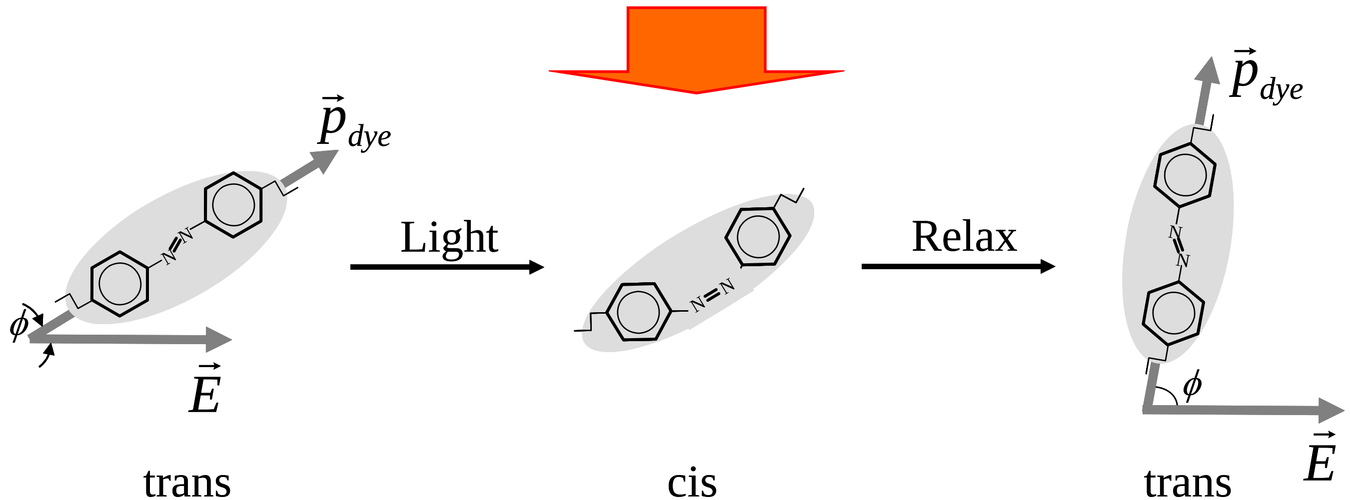
Incorporating the azodye DR13 into the microstructure



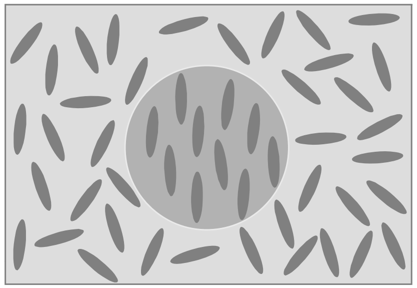
Birefringent microstructures



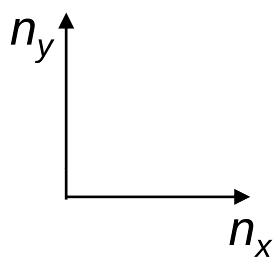
Molecular orientation by excitation with linearly polarized light



After alignment

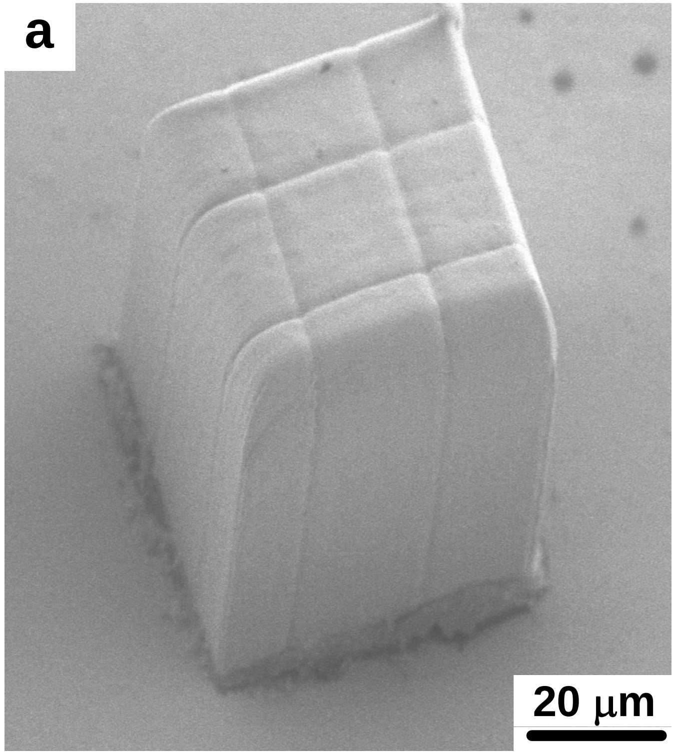


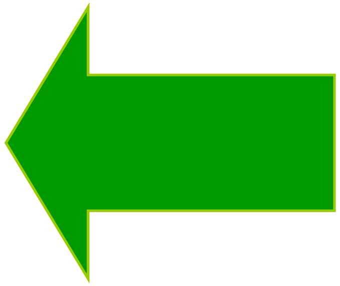
Optically Induced birefringence



$$n_y > n_x$$

Birefringent microstructures



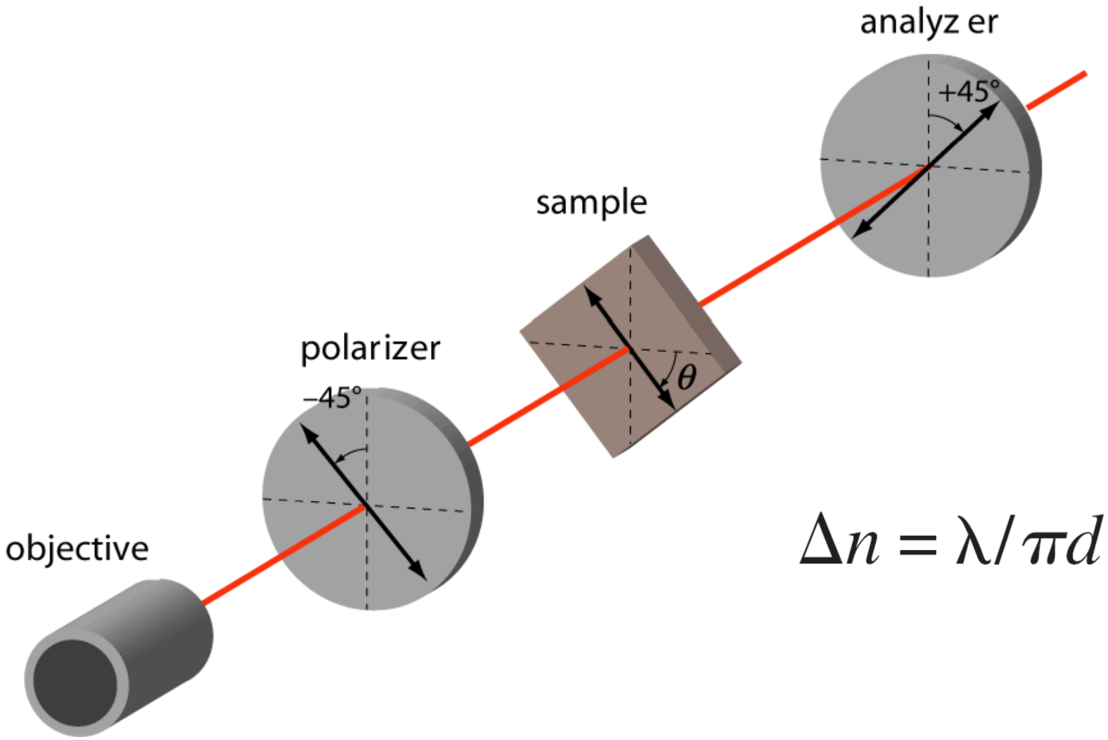


Ar+ ion laser irradiation

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

Birefringent microstructures

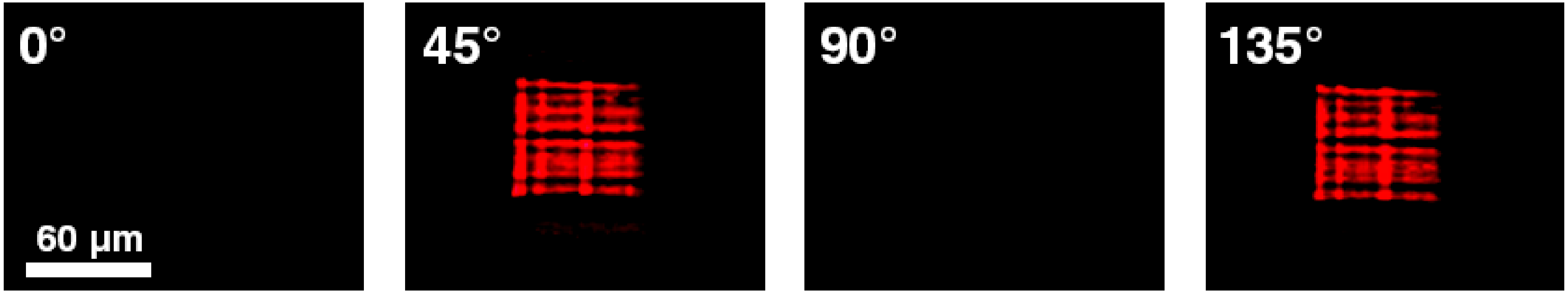
The sample was placed under an optical microscope between crossed polarizers and its angle was varied with respect to the polarizer angle



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

Birefringent microstructures

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



$\Delta n = 5x10^{-5}$

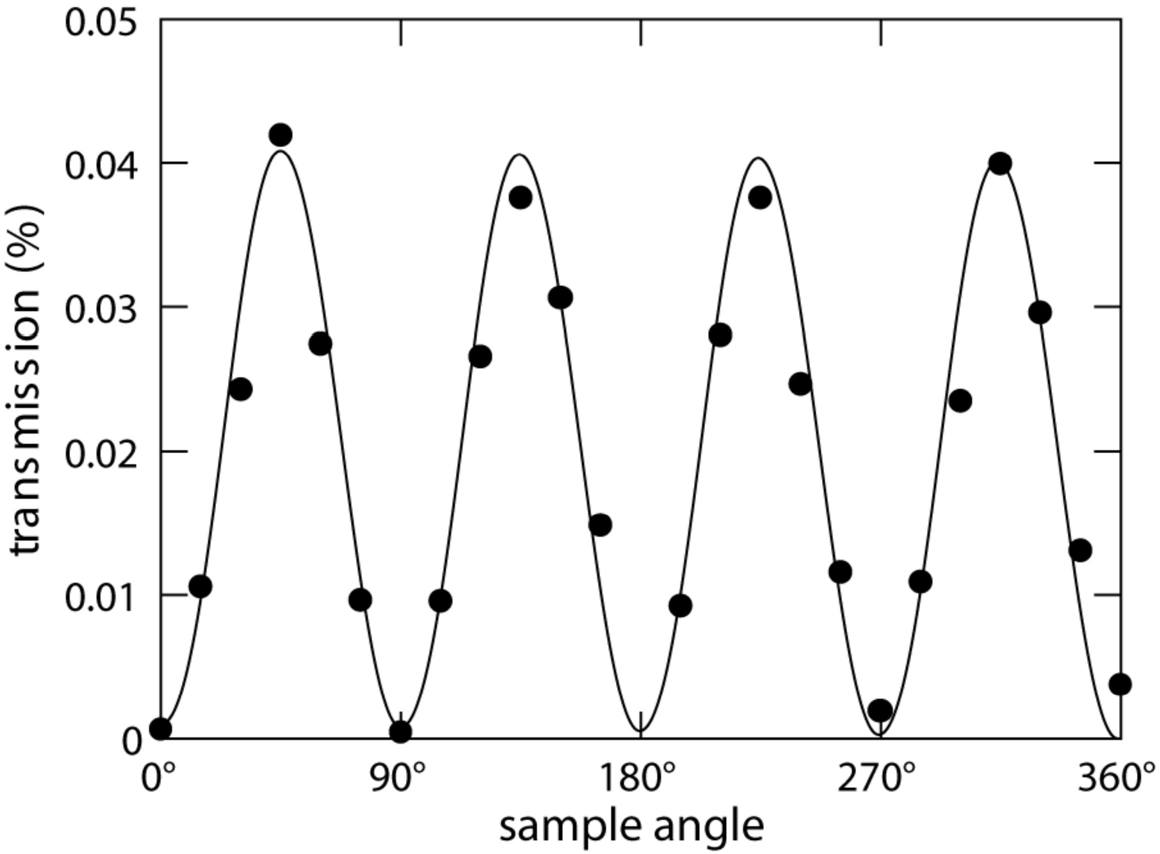
This birefringence can be completely erased by irradiating the sample with circularly polarized light.

Applications: micro-optical switch, micro-optical storage

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

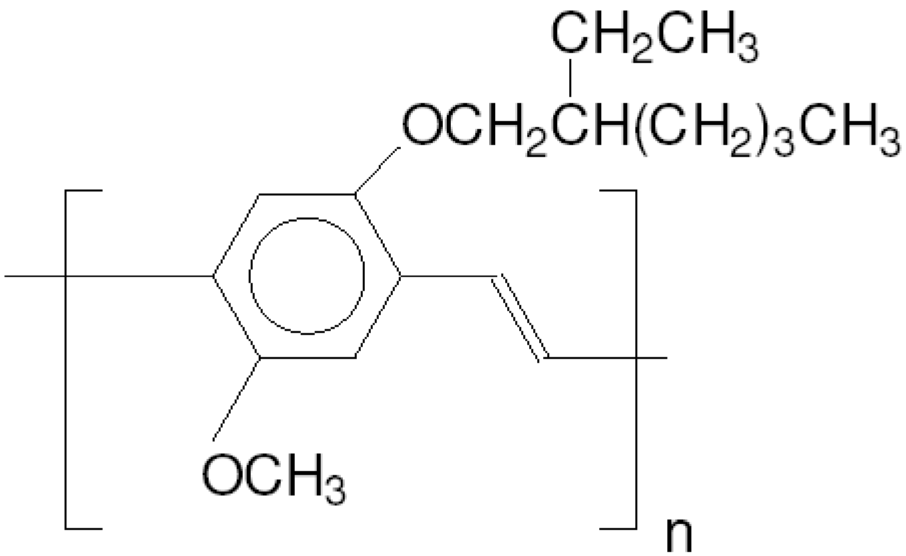
Birefringent microstructures

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



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

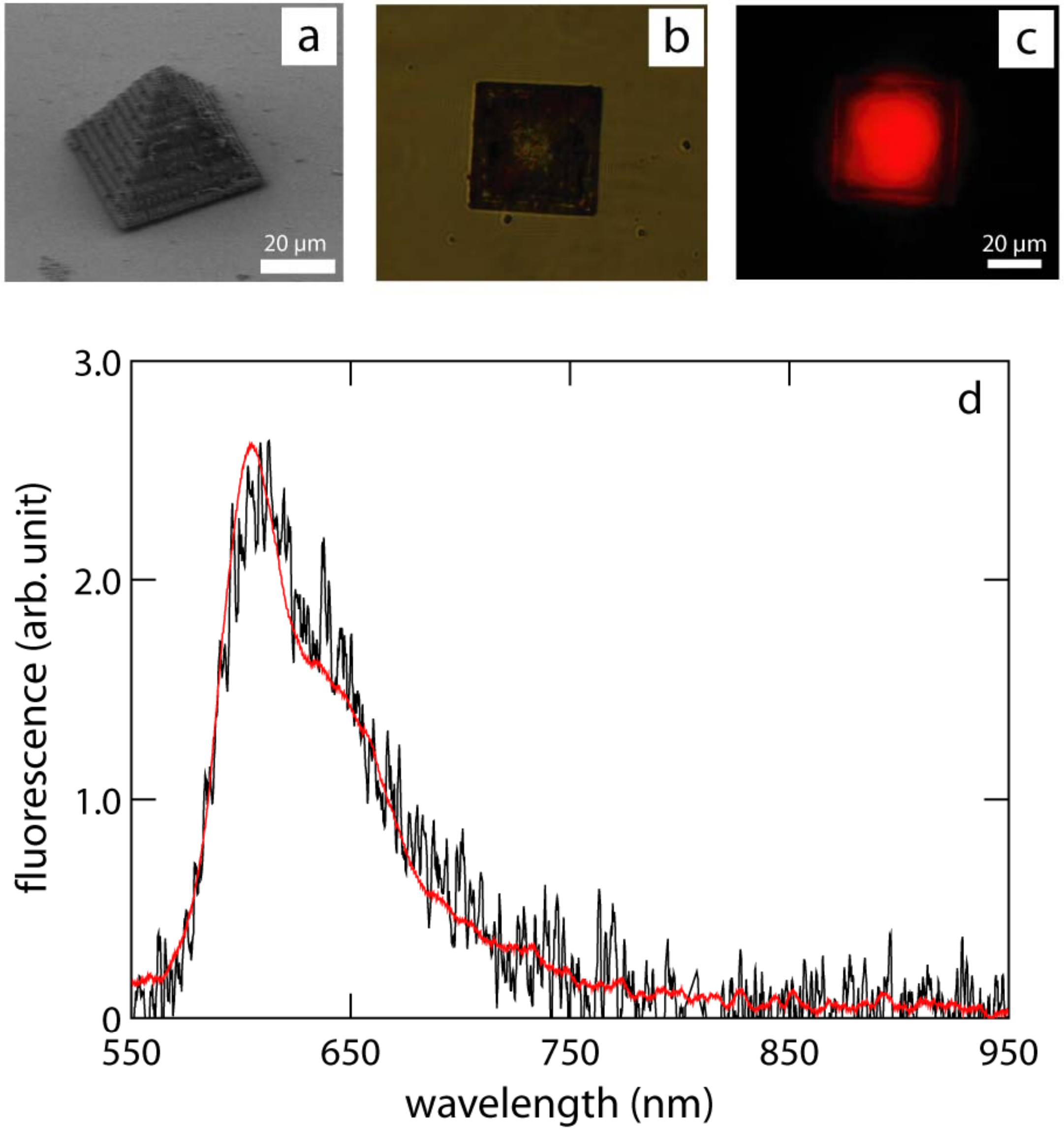
microstructure containing MEH-PPV



MEH-PPV

Fluorescence
Electro Luminescent
Conductive

microstructure containing MEH-PPV



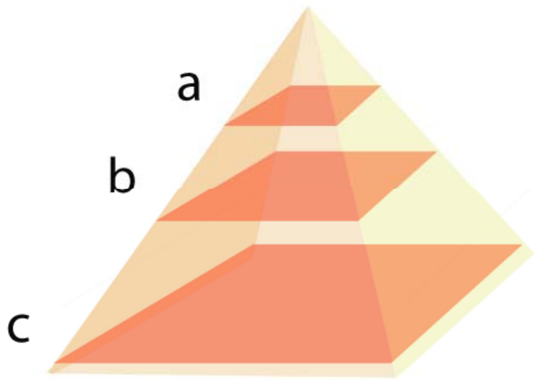
(a) Scanning electron microscopy

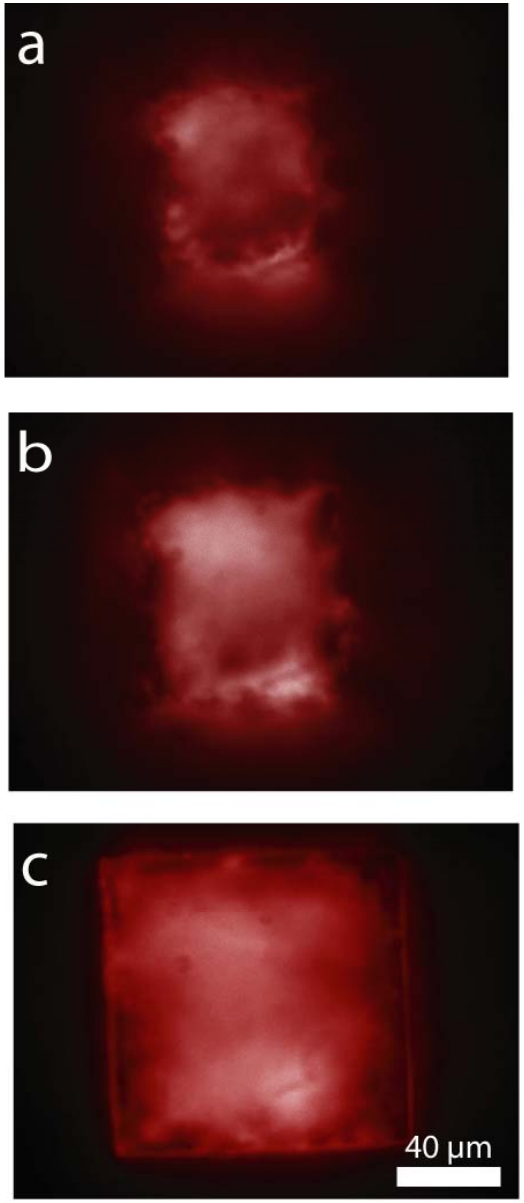
(b,c) Fluorescence microscopy of the microstructure with the excitation OFF (b) and ON (c)

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

Applied Physics Letters 95 113309 (2009)

microstructure containing MEH-PPV

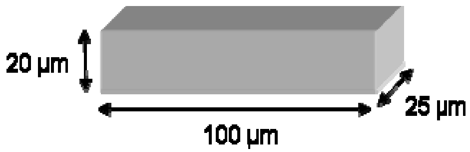


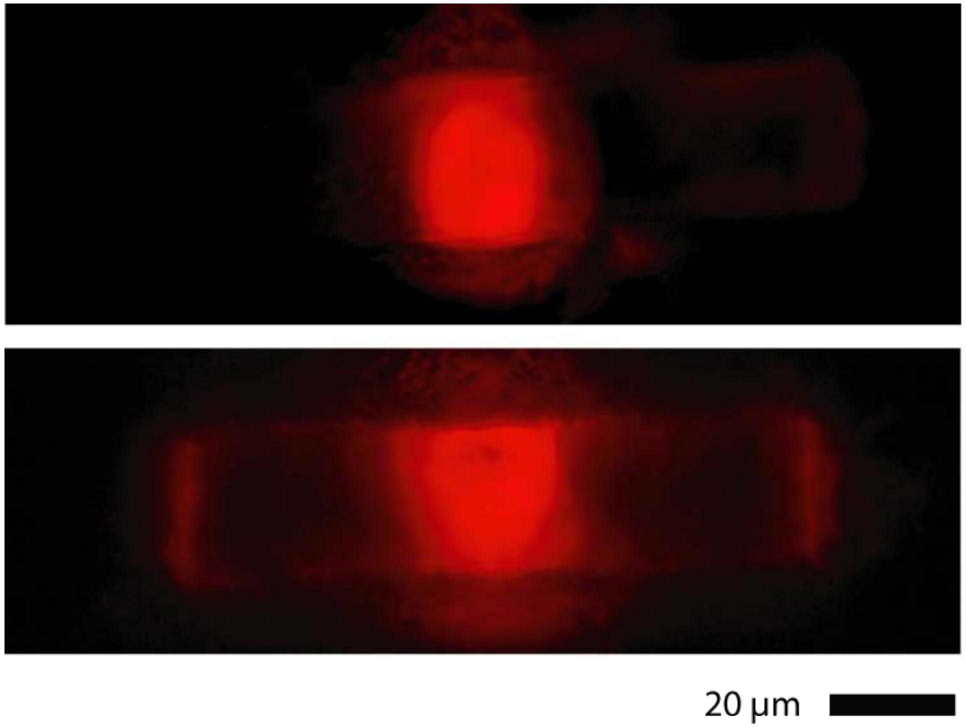


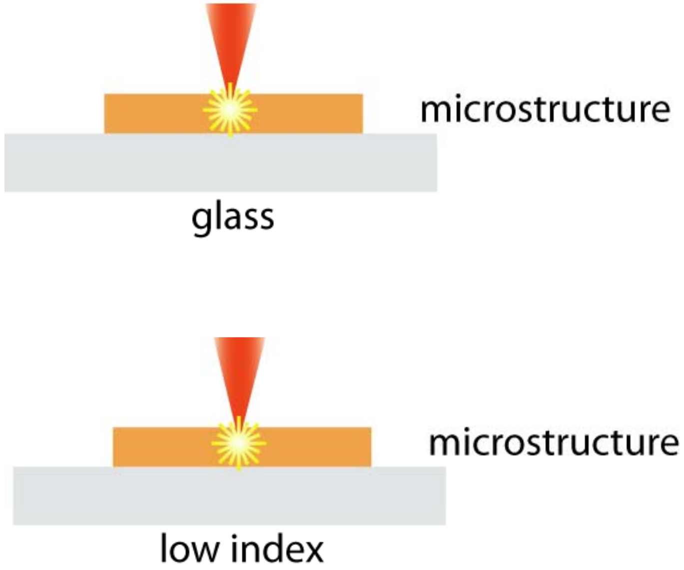
Fluorescent confocal microscopy images in planes separated by 16 μm in the pyramidal microstructure.

Applied Physics Letters 95 113309 (2009)

microstructure containing MEH-PPV



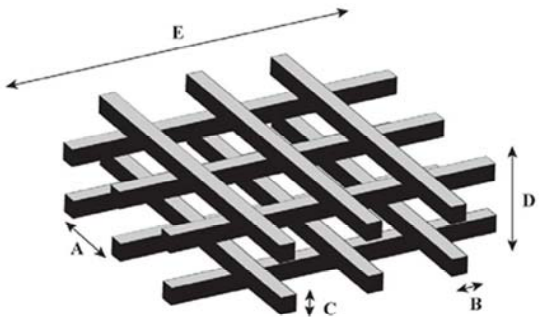




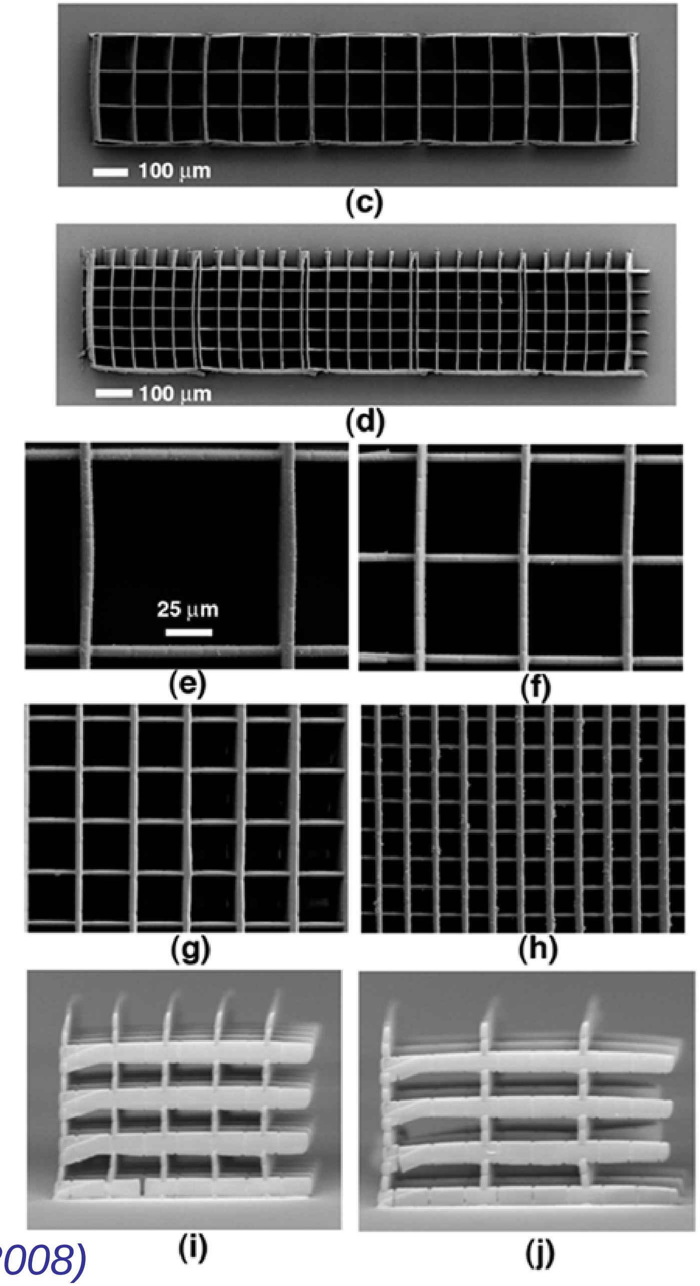
waveguiding of the microstructure fabricated on porous silica substrate (*n*= 1.185)

Applications: micro-laser; fluorescent microstructures; conductive microstructures

3D cell migration studies in micro-scaffolds



schematic of the scaffold



SEM of the scaffolds

110 µm pore size

52 µm pore size

Top view

110, 52, 25, 12 µm pore size

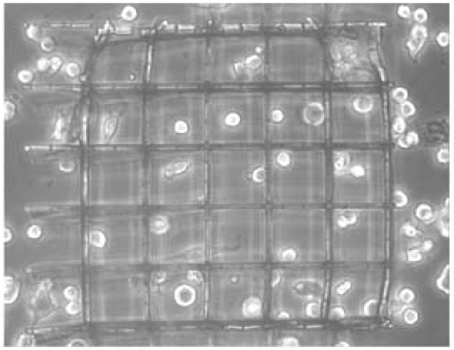
Side view

25, 52 µm pore size

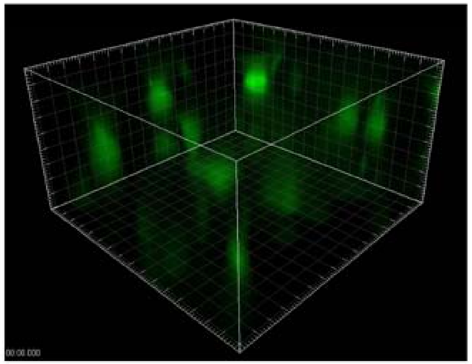
Advanced Materials, 20, 4494-4498 (2008)

cell migration

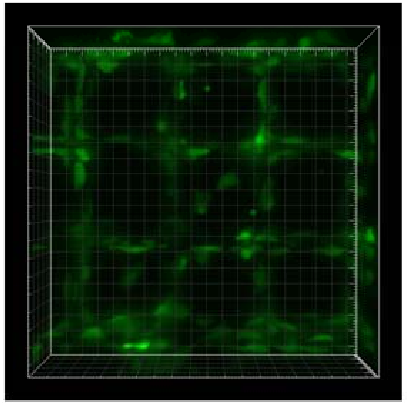
50 μm pore size after 5 hours



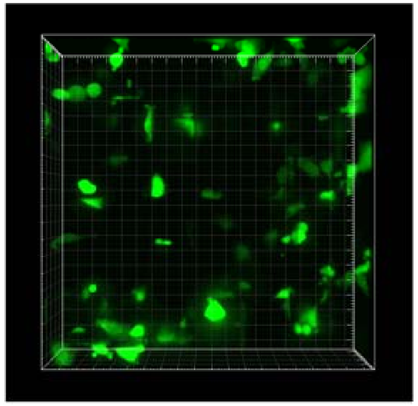
(a)



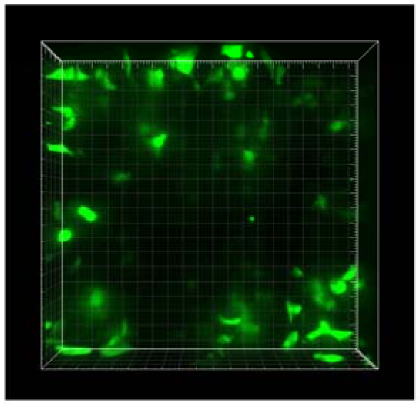
(b)



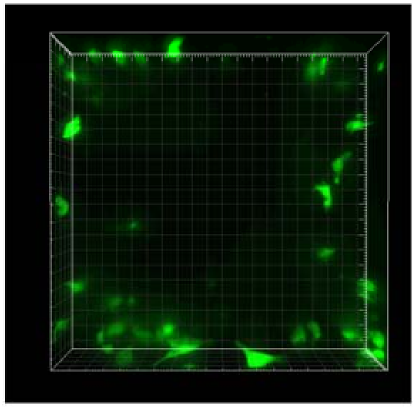
(c)



(d)



(e)



(f)

c-d: 110, 52, 25 and 12 μm

Acknowledgments

FAPESP
CAPES
CNPq

NSF
ARO

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Obrigado!

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