

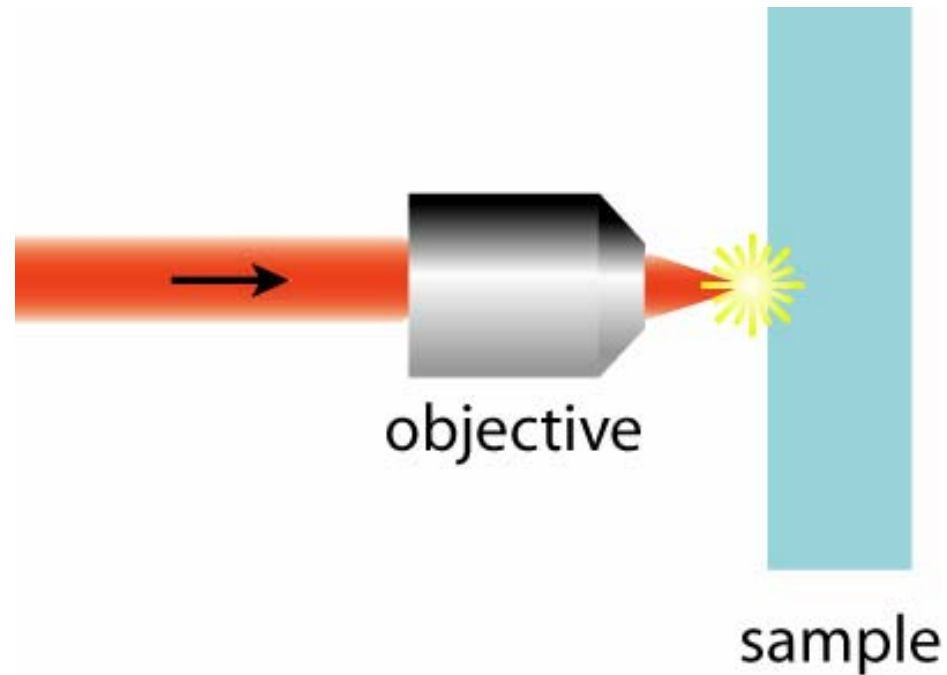
Sculpturing with light: micro/nanofabrication using ultrashort pulses

Prof. Dr. Cleber R. Mendonca

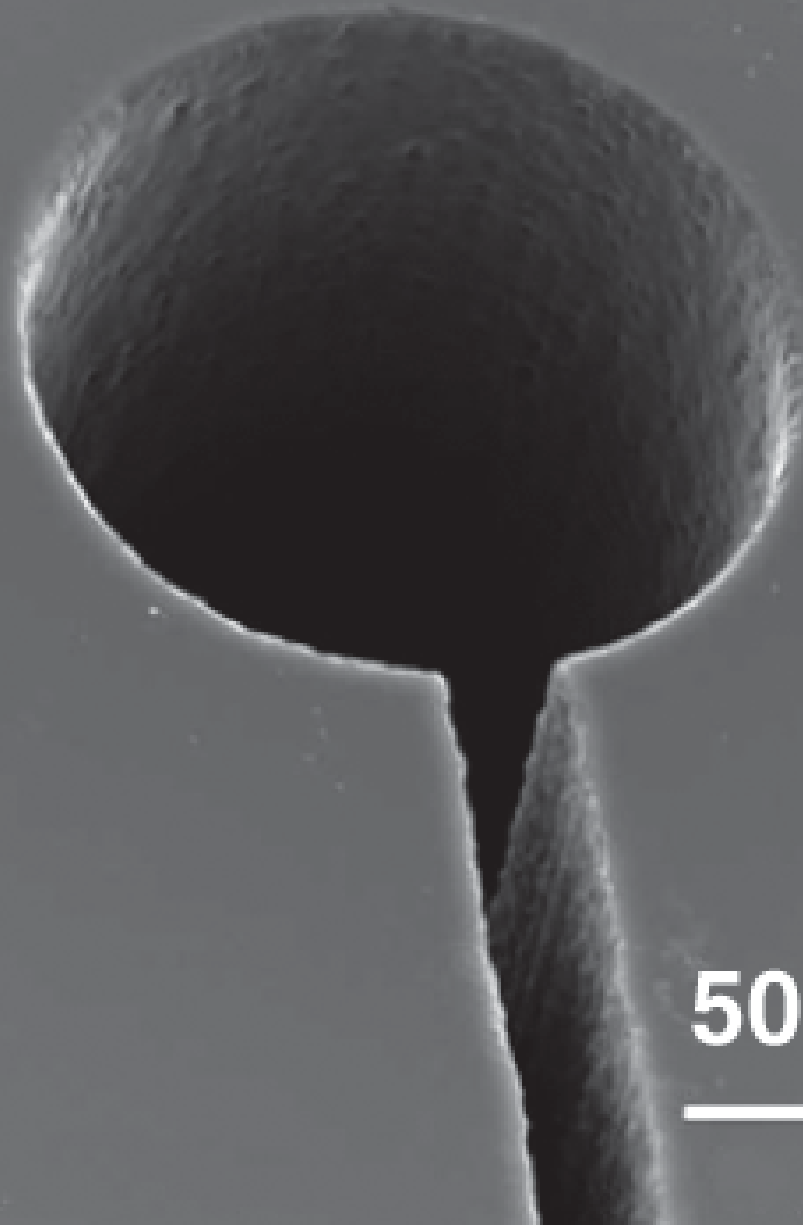


laser microfabrication

focus laser beam on material's surface

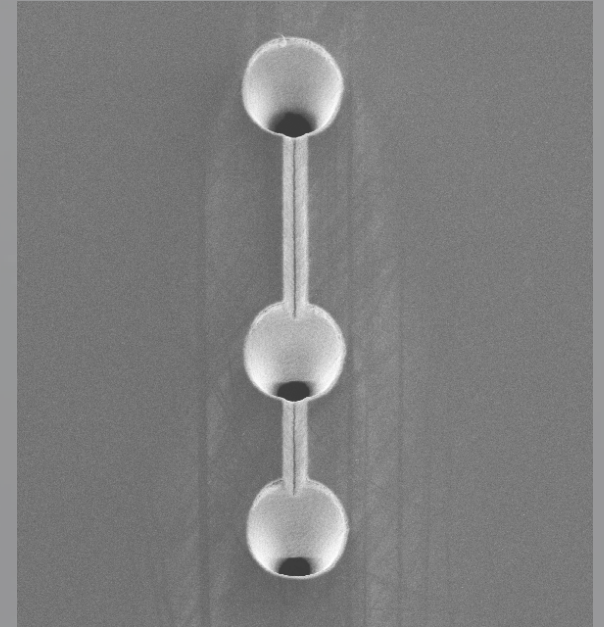
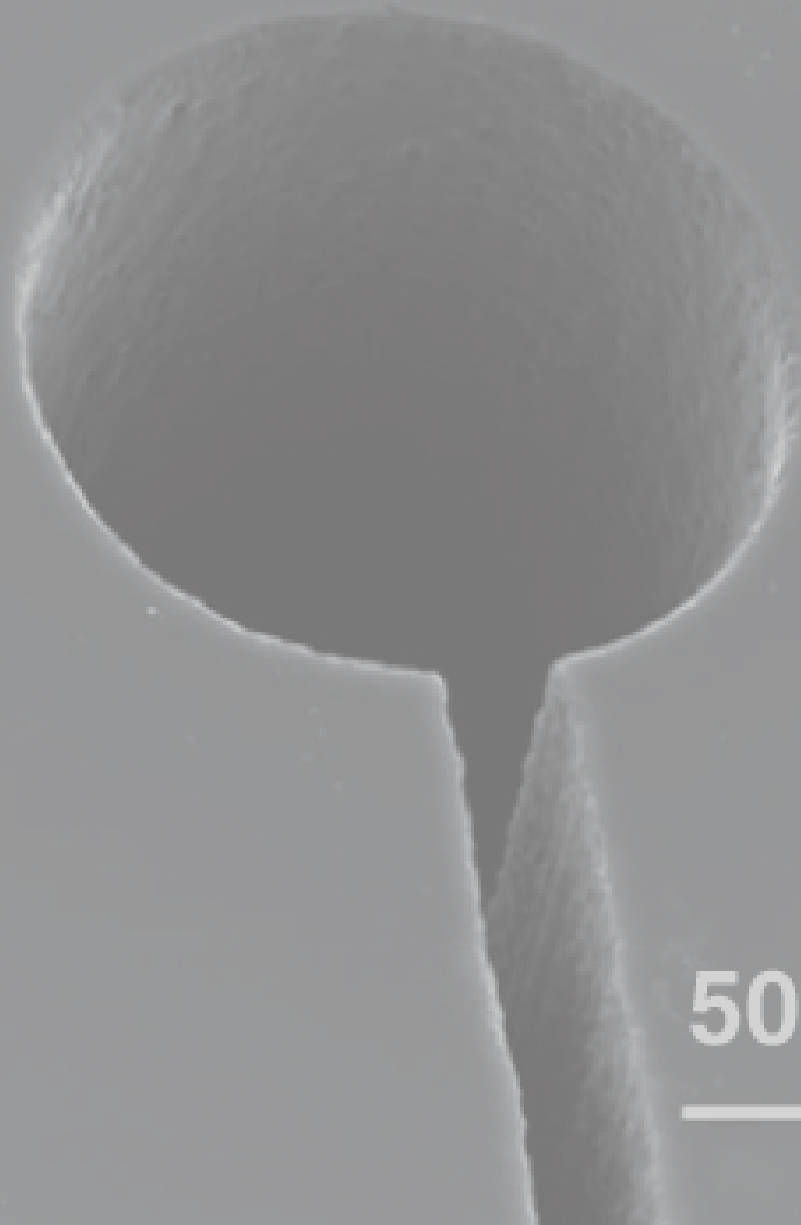


laser microfabrication



50 μm

laser microfabrication



50 μm

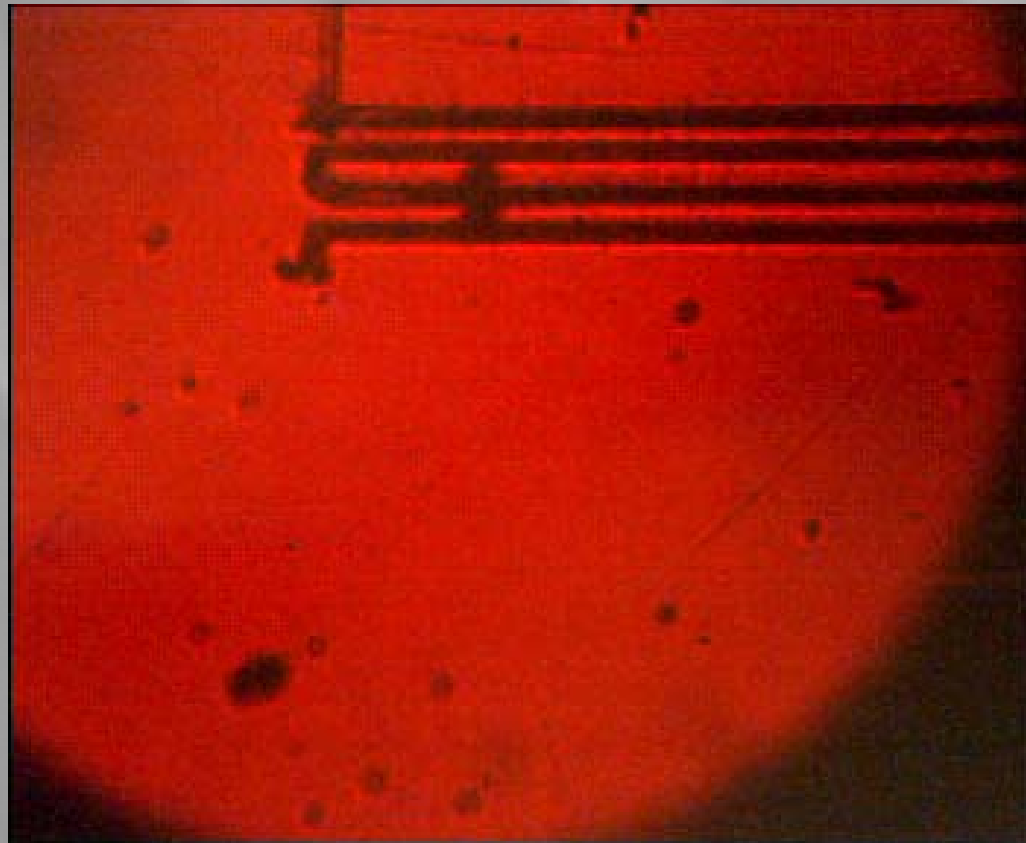
laser microfabrication

surface microstructuring

laser microfabrication

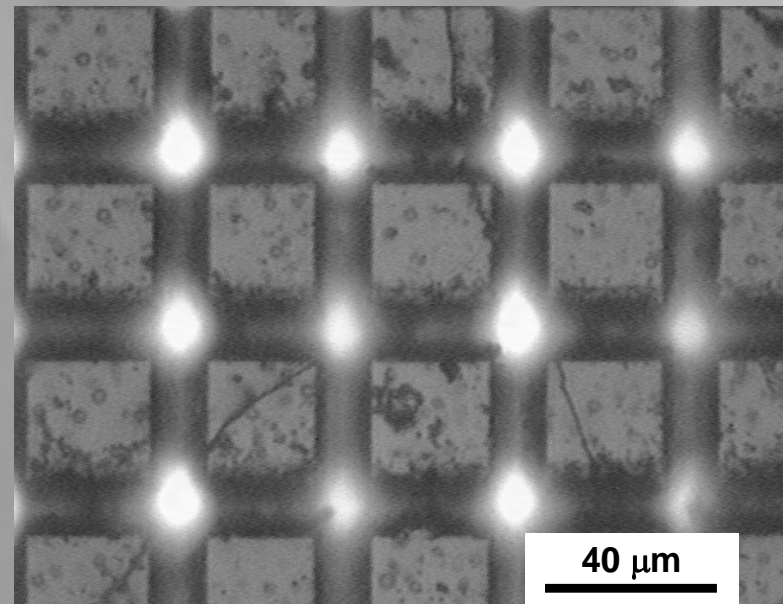
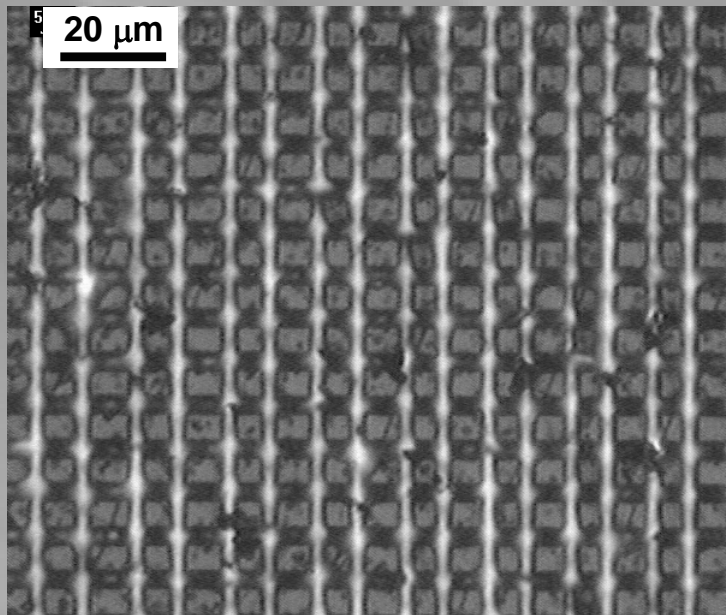
superhydrophobic surfaces

azopolymeric films micromachined with 100 ps pulses at 532 nm



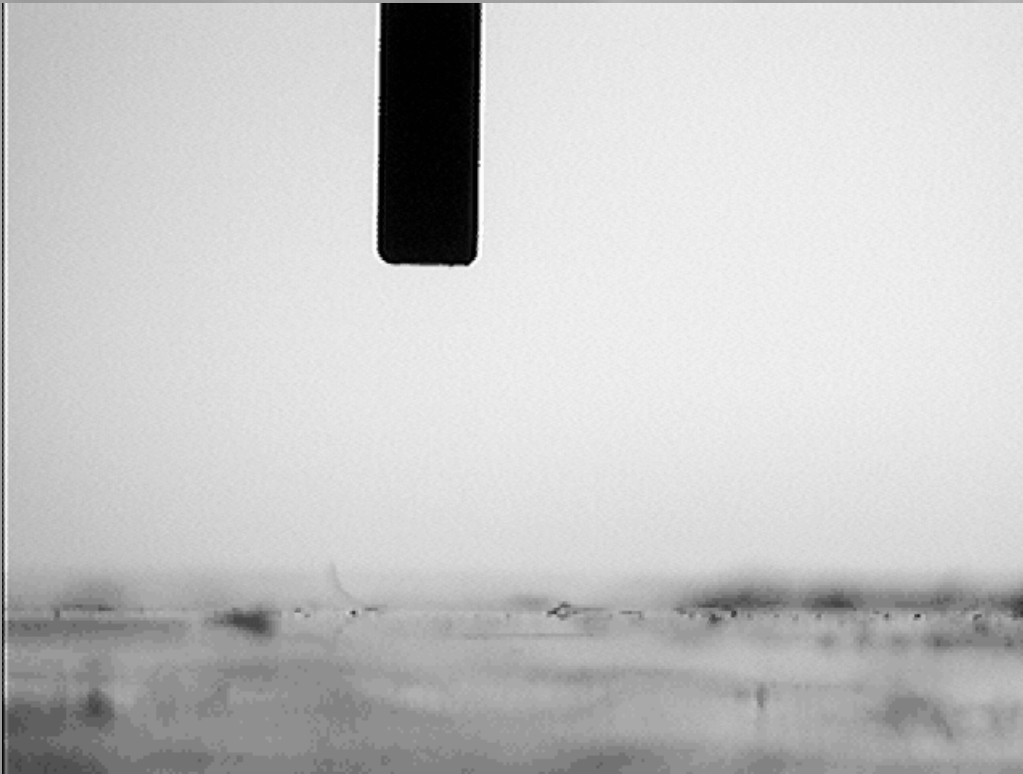
laser microfabrication

examples of fabricated surfaces

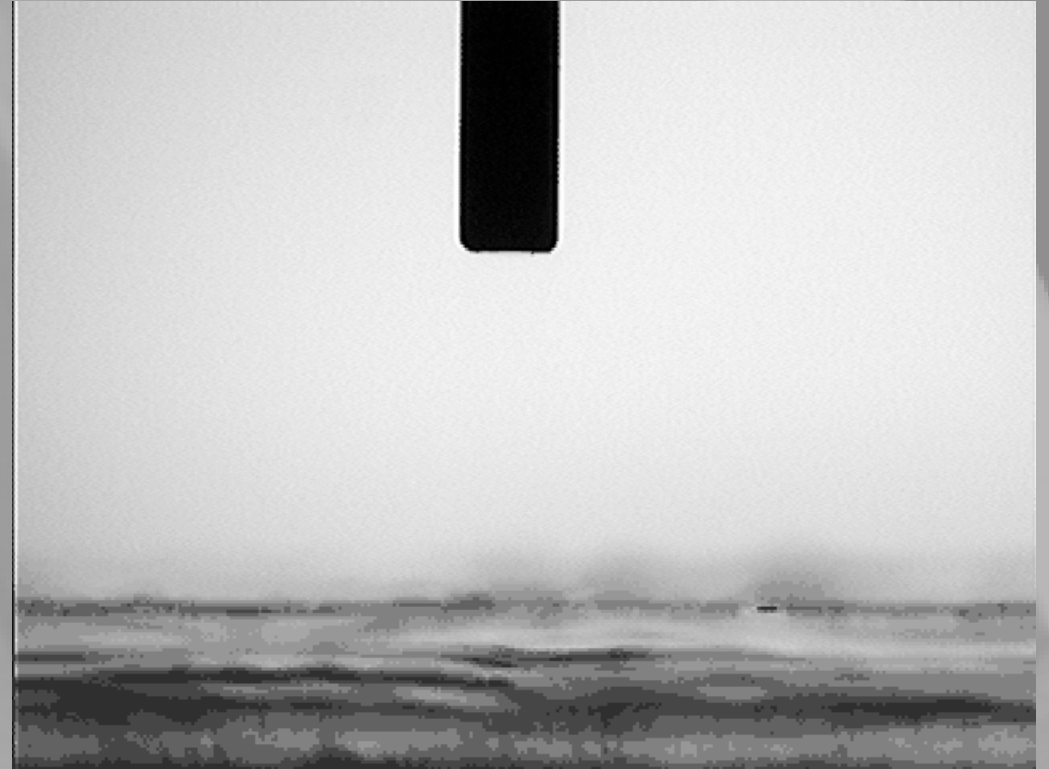


laser microfabrication

Superhydrophobic surfaces



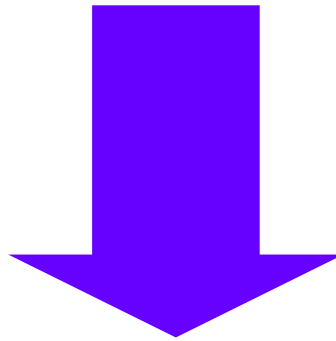
flat surface



microstructured surface

fs-laser microfabrication

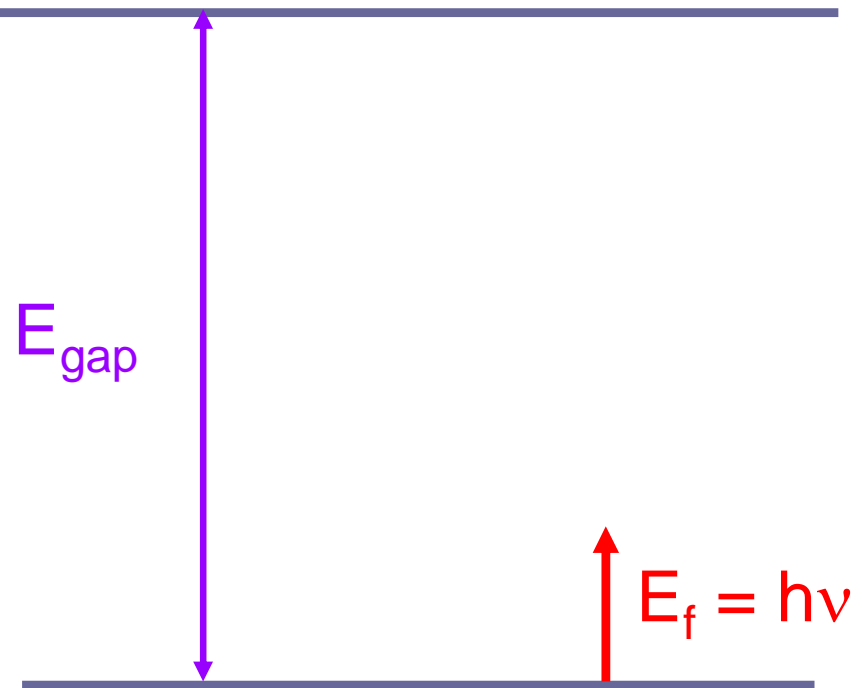
photon energy $<$ bandgap



nonlinear interaction

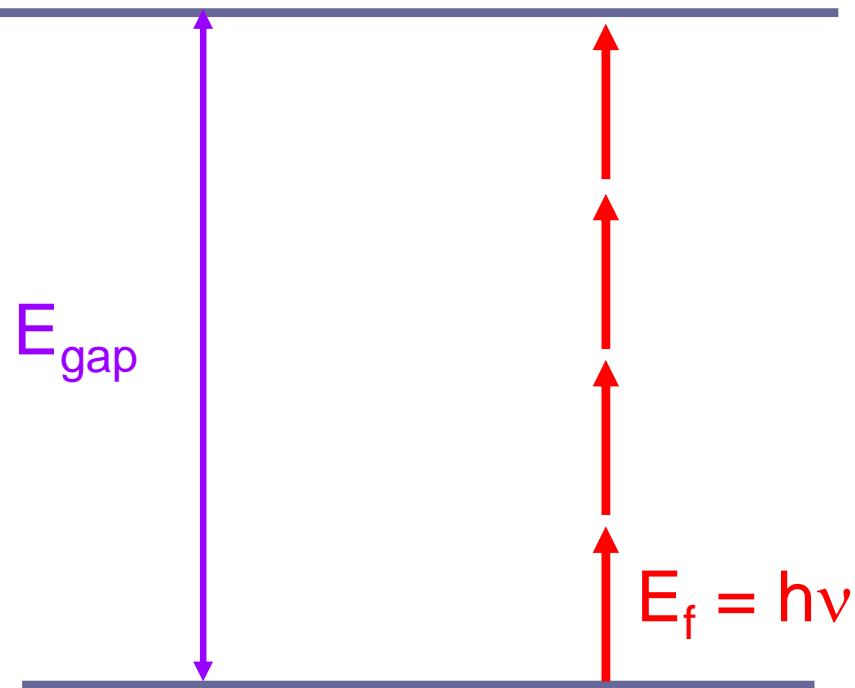
fs-laser microfabrication

nonlinear interaction



fs-laser microfabrication

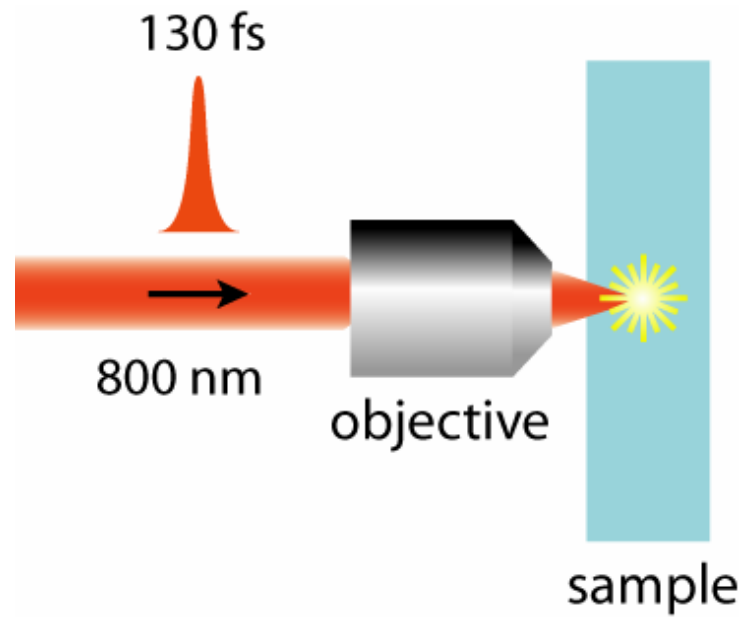
nonlinear interaction



multiphoton absorption

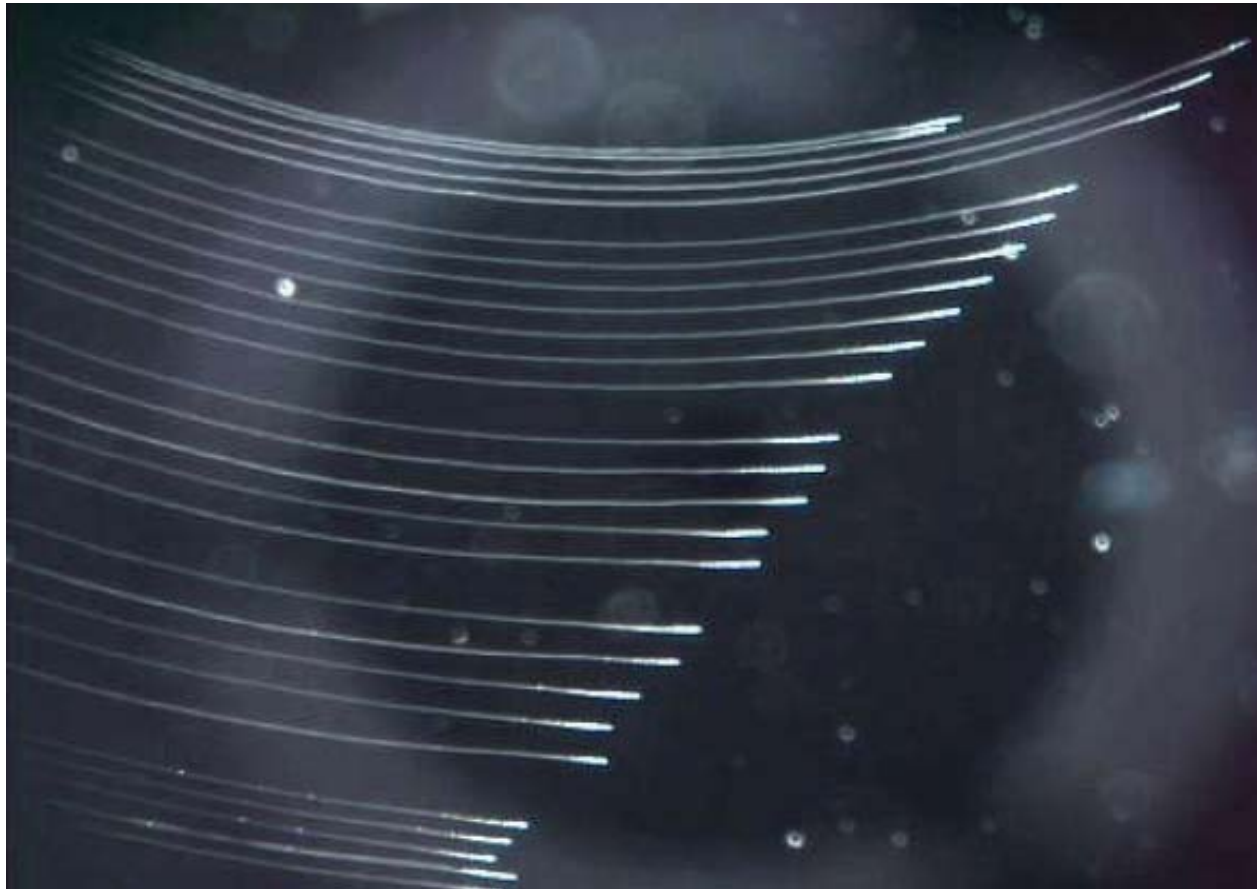
fs-laser microfabrication

focus laser beam inside material



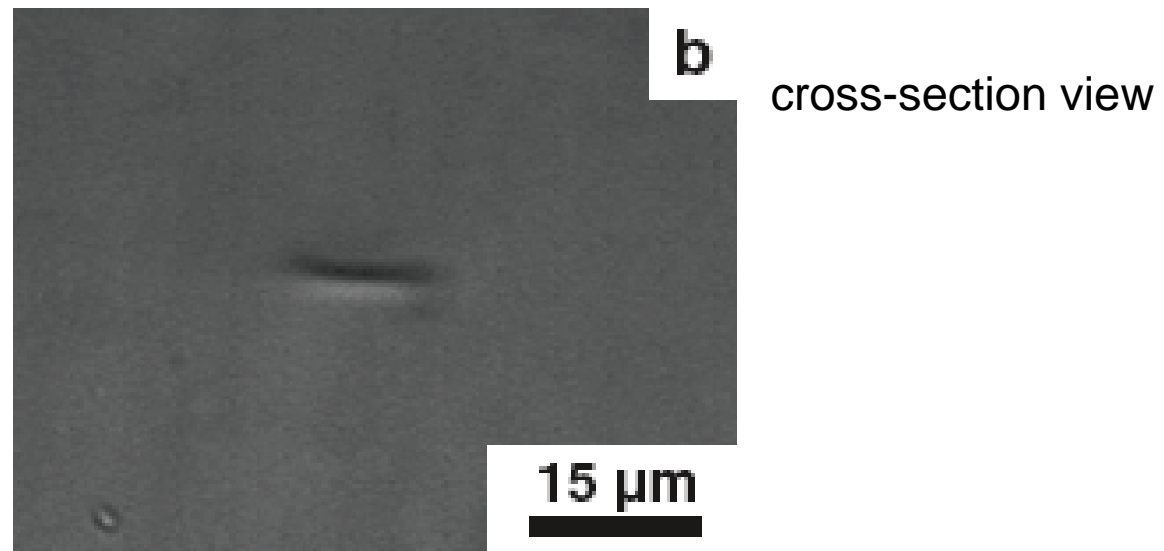
fs-laser microfabrication

curved waveguides inside glass



fs-laser microfabrication

3D waveguides in PMMA



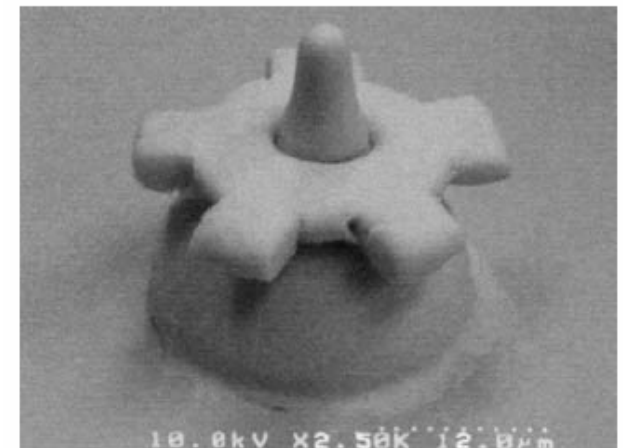
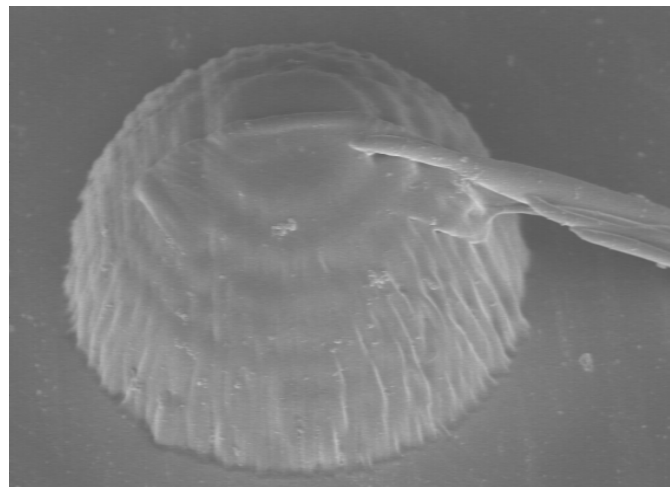
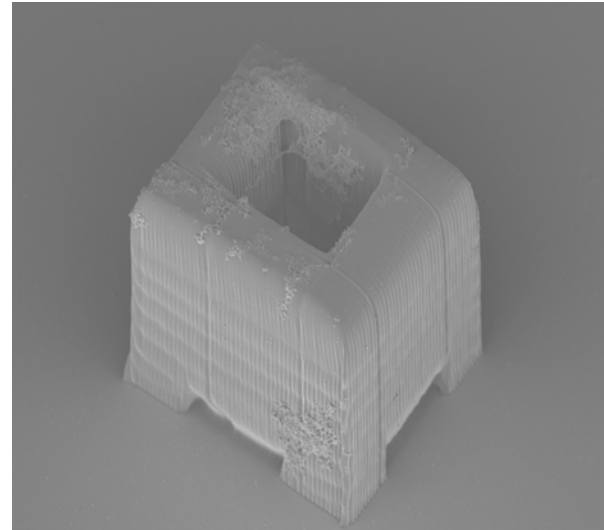
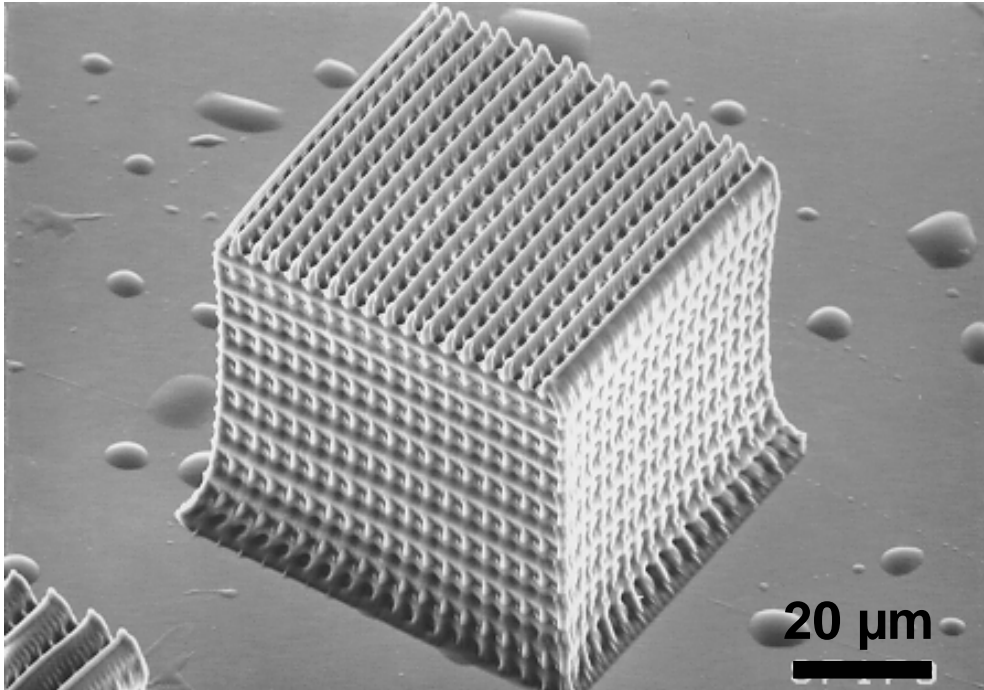
fs-laser microfabrication

Novel concept:

build a microstructure using fs-laser and nonlinear optical processes

two-photon polymerization

photonic crystal – J. W. Perry



two-photon polymerization

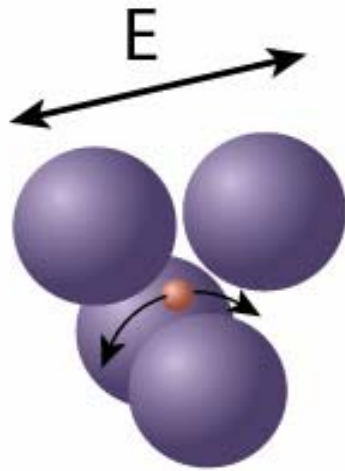
applications

- micromechanics
- waveguides
- microfluidics
- biology
- optical devices

Outline

- two-photon polymerization microfabrication
- microstructures containing MEH-PPV
- waveguiding the MEH-PPV emission
- other studies
- summary

Nonlinear Optics



anharmonic oscillator

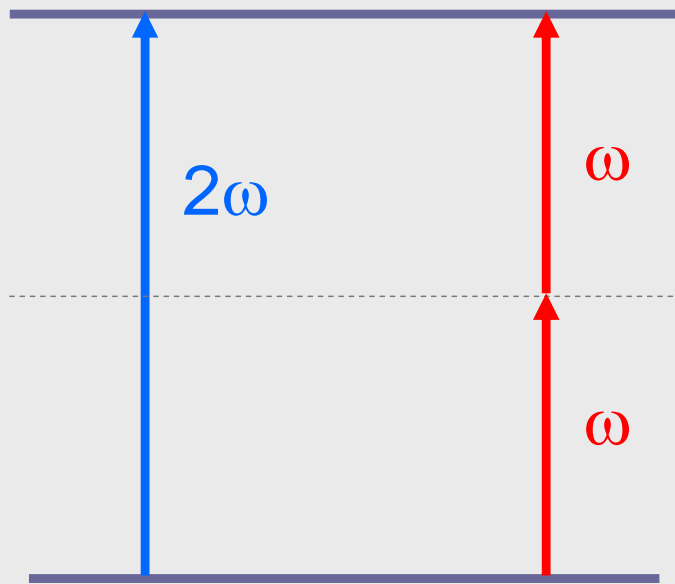
high light intensity

$$E_{\text{rad.}} \sim E_{\text{inter.}}$$

nonlinear polarization response

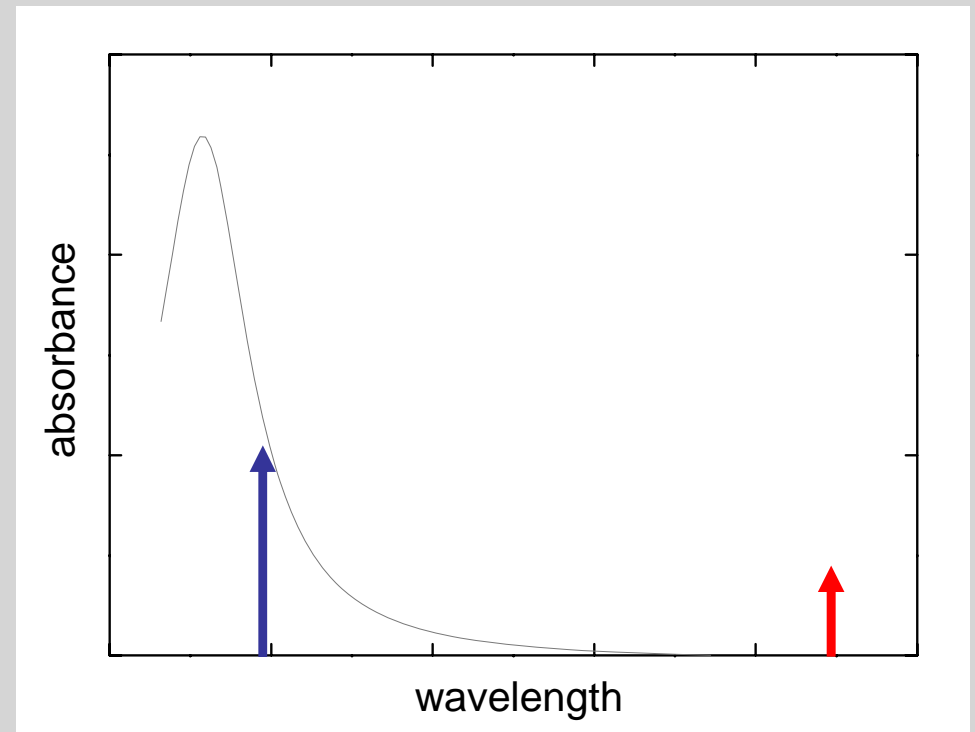
$$P = \chi^{(1)} E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \dots$$

Two-photon absorption



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

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



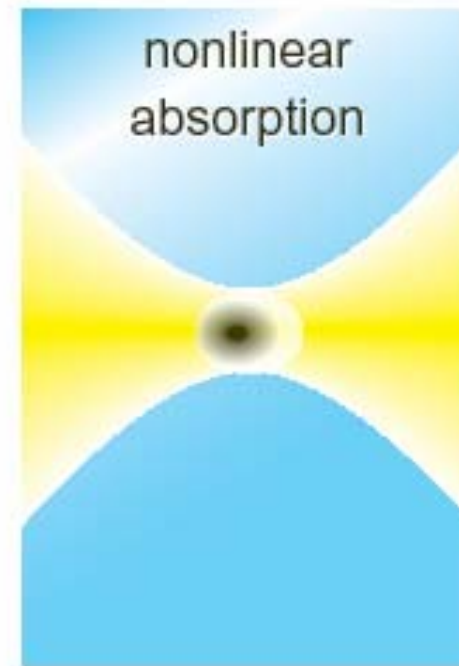
Two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication



$$\alpha = \alpha_0$$



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

Two-photon absorption

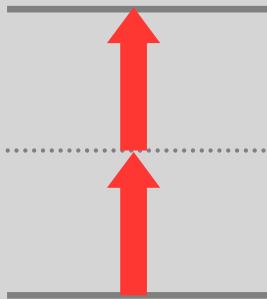


spatial confinement of excitation

Two-photon polymerization

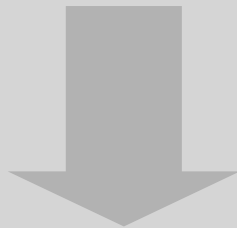


Photoinitiator is excited by ***two-photon absorption***



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

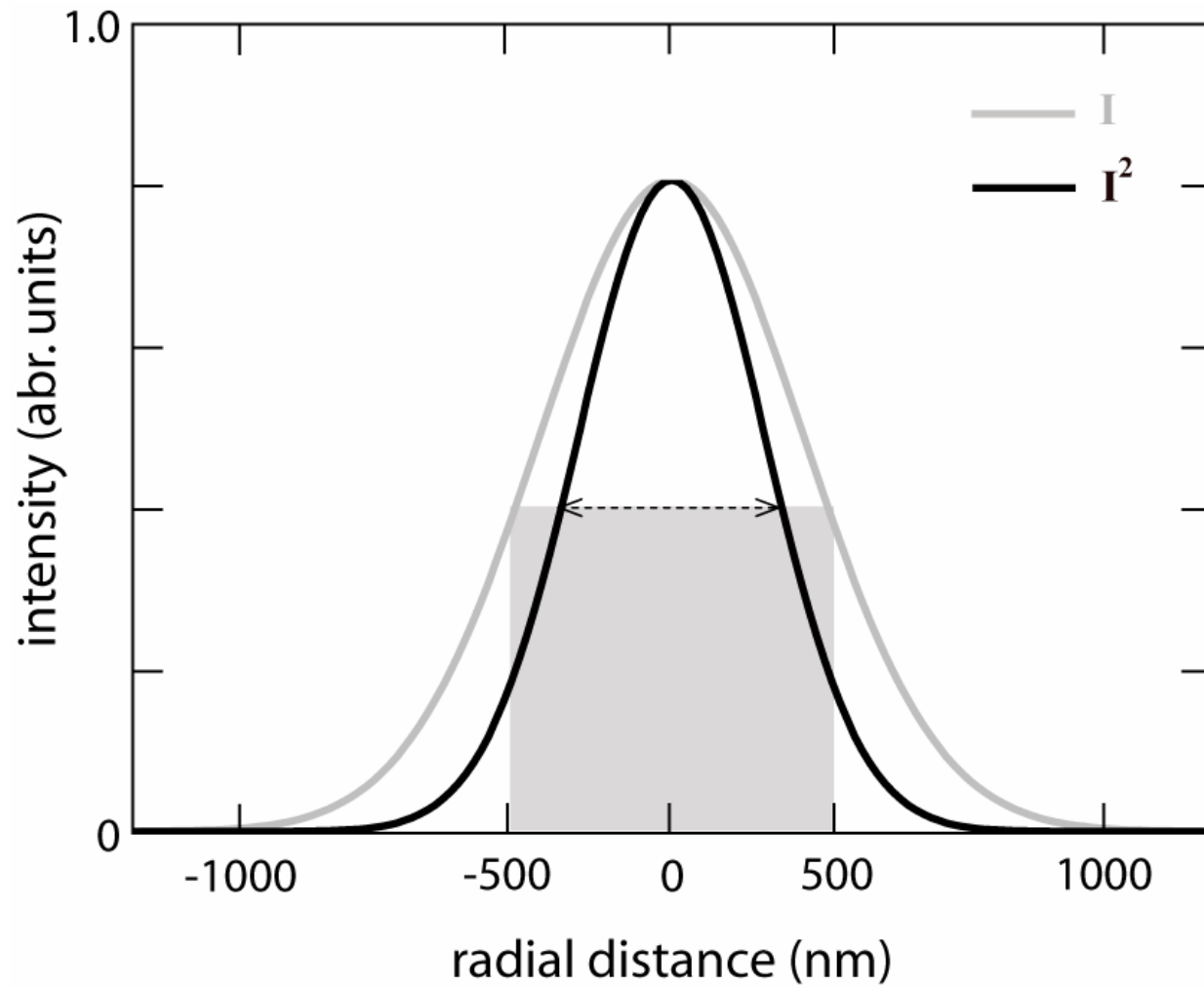
The polymerization is confined to the focal volume.



High spatial resolution

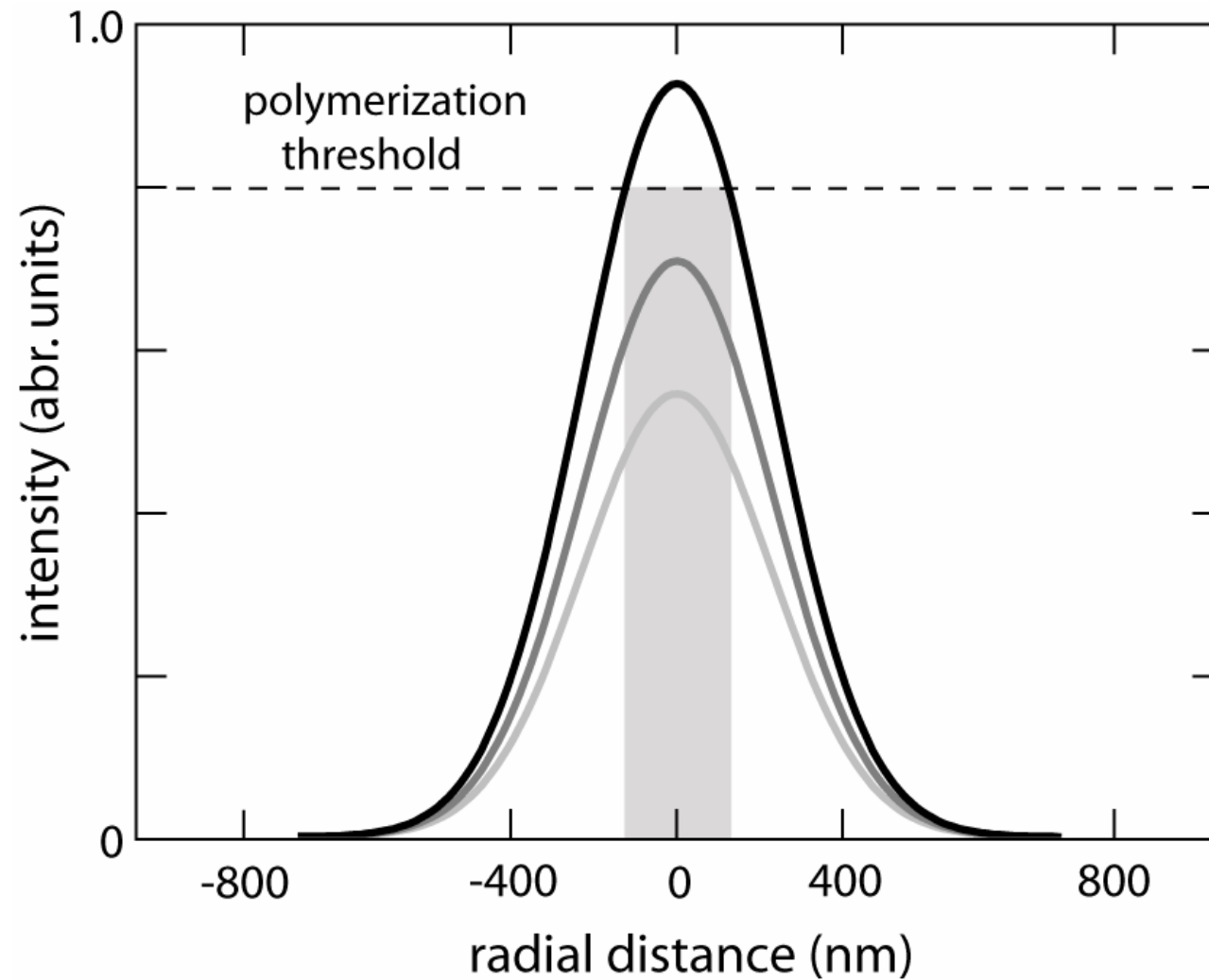


Two-photon polymerization



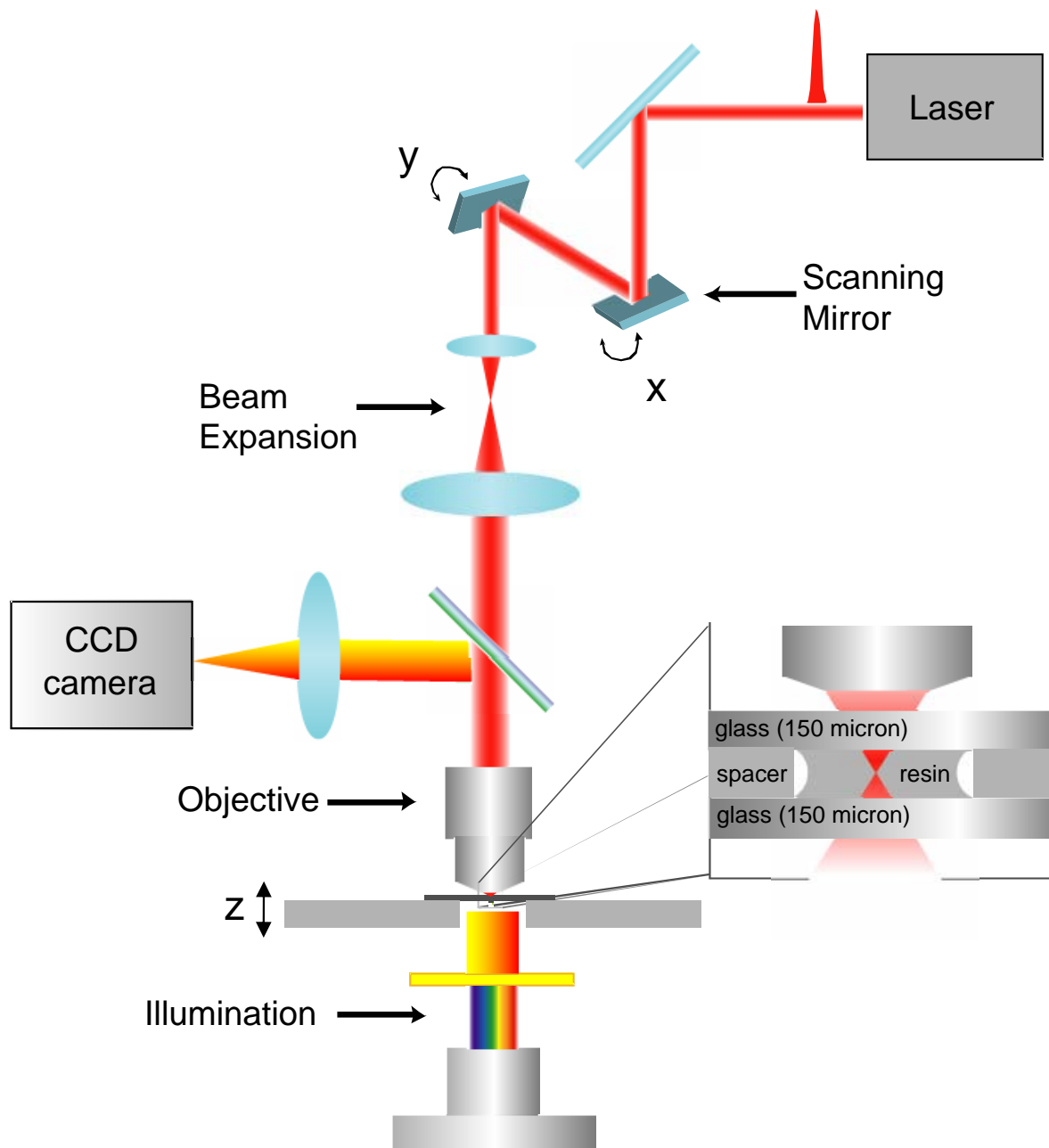
bellow the diffraction limit

Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



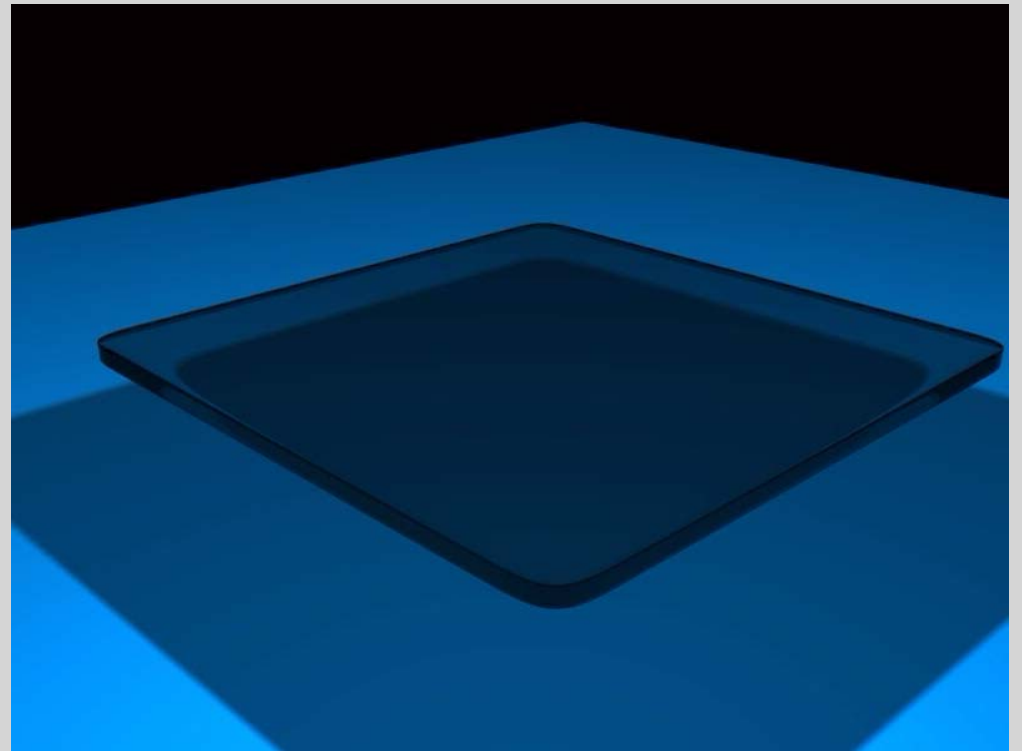
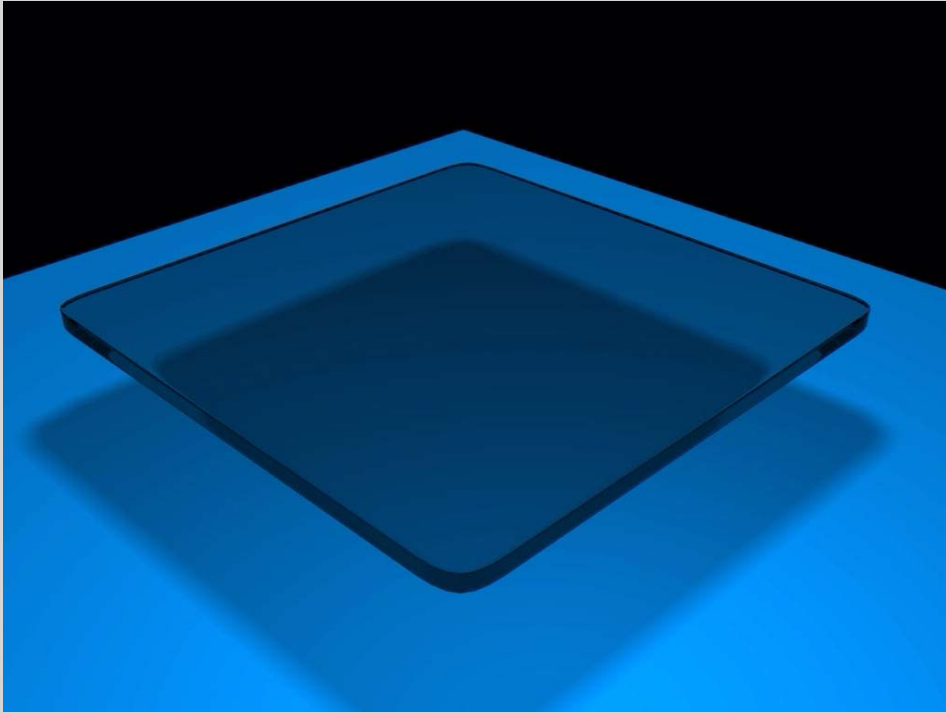
Ti:sapphire laser oscillator

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

Objective

40 x
0.65 NA

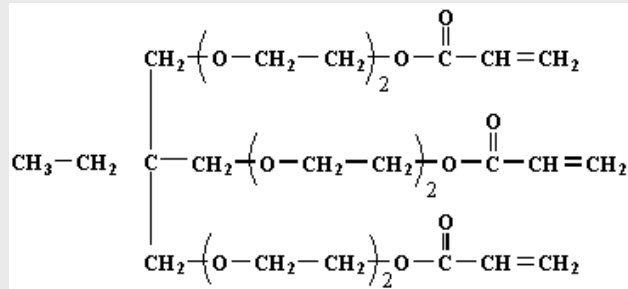
Two-photon polymerization



Resin preparation

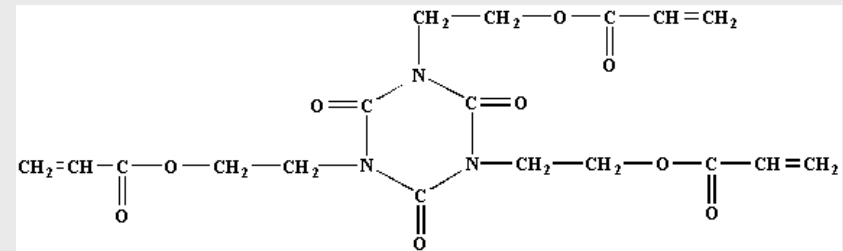
Monomers

Monomer A



reduces the shrinkage upon polymerization

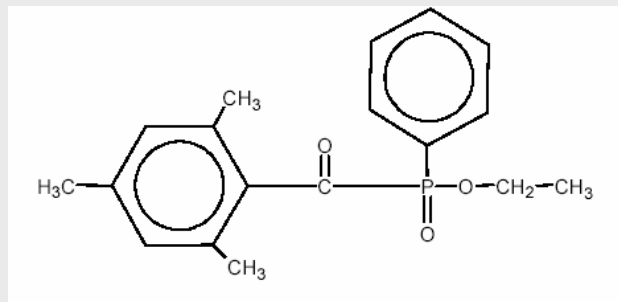
Monomer B



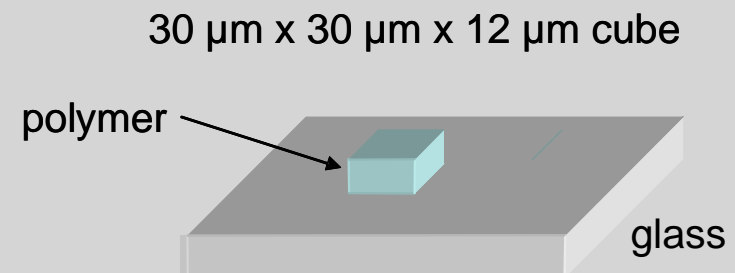
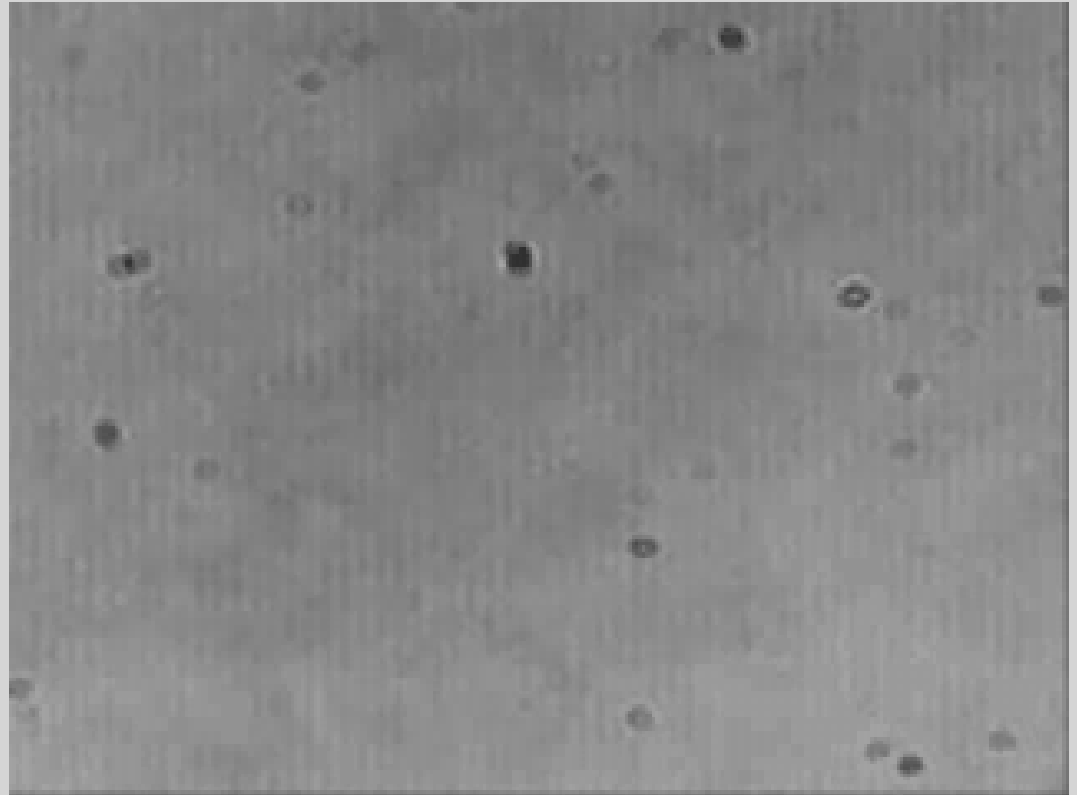
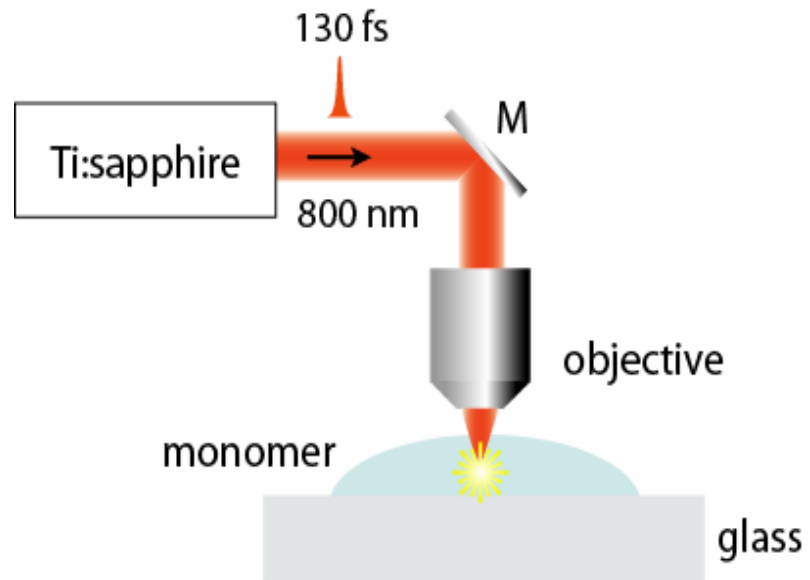
gives hardness to the polymeric structure

Photoinitiator

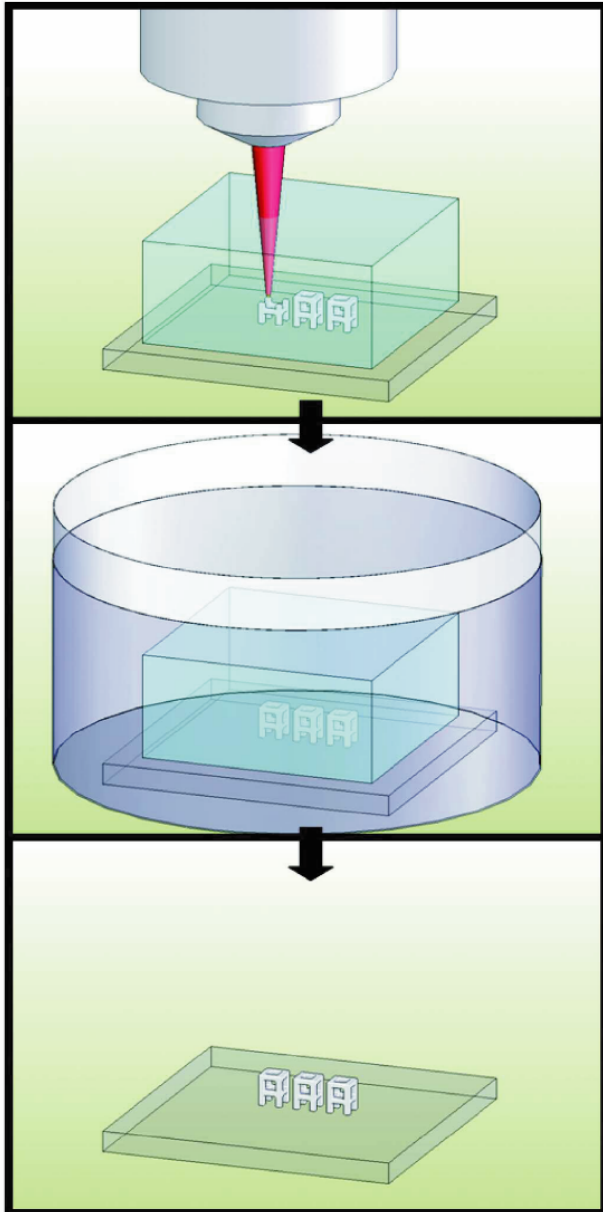
Lucirin TPO-L



Two-photon polymerization



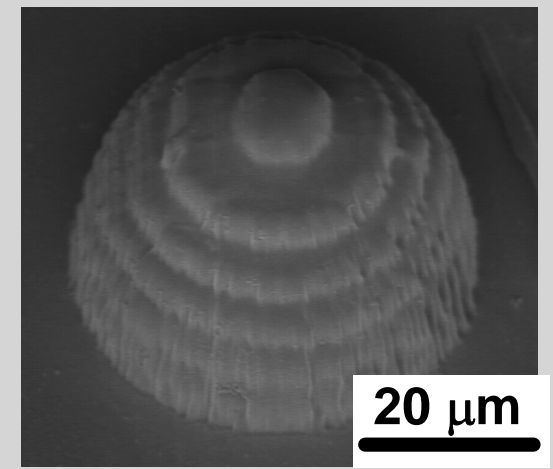
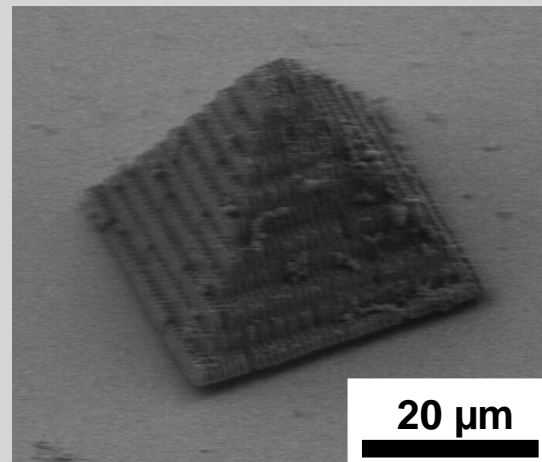
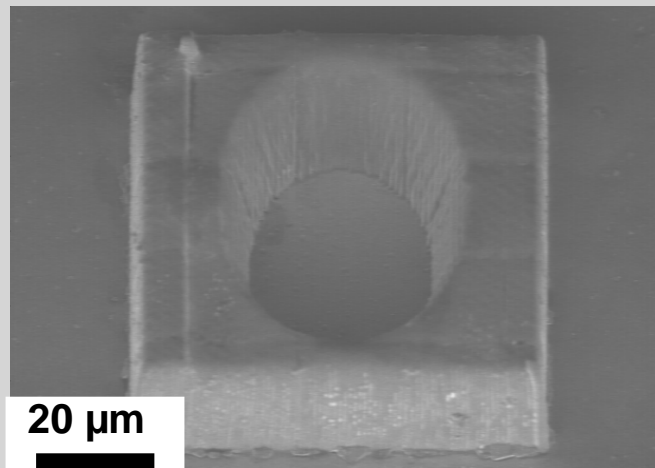
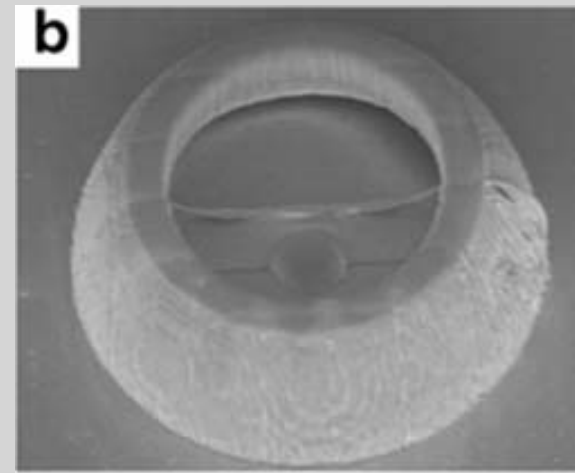
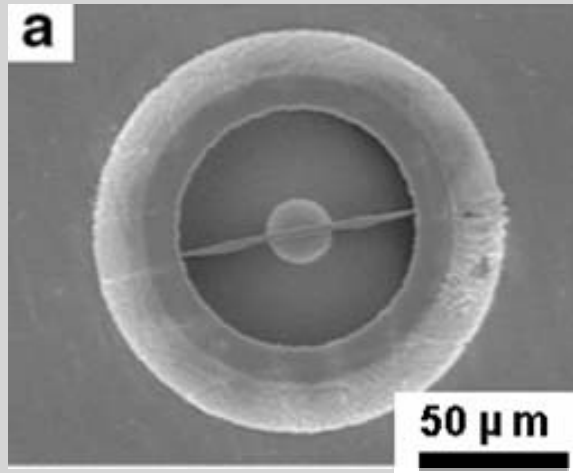
Two-photon polymerization



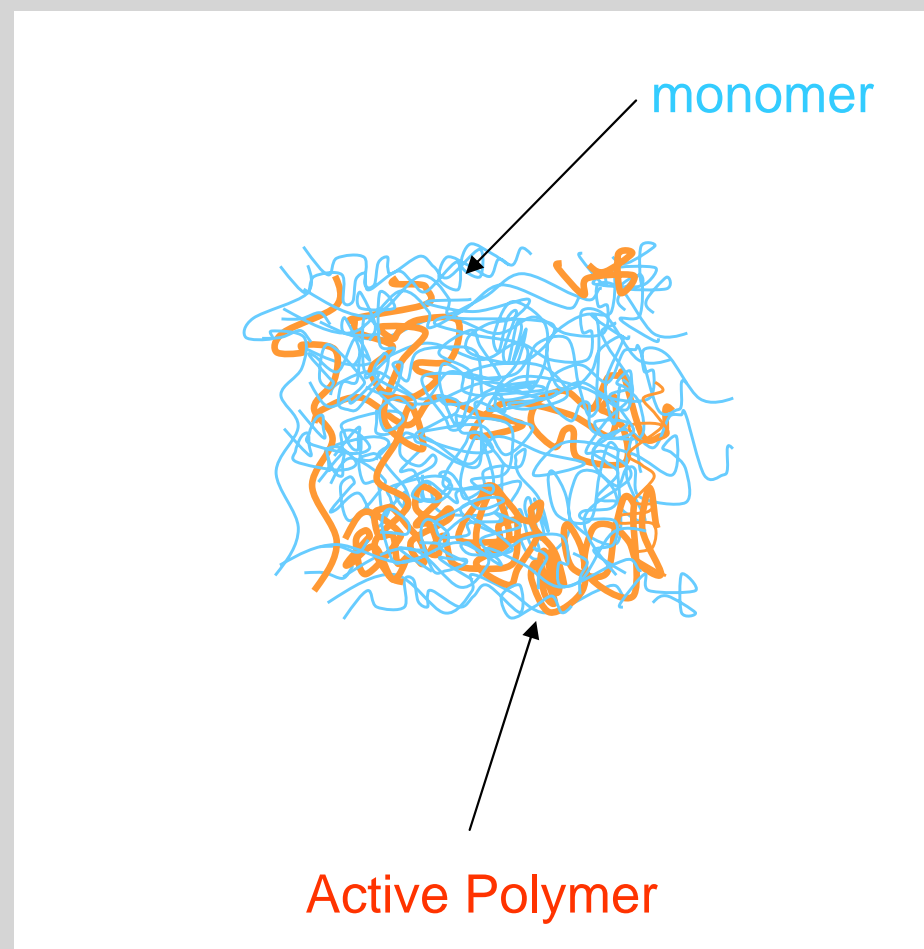
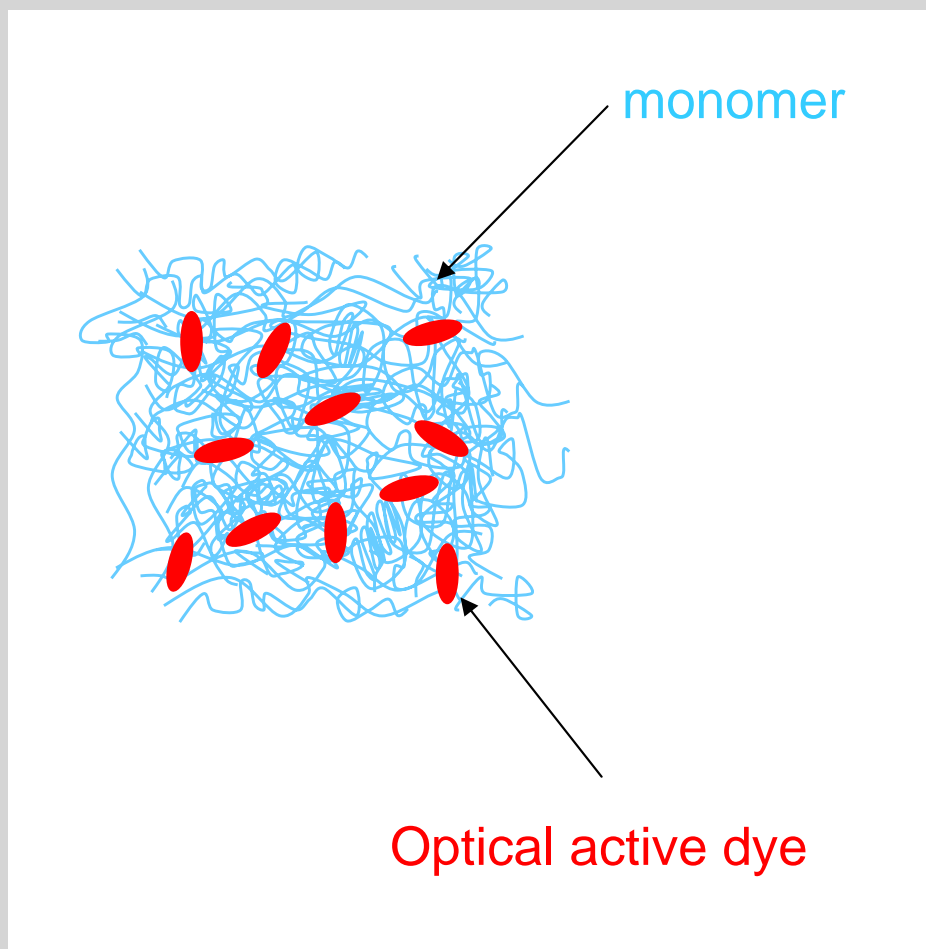
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

Two-photon polymerization

Microstructures fabricated by two-photon polymerization

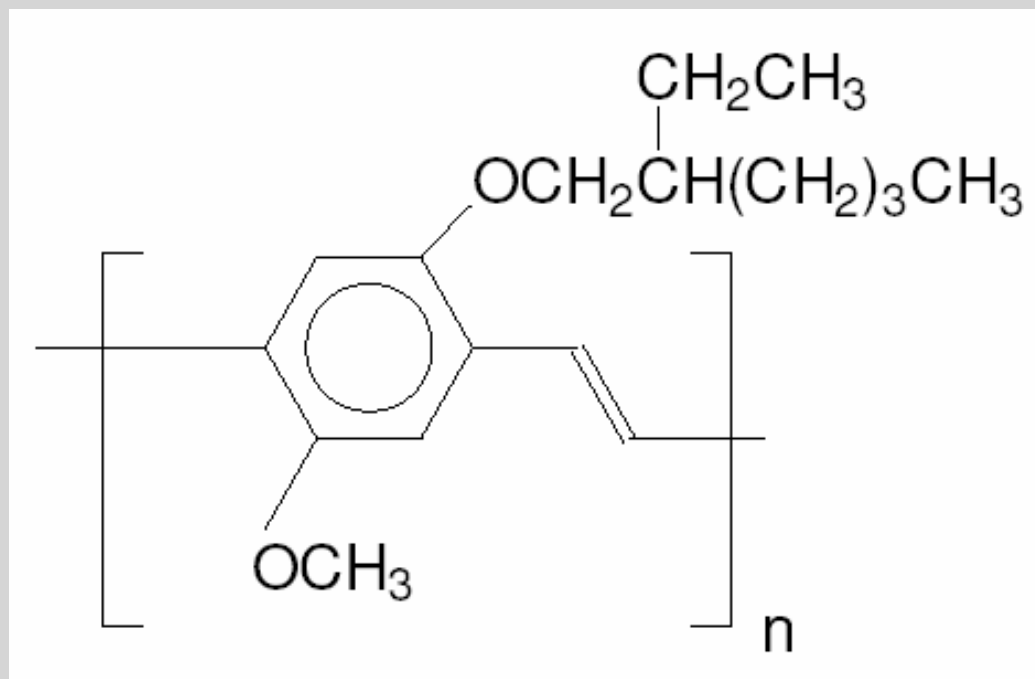


Microstructures containing active compounds



Microstructures containing MEH-PPV

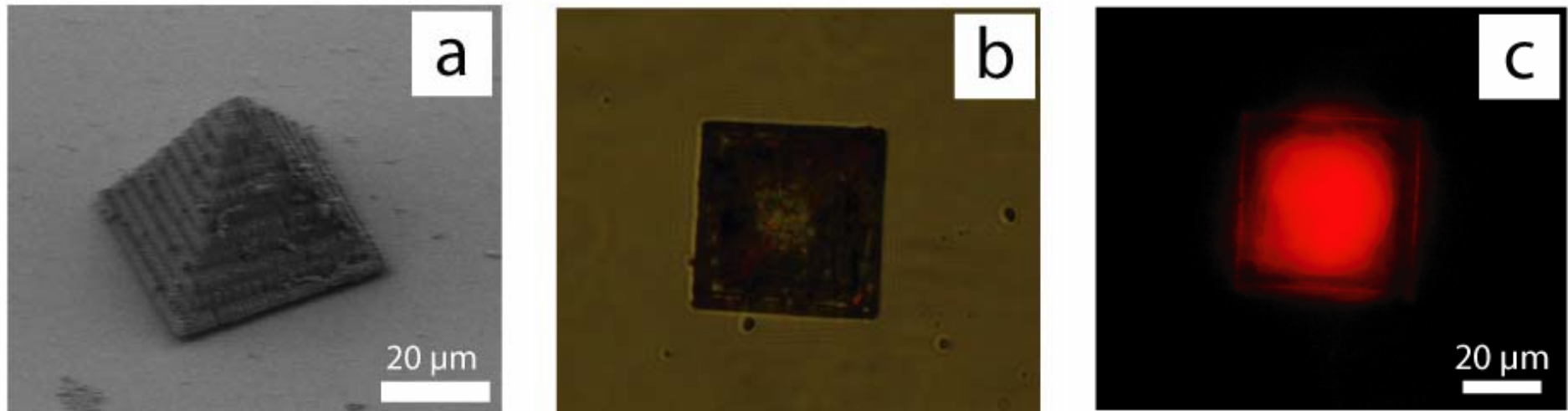
MEH-PPV



Fluorescence
Electro Luminescent
Conductive

Microstructures containing MEH-PPV

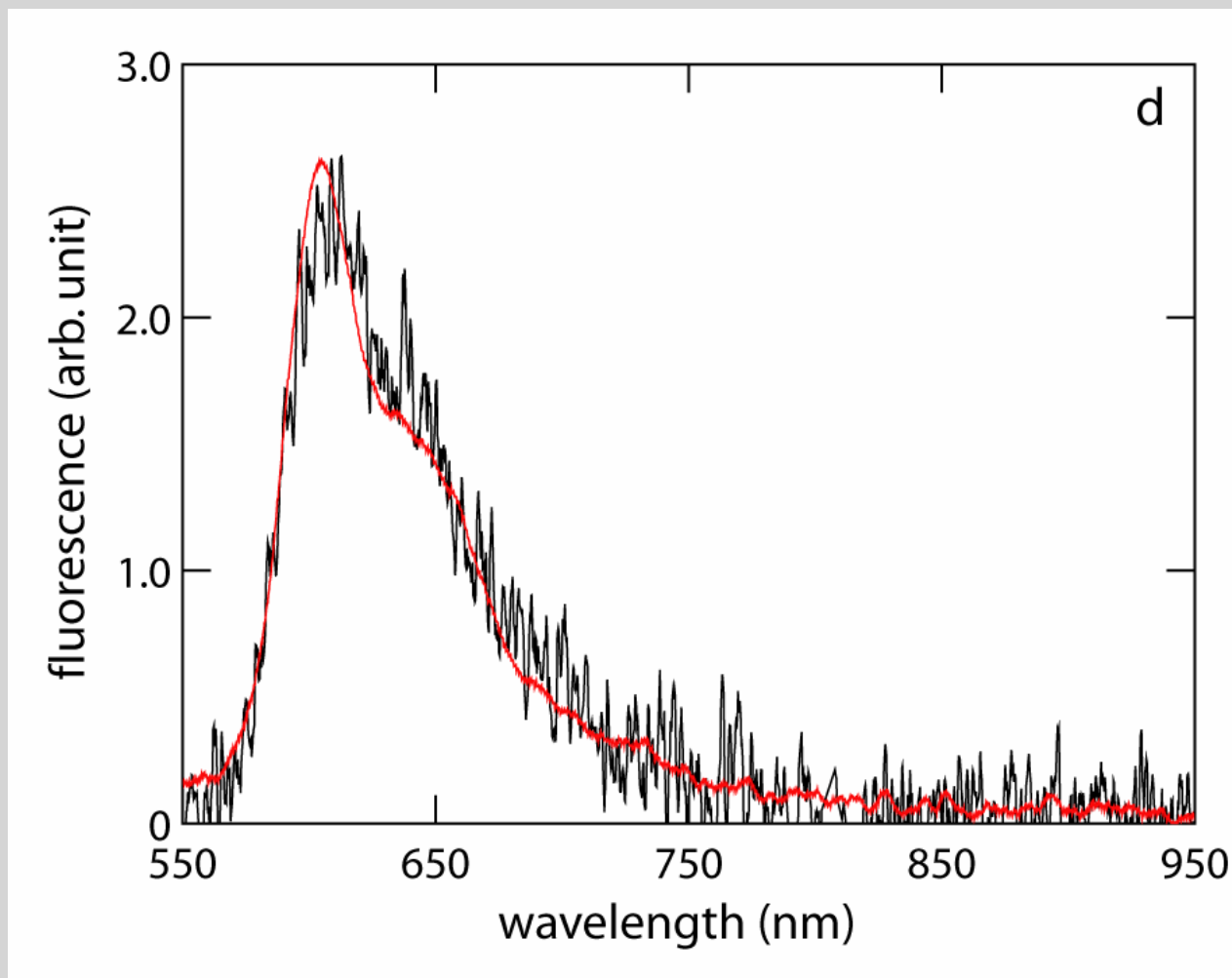
MEH-PPV: up to 1% by weight
laser power 40 mW



a - Scanning electron microscopy

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

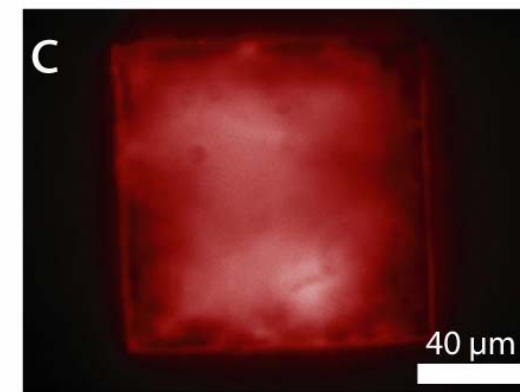
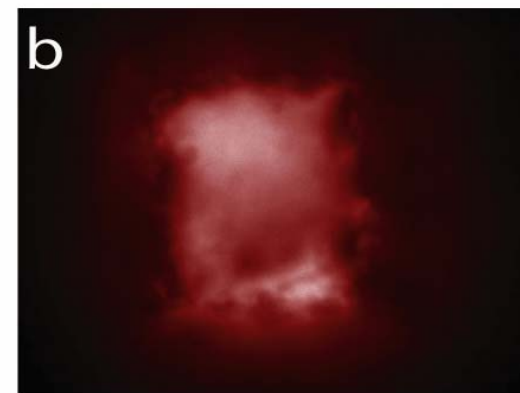
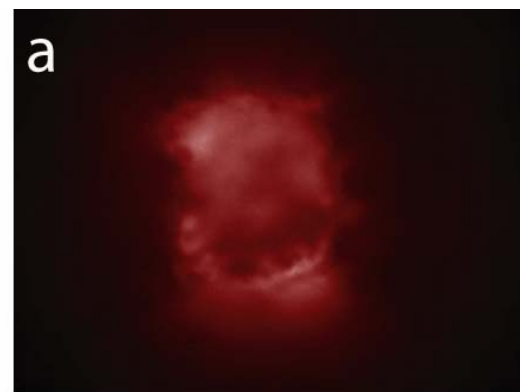
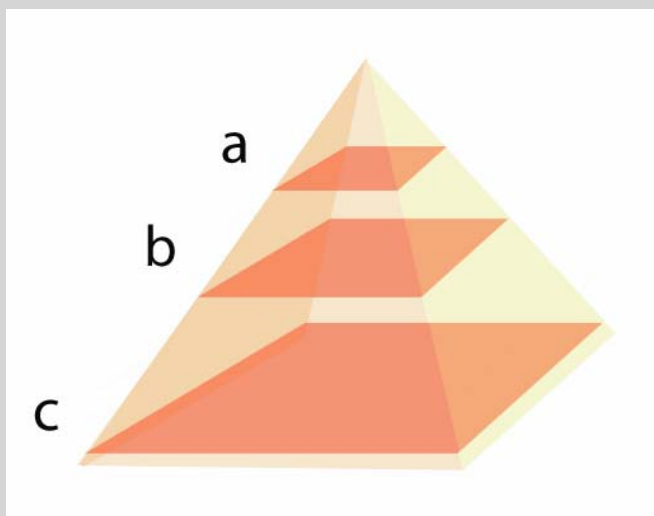
Microstructures containing MEH-PPV



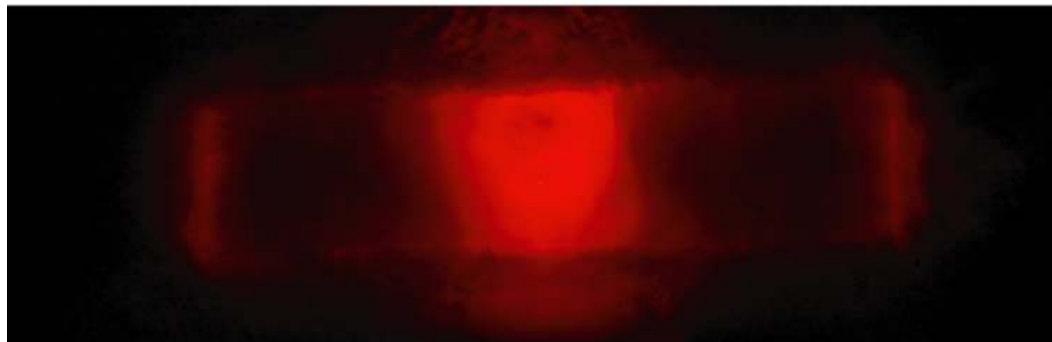
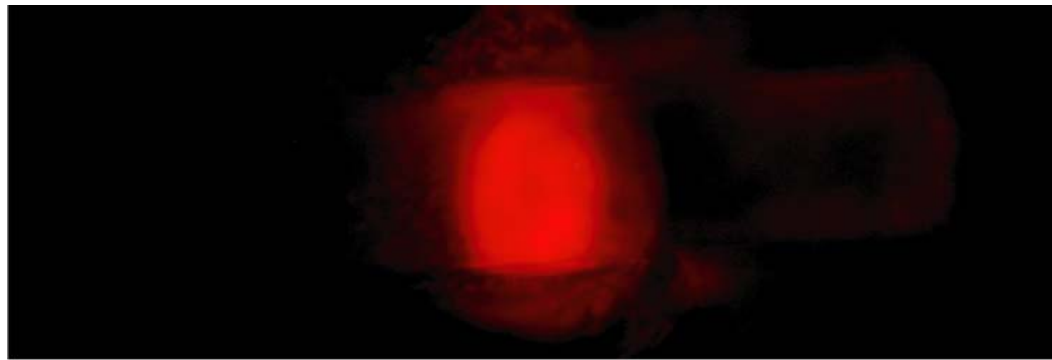
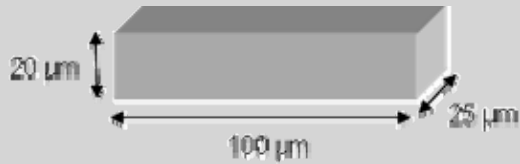
d - Emission of the microstructure (black line) and of a film with the same composition (red line)

Microstructures containing MEH-PPV

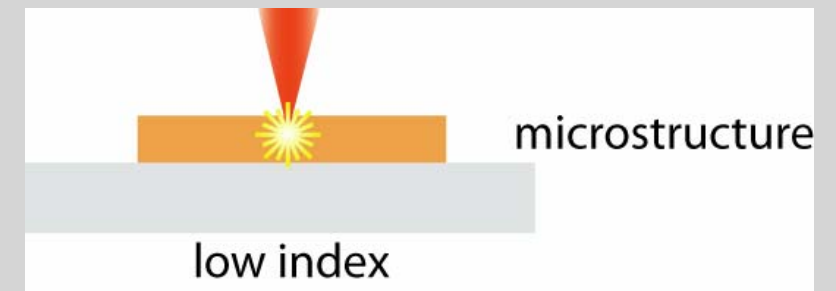
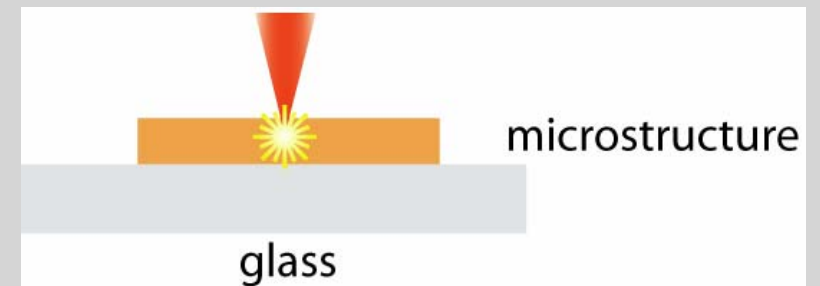
Fluorescent confocal microscopy images in planes separated by $16\text{ }\mu\text{m}$ in the pyramidal microstructure.



Microstructures containing MEH-PPV



20 μm 

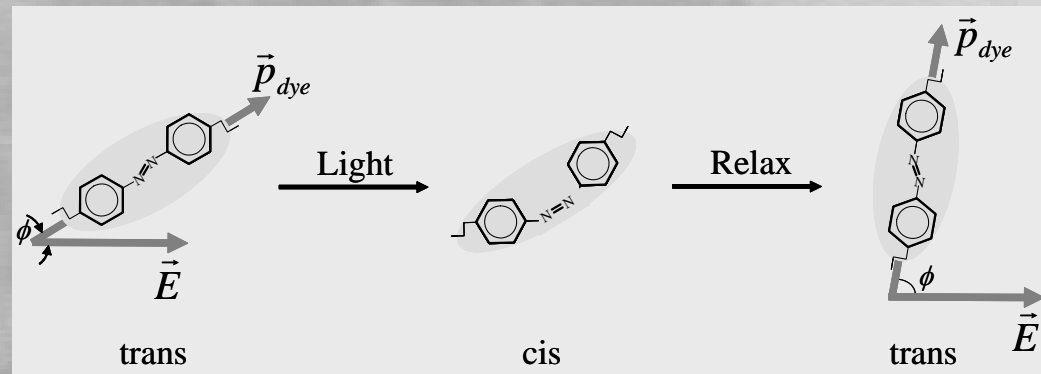
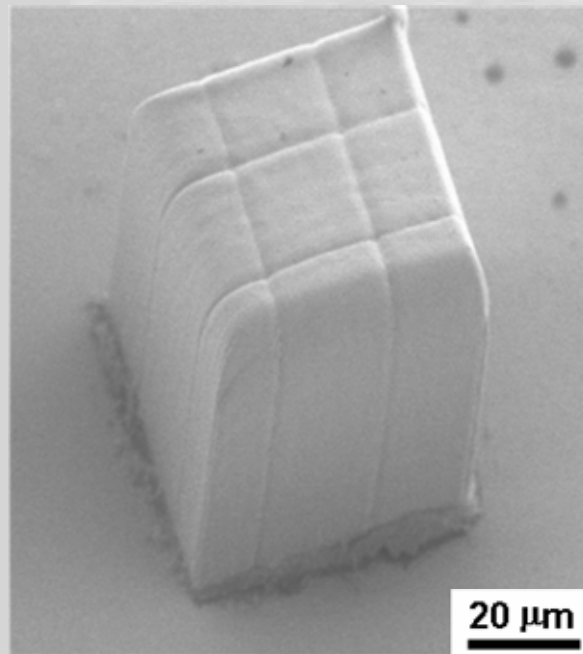


waveguiding of the microstructure fabricated on porous silica substrate ($n= 1.185$)

Applications: micro-laser; fluorescent microstructures; conductive microstructures

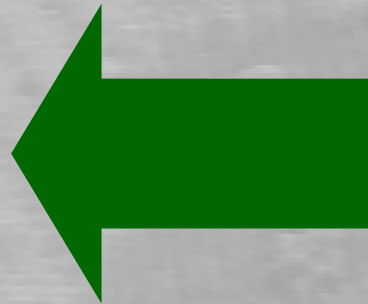
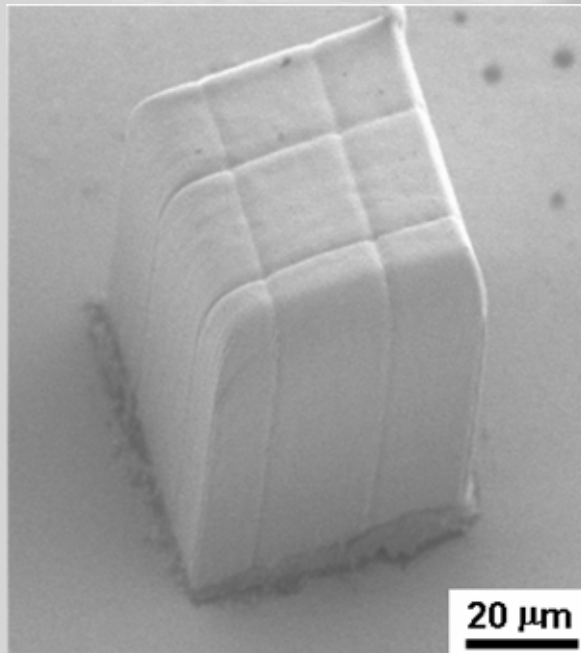
Other studies

- microstructures for optical storage – birefringence



Other studies

- microstructures for optical storage – birefringence



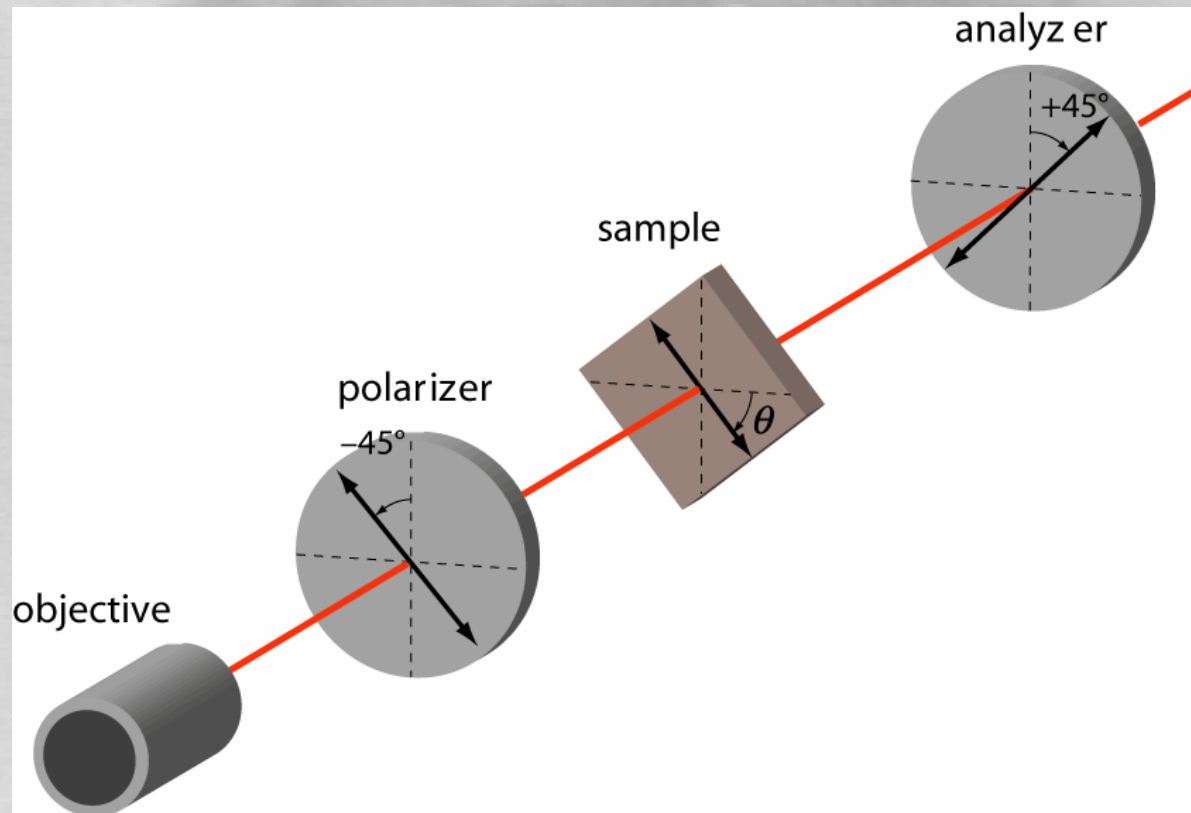
Ar⁺ ion laser irradiation

- 514.5 nm
- one minute
- intensity of 600 mW/cm²

Other studies

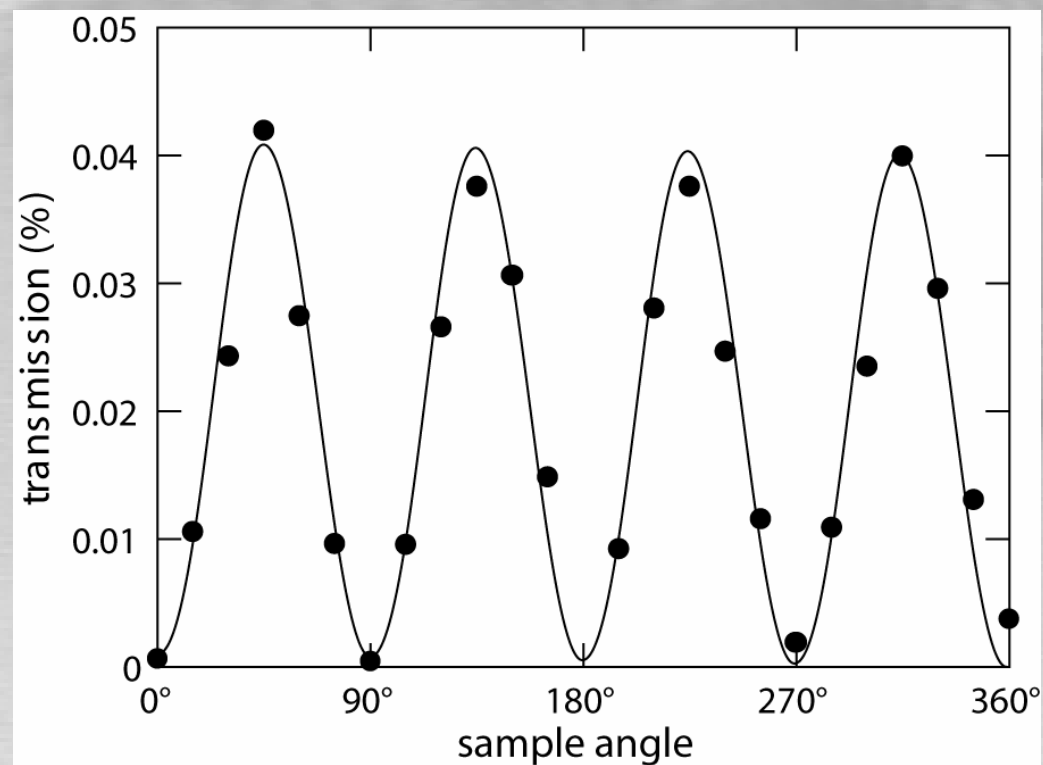
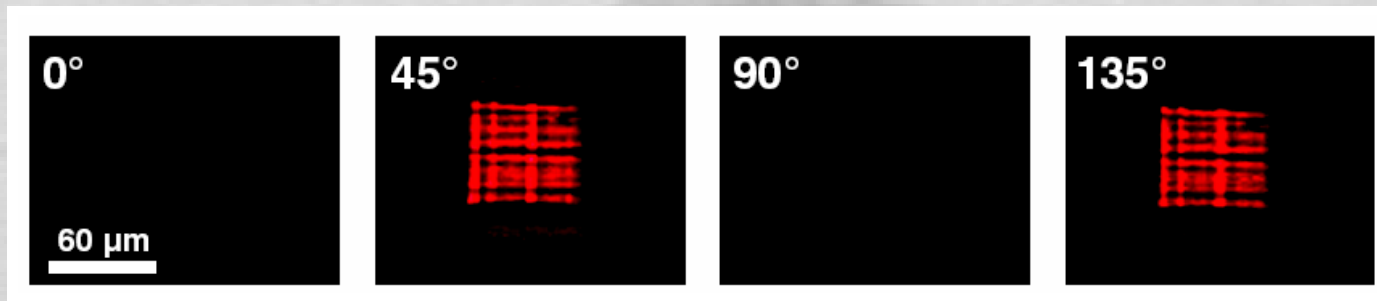
- microstructures for optical storage – birefringence

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



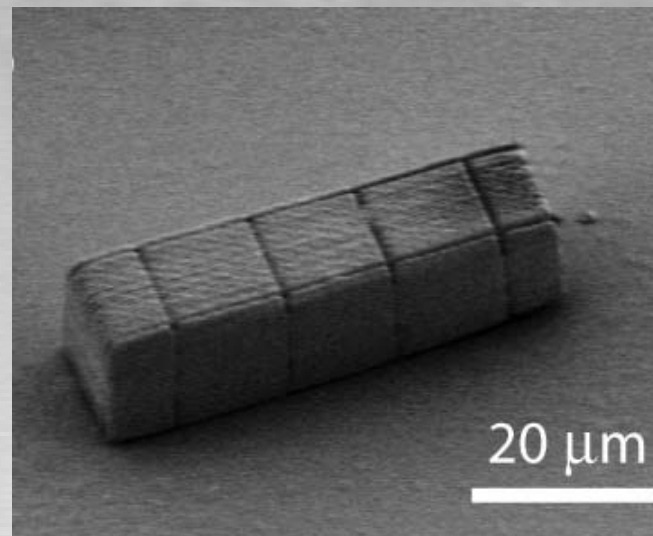
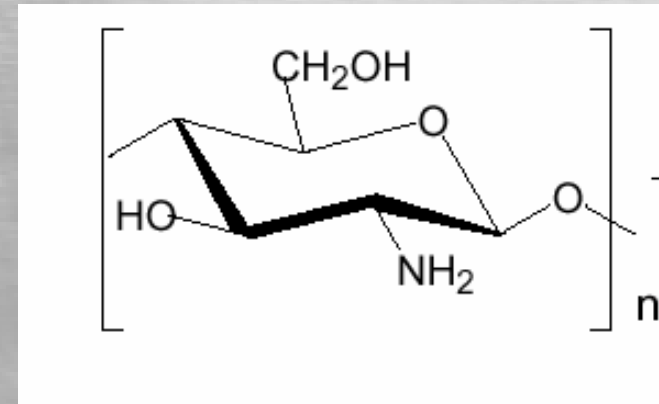
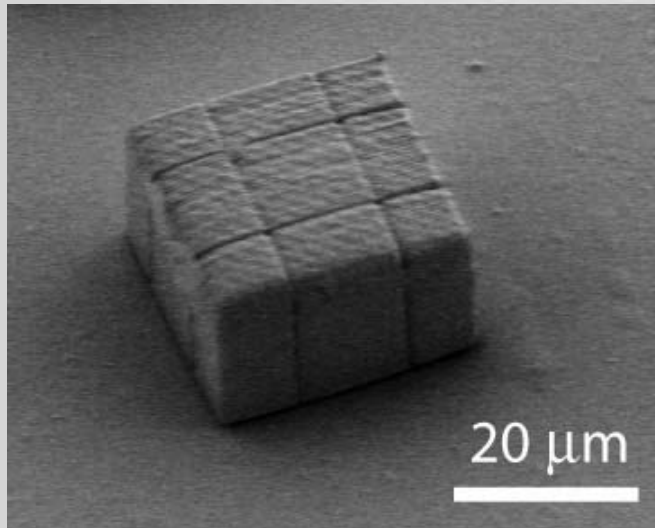
Other studies

- microstructures for optical storage – birefringence



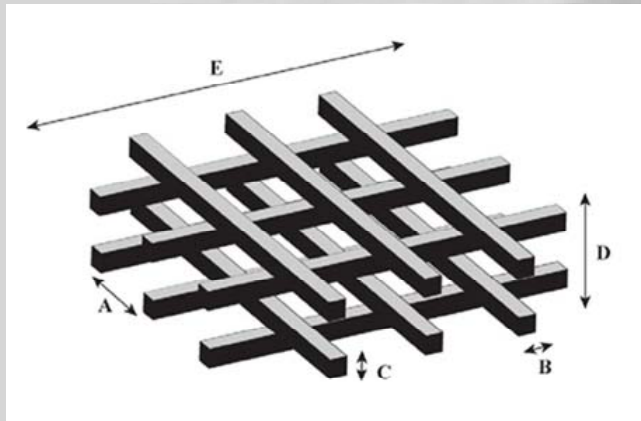
Other studies

- microstructures containing biopolymer - chitosan



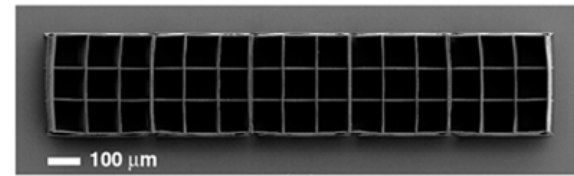
Other studies

- 3D cell migration studies in micro-scaffolds



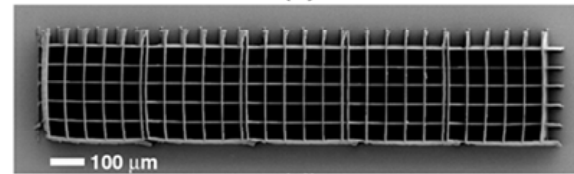
SEM of the scaffolds

110 μm pore size



(c)

52 μm pore size



(d)

Top view



(e)

(f)

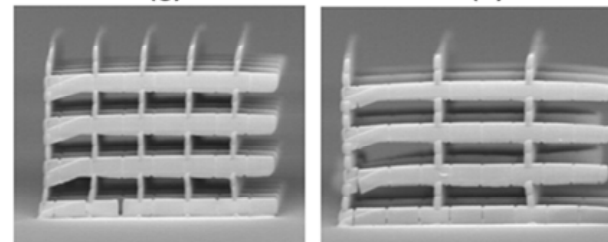
110, 52, 25, 12 μm pore size



(g)

(h)

Side view

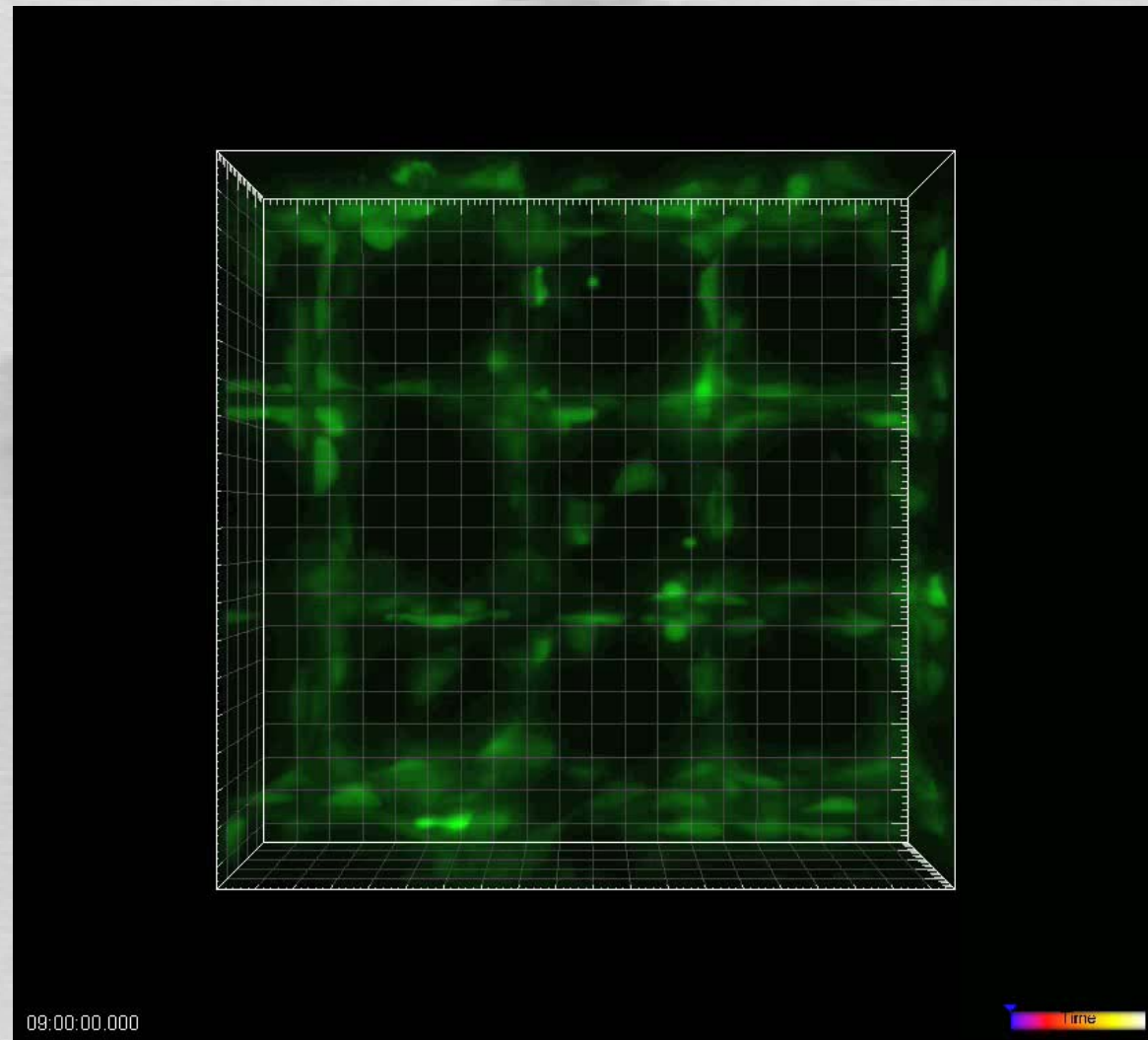


(i)

(j)

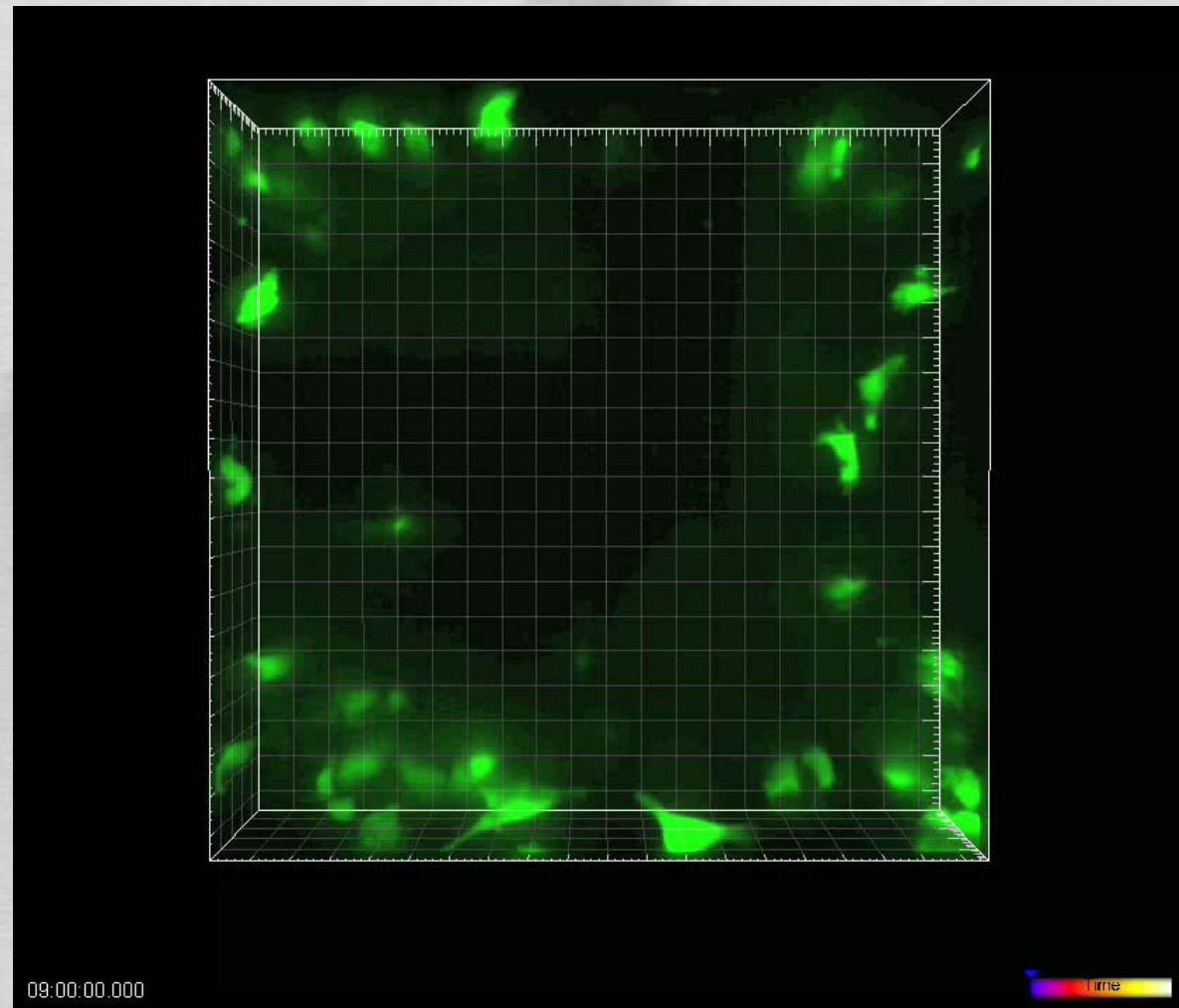
25, 52 μm pore size

Other studies



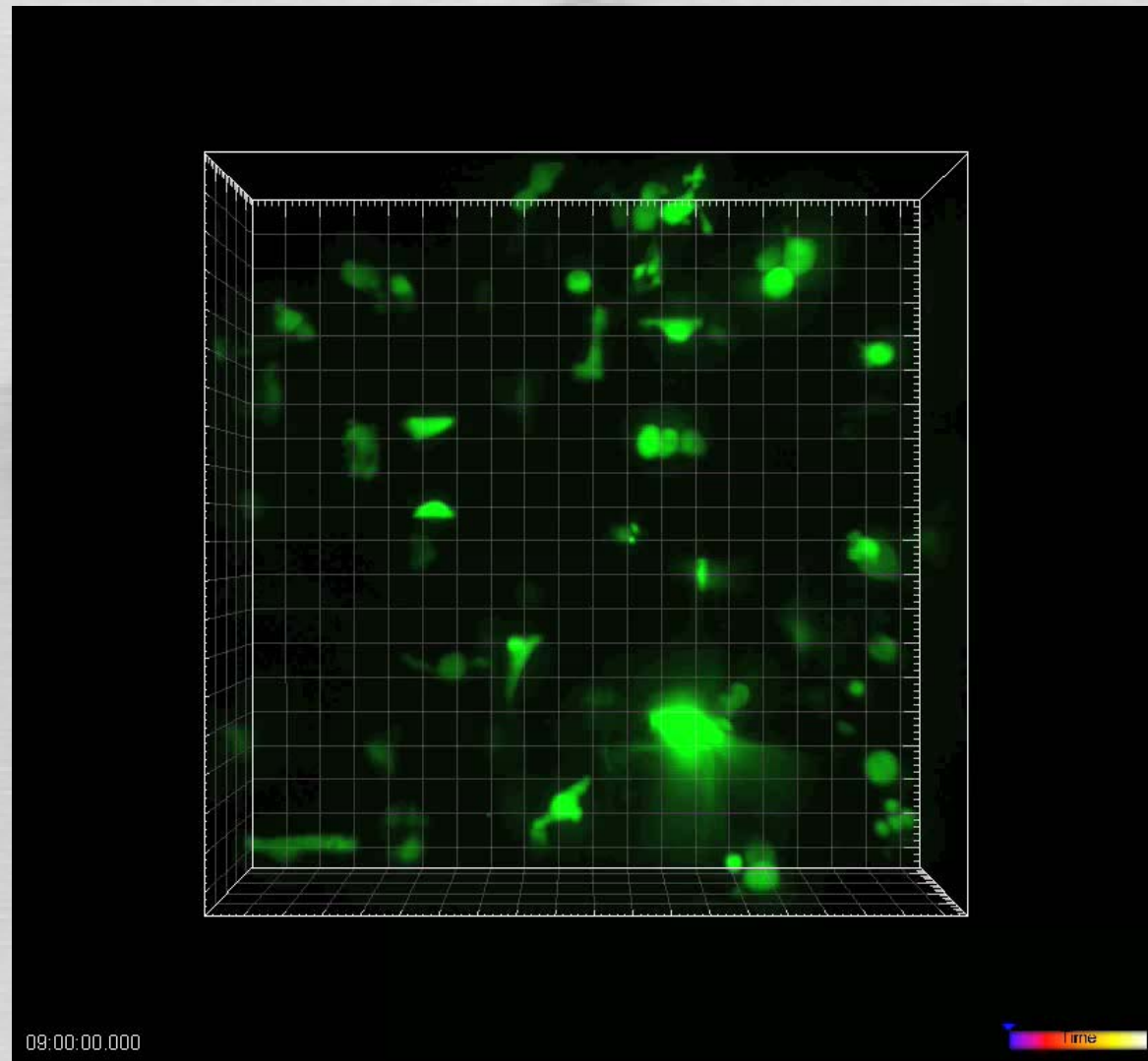
110 μm pore size

Other studies



12 μm pore size

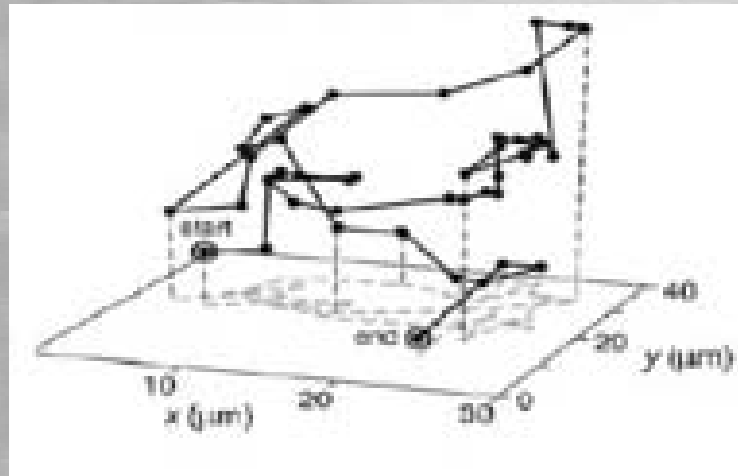
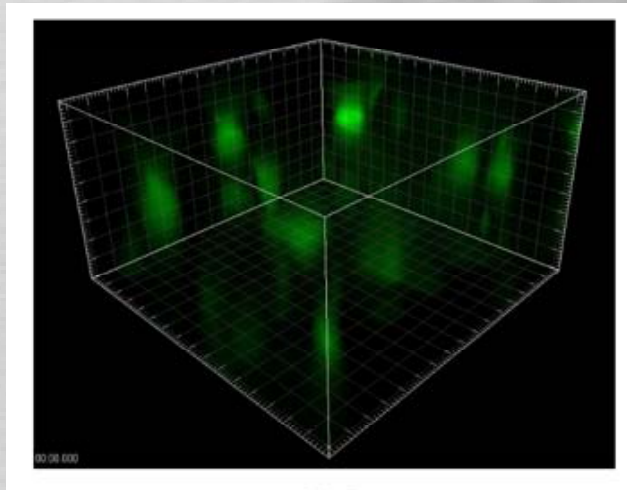
Other studies



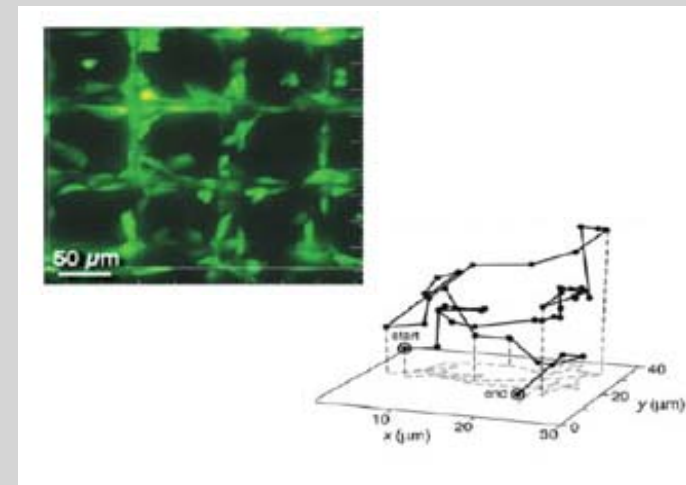
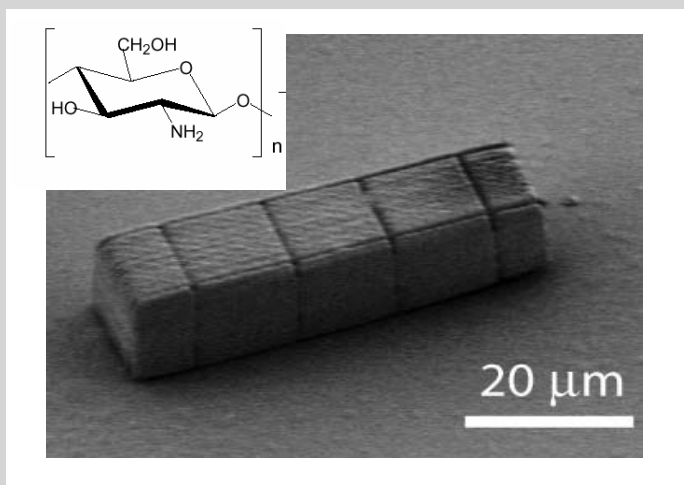
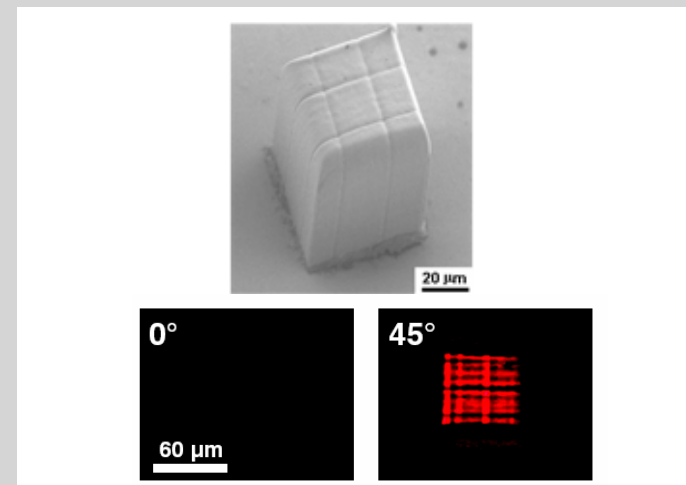
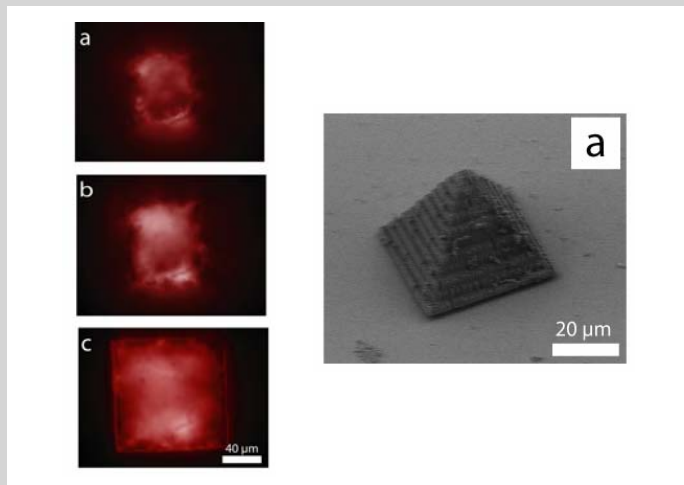
52 µm pore size

Other studies

- 3D cell migration studies in micro-scaffolds



Summary



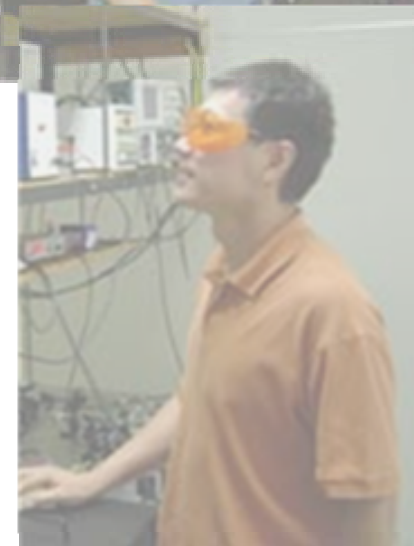
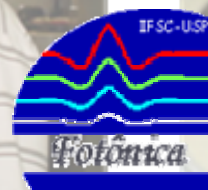
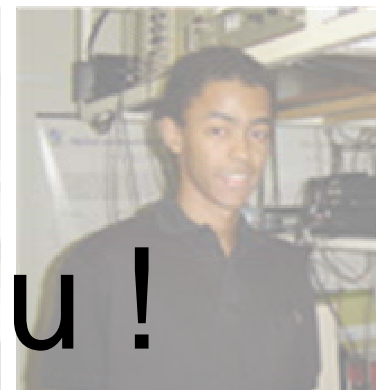
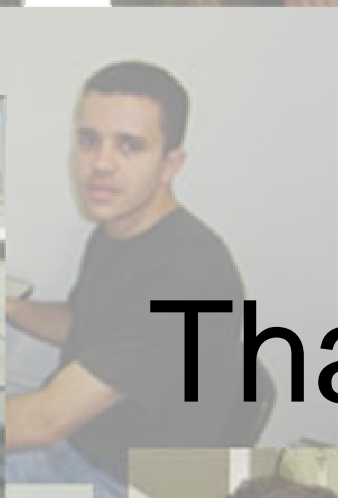
Acknowledgments

FAPESP
CAPES
CNPq

NSF
ARO

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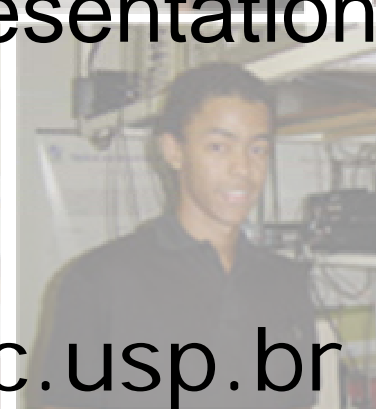
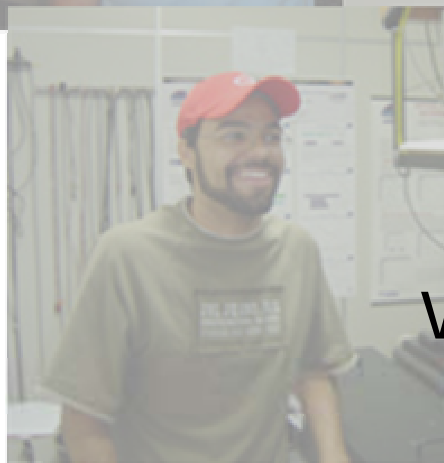


Thank you !

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