

Microfabrication in organic systems using ultrashort pulses

Prof. Dr. Cleber R. Mendonca

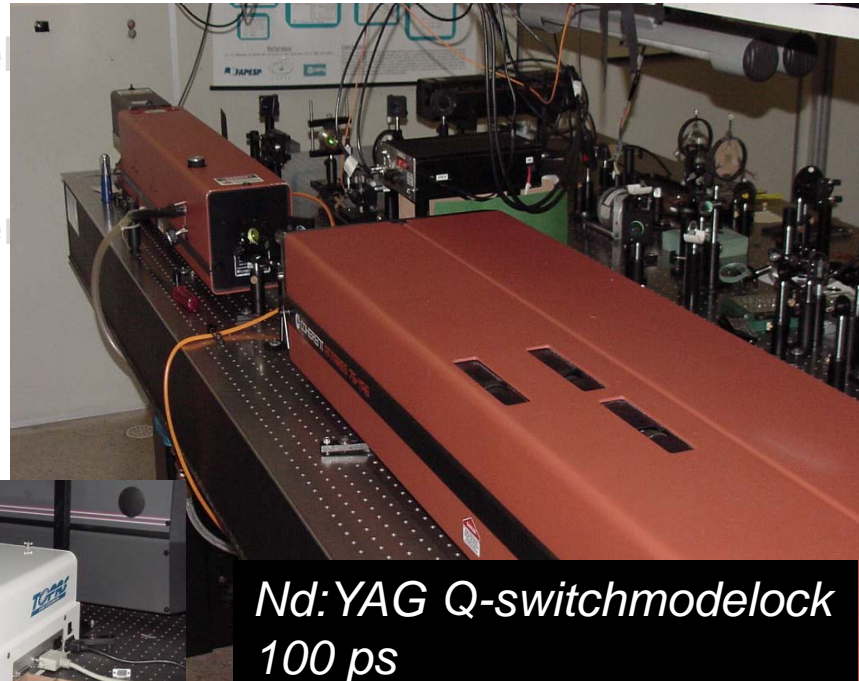
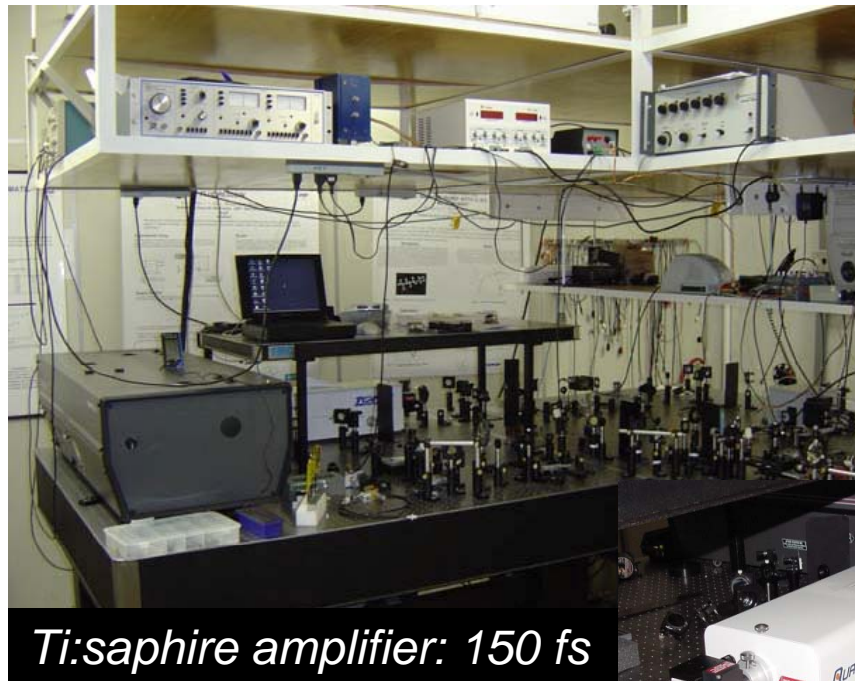


research areas

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

research areas

- study of optical nonlinearities in organic materials

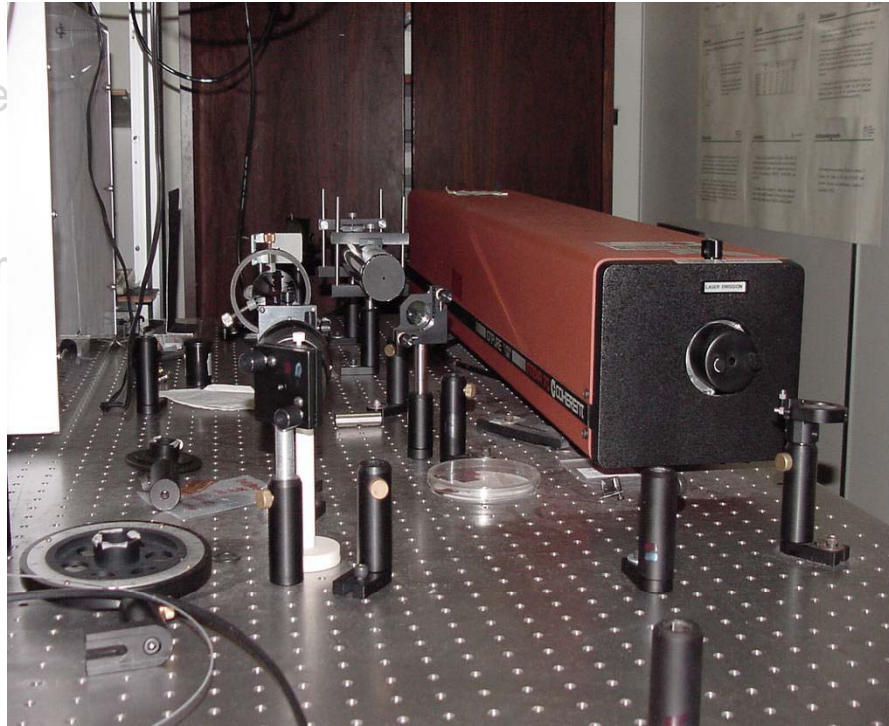


research areas

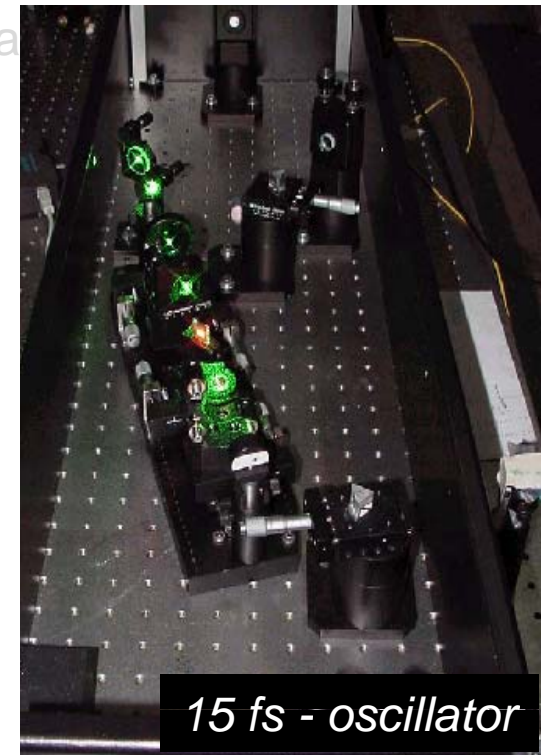
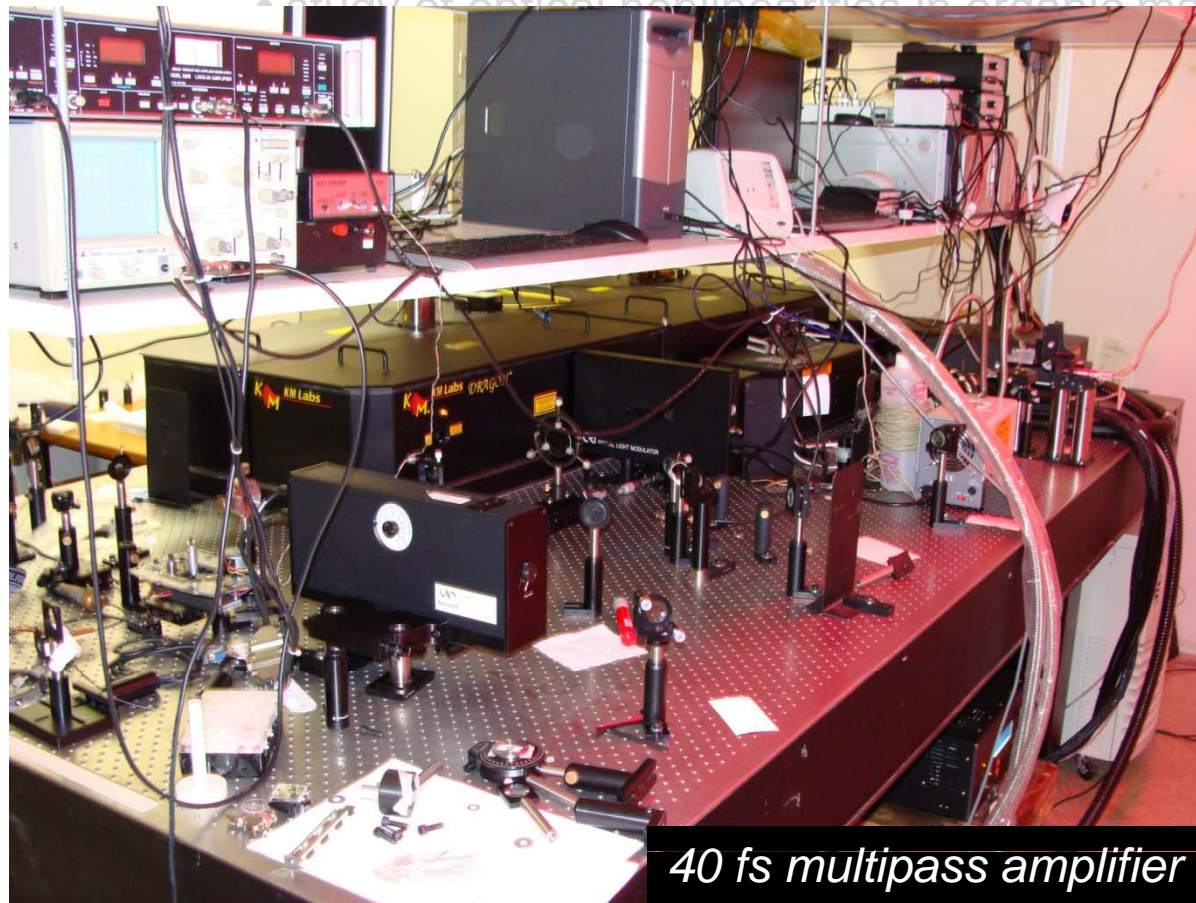
- study of optical nonlinearities in organic materials
- optical storage and surface relief gratings in azopolymers

• cohere

• fs-laser

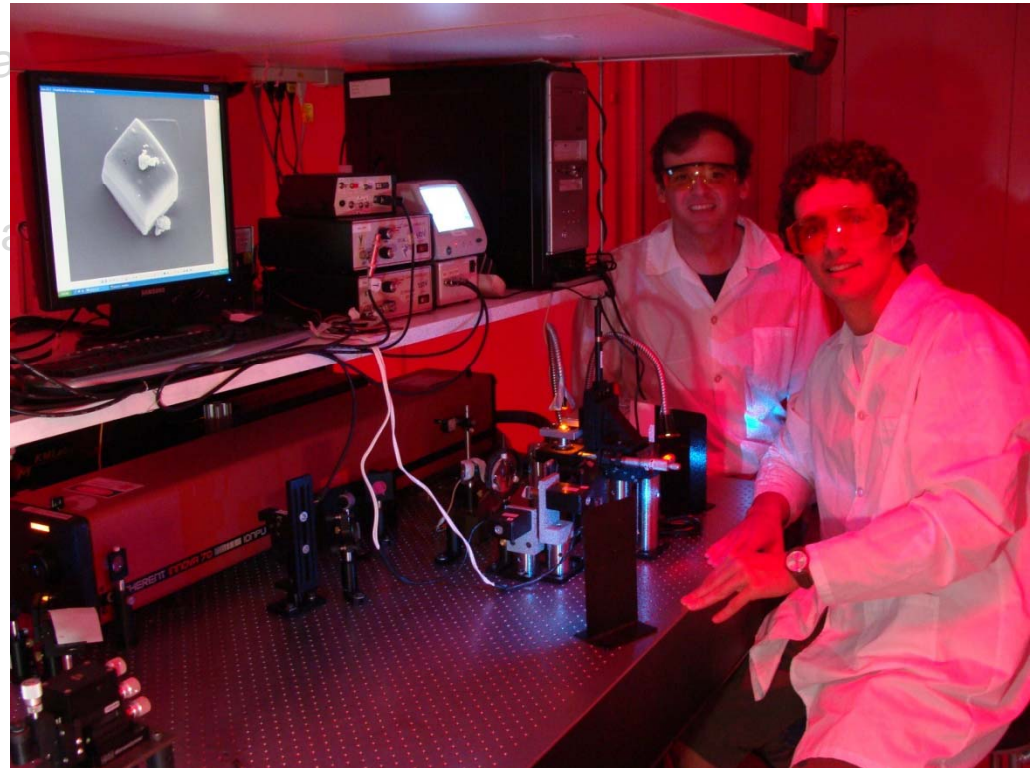


research areas



research areas

- study of optical nonlinear
- optical storage and surf
- coherent control of light
- fs-laser microfabrication



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

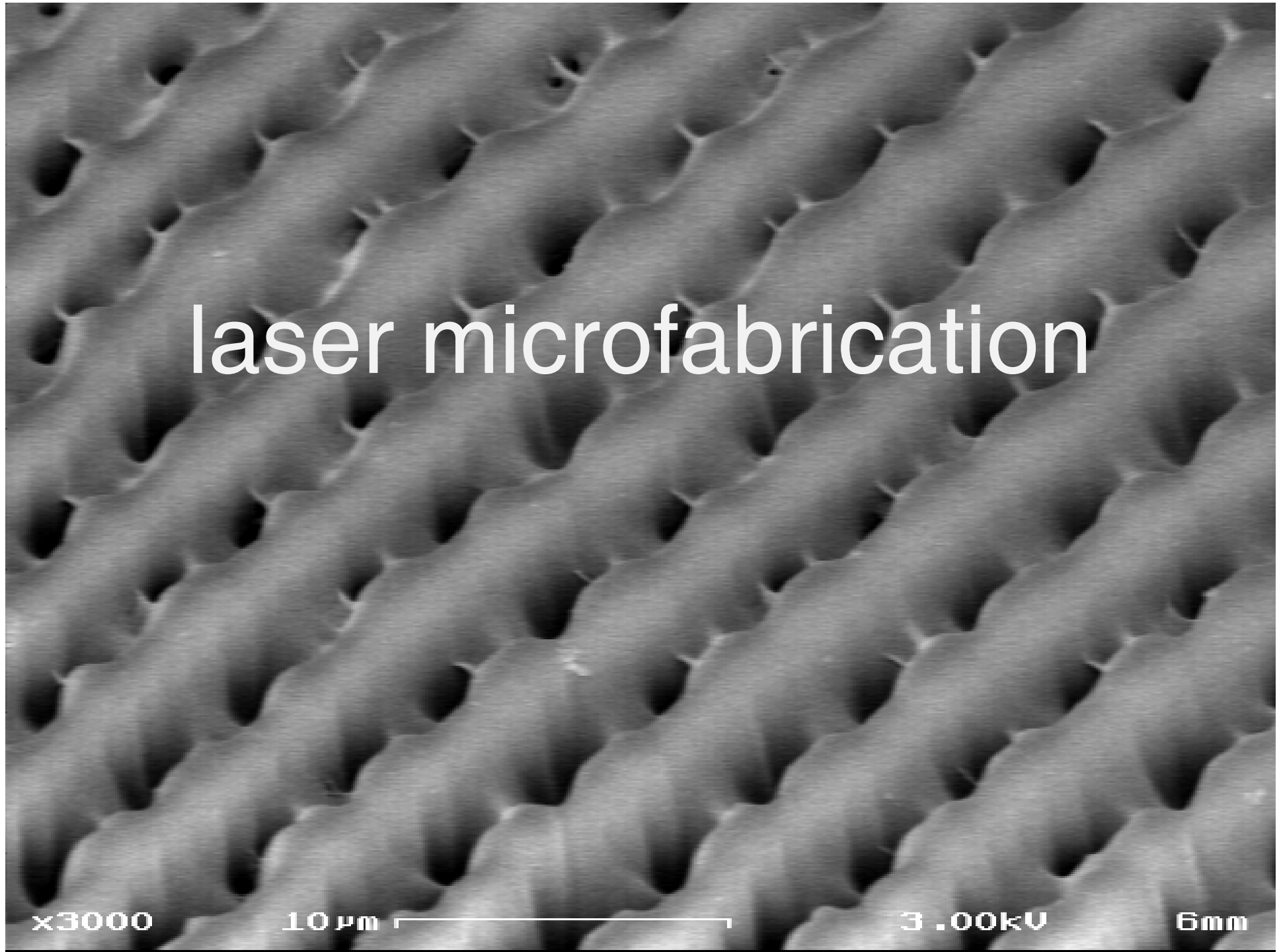
laser microfabrication

x3000

10 μm

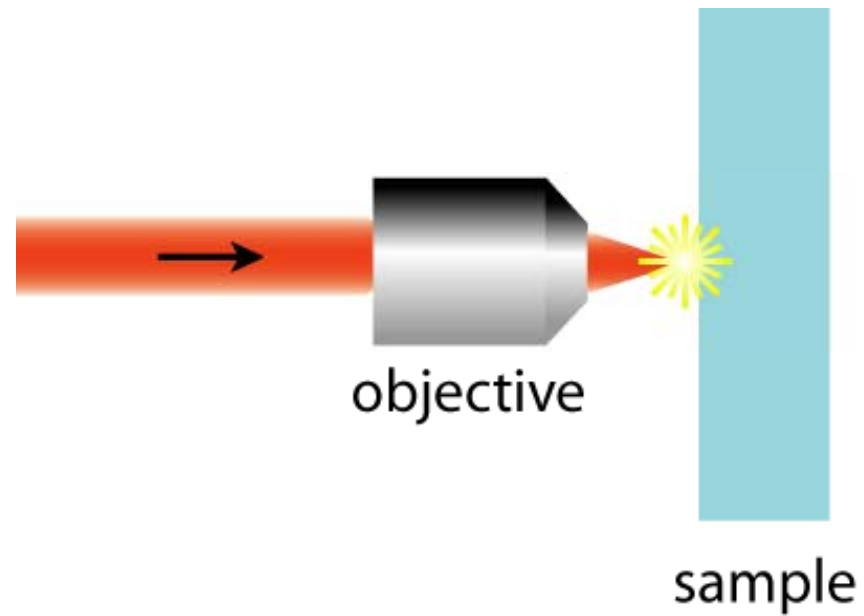
3.00kV

6mm

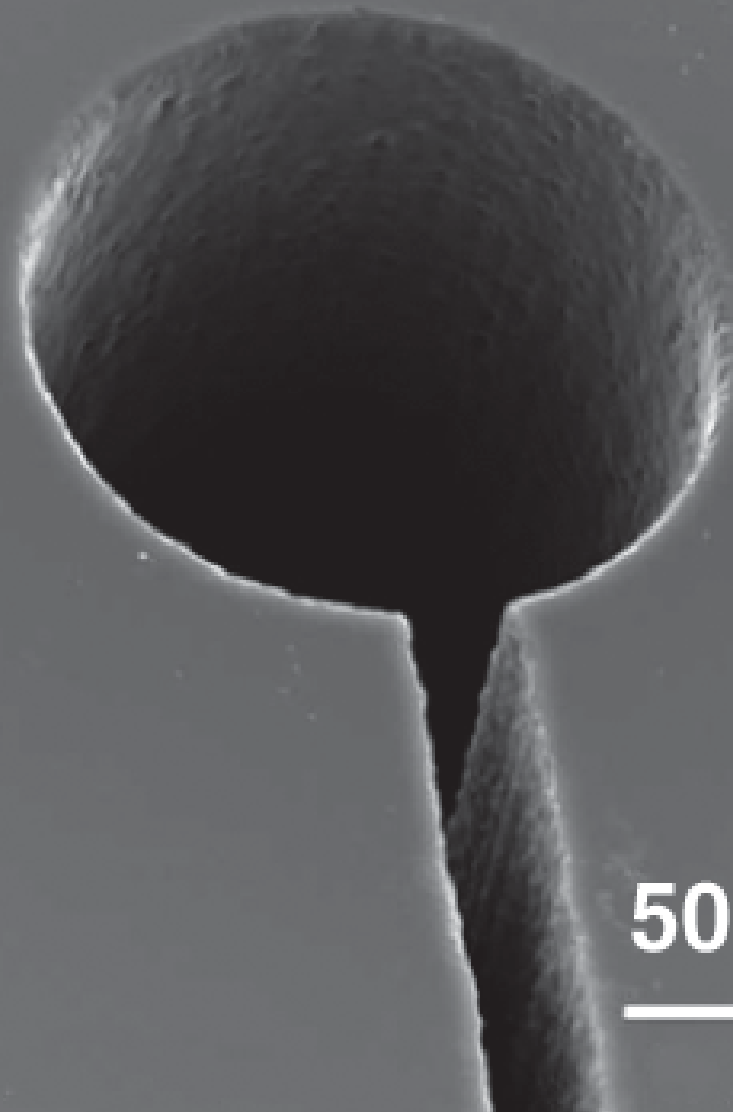


laser microfabrication

focus laser beam on material's surface



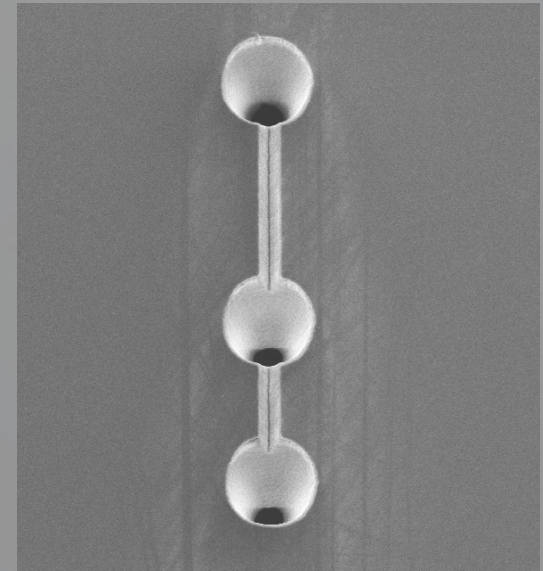
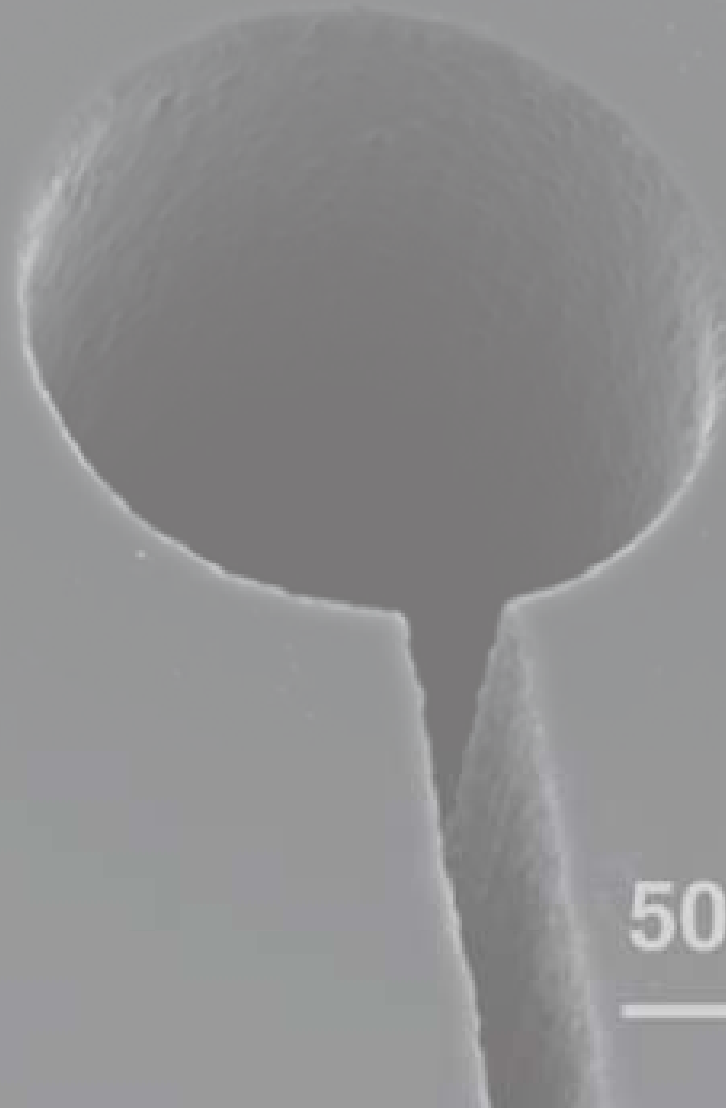
laser microfabrication



50 μm



laser microfabrication



50 μm

laser microfabrication

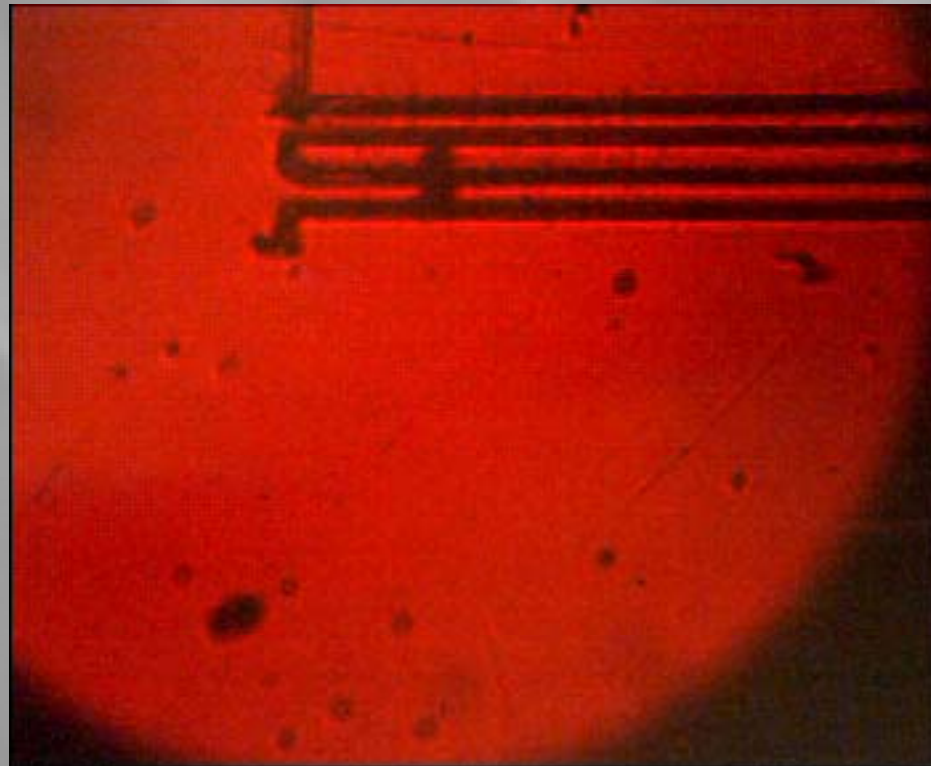
surface microstructuring



laser microfabrication

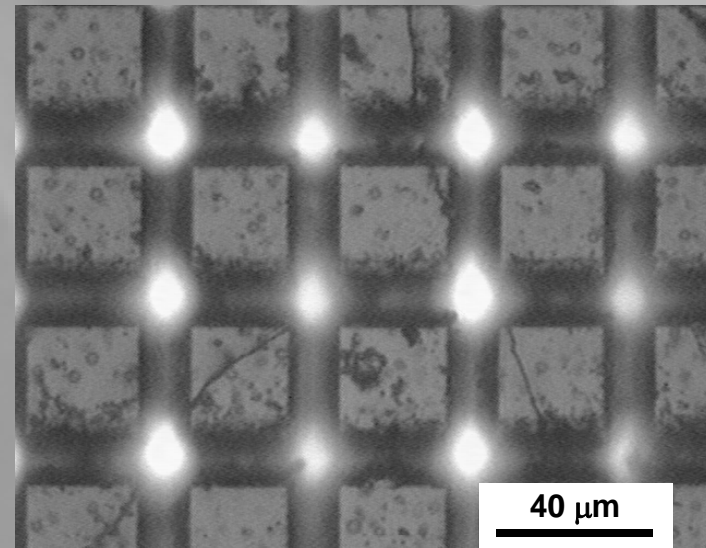
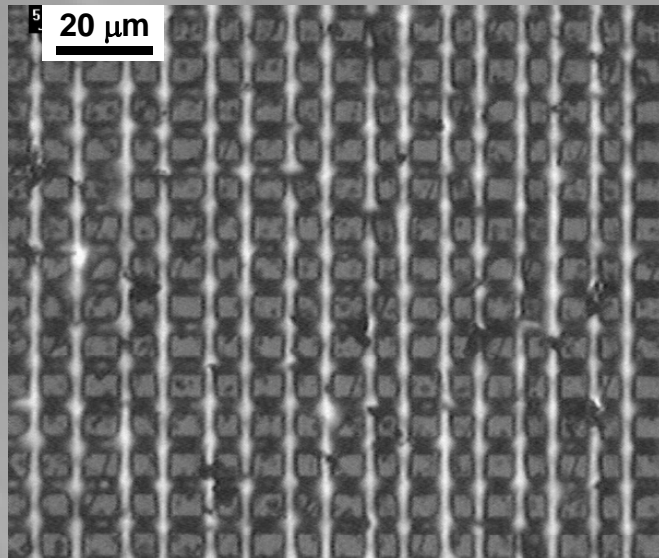
superhydrophobic surfaces

azopolymeric films micromachined with 100 ps pulses at 532 nm



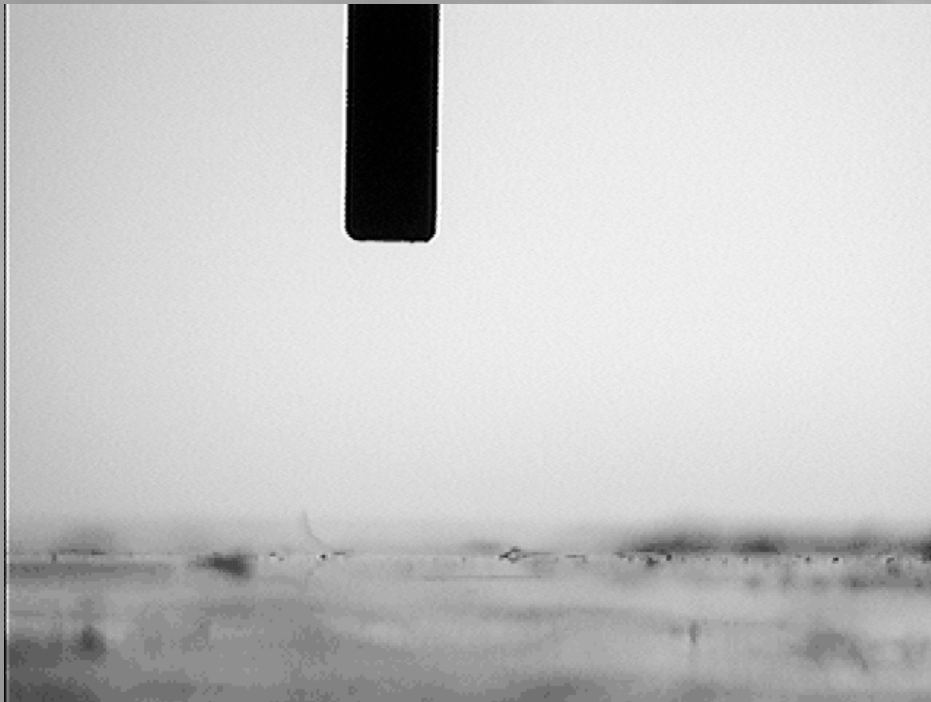
laser microfabrication

examples of fabricated surfaces

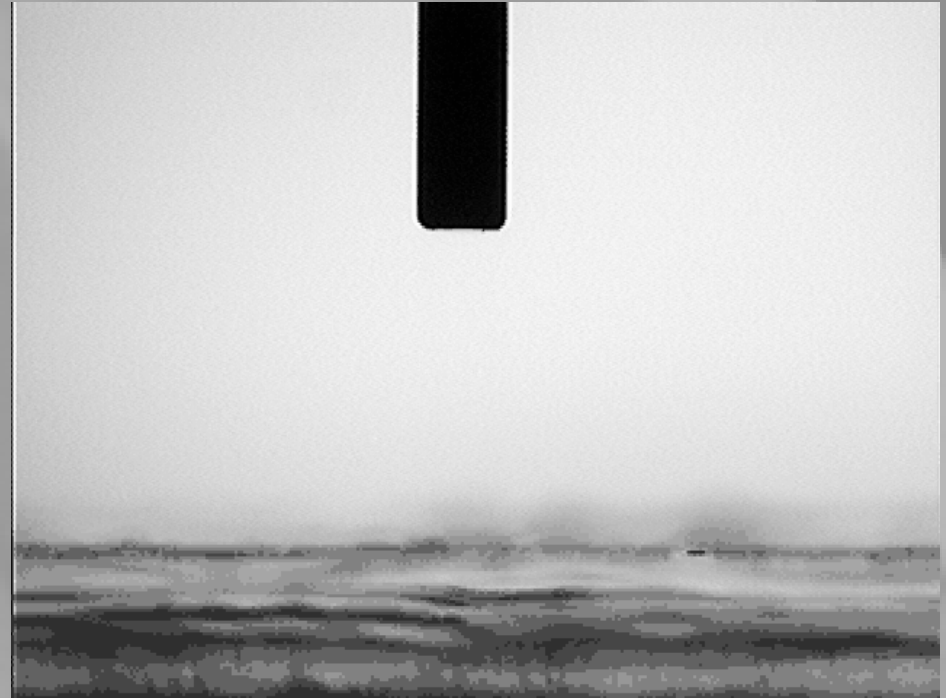


laser microfabrication

Superhydrophobic surfaces



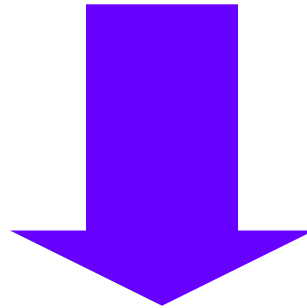
flat surface



microstructured surface

fs-laser microfabrication

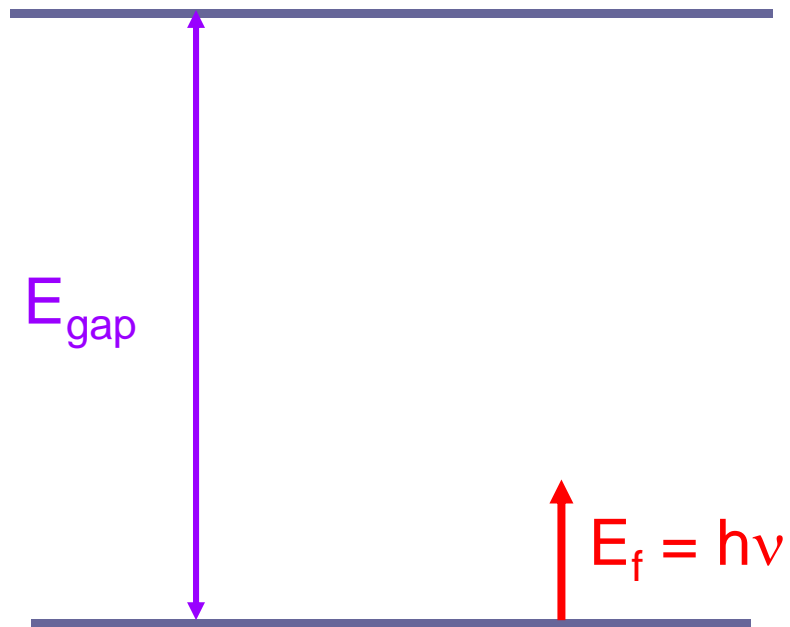
photon energy $<$ bandgap



nonlinear interaction

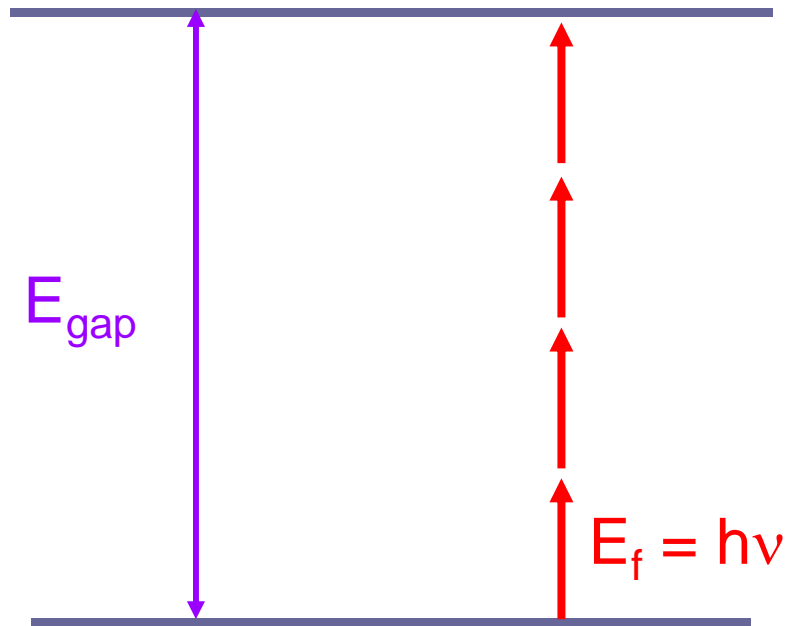
fs-laser microfabrication

nonlinear interaction



fs-laser microfabrication

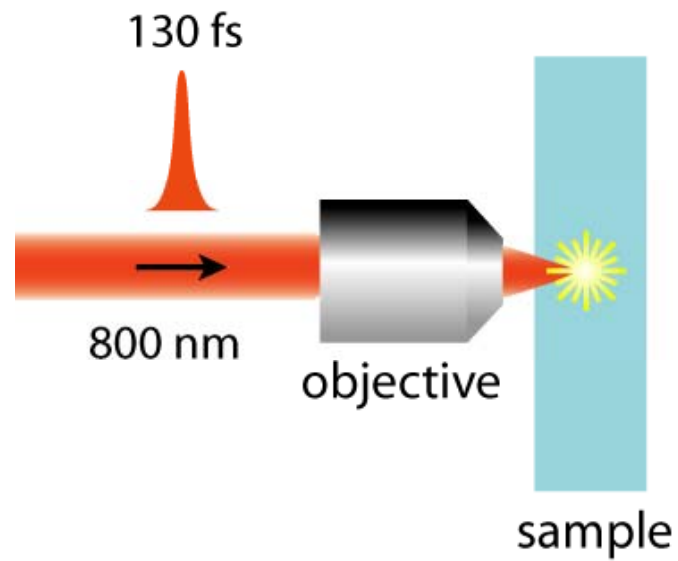
nonlinear interaction



multiphoton absorption

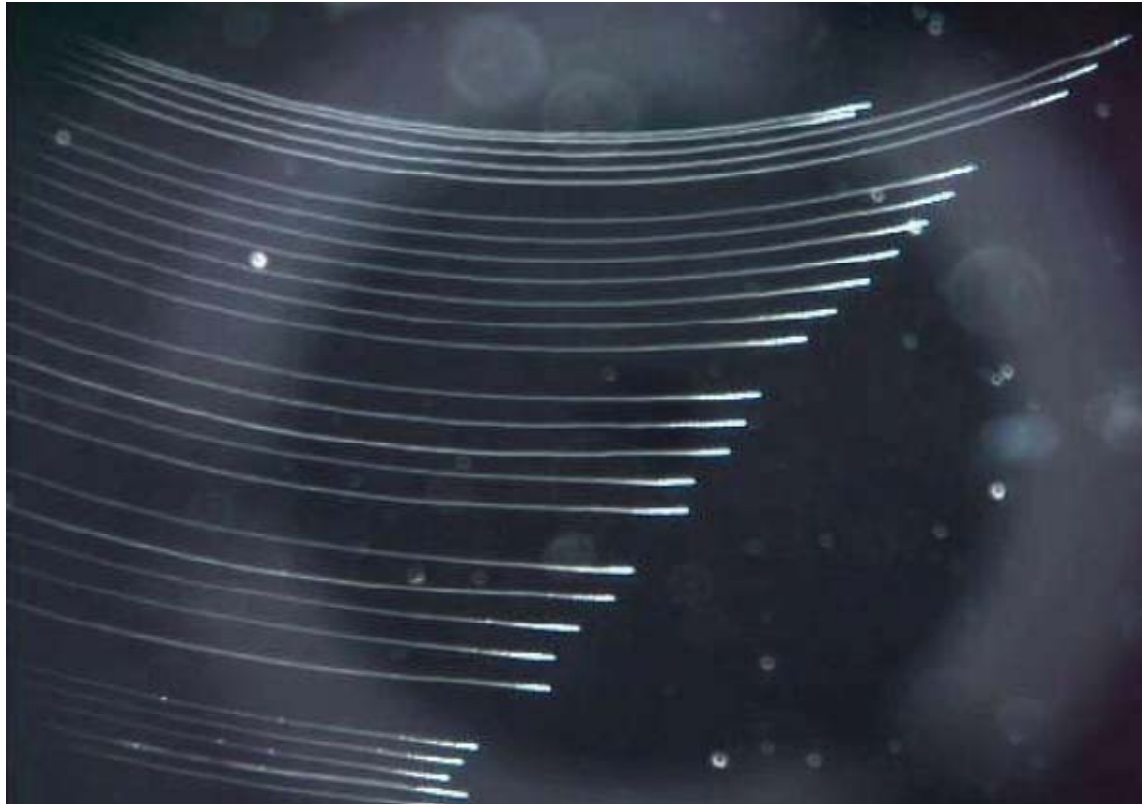
fs-laser microfabrication

focus laser beam inside material



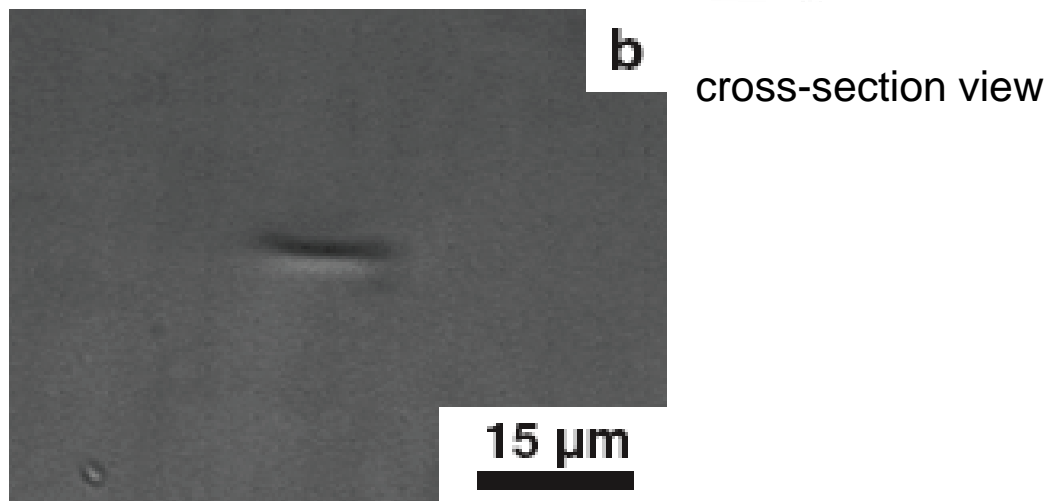
fs-laser microfabrication

curved waveguides inside glass



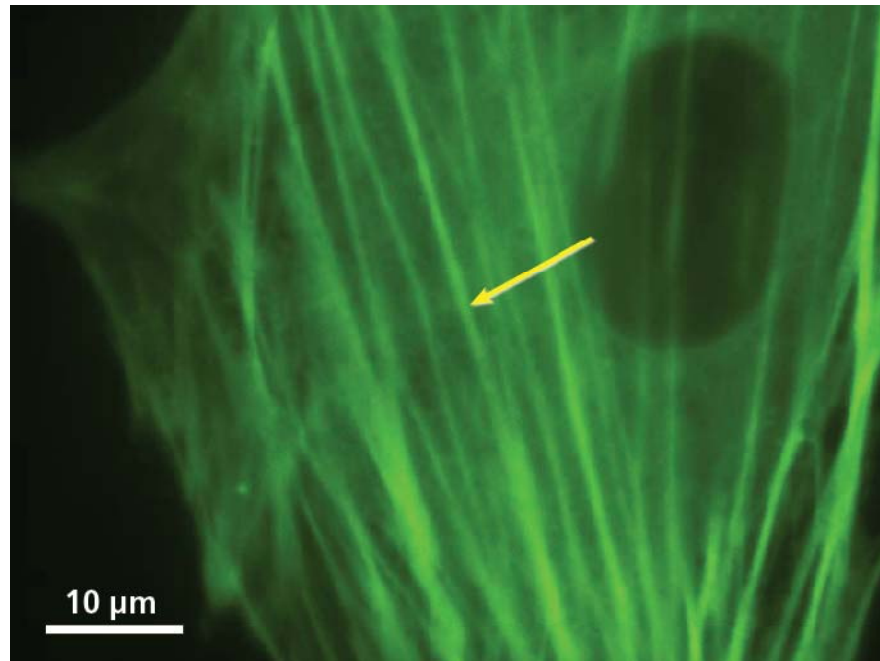
fs-laser microfabrication

3D waveguides in PMMA



fs-laser microfabrication

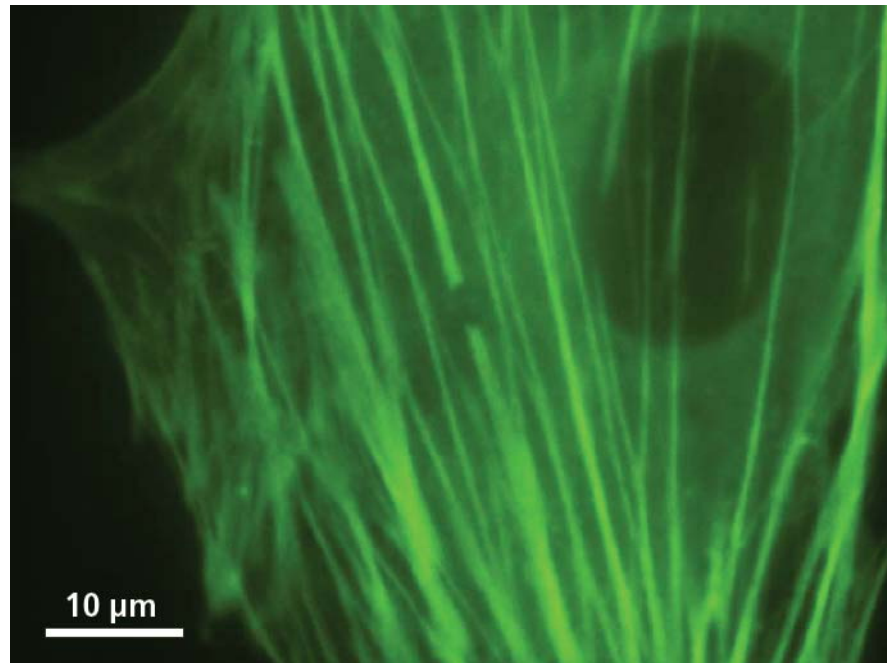
cut a single fiber bundle inside a cell



I. Maxwell, E. Mazur – Harvard University

fs-laser microfabrication

Cut a single fiber bundle inside a cell



I. Maxwell, E. Mazur – Harvard University

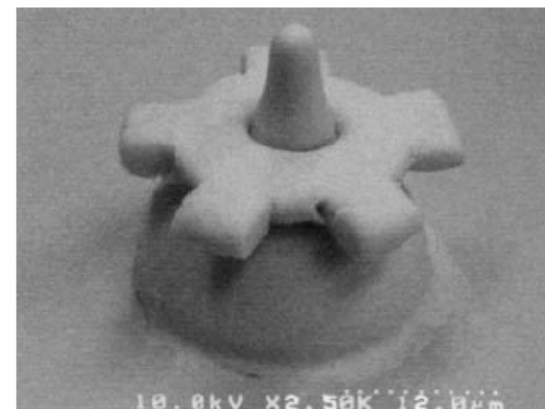
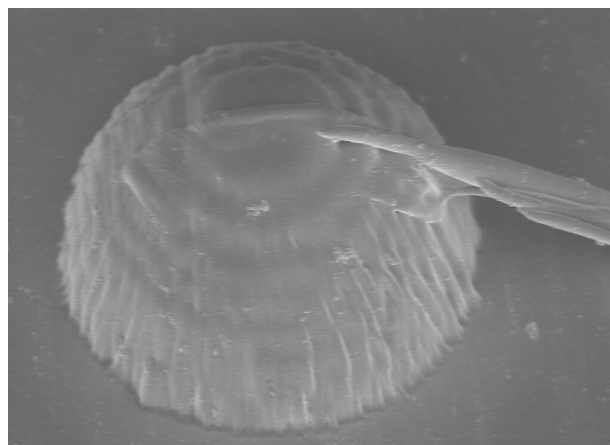
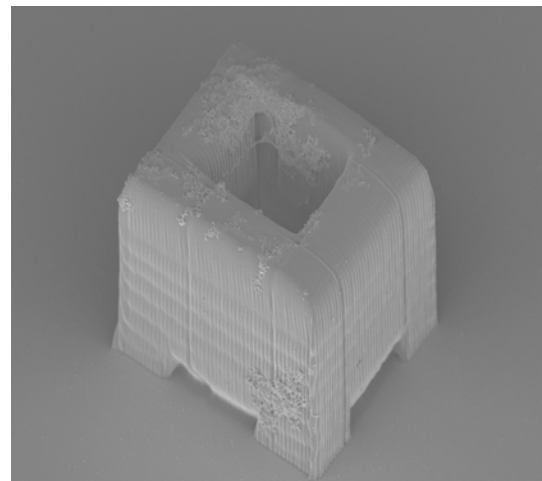
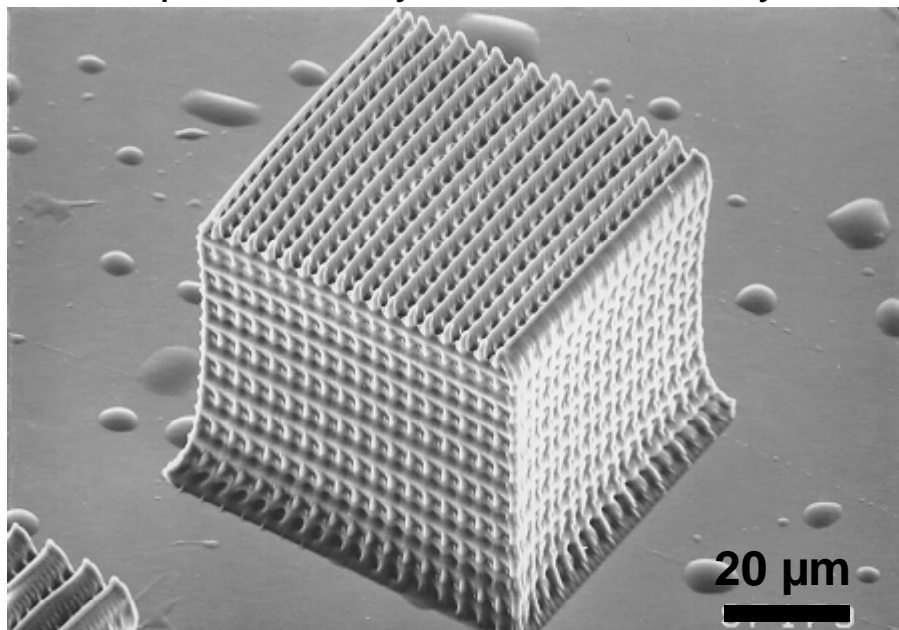
fs-laser microfabrication

Novel concept:

build a microstructure using fs-laser and nonlinear optical processes

two-photon polymerization

photonic crystal – J. W. Perry



two-photon polymerization

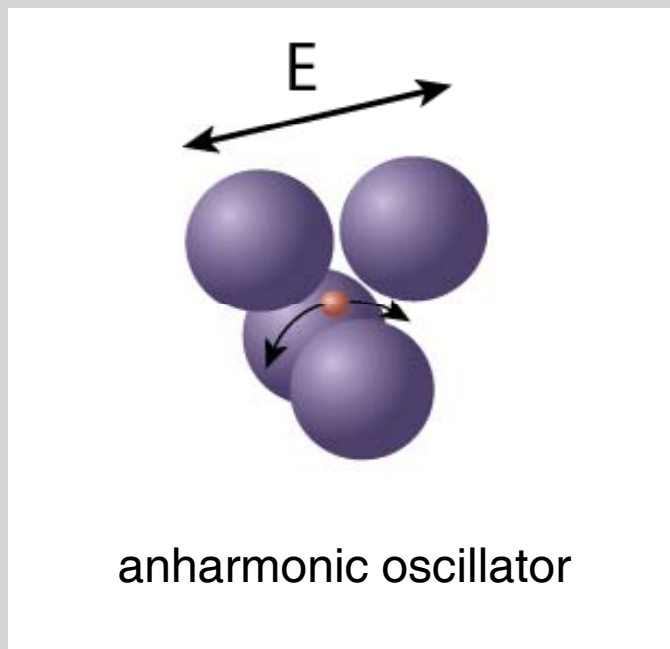
applications

- 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



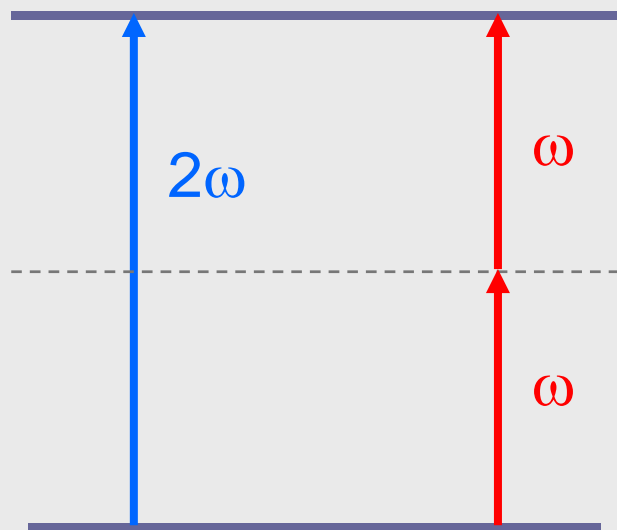
high light intensity

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

nonlinear polarization response

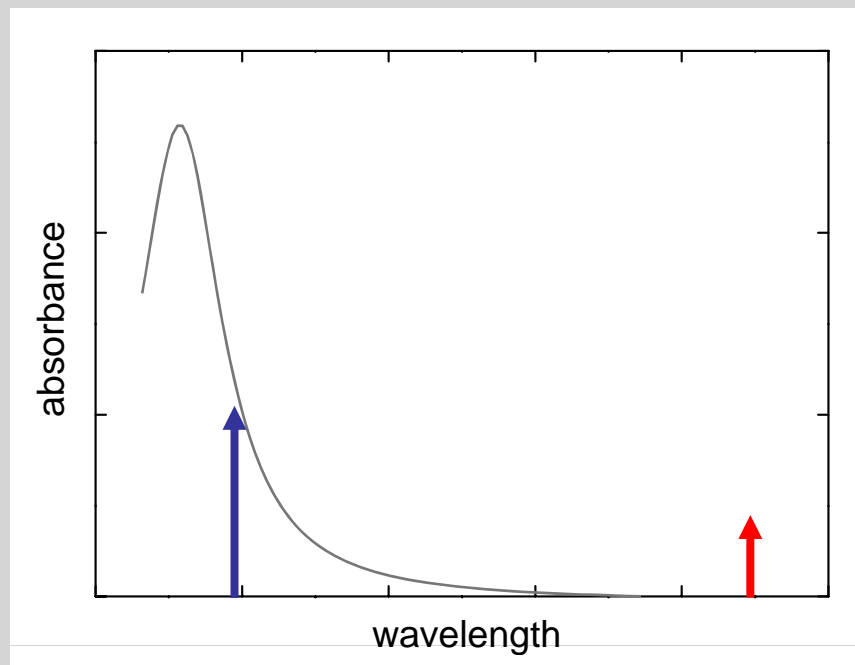
$$P = \chi^{(1)} E + \chi^{(2)} E^2 + \chi^{(3)} E^3 + \dots$$

Two-photon absorption



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

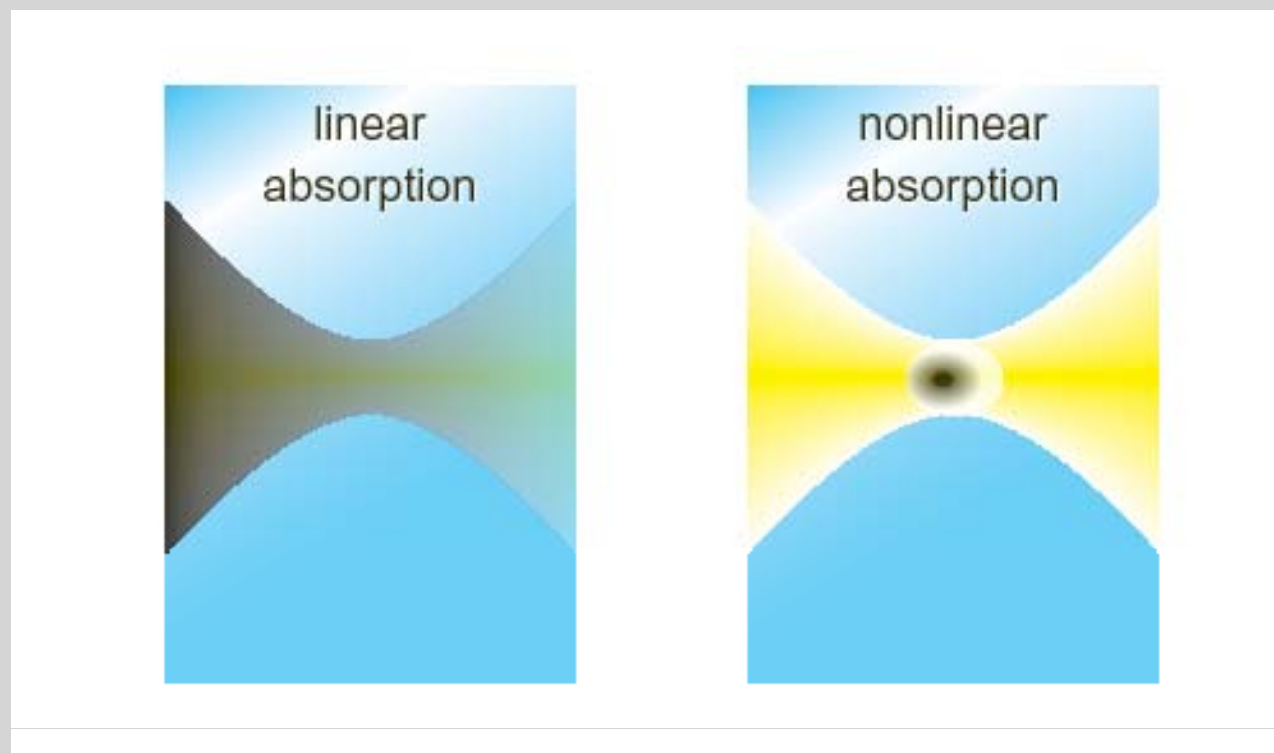
Third order processes $\chi^{(3)}$



Two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication



$$\alpha = \alpha_0$$

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

Two-photon absorption

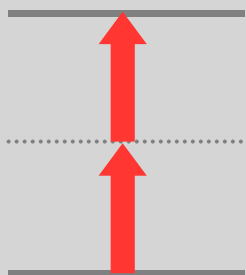


spatial confinement of excitation

Two-photon polymerization

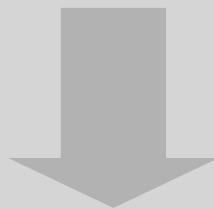


Photoinitiator is excited by ***two-photon absorption***



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

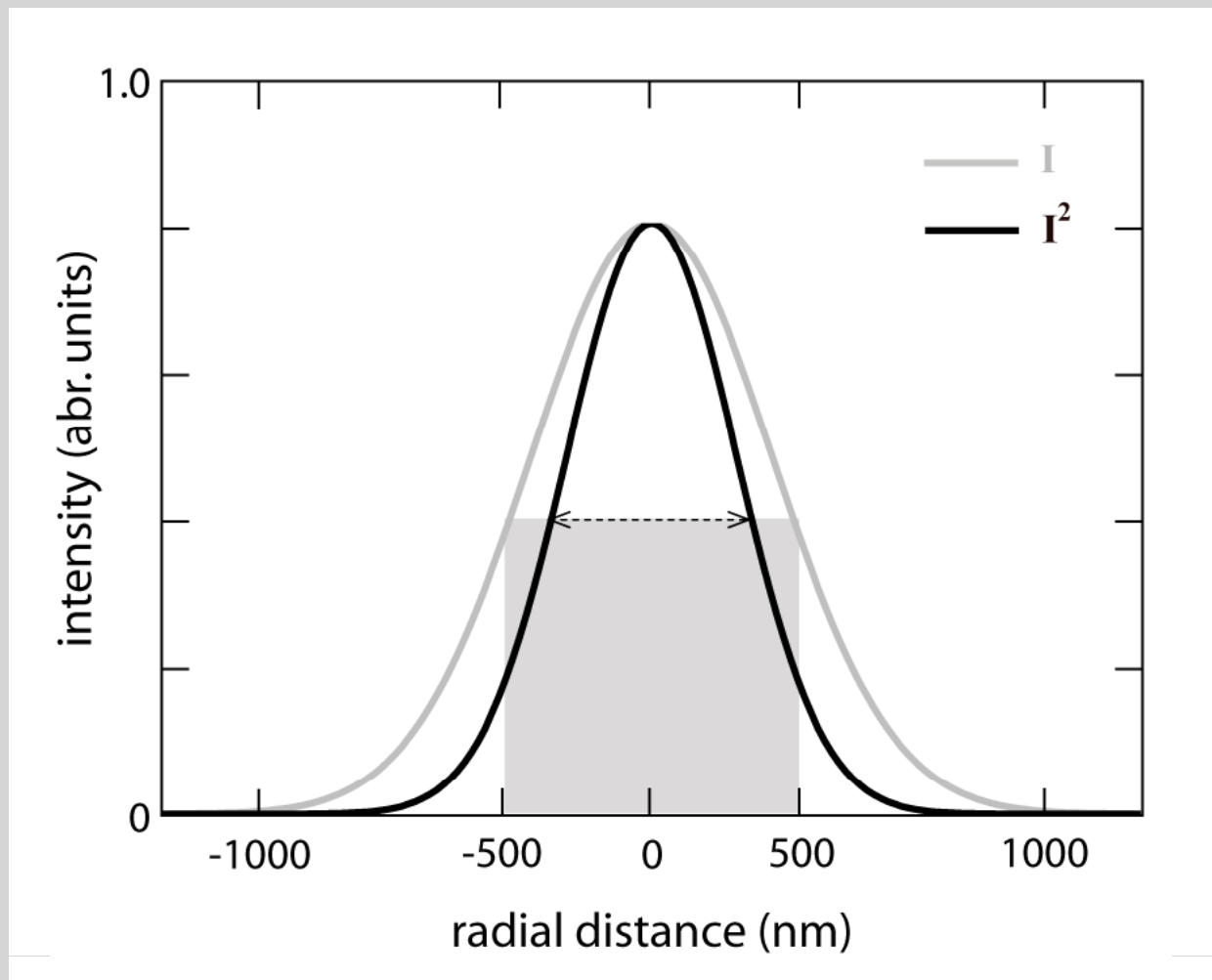
The polymerization is confined to the focal volume.



High spatial resolution

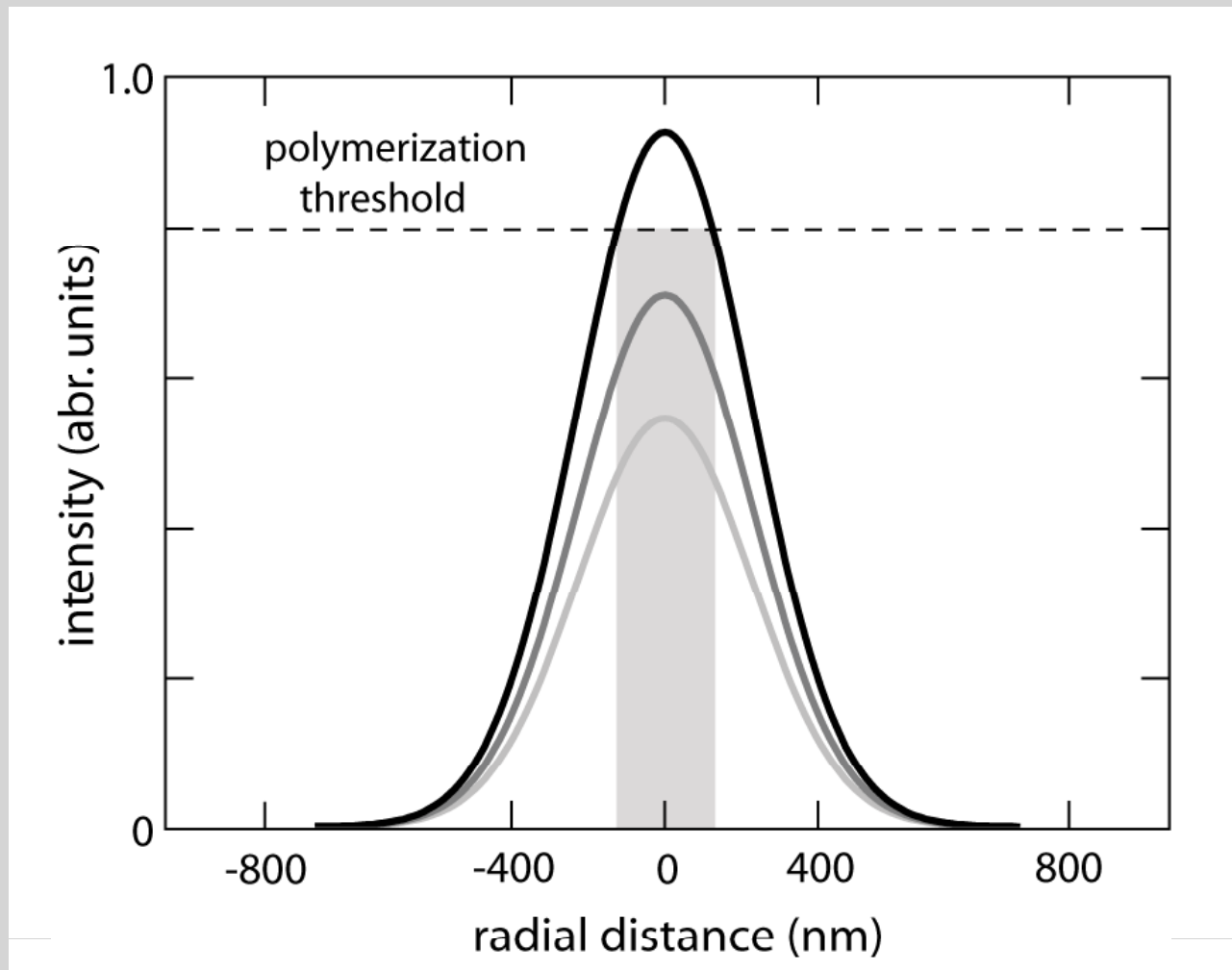


Two-photon polymerization



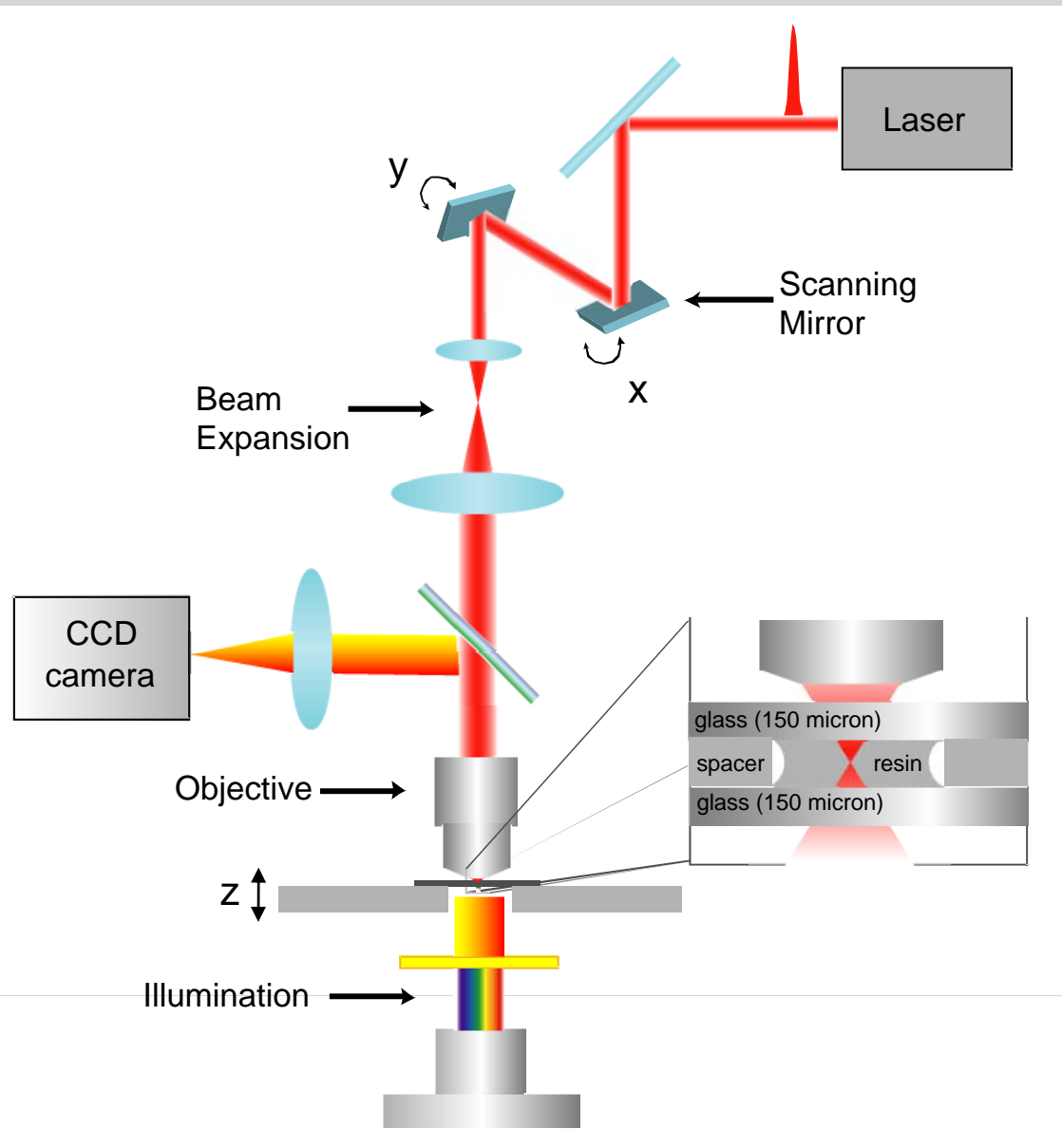
bellow the diffraction limit

Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



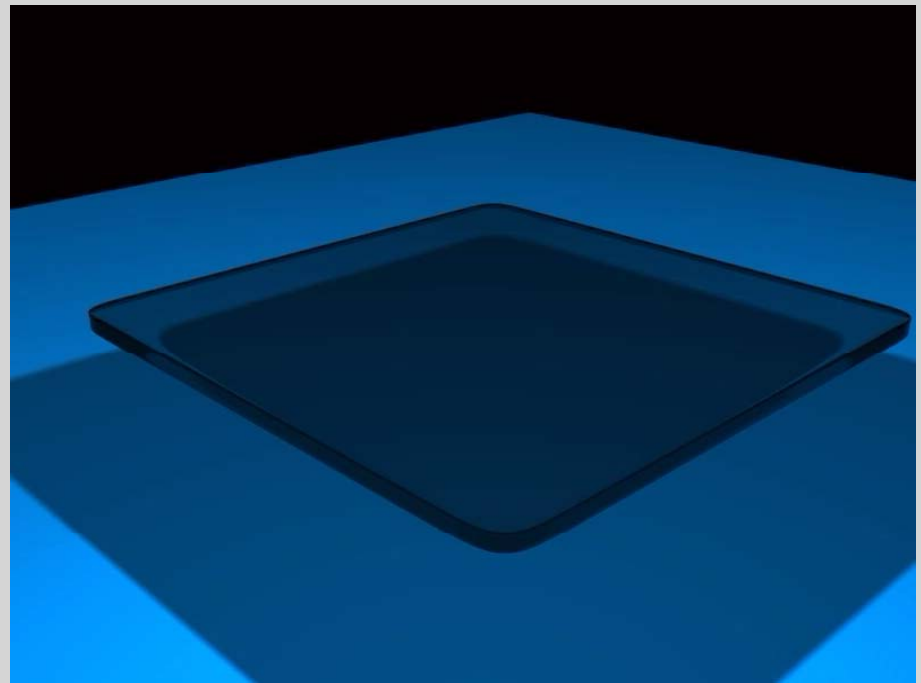
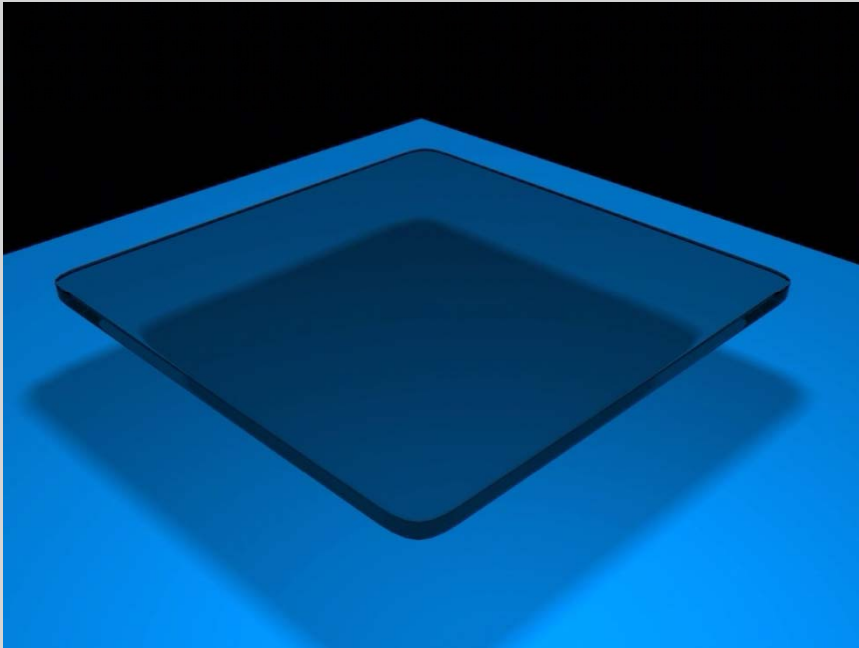
Ti:sapphire laser oscillator

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

Objective

40 x
0.65 NA

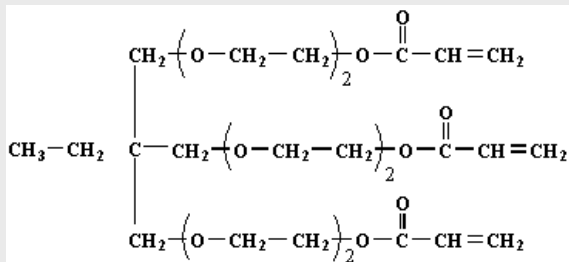
Two-photon polymerization



Resin preparation

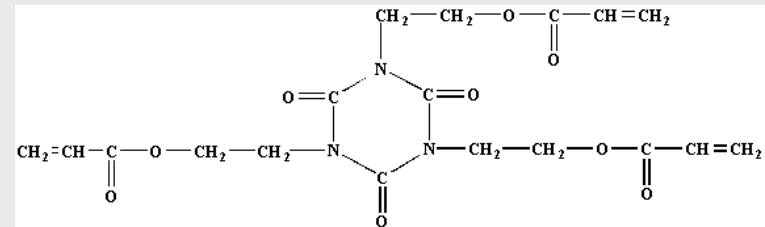
Monomers

Monomer A



reduces the shrinkage upon polymerization

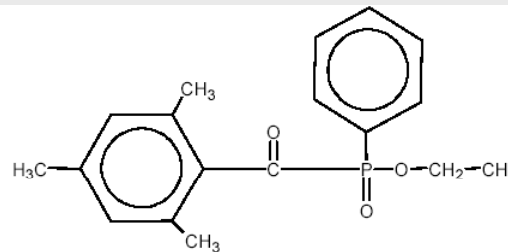
Monomer B



gives hardness to the polymeric structure

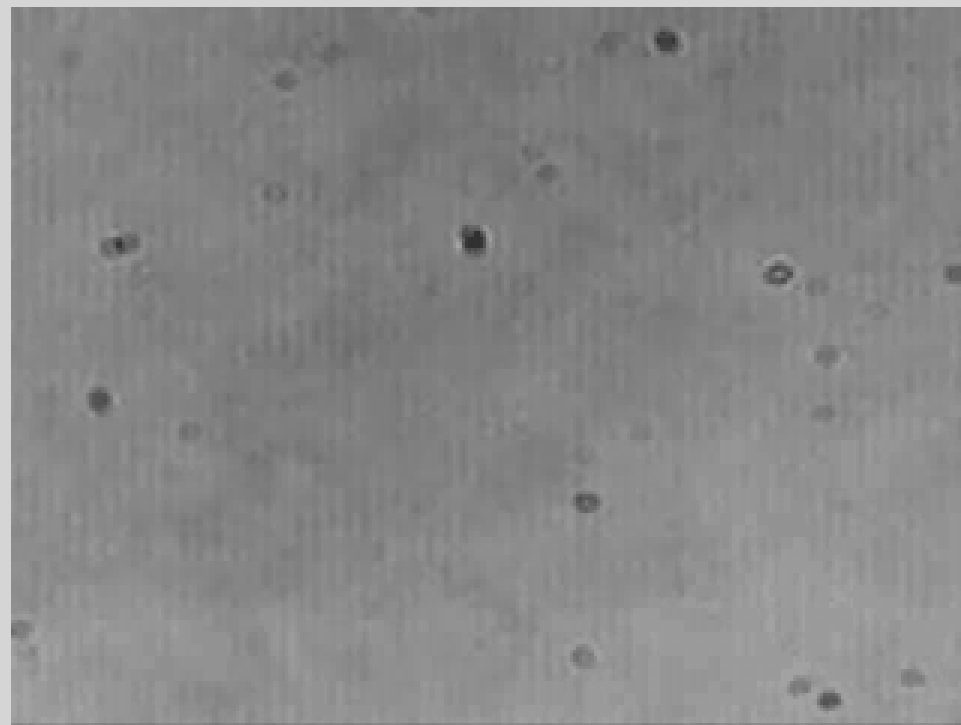
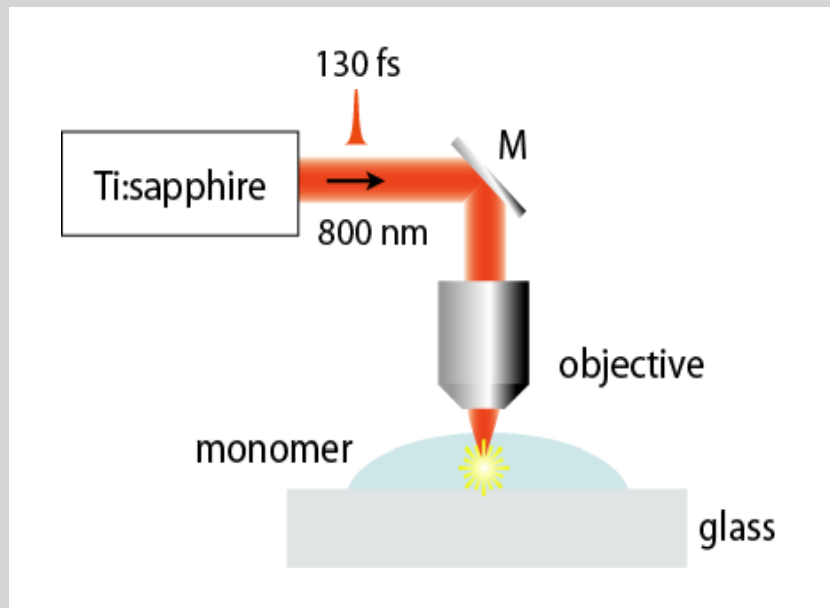
Photoinitiator

Lucirin TPO-L

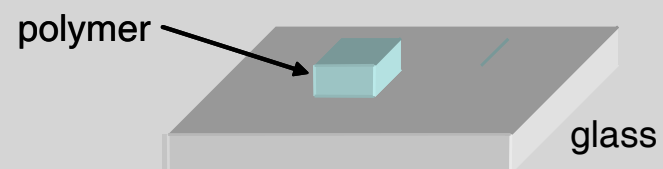


Appl. Phys. A, 90, 633–636 (2008)

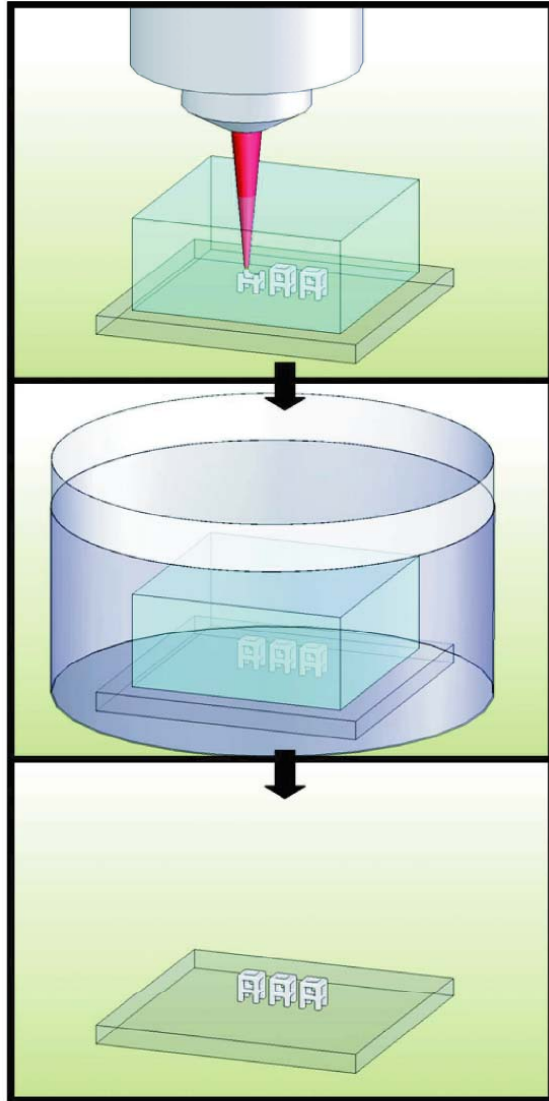
Two-photon polymerization



30 μm x 30 μm x 12 μm cube



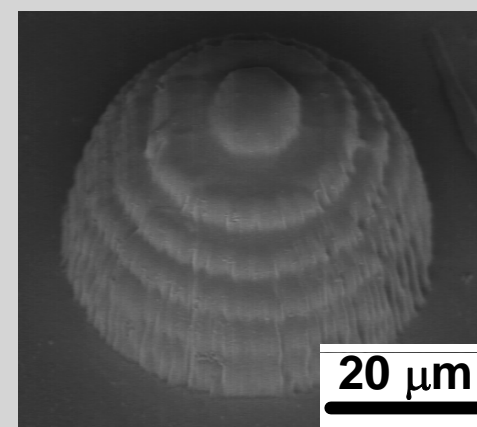
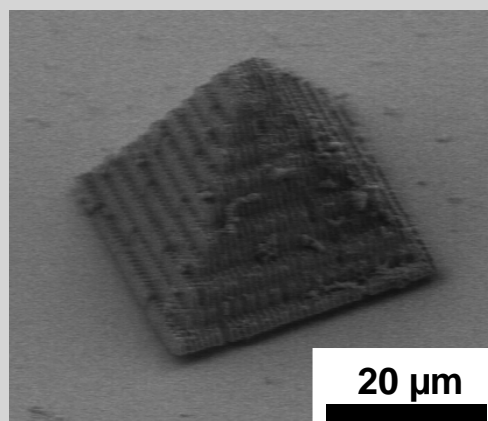
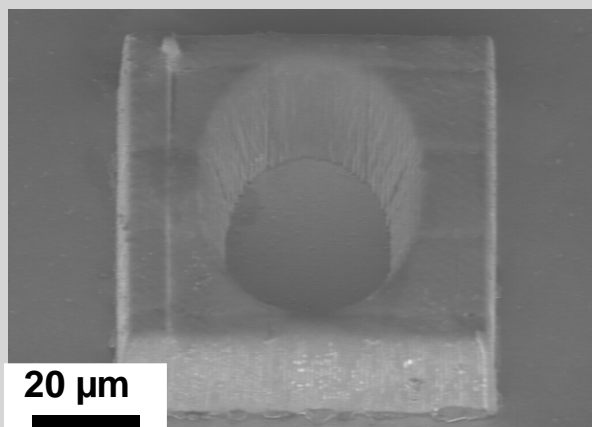
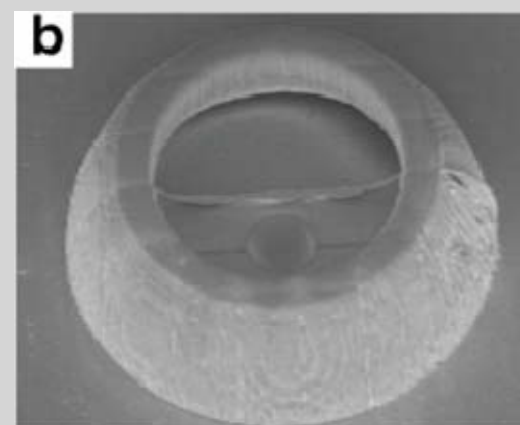
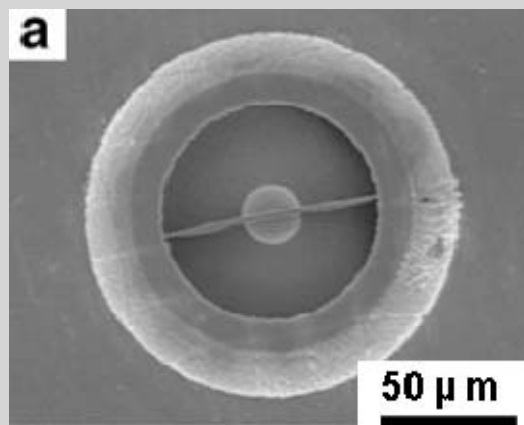
Two-photon polymerization



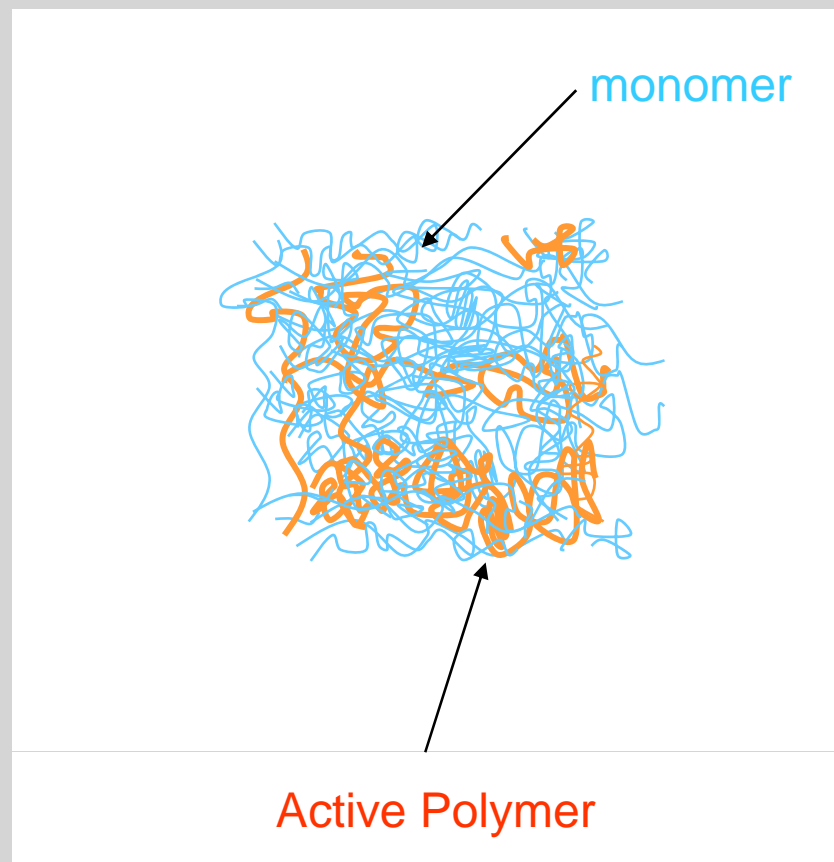
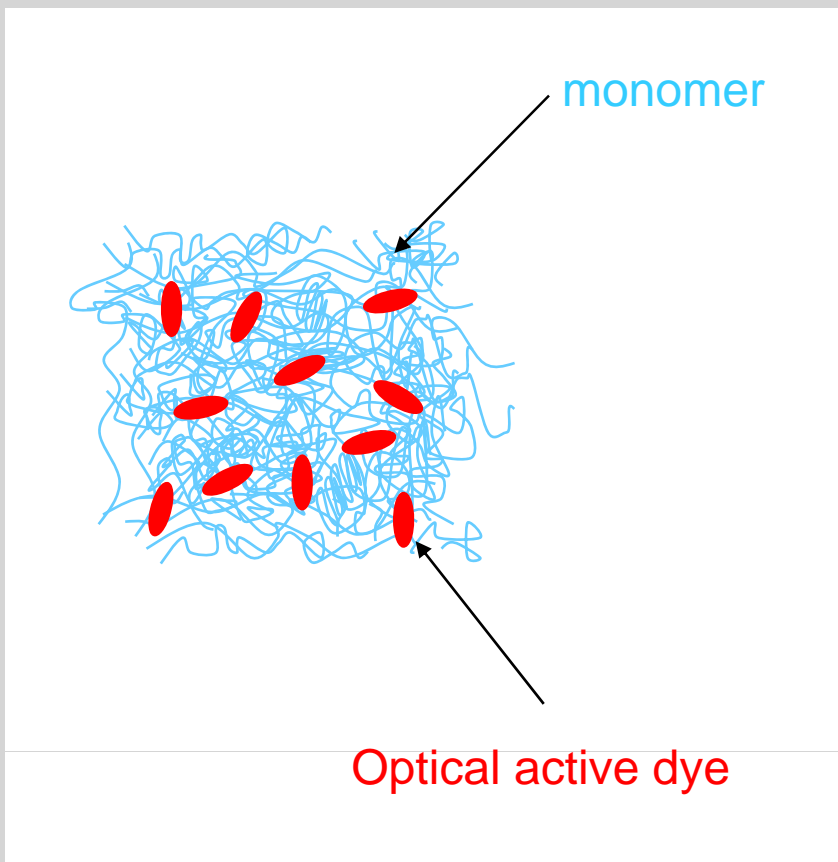
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

Two-photon polymerization

Microstructures fabricated by two-photon polymerization

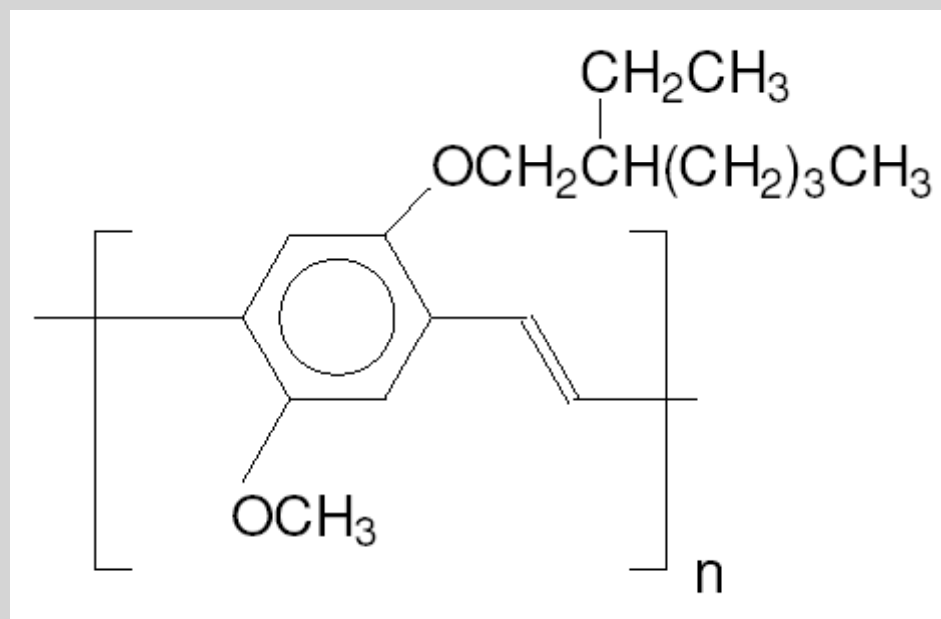


Microstructures containing active compounds



Microstructures containing MEH-PPV

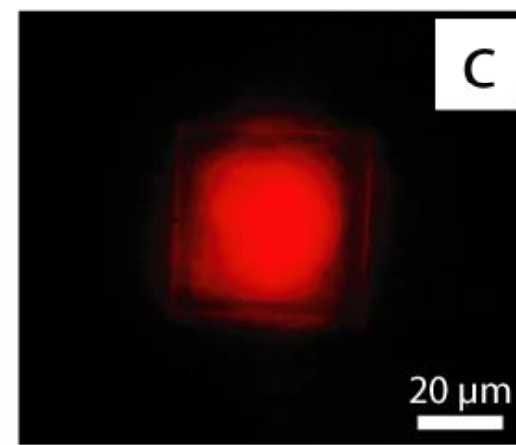
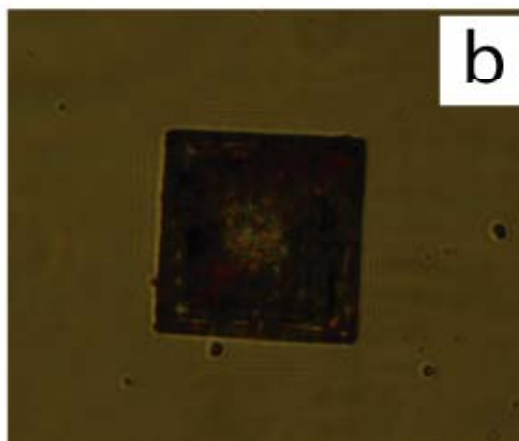
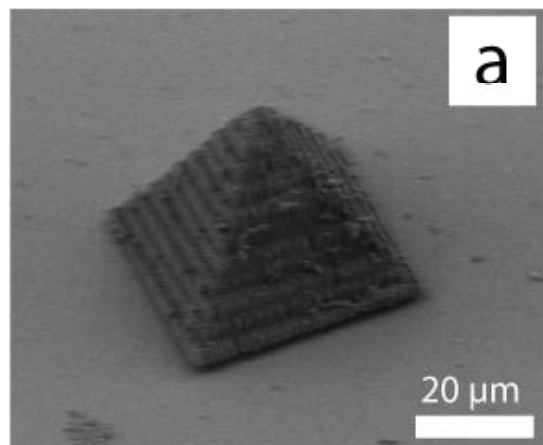
MEH-PPV



Fluorescence
Electro Luminescent
Conductive

Microstructures containing MEH-PPV

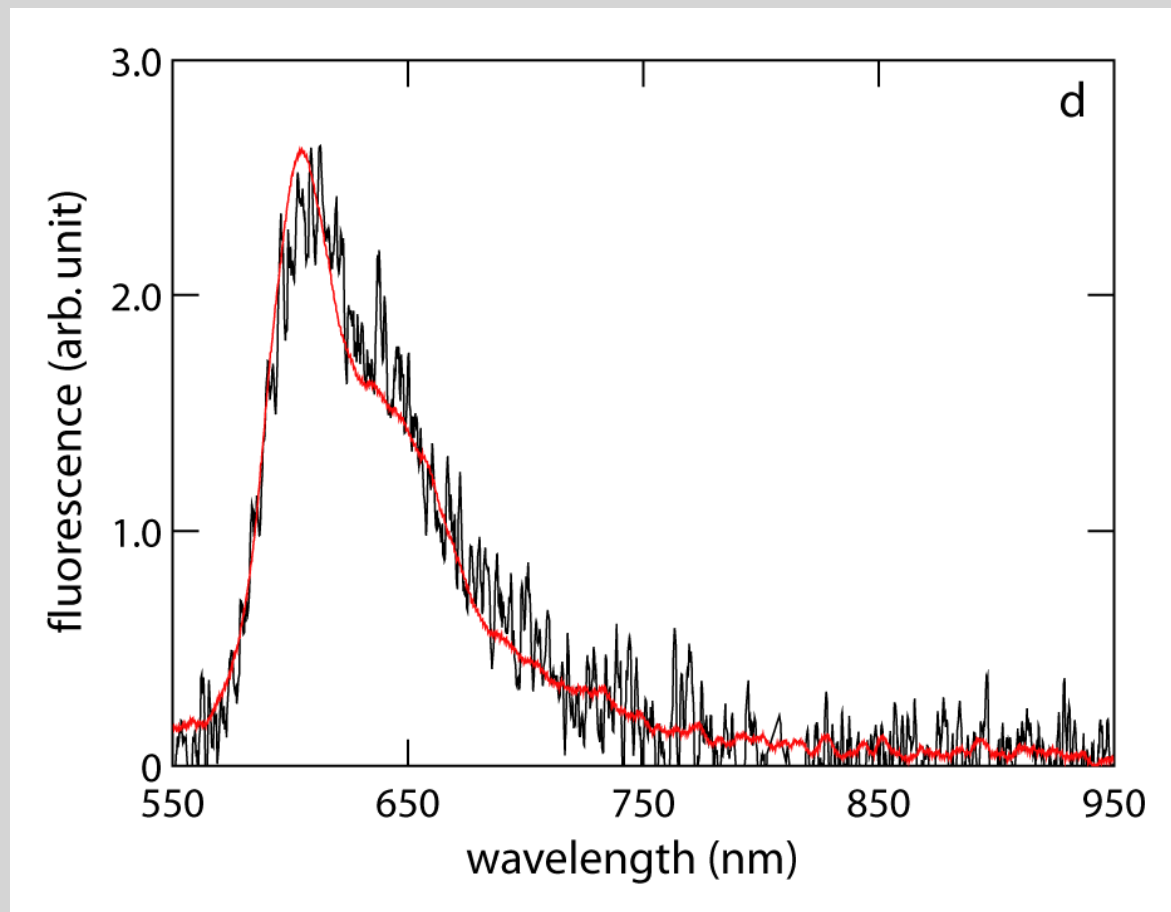
MEH-PPV: up to 1% by weight
laser power 40 mW



a - Scanning electron microscopy

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

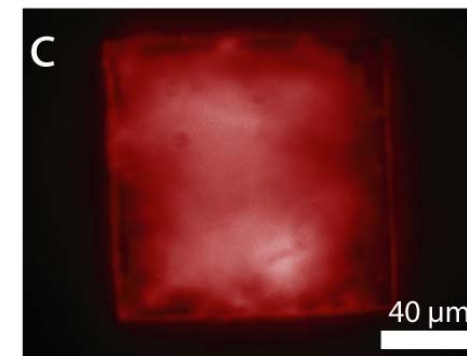
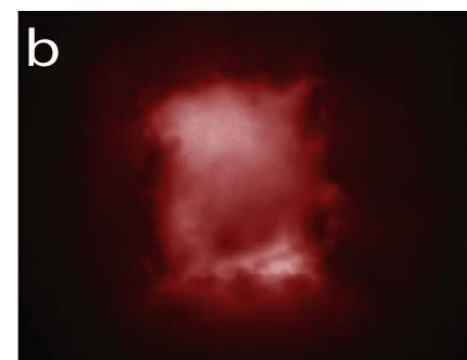
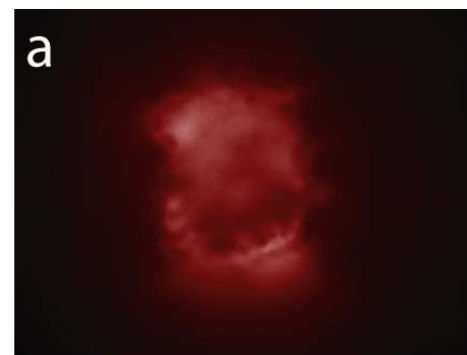
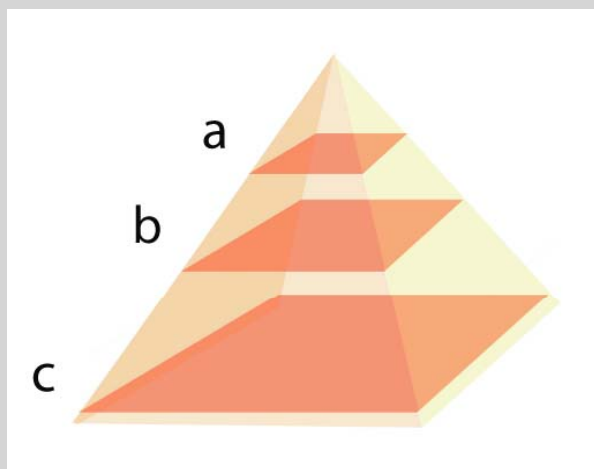
Microstructures containing MEH-PPV



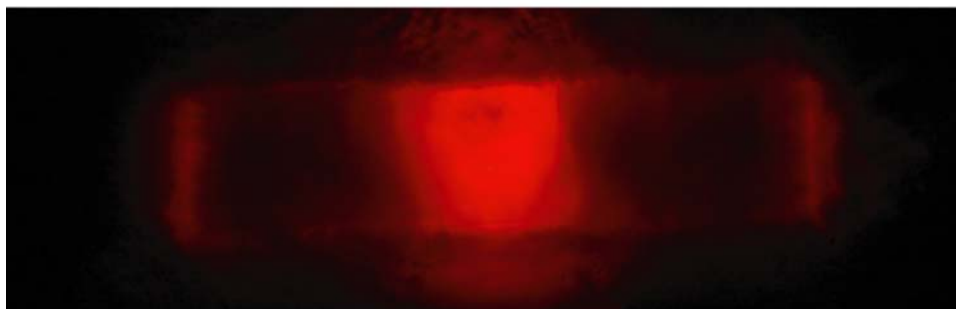
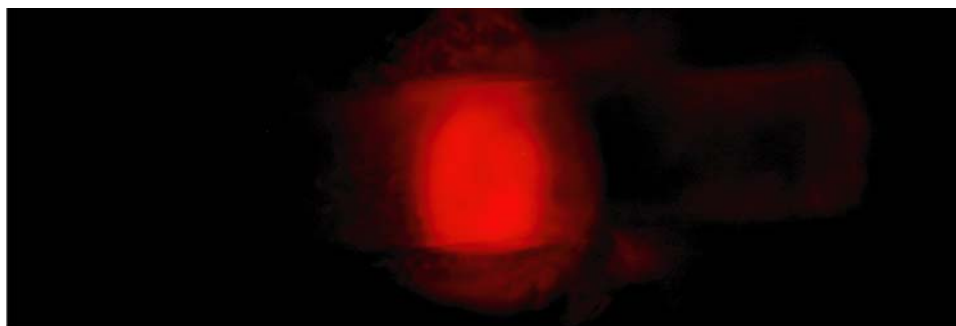
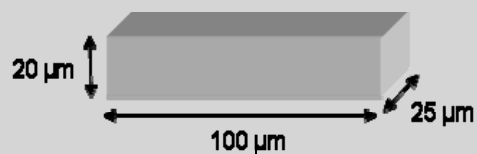
d - Emission of the microstructure (black line) and of a film with the same composition (red line)

Microstructures containing MEH-PPV

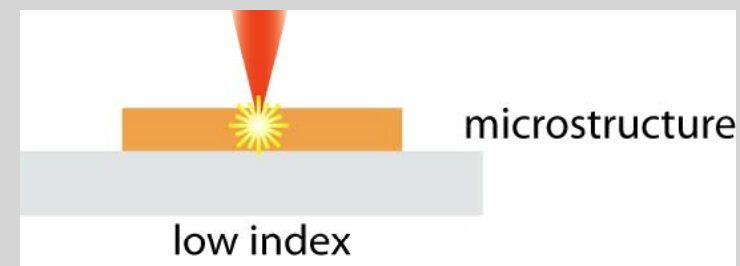
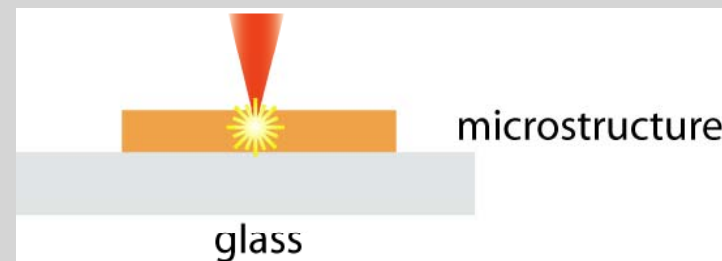
Fluorescent confocal microscopy images in planes separated by $16\ \mu\text{m}$ in the pyramidal microstructure.



Microstructures containing MEH-PPV



20 μm 

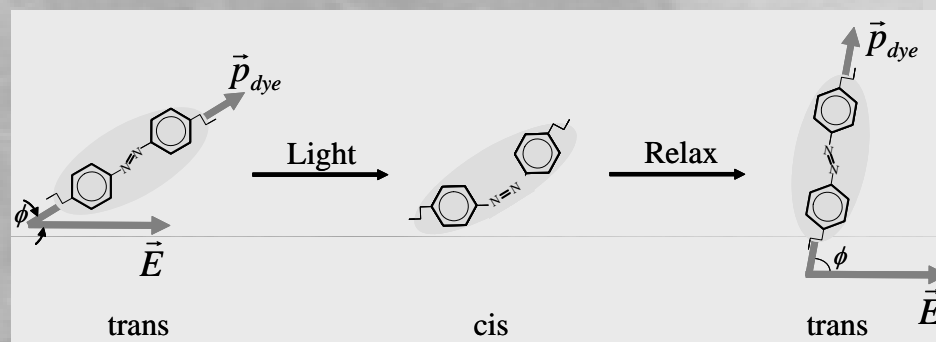
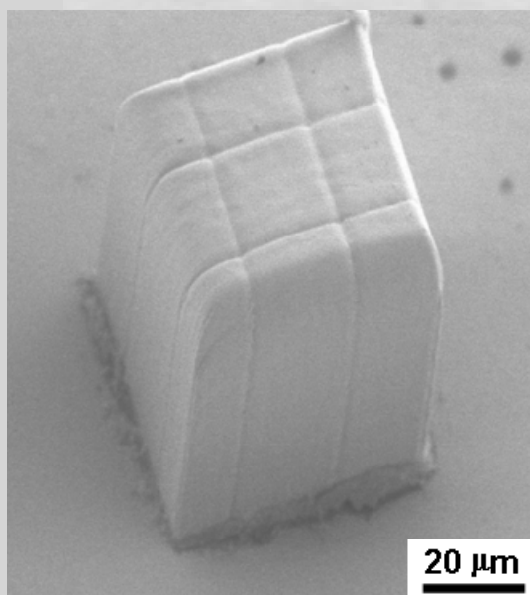


waveguiding of the microstructure fabricated on porous silica substrate ($n= 1.185$)

Applications: micro-laser; fluorescent microstructures; conductive microstructures

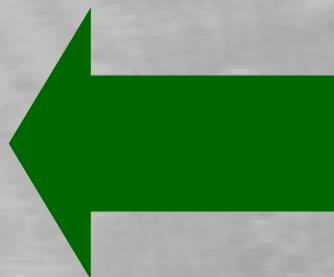
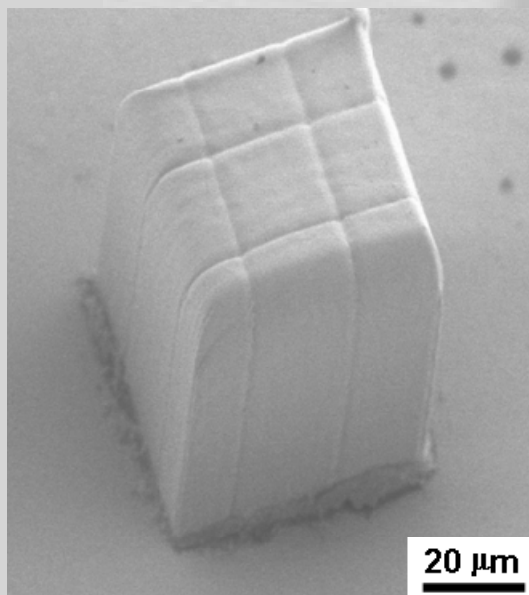
Other studies

- microstructures for optical storage – birefringence



Other studies

- microstructures for optical storage – birefringence



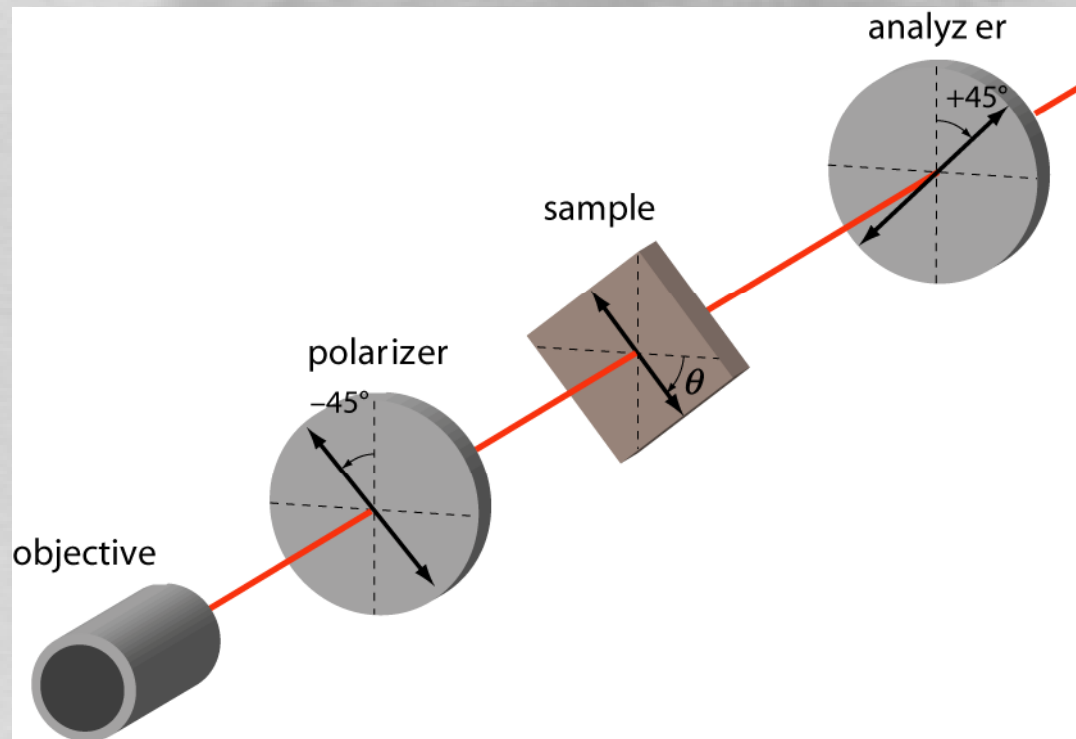
Ar⁺ ion laser irradiation

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

Other studies

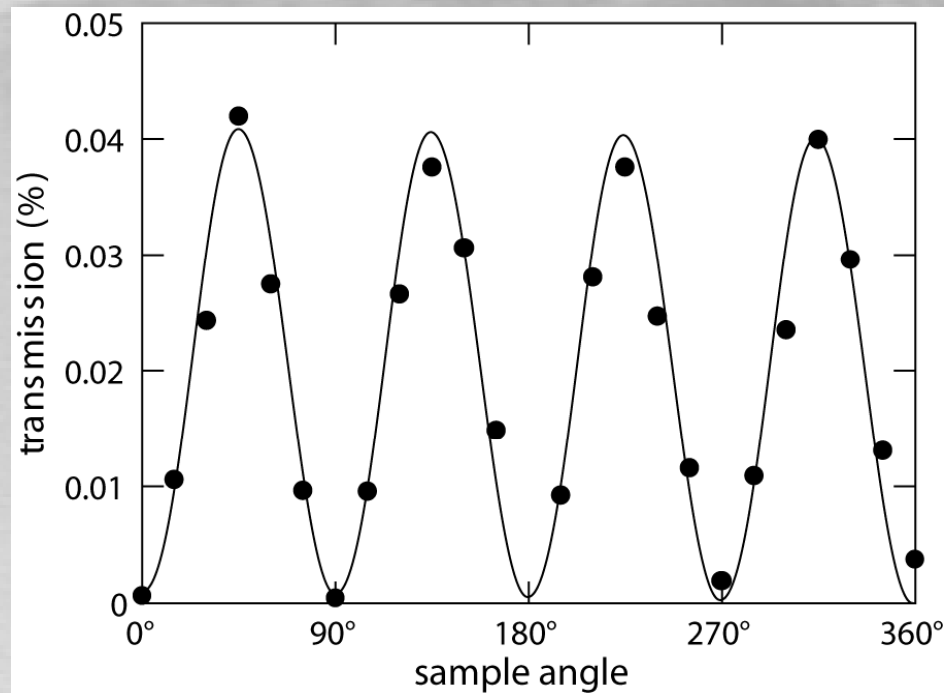
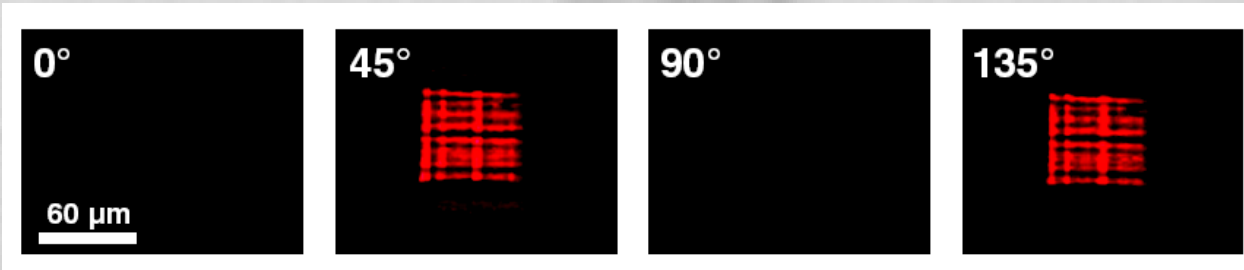
- microstructures for optical storage – birefringence

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



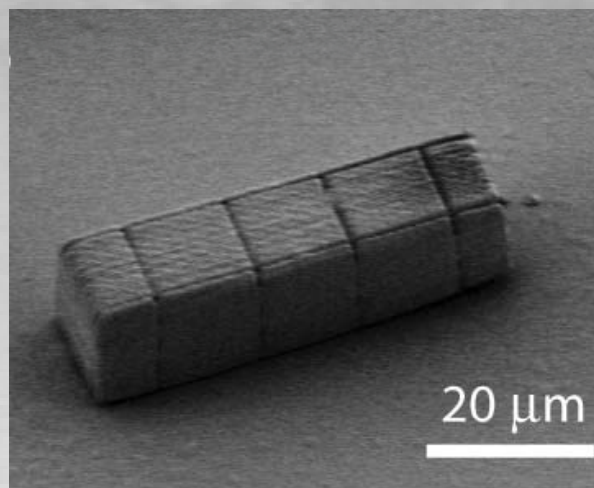
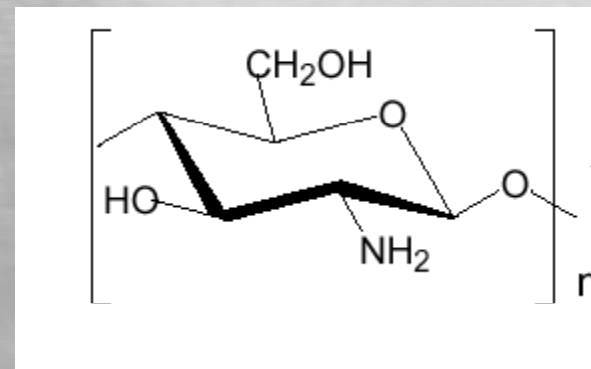
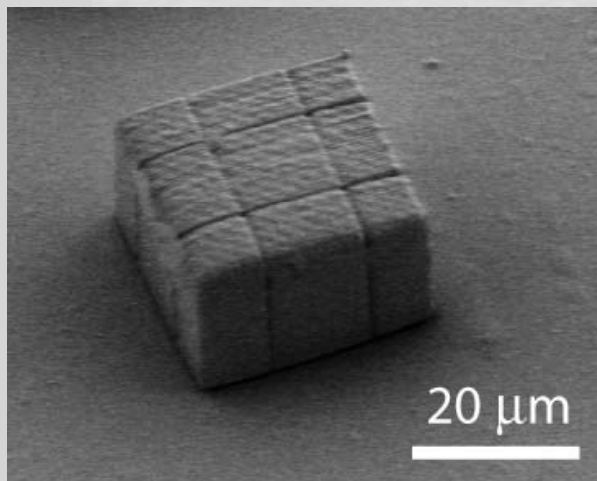
Other studies

- microstructures for optical storage – birefringence



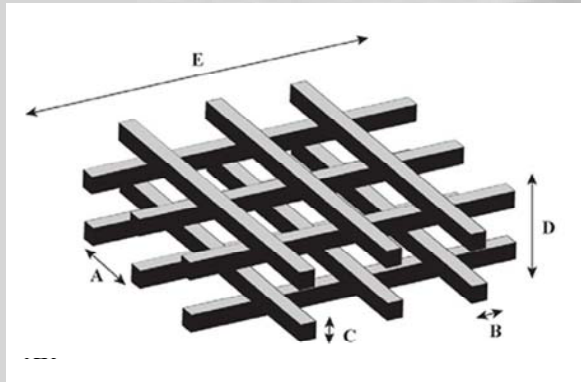
Other studies

- microstructures containing biopolymer - chitosan

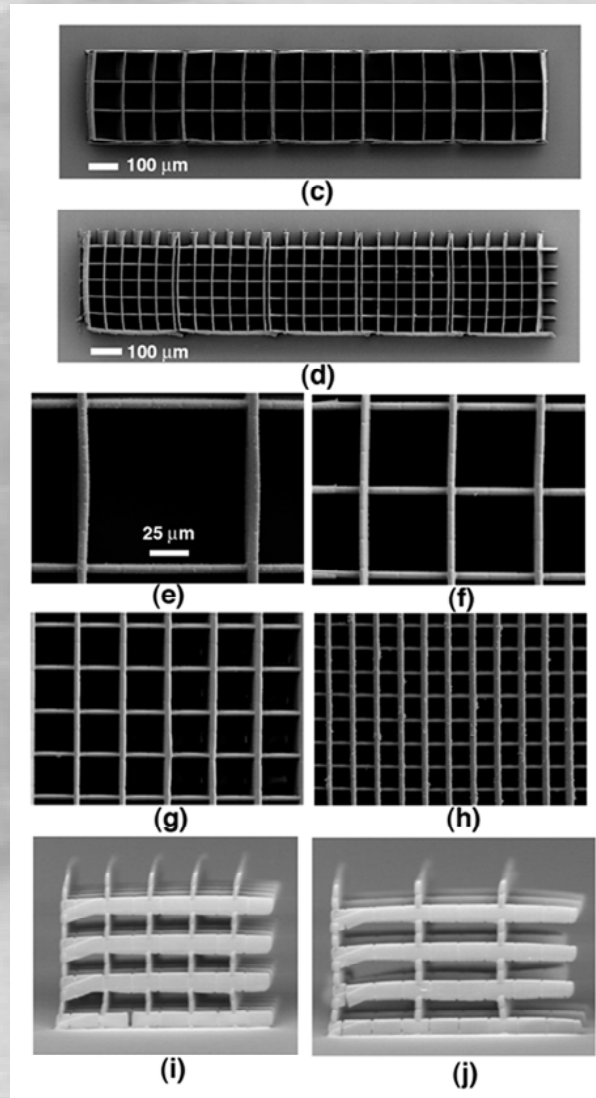


Other studies

- 3D cell migration studies in micro-scaffolds



SEM of the scaffolds



110 μm pore size

52 μm pore size

Top view

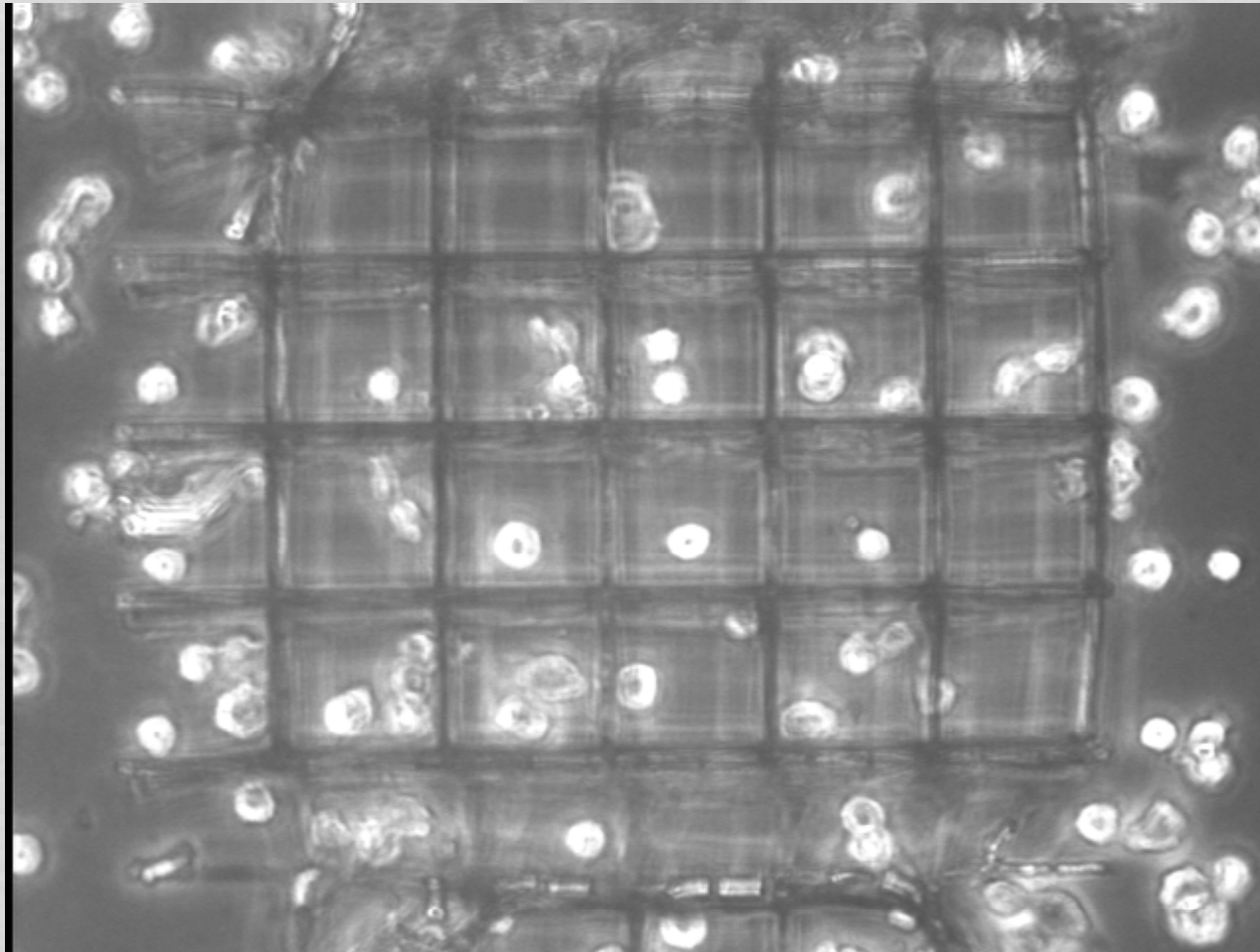
110, 52, 25, 12 μm pore size

Side view

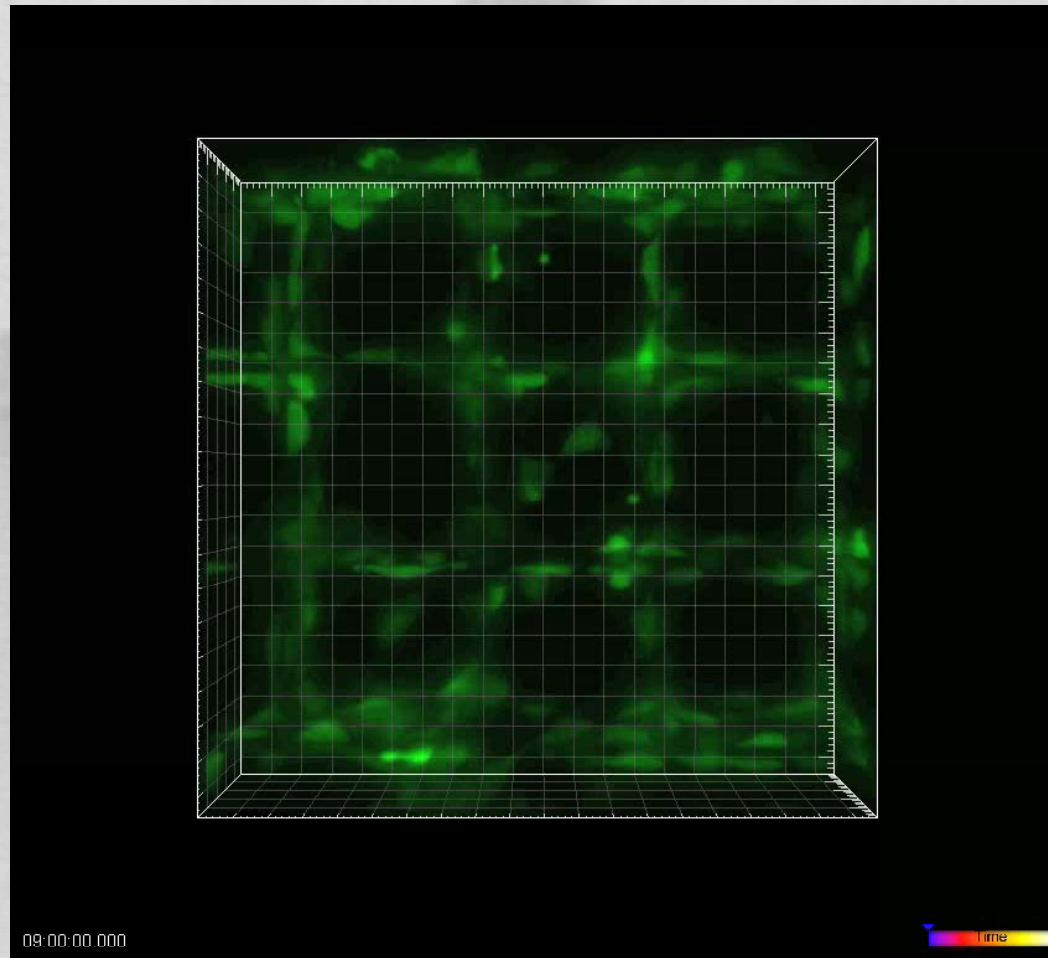
25, 52 μm pore size

Other studies

50 μm pore size

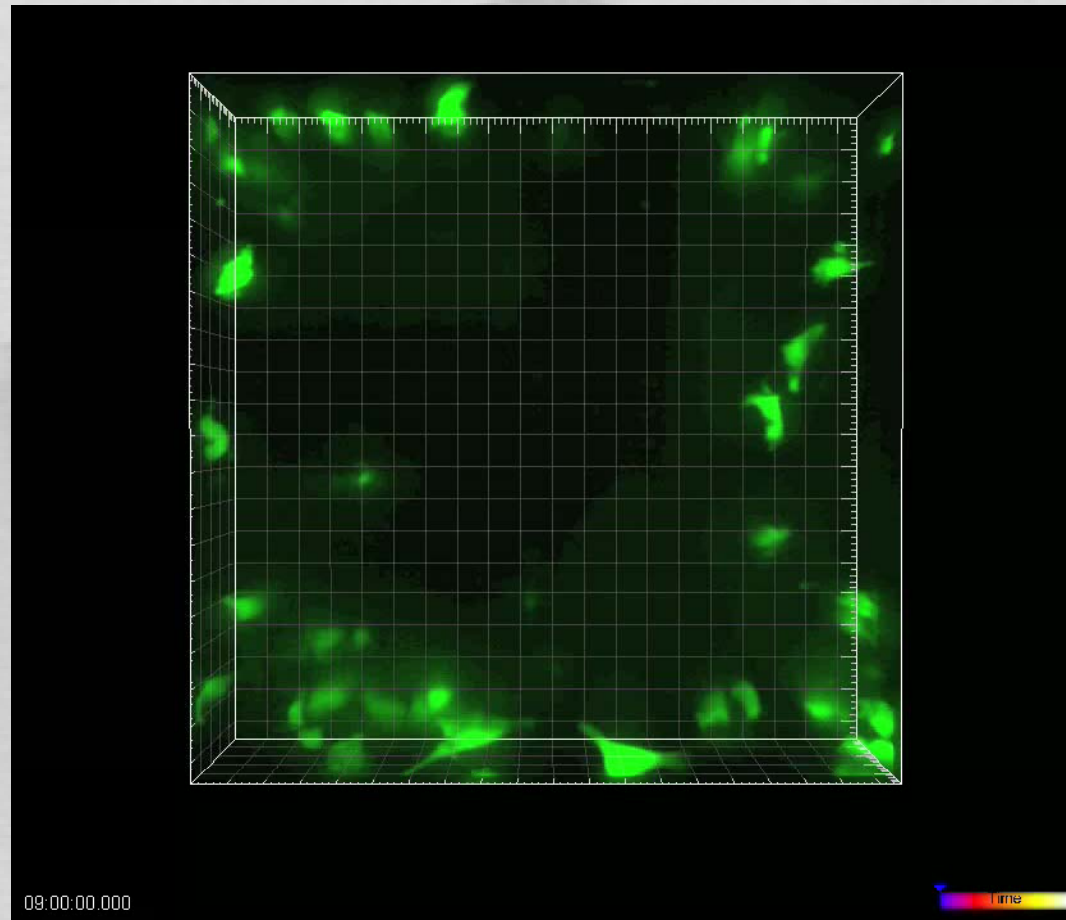


Other studies



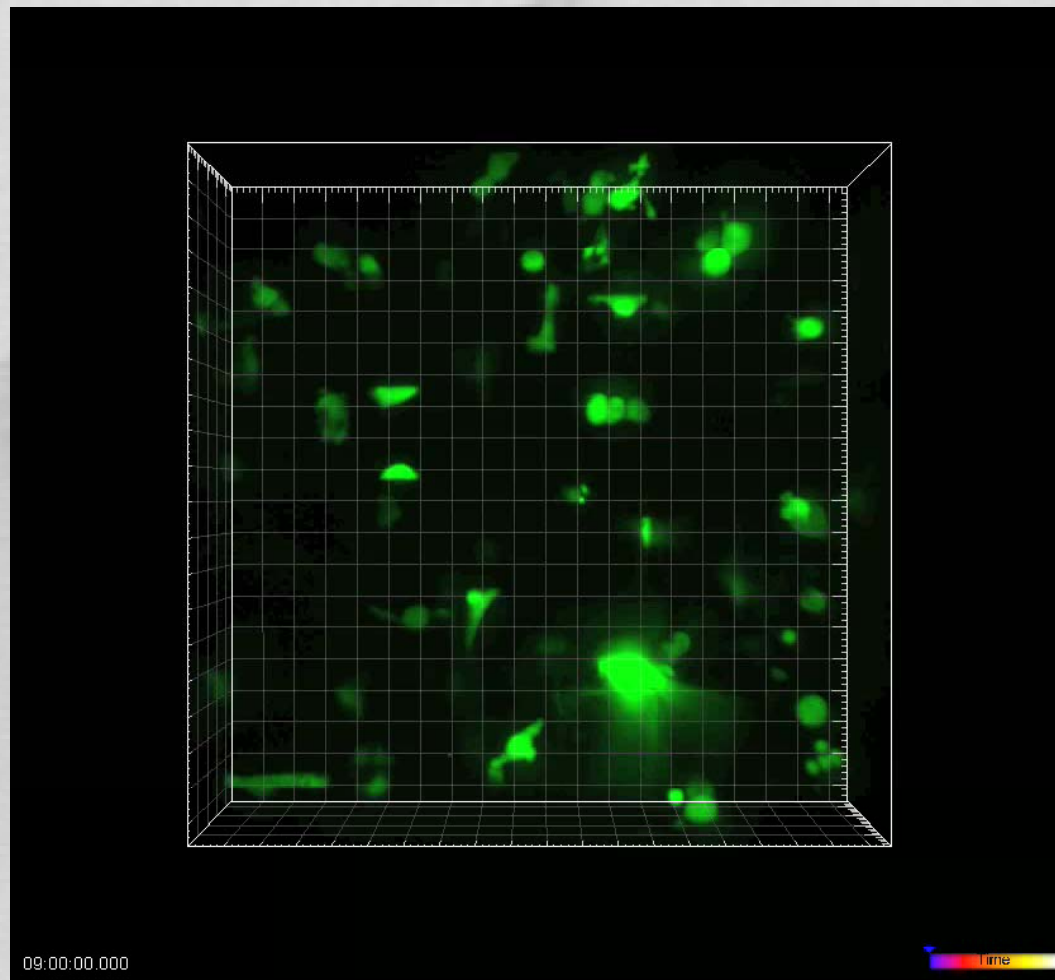
110 μm pore size

Other studies



12 μm pore size

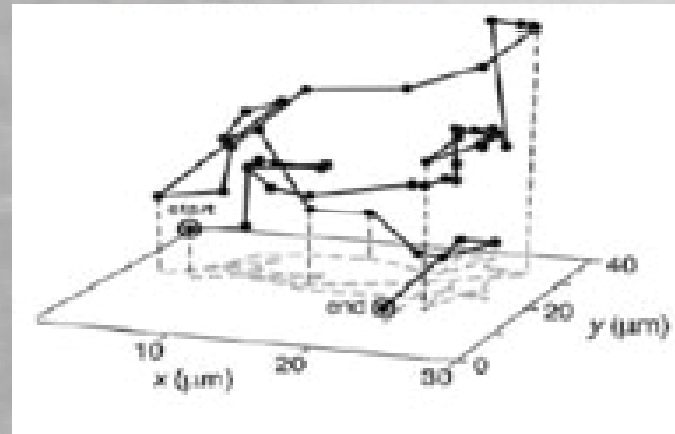
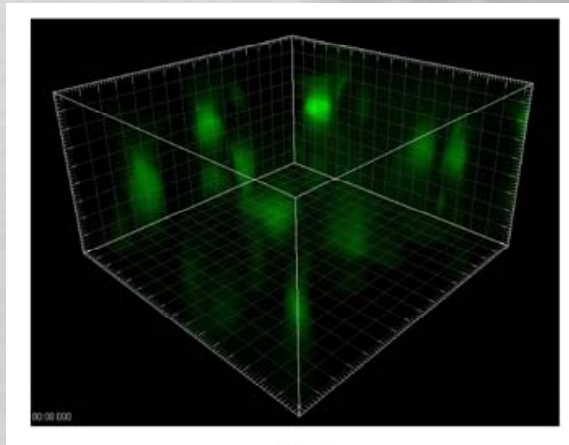
Other studies



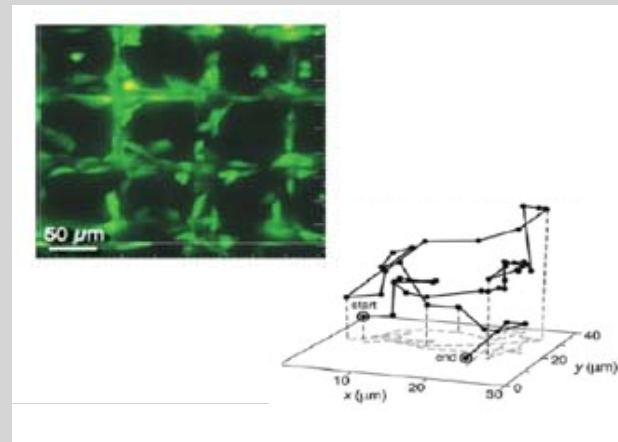
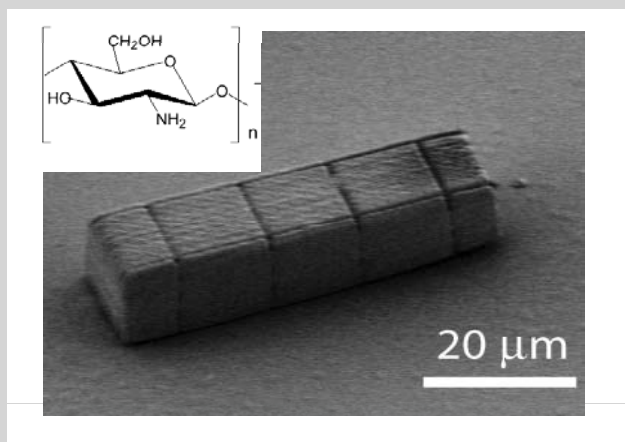
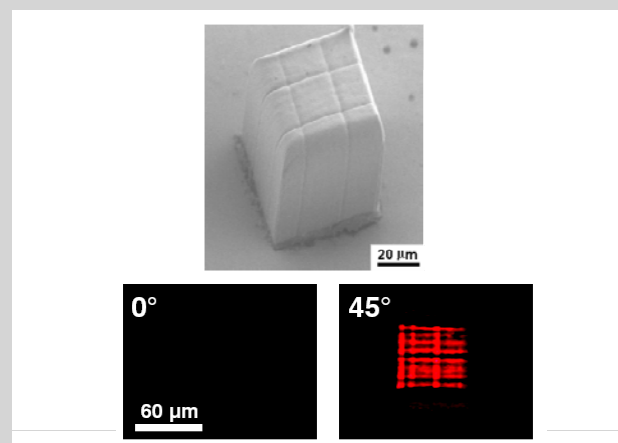
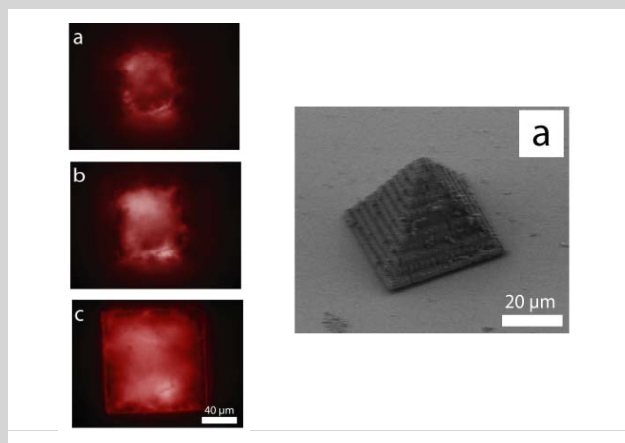
52 μm pore size

Other studies

- 3D cell migration studies in micro-scaffolds



Summary



Acknowledgments

FAPESP
CAPES
CNPq

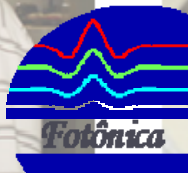
NSF
ARO

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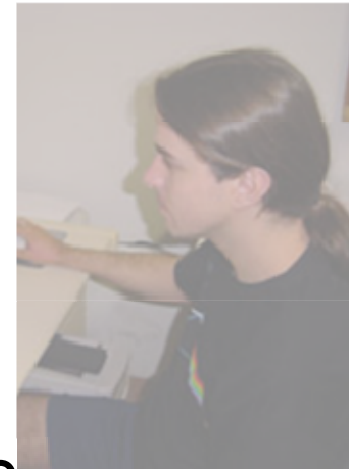
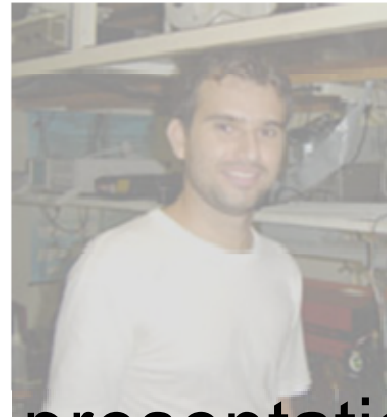




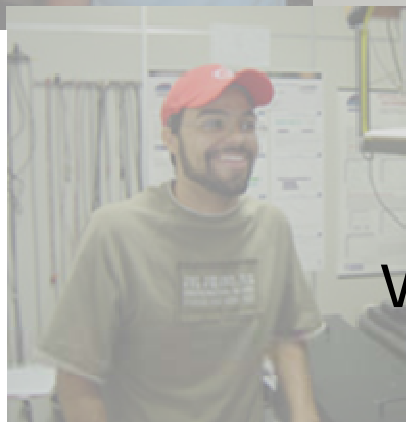
Thank you !



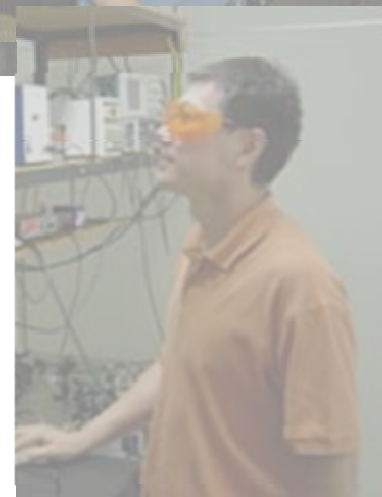
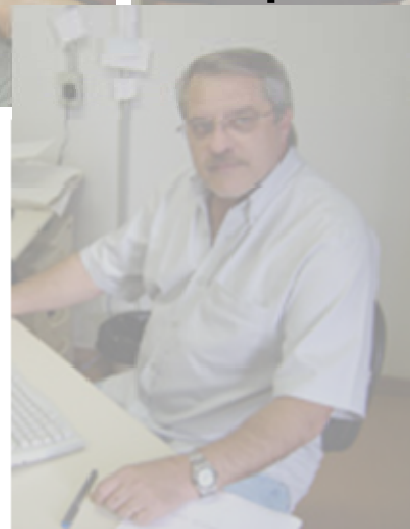
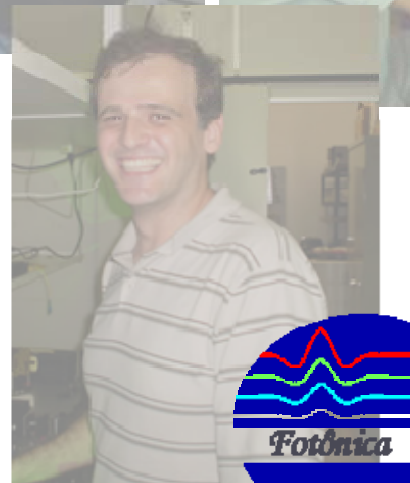
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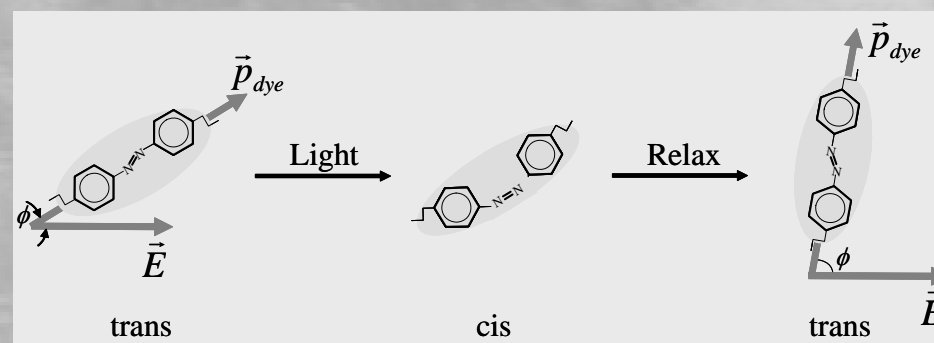
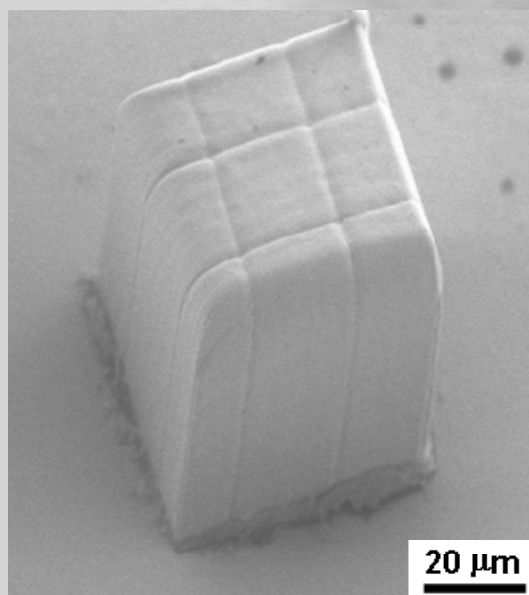
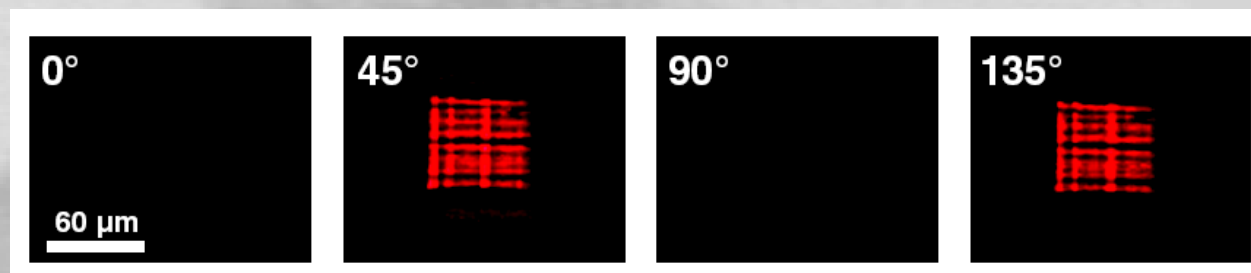


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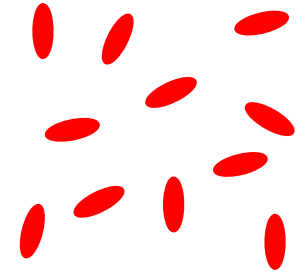


Other studies

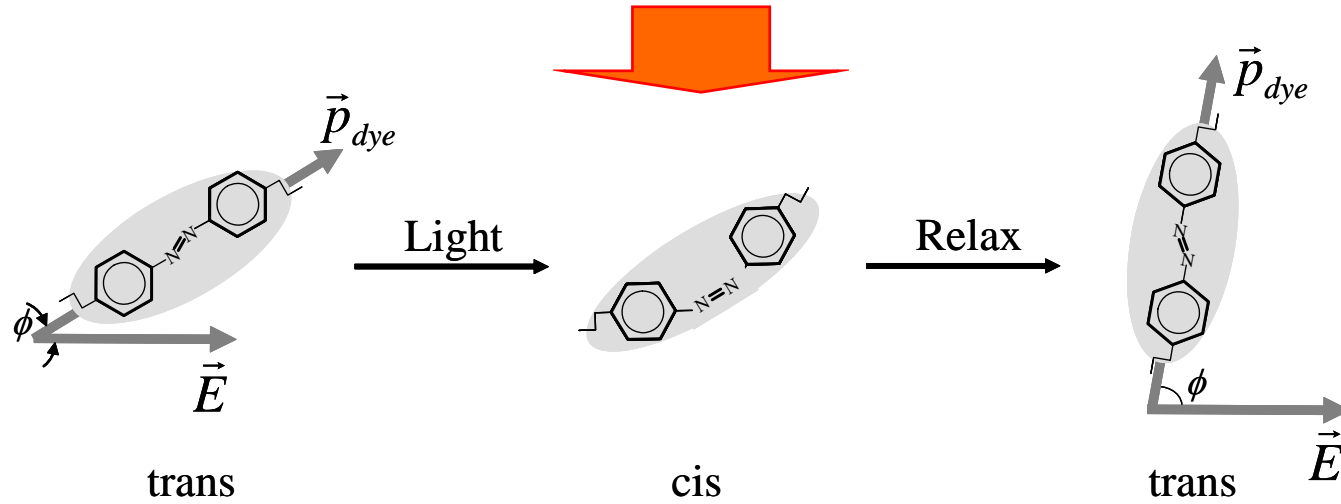
- microstructures for optical storage – birefringence



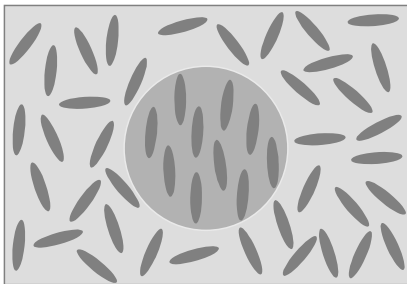
Birefringent microstructures



Molecular orientation by excitation with linearly polarized light



After alignment

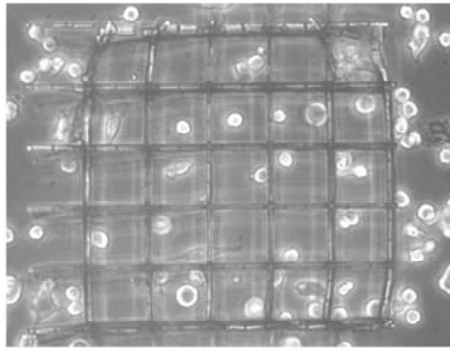


Optically Induced birefringence

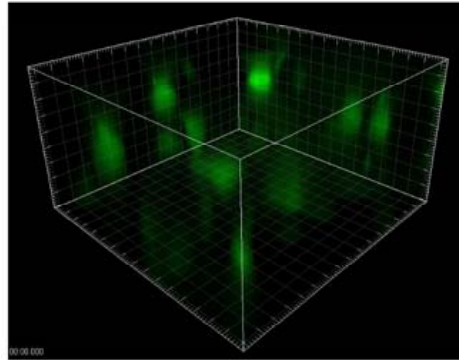
$n_y > n_x$

cell migration

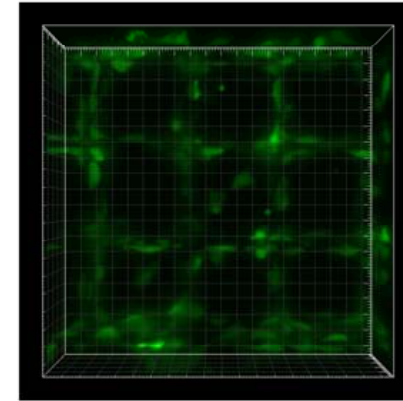
50 μm pore size after 5 hours



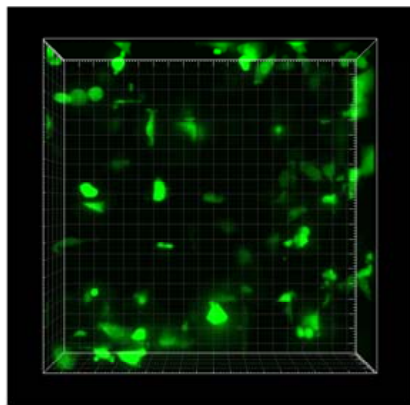
(a)



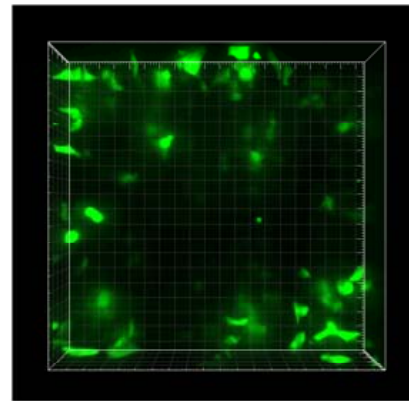
(b)



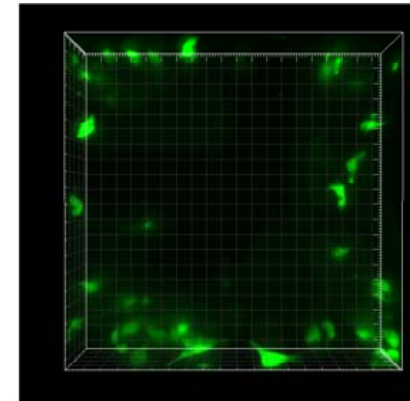
(c)



(d)



(e)



(f)

c-d: 110, 52, 25 and 12 μm