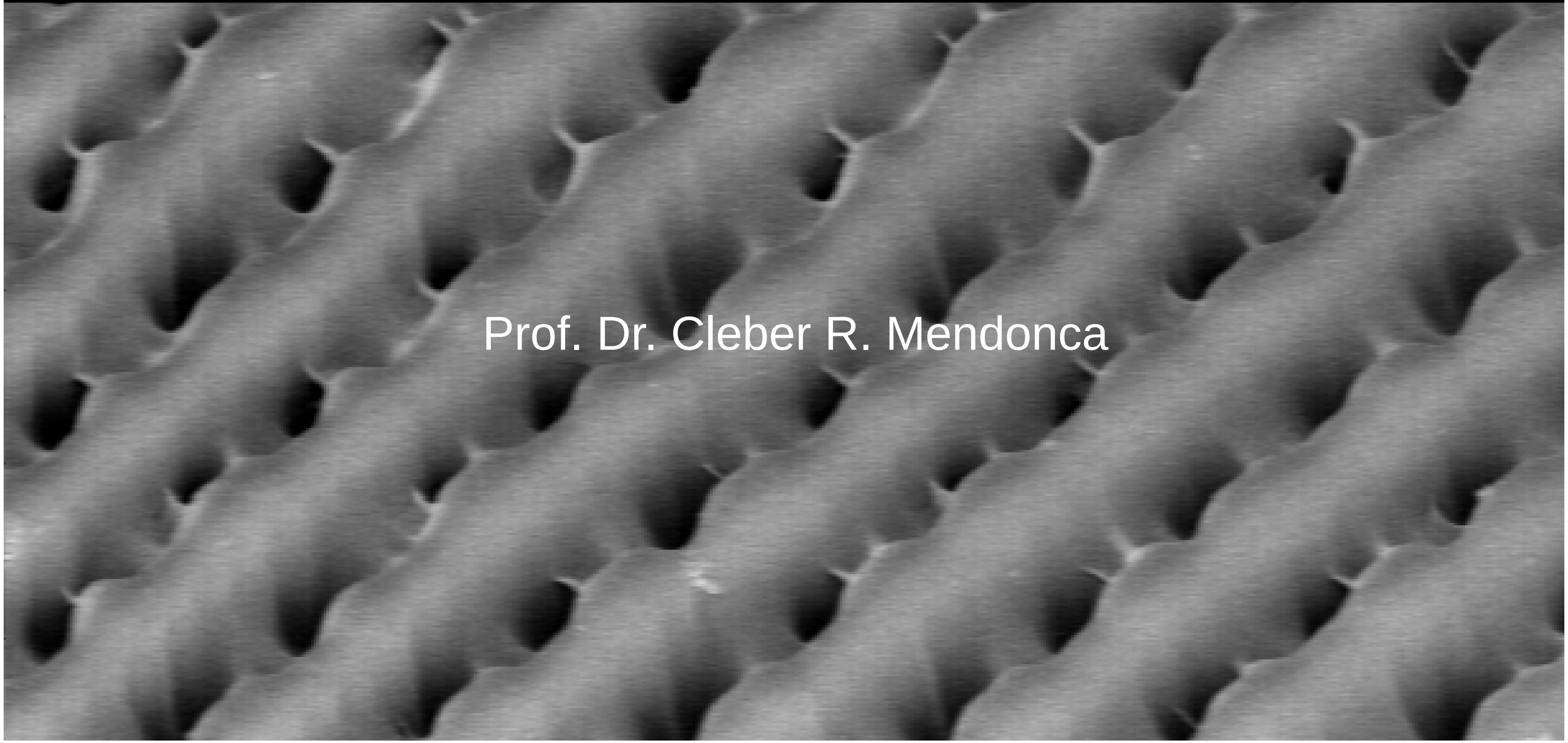
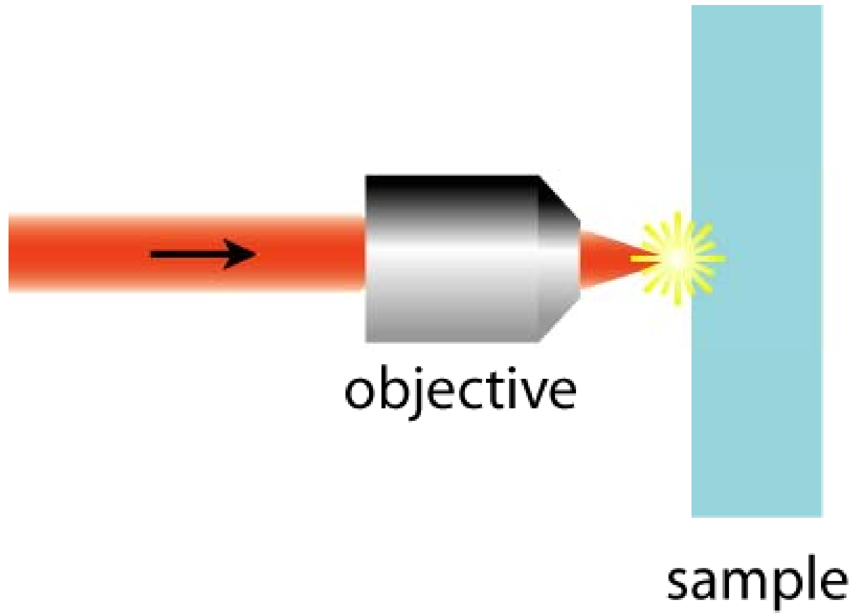
Sculpturing with light: micro/nanofabrication using ultrashort pulses



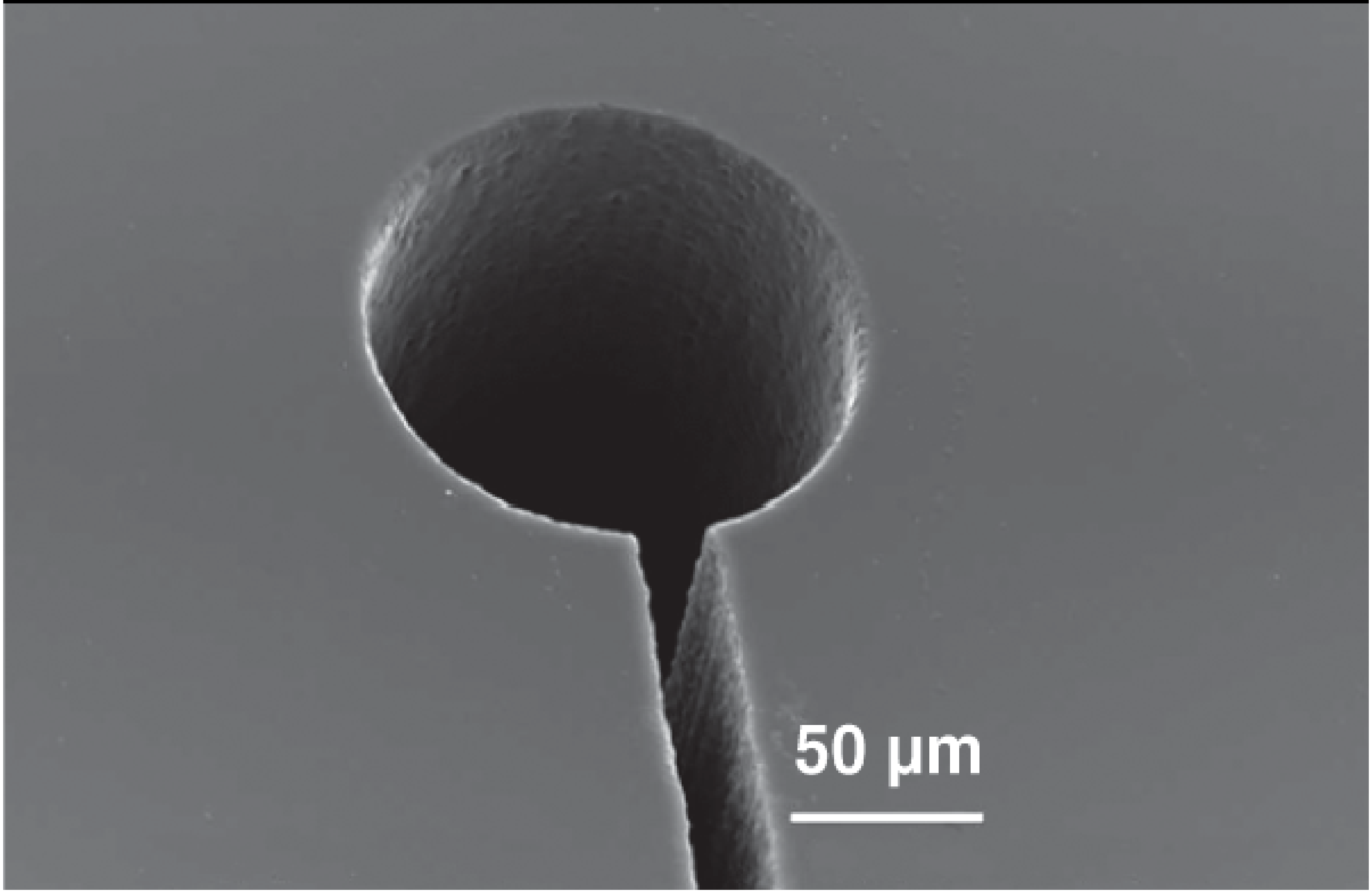
Prof. Dr. Cleber R. Mendonca

laser microfabrication

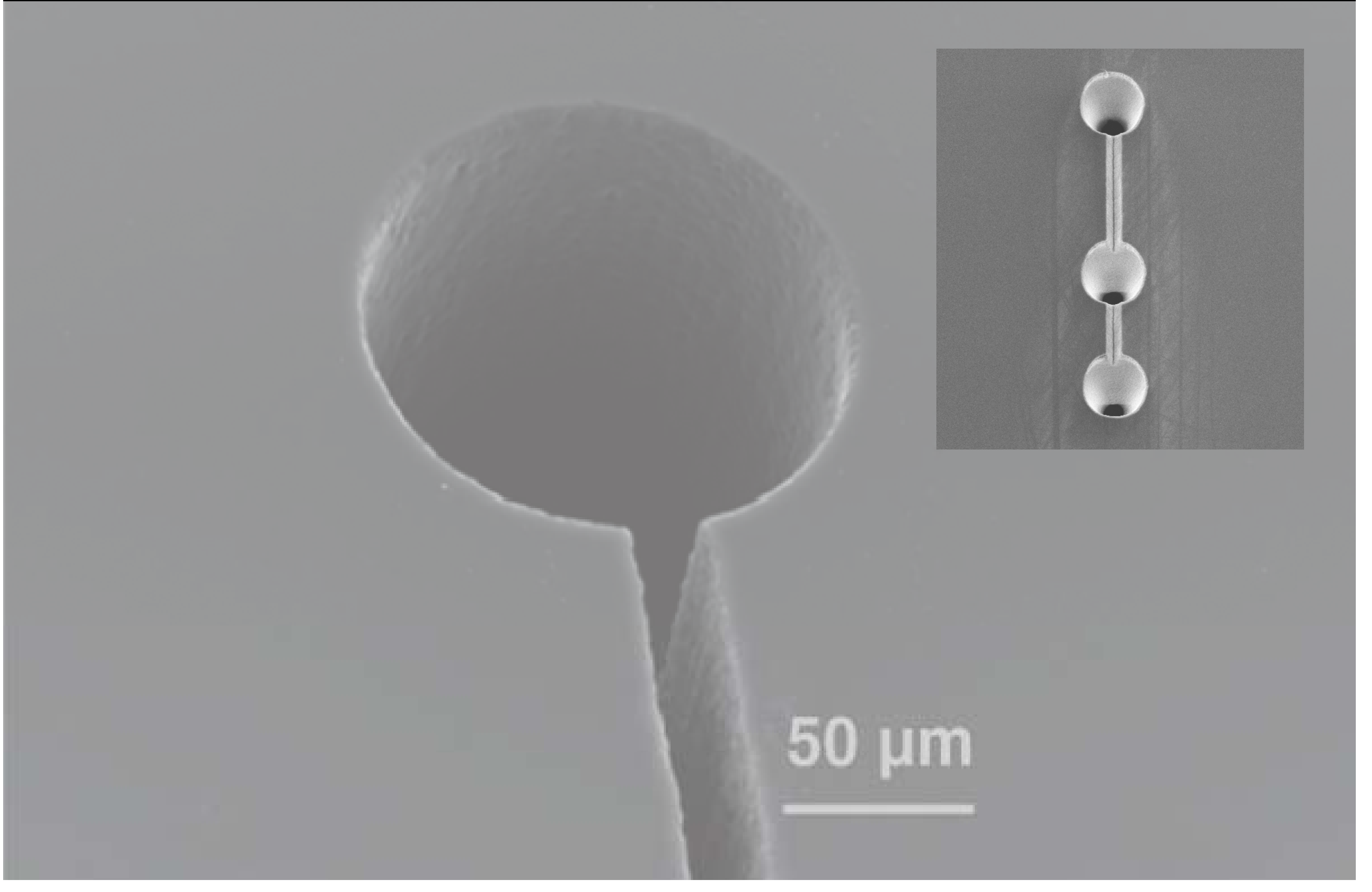
focus laser beam on material's surface



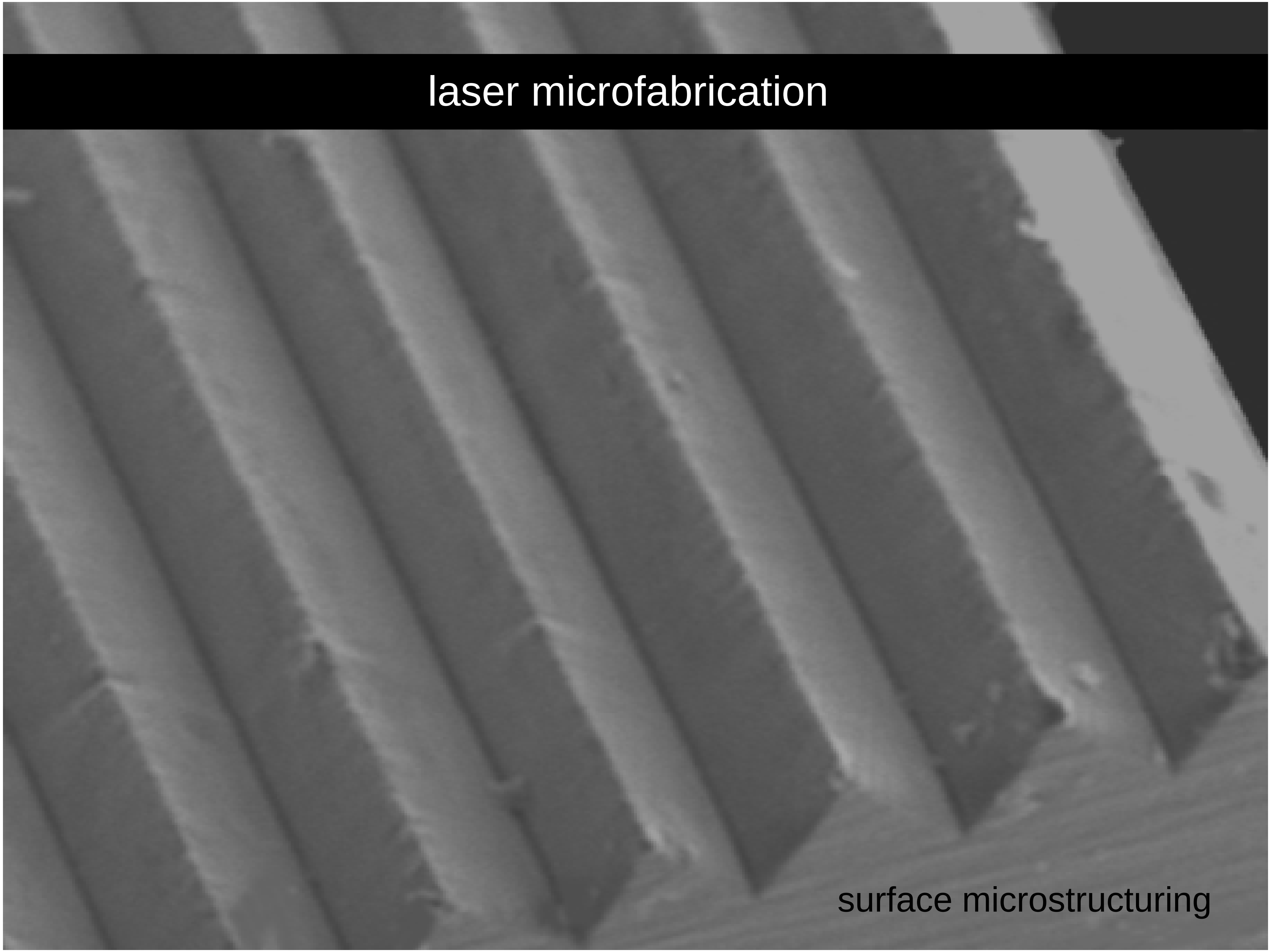
laser microfabrication



laser microfabrication



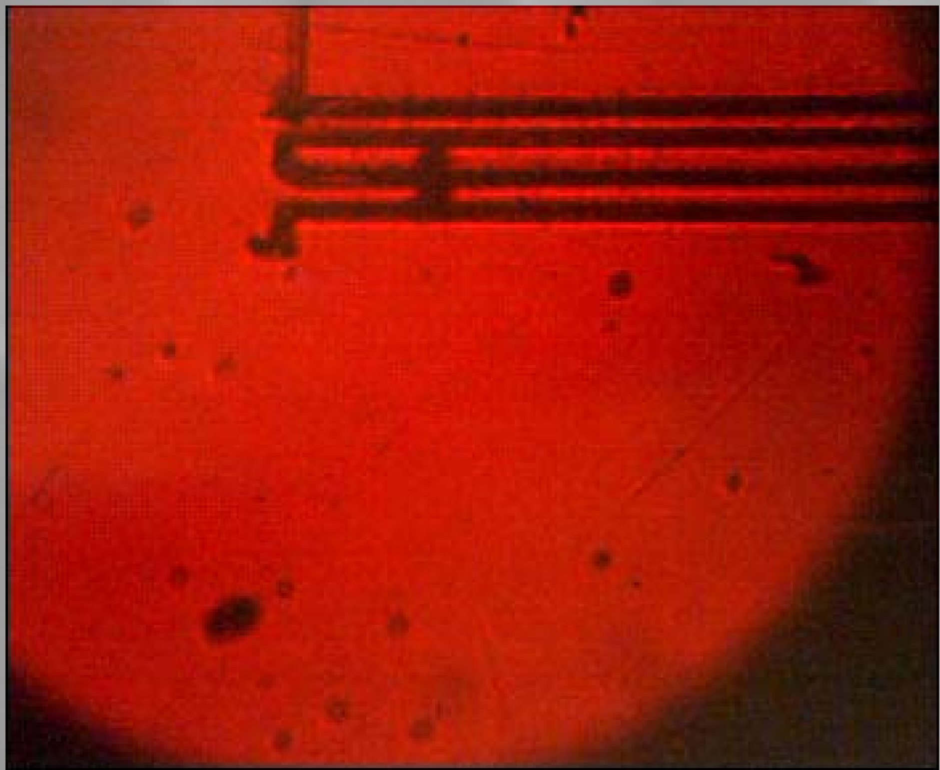
laser microfabrication



laser microfabrication

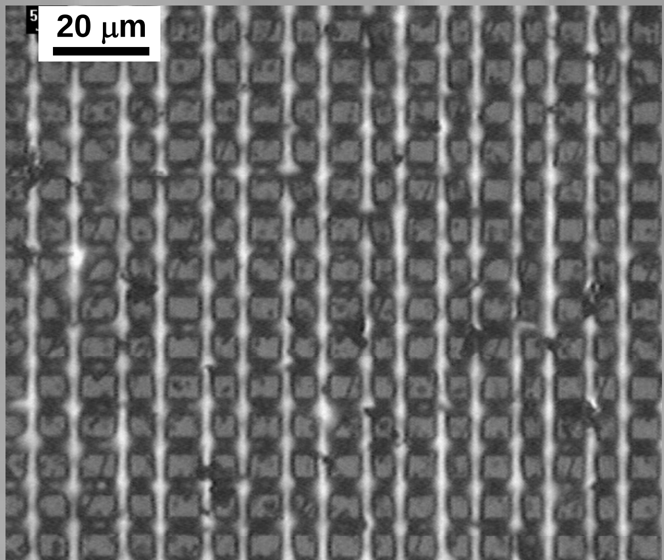
superhydrophobic surfaces

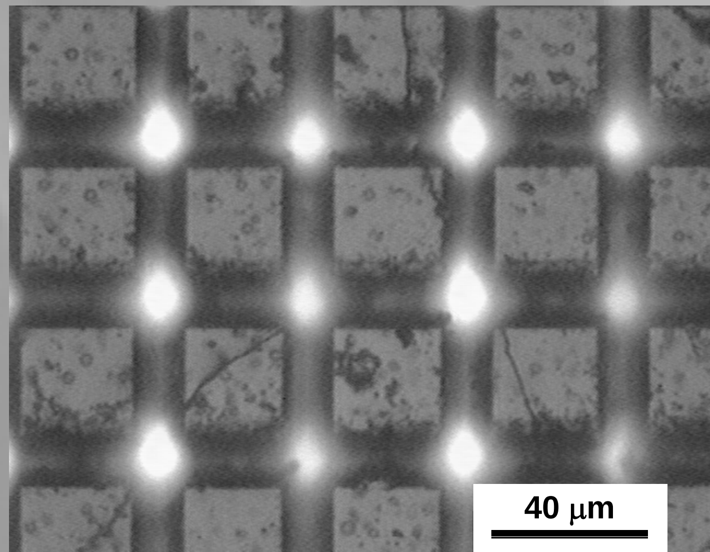
azopolymeric films micromachined with 100 ps pulses at 532 nm



laser microfabrication

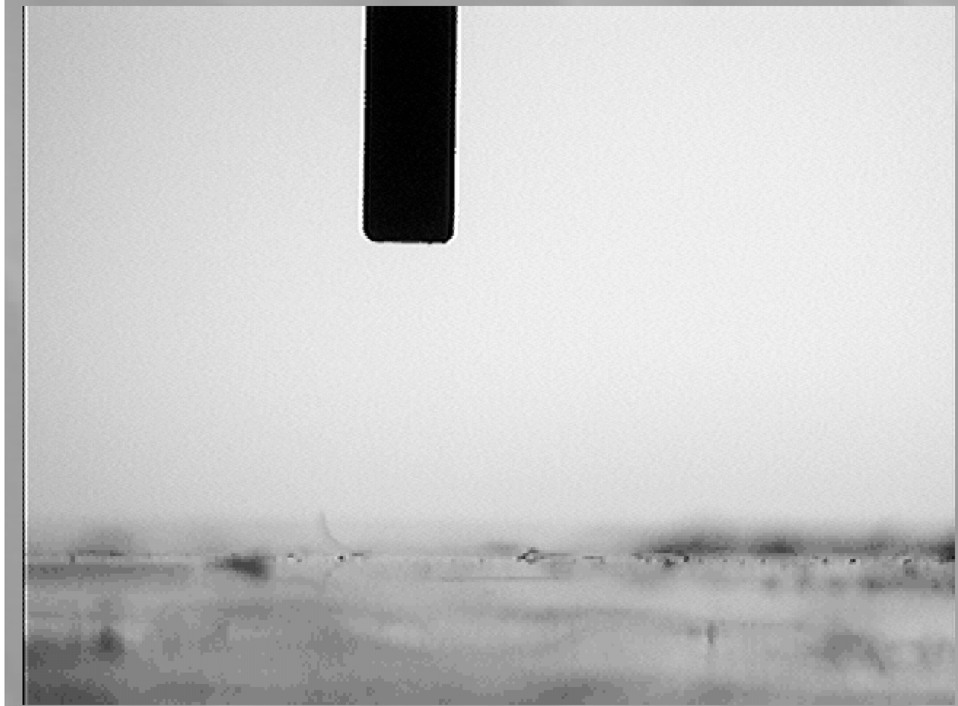
examples of fabricated surfaces



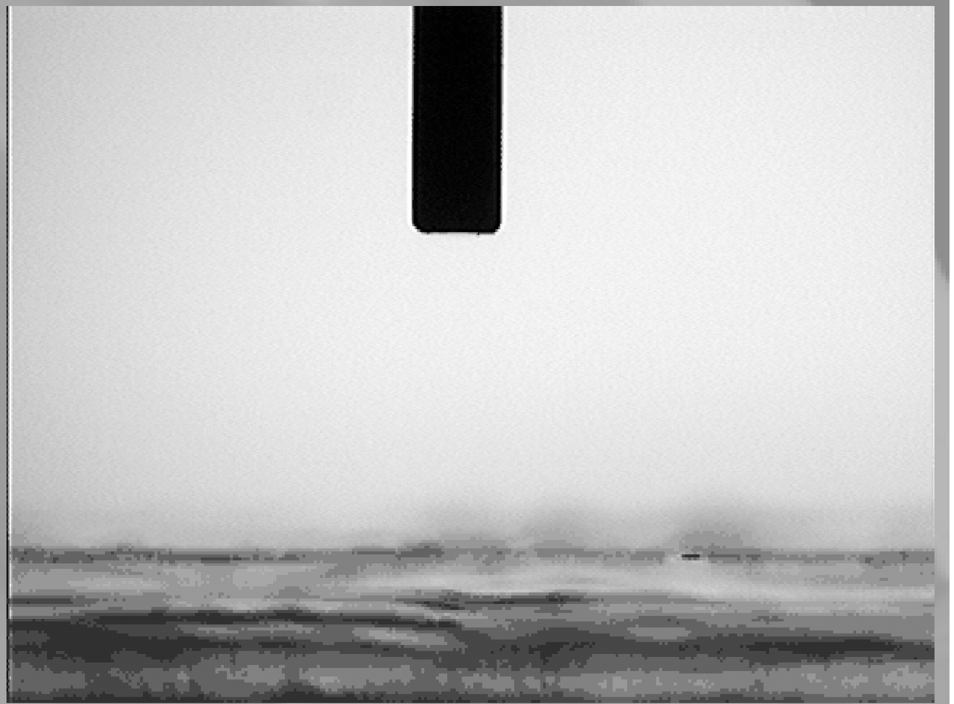


laser microfabrication

Superhydrophobic surfaces



flat surface



microstructured surface

fs-laser microfabrication

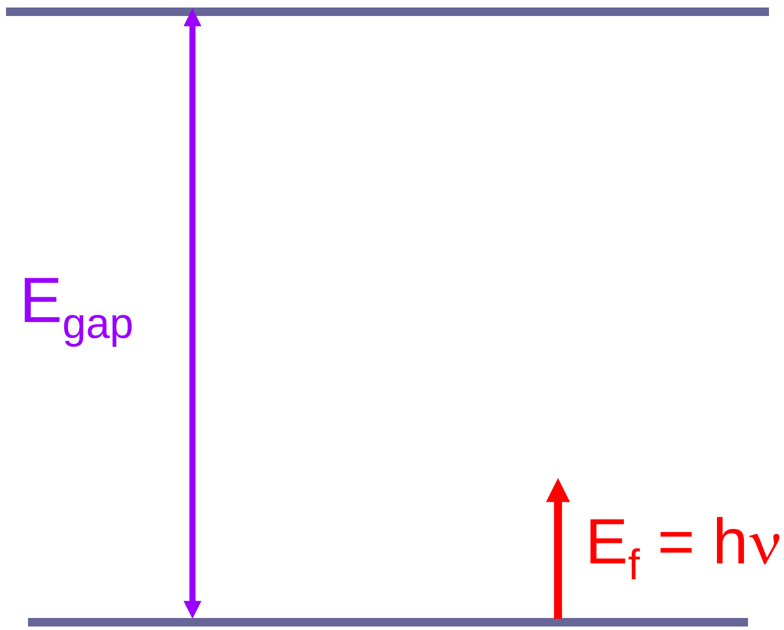
photon energy < bandgap

↓

nonlinear interaction

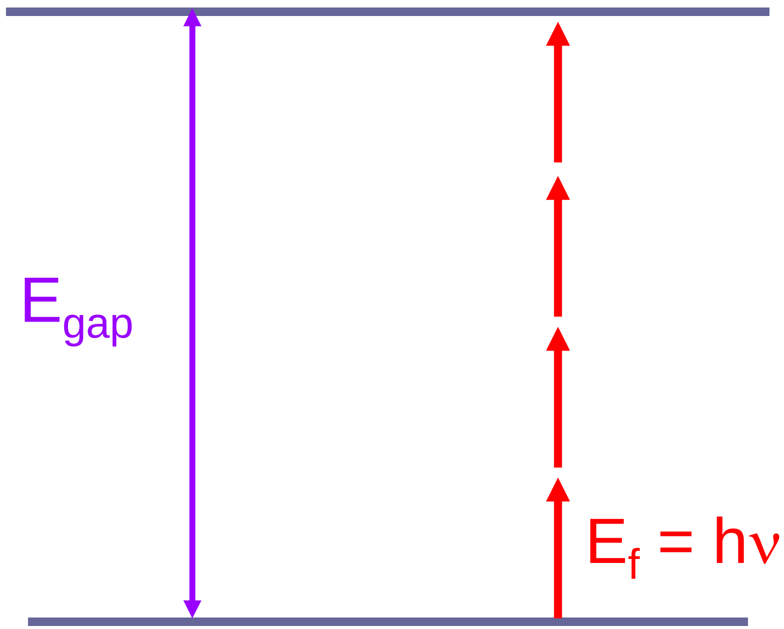
fs-laser microfabrication

nonlinear interaction



fs-laser microfabrication

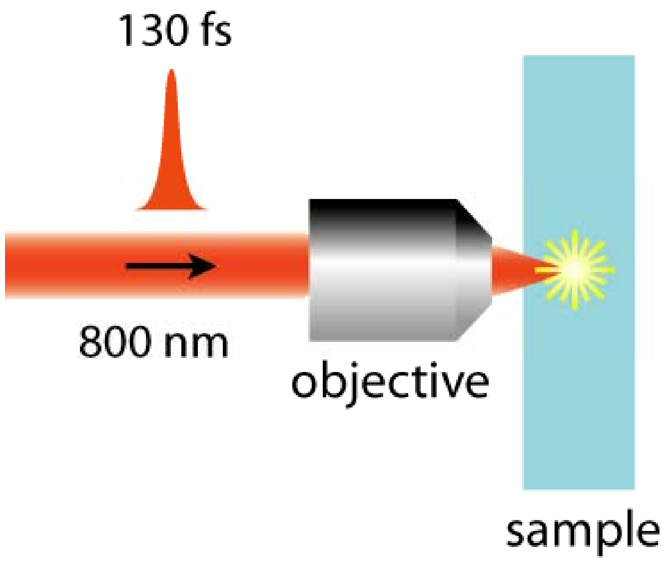
nonlinear interaction



multiphoton absorption

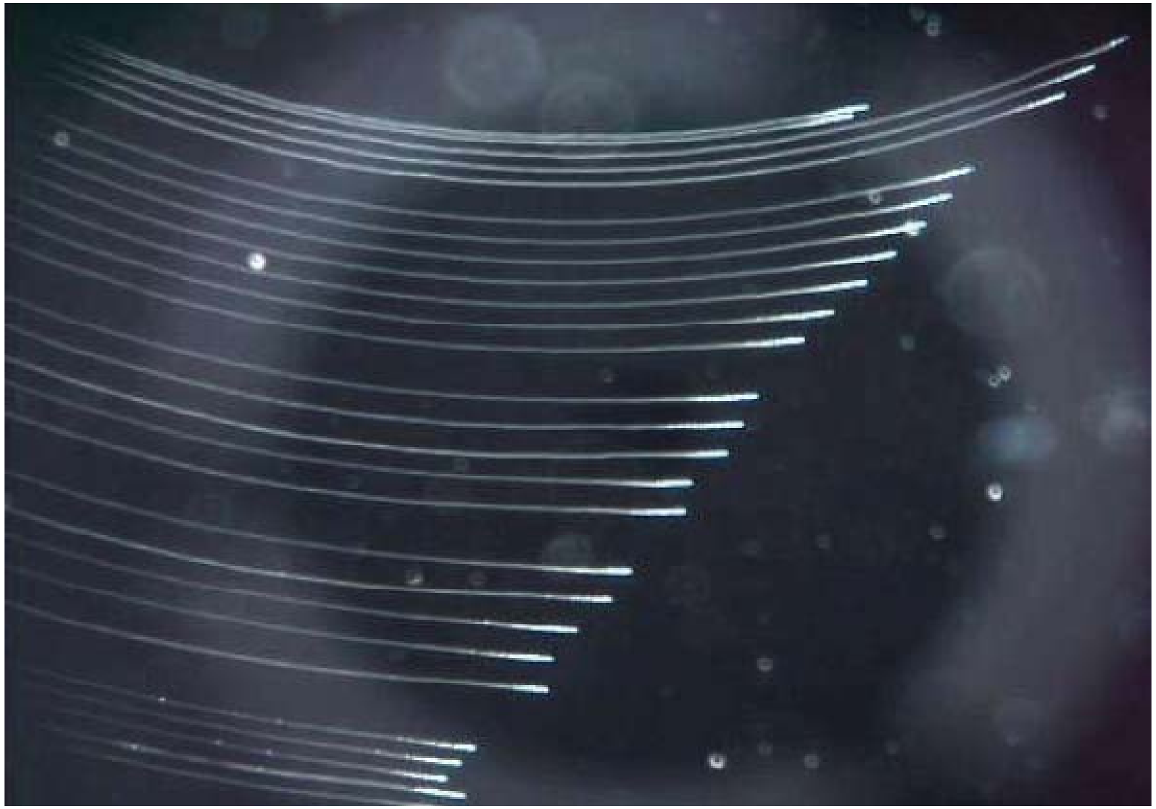
fs-laser microfabrication

focus laser beam inside material



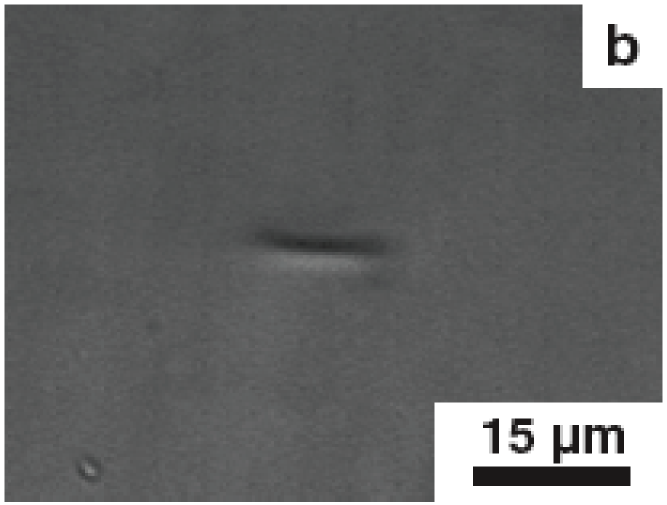
fs-laser microfabrication

curved waveguides inside glass



fs-laser microfabrication

3D waveguides in PMMA



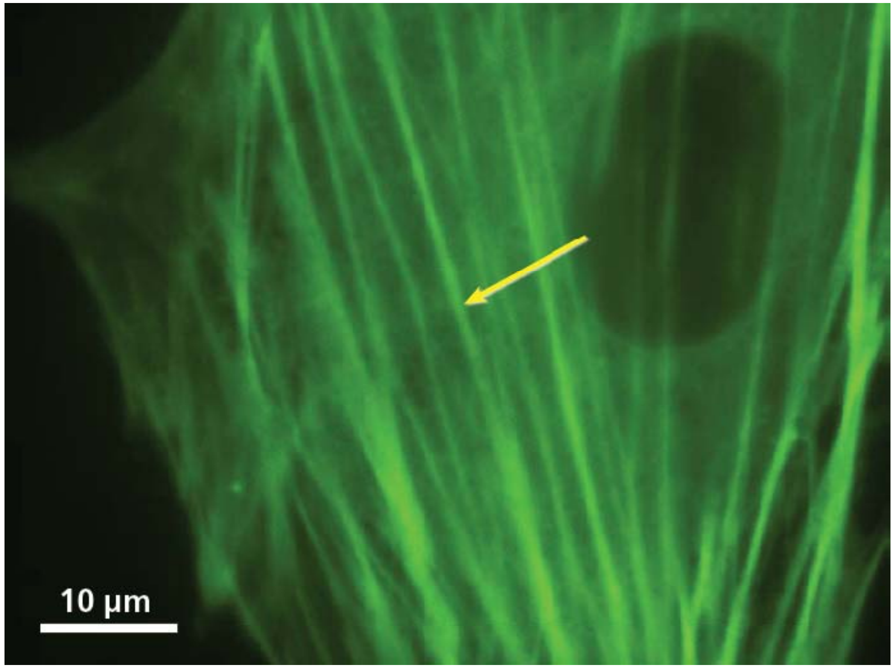
cross-section view

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

Optics Express, 16, 200-205 (2008)

fs-laser microfabrication

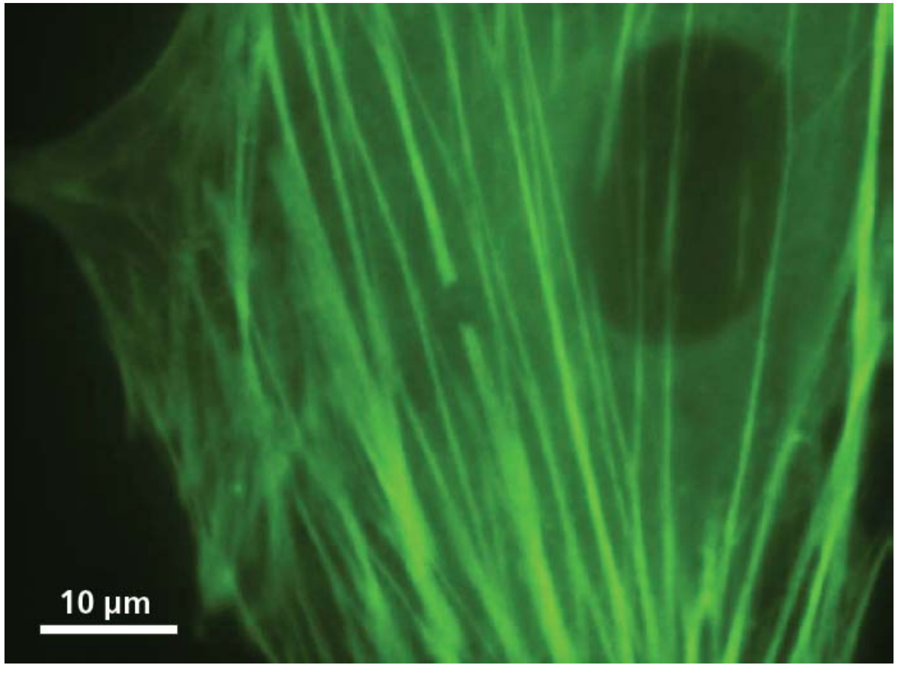
cut a single fiber bundle inside a cell



I. Maxwell, E. Mazur – Harvard University

fs-laser microfabrication

Cut a single fiber bundle inside a cell



I. Maxwell, E. Mazur – Harvard University

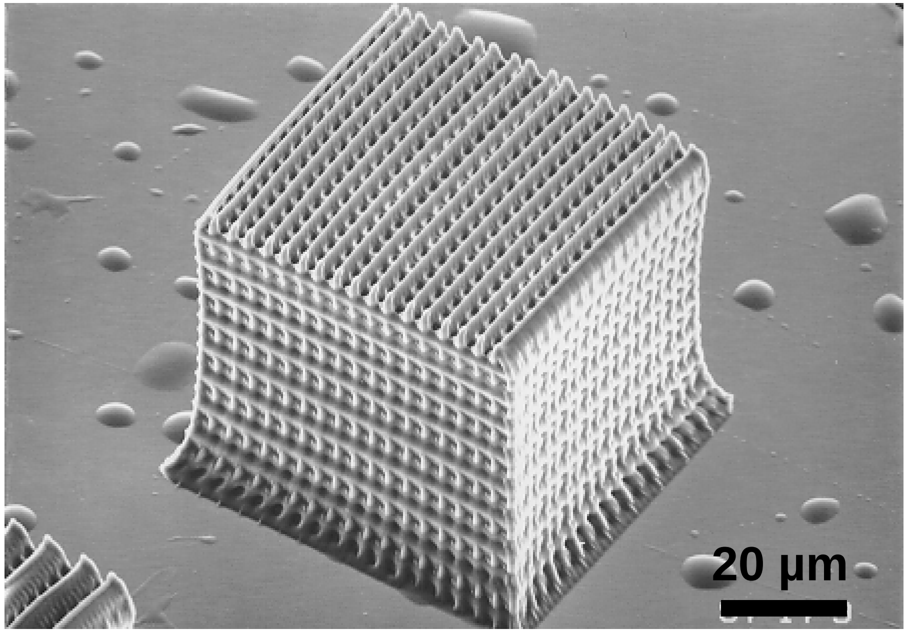
fs-laser microfabrication

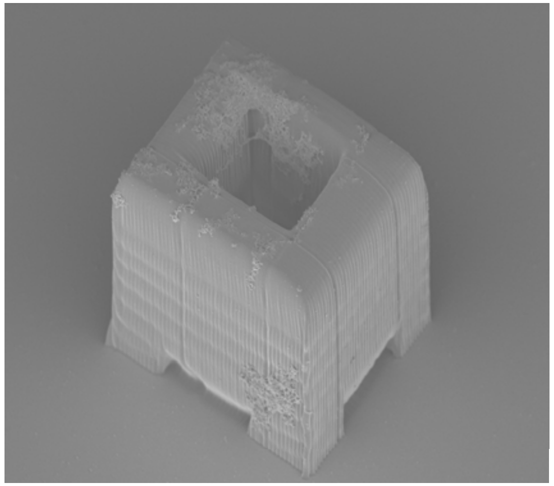
Novel concept:

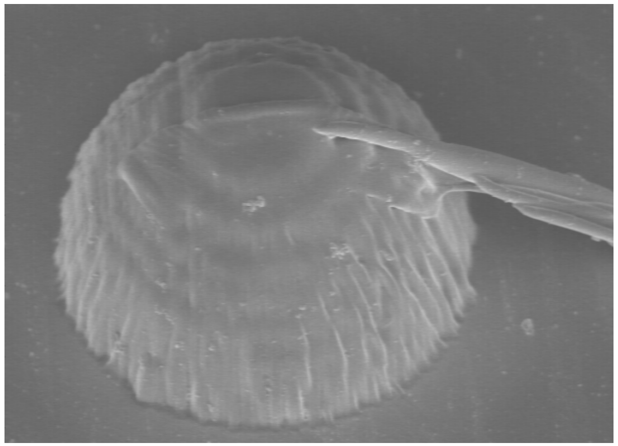
build a microstructure using fs-laser and nonlinear optical processes

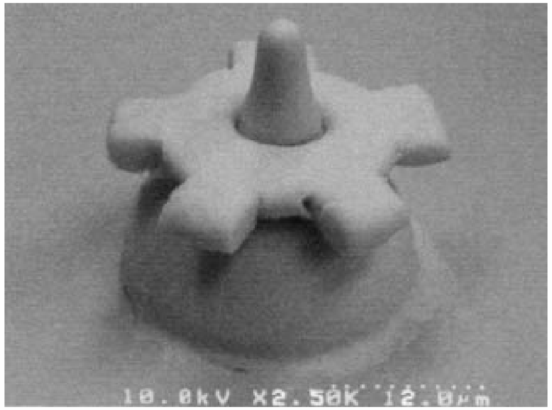
two-photon polymerization

photonic crystal – J. W. Perry









two-photon polymerization

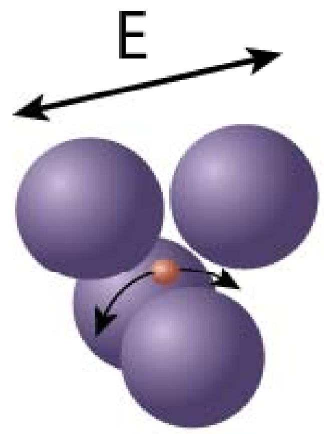
applications

- 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



anharmonic oscillator

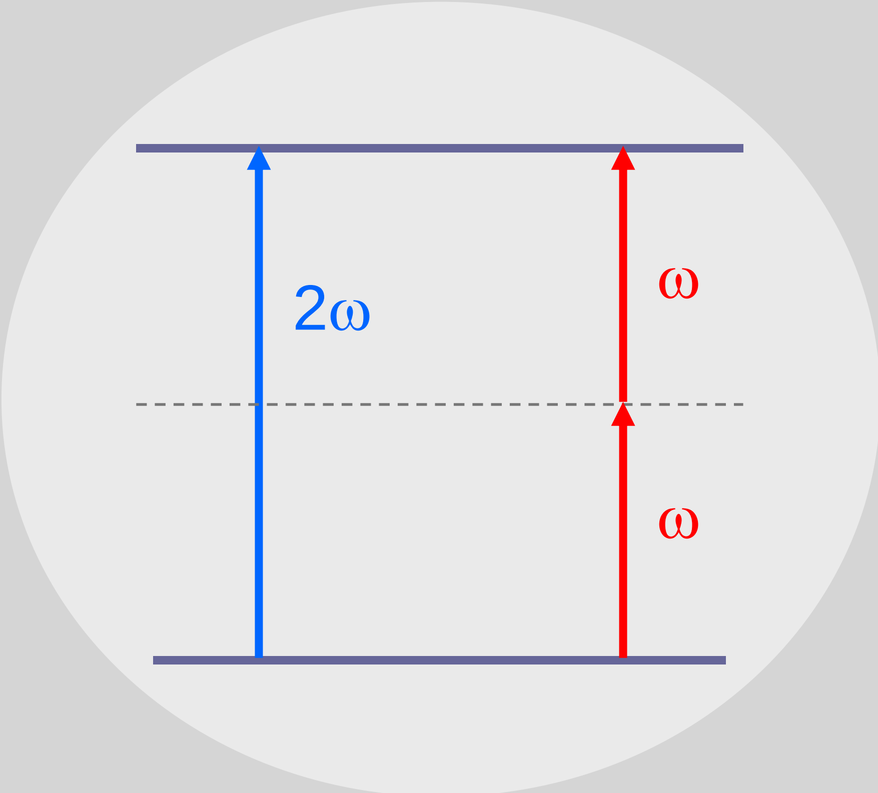
high light intensity

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

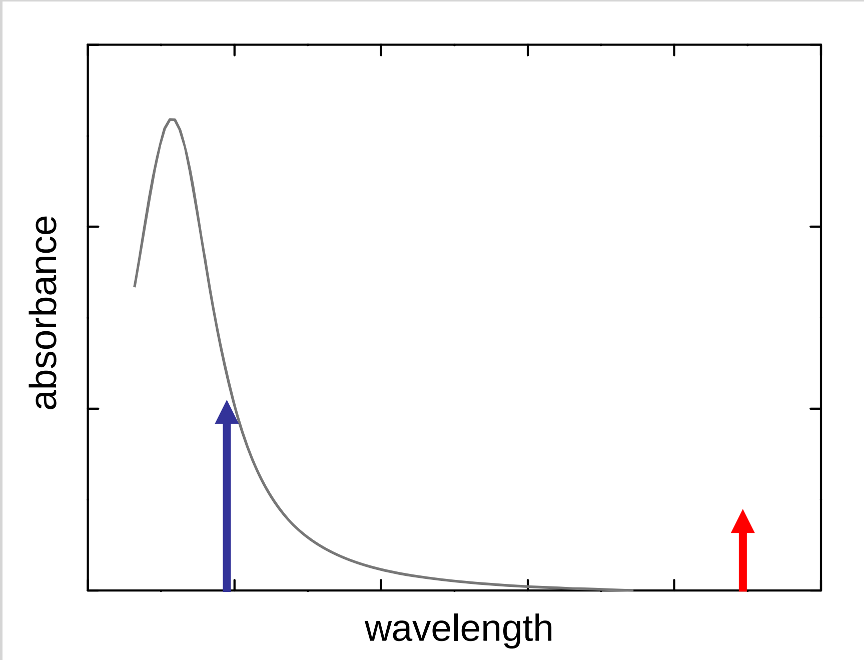
nonlinear polarization response

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

Two-photon absorption



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

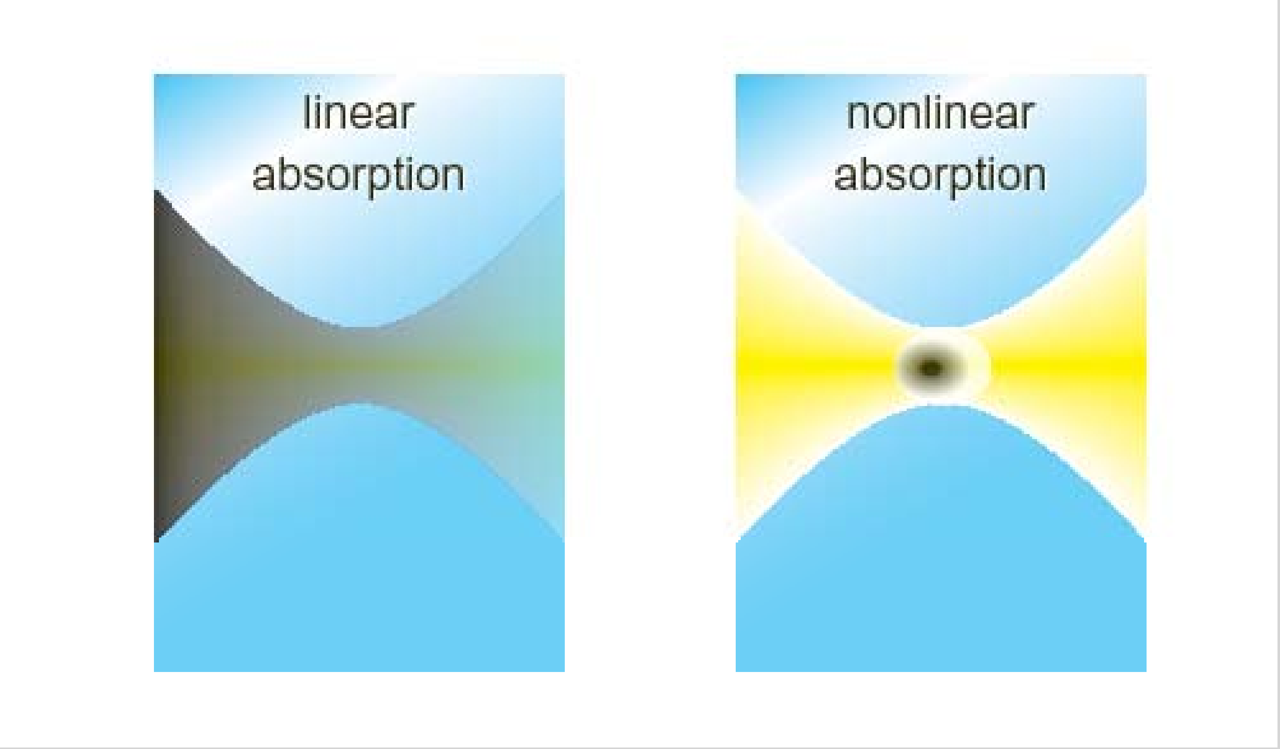


$$\alpha = \alpha_0 + \beta I$$

Two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication



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

Two-photon absorption

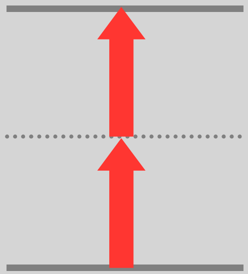
spatial confinement of excitation

Two-photon polymerization

Monomer + Photoinitiator $\rightarrow$ *Polymer*

light

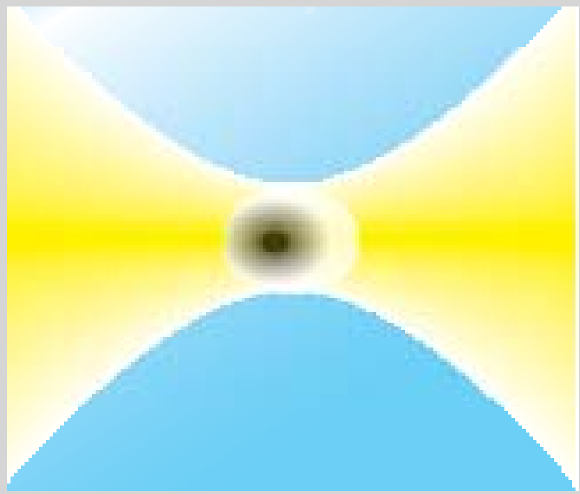
Photoinitiator is excited by ***two-photon absorption***



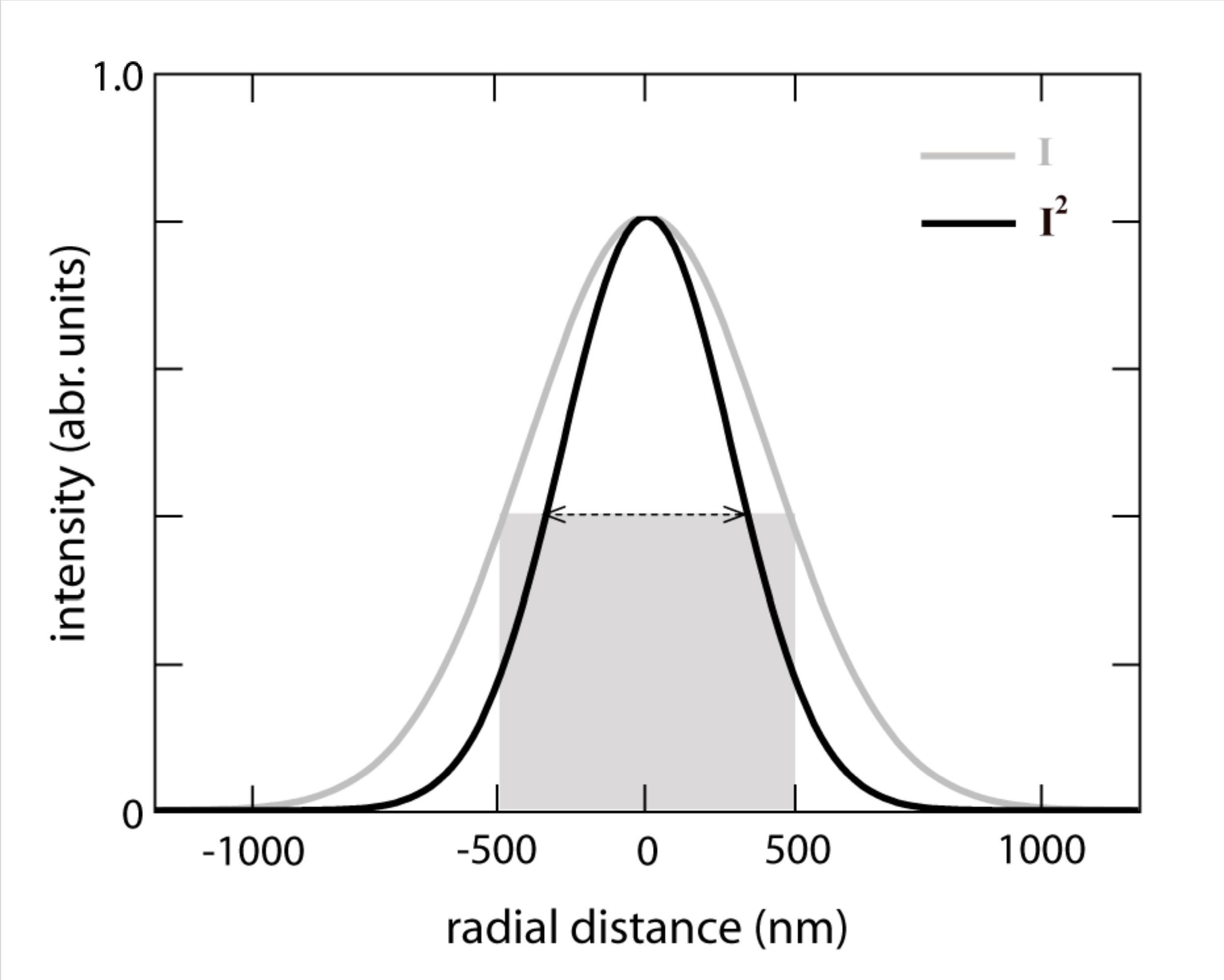
$$R_{2PA} \propto I^2$$

The polymerization is confined to the focal volume.

High spatial resolution

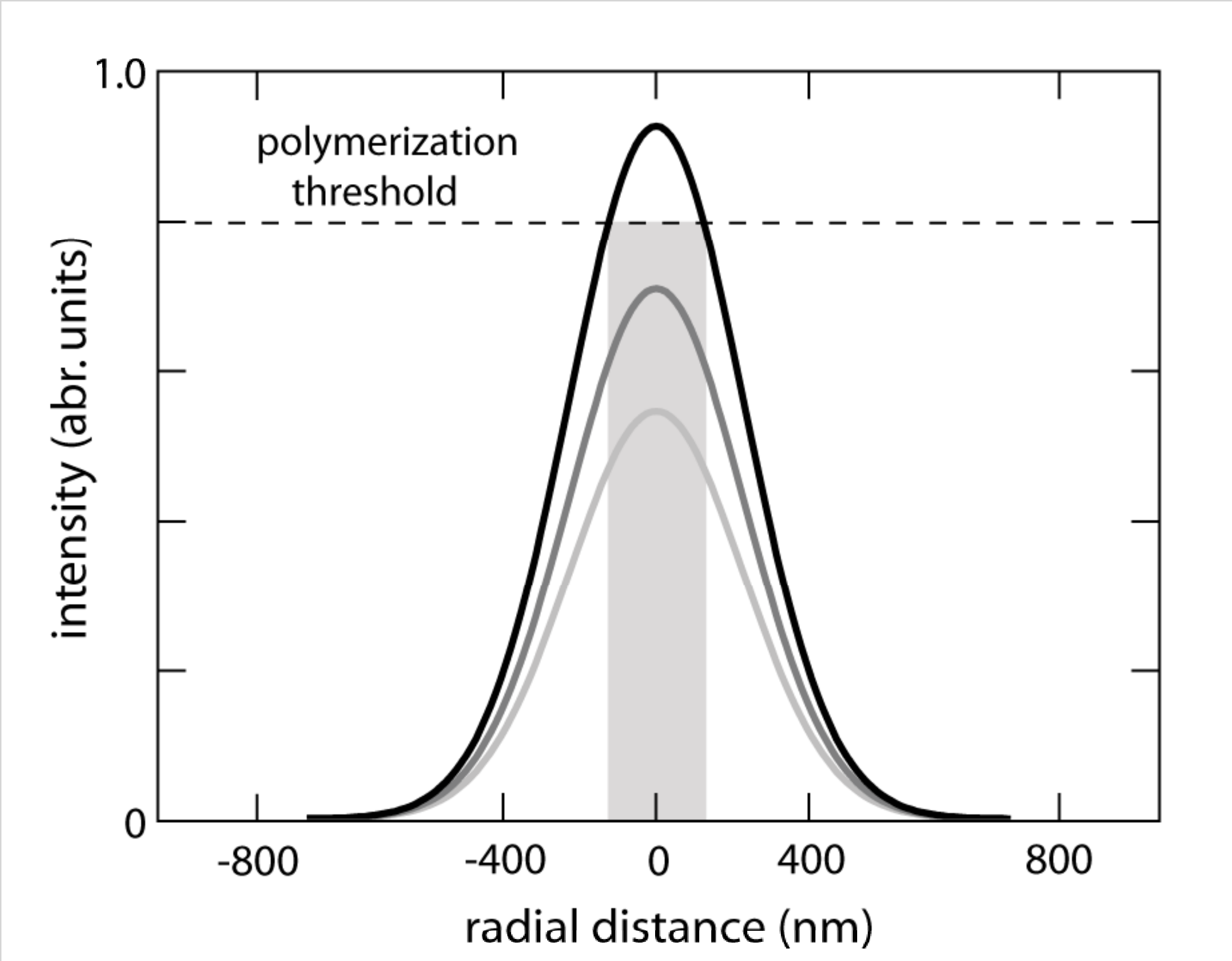


Two-photon polymerization



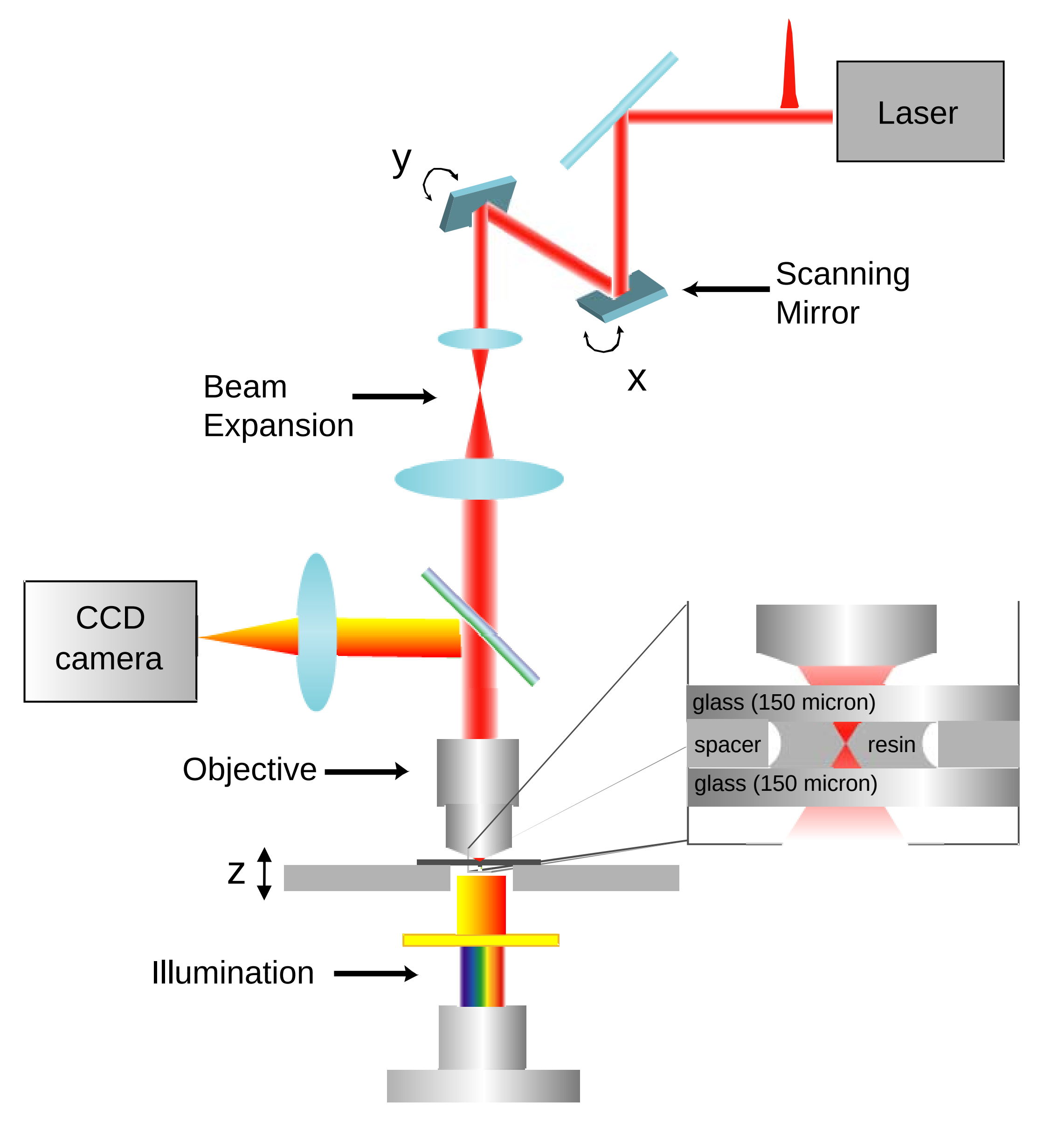
bellow the diffraction limit

Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



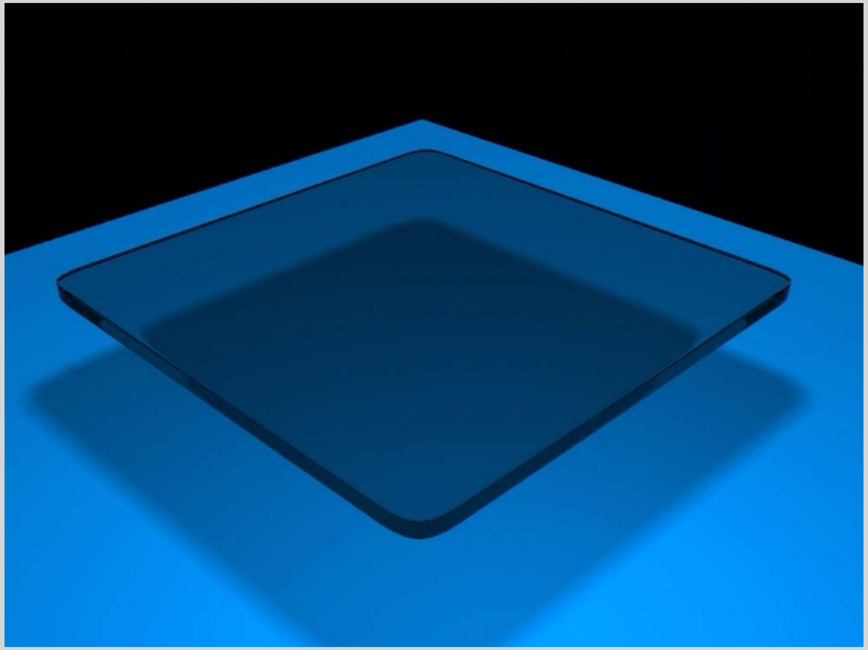
Ti:sapphire laser oscillator

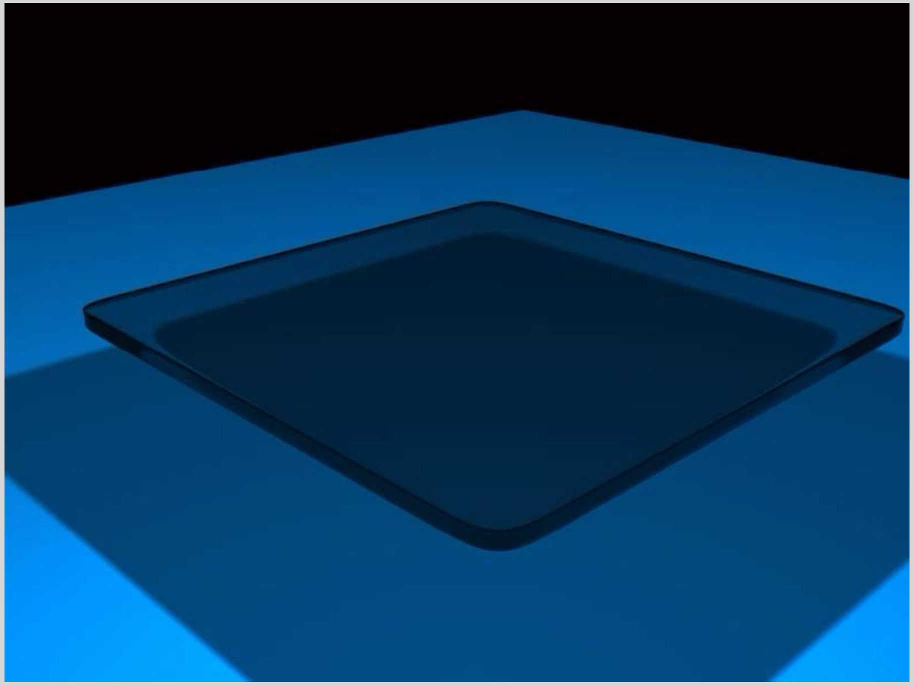
- 130 fs
- 800 nm
- 76 MHz
- 20 mW

Objective

40 x
0.65 NA

Two-photon polymerization

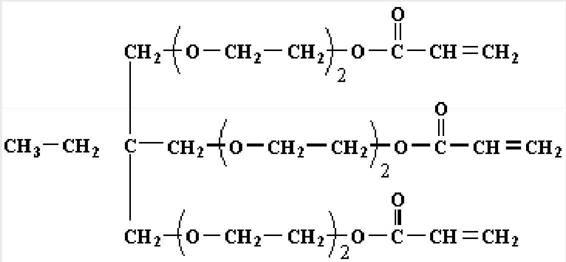




Resin preparation

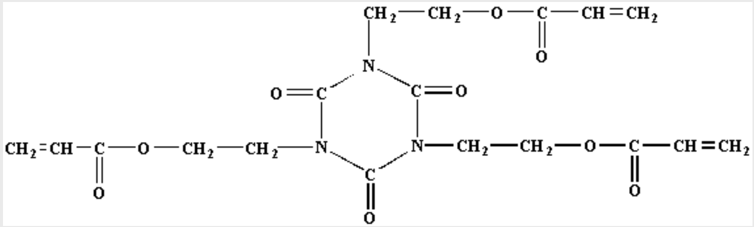
Monomers

Monomer A



reduces the shrinkage upon polymerization

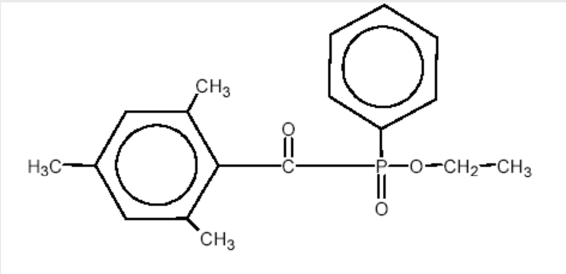
Monomer B



gives hardness to the polymeric structure

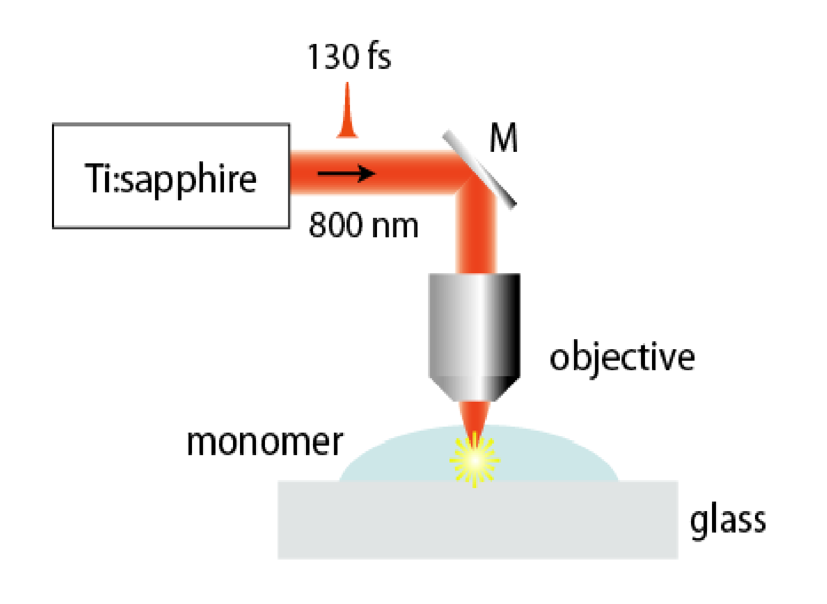
Photoinitiator

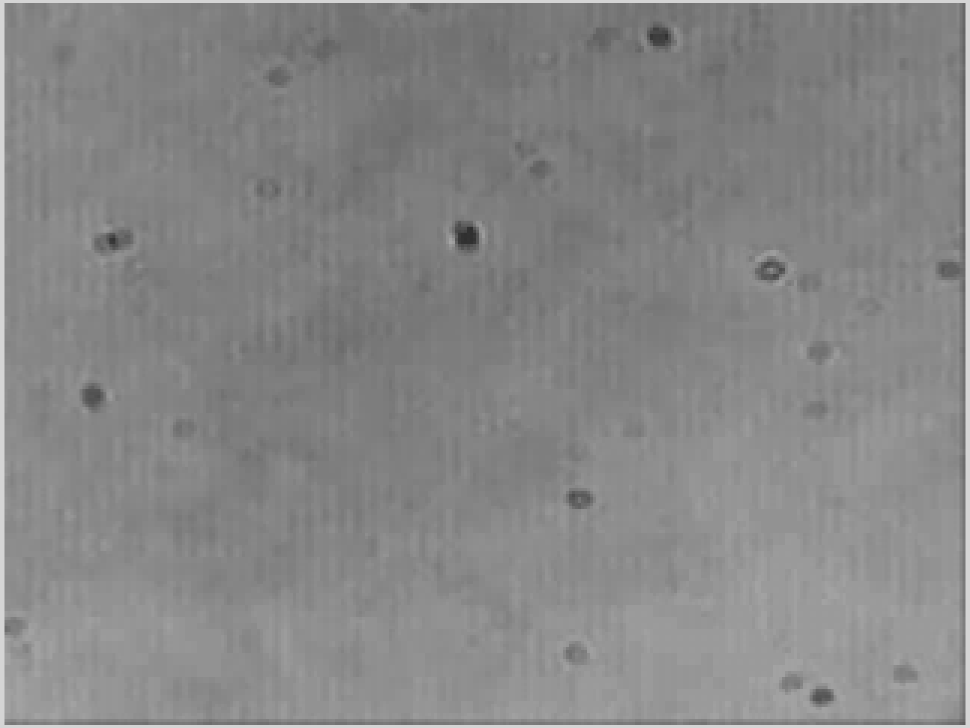
Lucirin TPO-L



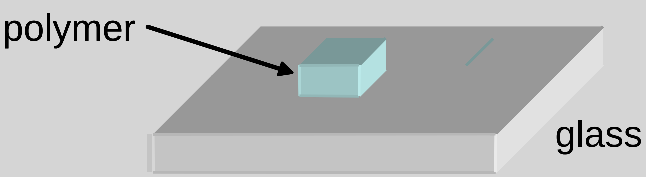
Appl. Phys. A, 90, 633–636 (2008)

Two-photon polymerization

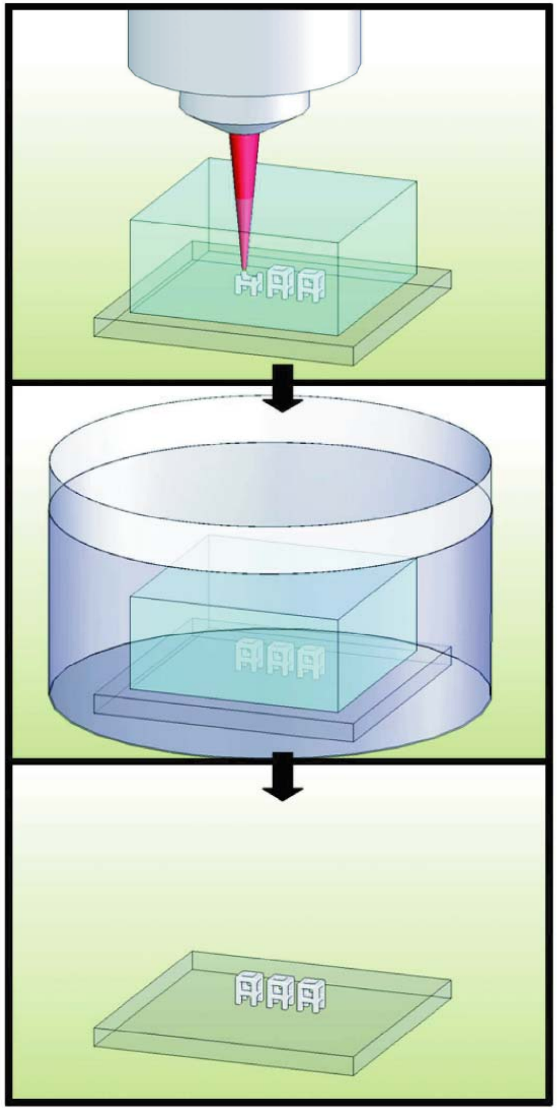




30 µm x 30 µm x 12 µm cube



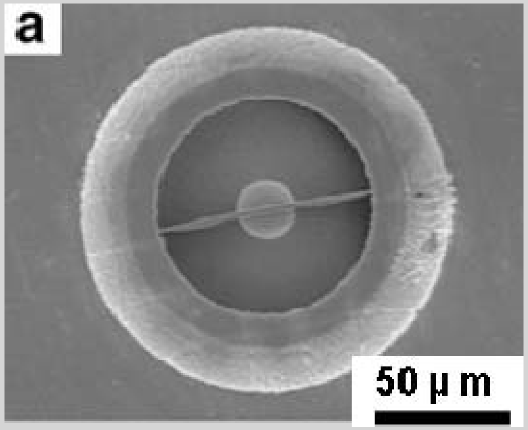
Two-photon polymerization

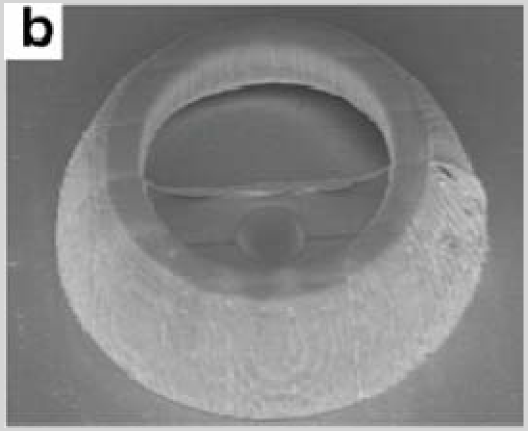


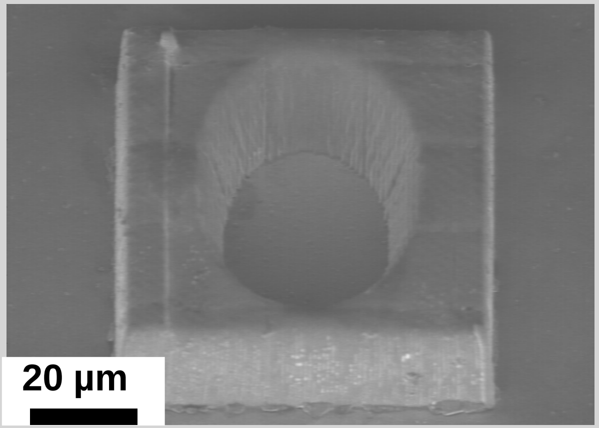
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

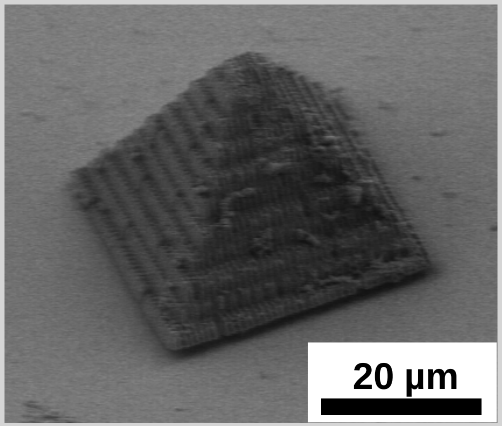
Two-photon polymerization

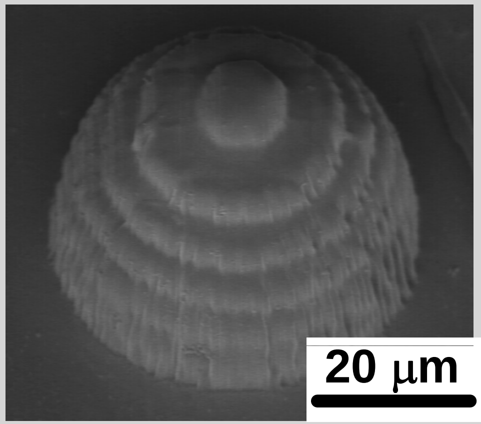
Microstructures fabricated by two-photon polymerization



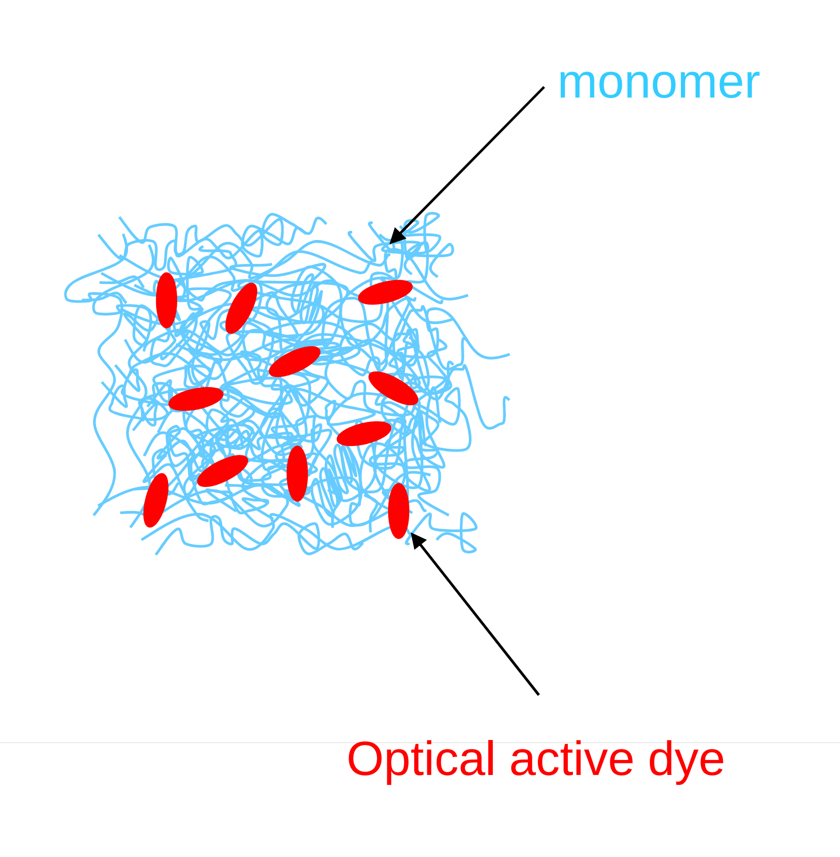


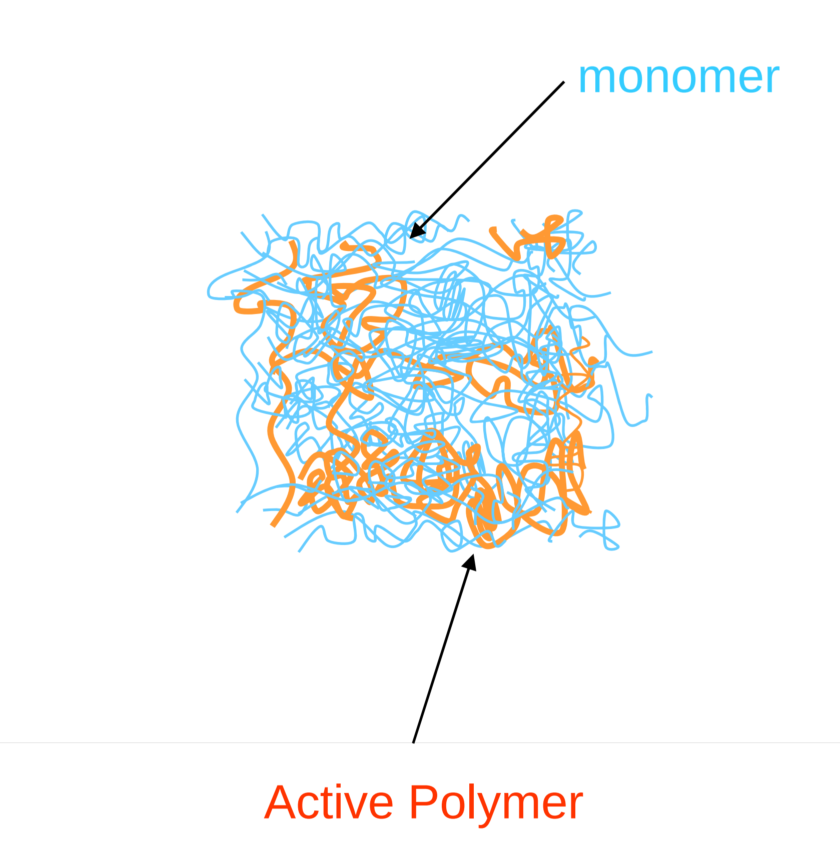






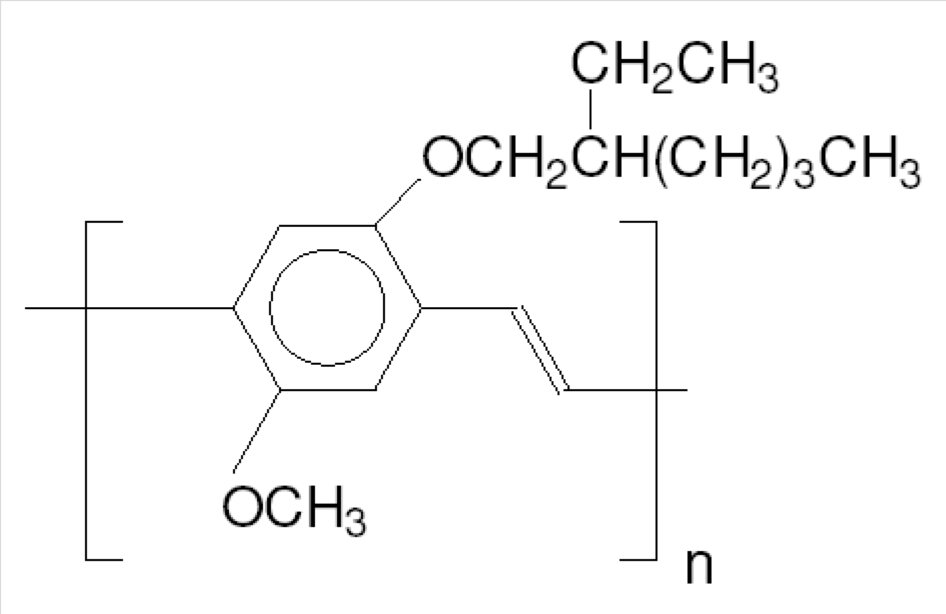
Microstructures containing active compounds





Microstructures containing MEH-PPV

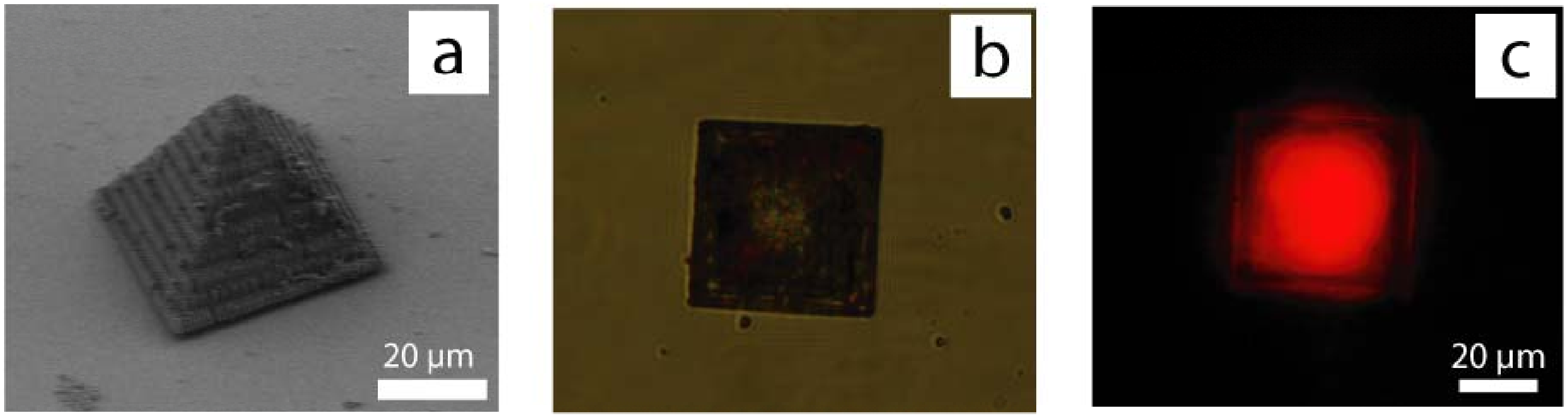
MEH-PPV



Fluorescence
Electro Luminescent
Conductive

Microstructures containing MEH-PPV

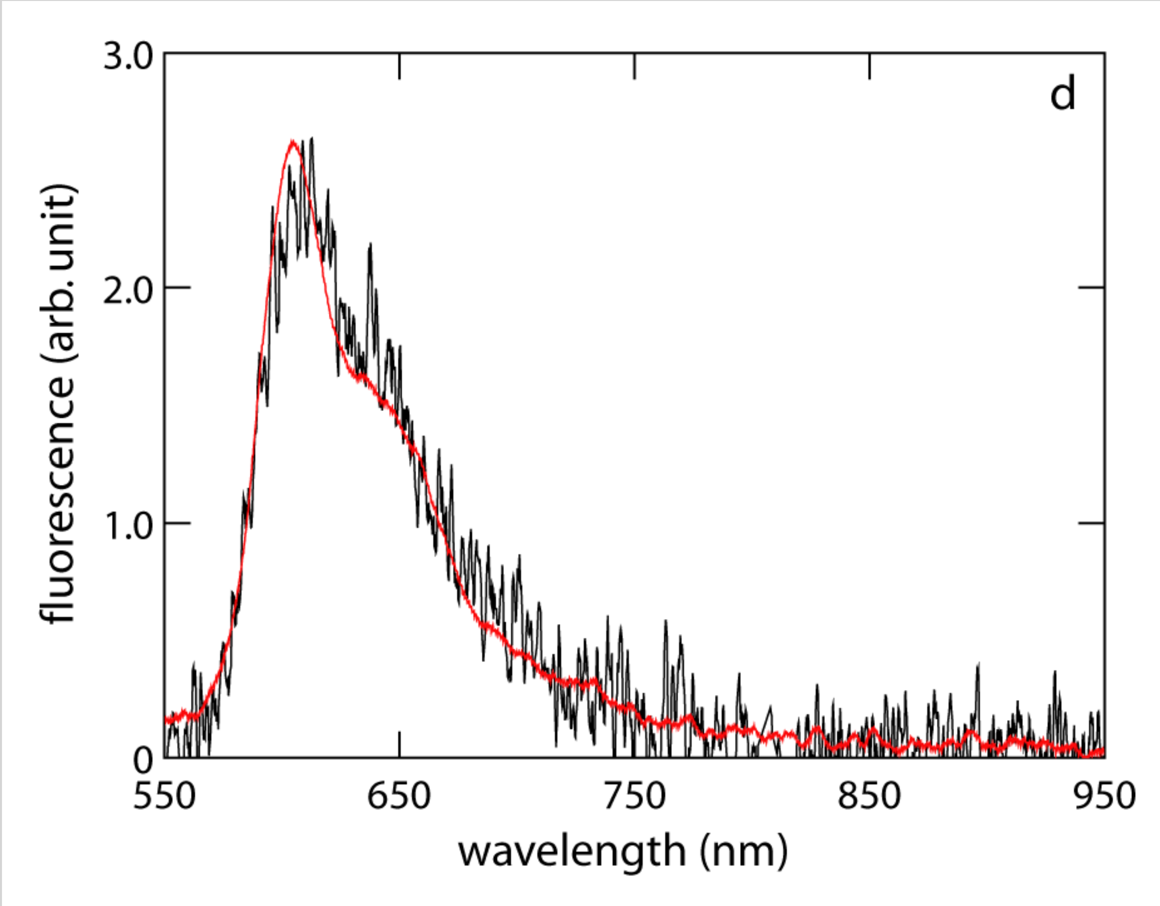
MEH-PPV: up to 1% by weight
laser power 40 mW



a - Scanning electron microscopy

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

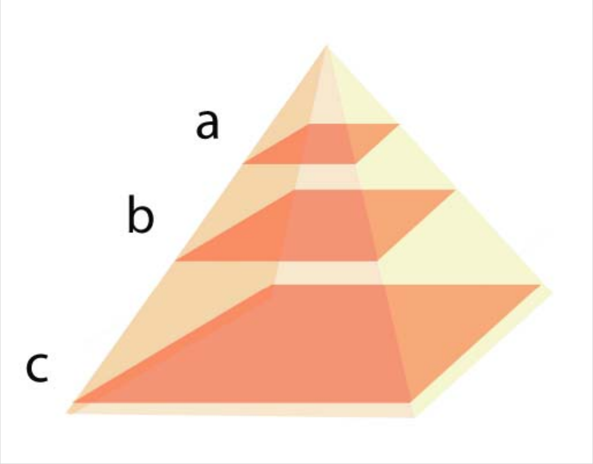
Microstructures containing MEH-PPV

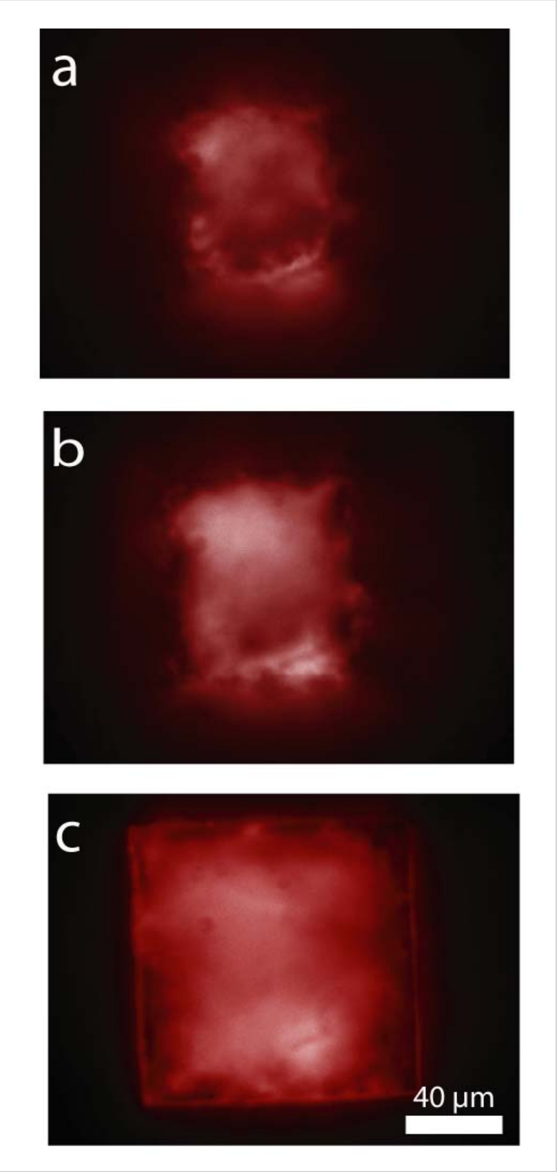


d **-** Emission of the microstructure (black line) and of a film with the same composition (red line)

Microstructures containing MEH-PPV

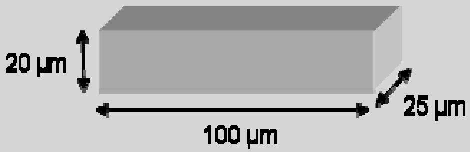
Fluorescent confocal microscopy images in planes separated by 16 μm in the pyramidal microstructure.

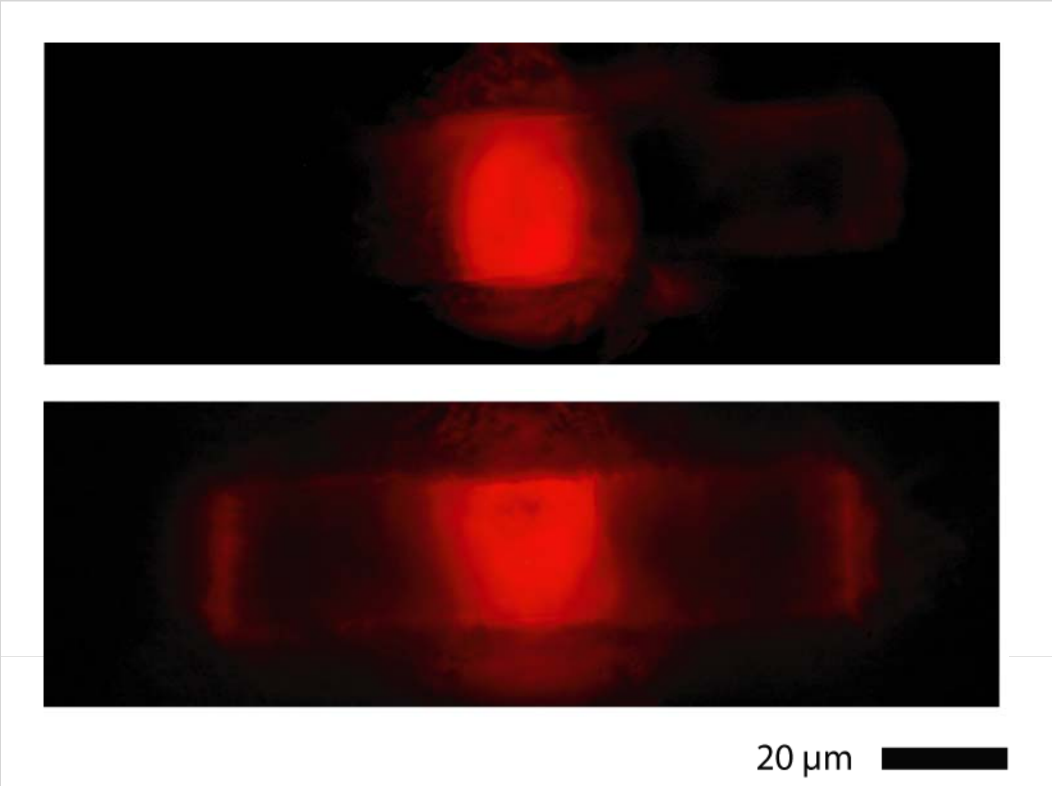


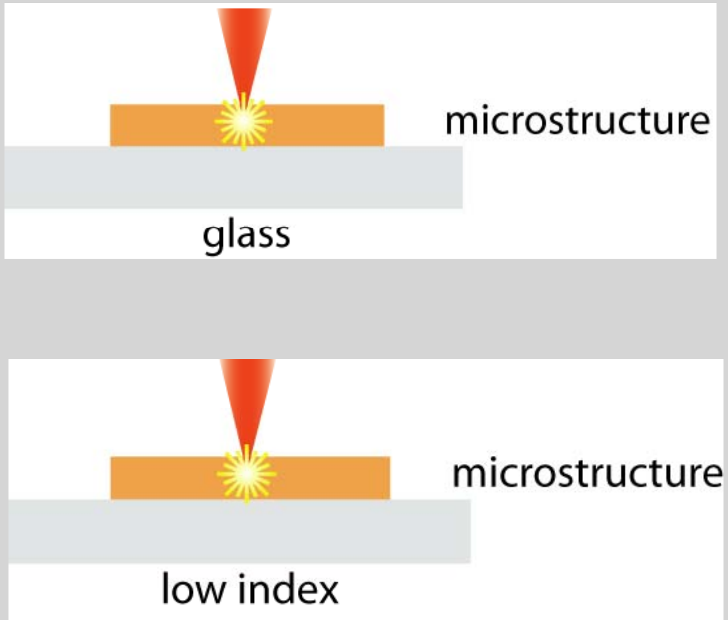


Appl. Phys. Lett 95, 113309 (2009)

Microstructures containing MEH-PPV





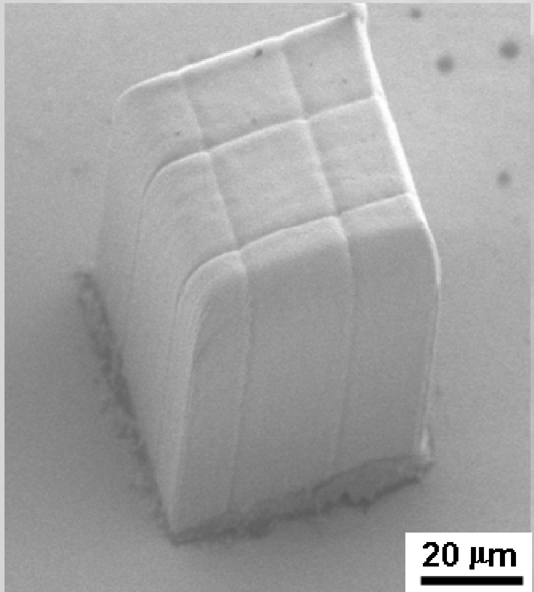


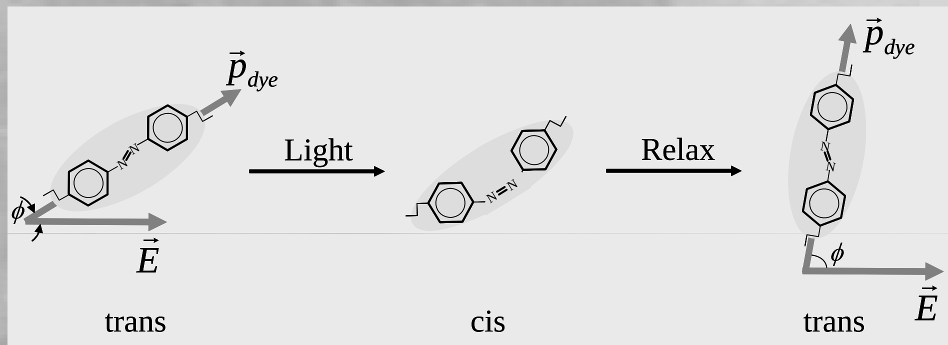
waveguiding of the microstructure fabricated on porous silica substrate (n= 1.185)

Applications: micro-laser; fluorescent microstructures; conductive microstructures

Other studies

- microstructures for optical storage – birefringence

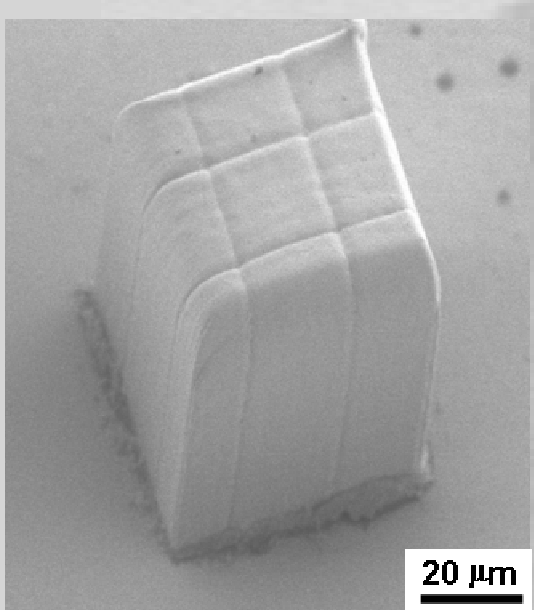




J. Appl. Phys., 102, 13109-1-13109-4 (2007)

Other studies

- microstructures for optical storage – birefringence



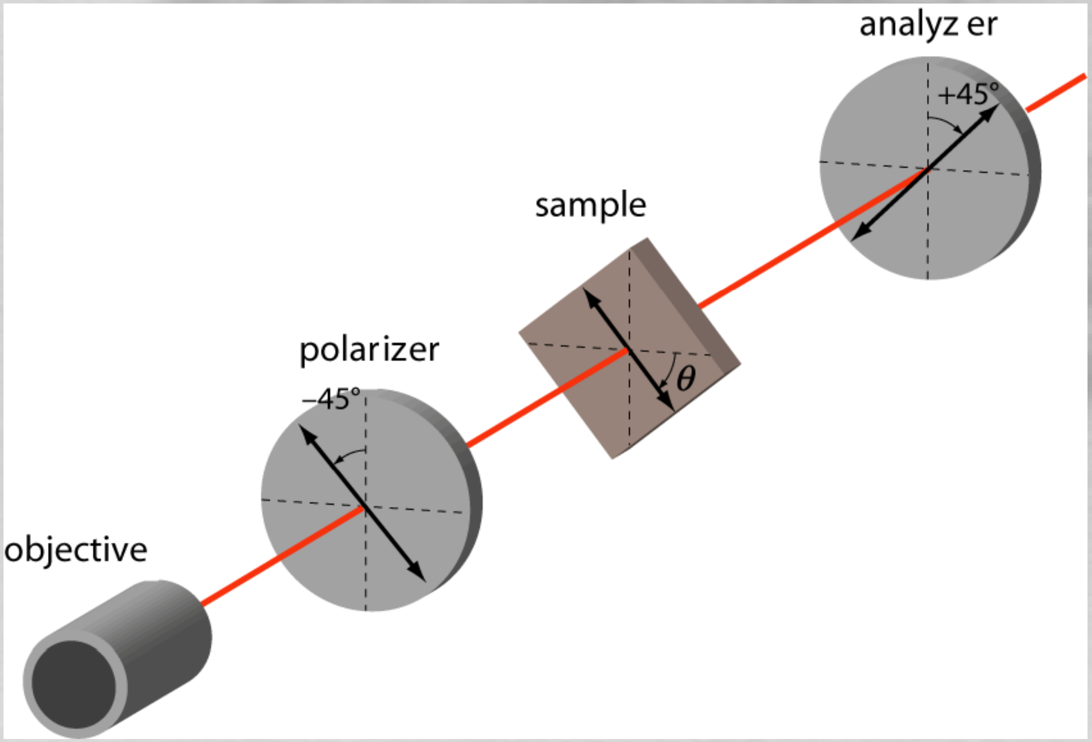
Ar^+ ion laser irradiation

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

Other studies

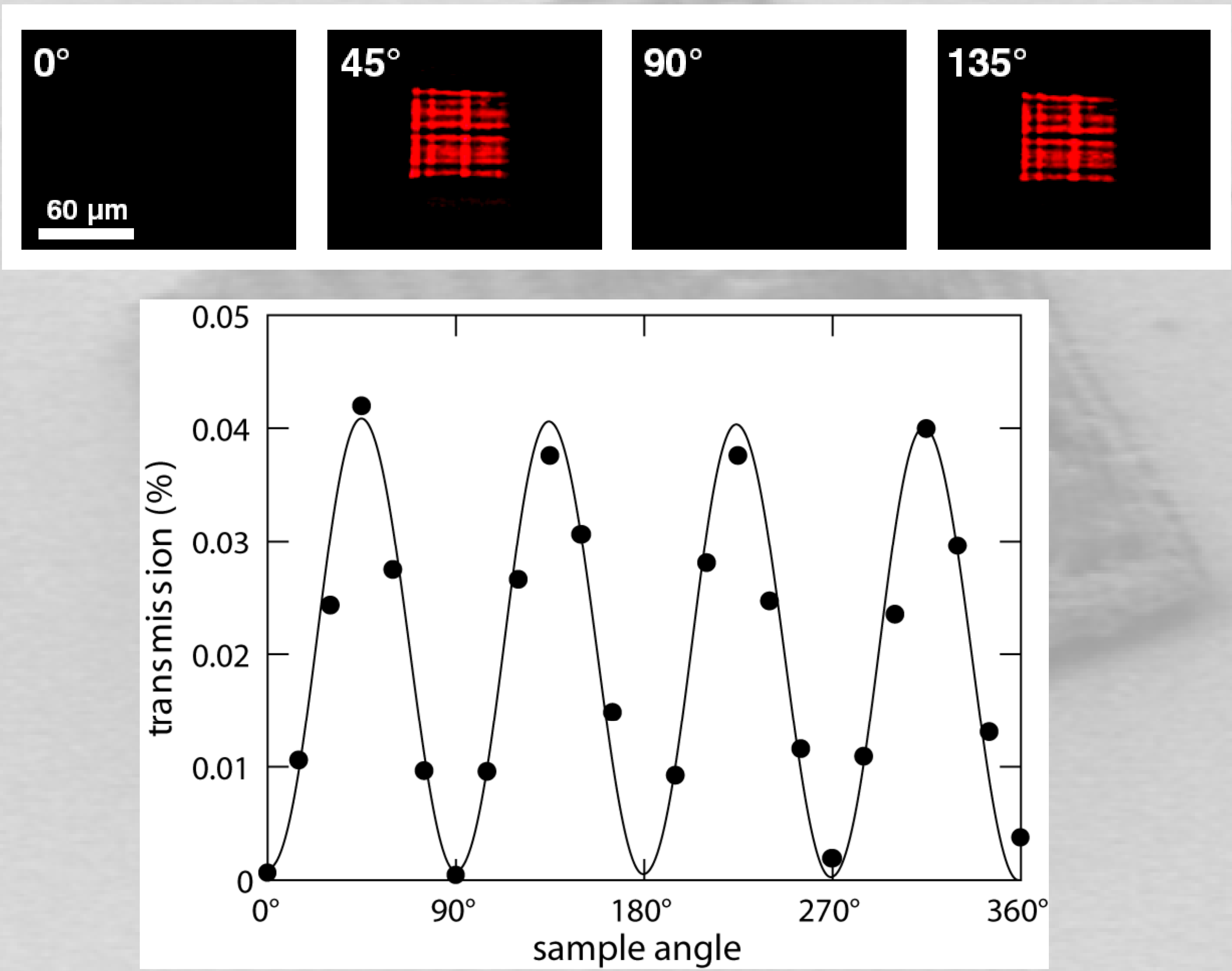
- microstructures for optical storage – birefringence

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



Other studies

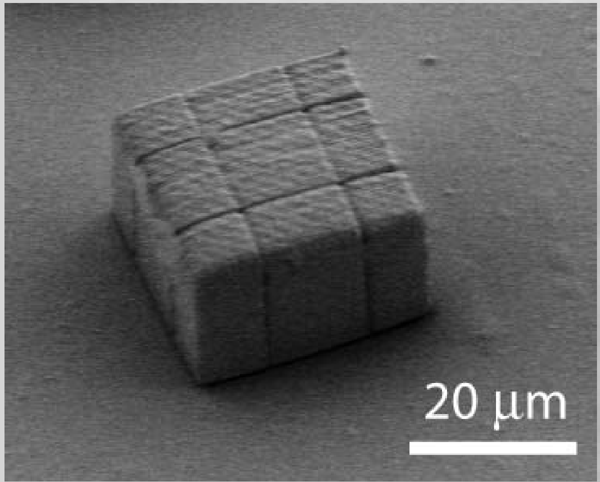
- microstructures for optical storage – birefringence

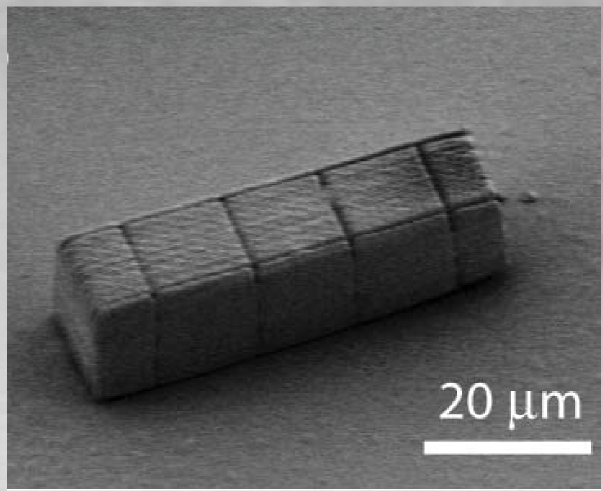


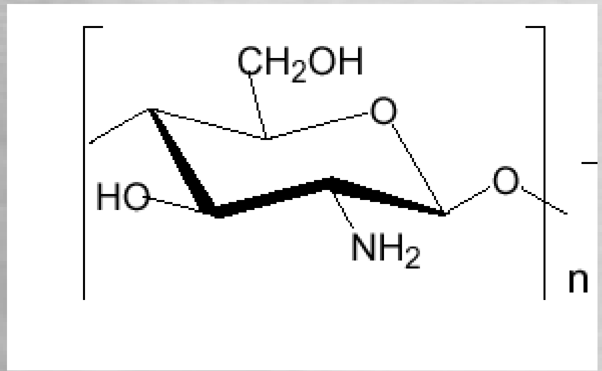
J. Appl. Phys., 102, 13109-1-13109-4 (2007)

Other studies

- microstructures containing biopolymer - chitosan



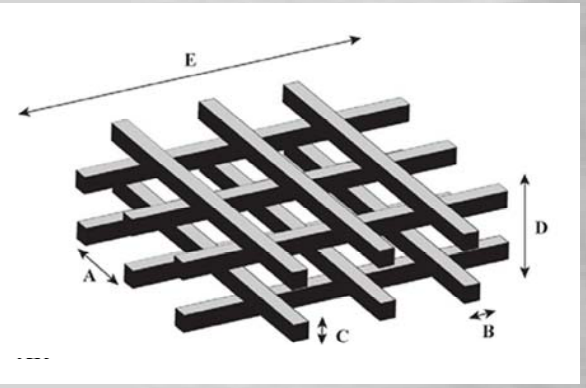




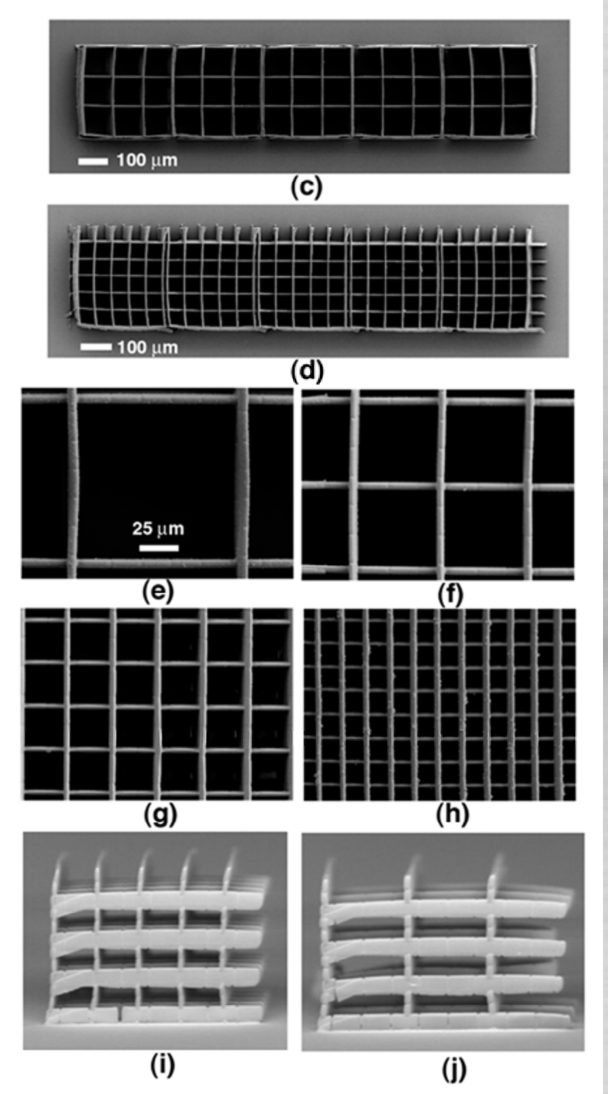
J. Nanoscience and Nanotechnology (in press)

Other studies

- 3D cell migration studies in micro-scaffolds



SEM of the scaffolds



110 µm pore size

52 µm pore size

Top view

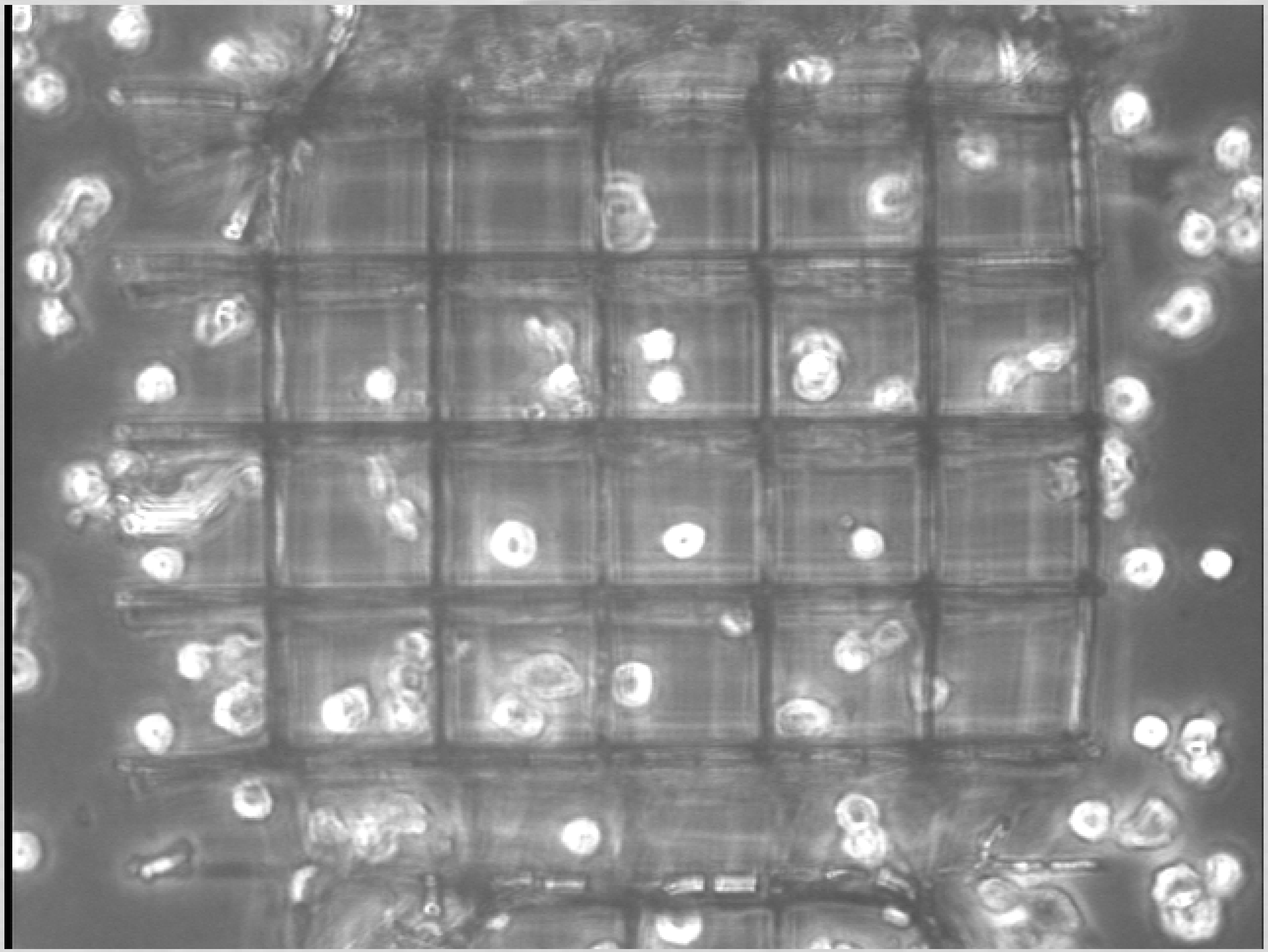
110, 52, 25, 12 µm pore size

Side view

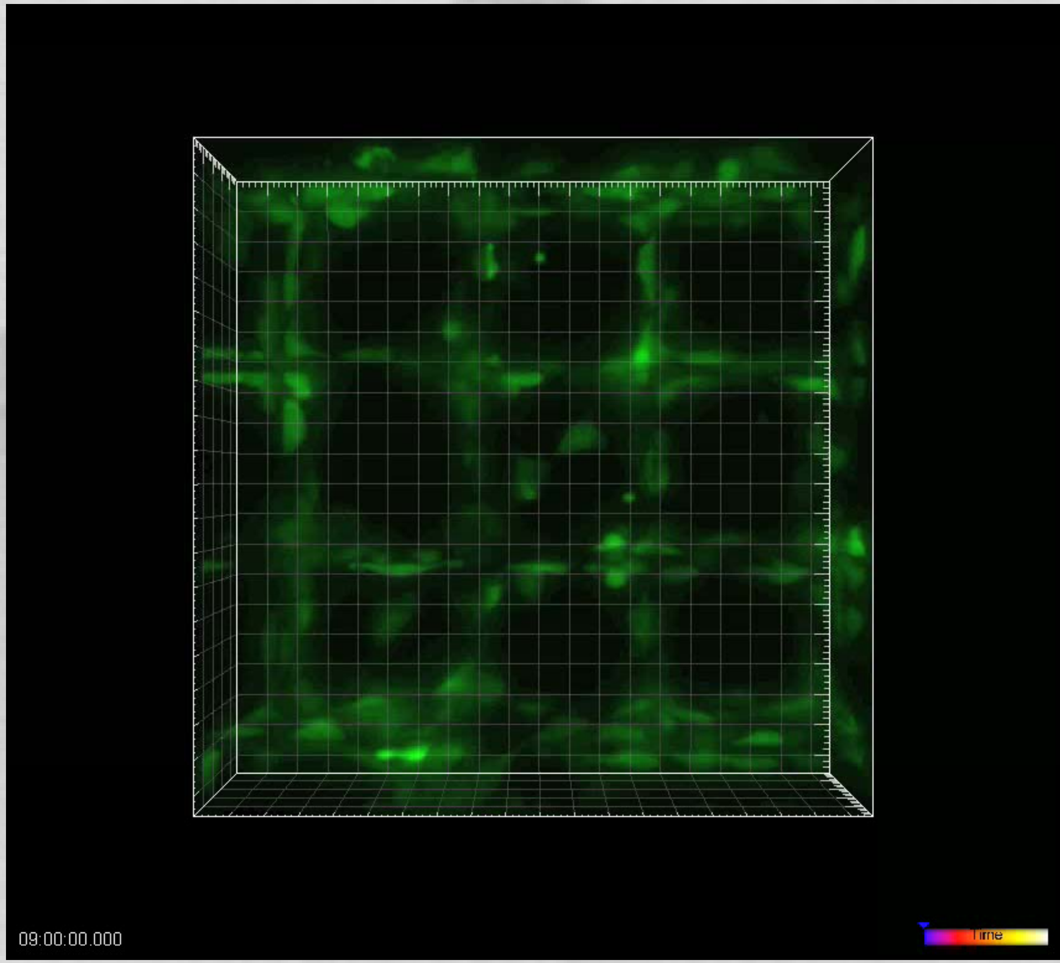
25, 52 µm pore size

Other studies

50 μm pore size

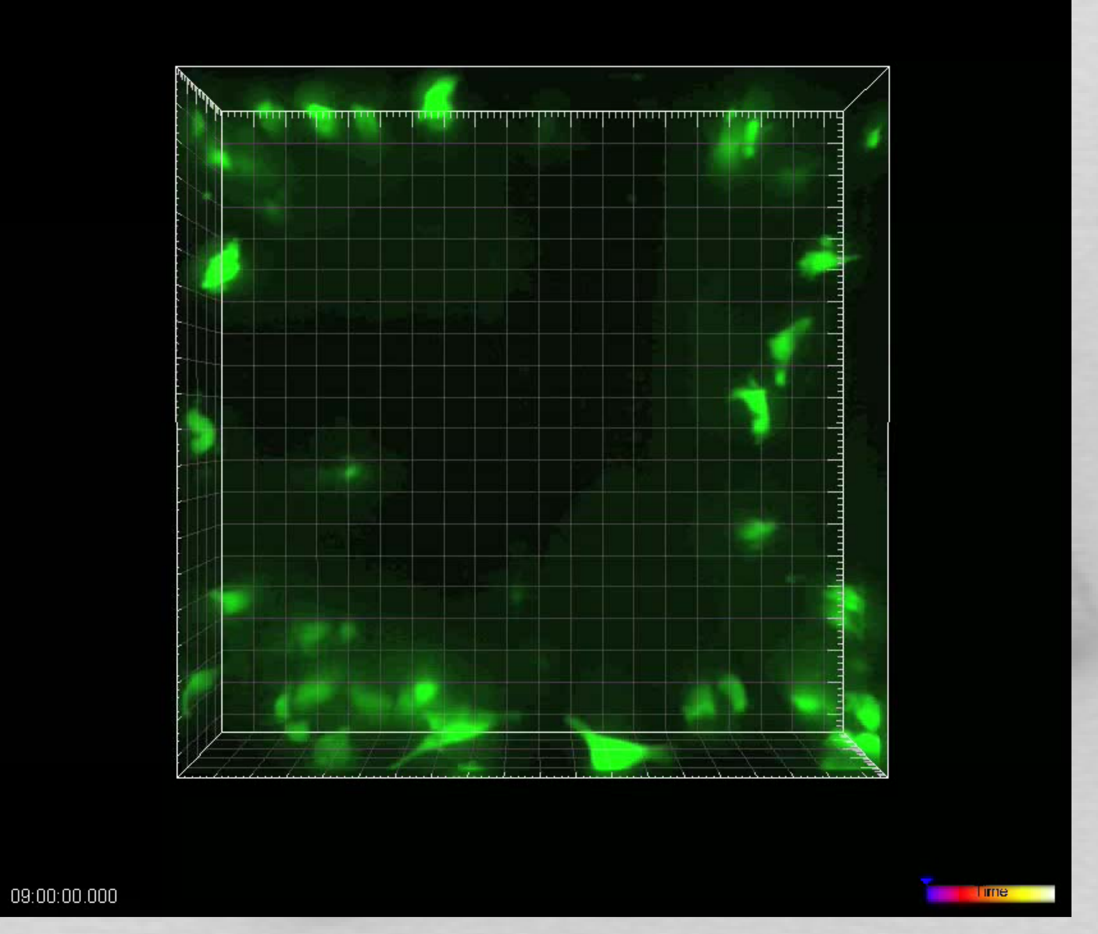


Other studies



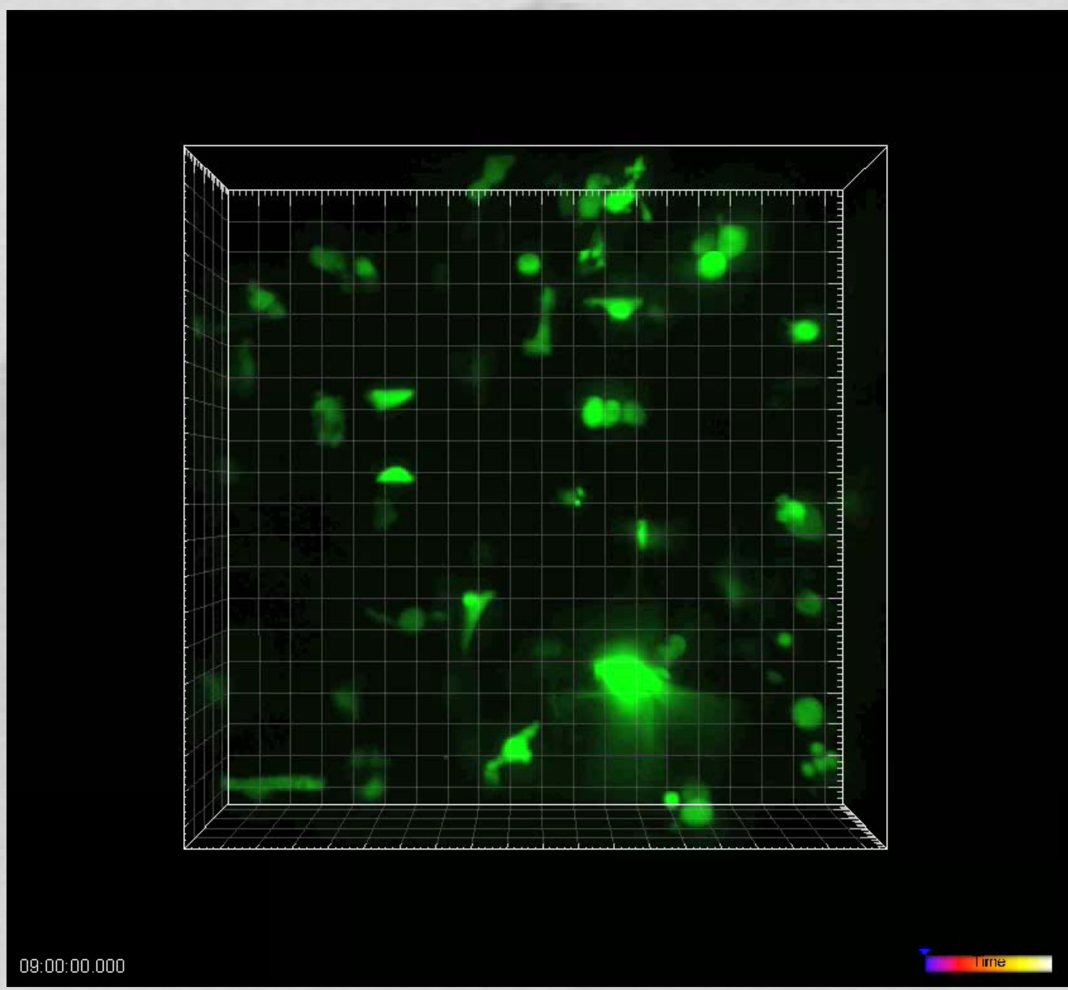
110 μm pore size

Other studies



12 μm pore size

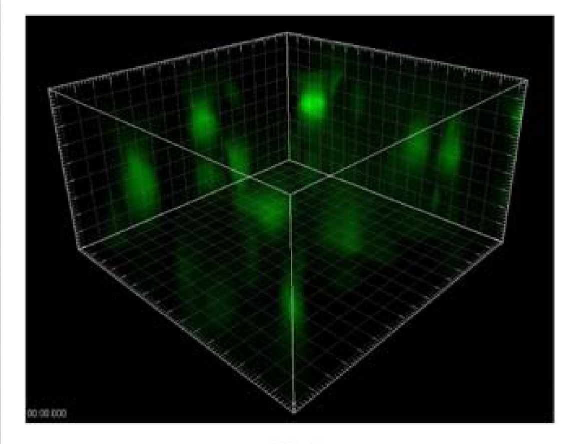
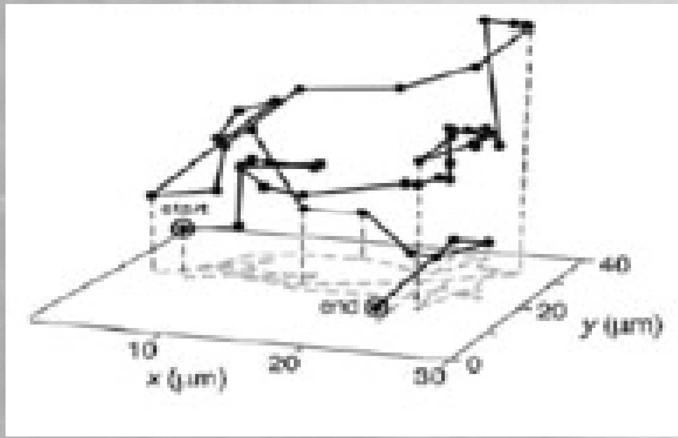
Other studies



52 μm pore size

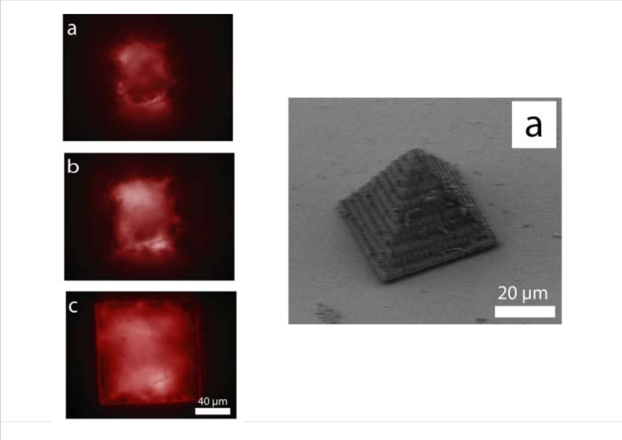
Other studies

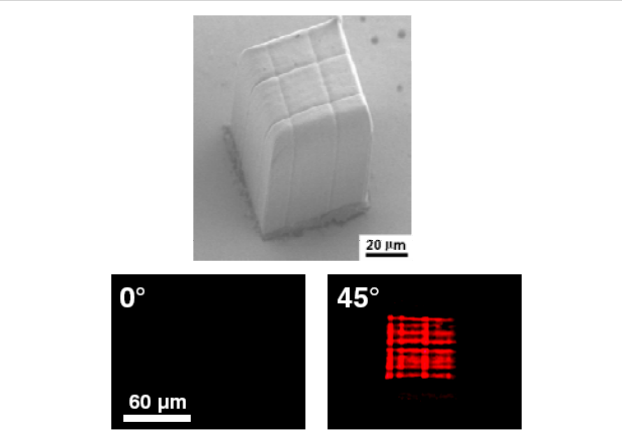
- 3D cell migration studies in micro-scaffolds

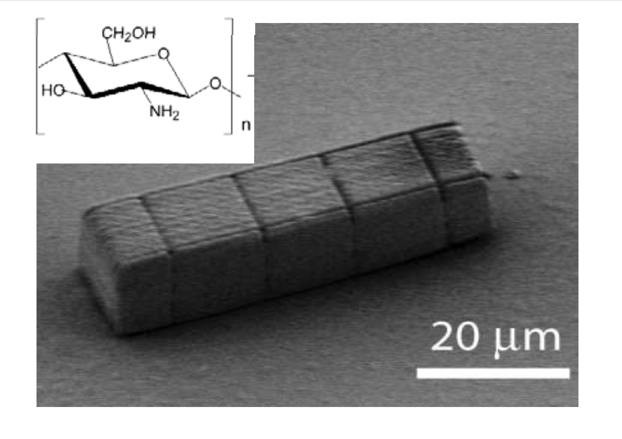
 

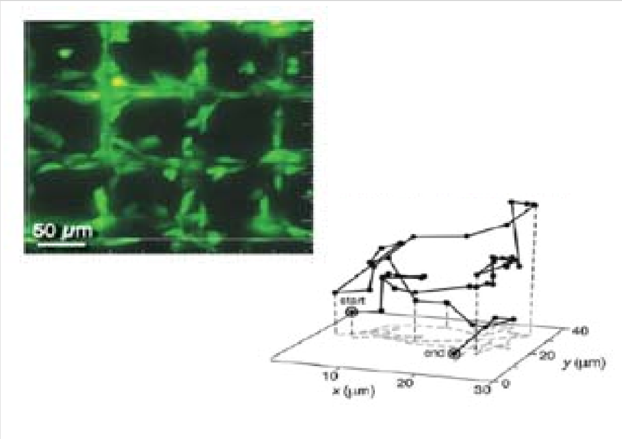
Advanced Materials, 20, 4494-4498 (2008)

Summary









Applied Physics Letters (submitted)

Acknowledgments

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Thank you !

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