Two-photon polymerization of optically active microstructures for photonic applications

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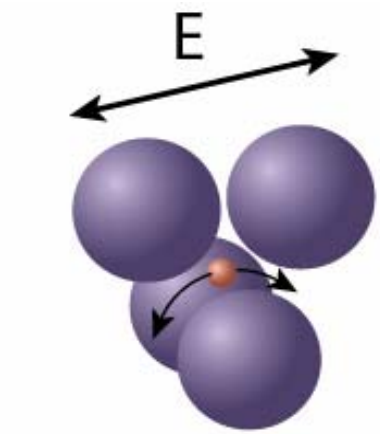
Outline

- two-photon polymerization microfabrication
- birefringent microstructures
- microstructures containing MEH-PPV
- summary

Nonlinear Optics



anharmonic oscillator

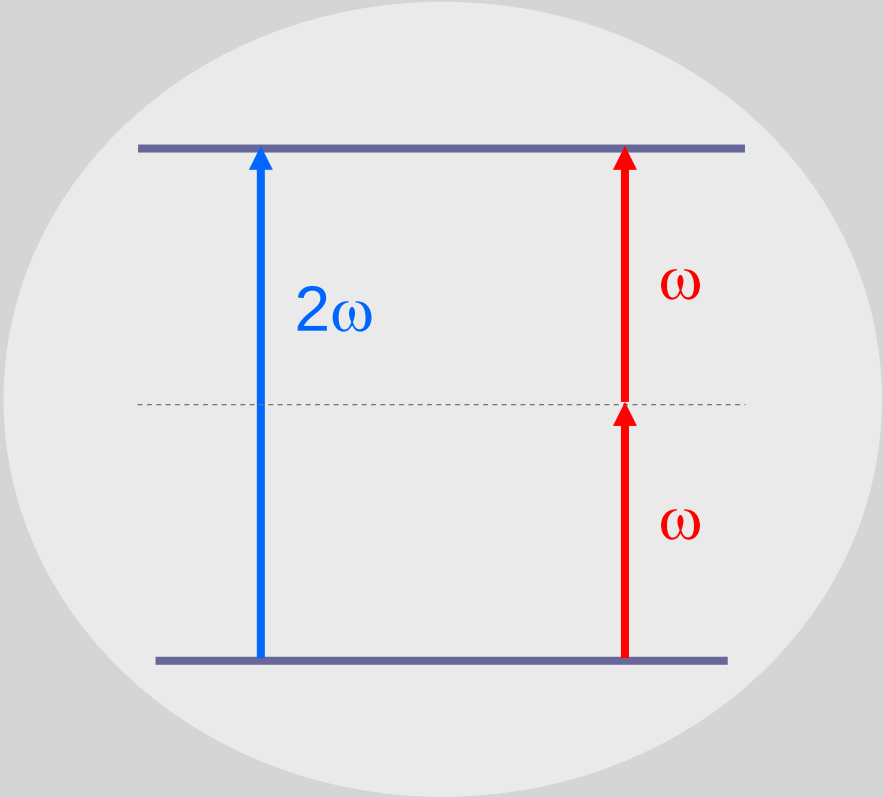
high light intensity

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

nonlinear polarization response

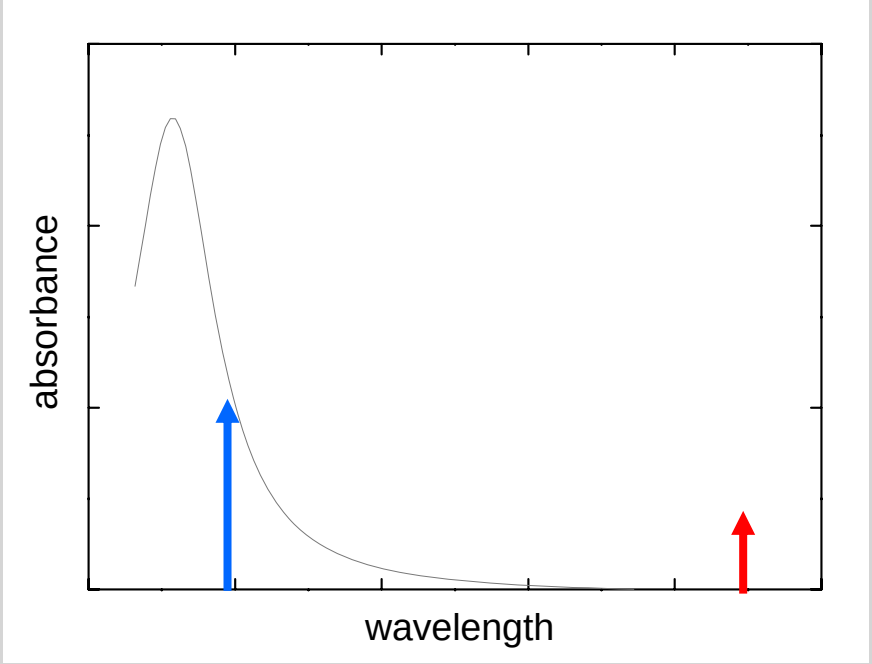
$$P = \chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \ldots$$

Two-photon absorption



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

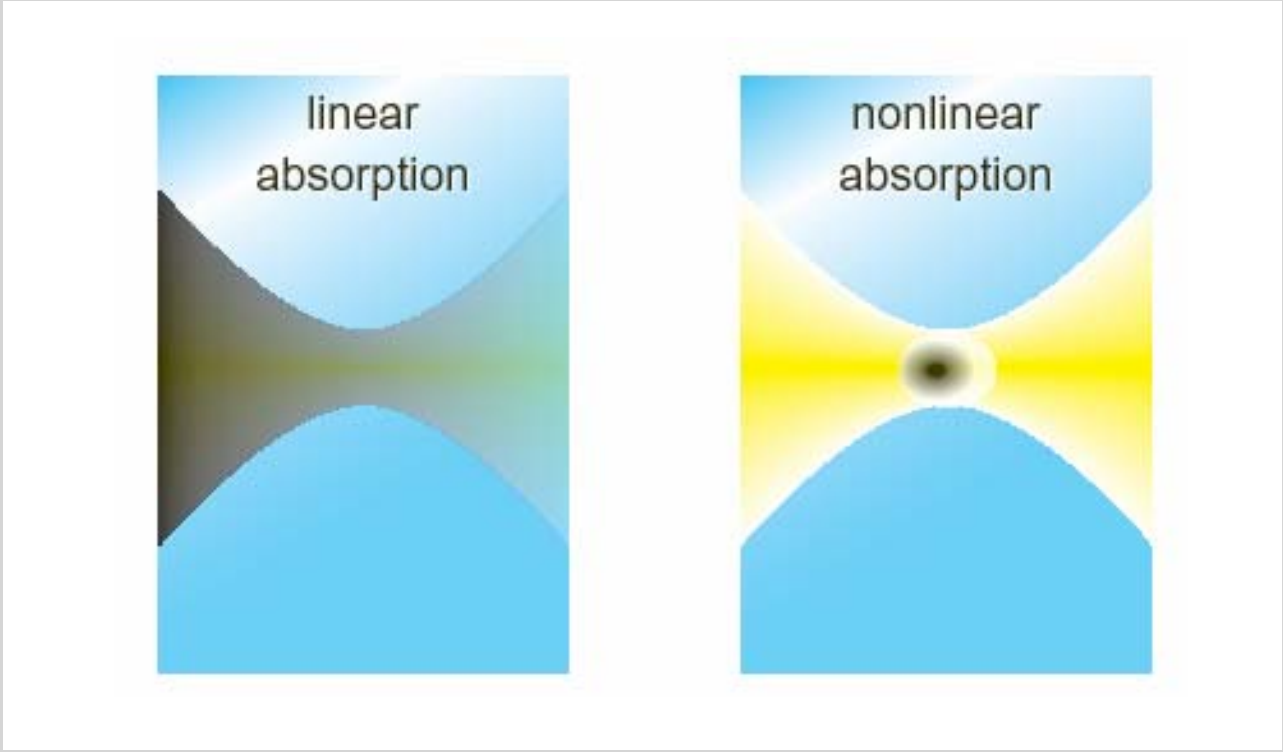
$$\alpha = \alpha_0 + \beta I$$



Two-photon absorption

Nonlinear interaction provides spatial confinement of the excitation

fs-microfabrication



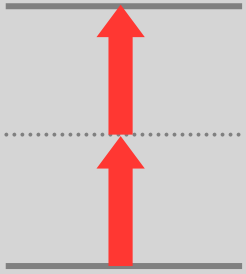
$$\alpha = \alpha_0 \qquad \alpha = \alpha_0 + \beta I$$

Two-photon polymerization

Monomer + Photoinitiator $\rightarrow$ *Polymer*

light

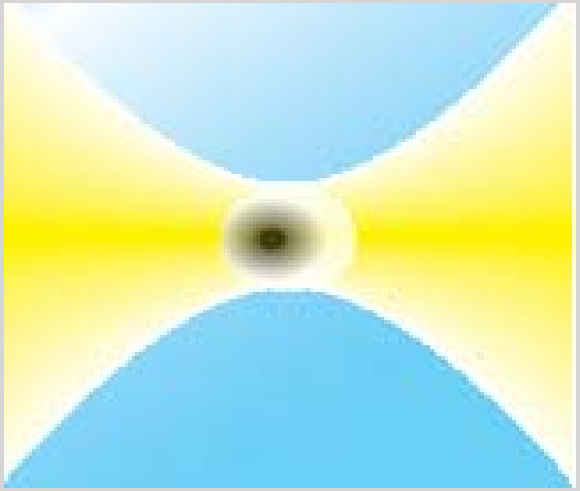
Photoinitiator is excited by ***two-photon absorption***



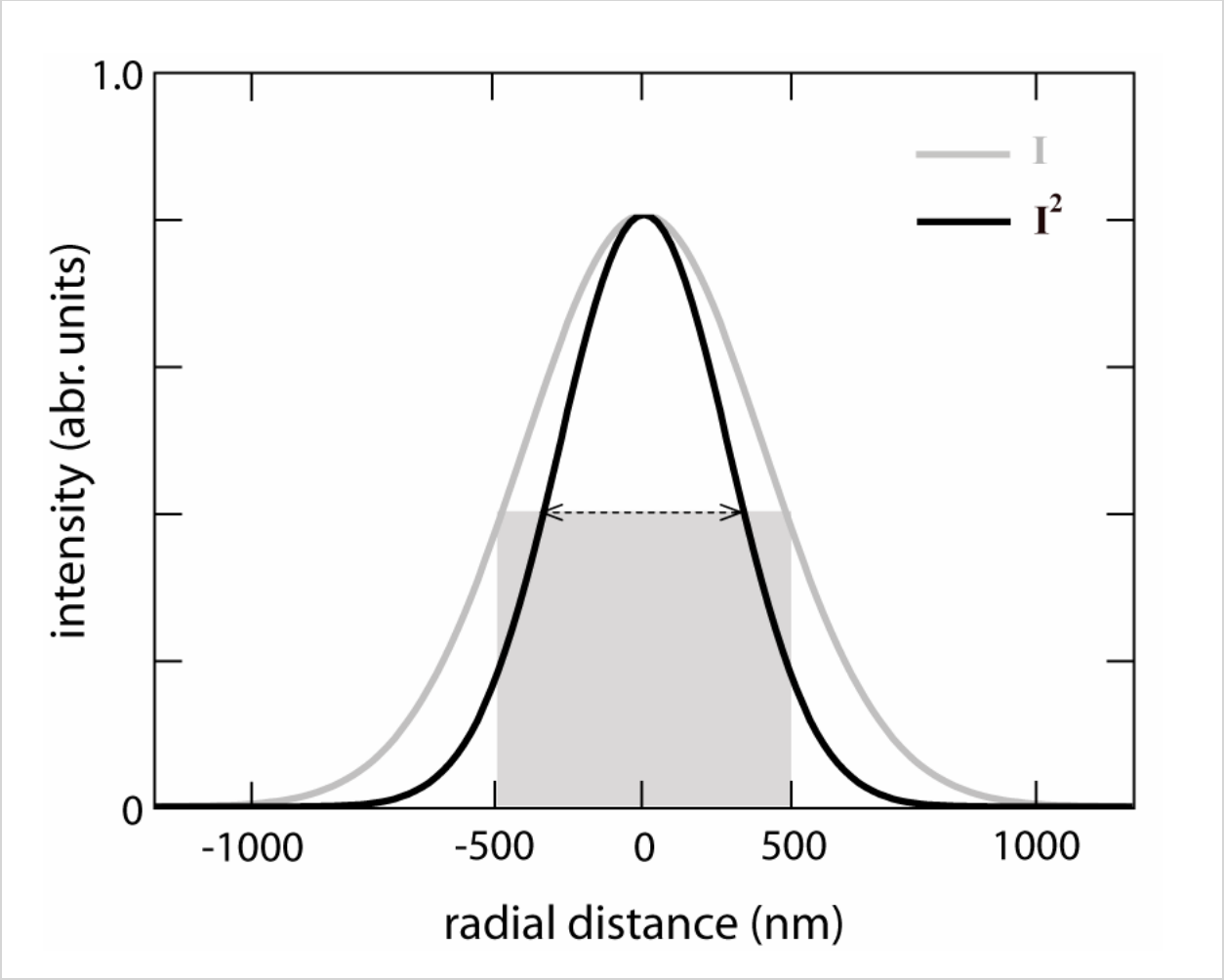
$$R_{2PA} \propto I^2$$

The polymerization is confined to the focal volume.

High spatial resolution

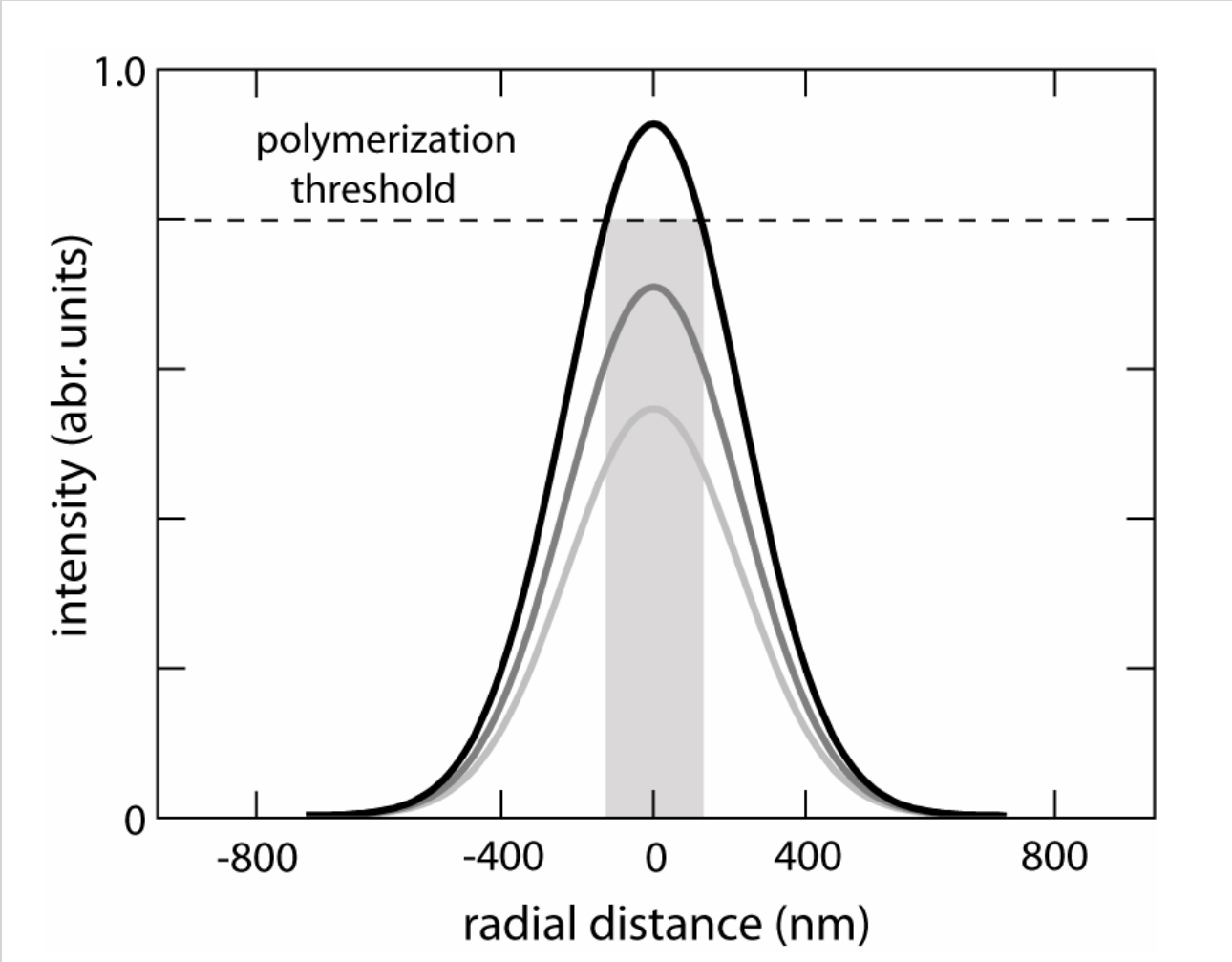


Two-photon polymerization



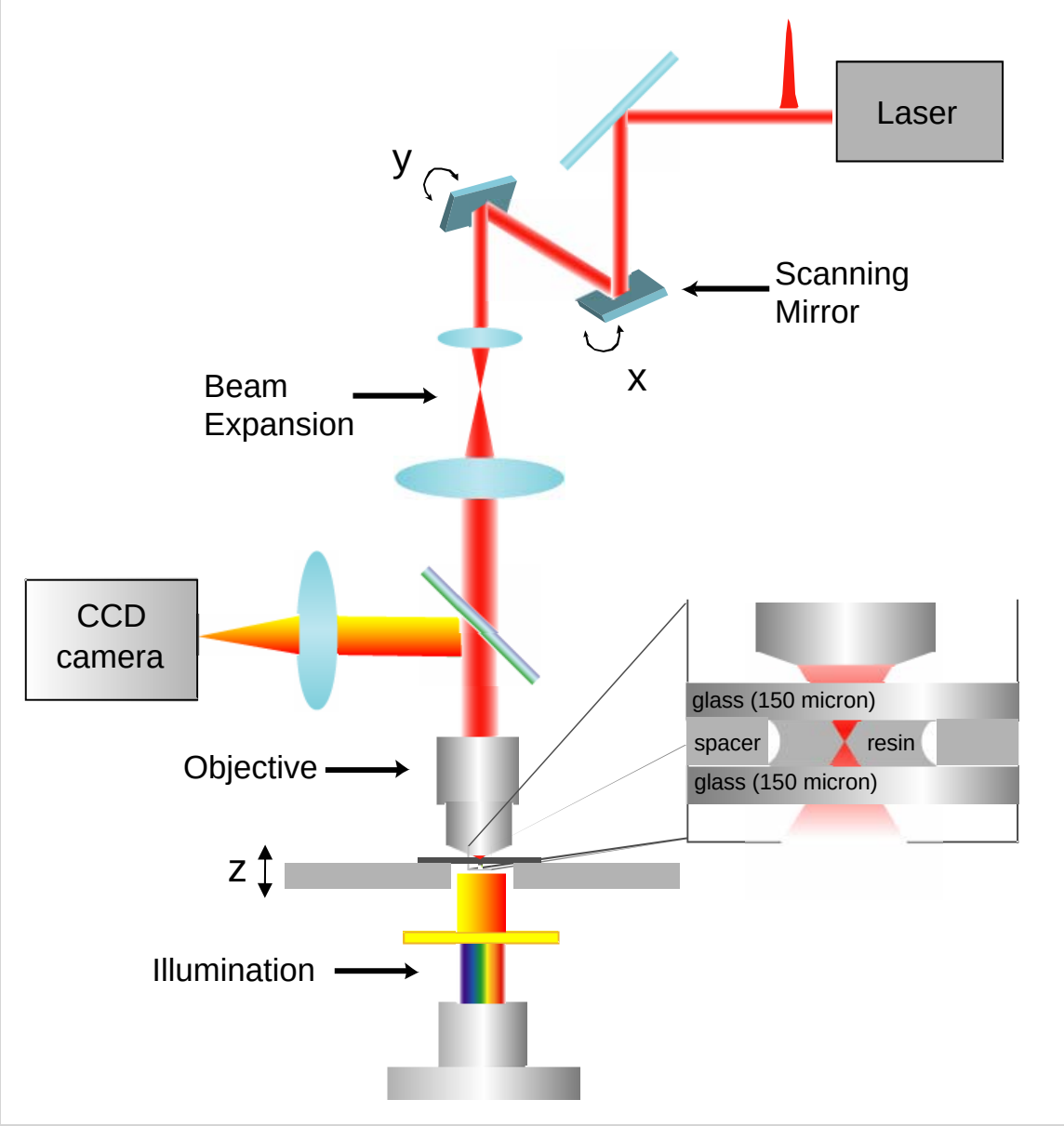
bellow the diffraction limit

Two-photon polymerization



even higher spatial resolution

Two-photon polymerization setup



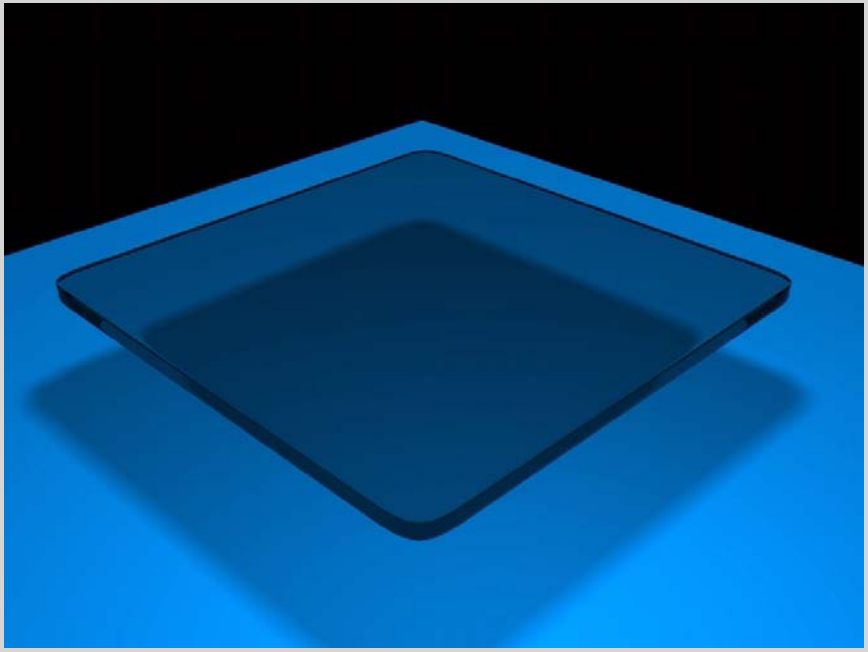
Ti:sapphire laser oscillator

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

Objective

40 x
0.65 NA

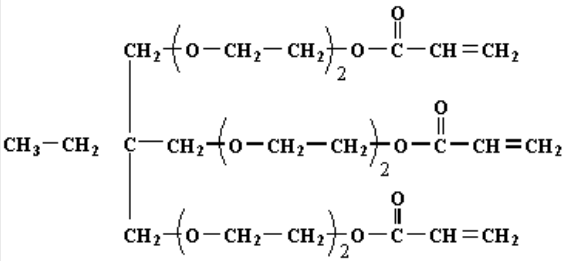
Two-photon polymerization



Resin preparation

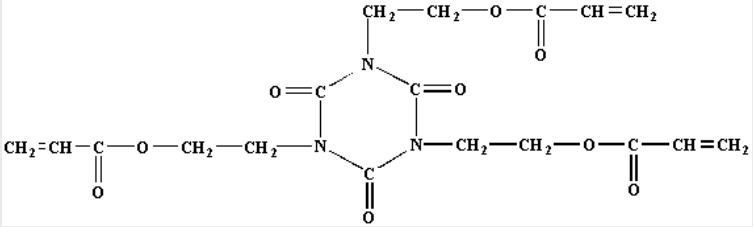
Monomers

Monomer A



reduces the shrinkage upon polymerization

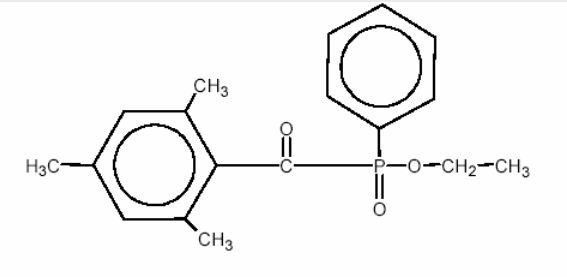
Monomer B



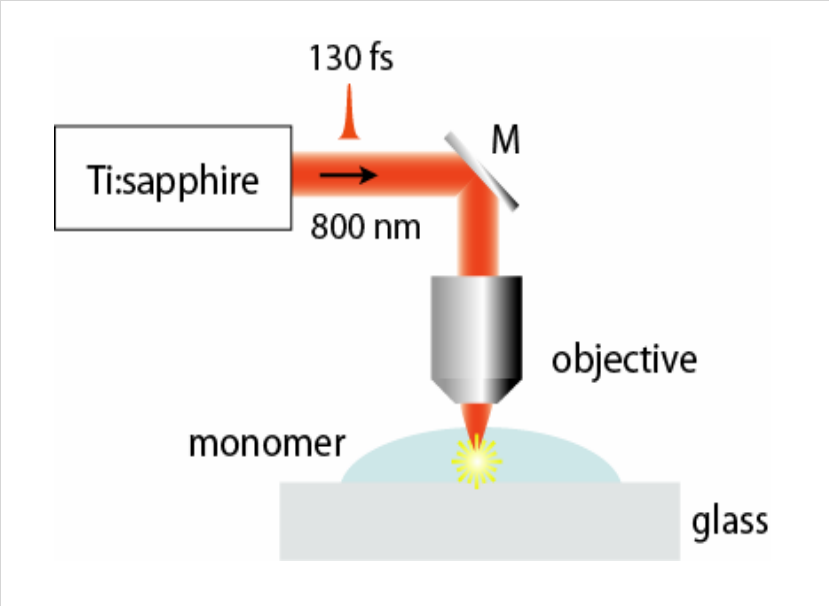
gives hardness to the polymeric structure

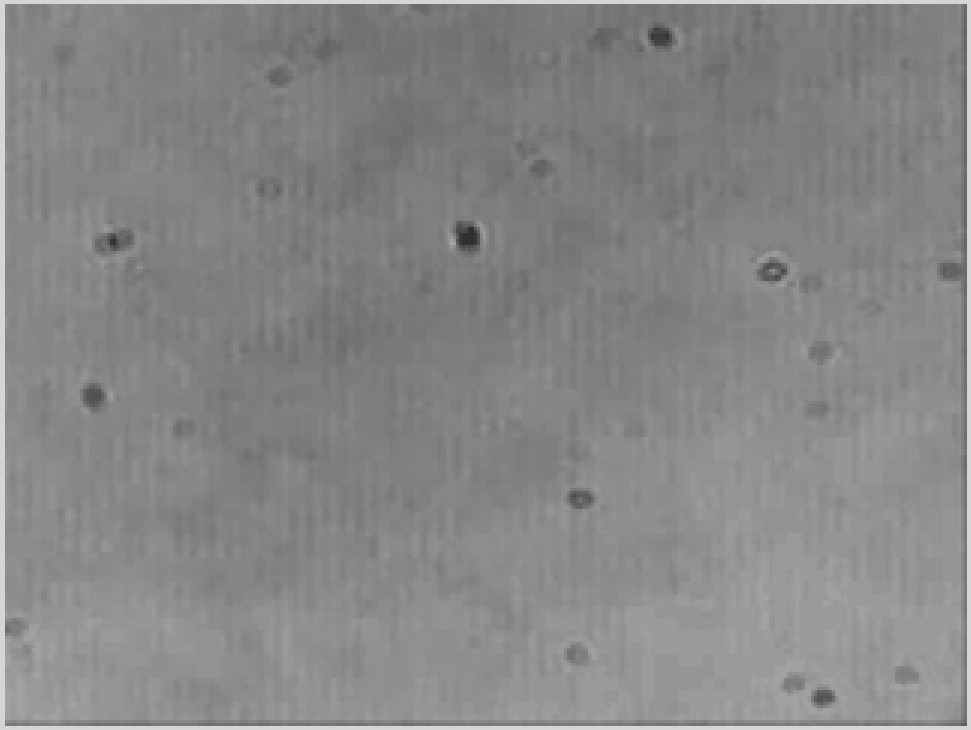
Photoinitiator

Lucirin TPO-L

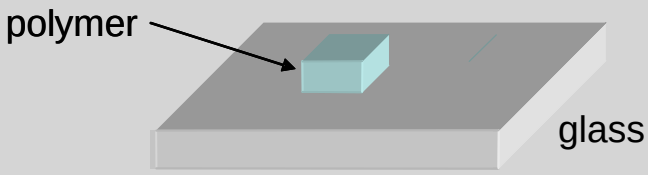


Two-photon polymerization

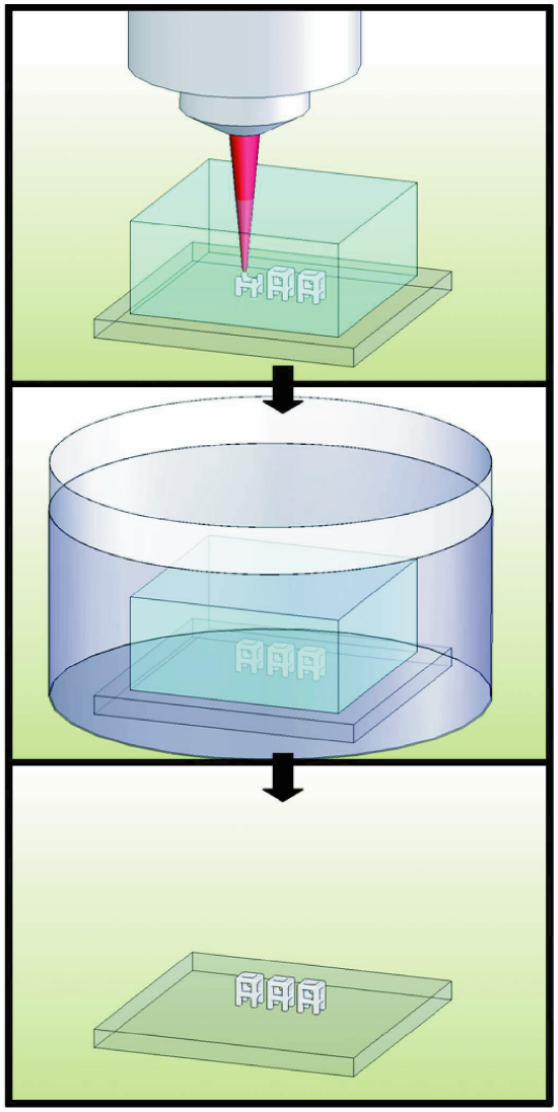




30 µm x 30 µm x 12 µm cube



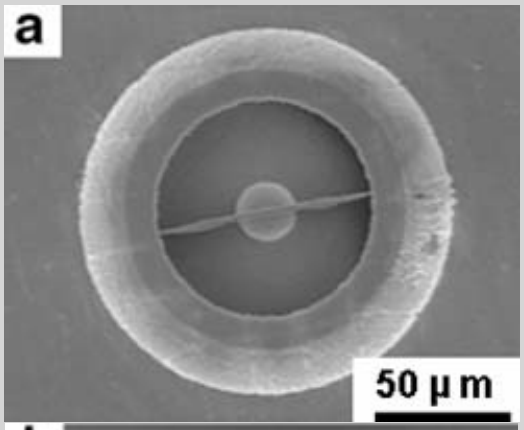
Two-photon polymerization

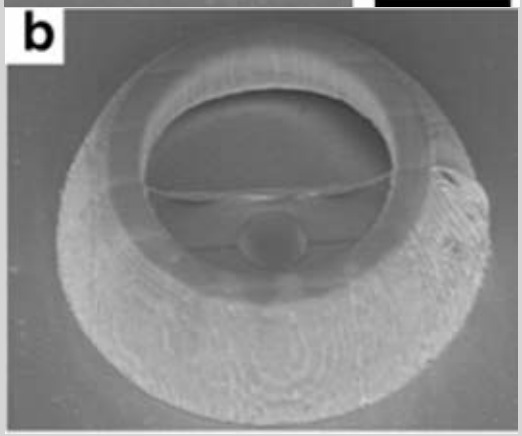


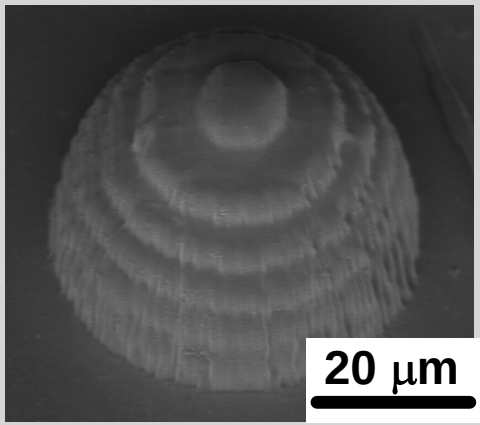
After the fabrication, the sample is immersed in ethanol to wash away any unsolidified resin and then dried

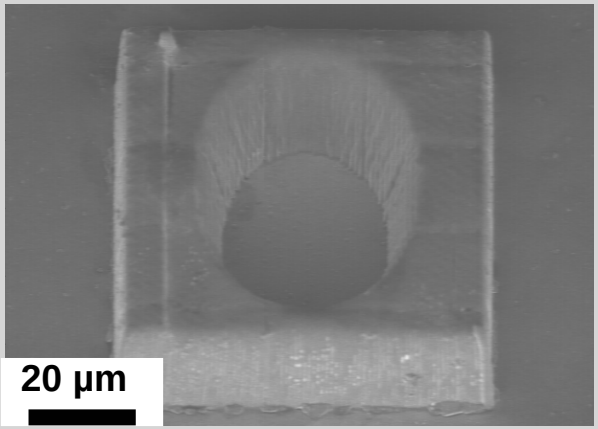
Two-photon polymerization

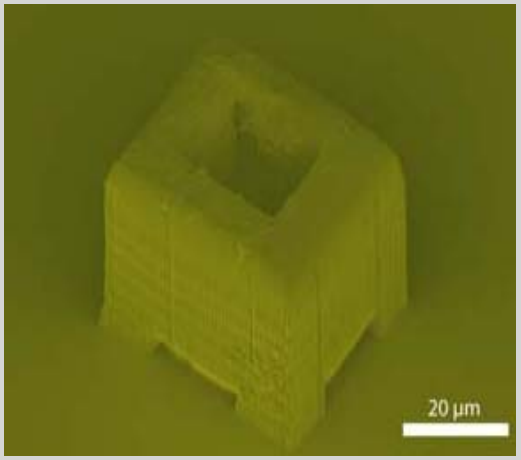
Microstructures fabricated by two-photon polymerization



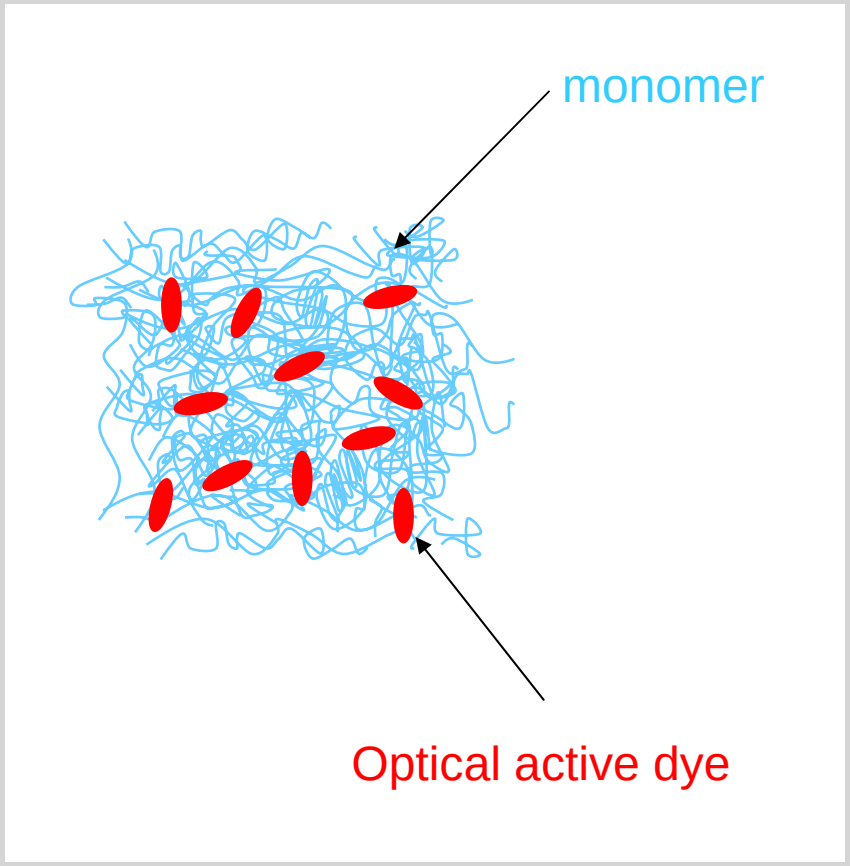


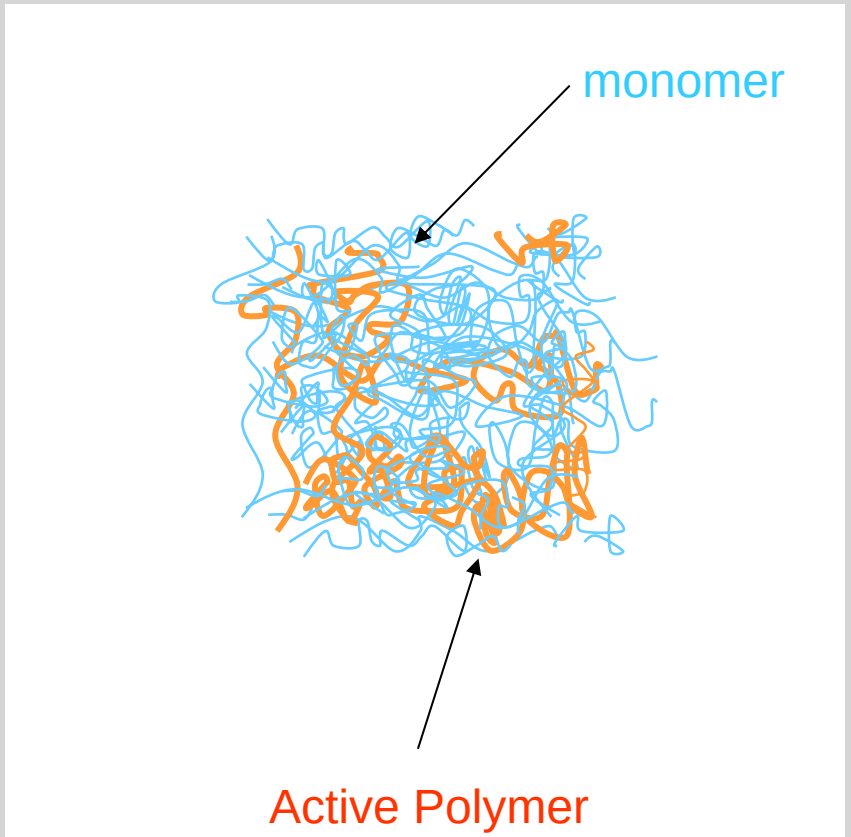






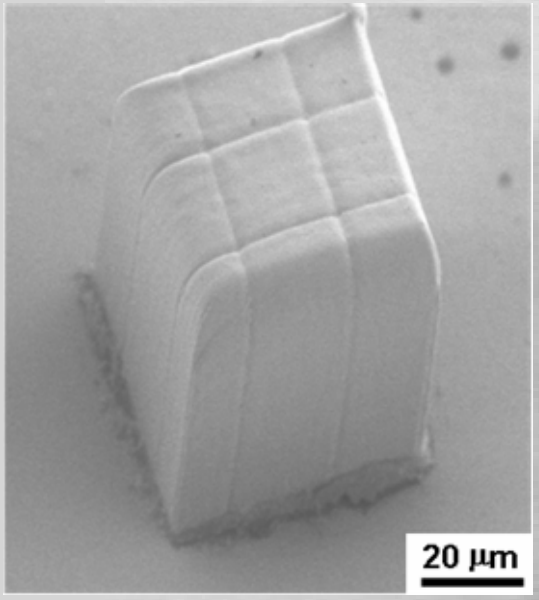
Microstructures containing active compounds

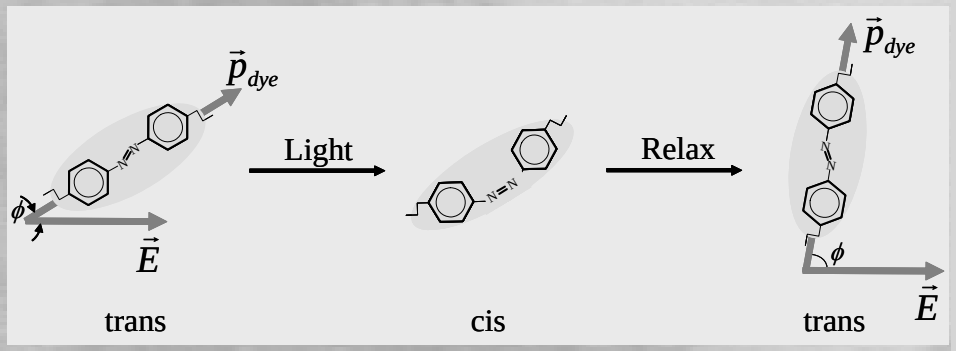




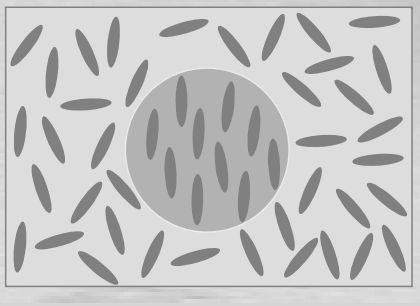
Birefringent microstructures

- microstructures for optical storage – birefringence

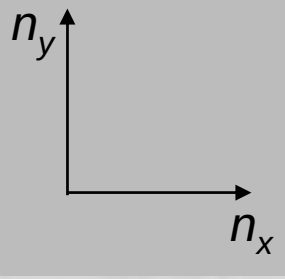




After alignment



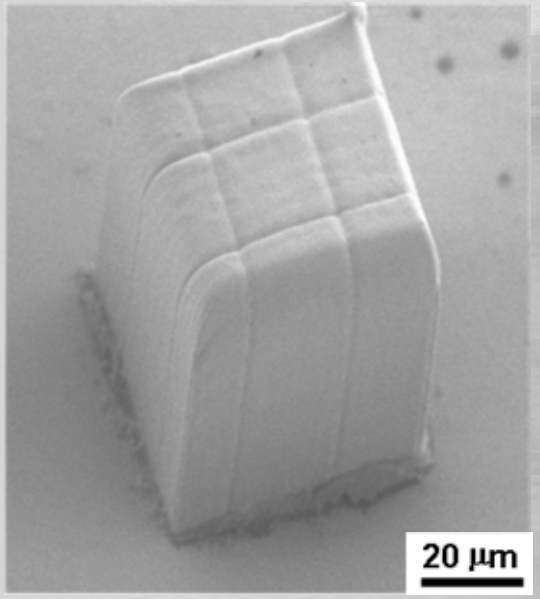
Optically Induced birefringence



$$n_y > n_x$$

Birefringent microstructures

- microstructures for optical storage – birefringence

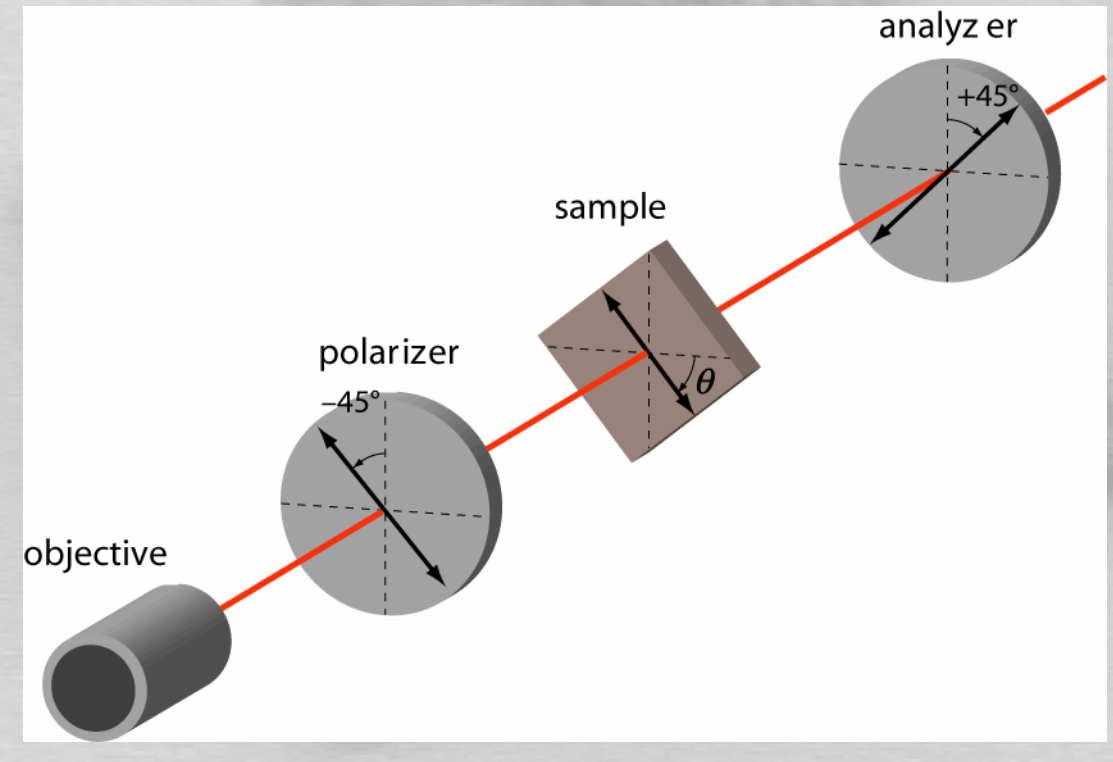


Ar+ ion laser irradiation

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

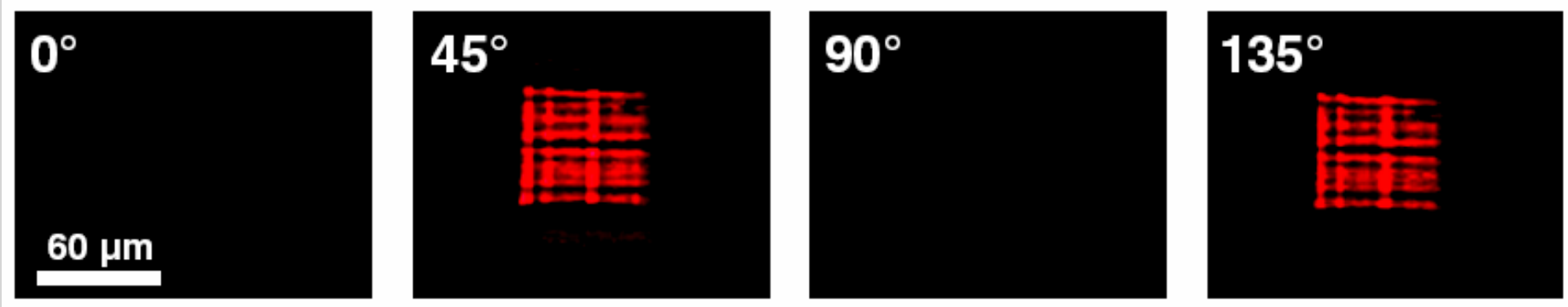
Birefringent microstructures

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



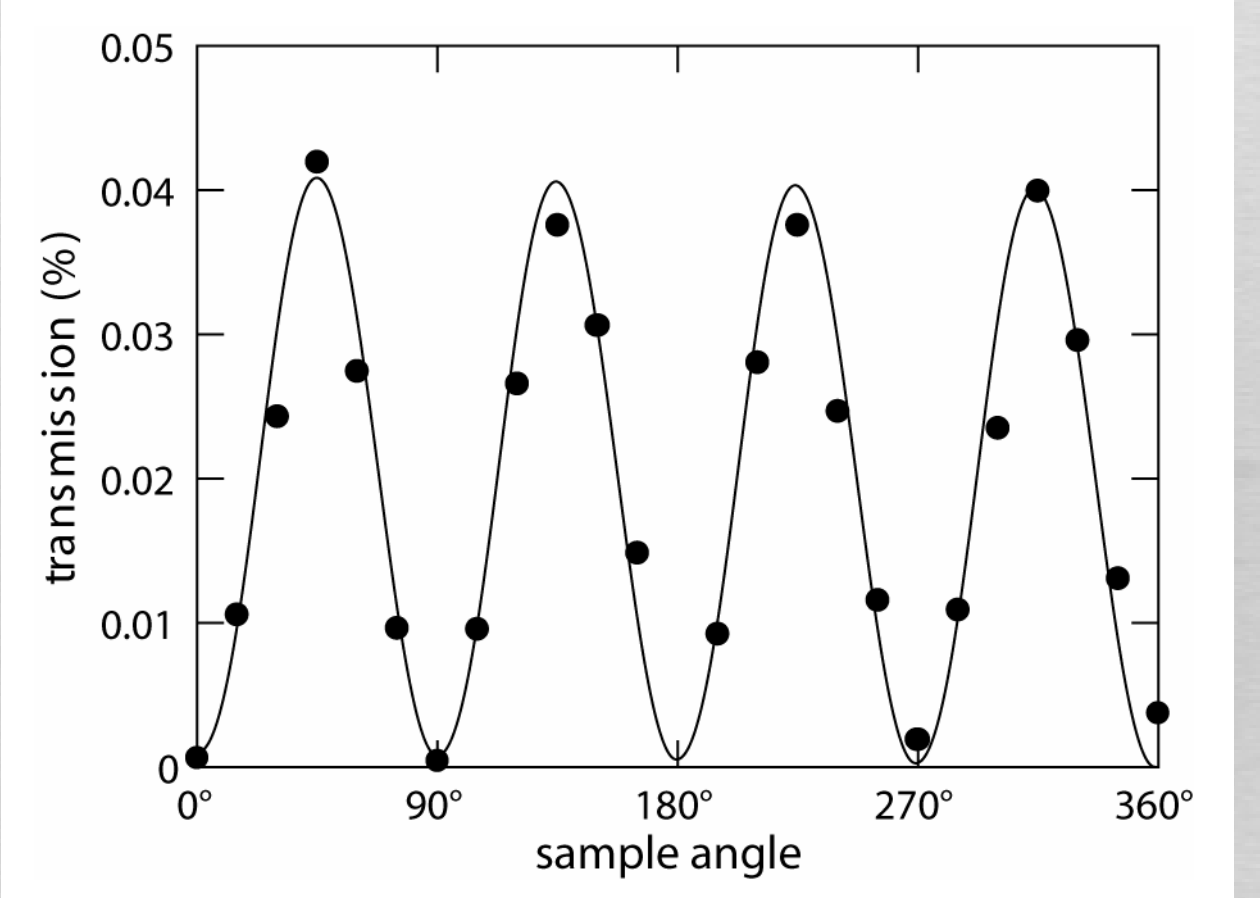
Birefringent microstructures

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.

Birefringent microstructures

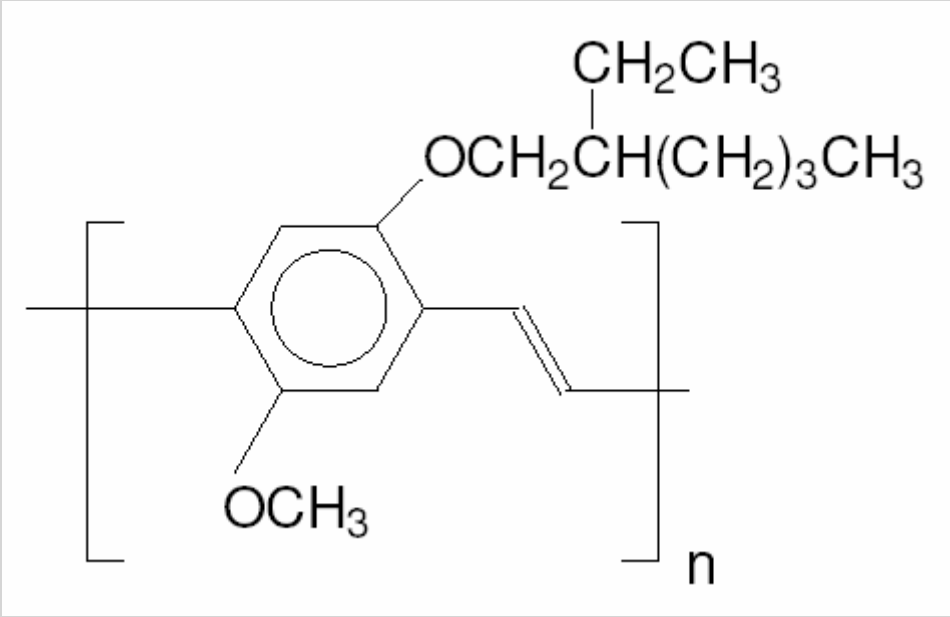


$\Delta n = 5 \times 10^{-5}$

Applications: micro-optical switch, micro-optical storage

Microstructures containing MEH-PPV

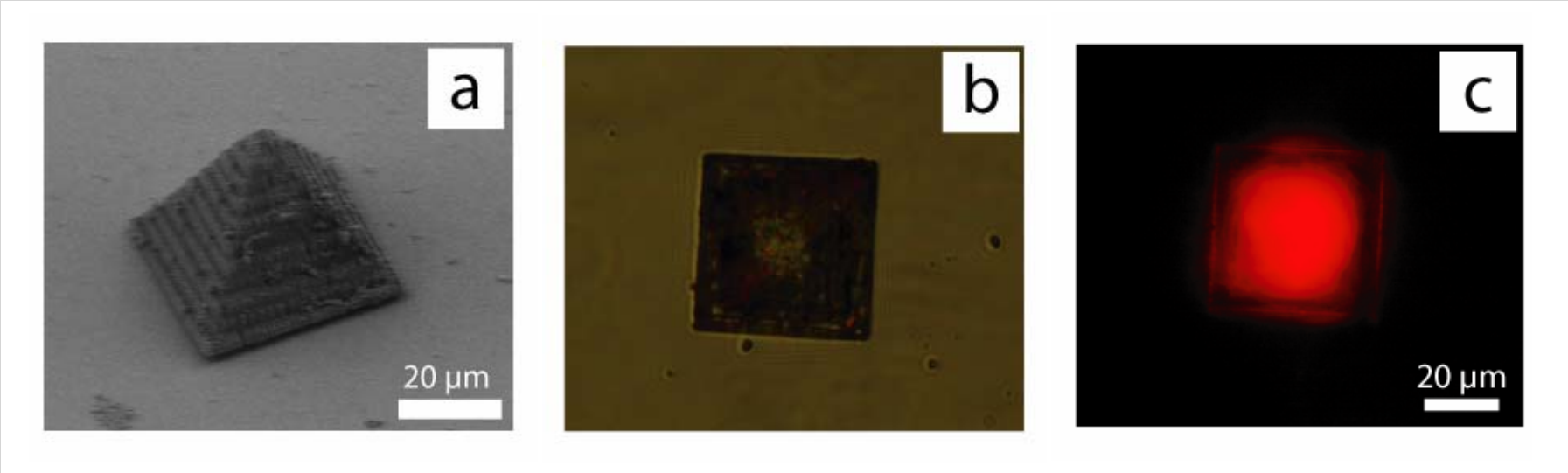
MEH-PPV



Fluorescence
Electro Luminescent
Conductive

Microstructures containing MEH-PPV

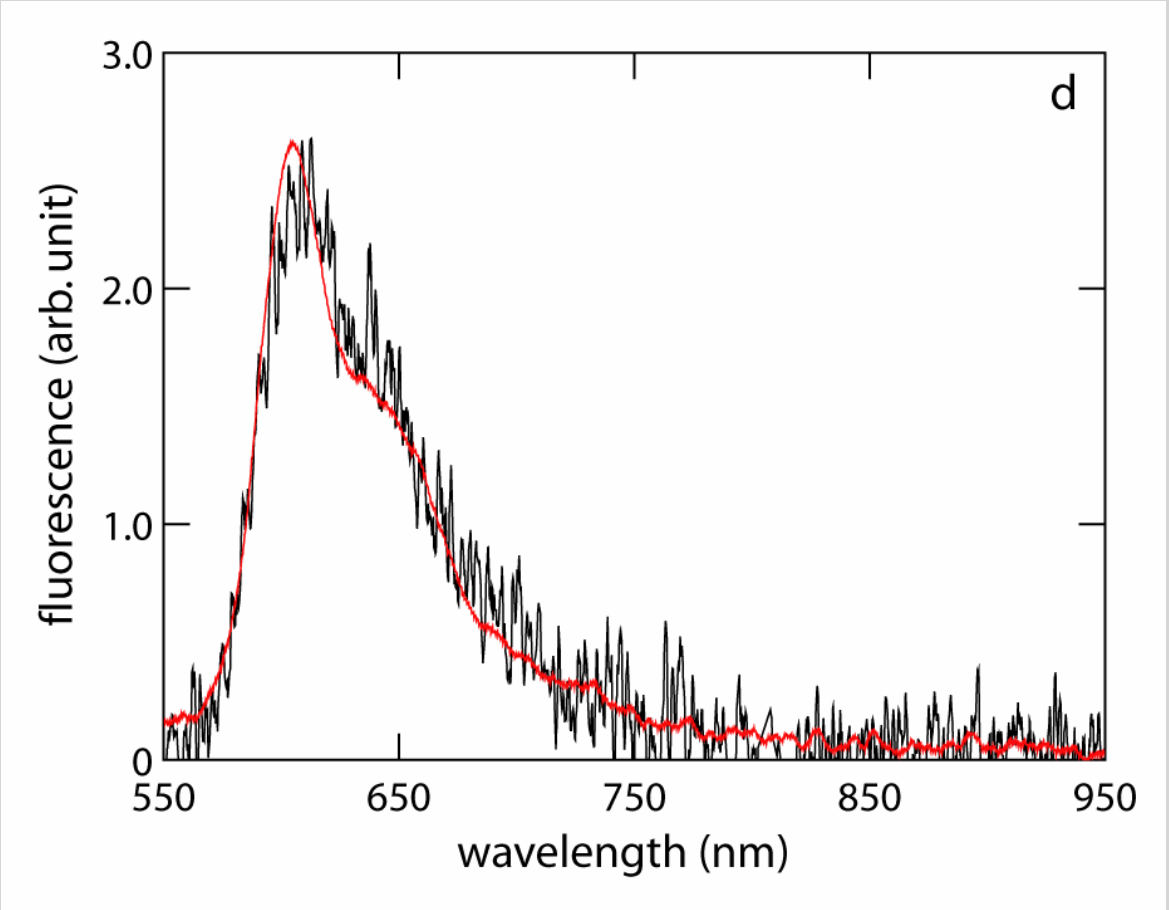
MEH-PPV: up to 1% by weight
laser power 40 mW



a - Scanning electron microscopy

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

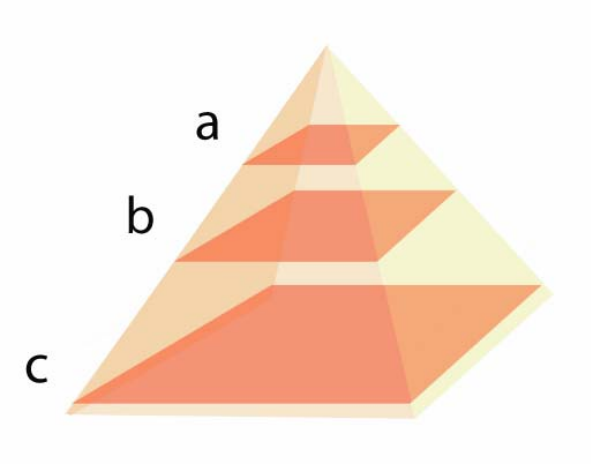
Microstructures containing MEH-PPV

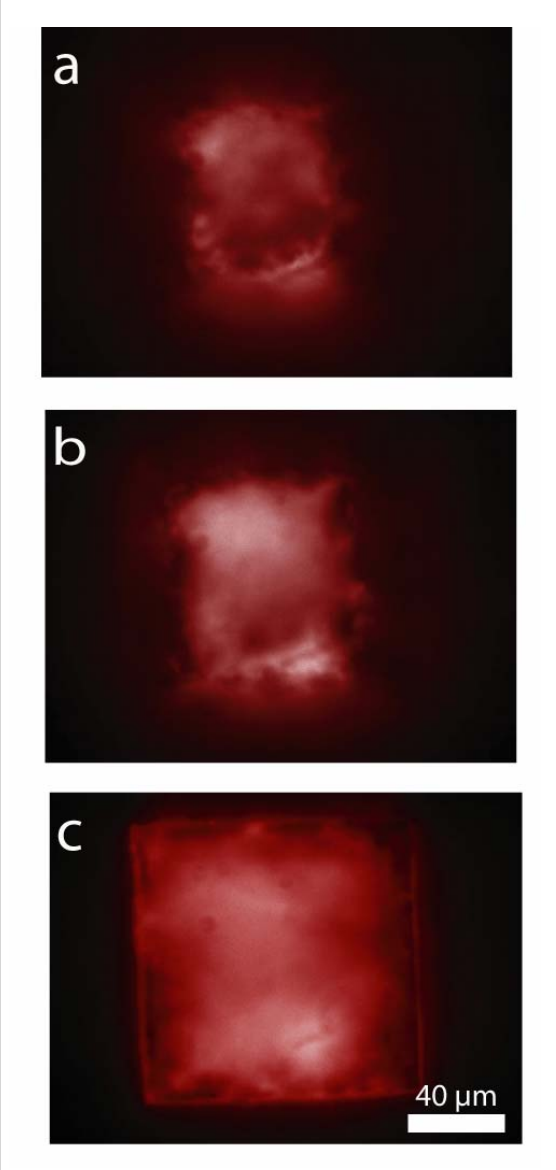


d - Emission of the microstructure (black line) and of a film with the same composition (red line)

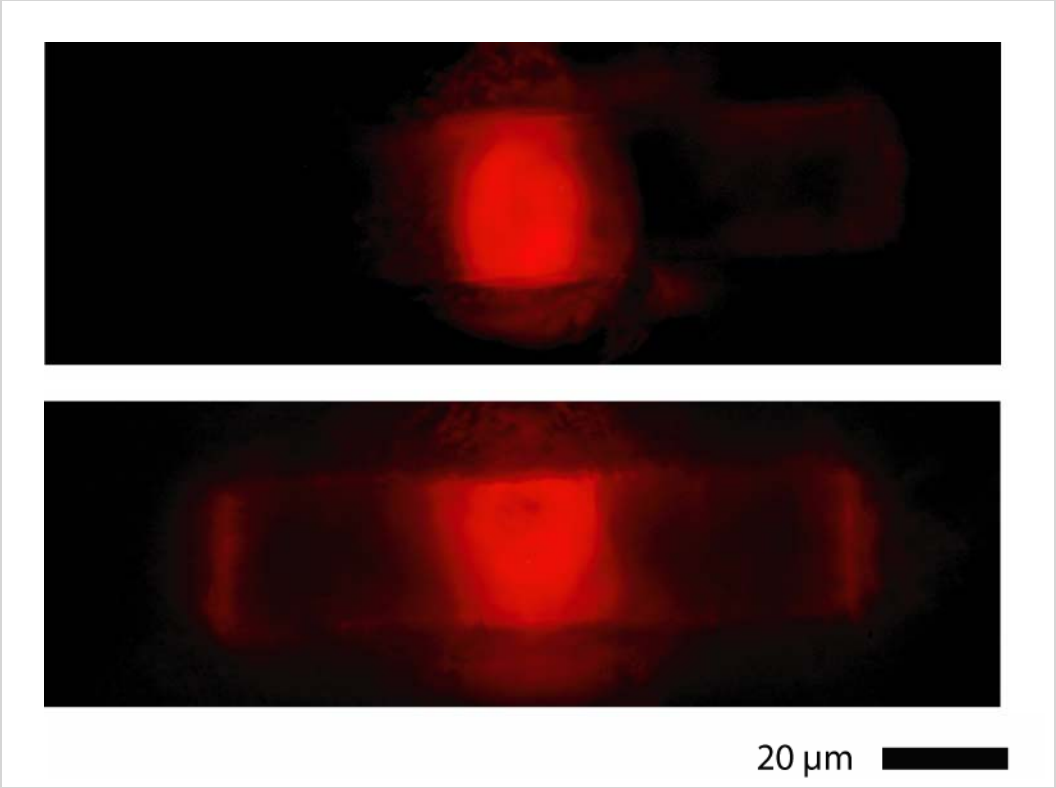
Microstructures containing MEH-PPV

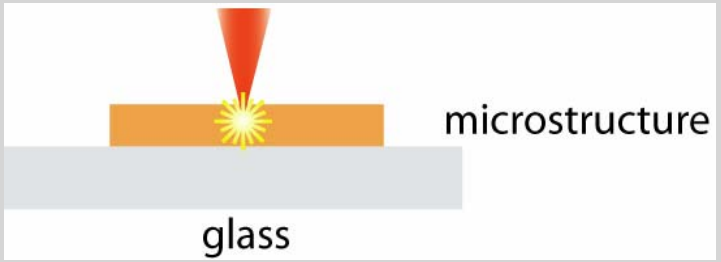
Fluorescent confocal microscopy images in planes separated by 16 μm in the pyramidal microstructure.

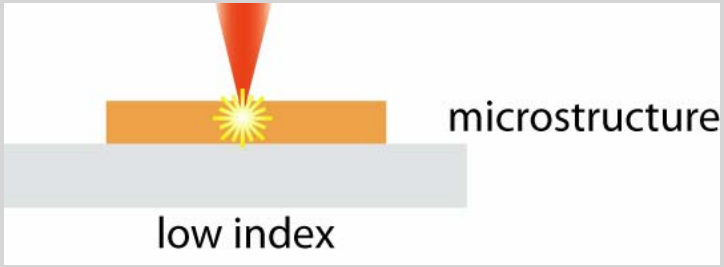




Microstructures containing MEH-PPV



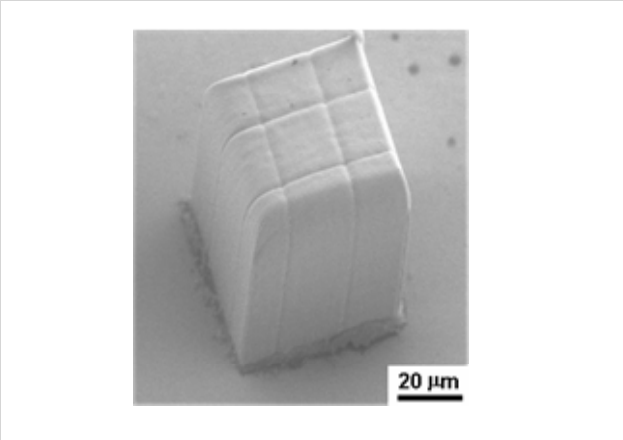


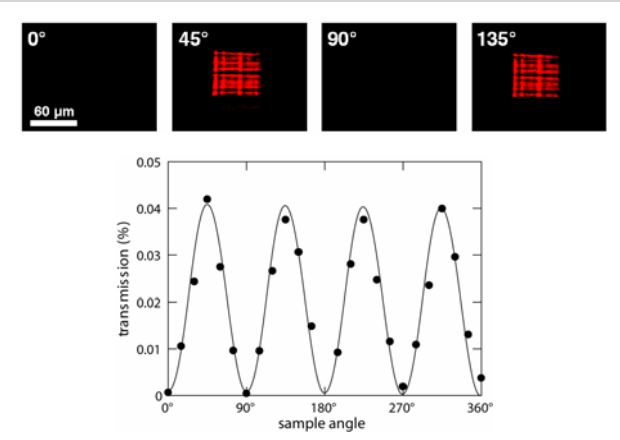


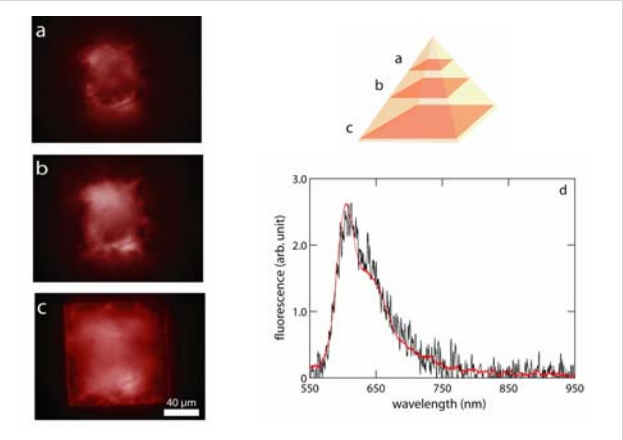
waveguiding of the microstructure fabricated on porous silica substrate (n= 1.185)

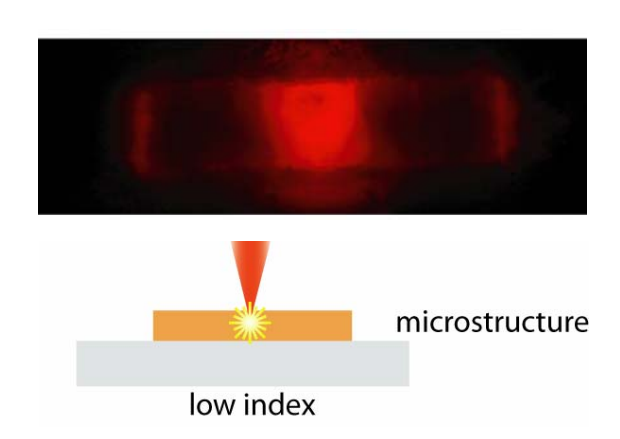
Applications: micro-laser; fluorescent microstructures; conductive microstructures

Summary


20 µm


0°
45°
90°
135°
60 µm
transmission (%)
0.05
0.04
0.03
0.02
0.01
0
0°
90°
180°
270°
360°
sample angle


a
b
c
40 µm
a
b
c
d
fluorescence (arb. unit)
3.0
2.0
1.0
0
550
650
750
850
950
wavelength (nm)


microstructure
low index

Acknowledgments

FAPESP
CAPES
CNPq

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