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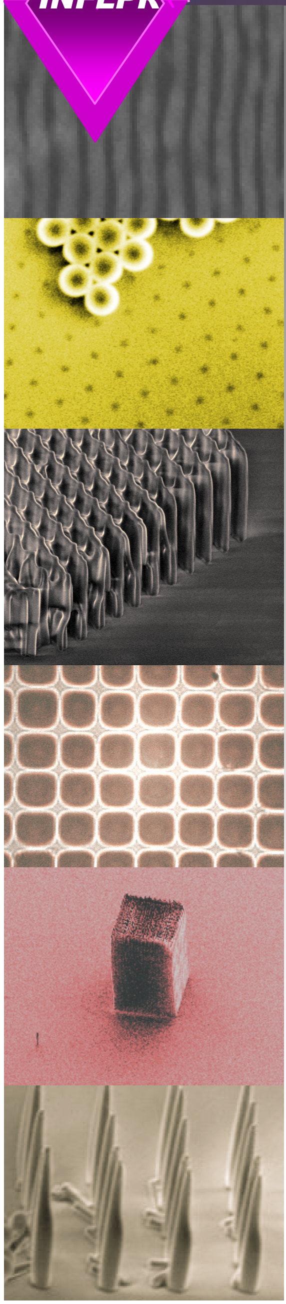

# 2D and 3D Geometries produced by Ultrashort Laser Pulses

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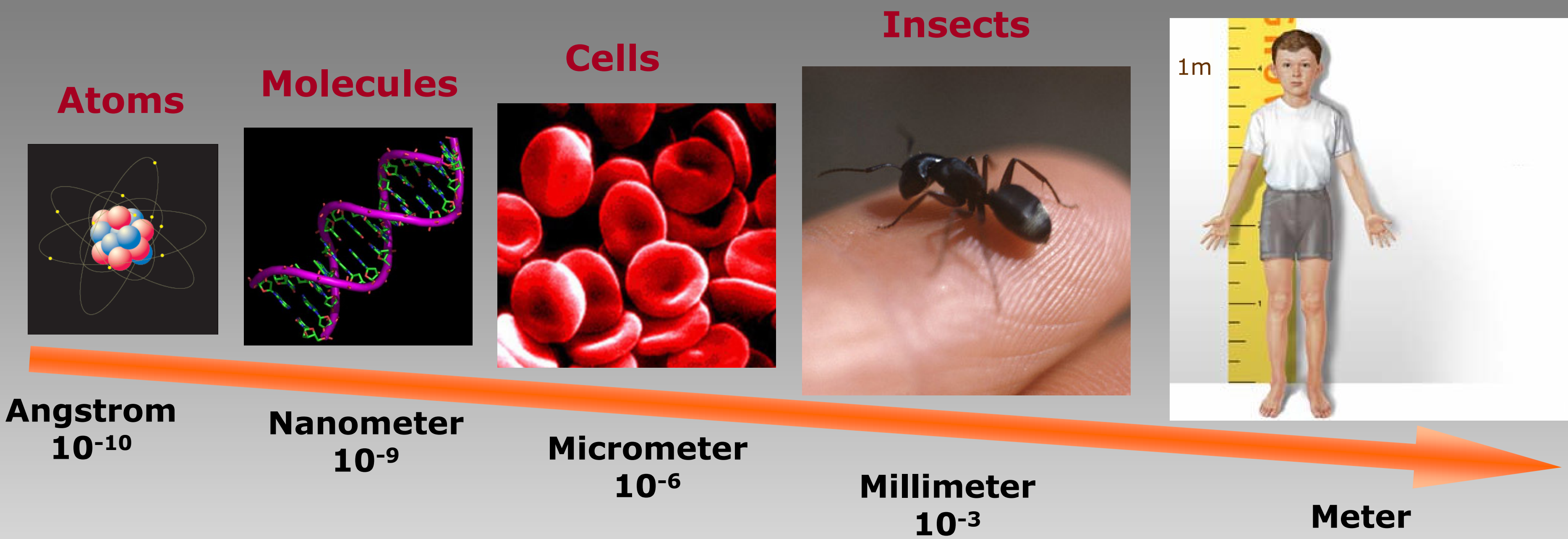
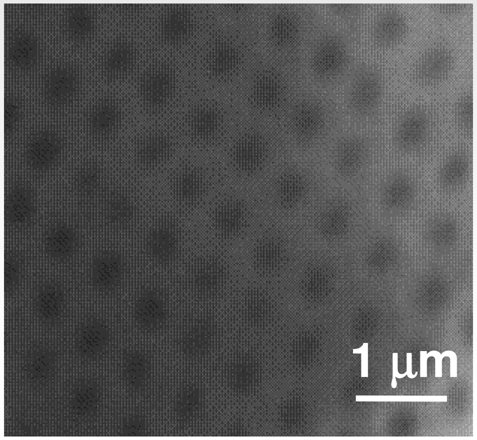
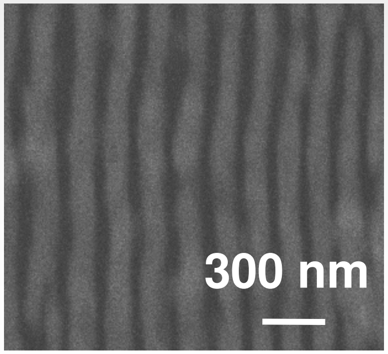
**http://ssll.inflpr.ro**

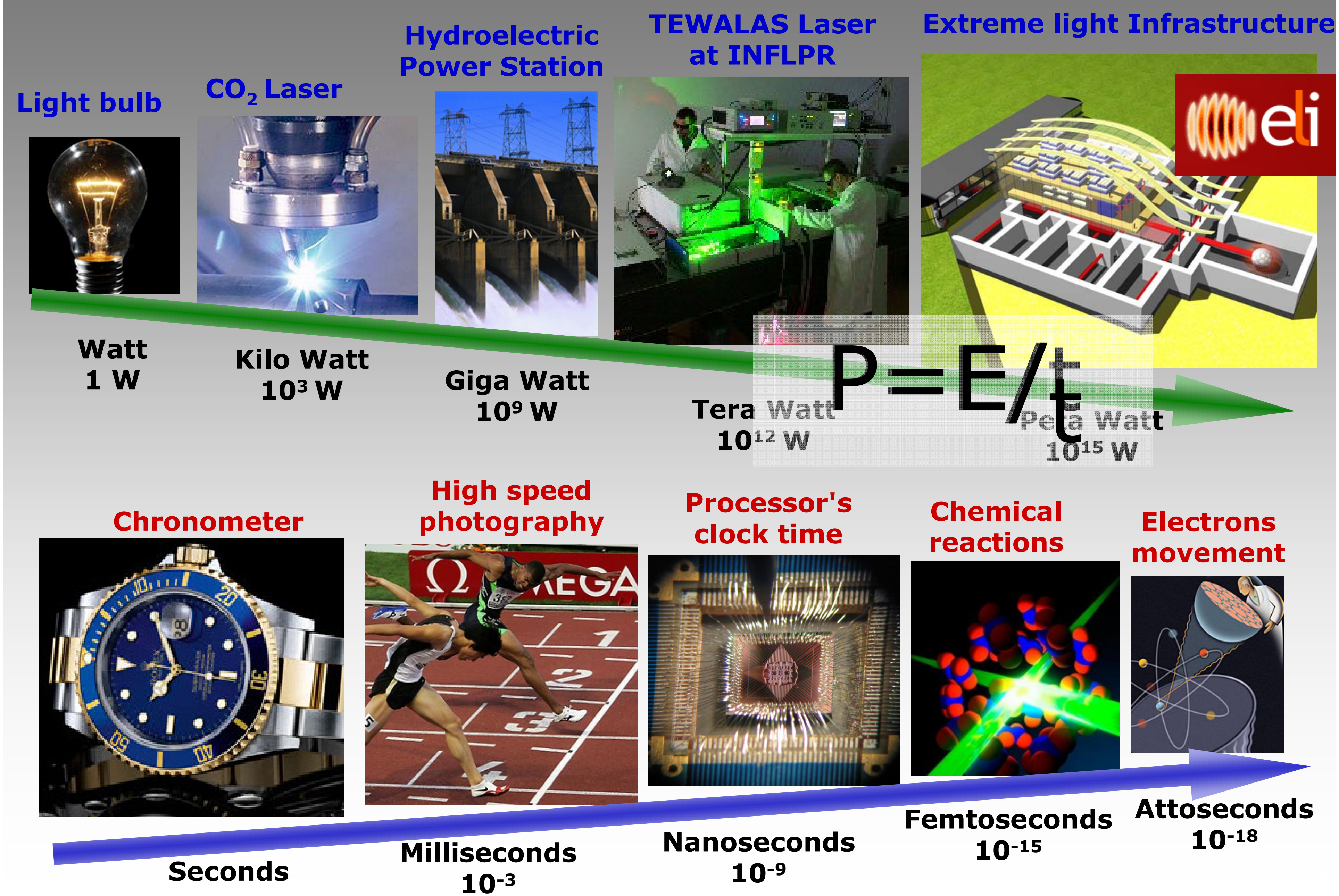



Nanostructures produced by laser



# Lasers with high power and ultrashort pulse duration



# Applications of femtosecond lasers

Low pulse energy (nJ)

- Dynamics of chemical reactions;
- High resolution laser scanning microscopy.

Medium pulse energy (mJ)

- laser microprocessing: laser ablation or photo-induced chemical reactions (material modification by nonlinear absorption);
- generation of THz radiation.

**Ultra intense laser beams (J)**

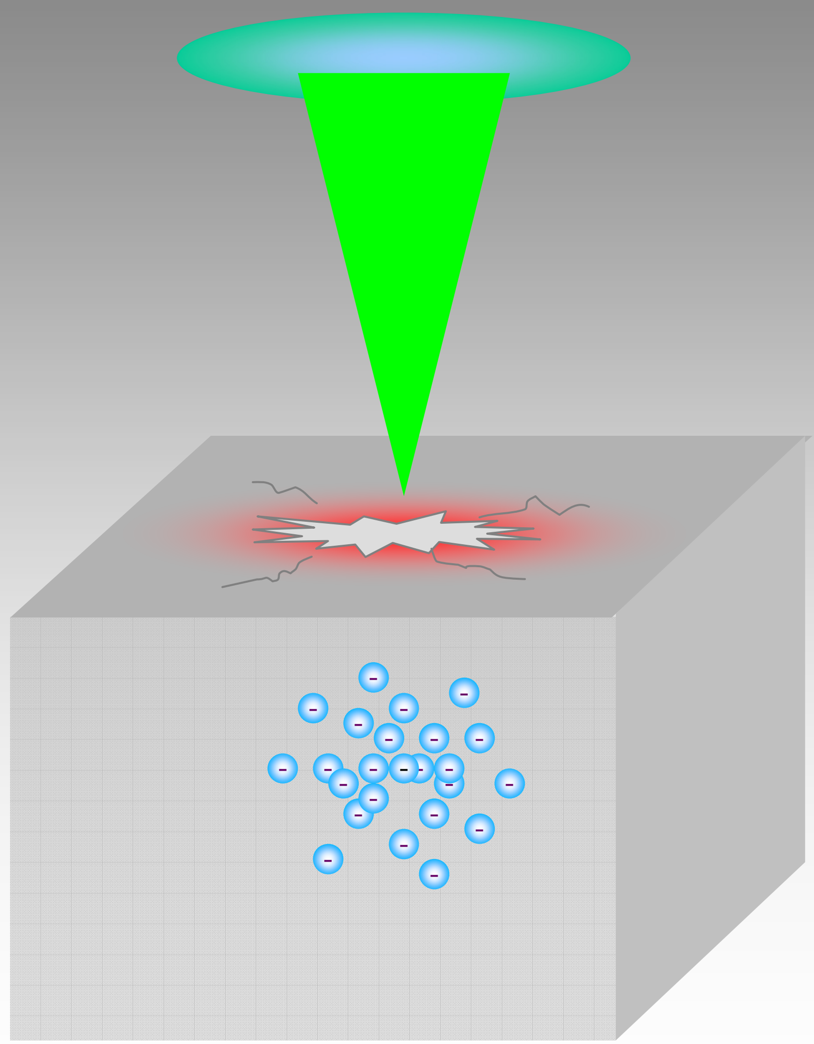
- **accelerated electron, X-Rays (TW lasers);**
- **protons beams, accelerated ions, Gamma rays (PW lasers**

# Microprocessing techniques with ultrashort lasers pulses

- **Laser ablation with sub-micrometer resolution**
- **Two-Photon Photopolymerization (TPP)**
- **Near-field laser lithography**
- **Laser Induced Forward Transfer (LIFT)**
- **Two-Photons Excited Spectroscopy (TPE)**

# Interaction of materials with intense laser beam

Long laser pulses (ns)



- Focused laser beam create free electrons in the irradiated material.

$$h\nu = E_g \quad \text{- linear absorption}$$

$$N \times h\nu = E_g \quad \text{- nonlinear absorption}$$

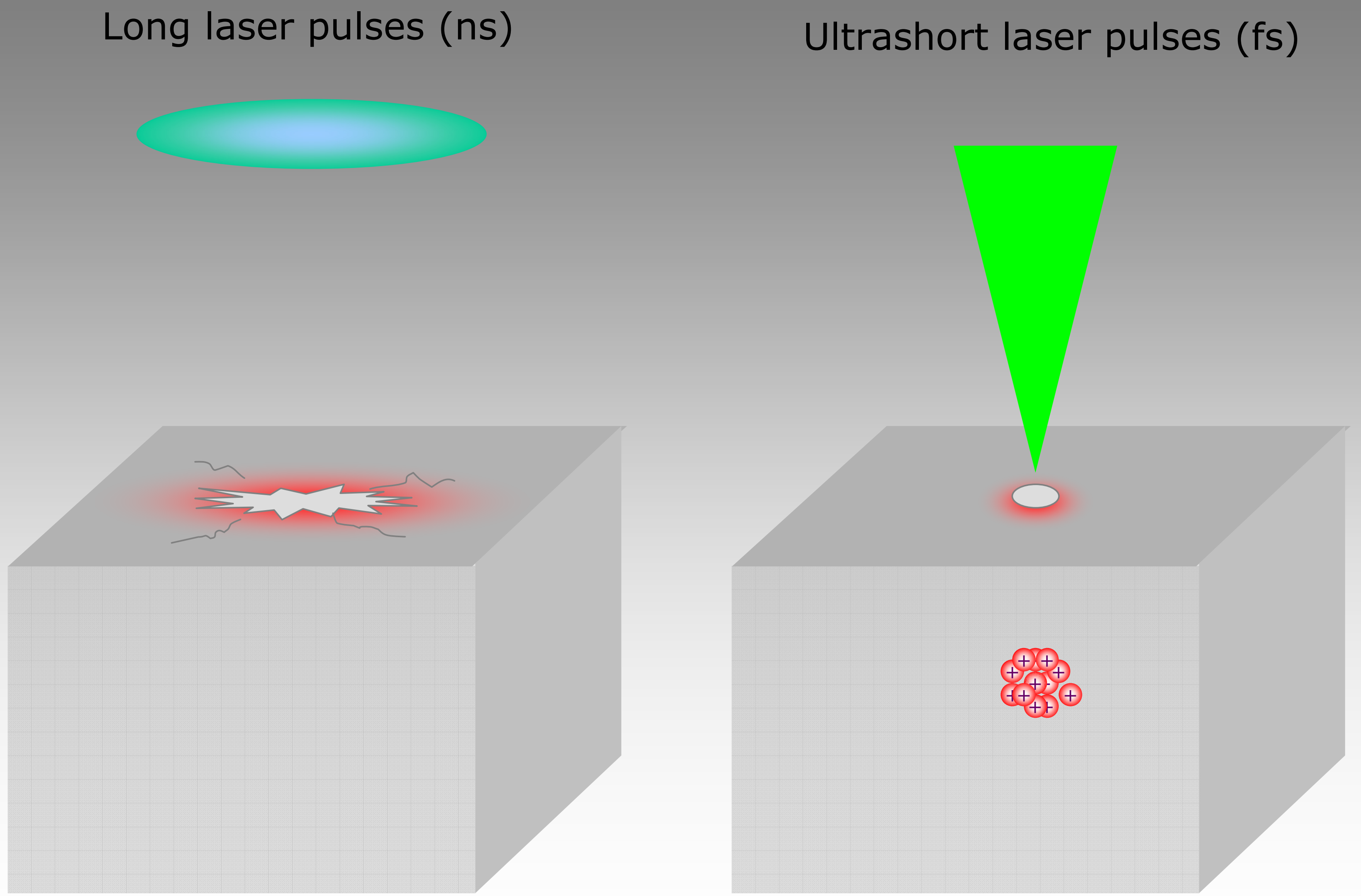
- The free electrons interact with the crystal lattice heating the irradiated area.

- At laser pulses longer than the thermal diffusion time a large area is heated around the irradiated spot.

- When the temperature of the material reaches the vaporization temperature, the material is locally removed from the target by vaporization.

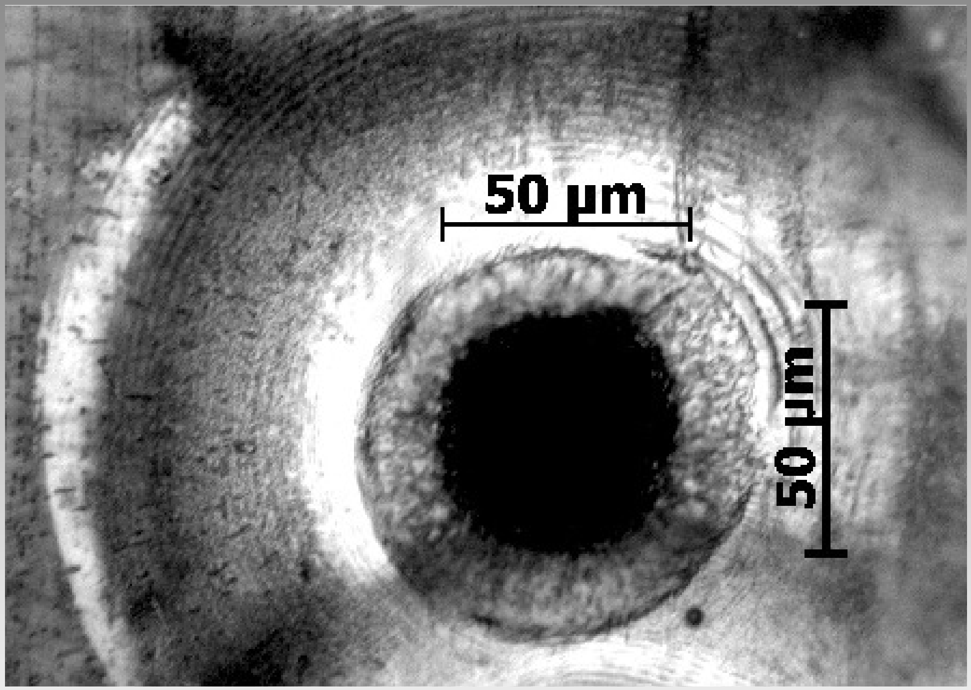
A crated is formed. The adjacent area is thermally affected resulting cracks and debris.

# Interaction of materials with intense laser beam

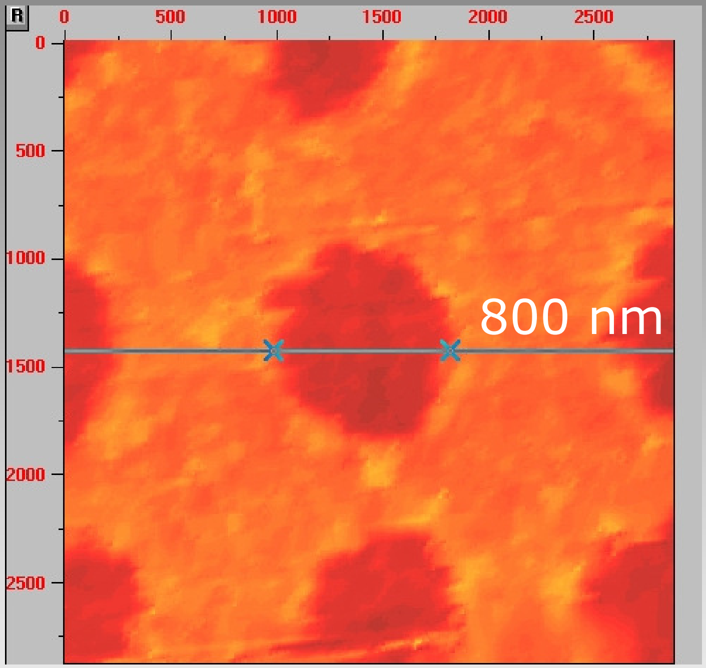


# Nanosecond versus femtosecond laser processing

**Laser processing with <u>ns</u> pulses**




**Laser processing with <u>fs</u> pulses**




**Long pulses:** The heat affected zone is much larger than the laser irradiated area.

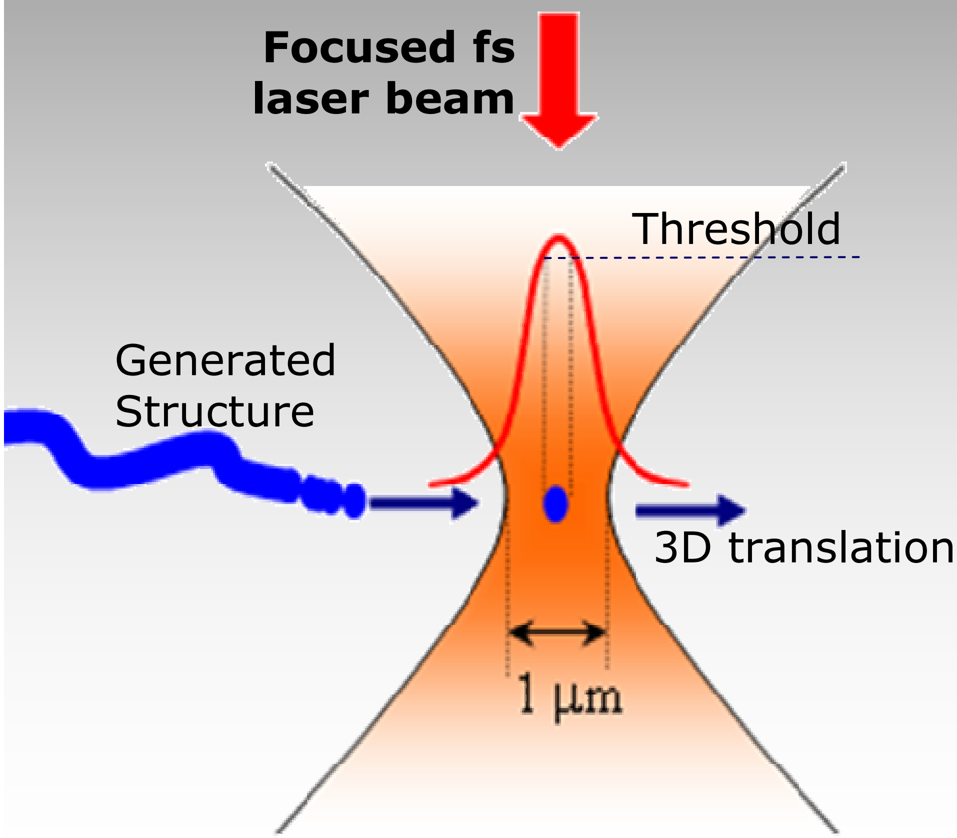
**Short pulses:** nonlinear absorption in the center of a focalized beam induces material modification at submicrometer size => micro and nanostructuring

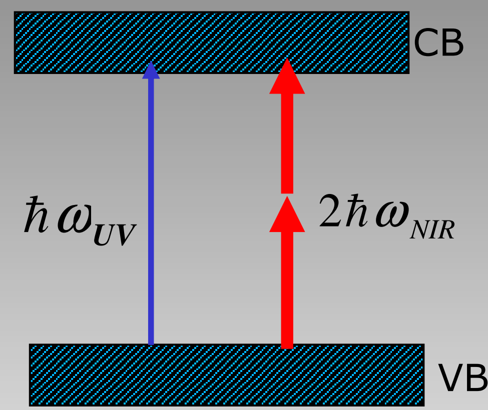
# How to overcome the diffraction limit by a femtosecond laser?

**Femtosecond laser beam easily induces nonlinear absorption in the center of a focused spot.**

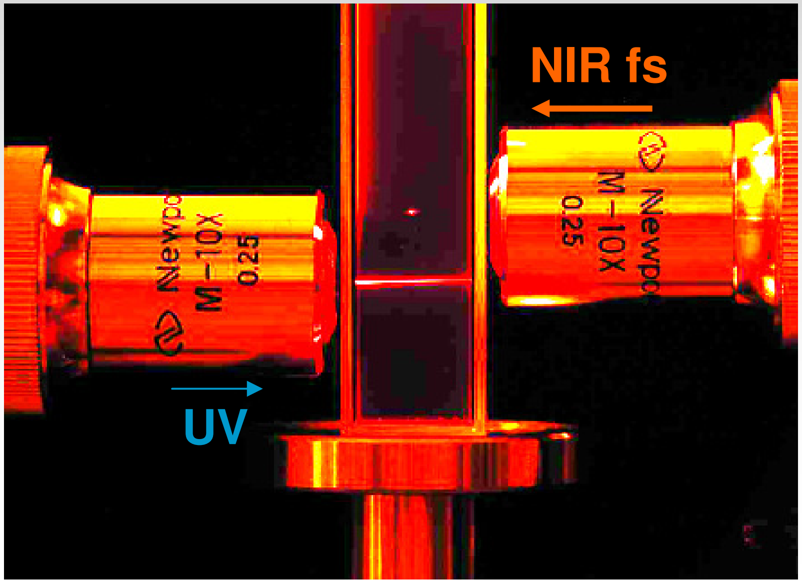
**Two-photons or multiphotons absorption:**

- *photochemical reaction (photopolymerization)*
- *glass densification (waveguide in glasses)*
- *laser ablation*

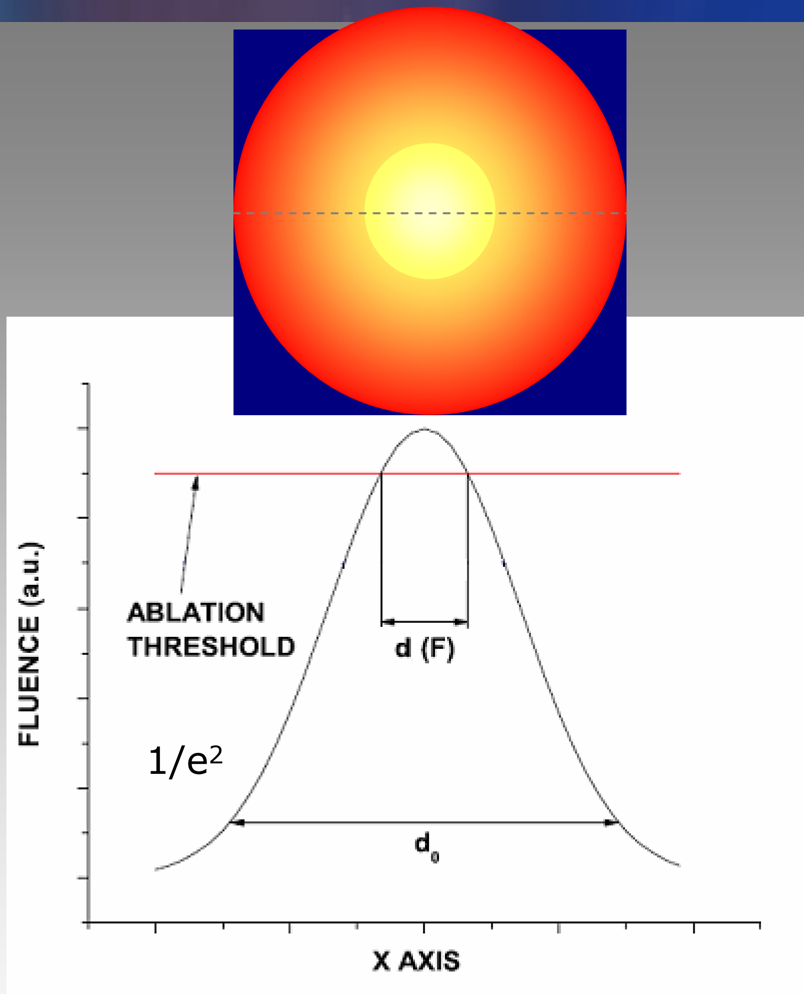



**NIR two-photon vs. UV absorption**



# Laser spot diameter vs ablated spot

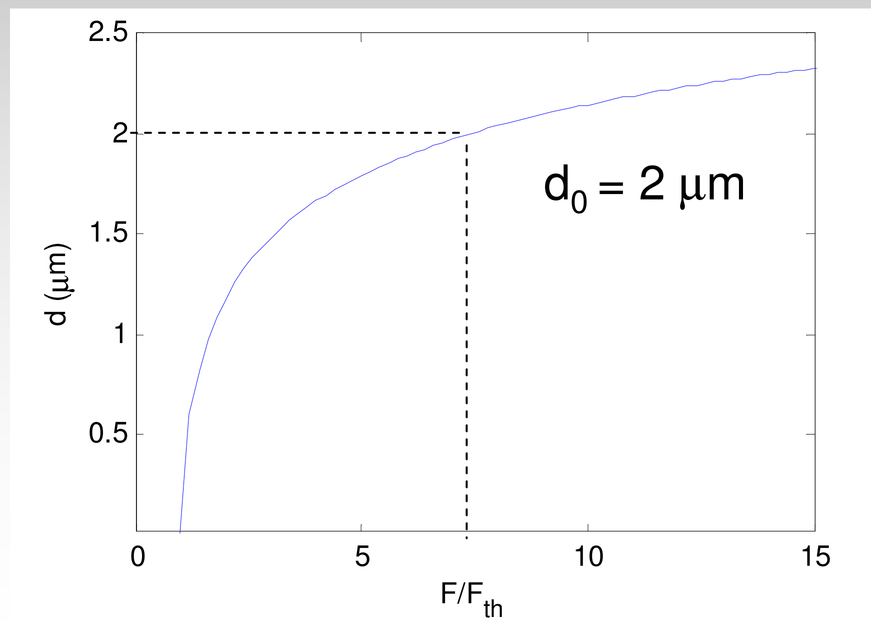



$$d_0 = \frac{2M^2\lambda}{\pi NA} \approx \frac{\lambda}{NA}$$

$d_0$ – minimum diameter of the focused laser beam

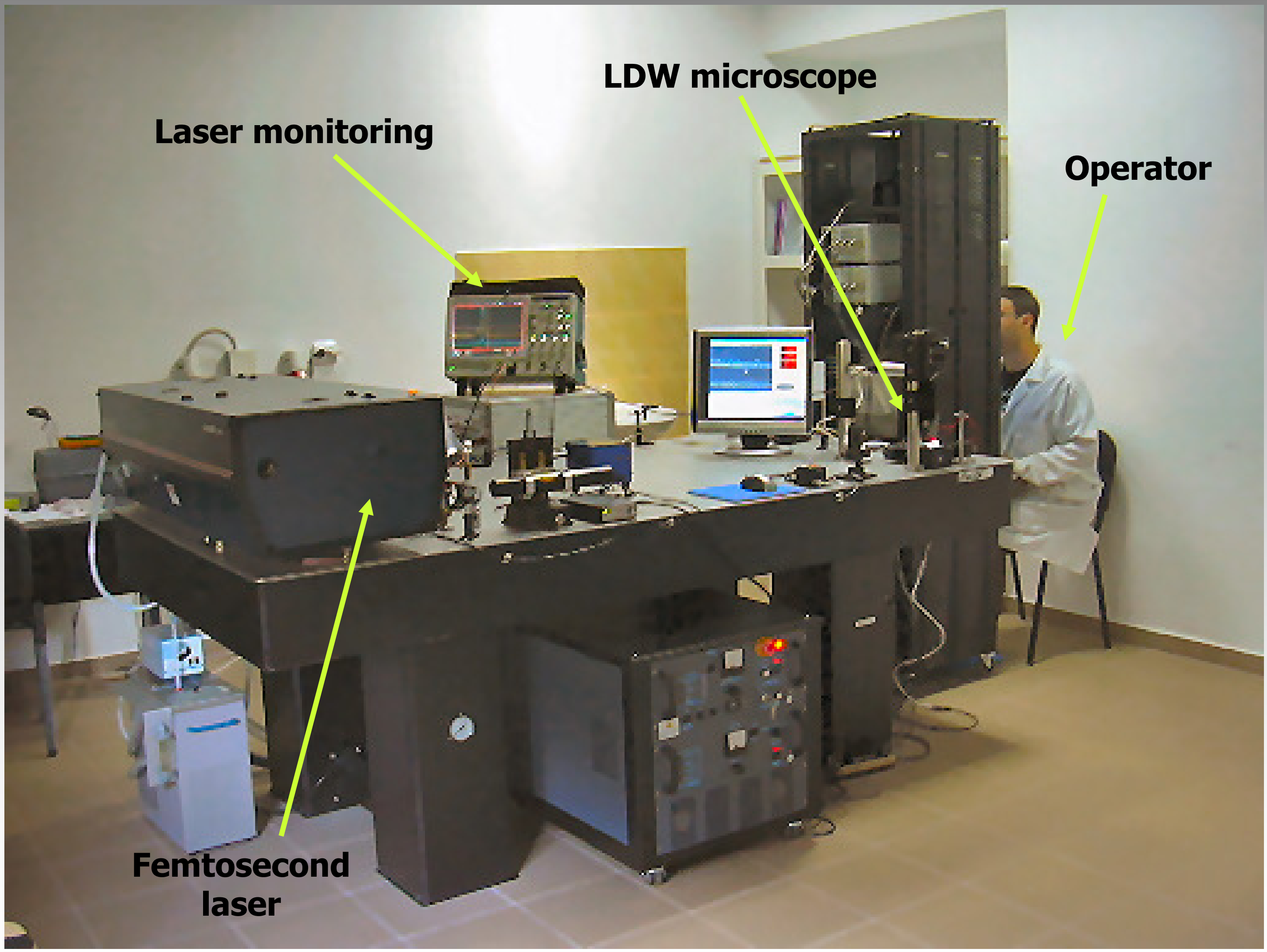
*NA* – numerical aperture

$$d(F) = \frac{d_0}{\sqrt{2}}\sqrt{\ln(F / F_{th})}$$

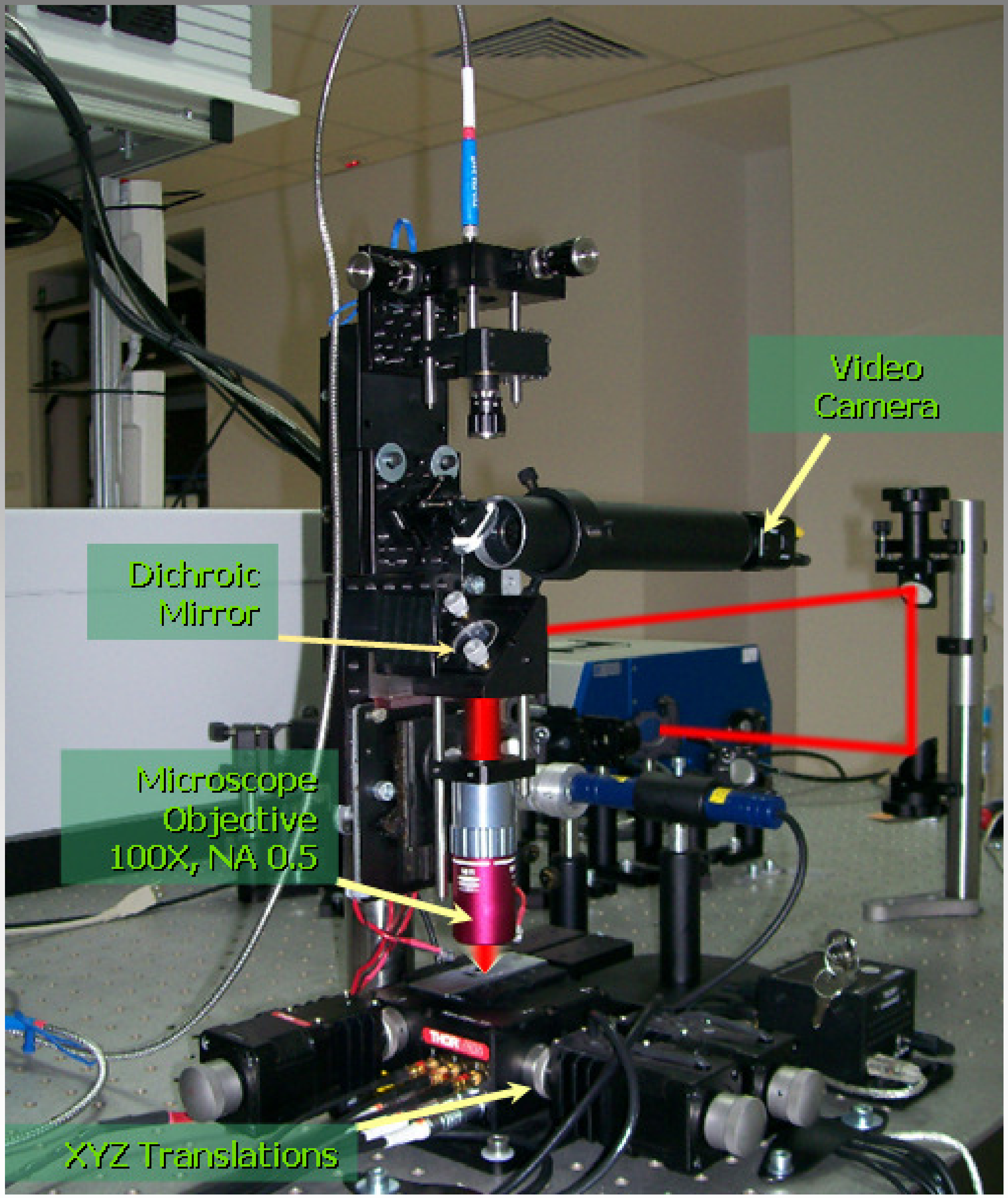



When the laser fluence (intensity) is kept just above the ablation threshold the material will be processed with precision under the diffraction limit.

# Laser Direct-Writing (LDW) with femtosecond laser



# Opto-mechanical system for micro/nano-structuring




Laser sources

- Clark MXR - CPA2101:
  - wavelength 775 nm ,
  - pulse duration 200 fs,
  - repetition rate 2KHz ;
- Femtolasers – Synergy Pro:
  - 790 nm, 20 fs, 75 MHz .
- Specta Physics – Tsunami:
  - 750-850 nm, 80 fs, 80MHz ;

Translation system XYZ

- stepper: 4x4x4 $mm^3$ or 50x50x25 $mm^3$.
  - precision 400 nm.
- piezo: 20x20x20 $\mu m^3$

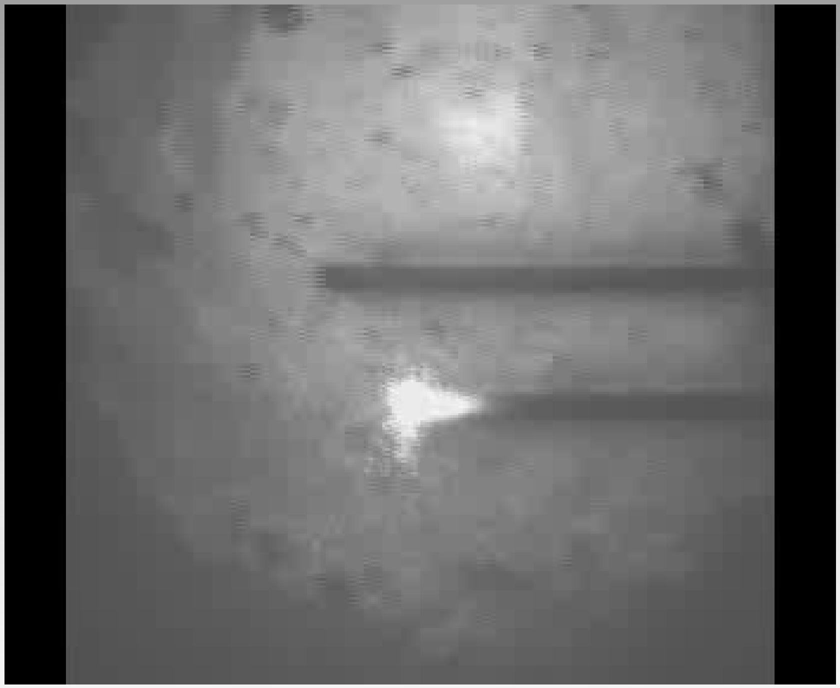
Focusing optics

- 10X to 100X
- NA from 0.2 to 1.4 (immersion oil).

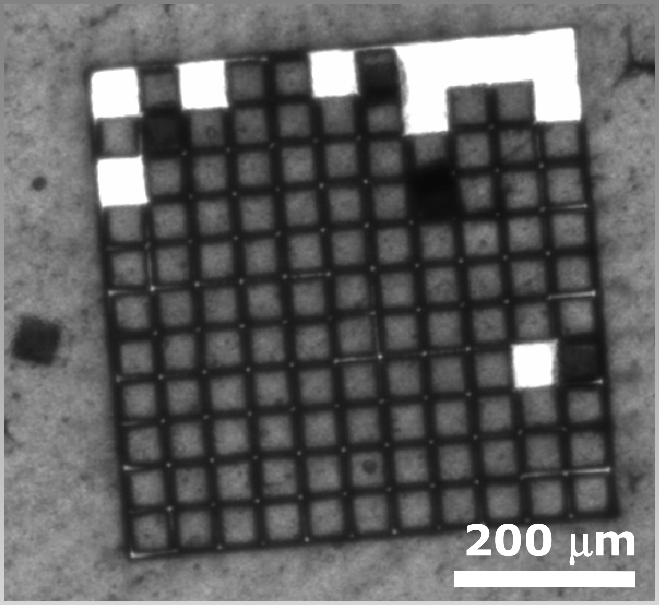
Visualization

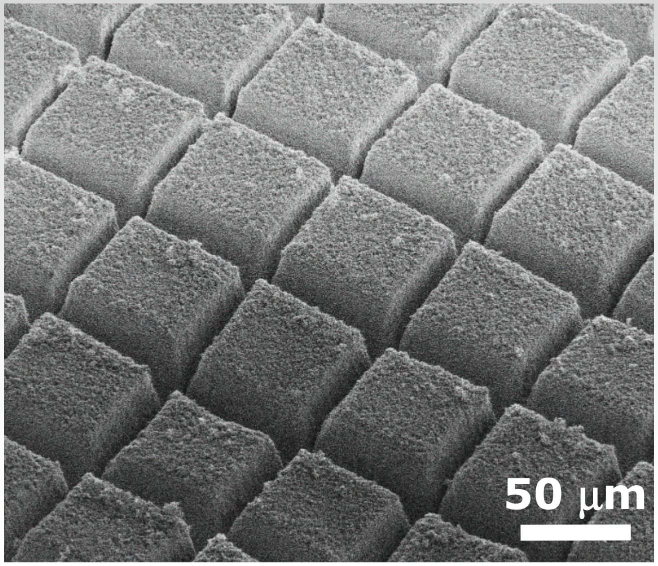
- CCD camera 768 x 494 pixels.
- image rezolution < 1 $\mu$m

# Microstructures fabricated by femtosecond laser ablation

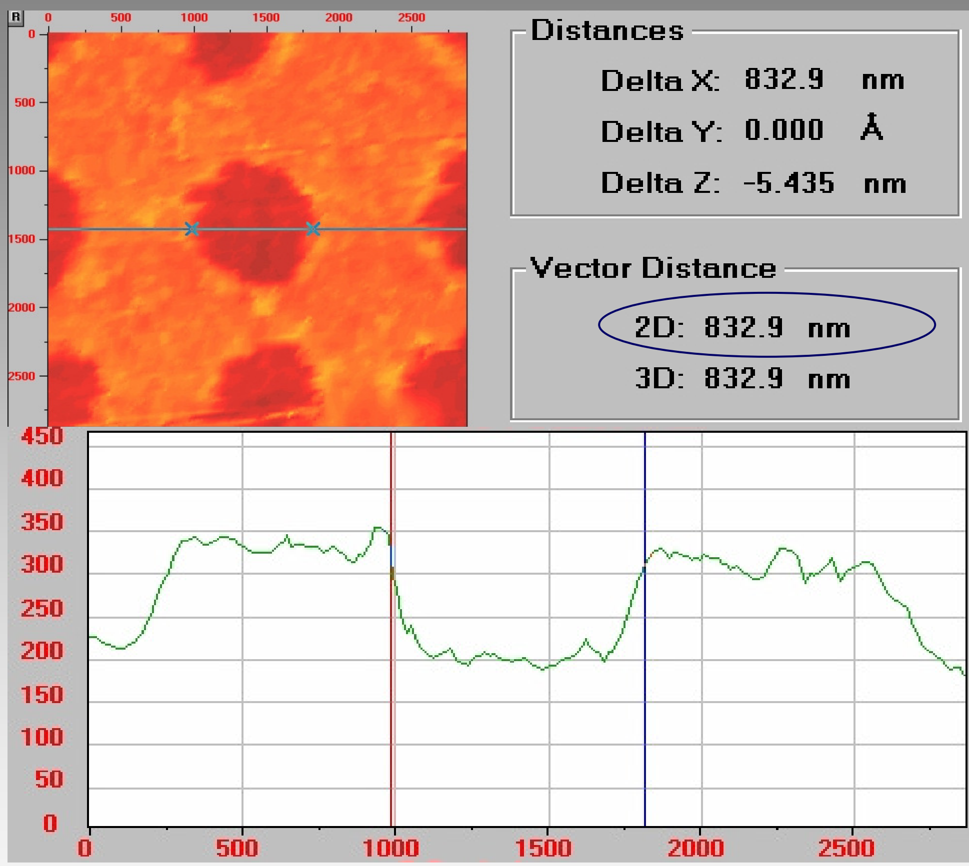


Laser ablation of alumina target
(100 μm thickness)



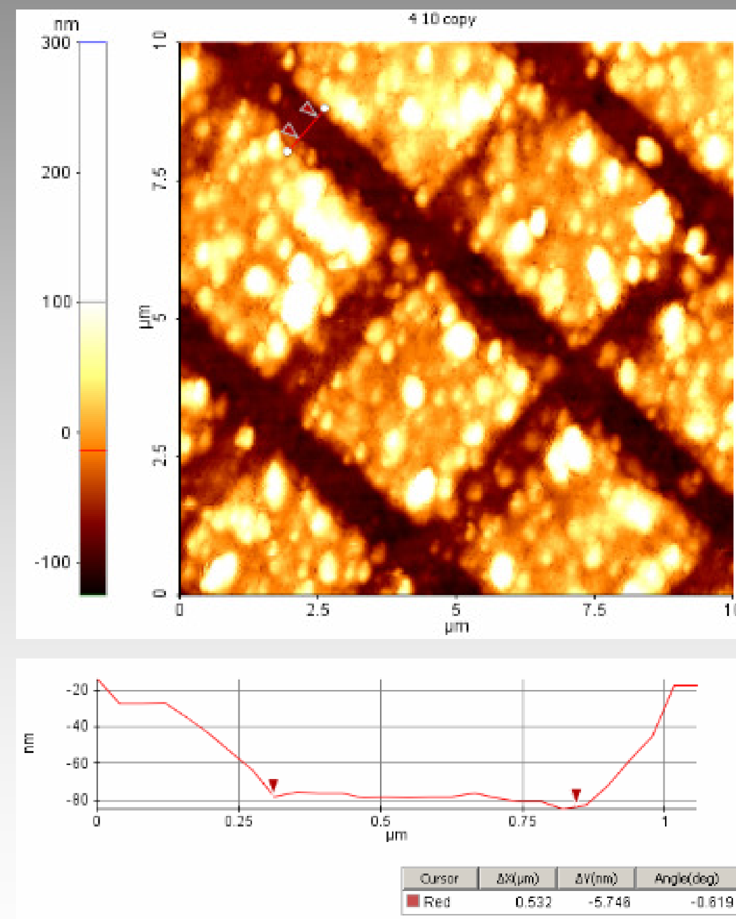



# Laser ablation with sub-micrometer resolution

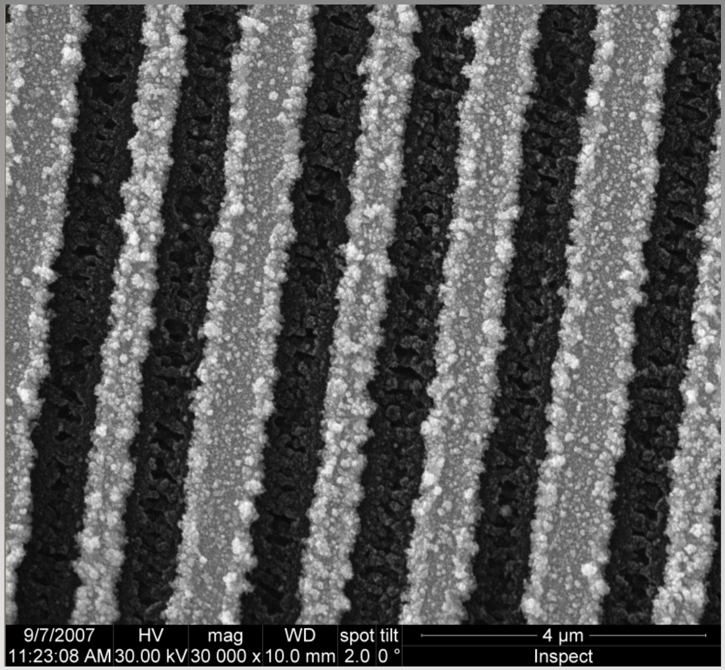


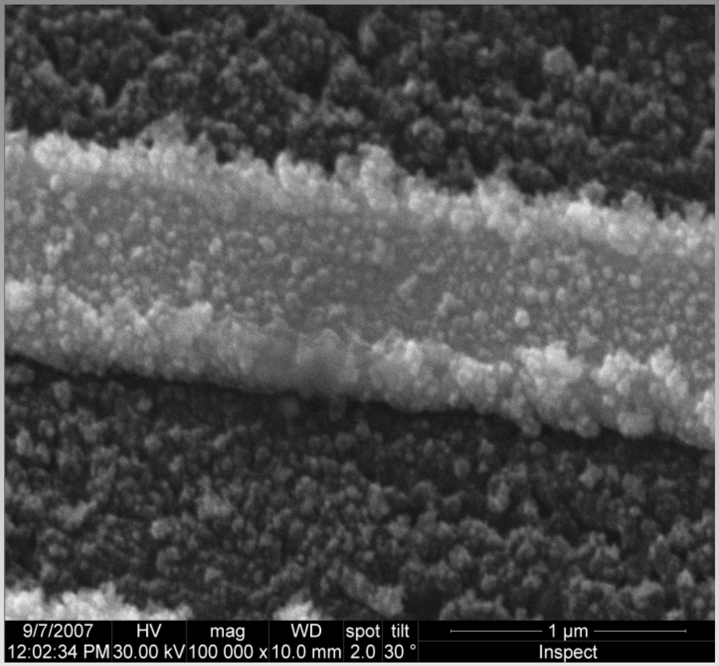

Laser ablated holes on gold film 100 nm.
Diameter ~ 830 nm.

Structures on Co/Cu/Co films
Grooves width < 500 nm



# Laser ablation with sub-micrometer resolution

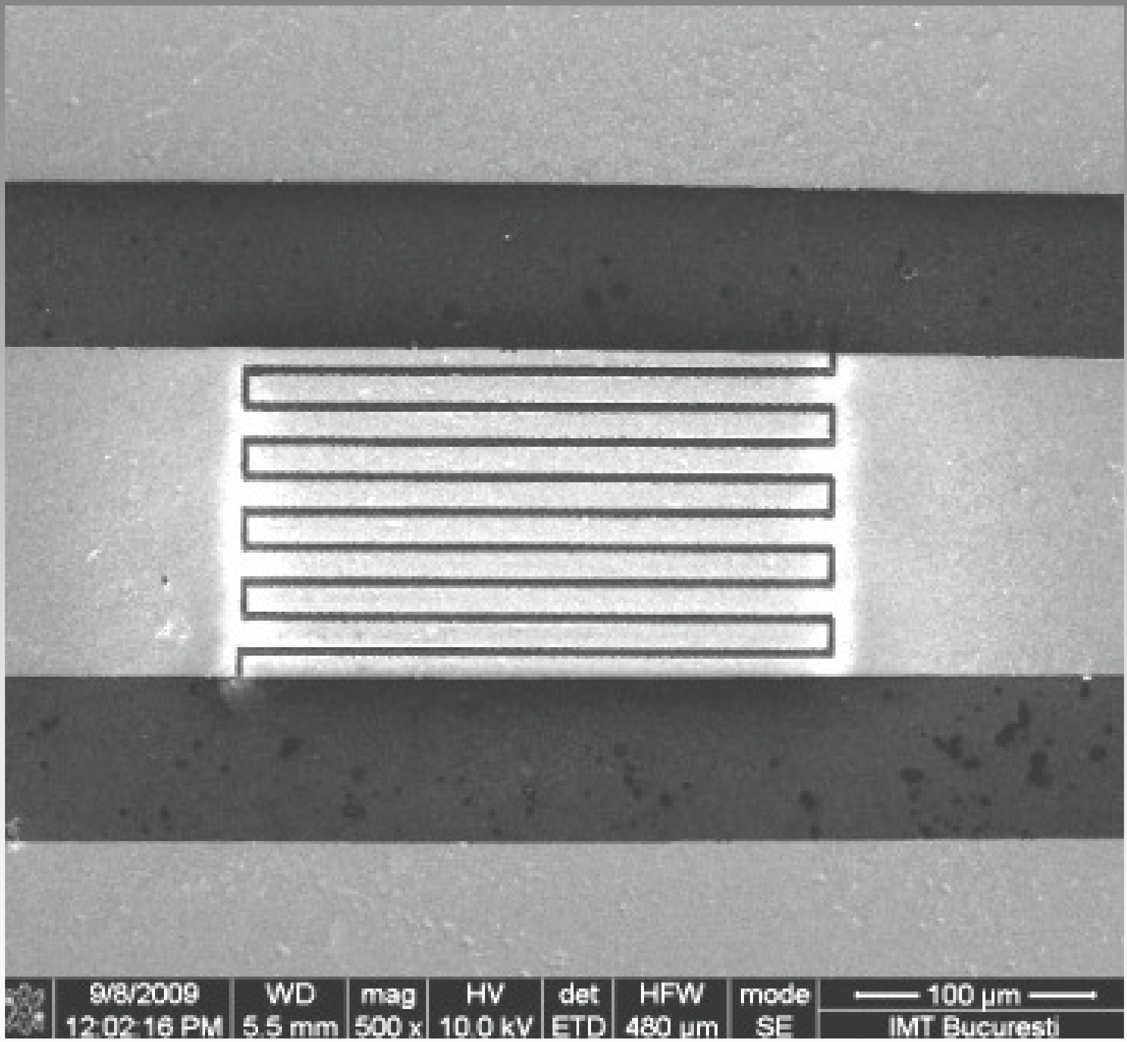



100 nm gold thin-film deposited on glass. Structures period of 2 µm. Laser wavelength 775 nm, duration 200 fs.

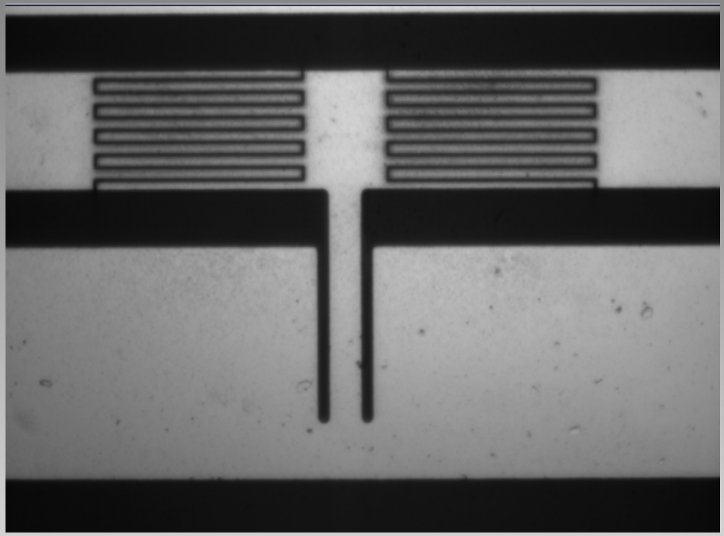
Structures such as interdigital capacitors, electrodes for micro-sensors, etc. can be produced by laser ablation on metallic films, semiconductors, or ceramics usually difficult to be processed by chemical etching.

# Interdigital capacitors fabricated by femtosecond laser

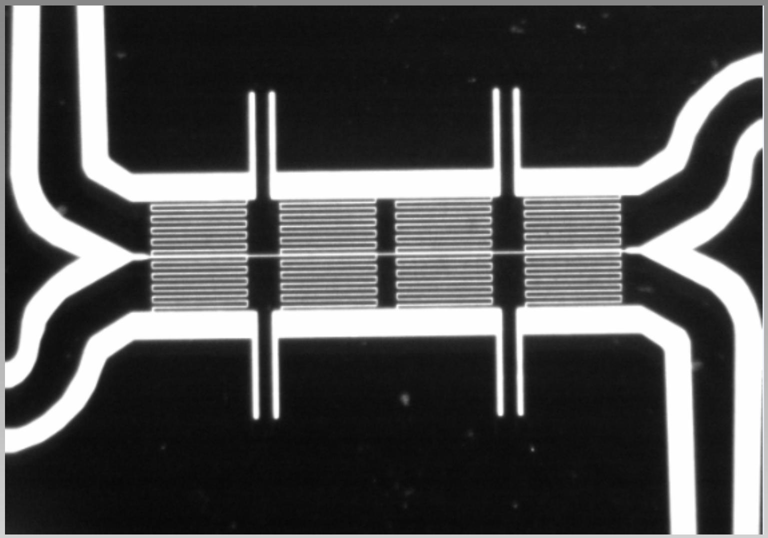


# Microwave devices fabricated by femtosecond laser ablation

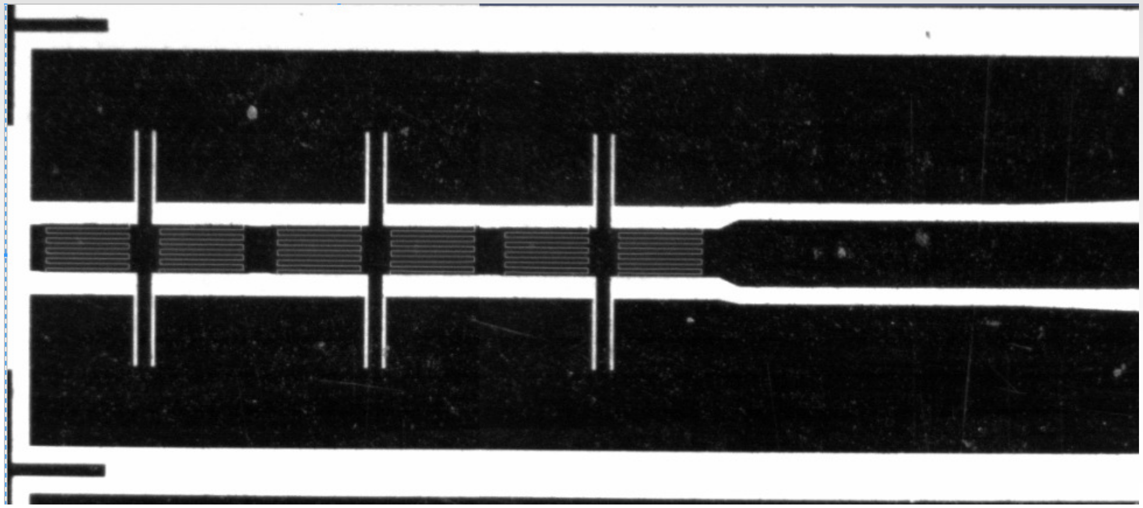
Pass-Band Filter



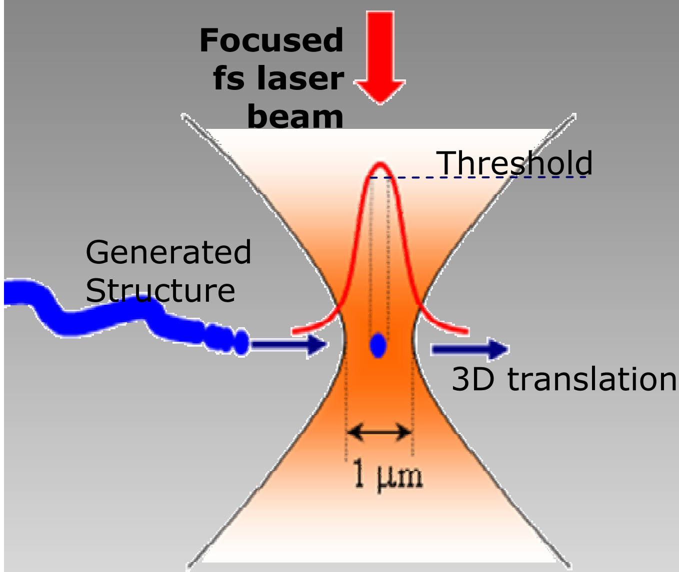
Directional coupler

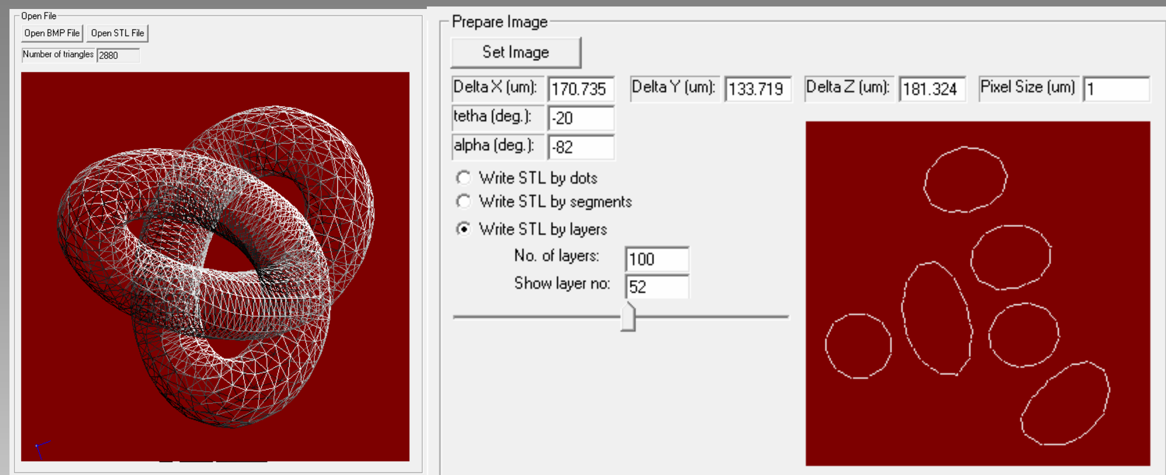


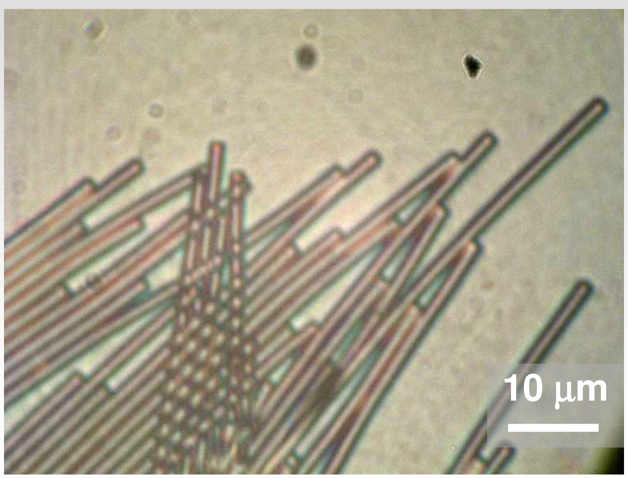
Microwave antenna

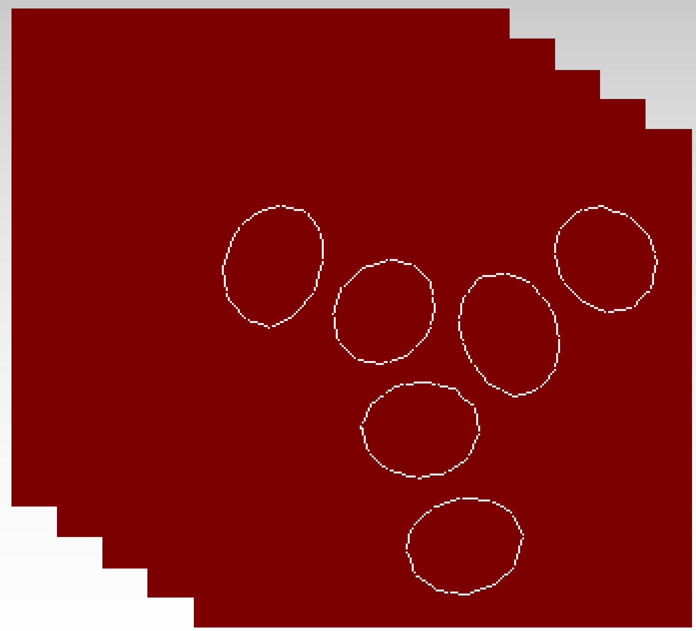


# Direct Laser Writing in photopolymers: 3D micro-lithography



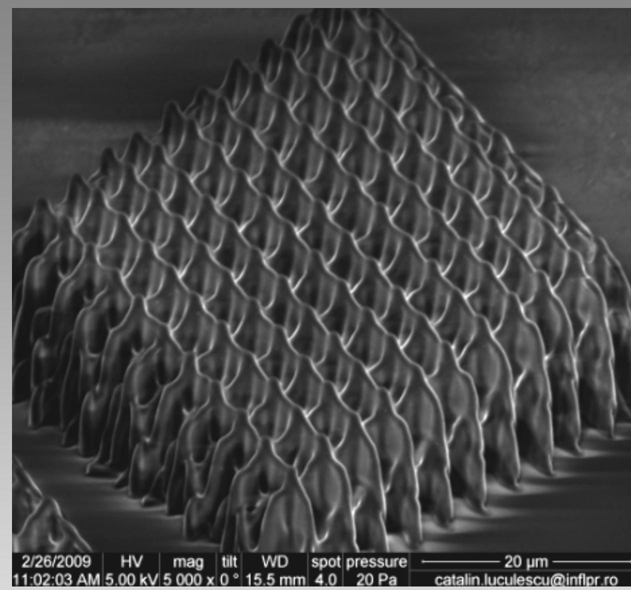
# Microstructures produced by TPP in photopolymers

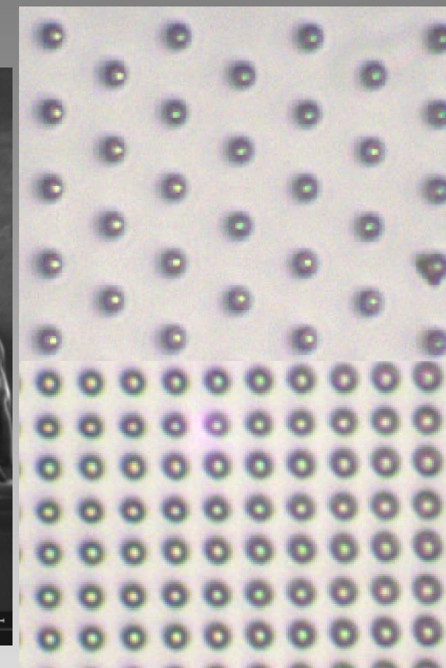
SU-8, ORMOCERs, ORMOSIL, PMMA

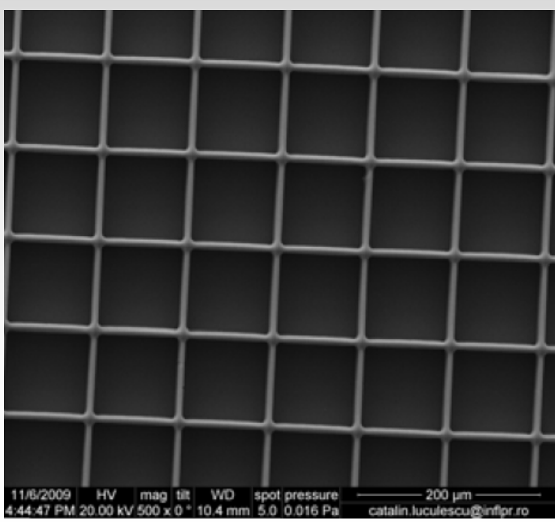
Applications :

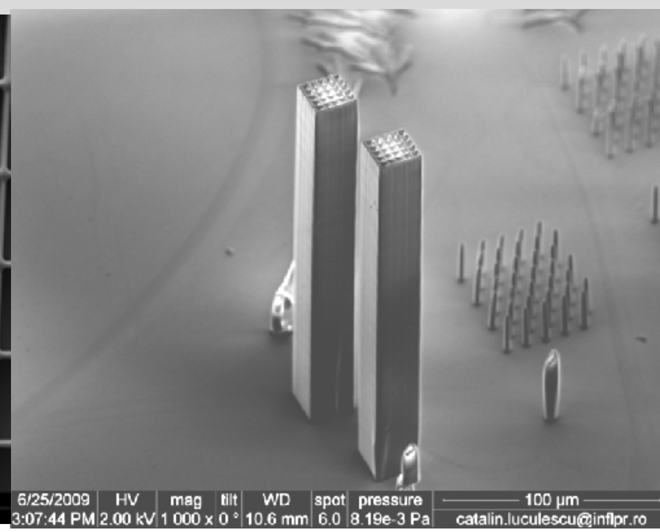
- Micro-optics components:
  microlenses, photonic crystals, waveguides, optical couplers;
- OCT calibration samples;
- Biocompatible microstructures;
- Micro-fluidics.

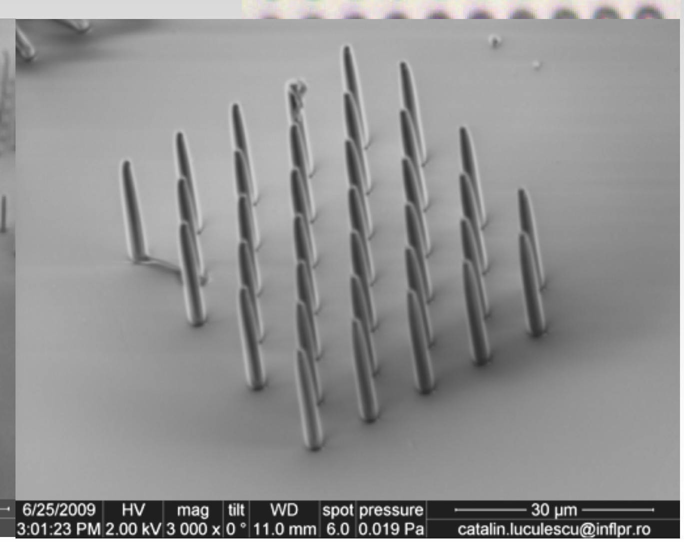
*F. Jipa et al., J. Optoel. Adv. Mat. 2010.*



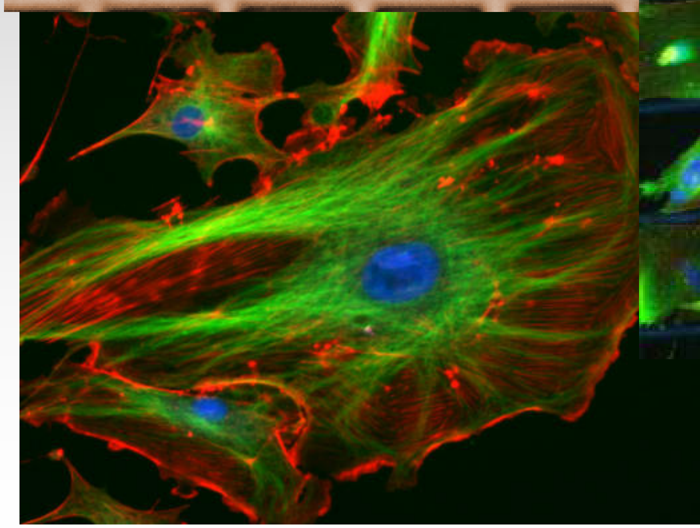


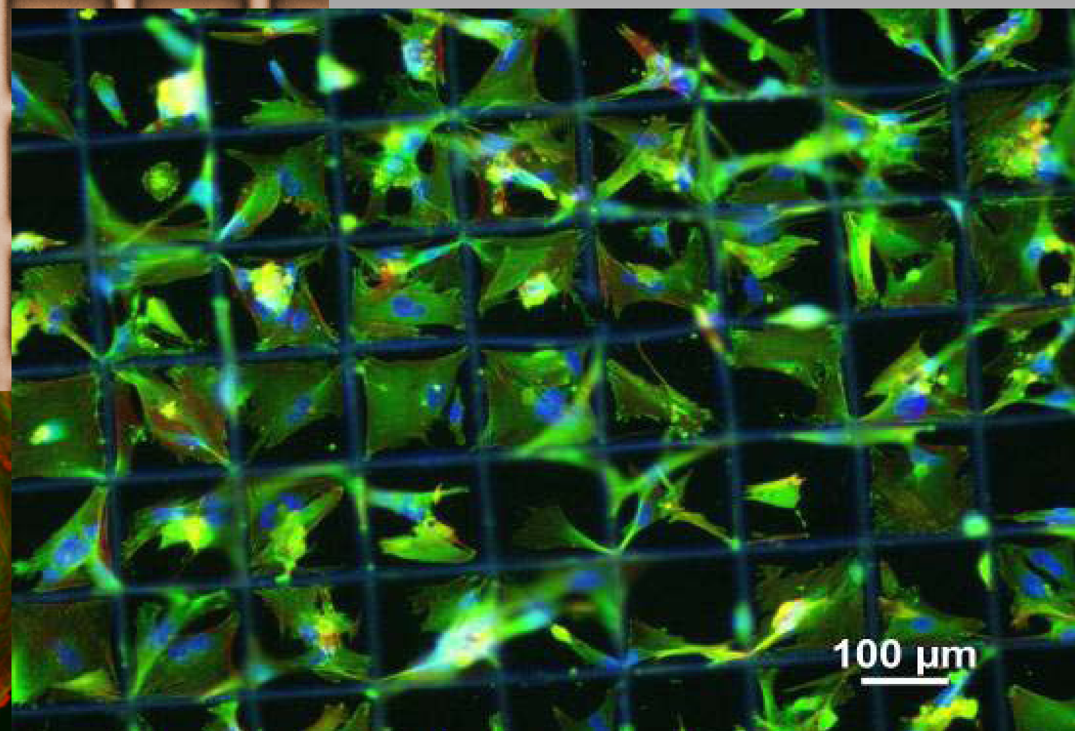



# Applications of 3D TPP in Life Sciences

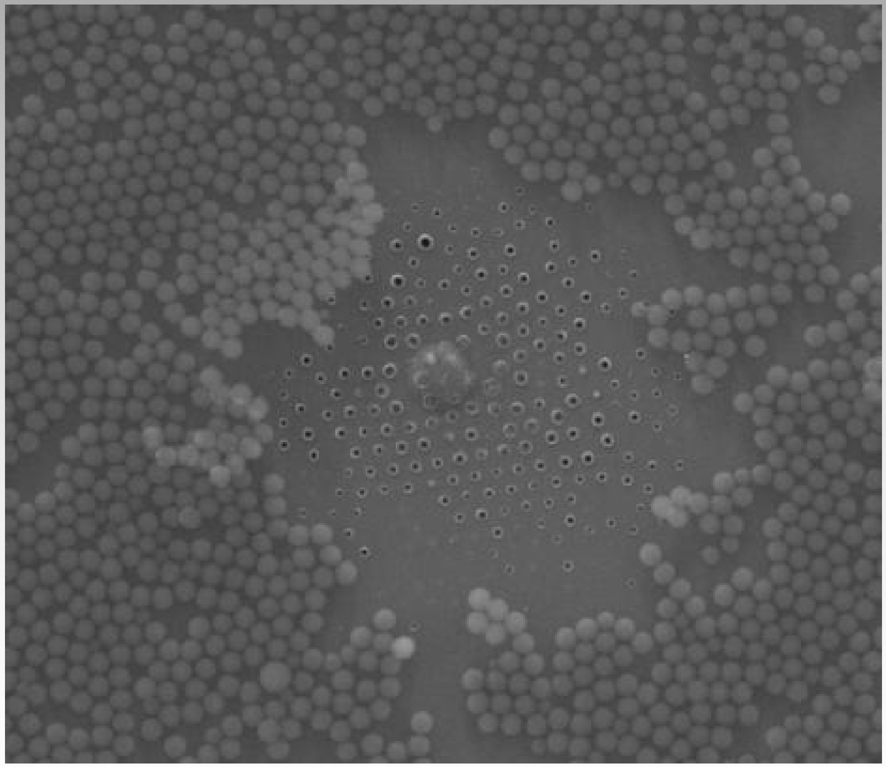
**Scaffolds for live cells**

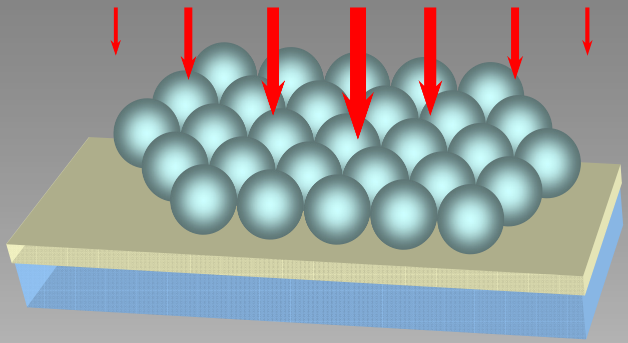




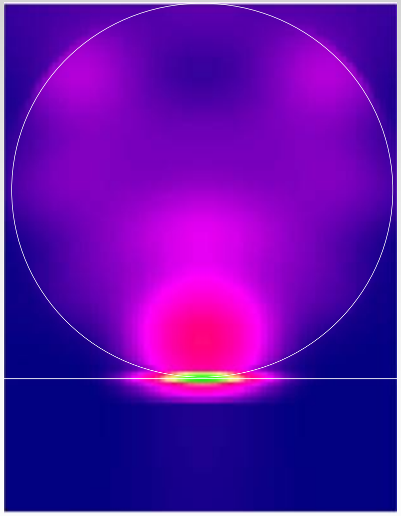
# Near-field laser lithography on colloidal nanoparticles

The field enhancement at the interface of a monolayer of colloidal nanoparticles with a solid substrate produces nanoholes by laser ablation.





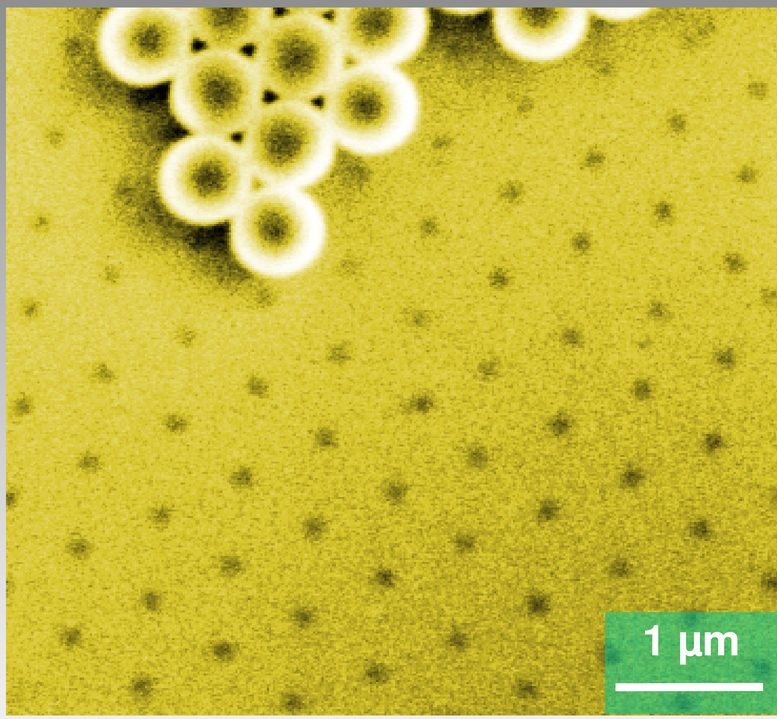
700 nm diameter Silica spheres deposited on glass substrate with an intermediate 50 nm thick gold layer.



*M. Ulmeanu et al., J.Appl.Phys. 2009*

# Structures obtained by near-field laser ablation

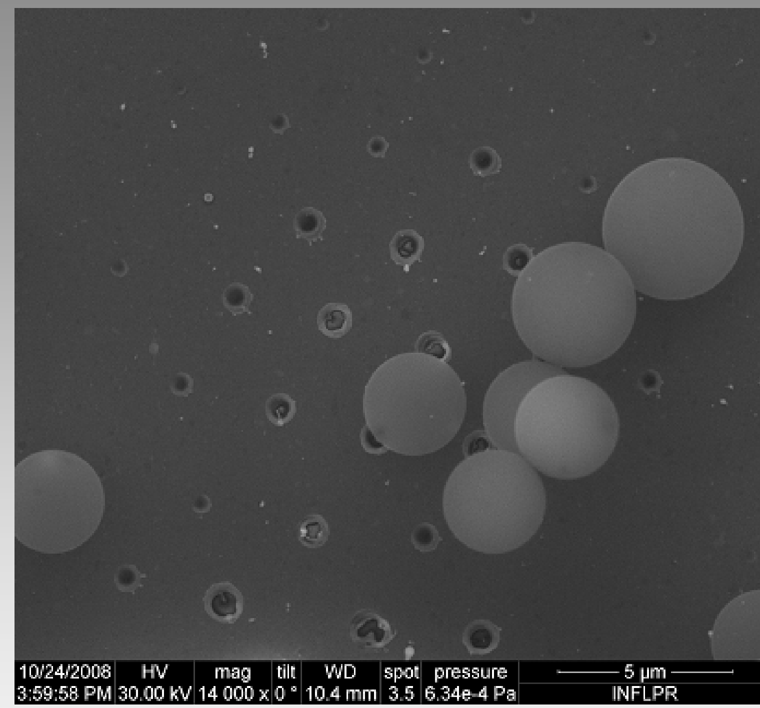
Glass substrate




Laser fluence 6 $J/cm^2$

Laser **532 nm**, 450 ps
Spheres dimension: **700 nm**
Structure dimension : ~**110 nm**

Gold Film – 50 nm



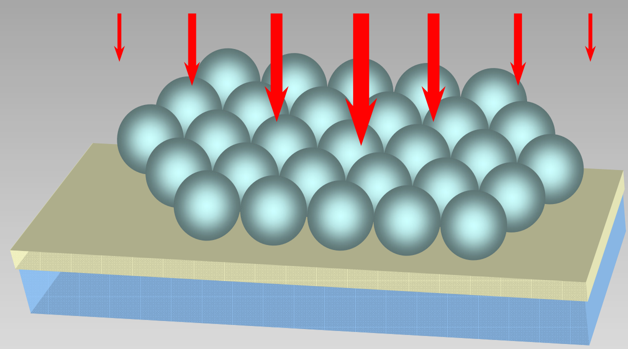

Laser fluence 0.5 $J/cm^2$

Laser **532 nm**, 450 ps
Spheres dimension: **3 µm**
Structure dimension : ~**350 nm**

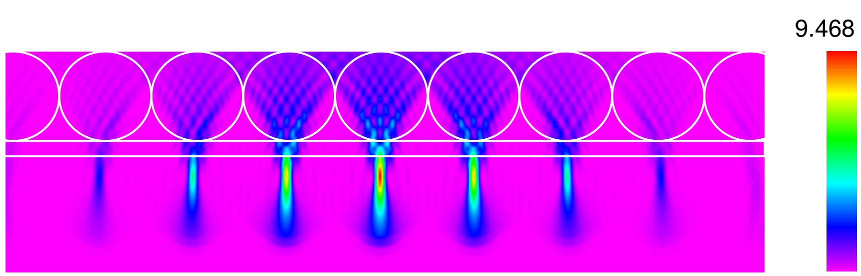
# Parallel processing of photopolymers using colloidal particles

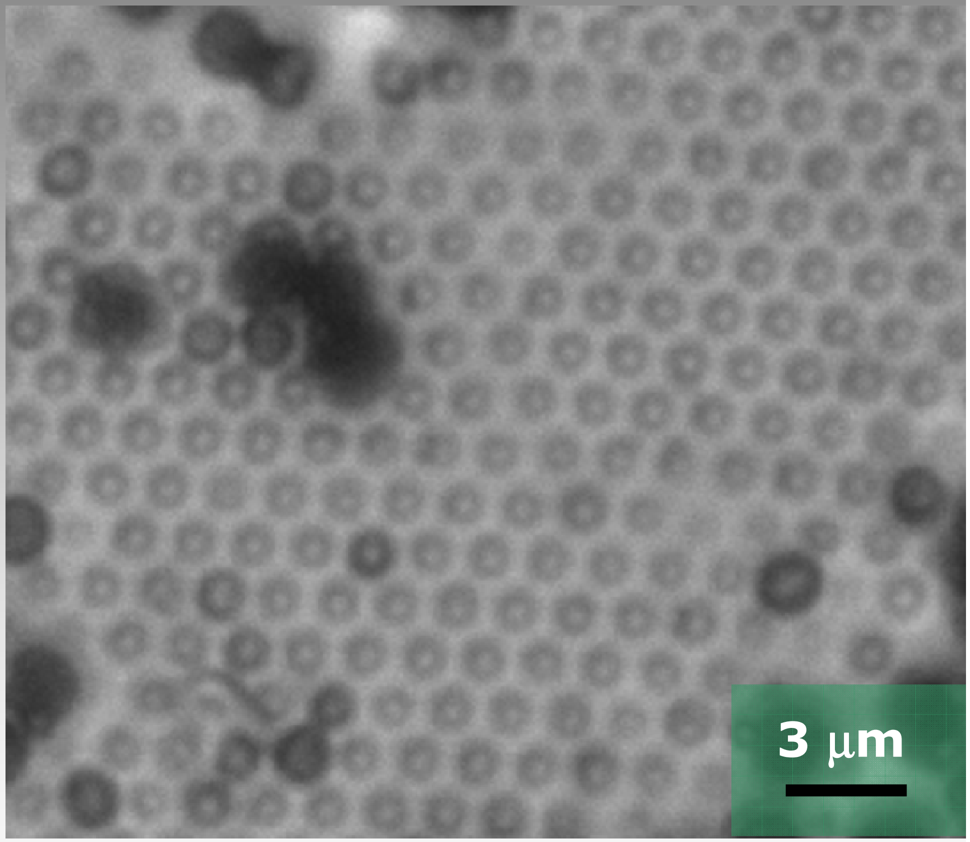
Spheres of polystyrene (1.5 μm diameter) are deposited of SU-8 thin film.

The monolayer of PS spheres are irradiated by fs laser beam.



Numerical FDTD simulation shows an optical field enhancement with a factor of 9.

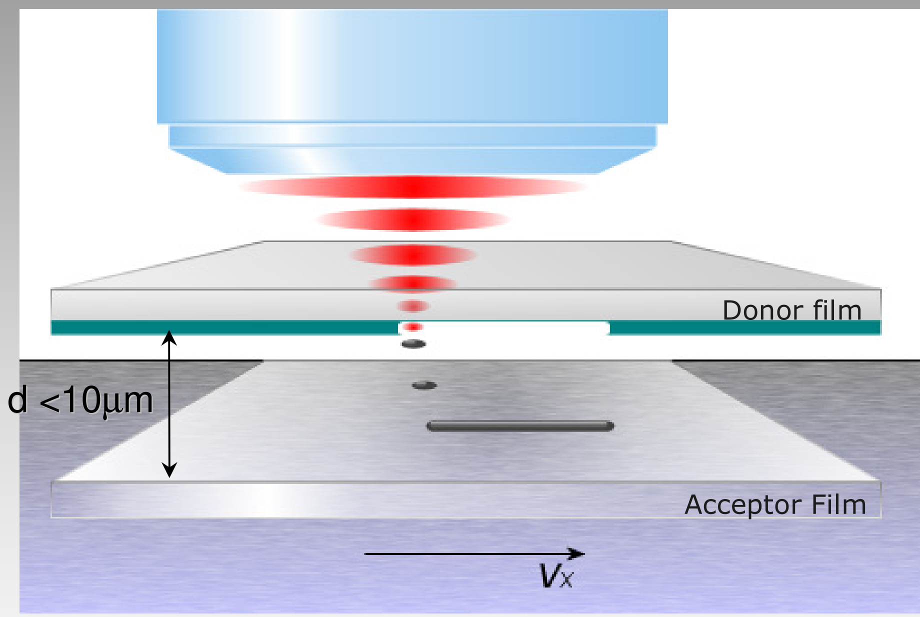


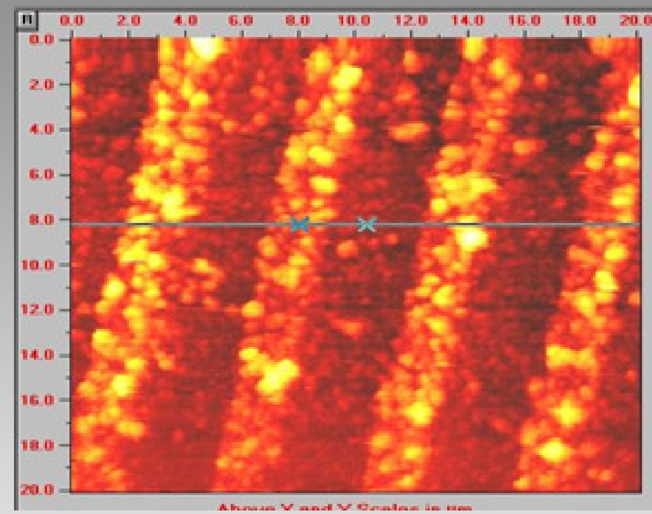



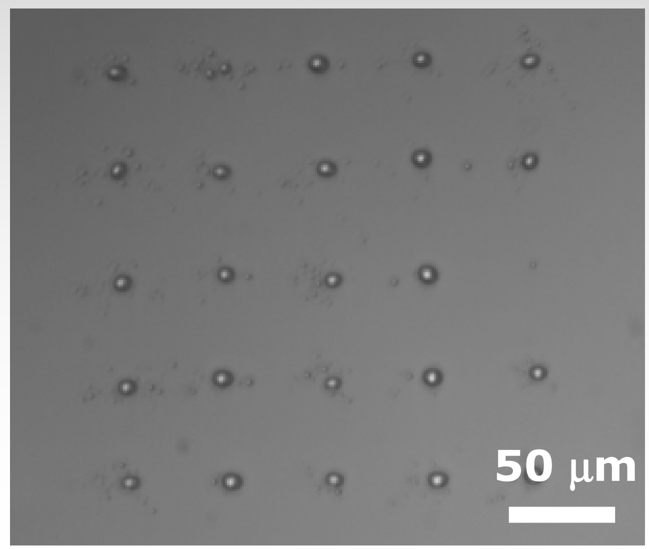

TPP occurs in optical near-filed enhancement regime.

# Laser Induced Forward Transfer (LIFT)

Semiconductors, polymers, biological tissues can be transferred by laser from a donor substrate to an acceptor substrate. The size of transferred material is at the order of few microns.



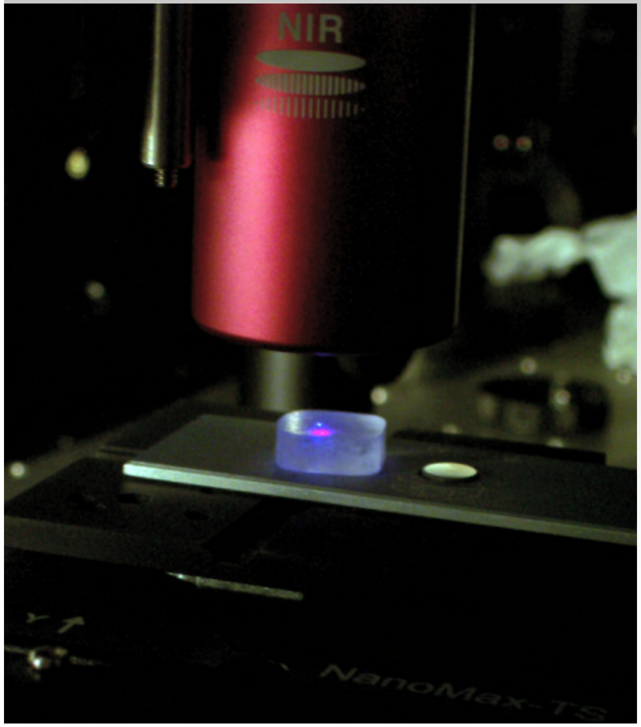


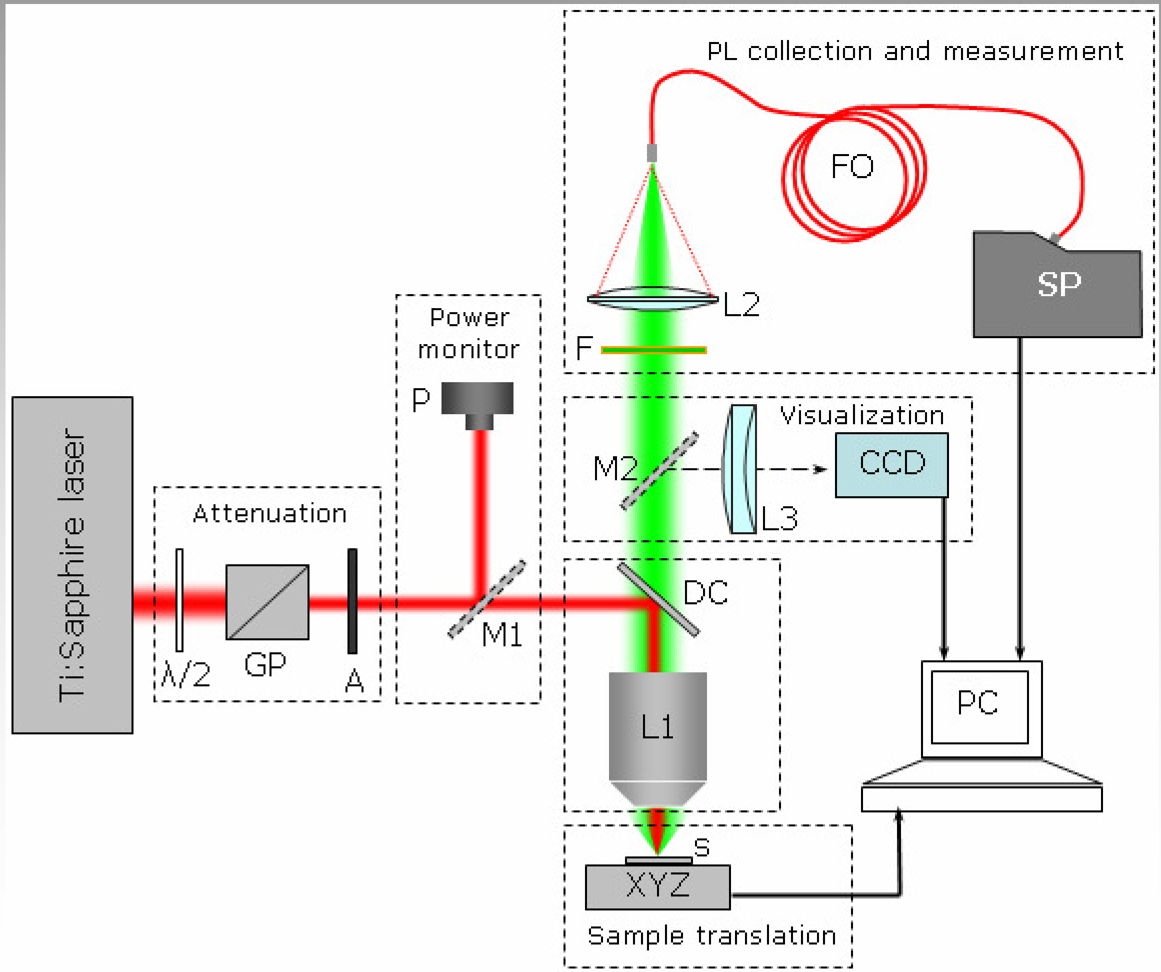

**Droplets of polymers and lines of semiconductor are transferred by laser.**

# Two-Photon Excitation Spectroscopy

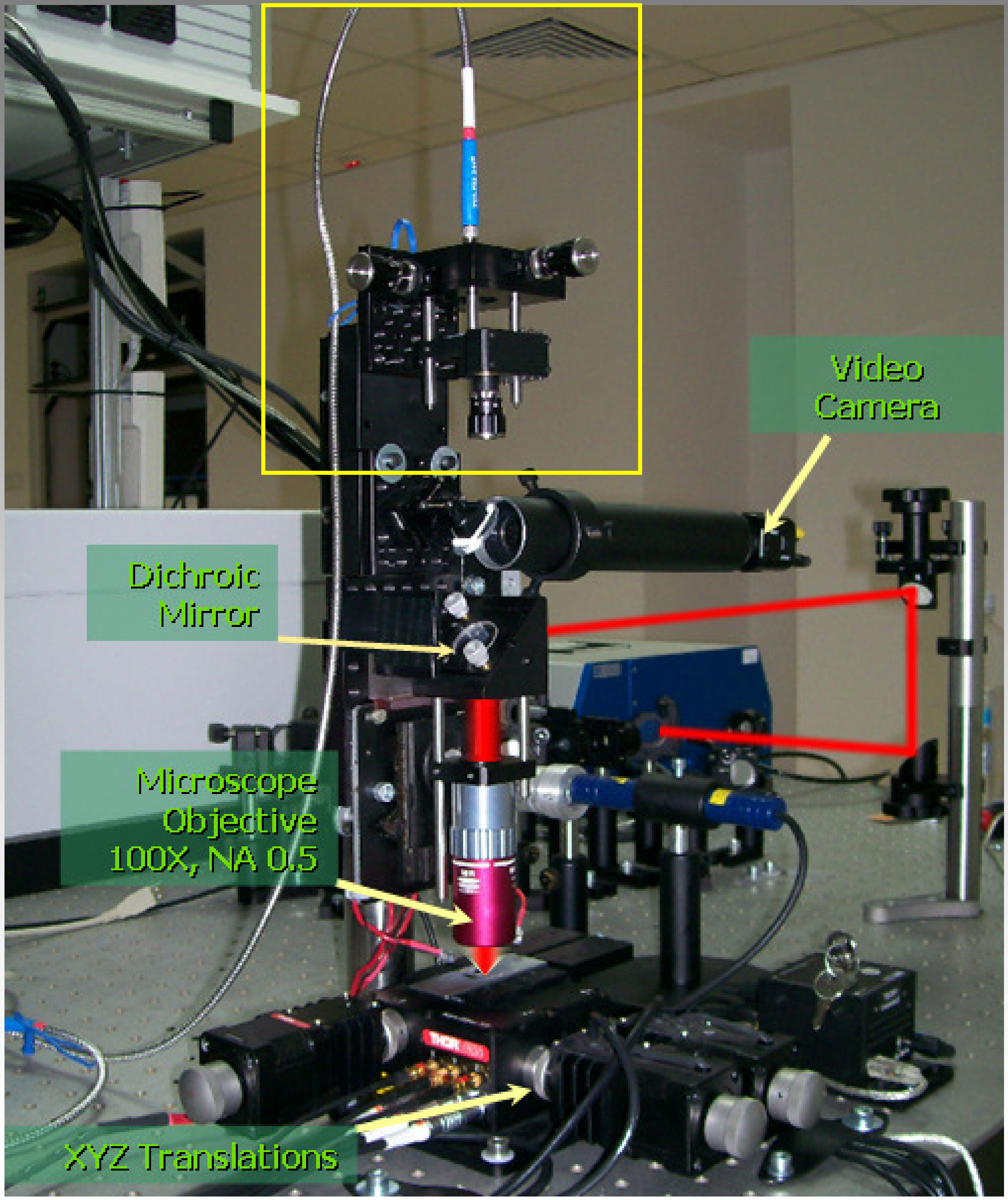
In the confocal configuration, the DLW workstation is connected through an optical fiber to a spectrometer. A 100 μm optical fiber gives about 5 μm lateral resolution on the sample.

By scanning the sample surface the TPE microscopy image can be recorded.

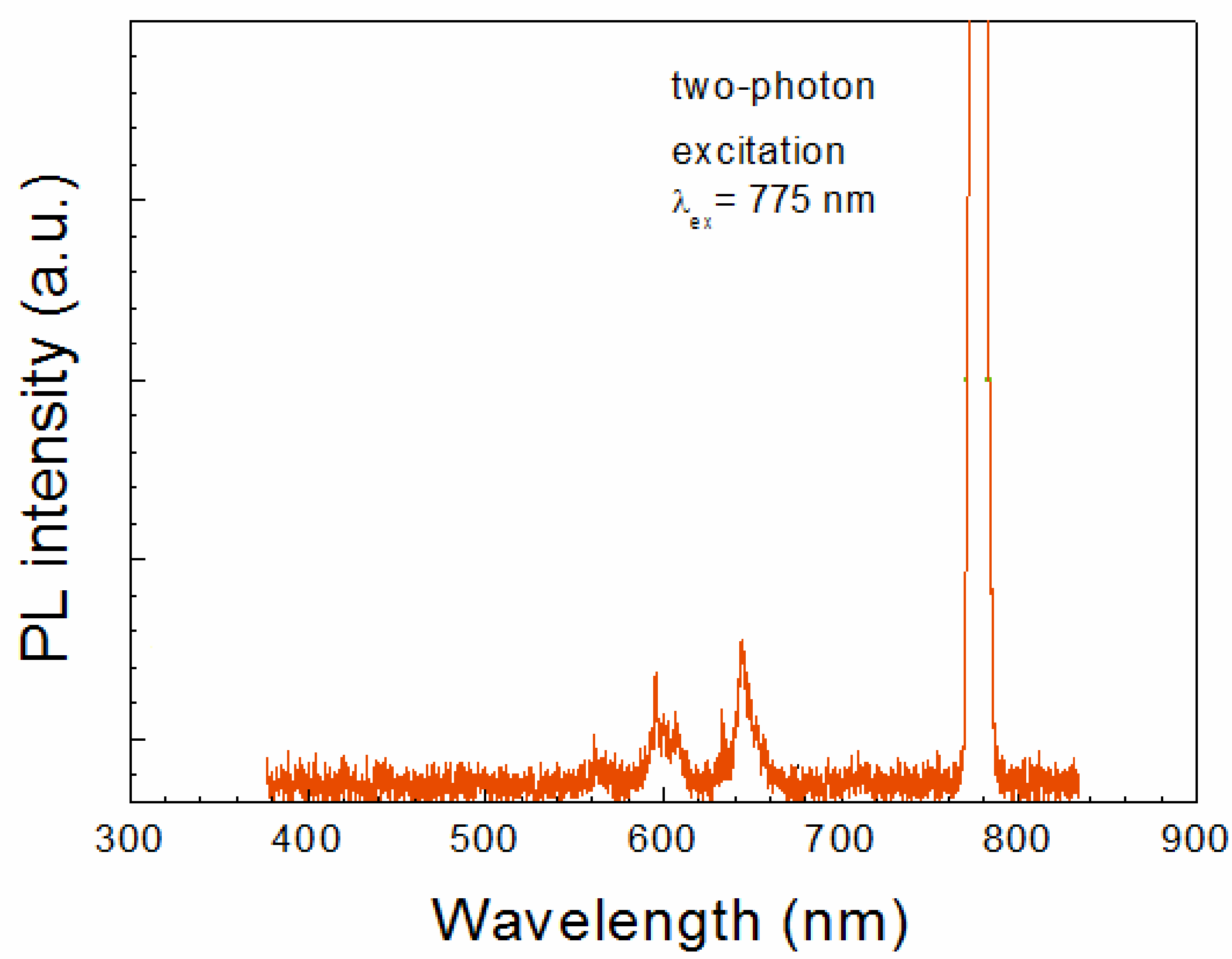


# Set-up for TPE-Spectroscopy

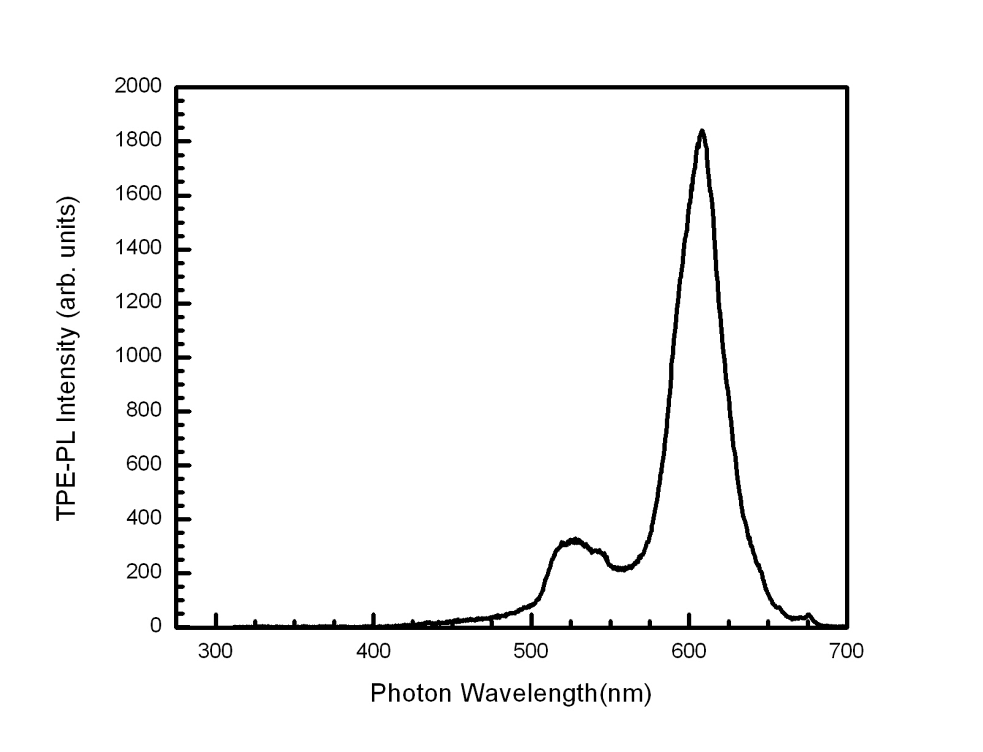


# Typical TPE-PL spectra

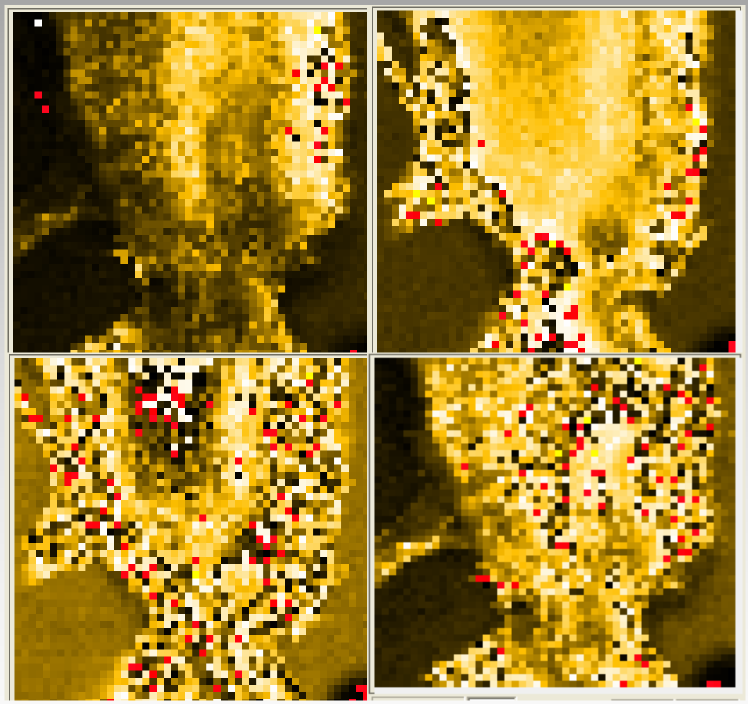


# TPE Microscopy – work in progress

By scanning the sample in XY, a map of TPE-PL intensity can be recorded.




Reconstructed images of a biological sample at different depths inside the sample.



# Conclusions

- ✓ A laser direct writing system was configured for laser processing with femtosecond laser pulses.
- ✓ The laser set-up is compatible with laser processing and characterisation techniques, such as laser ablation, near-field lithography, LIFT, TPP, TPE Spectroscopy.
- ✓ The system allows us to obtain 2D and 3D structures with submicrometric precision.
- ✓ The obtained structures have applications for micro-sensors, micro-optics, metamaterials, micro-fluidics, etc.

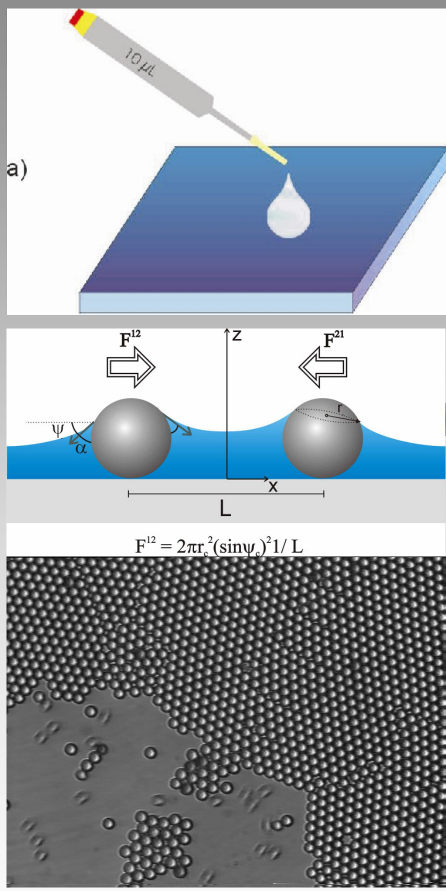

## Solid State Lasers Group

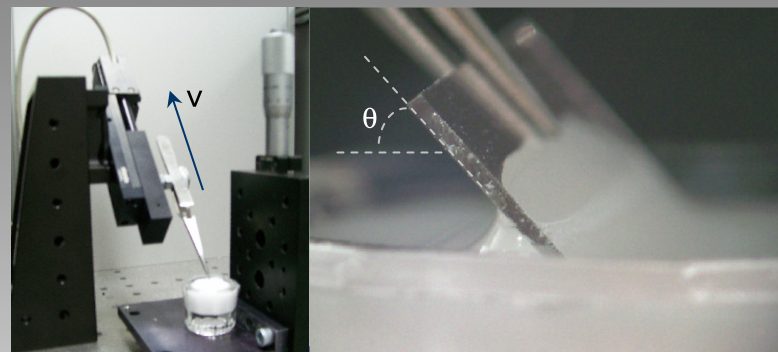
http://ssll.inflpr.ro/

This work is supported by National Agency of Scientific Research trough the projects:
CNCSIS IDEI268, FEMAT, METALASER, FOTOPOL

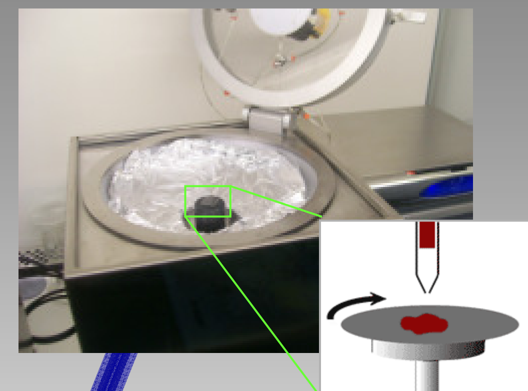
**Thank you for your attention!**

# Self-organization of mono-layers of colloidal nanoparticles

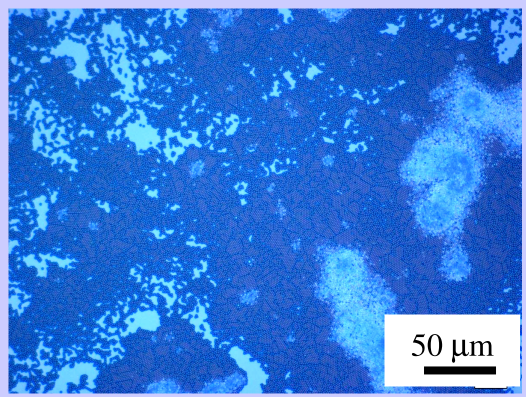


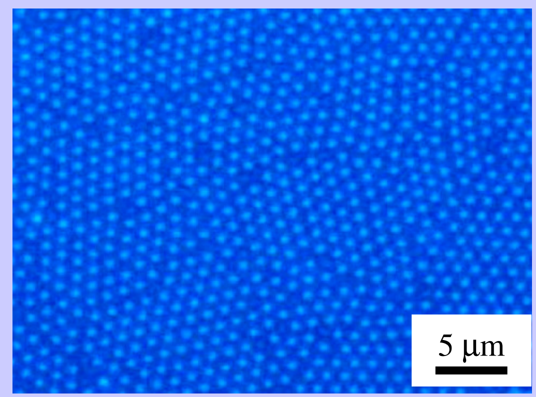




Spin coating



Mono-layers of spheres




*M. Ulmeanu, Colloids and Surf. 2009*