Optical polarization based logical gate system of ON-OFF type using SPR periodic arrays

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Why metal/gold?

- high chemical stability
- high plasmon resonance of gold nanoparticles
- controllable range of densities
- extended applications

Why metallic colloids (nanoparticles)?

- small inhomogeneities to create effective macroscopic behaviors
- starting point for composite materials, micro- and nanostructured
- applications in opto-electronics such as spectral filtering, sensor detection, and metamaterials, man-made objects that have properties often absent in nature ($n<0$)

Outline

- Metallic periodic micro-/nanostructure induced by direct light writing in films: principle and obtaining
- Optical microscopy imaging
- UV-Vis spectroscopic investigations
- Polarization testing
- Conclusion

Material Composite

Doped Polymer Matrix :

- polystyren sulfonic acid (PSS) 18% (w/w) solution

- gold precursor : tetrachloroauric acid (III) $AuCl_4H \cdot 3H_2O$ (99.5%)

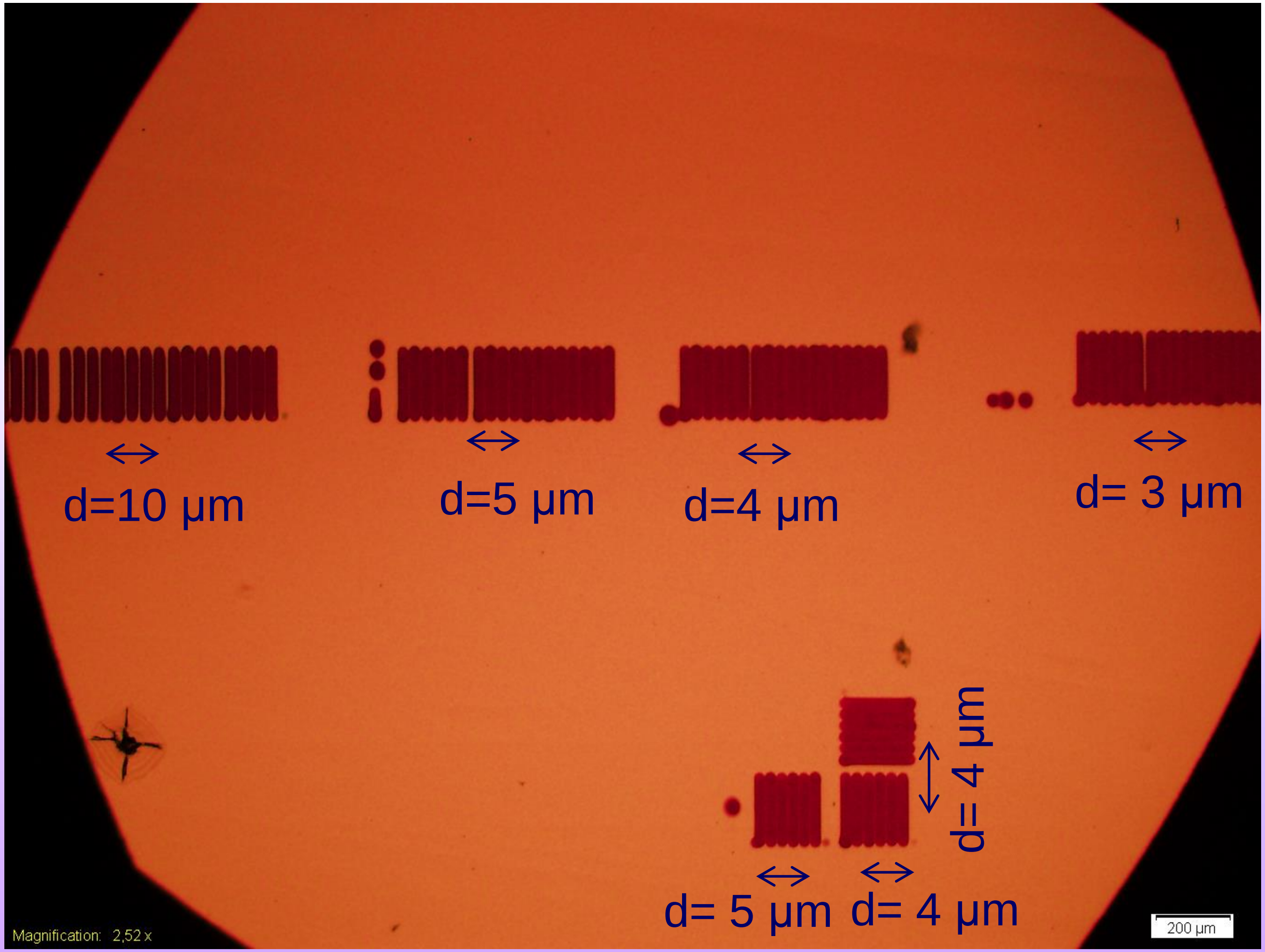
- photosensitizer: trisodium citrate $C_6H_5Na_3O_7 \cdot 2H_2O$

Composite Material

Doped Polymer Film

Grid: metallic micro-/nanostructures of neutral Au (0) generated by direct light writing lithography procedure

Periodical Au nanostructured patterns of gratings type



Dependence on:

- material
- particle size (smaller than the wavelength of illumination)

$C_{abs}=(k/\varepsilon_0)\mathrm{Im}[\alpha\omega)]$

abs. cross-section

$C_{Scat}=(k^4/6\pi\varepsilon_0^2)I\alpha\omega$

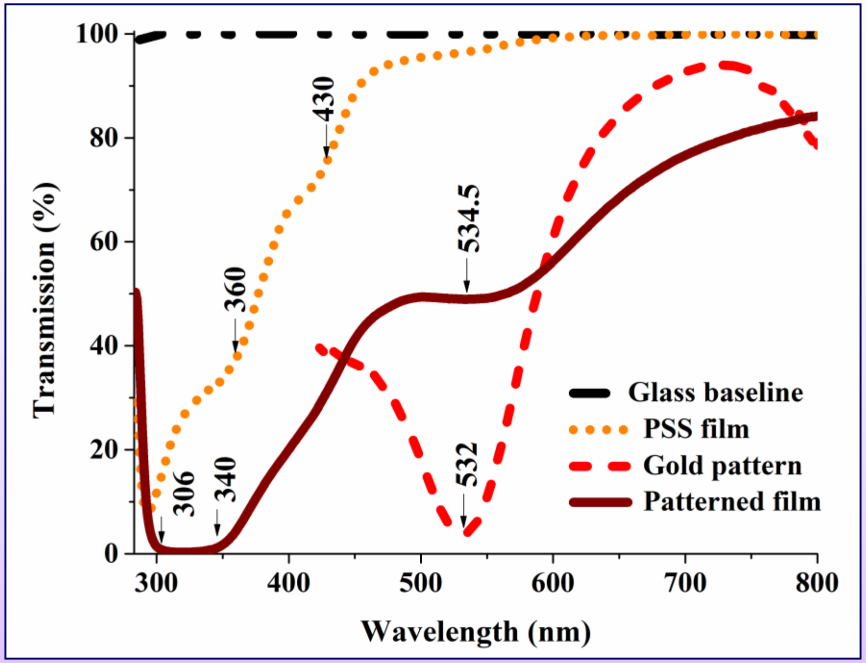
scat. cross-section

Both cross-sections are dependent on the polarizability of the particle, which is proportional to the size of them with R^3. Thus, as the particle size increase, re-radiation of the energy to the surrounding medium is expected to be dominant.

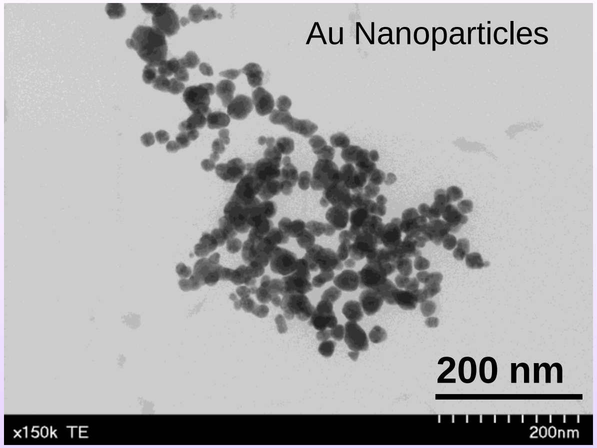
For the case of nanoparticles smaller than 60-70 nm, the image of the array cannot be identified with reflected light but can be noticed with transmission light.

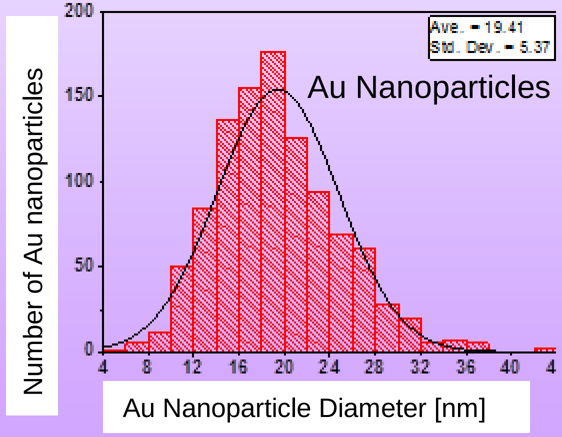
The extinction cross section is dominated by absorption while the larger particles can provide bright images both in the reflection and transmission modes.

UV-Vis investigations in the patterned gratings



TEM

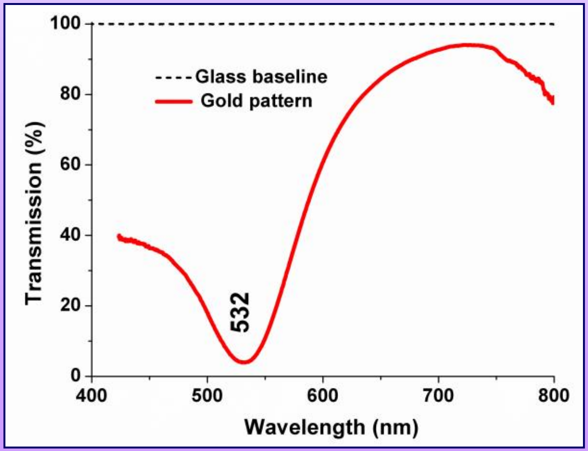




histogram

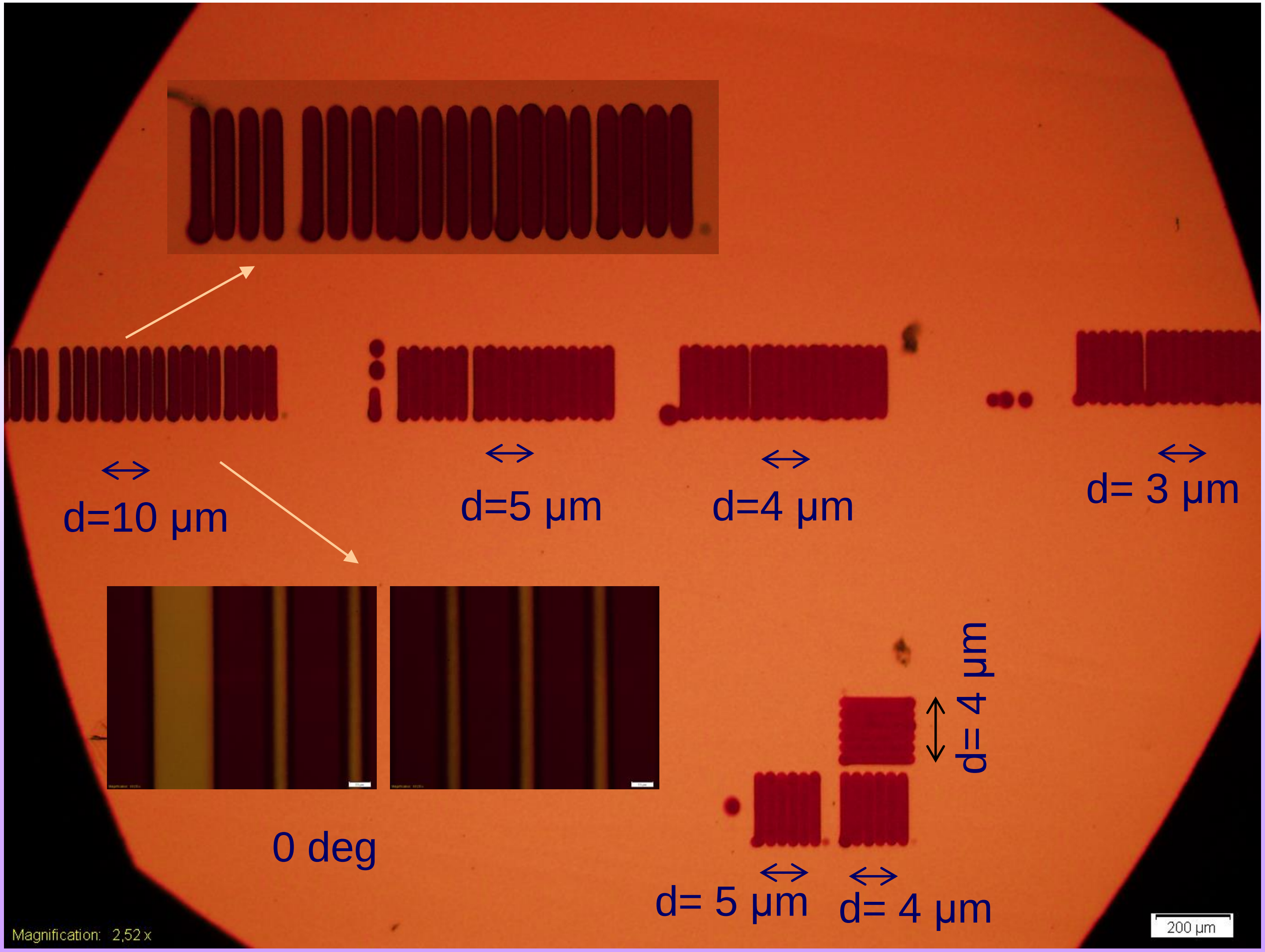
A.M.M. Gherman, N.Tosa, M.V. Cristea, V. Tosa, S. Porav, P.S. Agachi, Mater. Res.Express, 2018, 5, 085011.

N.Tosa, F. Toadere, Proc of SPIE 2018,10977, 109770O, 1-4.



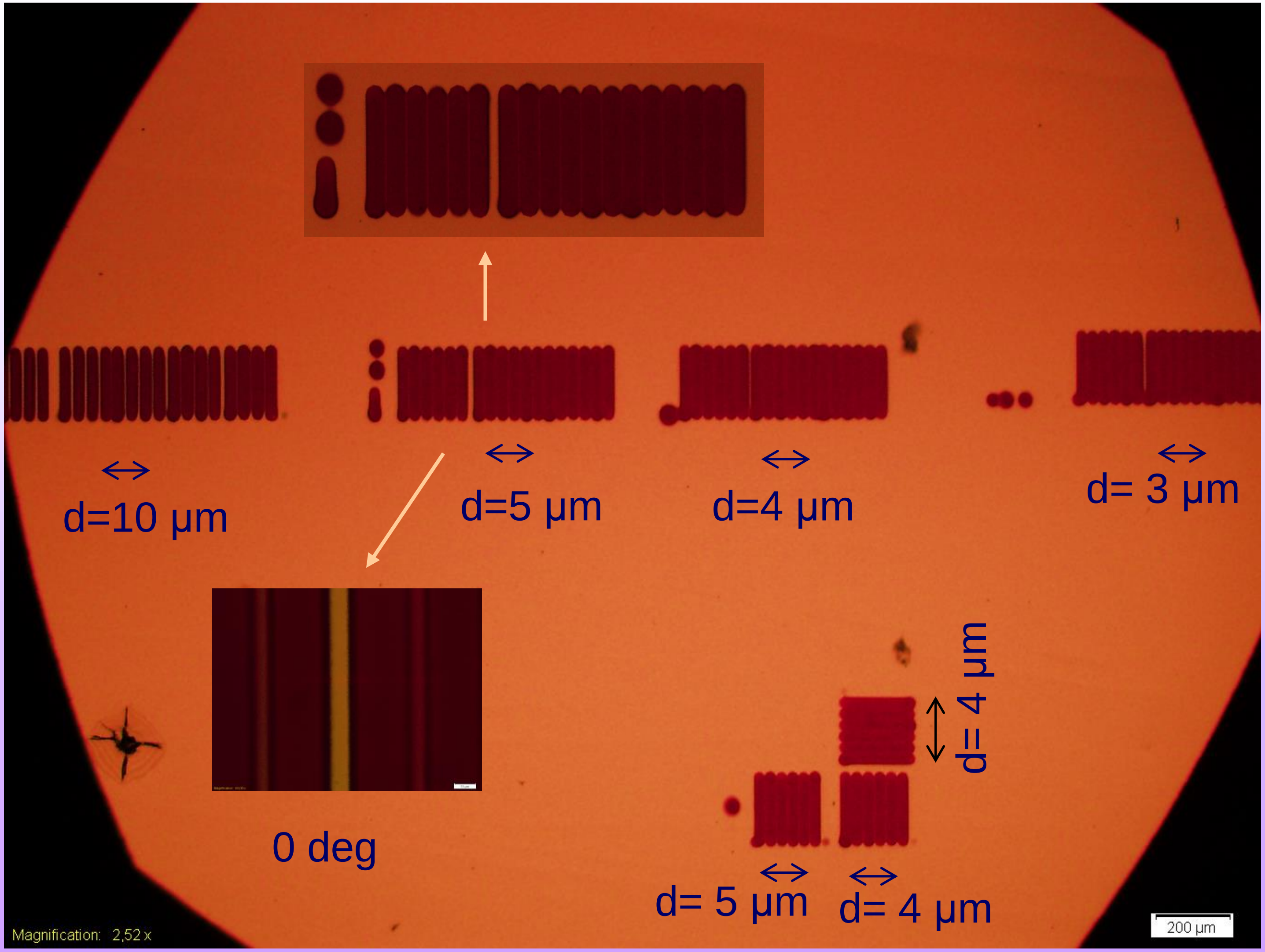
Attenuated transmission & uniform size distribution

Periodical Au nanostructured patterns of gratings type



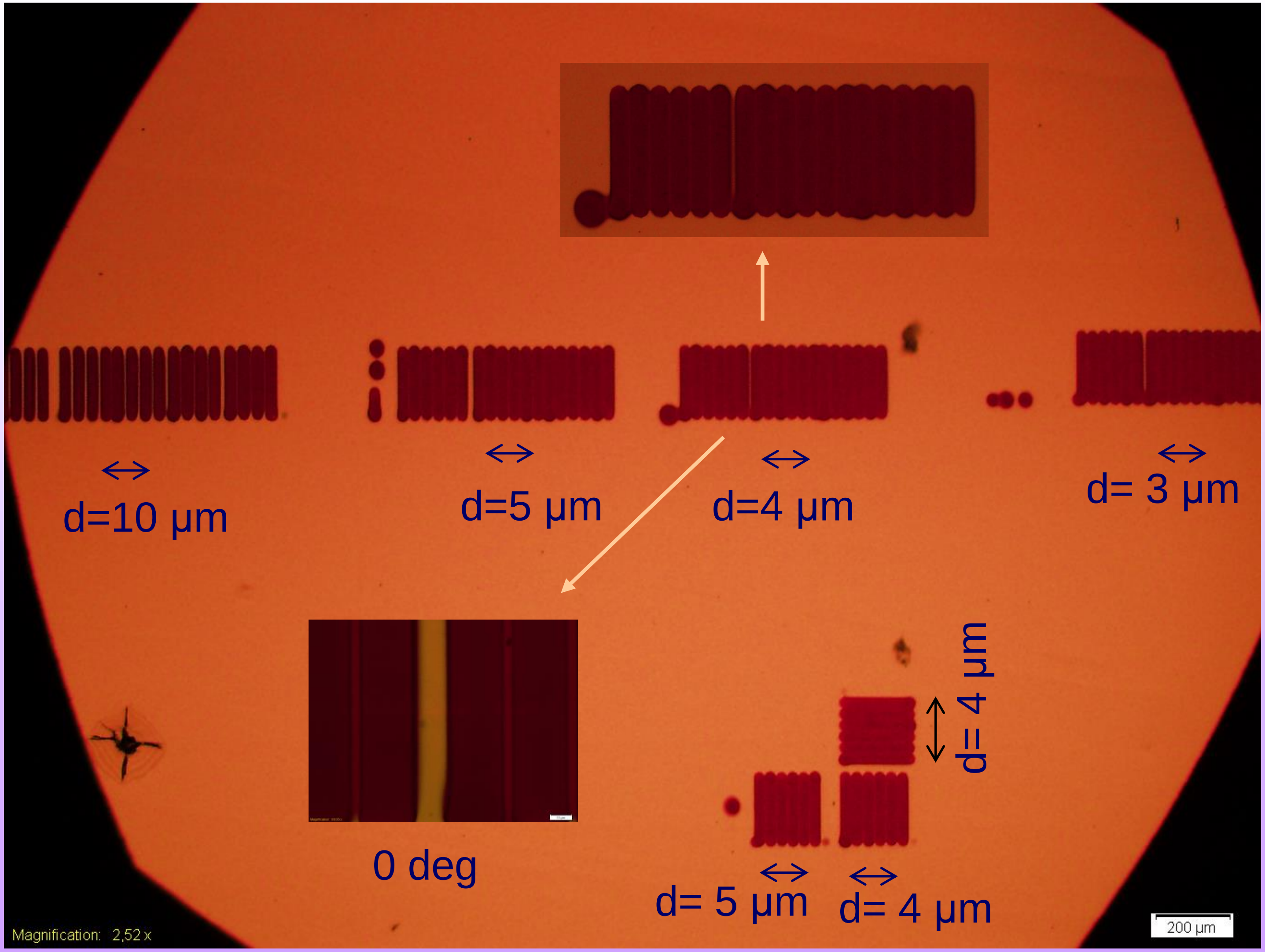
Period of the gratings: d=10 µm

Periodical Au nanostructured patterns of gratings type



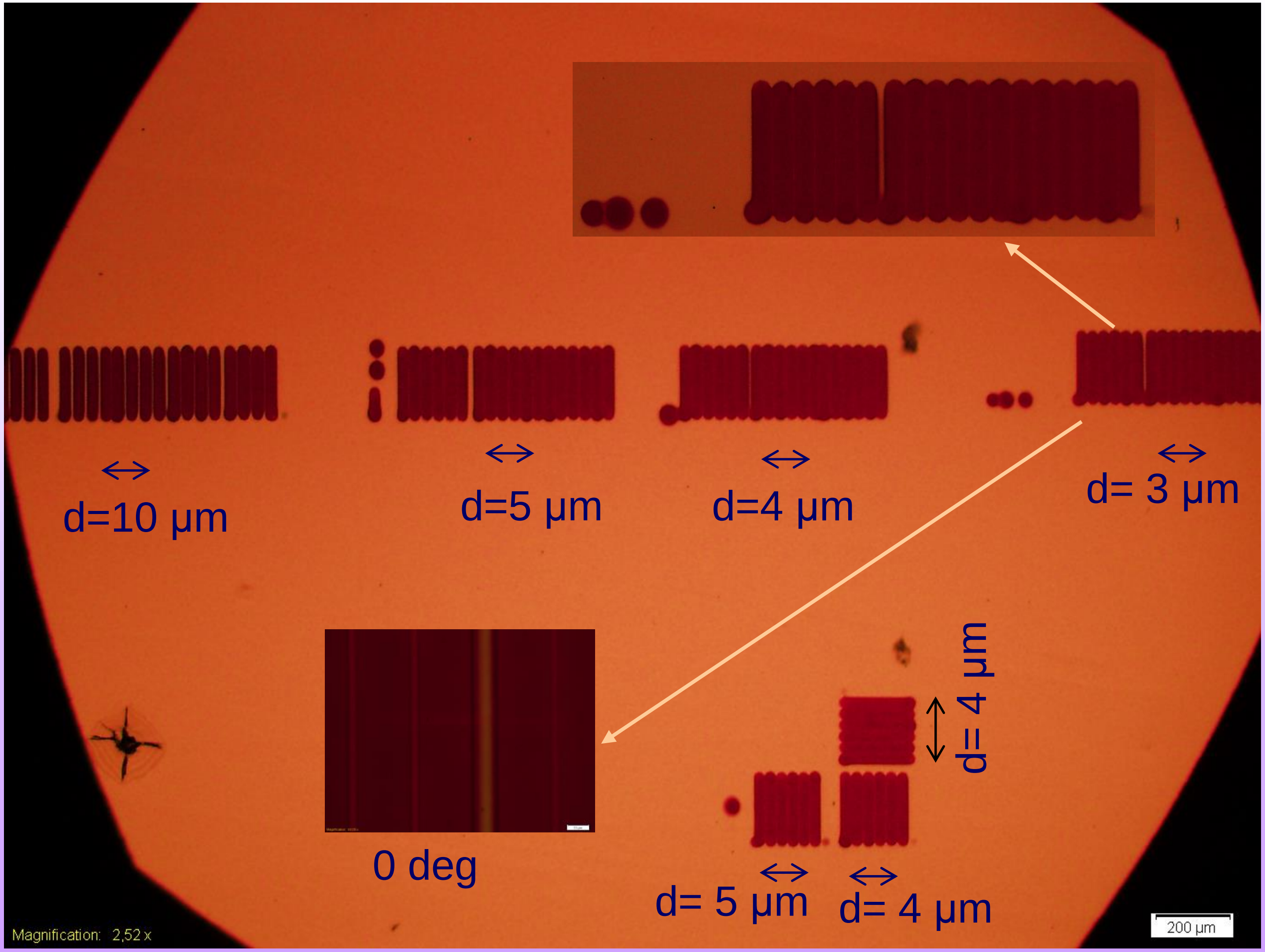
Period of the gratings: d=5 µm

Periodical Au nanostructured patterns of gratings type



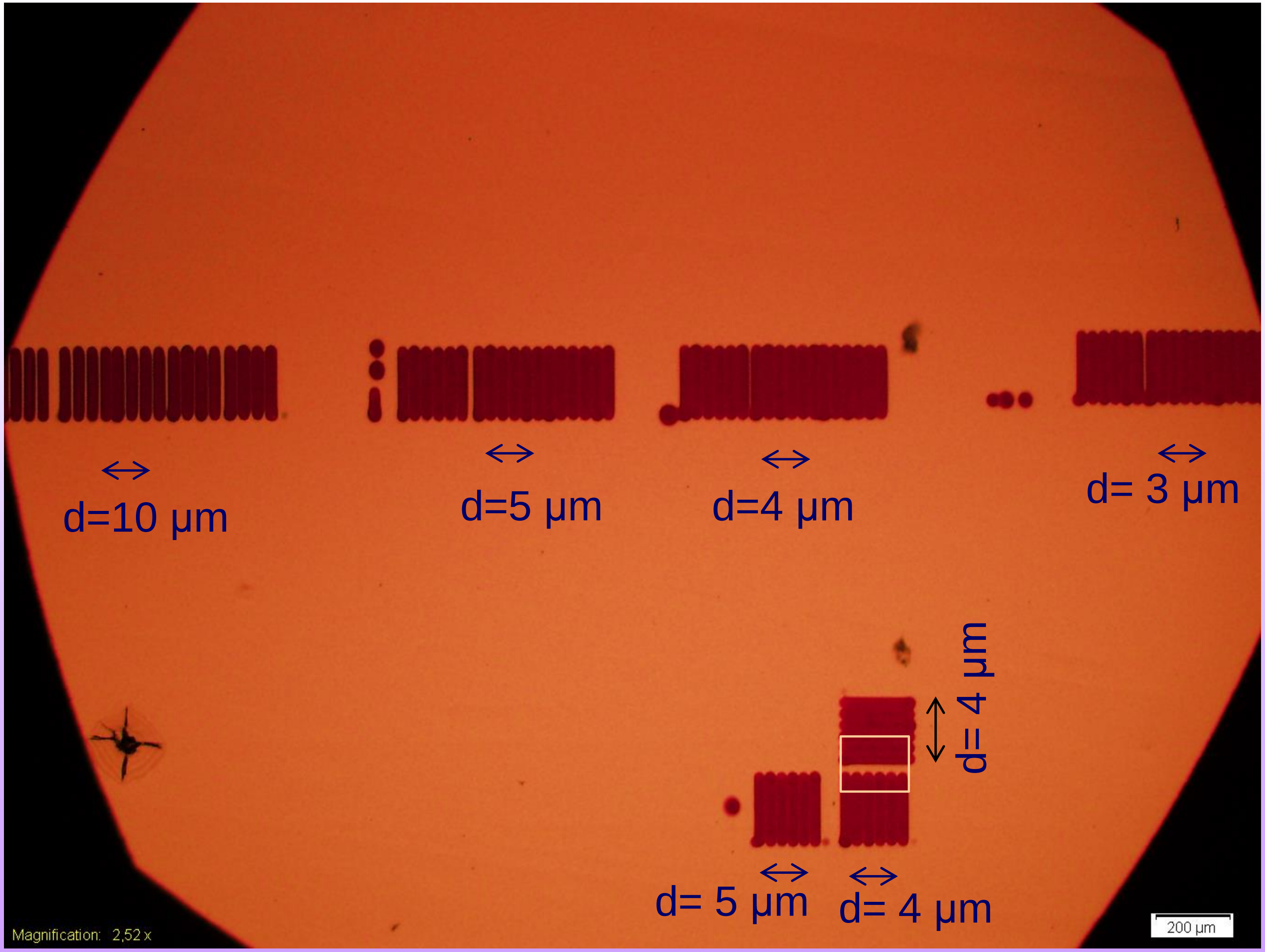
Period of the gratings: d=4 μm

Periodical Au nanostructured patterns of gratings type



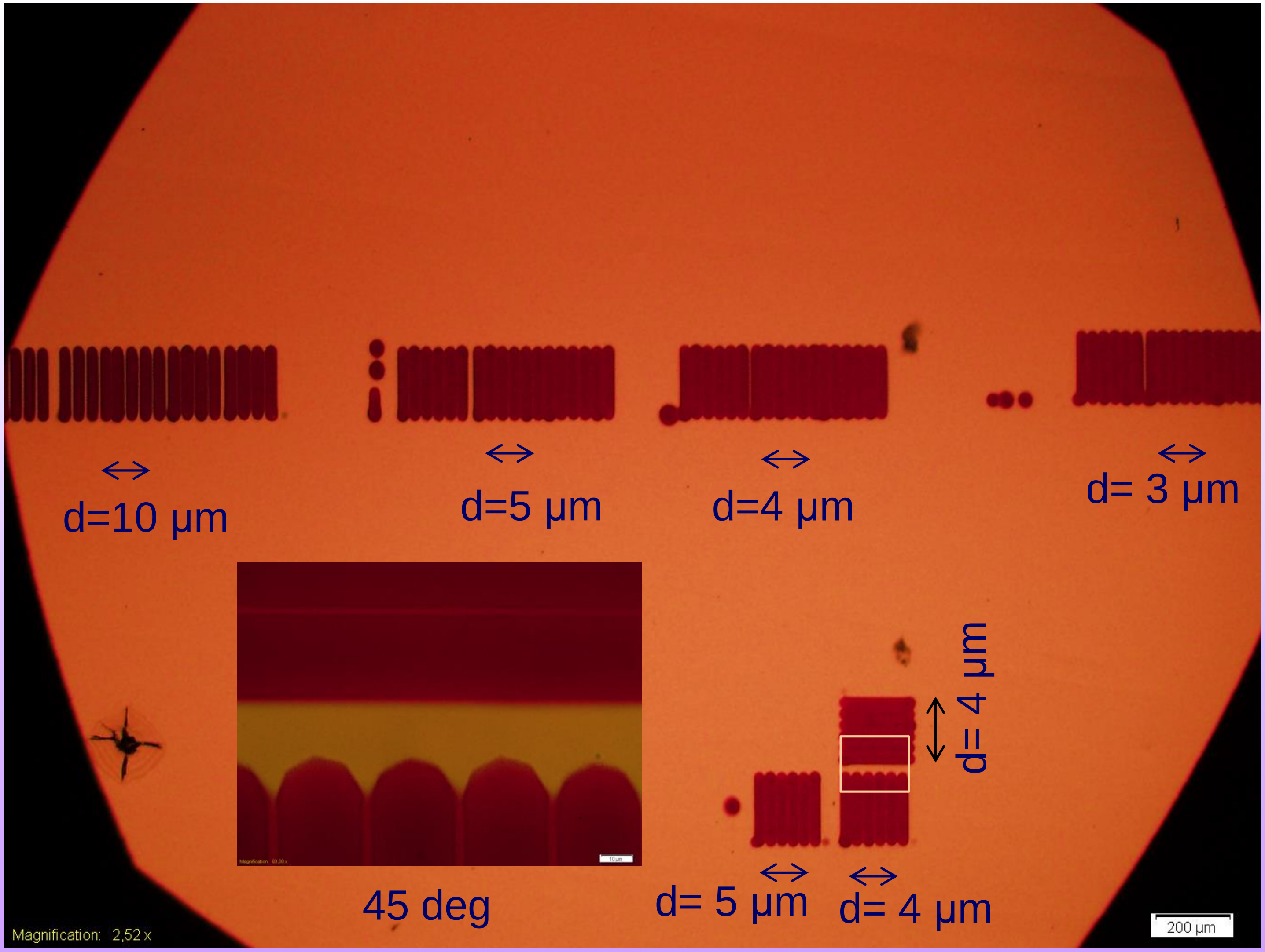
Period of the gratings: d= 3 µm

Periodical Au nanostructured patterns of gratings type



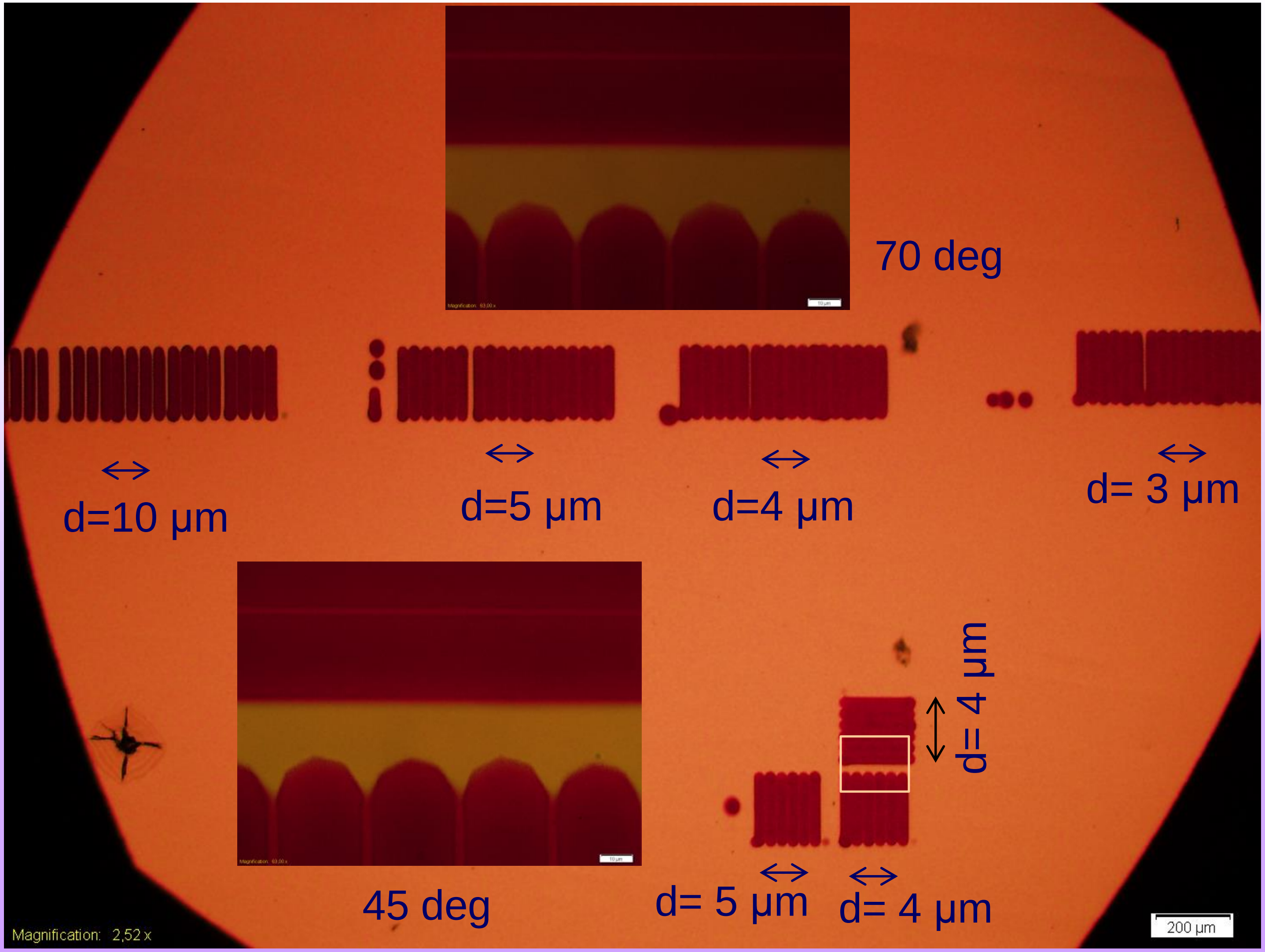
Period of the gratings: d=5 µm (V), d=4 µm (V and H)

Periodical Au nanostructured patterns of gratings type



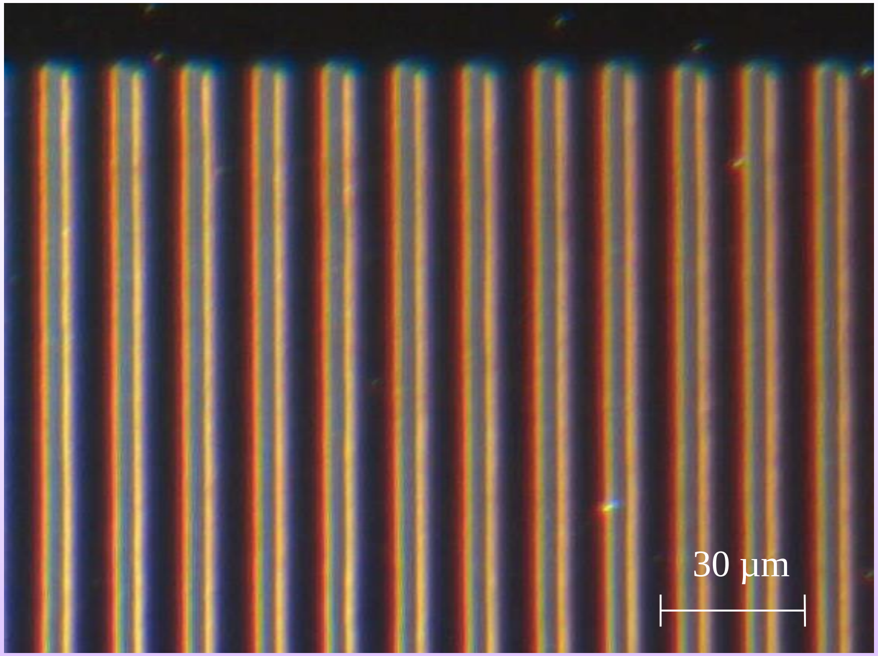
The polarization angle has no spectacular effect among the in contact lower size Au nanoparticles embedded in written patterns except a slighter narrowing of the period of the gratings in the horizontal configuration

Periodical Au nanostructured patterns of gratings type

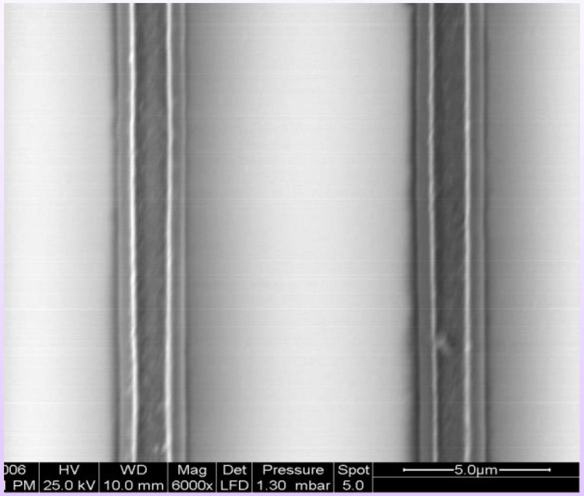


The polarization angle has no effect among in contact lower size Au nanoparticles embedded in the written patterns except attenuating the SPR response due to the light attenuation

Gold Wires on Polyimide Underlayered Glass



Optical image of a gold wires array
(in dark-field scattering)



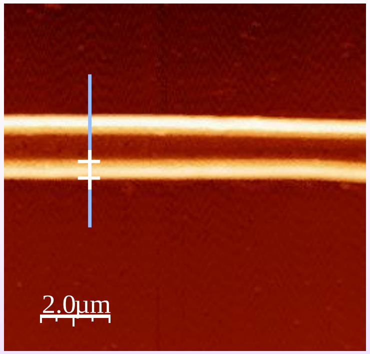
SEM image of two gold double wires

Direct laser writing, Two-photon absorption,
100x oil-immersed objective, NA 1.3

No red colour but yellow to orange now ⇨ The reflection will prevail instead of absorbtion/transmission due to the change of the refractive index of the patterns

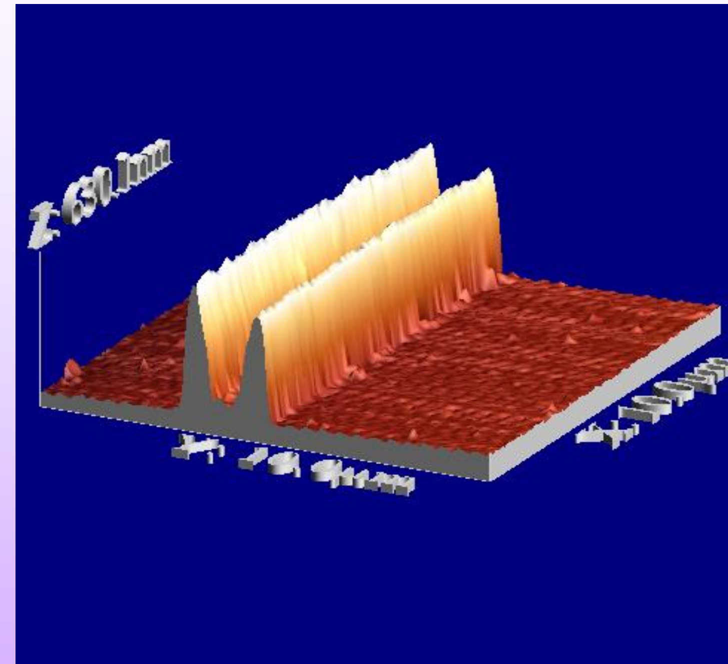
N. Tosa *et al.*, *Proc. of SPIE,* **2006,** 6195**,** 1-8.

Double Wire

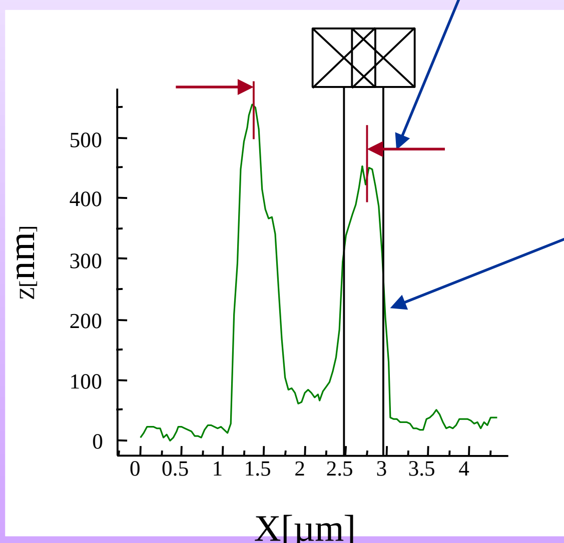


top view

AFM measurement of a typical gold wire



3D view



Distance between wires

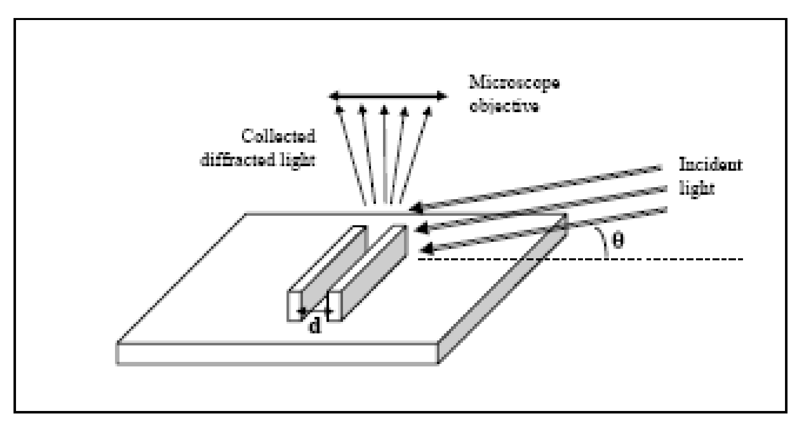
Width of the wire

cross section

Double wire due to the thermal effect induced by the colloids during the laser irradiation of the sample

N. Tosa *et al.*, *J. Optoelectron.Adv.Mater*, **2007**, 9(3), 641-645

Double Wire – Diffraction properties



Schematic view of the dark-field arrangement for a metallic double-wire shape

Optical image obtained with metallic double – wire shapes with increasing distances between the walls, from the left to the right

Diffraction intensity perpendicular to the sample:

$$I_d = K \cdot I_0 \cos^2(\pi/\lambda \cdot n \cdot d \cos(\theta))$$

$$\lambda_m = d \cdot \cos(\theta)/p \cdot n$$

$I = I_m \cdot \cos^2(\varphi/2)$ I_m at $\theta=0$

$\varphi = (2\pi d/\lambda) \cdot \sin\theta$

Sharp and very luminous colors are produced by metallic wires when observed in dark field.

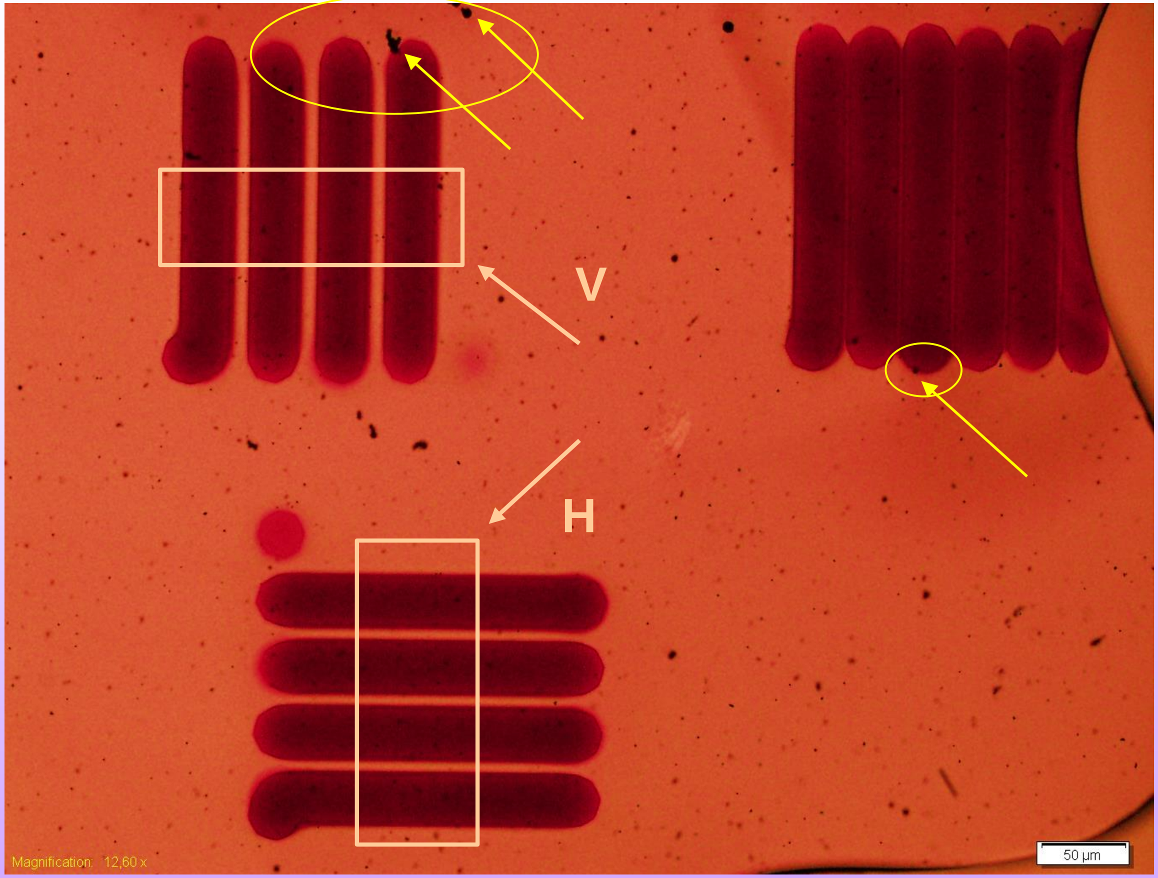
The plasmon surface waves can propagate along metallic wire even if it is of micrometer size.

The refractive index of metals is very high as compared to dielectric materials.

This huge refractive index difference leads to very high diffraction efficiencies.

N. Tosa *et al.*, *J. Optoelectron.Adv.Mater*, **2007**, 9(3), 641-645

Periodical Au nanostructured patterns of gratings type



Direct laser writing,
one-photon absorption,
100x oil-immersion,
NA 1.3

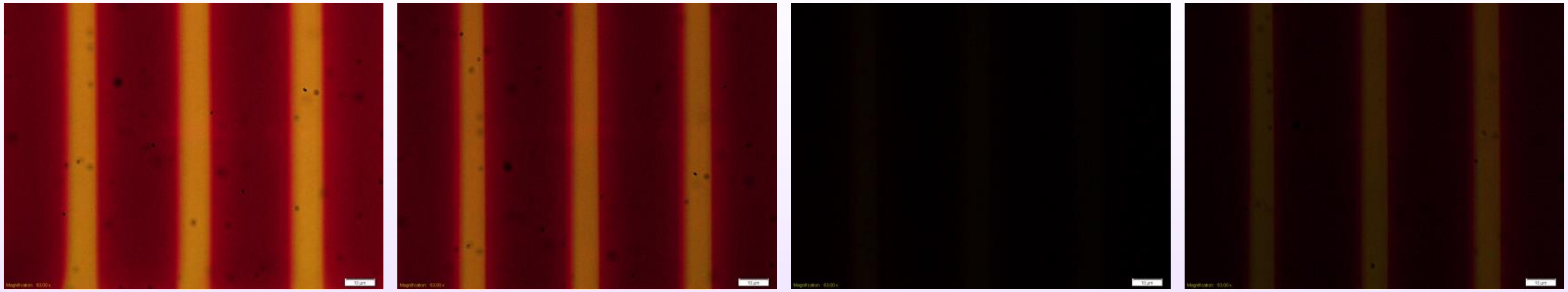
Period of the gratings:
- 13 µm for the horizontal and vertical group of 4 lines
- 5 µm for the vertical group of 6 lines

The nanostructured Au patterns exhibit very important surface plasmon resonances (SPR) as expected – see the red color due to the higher absorption cross-section.

The polarization angle affects in contact larger size Au nanoparticles outside of written patterns

Polarization effect on vertical and horizontal SPR gratings

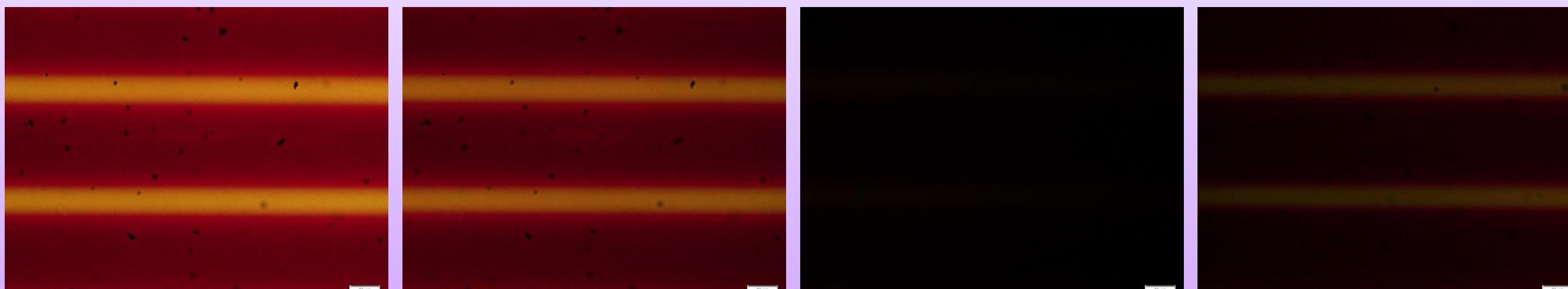
V



0 deg (II) | 45 deg | 90 deg (┴) | 135 deg

ON | | **OFF** |

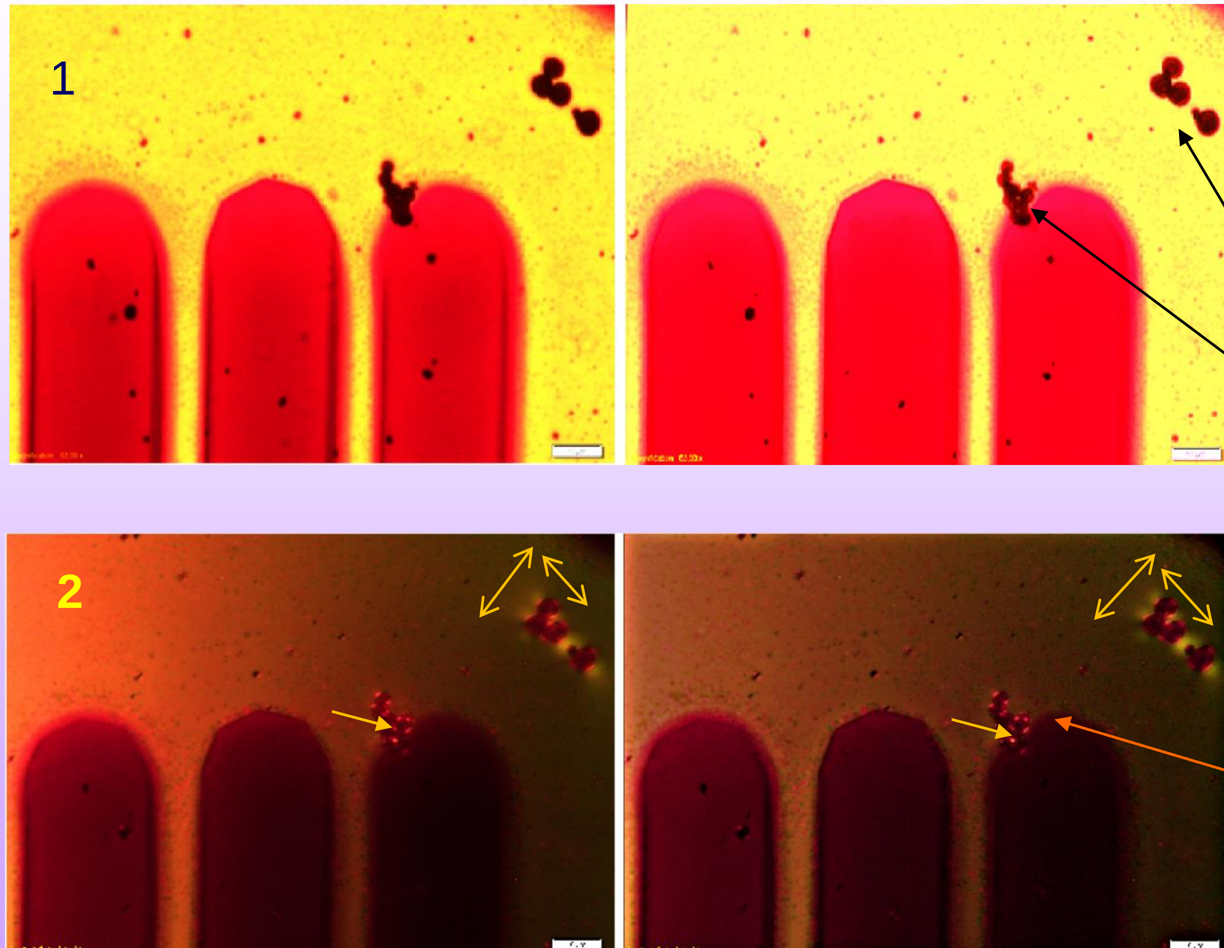
H



The polarization angle affect the absorbance/transmission of the in contact lower size Au nanoparticles embedded in the written patterns

The lower RI regions appear to be narrower for horizontal lines comparison with the vertical lines embedding in contact lower size Au nanoparticles

Polarization effect on Au nanostructured patterns: ordered and agglomerated



ON

1- polarization angle 0 (II)
2- polarization angle 90 (┴)

No mode

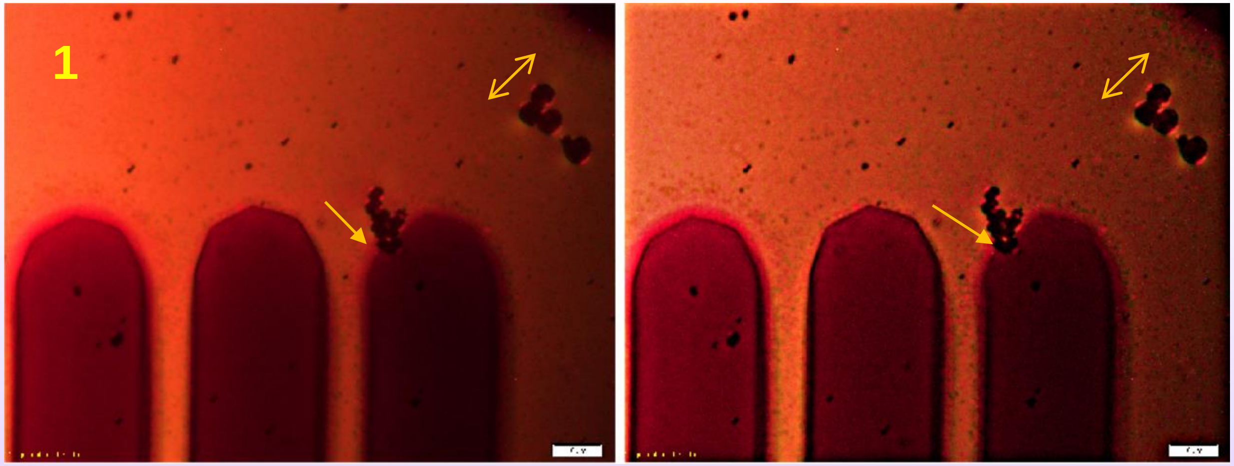
OFF

All modes

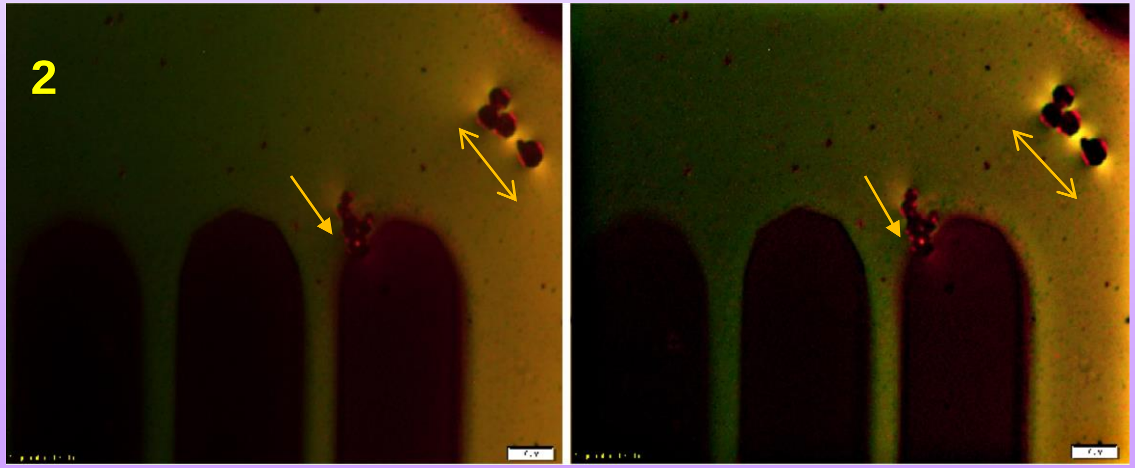
Polarization angle has no effect among ordered and in contact lower size Au nanoparticles embedded in the written patterns

Polarization angle affects the agglomerated and in contact larger size Au nanoparticles outside of the written patterns

Polarization effect on Au nanostructured patterns: ordered and agglomerated



ON'

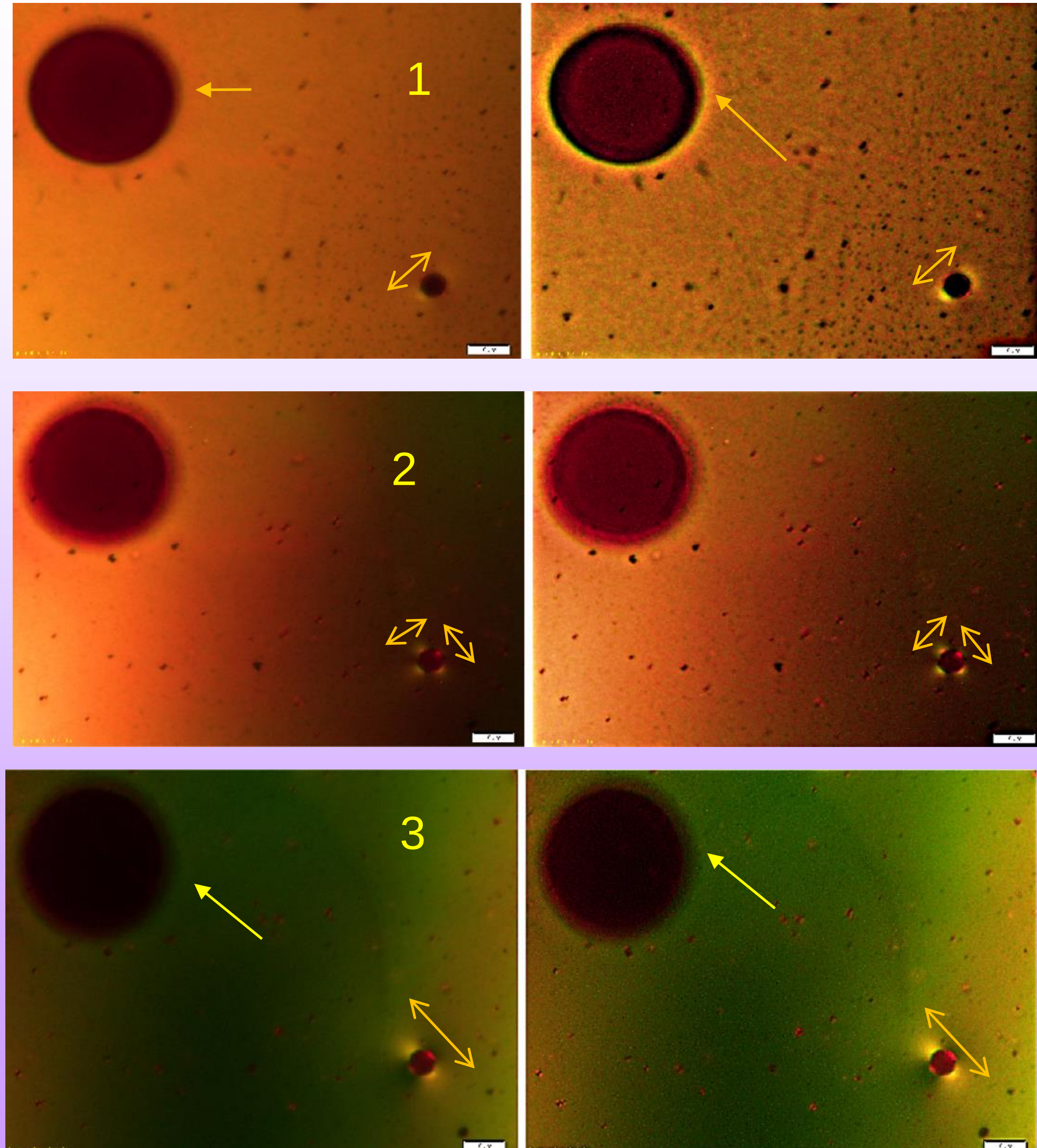


OFF'

1- polarization angle 70
2 - polarization angle 110

The polarization angle affects the plasmonic coupling modes

Polarization effect in round Au patterns: nanostructured and bulk



ON’

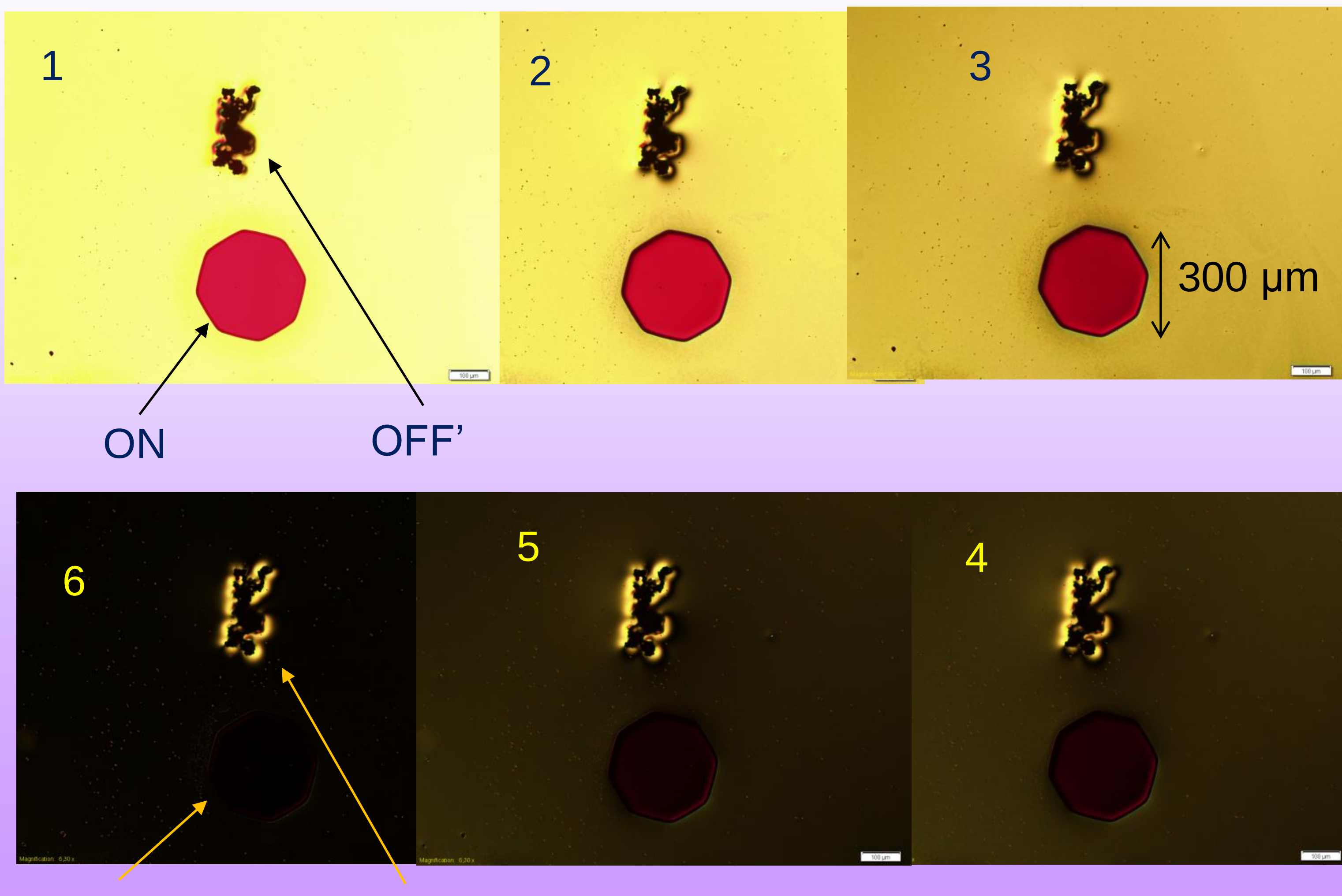
OFF’

1- polarization angle 70
2 – polarization angle 90
2 - polarization angle 110

The polarization angle affects the plasmonic modes

Polarization effect on Au nanostructured patterns: ordered and agglomerated

1 - polarization angle: 0 ON/   OFF'
6 - polarization angle 90 OFF/   ON'



The polarization angle affects the plasmonic coupling modes

CONCLUSIONS

- Periodical arrays of gold nanostructured patterns in transparent polymer films has been drawn using direct laser writing (DLW)
- DLW is a maskless procedure with spatial control of the process, confined in at the focal point, which selectively generates well defined patterns of tunable sizes and periodicities
- Metallic microstructures contain nanoparticles with size and shape uniformly distributed along the pattern
- The nature of the light interaction with particles, whether is absorption or scattering, is mainly dependent on the material and the size of the nanoparticles.
- Polarization angle has no effect among ordered and in contact lower size Au nanoparticles embedded in the written patterns
- Polarization angle affects the agglomerated and in contact larger size Au nanoparticles outside of the written patterns
- Changing the polarization angles the intensity of the colors decrease to cut-off, allowing to build an optical polarization based logical gate device of ON-OFF type in the SPR periodic array.

Acknowledgements

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Thank you for your attention!