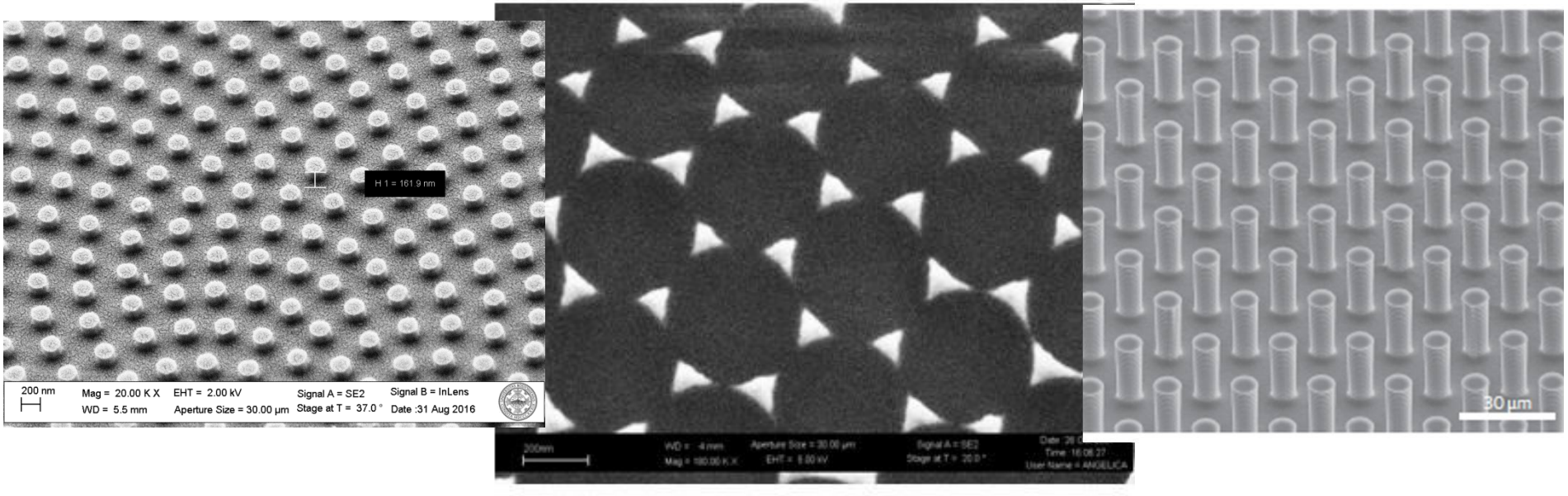
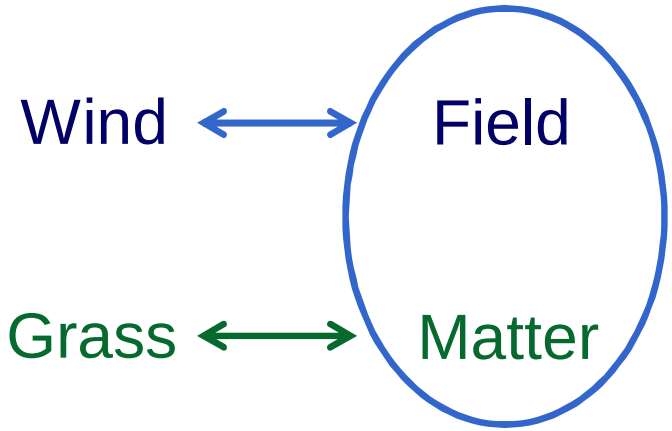
Metamateriali per fotonica e plasmonica



Lucia Fornasari, Congresso di Dipartimento, 13/09/2018

Dipartimento di Fisica, Università degli Studi di Pavia

Metamaterials: an analogy



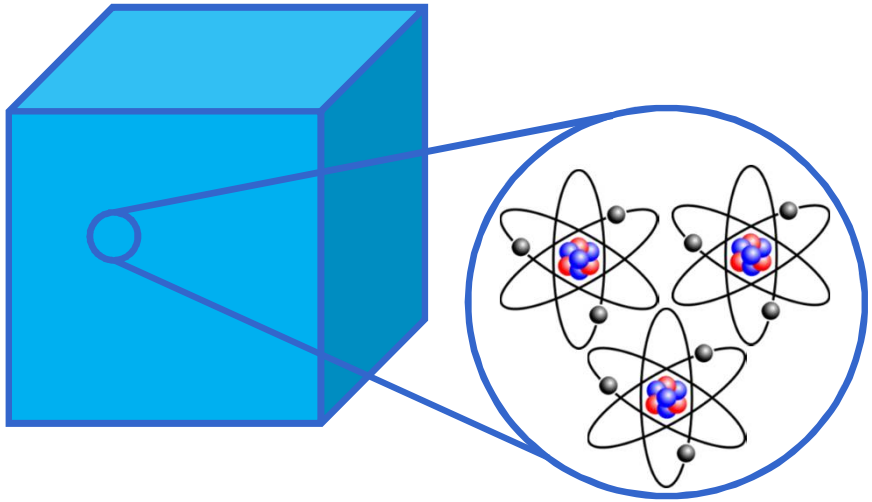
If the field-matter interaction is understood, it is possible to take advantage of it.

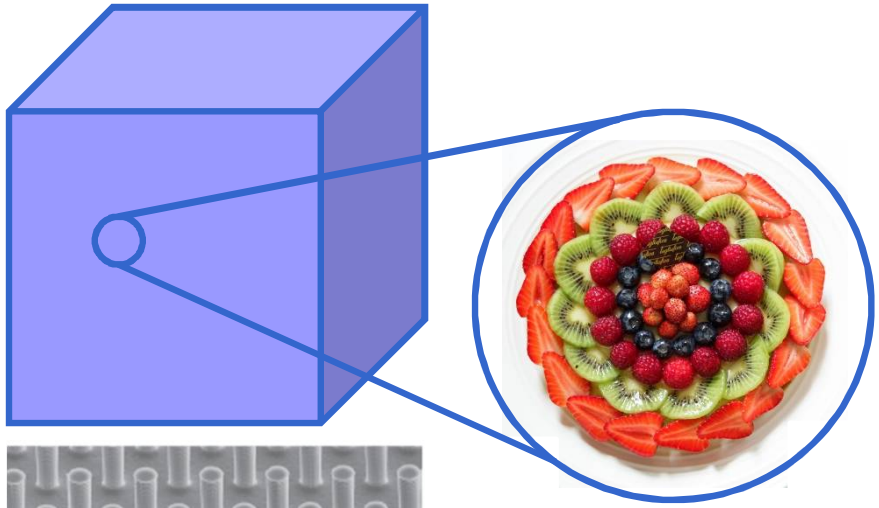
Metamaterials

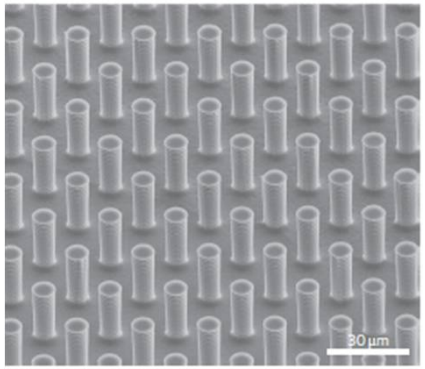
Metamaterials are artificially structured materials used to control and manipulate light, sound and other physical phenomena.

Conventional materials: properties derive from their constituent atoms.

Metamaterials: properties derive from their constituent units. These units can be engineered as we please.

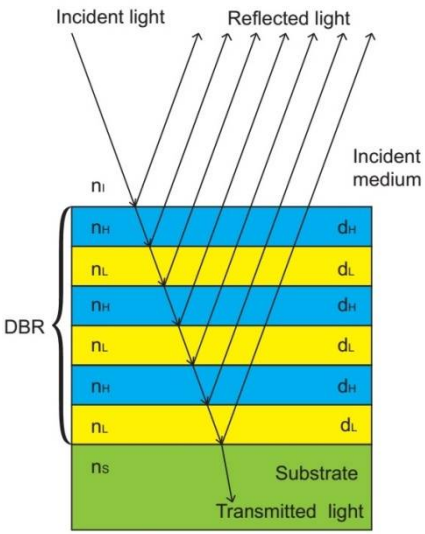


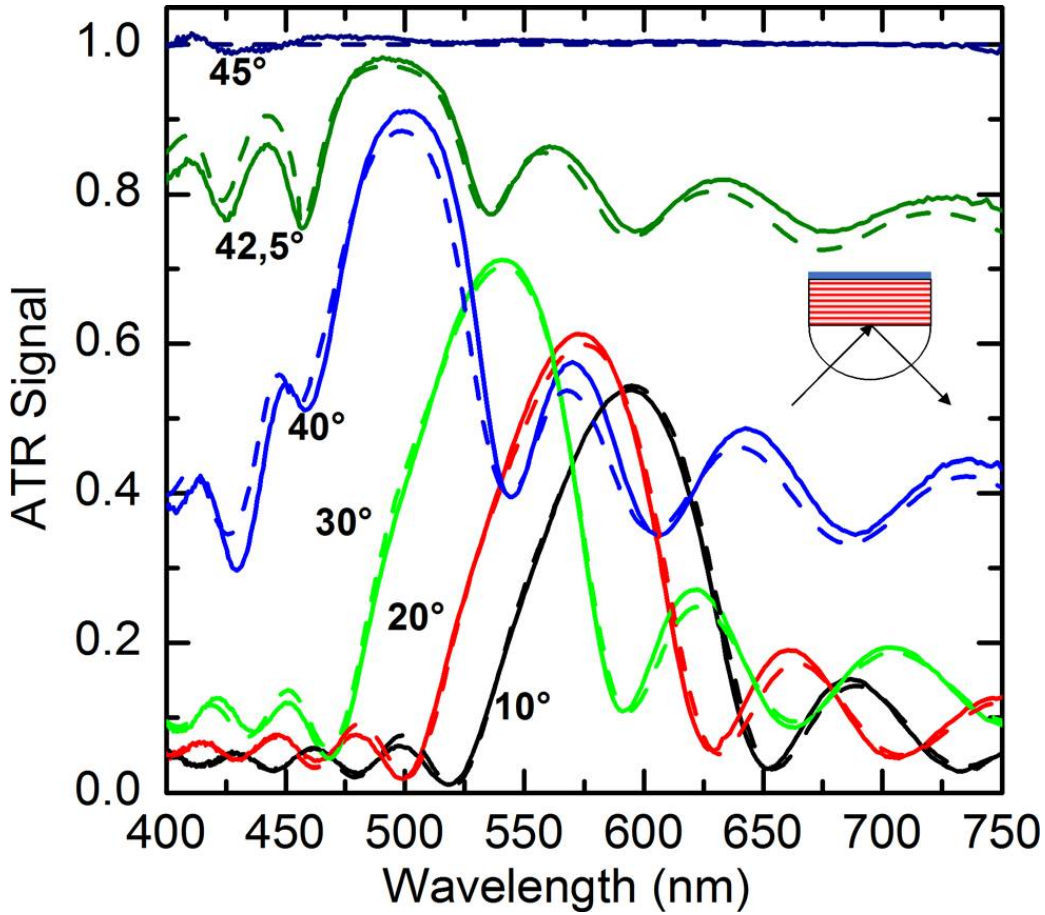




"**Meta-**" means "altered, changed" or higher, beyond"

Example: the Distributed Bragg Reflector (DBR)



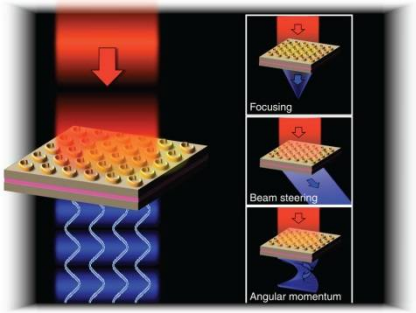


Periodic modulation of refractive index ~ λ ⟶ Band gap

Fornasari et al., Applied Physics Letters **105**, 053303 (2014)

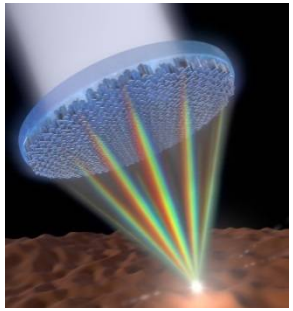
Motivations: fundamentals and applicative issues

The light-matter interplay originates a multitude of effects



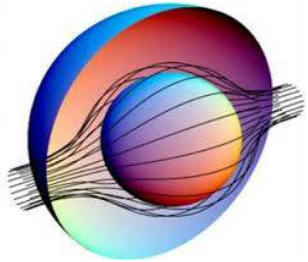
Beam shaping

Nature Comm. ***6****,* 7667 (2015)



Metalenses

Nature Nanotech. **13**, 220 (2018)



Invisibility Cloak

Science 349, 1310 (2015)

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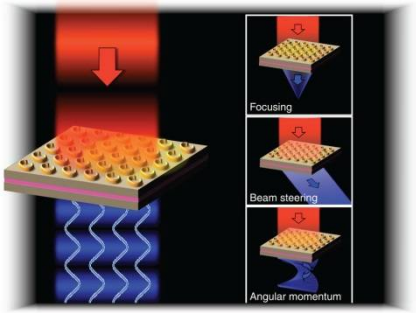

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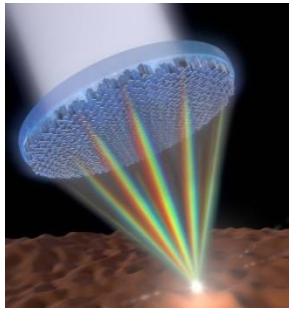

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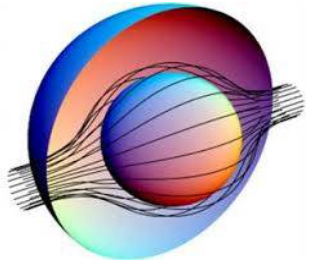
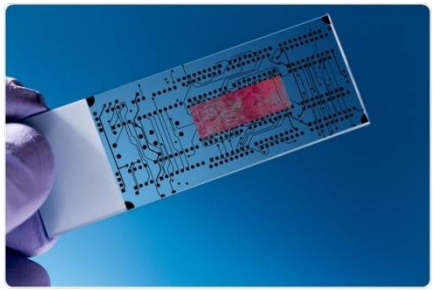


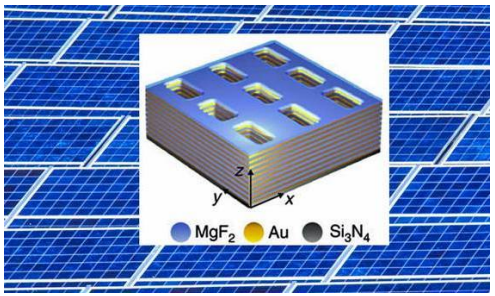
Invisibility Cloak

Science 349, 1310 (2015)

Strong technological fallout



Sensing

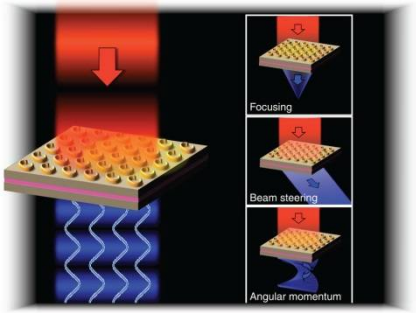


Sustainable energy

Devices

Motivations: fundamentals and applicative issues

The light-matter interplay originates a multitude of effects



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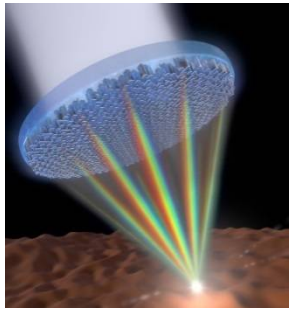

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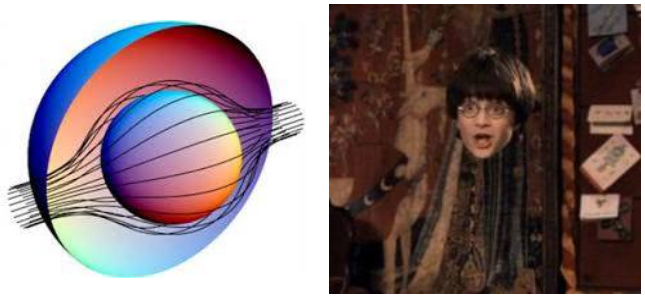

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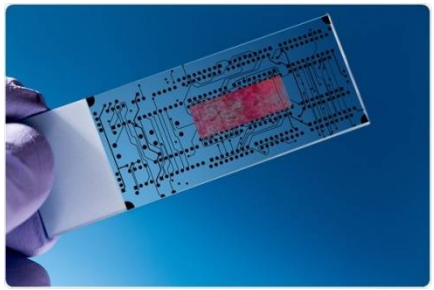
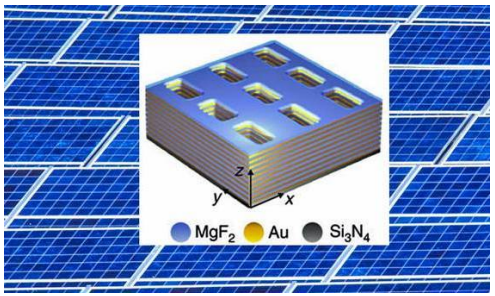


Sensing



Sustainable energy

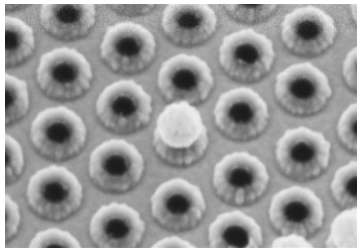
Devices

Control and enhancement of the electromagnetic field in matter

Research at UniPV

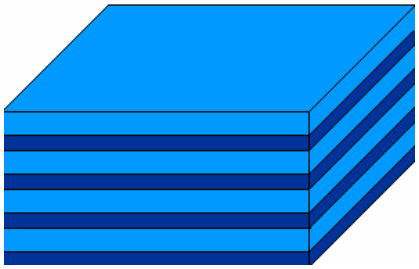
Plasmonic structure:

Gold nanostructured plasmonic surface

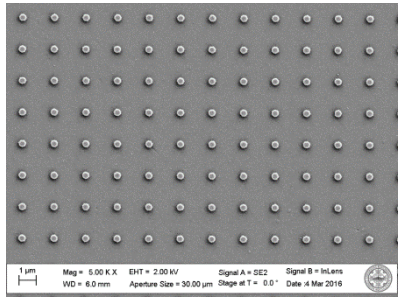


Photonic structures

Distributed Bragg Reflector

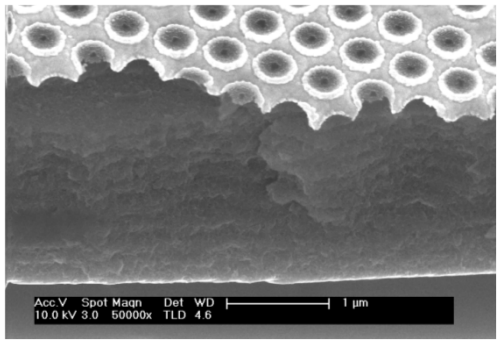


Passive Anapoles

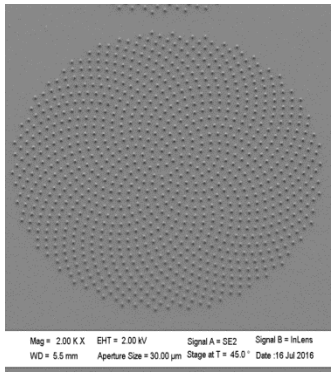


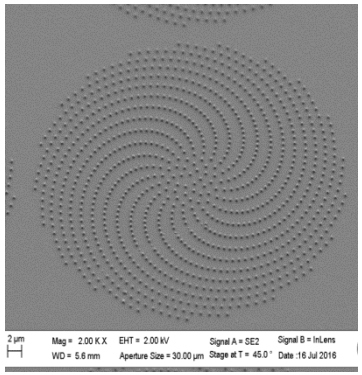
Hybrid plasmonic-photonic structures

Distributed Bragg Reflector + plasmonic nanostructure



Vogel spiral nanoparticles distribution





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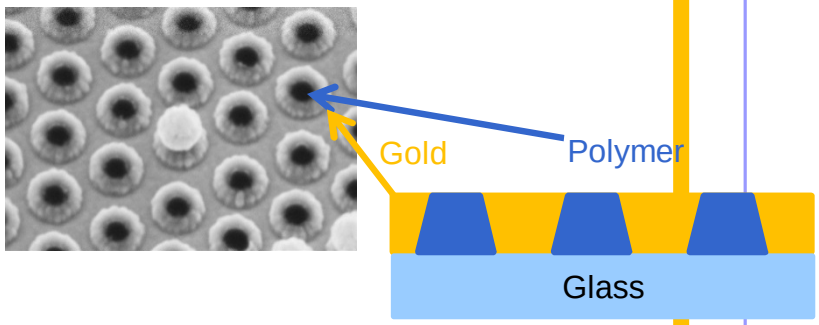

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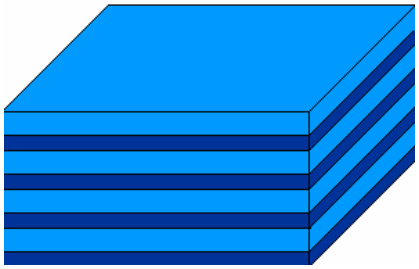

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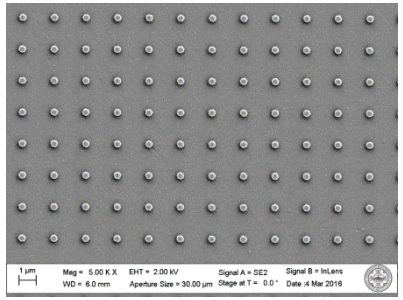

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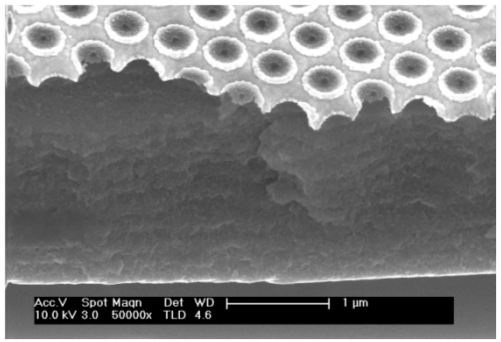

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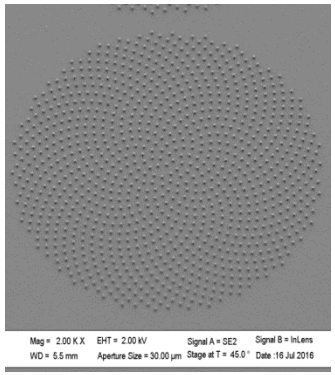
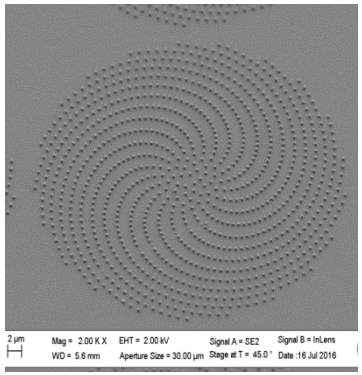


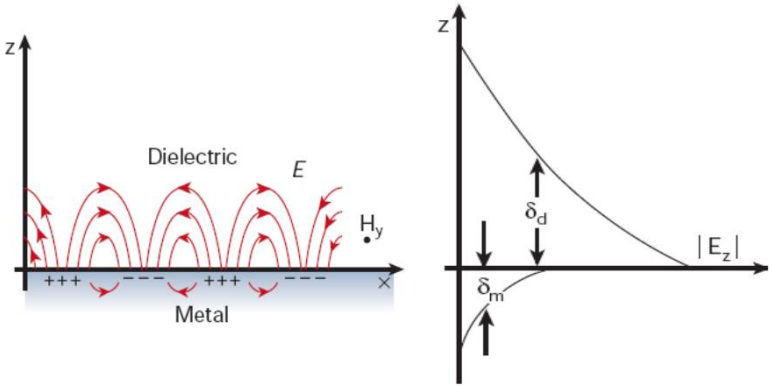


Surface plasmon

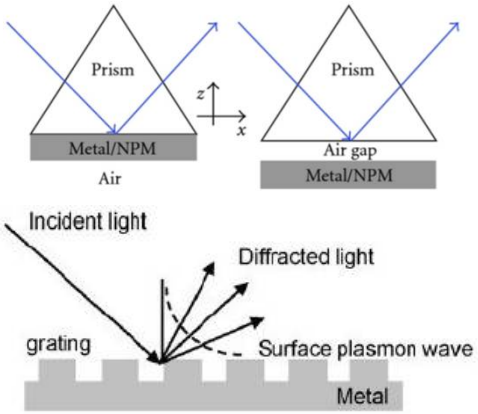
Plasmon : charge oscillation of free electrons in metals.

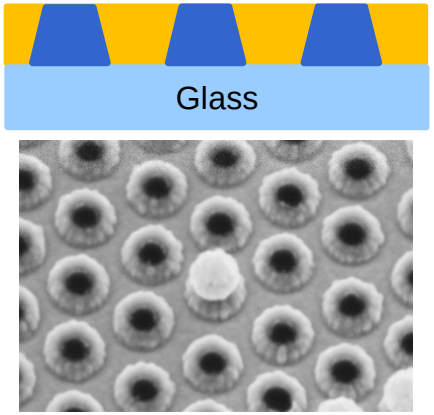
Propagating surface plasmon

Longitudinal Surface waves



Coupling strategies





Barnes et al., Nature **424**, 824 (2003)
Martin-Moreno et al., Phys. Rev. Lett. **86**, 1114 (2001)

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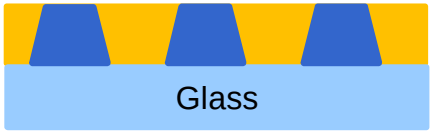

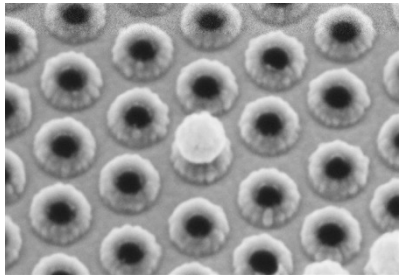

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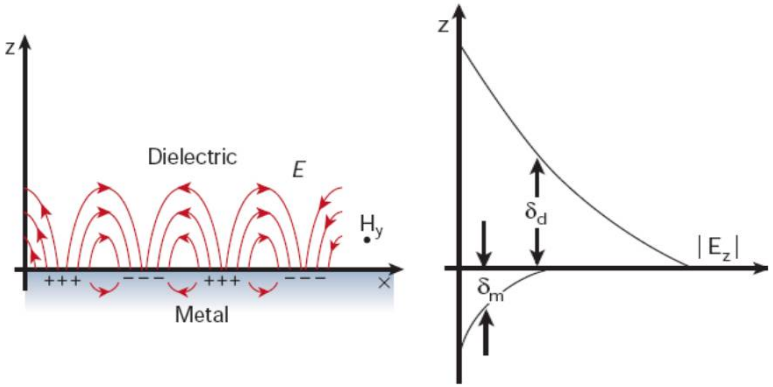

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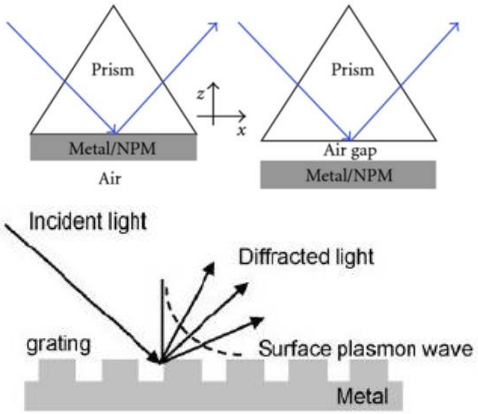
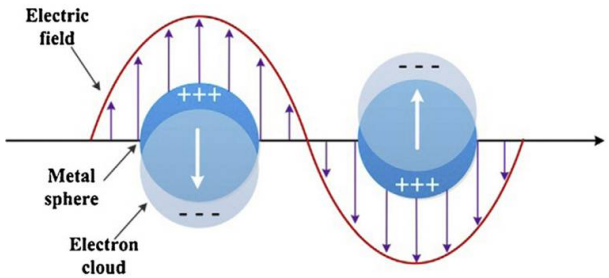
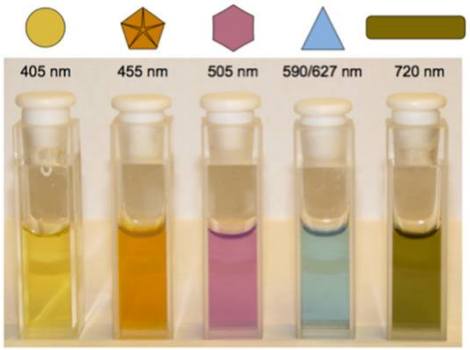


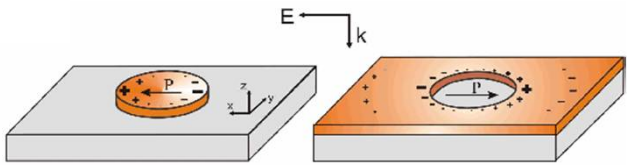
Localized surface plasmon

Nanoparticles





Holes in a gold film



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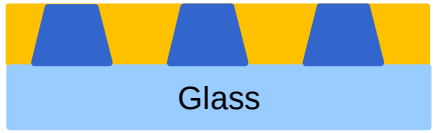

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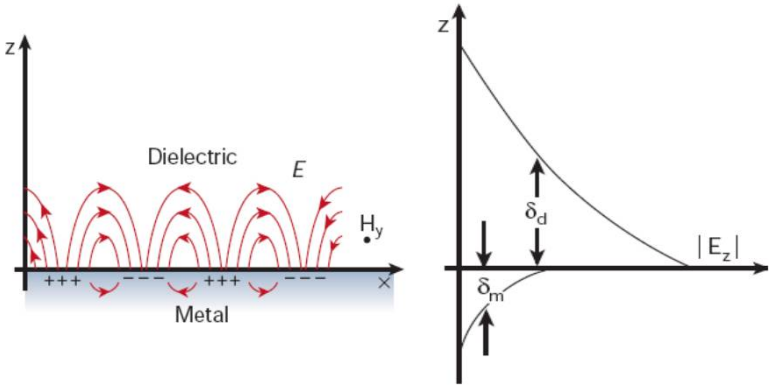

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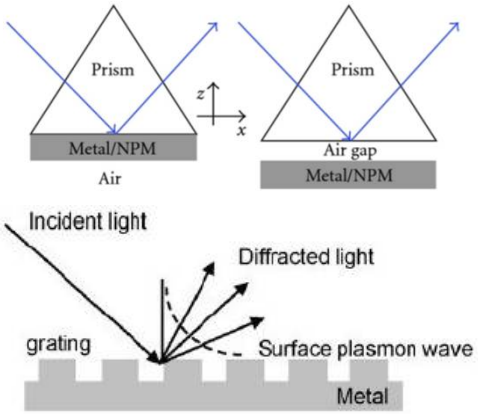
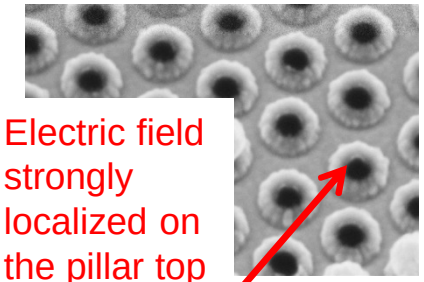
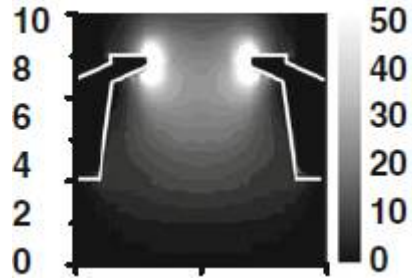




Electric field strongly localized on the pillar top



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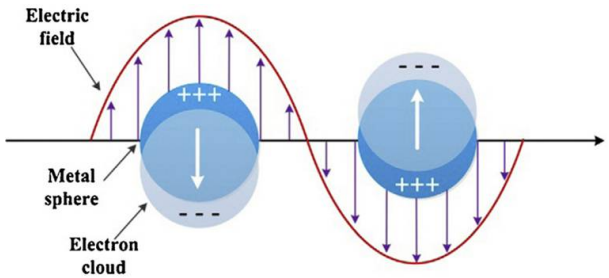

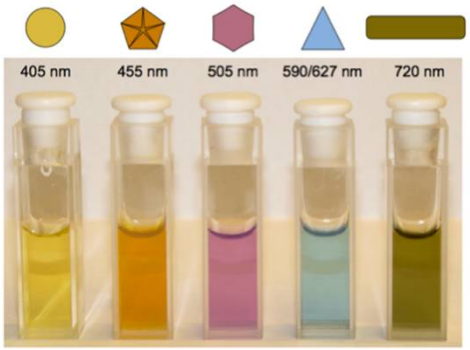

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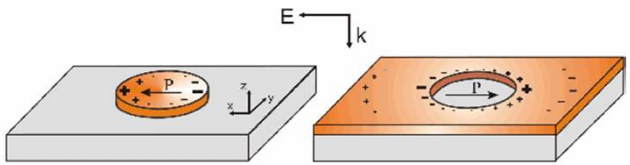

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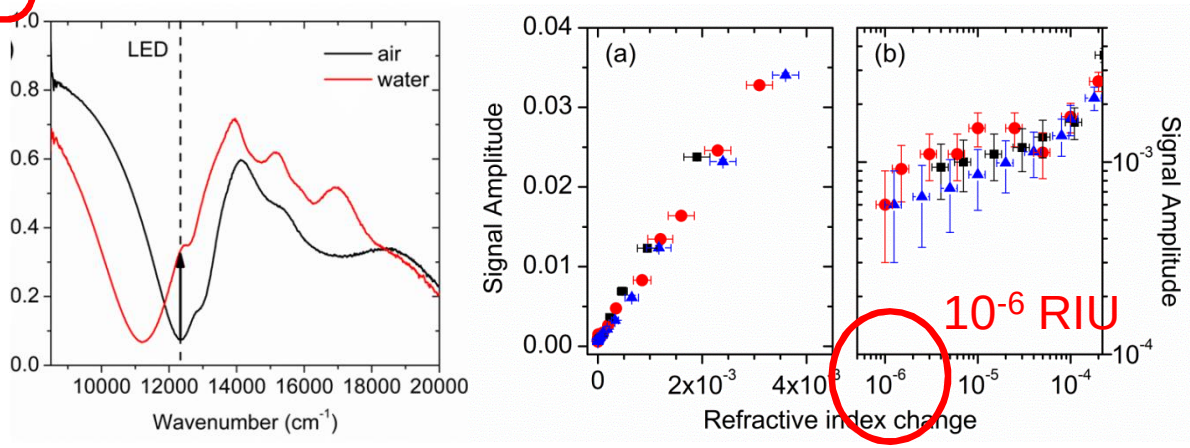
Imaging Nanoplasmonic sensor

Grating ~ Easy plasmonic coupling

Pillar ~ Strong field localization

→ Sensitivity to refractive index variations



Bottazzi B., Fornasari L. et al., J. Biomed. Opt. **19**(1), 017006 (2014)
Carpignano, F., Fornasari, L. et al., IET Conference Publications CP704 (2016)

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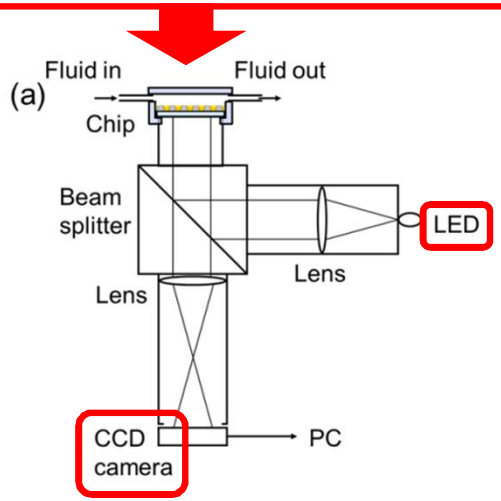
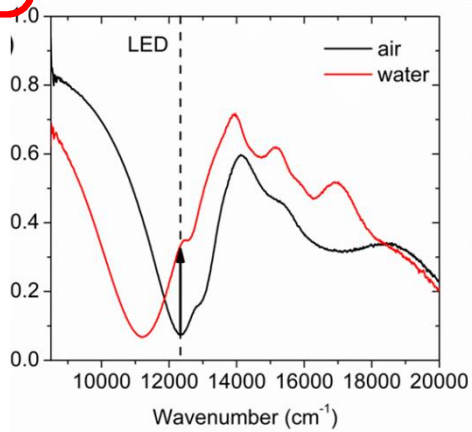
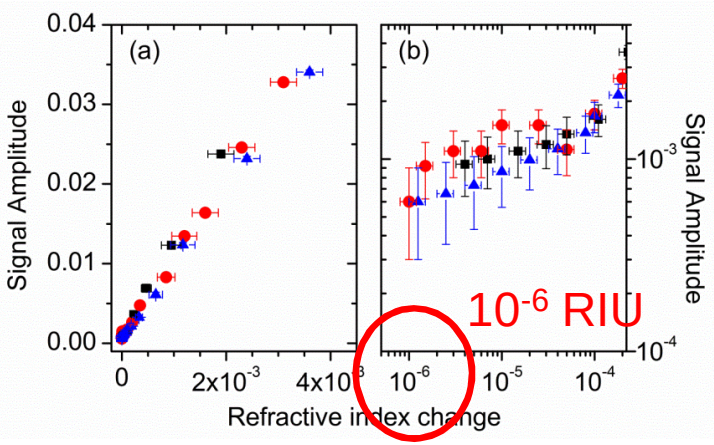
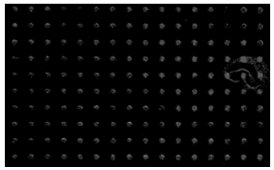


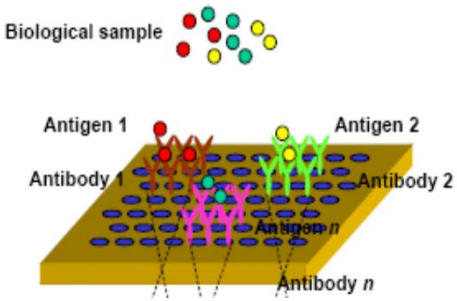


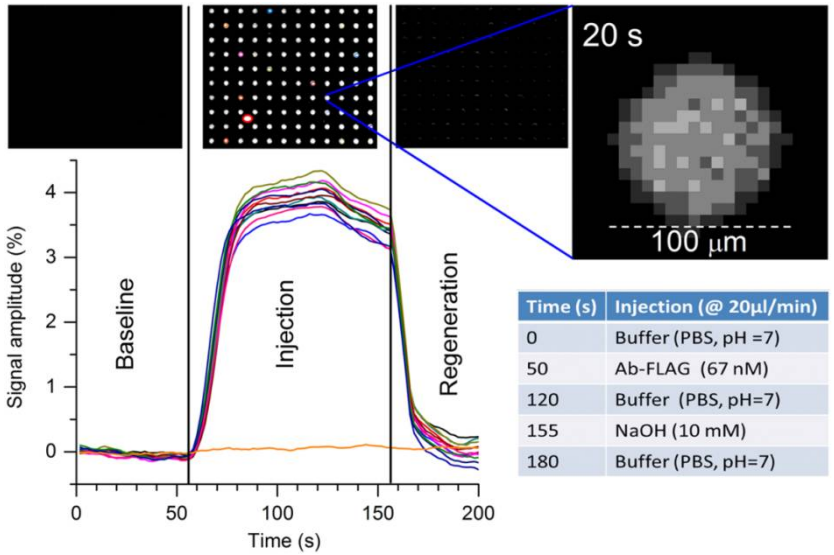


Functionalization



Spot diameter ~ 100 µm





Time (s)	Injection (@ 20µl/min)
0	Buffer (PBS, pH =7)
50	Ab-FLAG (67 nM)
120	Buffer (PBS, pH=7)
155	NaOH (10 mM)
180	Buffer (PBS, pH=7)

Label-free

Real-time

Imaging

Multiplexing capability

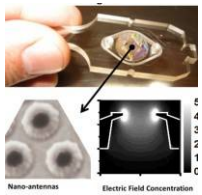
Bottazzi B., Fornasari L. et al., J. Biomed. Opt. **19**(1), 017006 (2014)

Carpignano, F., Fornasari, L. et al., IET Conference Publications CP704 (2016)

Project

Joint spin-off of the University of Pavia and of the JRC at Ispra.

- Development of a new type of plasmonic structure
- Development of portable sensing device



In the past different projects in different application fields:

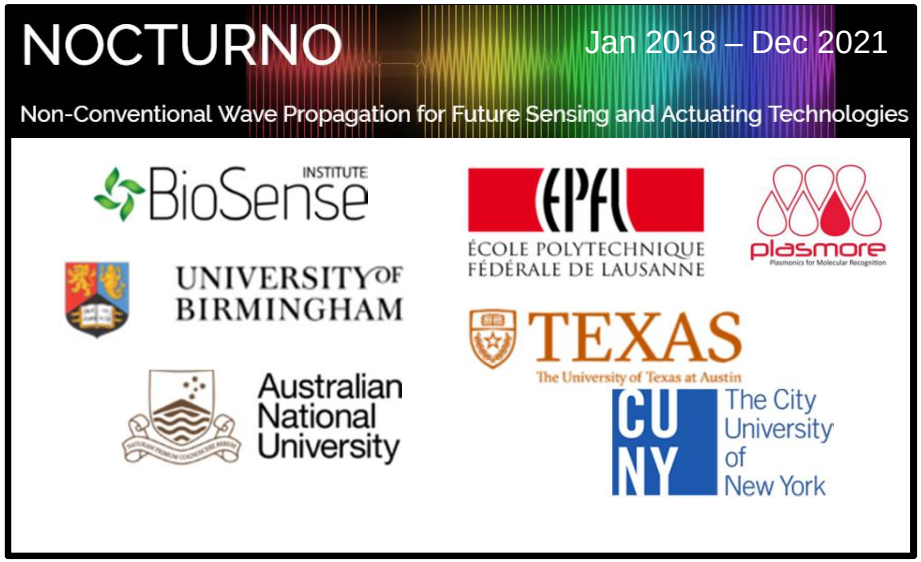
Food analysis: milk, beer…

Water analysis

Biomedical analysis

Proteomics

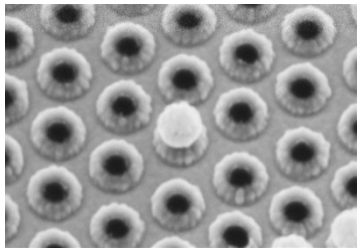
Actually



Research at UniPV

Plasmonic structure:

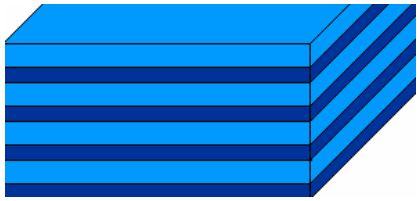
Gold nanostructured plasmonic surface



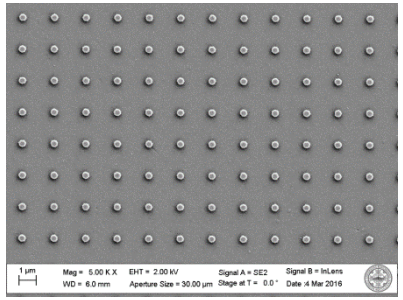
Photonic structures

Distributed Bragg Reflector

Fluorescence redistribution and enhancement

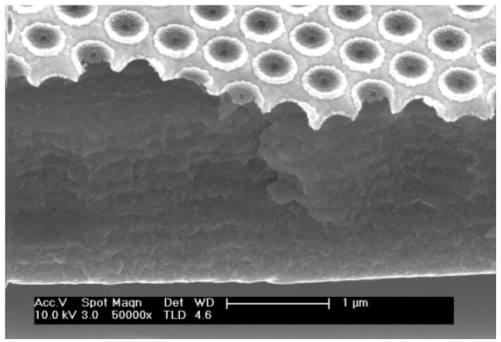


Passive Anapoles

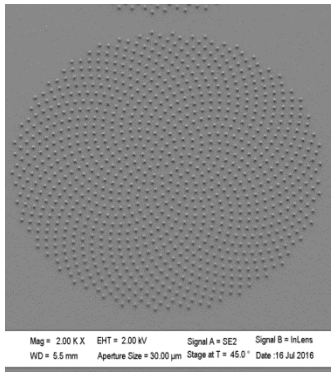


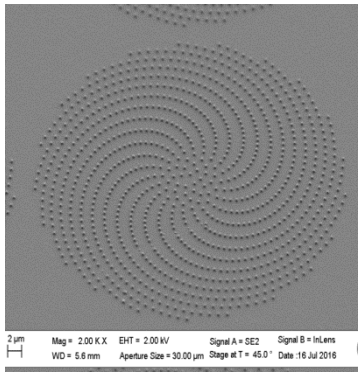
Hybrid plasmonic-photonic structures

Distributed Bragg Reflector + plasmonic nanostructure



Vogel spiral nanoparticles distribution



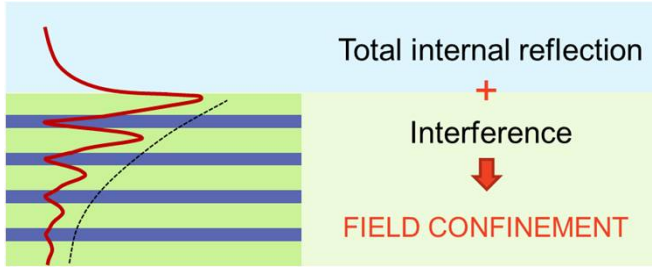


Cite this: *Phys. Chem. Chem. Phys.*, 2016, **18**, 14086

Demonstration of fluorescence enhancement *via* Bloch surface waves in all-polymer multilayer structures†

Lucia Fornasari,*[a] Francesco Floris,[a] Maddalena Patrini,[a] Davide Comoretto[b] and Franco Marabelli[a]

Bloch surface waves are modes that propagate at the surface of a photonic crystal. The field confinement is provided by total internal reflection and the photonic band gap.



The electromagnetic field is mainly confined at the interface.

Fornasari et al. APL **105**, 053303 (2014)

Cite this: *Phys. Chem. Chem. Phys.*, 2016, **18**, 14086

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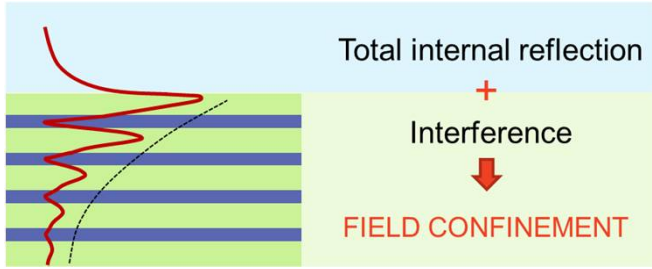
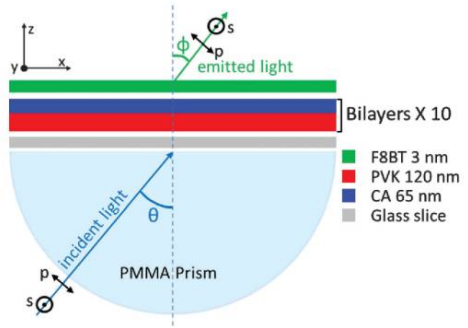
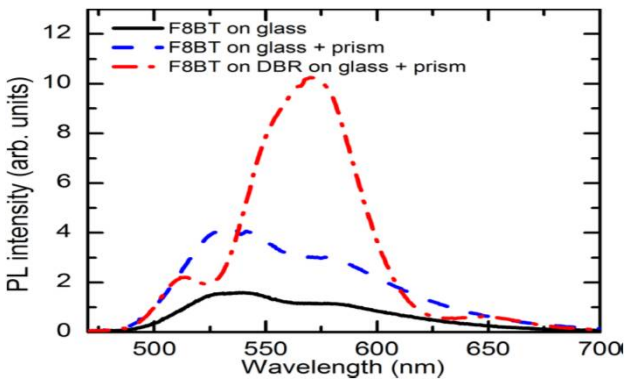
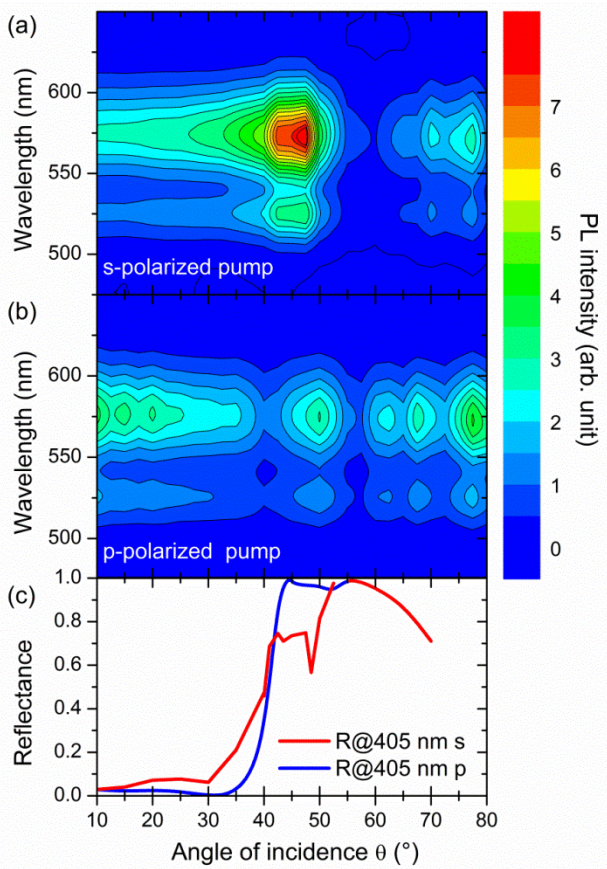


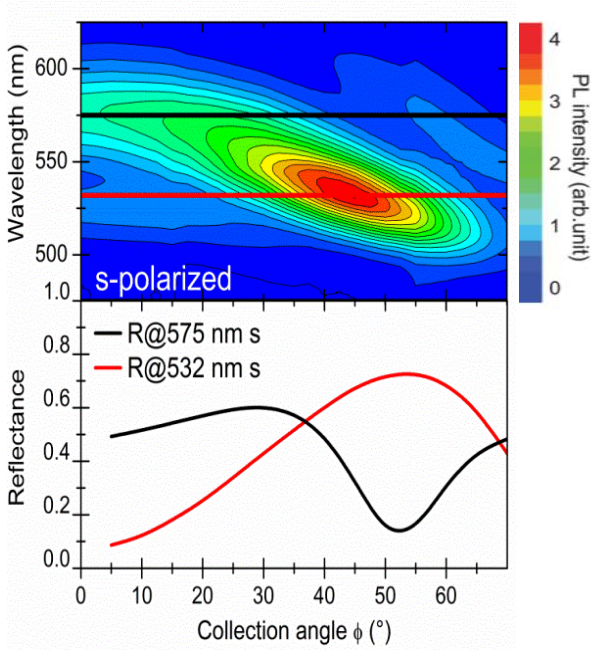
The electromagnetic field is mainly confined at the interface.

Coupling of the laser pump (405 nm) with the BSW







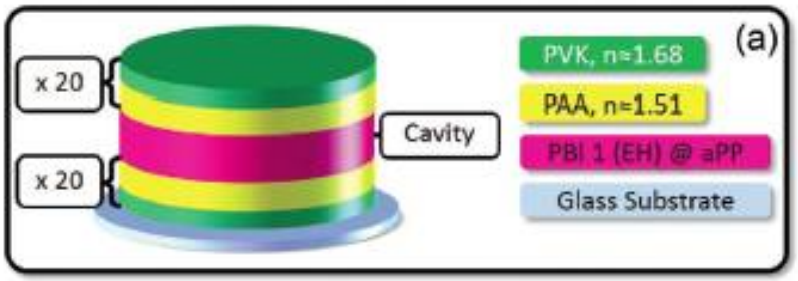


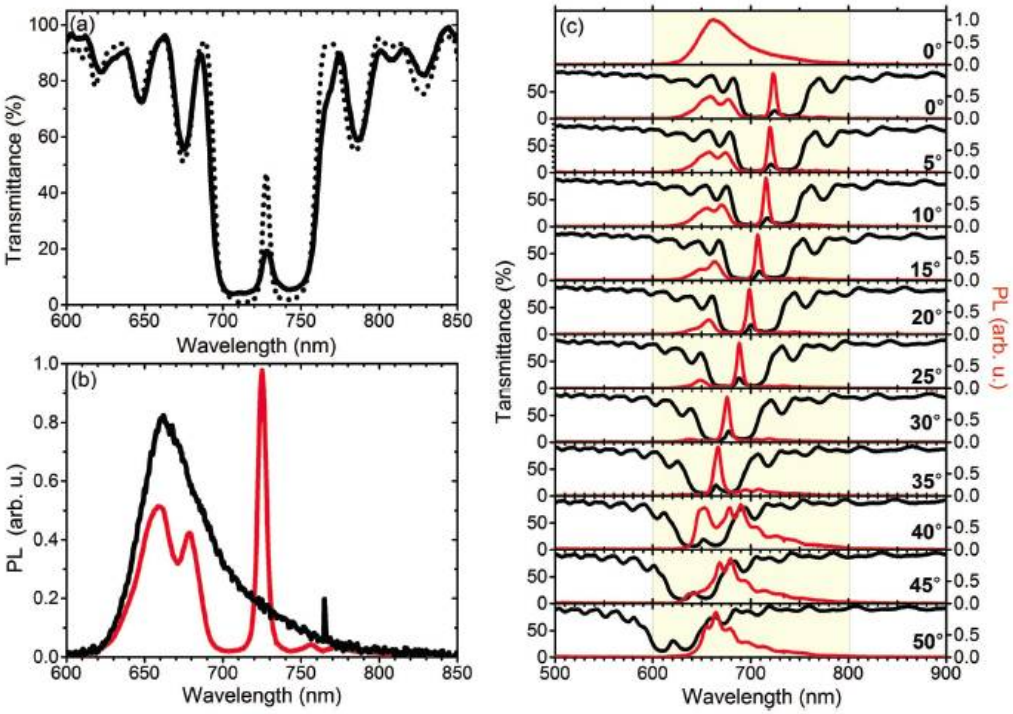
Fornasari et al. APL **105**, 053303 (2014)

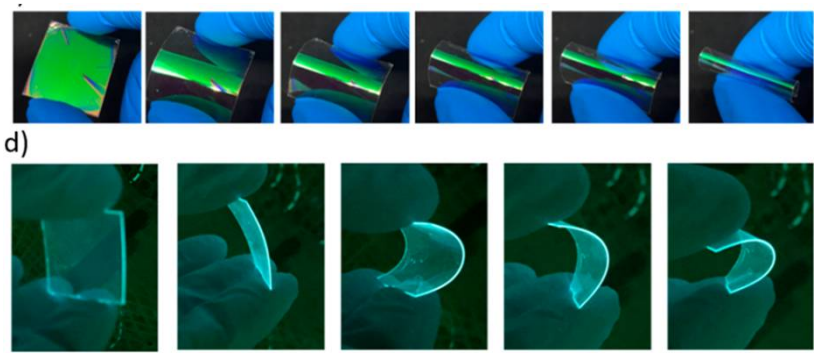
FULL PAPER
Planar Microcavities
Adv. Optical Mater. **2017**, *5*, 1700523
ADVANCED OPTICAL MATERIALS
www.advopticalmat.de

All-Polymer Photonic Microcavities Doped with Perylene Bisimide J-Aggregates

Paola Lova, Vincenzo Grande, Giovanni Manfredi, Maddalena Patrini, Stefanie Herbst, Frank Würthner, and Davide Comoretto**







⇒ Color-tunable light emitting devices

Based on a single active material

Highly flexible under mechanical bending

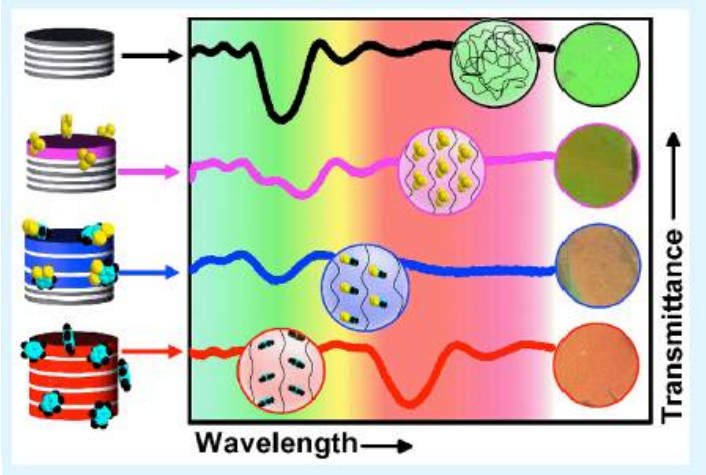
Interest for the integration of highly-emitting and easily processable supramolecular J-aggregates into polymer matrices. All-polymer processable materials are promising for the integration of solid-state active media into plastic photonic devices such as in lasing microcavity.

DOI: 10.1021/acsphotonics.7b01077
ACS Photonics 2018, 5, 867–874

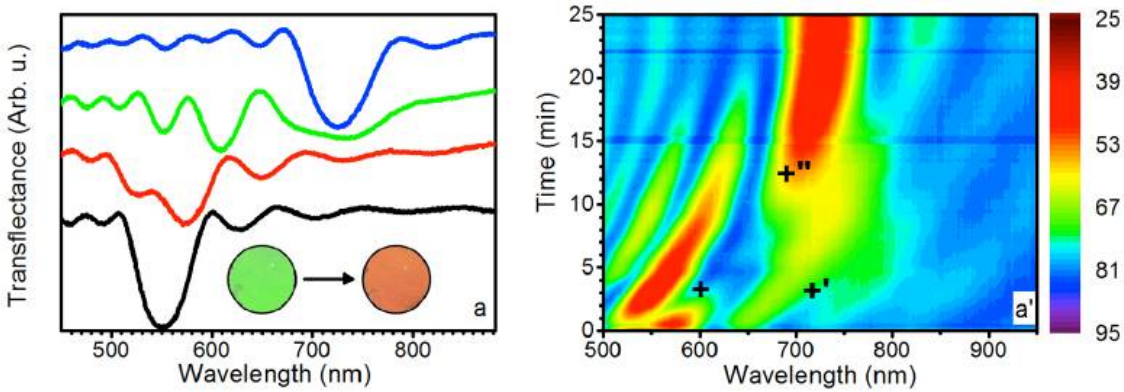
ACS APPLIED MATERIALS & INTERFACES
Research Article
www.acsami.org
DOI: 10.1021/acsami.6b10809
ACS Appl. Mater. Interfaces 2016, 8, 31941−31950

Label-Free Vapor Selectivity in Poly(*p*-Phenylene Oxide) Photonic Crystal Sensors

Paola Lova,[*,†,‡] Chiara Bastianini,[‡] Paolo Giusto,[‡] Maddalena Patrini,[§] Paola Rizzo,[∥] Gaetano Guerra,[∥] Mario Iodice,[⊥] Cesare Soci,[#] and Davide Comoretto[*,‡]



BENZENE



The phase transition of amorphous PPO thin films into semi-crystalline nanoporous **phases induced by the absorption of Volatile Organic Compounds vapors** allows DBR sensors with label-free selectivity.

The **visual colorimetric response of the sensor**, which does not require any signal transduction, could potentially make these systems effective safety devices.

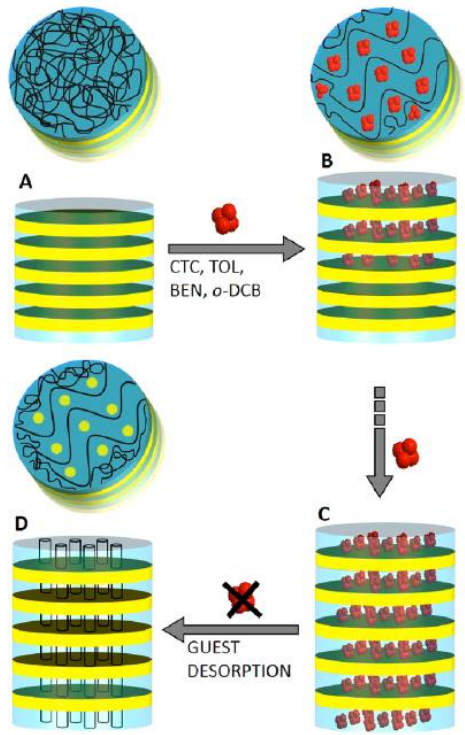
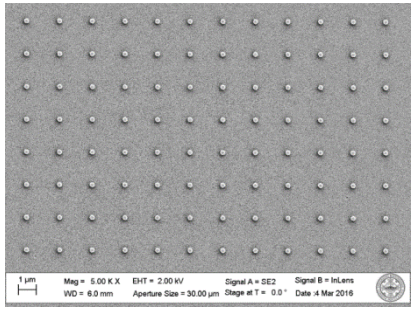
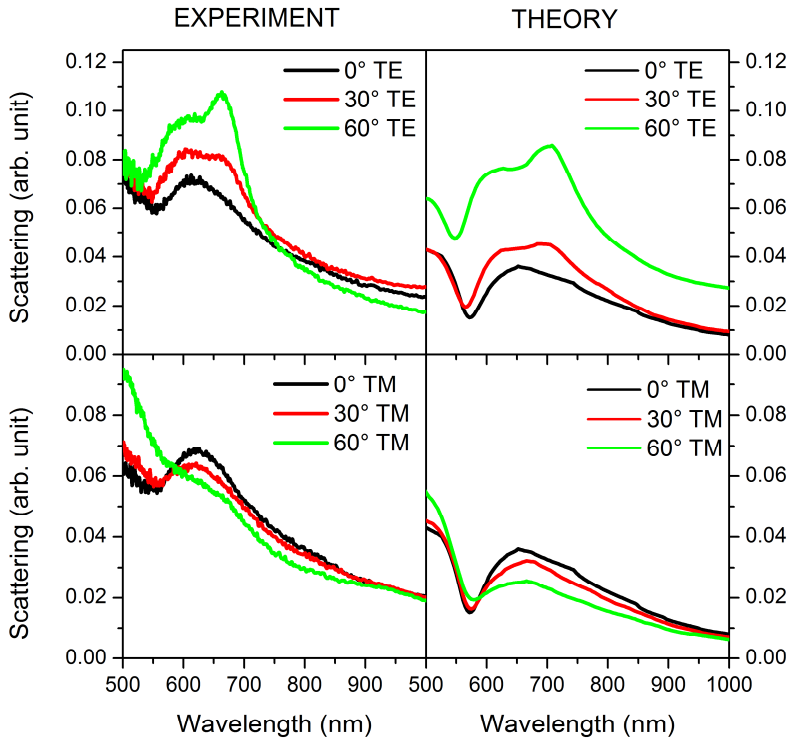


Figure 6. Schematic of the formation of PPO-VOC cocrystals within the DBR during vapor exposure (A, B) and of the guest desorption (C, D).

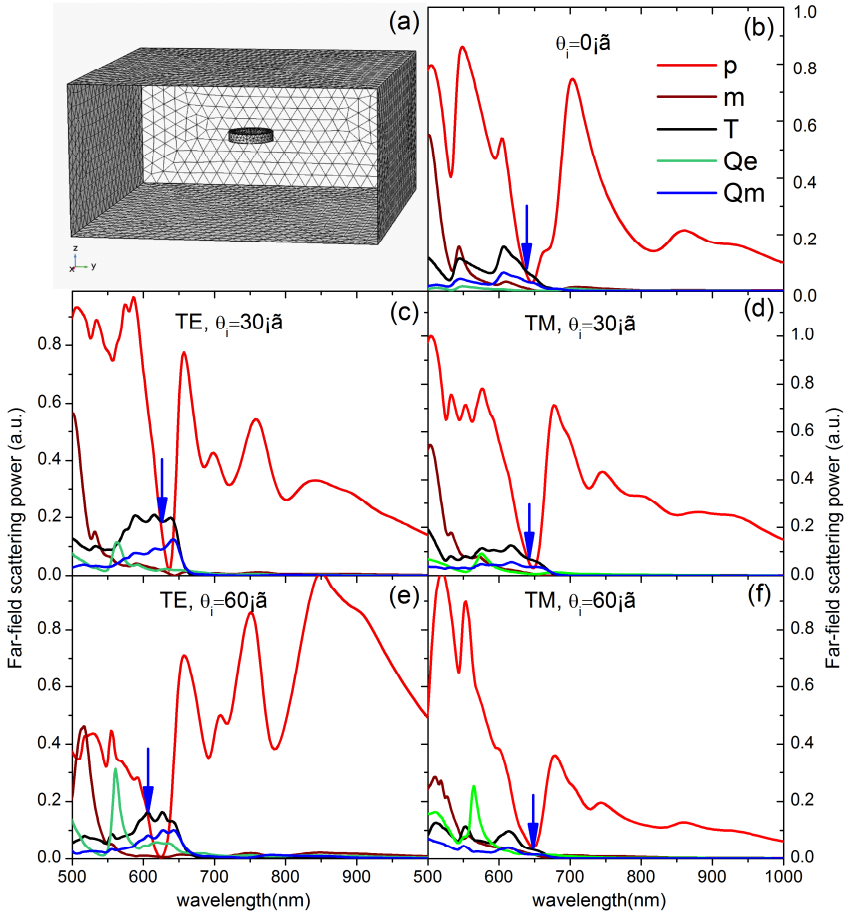
Passive Anapoles



Si cylinder :
height = 60 nm
diameter = 300 nm



Multipolar decomposition at variable incidence and polarization conditions



Anapole mode: interference between electric dipole and toroidal mode.

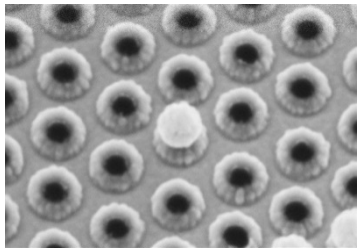
Decrease in scattering and increase in absorbed light.

Passive anapole device for absorption enhancement in the visible regime, in preparation.

Research at UniPV

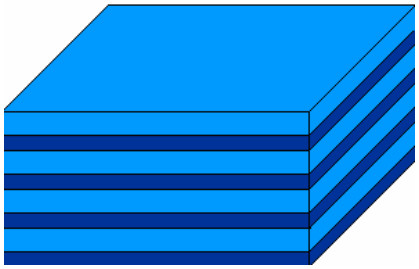
Plasmonic structure:

Gold nanostructured plasmonic surface

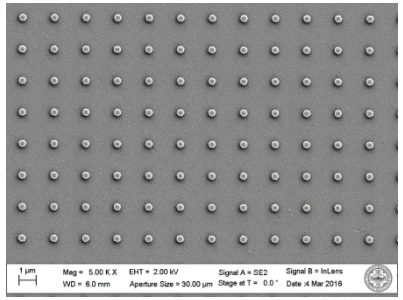


Photonic structures

Distributed Bragg Reflector

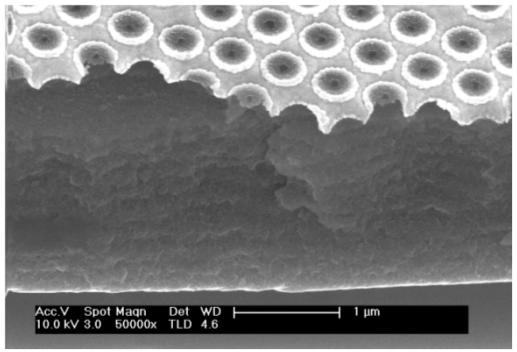


Passive Anapoles

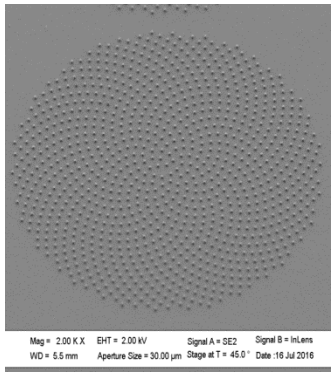


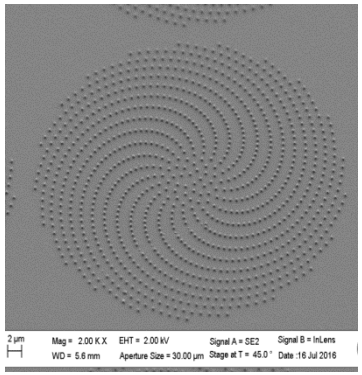
Hybrid plasmonic-photonic structures

Distributed Bragg Reflector + plasmonic nanostructure



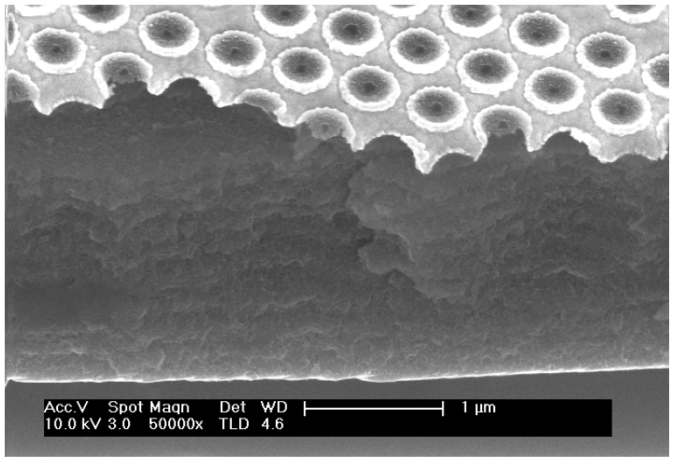
Vogel spiral nanoparticles distribution

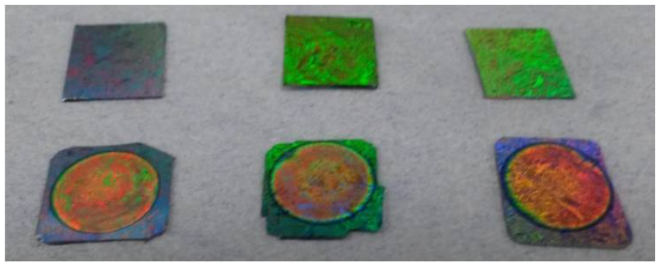




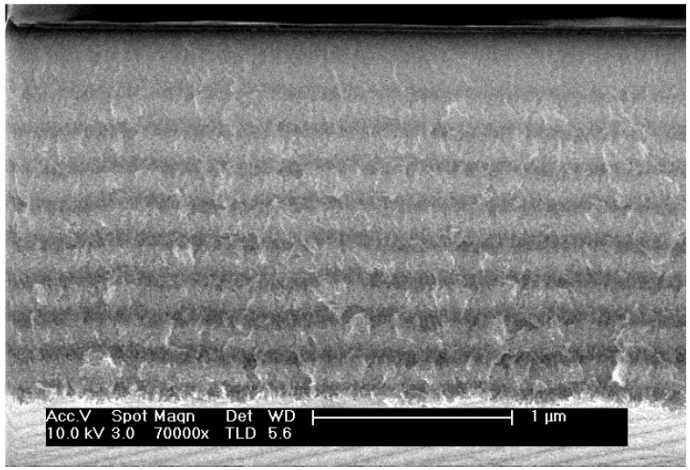
Hybrid plasmonic and photonic structure

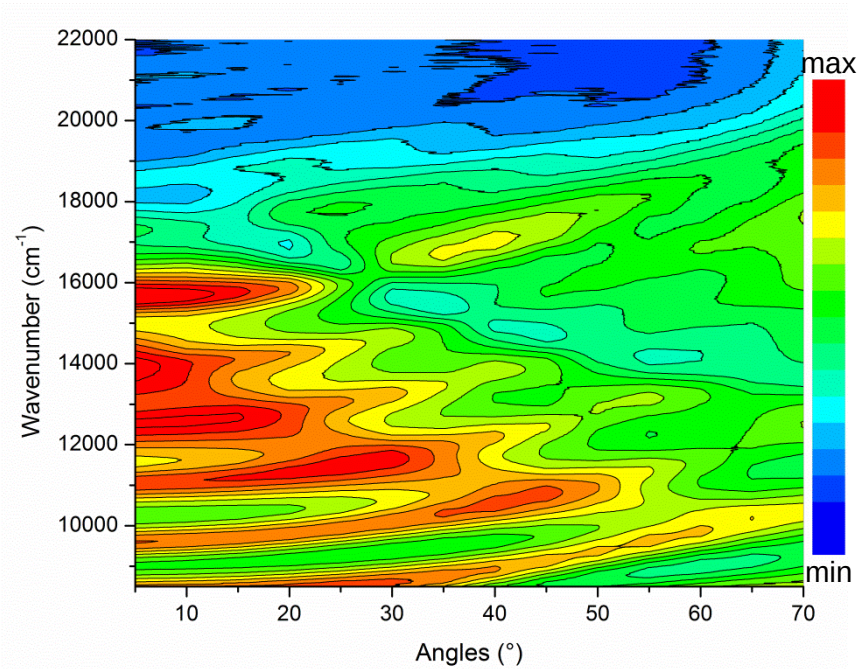
Nanostructured plasmonic surface





Porous silicon DBR



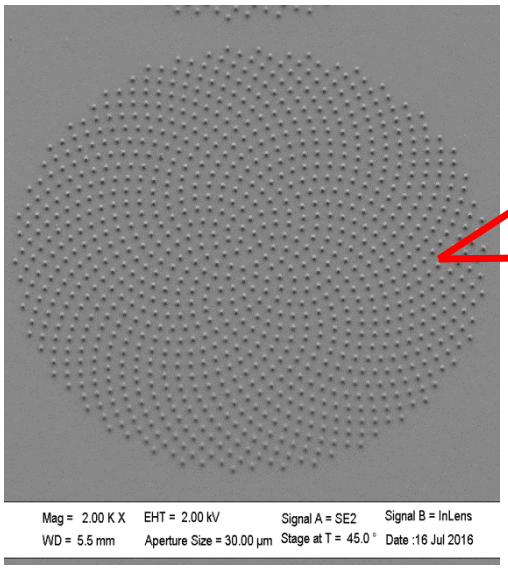


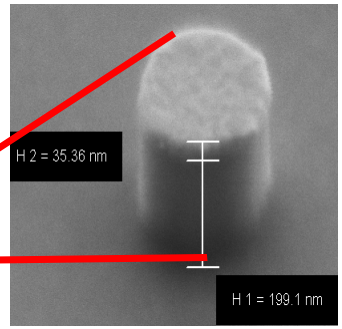
Complex optical response.
Interaction effects.

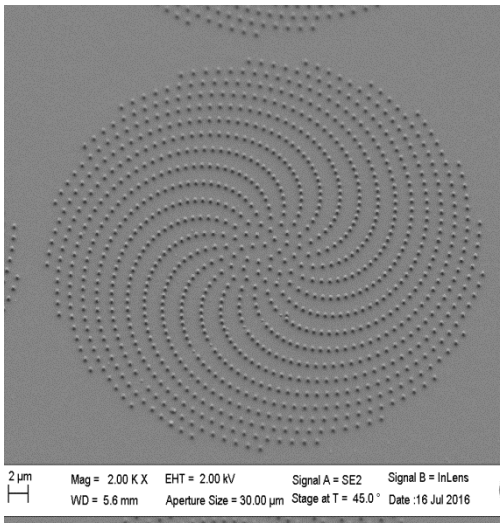
Hybrid photonic-plasmonic devices for enhanced sensitivity biosensor, Nanophotonics and Micro/Nano Optics Conference 2018

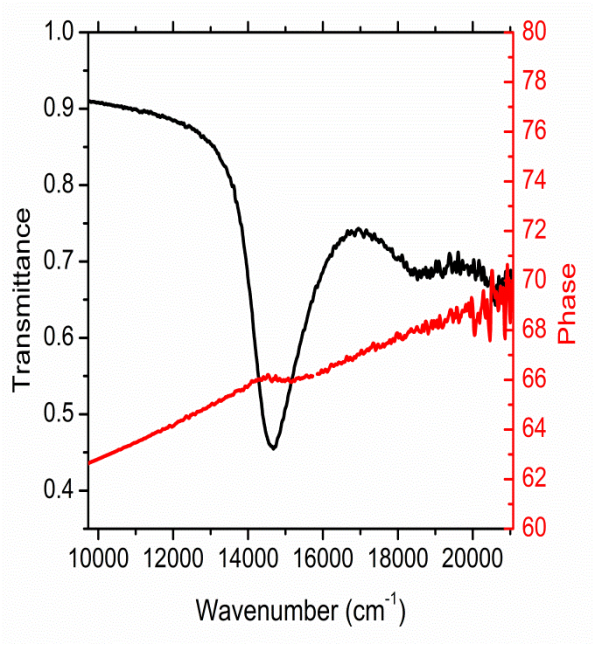
Vogel Spiral

Quasi-ordered structures



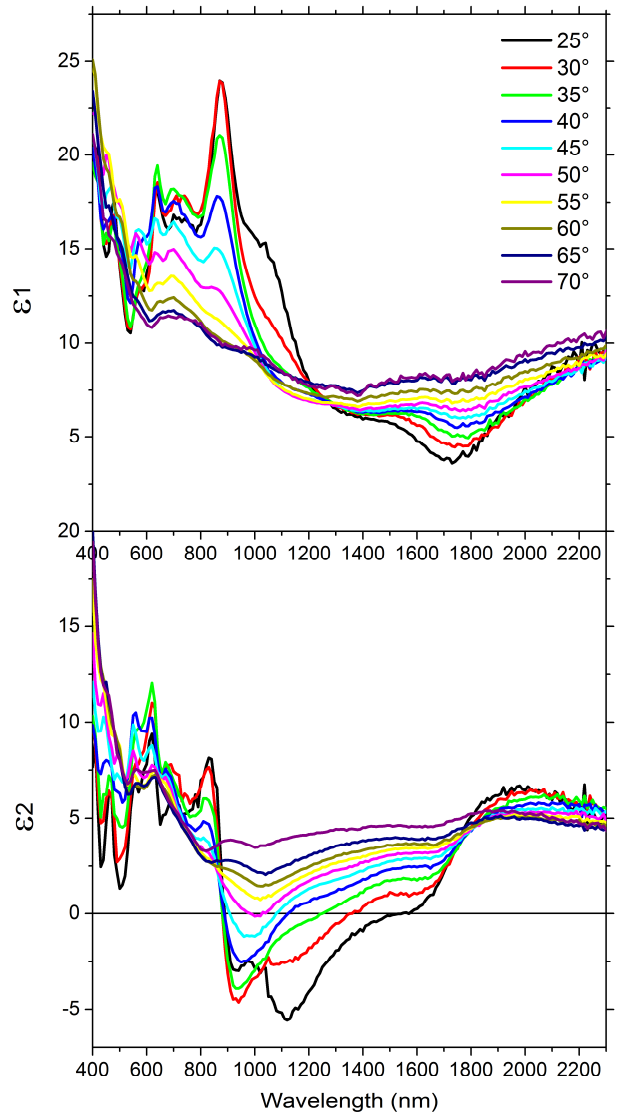






Phase effect

Negative ε2



paper in preparation

Conclusion

Plasmonic structure:

Gold nanostructured plasmonic surface

Photonic structures

Distributed Bragg Reflector

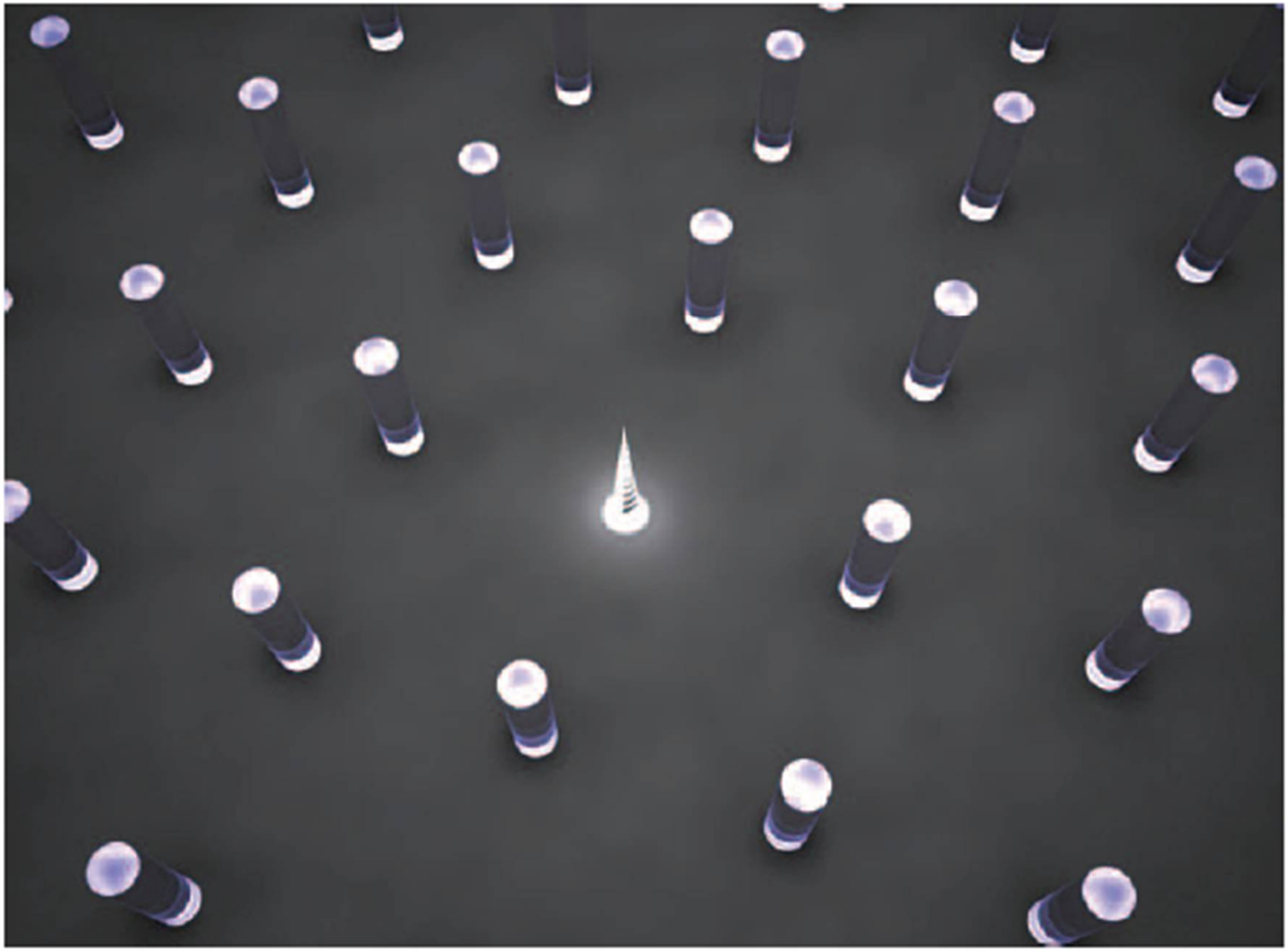
Passive Anapoles

Hybrid plasmonic-photonic structures

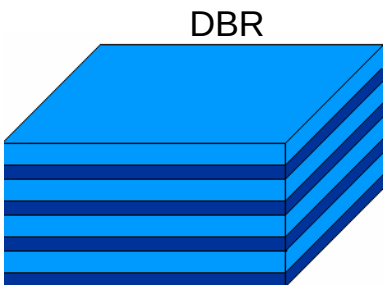
Vogel spiral nanoparticles distribution

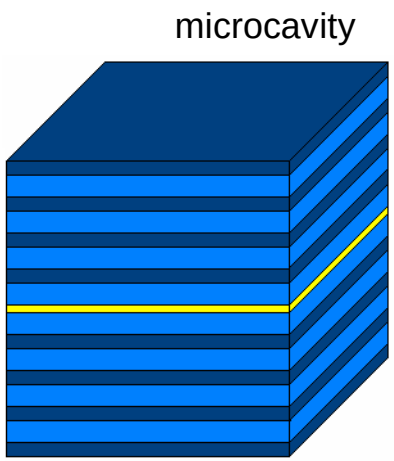
Distributed Bragg Reflector + plasmonic nanostructure

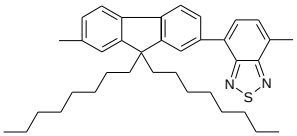
Thank you for your attention!



POLYMER DBR & MICROCAVITIES

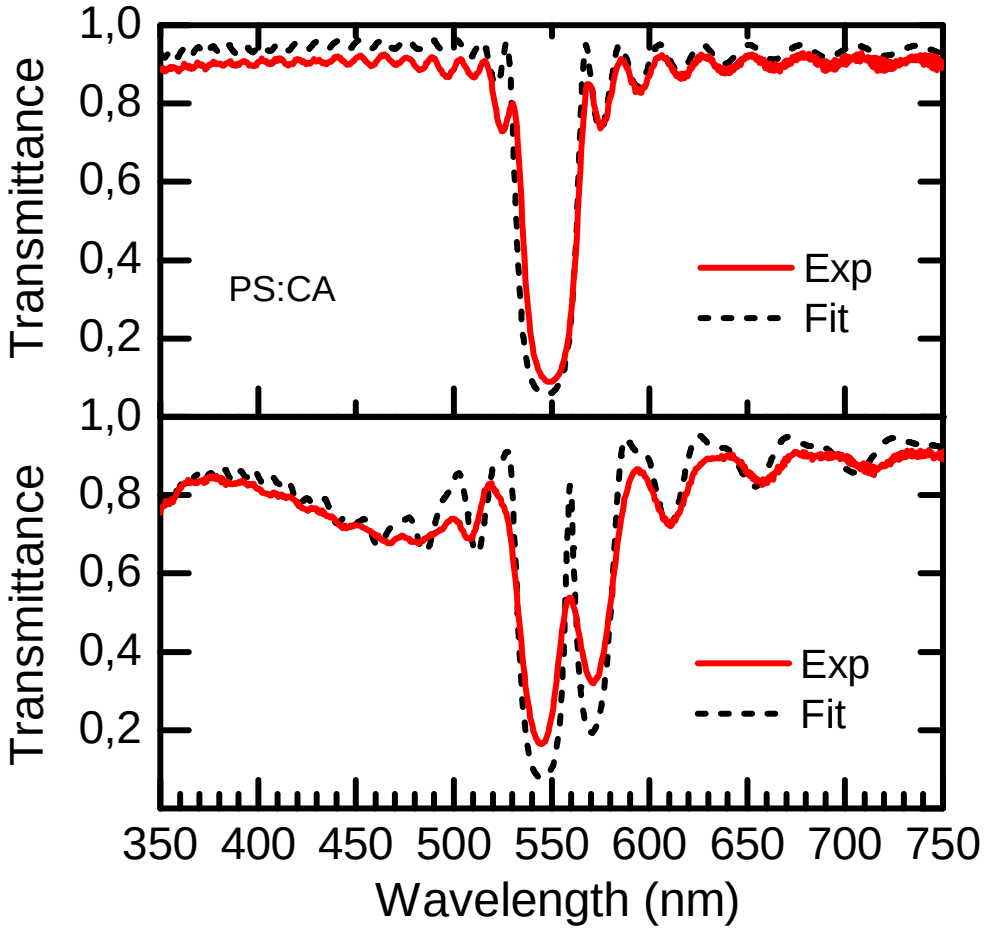






F8BT

10-150 nm



L. Frezza et al., J. Phys. Chem. C115, 19939 (11)

G. Canazza et al. Laser Physics Lett. 11, 035804 (14).

in the case of DBR, i.e. a 1D PhC, the gap is observed as minimum in transmission. With the microcavity, i.e. a layer different to the others, a sort of defect for the periodical structure, a typical feature is observed within the photonic band gap. This feature is called cavity mode. Photon with such energy, even if within the gap, are allowed to propagate. The aim is to insert in the cavity a fluorescent polymer, F8BT, with the cavity mode tuned over the fluorescence spectrum.