# Fibre optic sensors based on Colloidal Crystal structures

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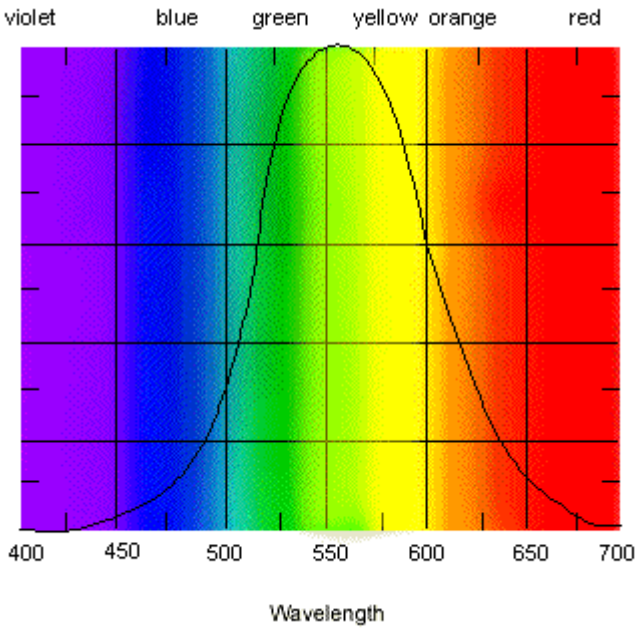
# Learning from Nature...

Photonic materials with structural color exist in Nature.

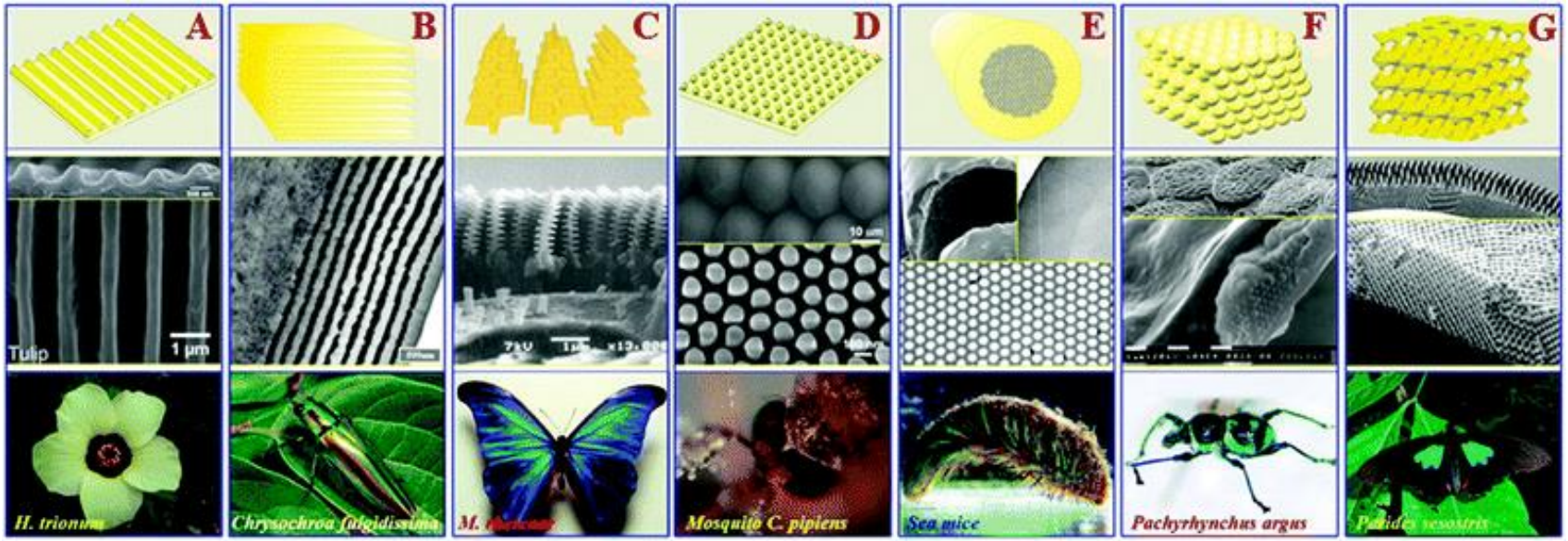





The color is due to the refraction of light in the periodic structure. Inspired by these biological displays from Nature, PhC have been developed as chromatic materials.

# Structural Colors as Photonic Crystal Structure

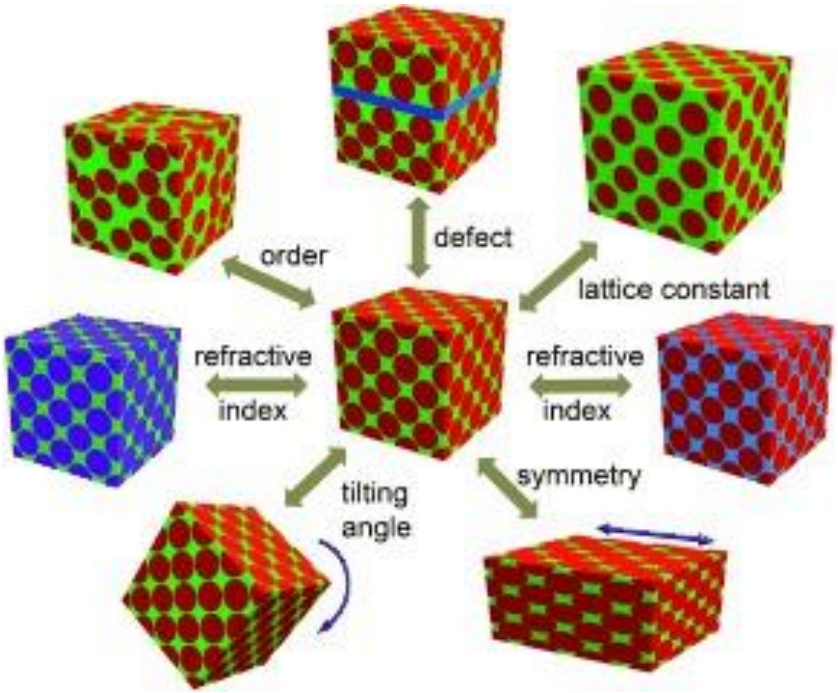
Photonic crystal (PhC) is a structure in which the refractive index has a periodic modulation on scales comparable with the wavelength of the light.



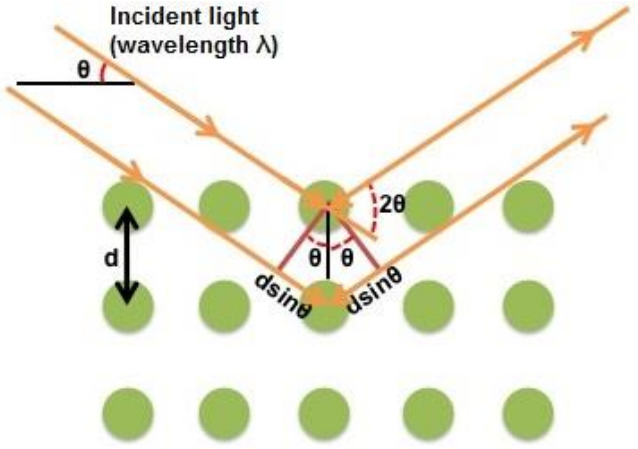

Many organism have the ability to tune their response to surrounding environment.

# **Photonic Crystal Structure:** tuning parameters

## Parameters space




## Combination of Snell's and Bragg's Law




$$\lambda = \sqrt{\frac{8}{3}} d\left(n^2 - sin^2\,\theta\right)^{1/2}$$

where

$$n^2 = n_{spheres}^2 V_{spheres} + n_{matrix}^2 V_{matrix}$$

# **Photonic Crystal Structure:** opal

## Building blocks

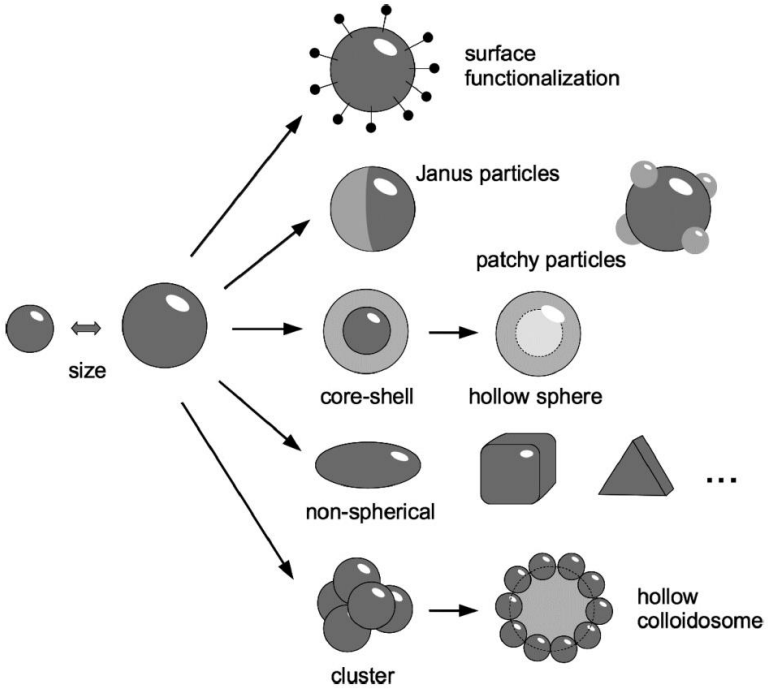
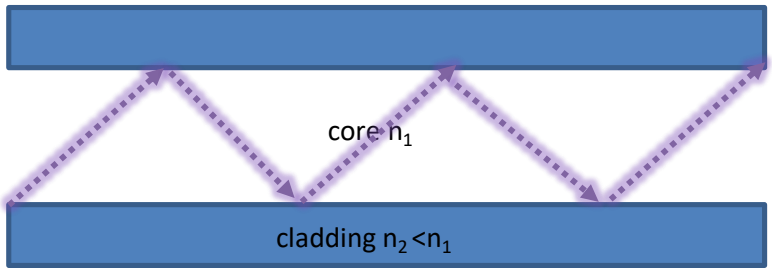



**Figure 3.** Evolving complexity of colloidal systems starting from simple spherical particles of a single material with varying dimension to surface-modified and internally structured objects.

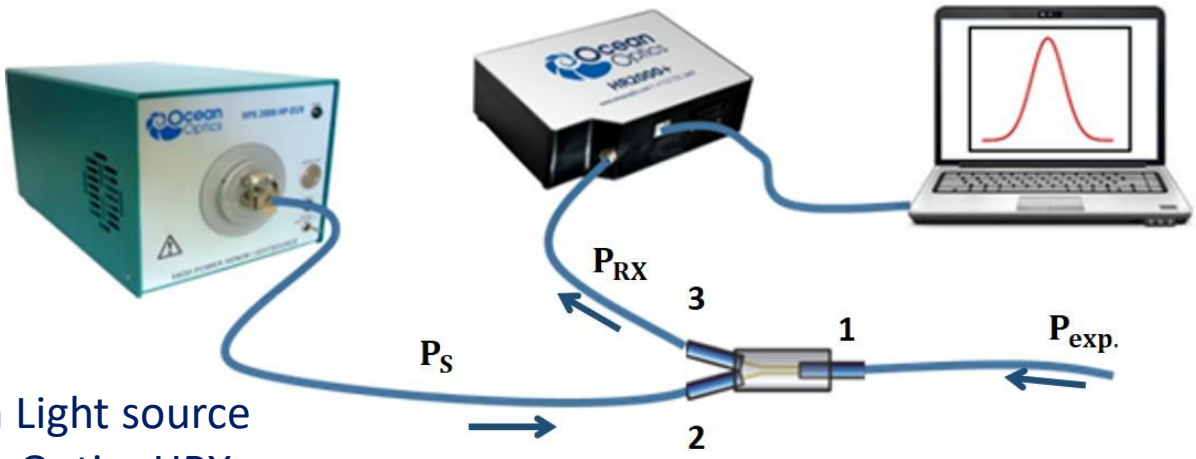
Building blocks assembly in opals

# Fiber Optic probes




Light transmission through a fiber optic: Total internal reflection

Optical spectrum analyzer (OceanOptics, HR 2000+)



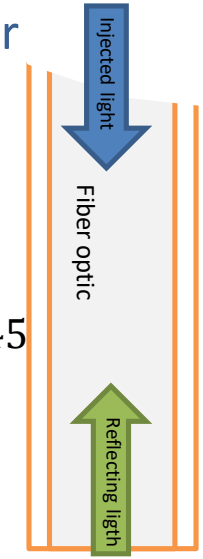

Xenon Light source (OceanOptics HPX-2000 185-2000nm)

UV-VIS multimode fiber optic
$D_{core}$=200 µm
$D_{cladding}$=240 µm

# Fiber Tip Optical Sensors

## Bare Fiber

$$n_{glass} = 1.45$$
$$n_{air} = 1$$



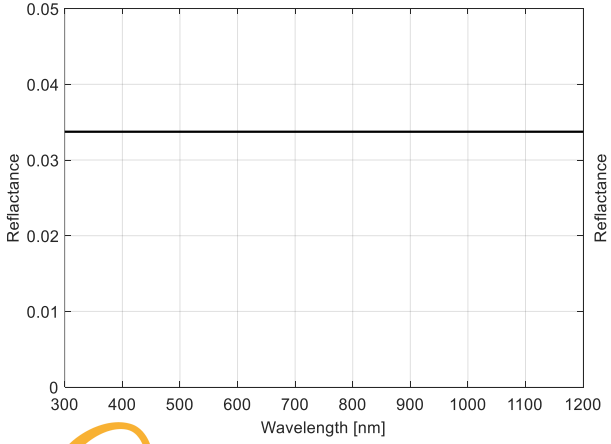

## Fabry-Perot

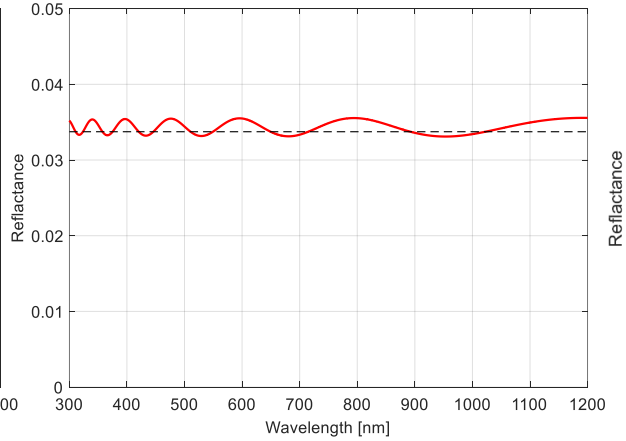
$$n_{glass} = 1.45$$
$$n_{layer} = 1.44$$
$$n_{air} = 1$$

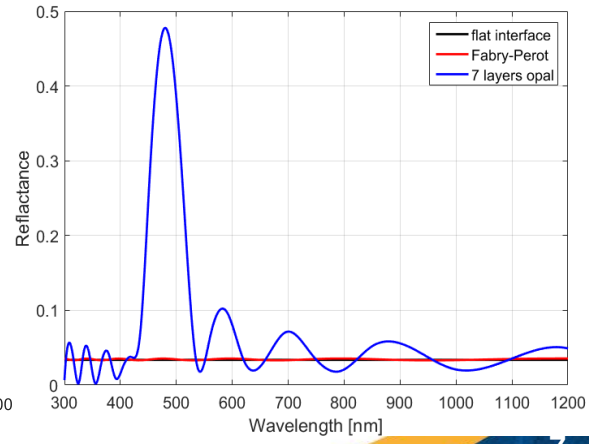

## Opals

$$n_{glass} = 1.45$$
$$n_{Spheres} = 1.59$$
$$n_{air} = 1$$
$$f = 0.74$$

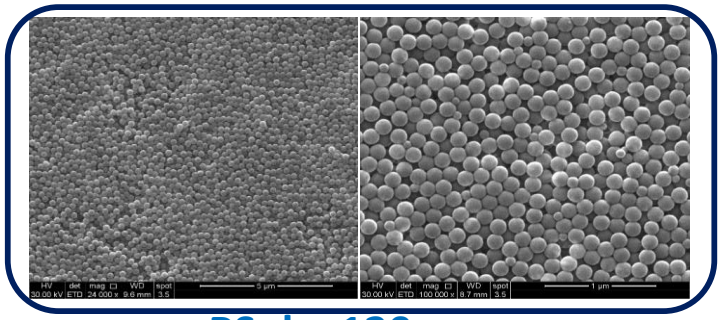
$$n_{eff} = f n_{Spheres} + + (1 - f) n_{air} = 1.44$$

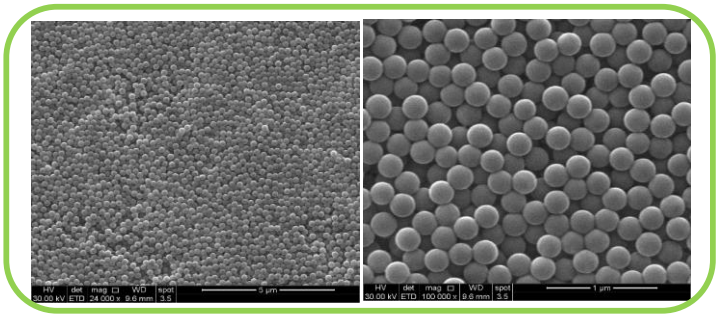



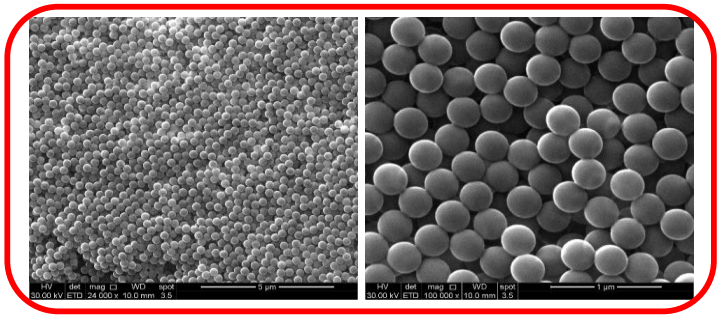
# **Synthesis of Optical Nanospheres:** Polystyrene



PS d = 120 nm

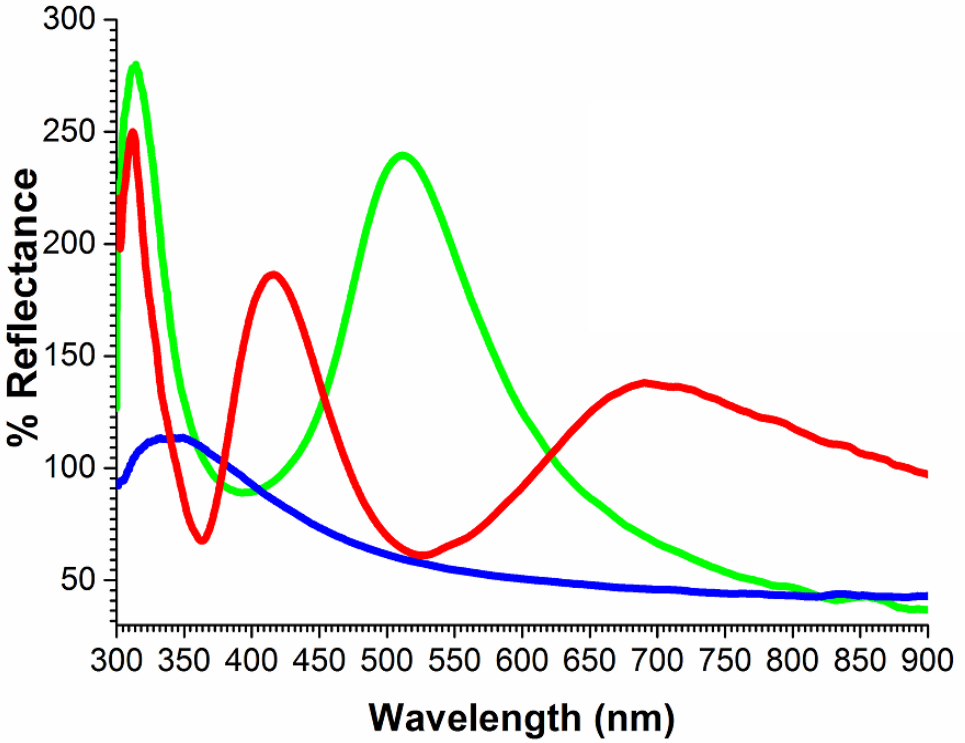


PS d = 230 nm



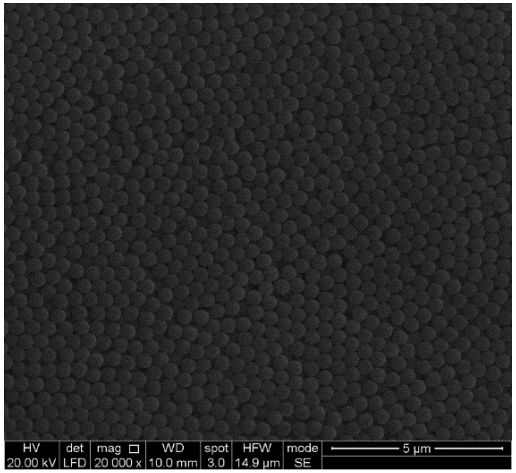
PS d = 300 nm

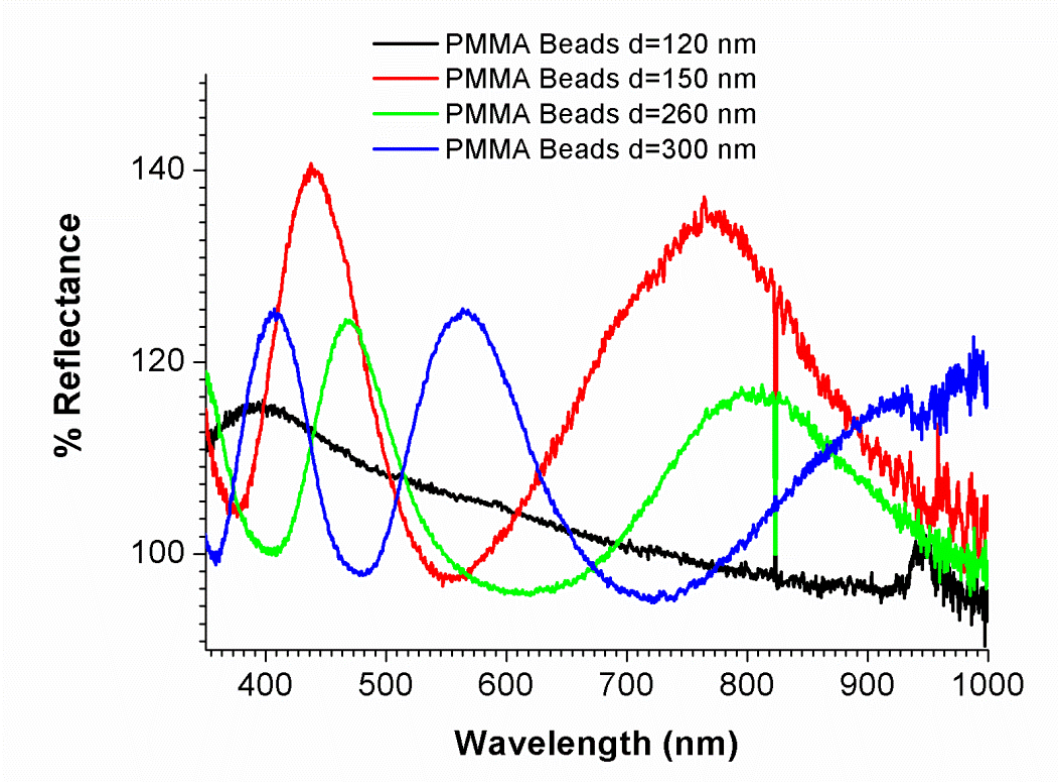
Synthesis of Polystyrene (PS) nanospheres *via* batch emulsion polymerization.



# **Synthesis of Optical Nanospheres** Polymethymetacrylate

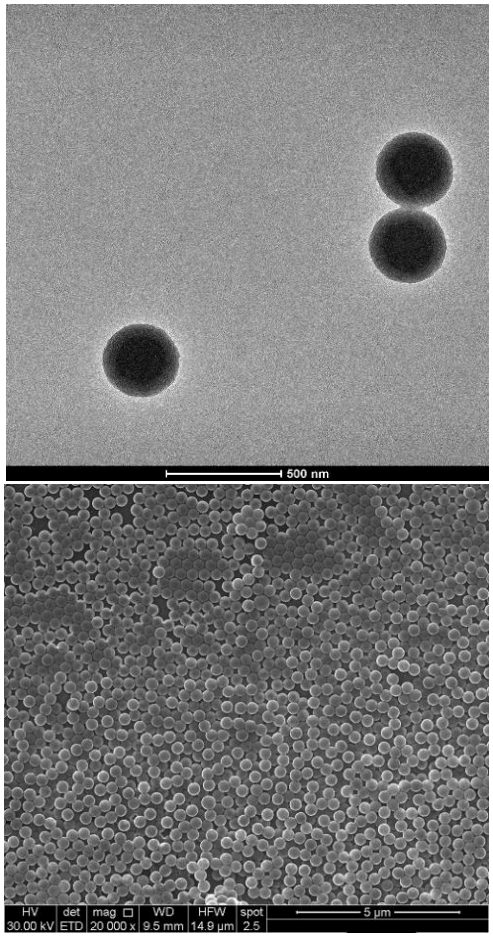
Synthesis of Polymethymetacrylate (PMMA) nanospheres *via* batch emulsion polymerization.

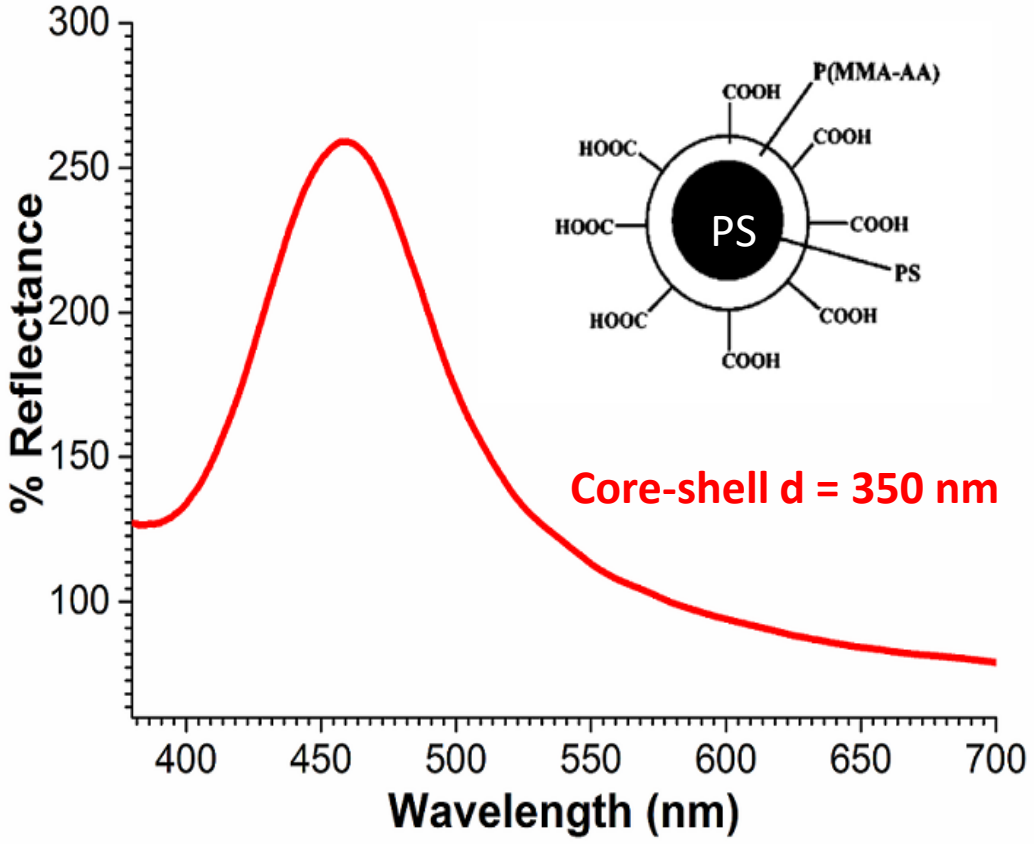


# **Synthesis of Optical Nanospheres:** Hydro phobic/philic core-shell

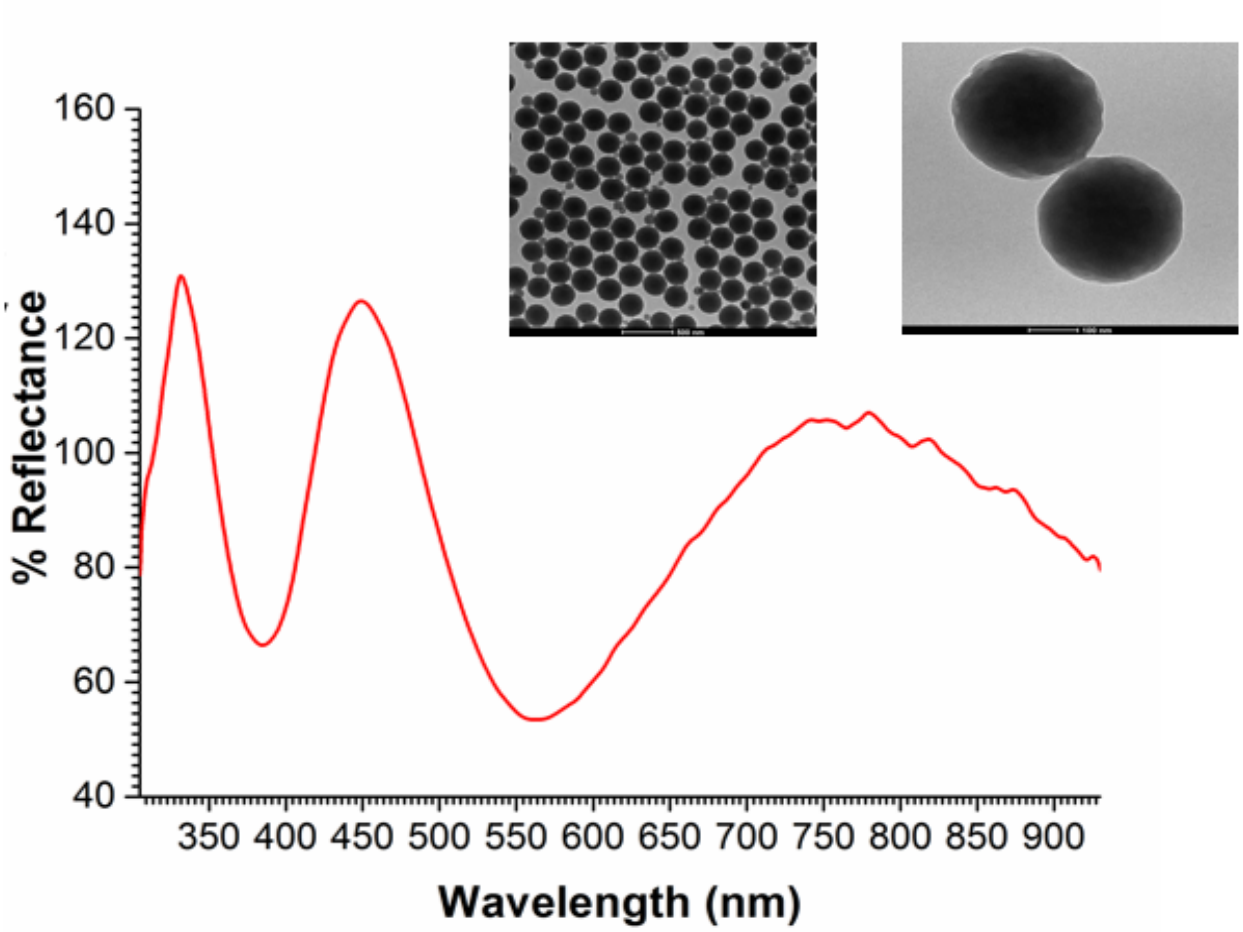
Synthesis of poly(styrene-methyl methacrylate-acrylic acid) (Poly(St-MMA-AA))Core-Shell nanospheres *via* batch emulsion polymerization.



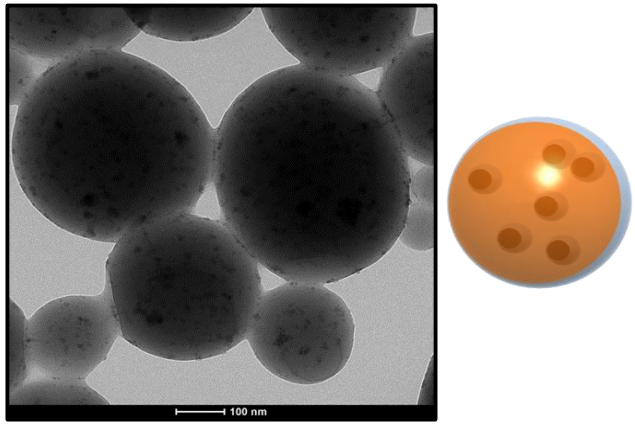



# **Synthesis of Optical Nanospheres:** hybrid hydrogel/polystyrene

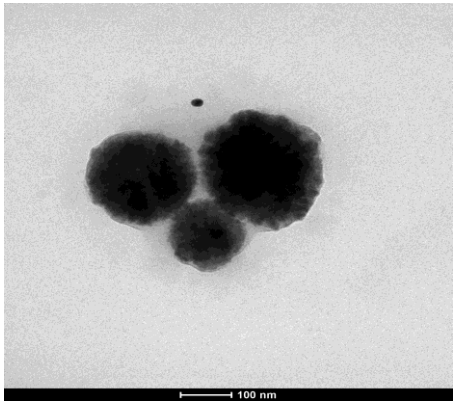
Synthesis poly-N-isopropylacrylamide (PNIPAM)-co –PS beads from styrene



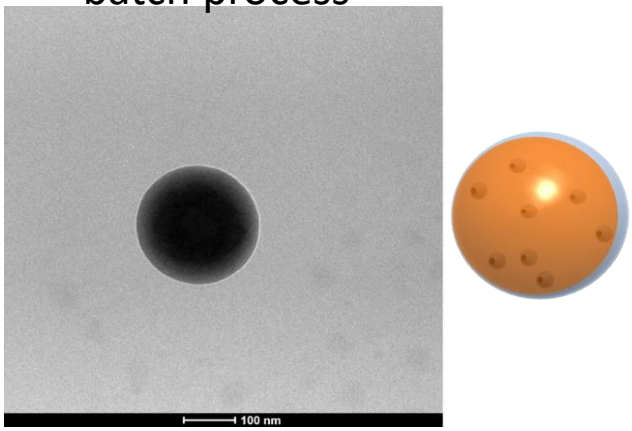
# **Synthesis of Optical Nanospheres:** magnetic spheres (batch)



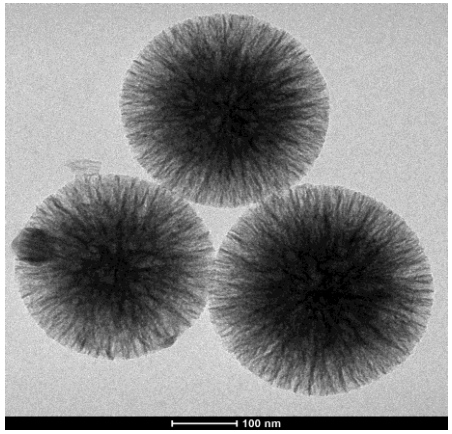

Magnetite/PS spheres by batch process




Magnetite cluster sphere



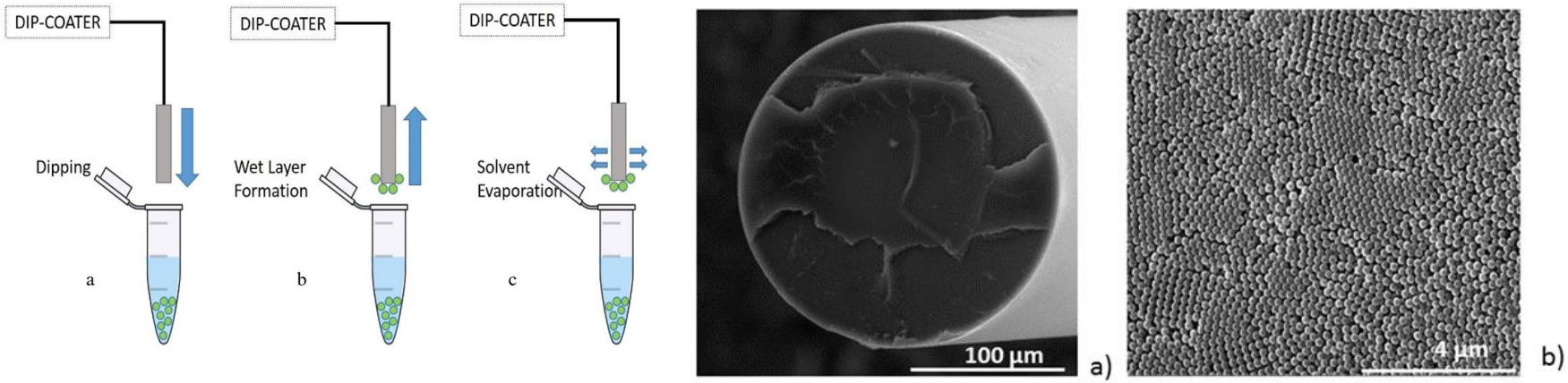

Magnetite/PS spheres by microfluidic process




Crystallised Magnetite sphere

# Self-assembled colloidal photonic crystal on the fiber optic tip

A new, simple and low cost approach is based on a 3D photonic crystal (PhC) structure deposited on the tip of a multimode optical fiber through the self-assembly of colloidal crystals (CCs) *via* a vertical deposition technique.

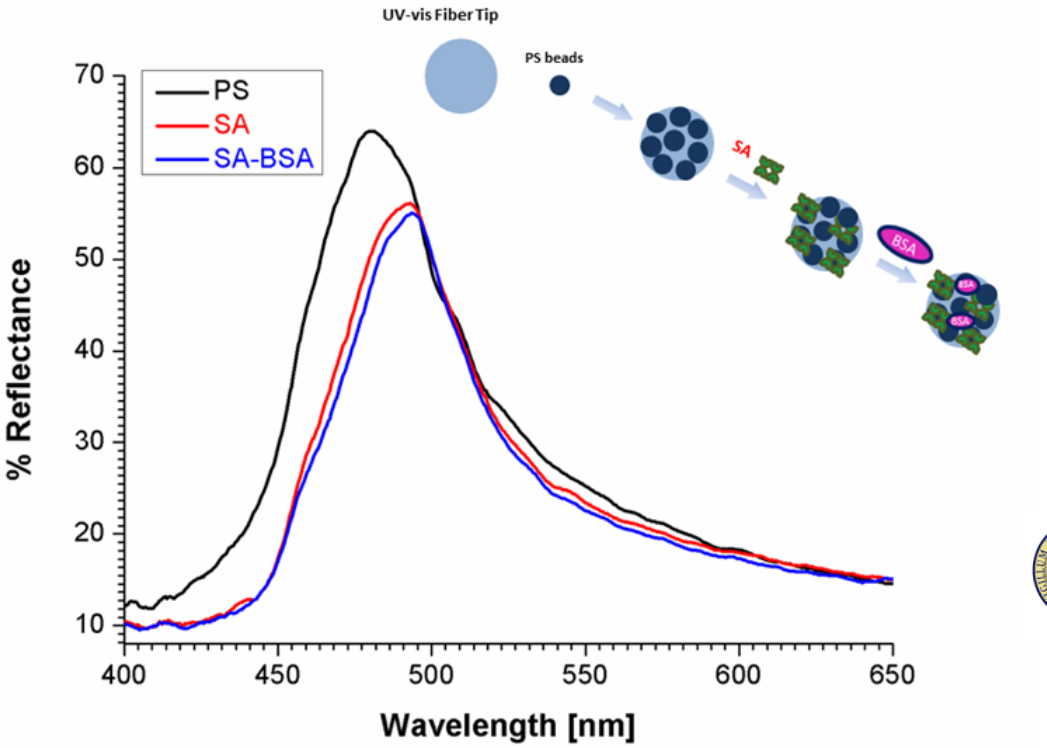



The colloidal crystal is made of polystyrene (PS) nanospheres with d= 200 nm

*GIORDANO, et al. Self-assembled colloidal photonic crystal on the fiber optic tip as a sensing probe. IEEE Photonics Journal, 2017, 9.2: 1-11.*

# Label Free optical biosensing at femtomolar detection limit

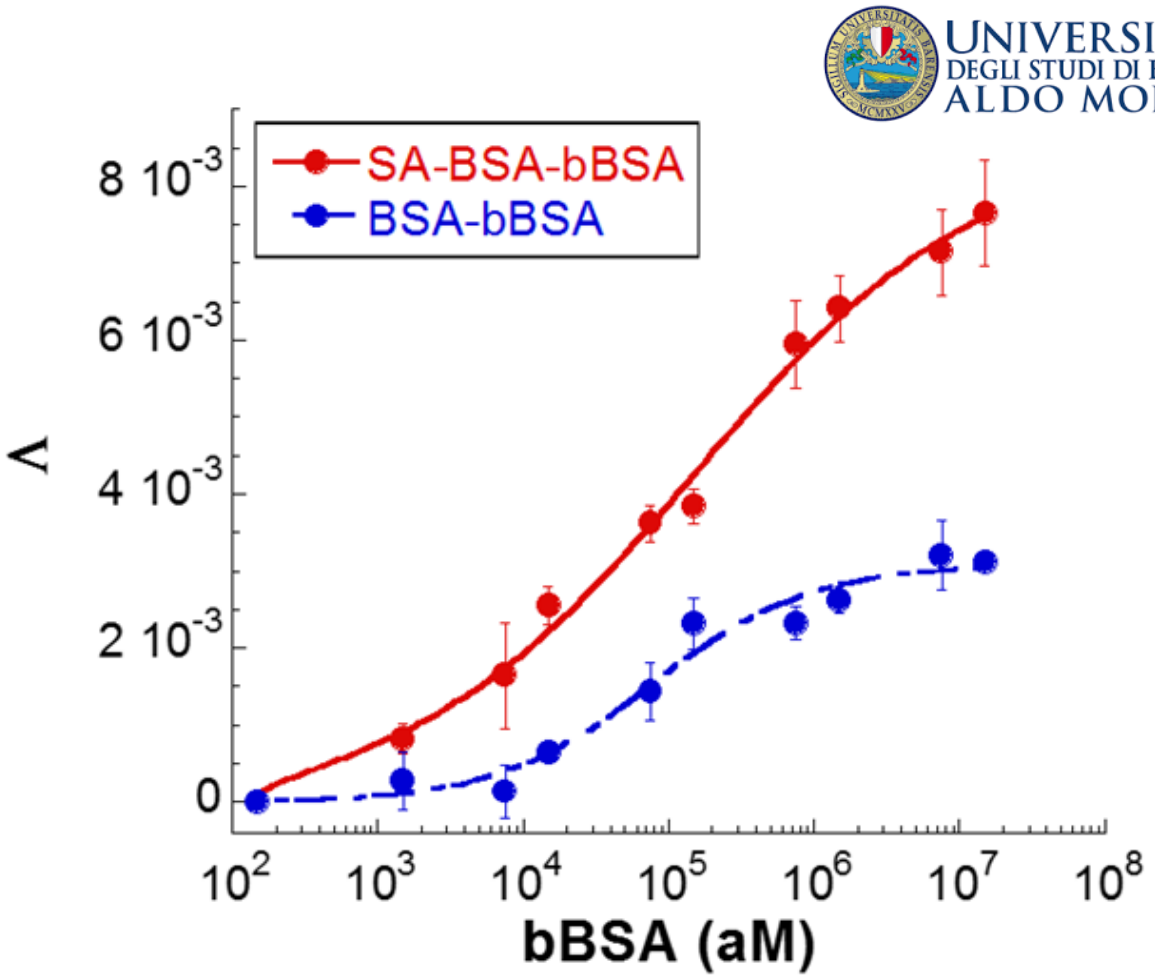
A new on-fiber biosensor based on functionalized photonic crystal (PhC) has been developed. We evaluated the performance of the biosensor using a standard streptavidin-biotin binding system.

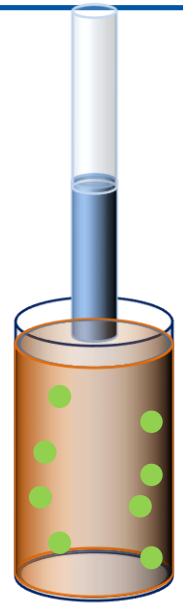


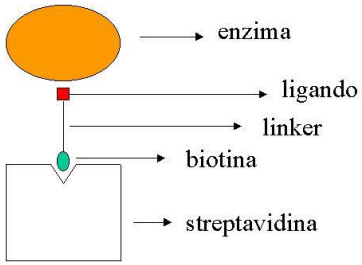

When SA in physisorbed to the PS nanospheres, the reflectance maximum shift to 502 nm meaning that SA proteins were stably attached to PS beads' surfaces.

GIORDANO, et al. Label-free optical biosensing at femtomolar detection limit. *Sensors and Actuators B: Chemical*, 2018, 255: 1097-1104.

# Label Free optical biosensing at femtomolar detection limit



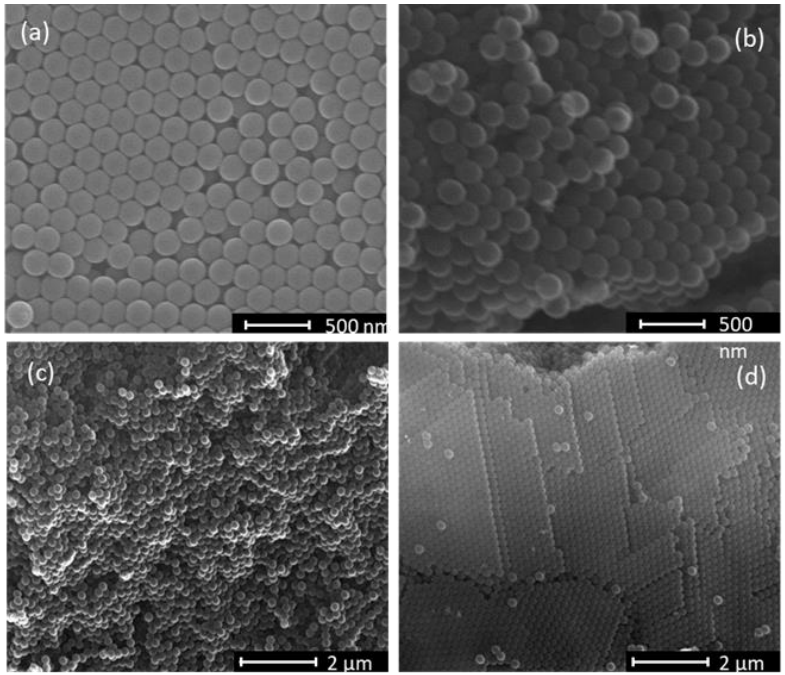



The minimum detectable concentration of bBSA is **1,5 fM**.

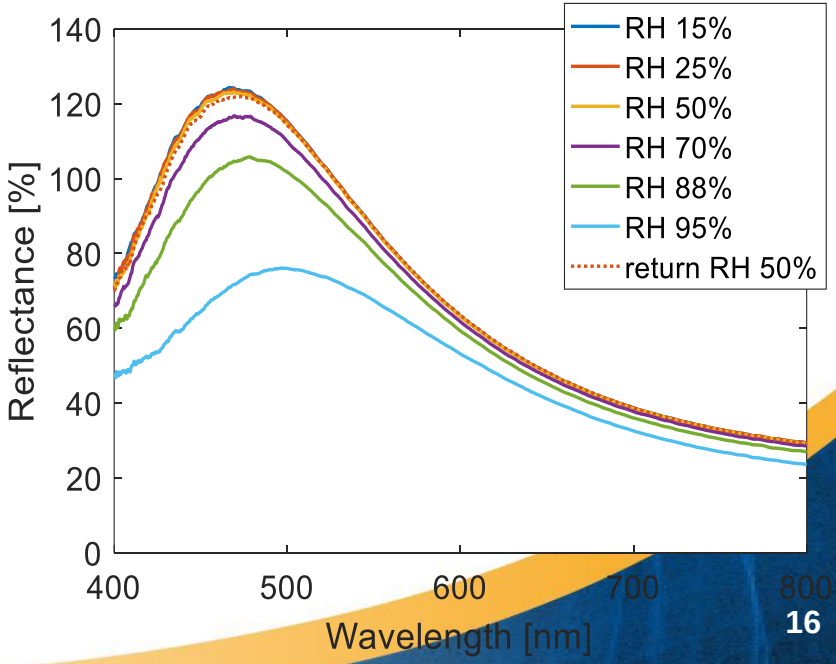
GIORDANO, et al. Label-free optical biosensing at femtomolar detection limit. *Sensors and Actuators B: Chemical*, 2018, 255: 1097-1104.

# Fiber Optic Humidity sensing by a Responsive Photonic Crystal

## Probes manufacturing and testing

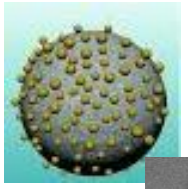


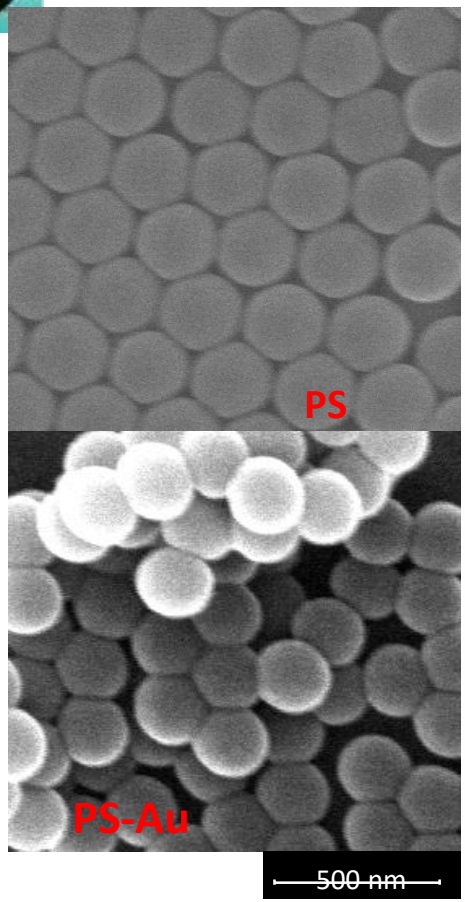

Fiber optic probes SEM images: (a) PS based probe and (b, c, d) PS-PNIPAM core shell probes at different magnifications and taken in different zones



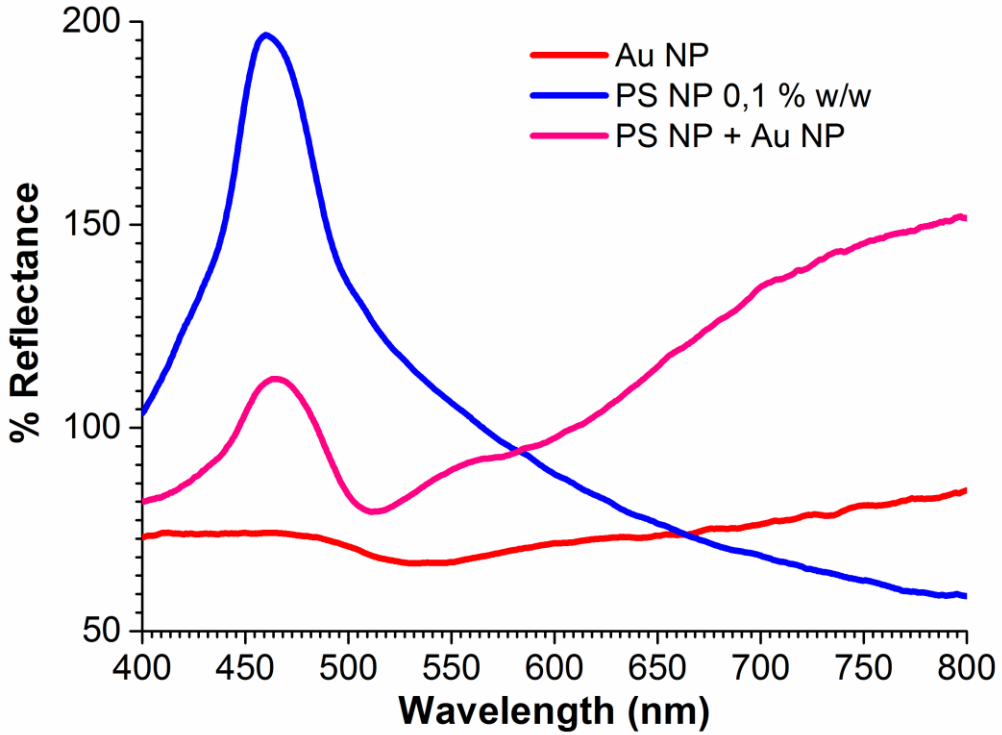

Reflected spectra of the probe as a function of the relative humidity.

# Synthesis of SERS nanoprobes: Au decorated PS nanospheres

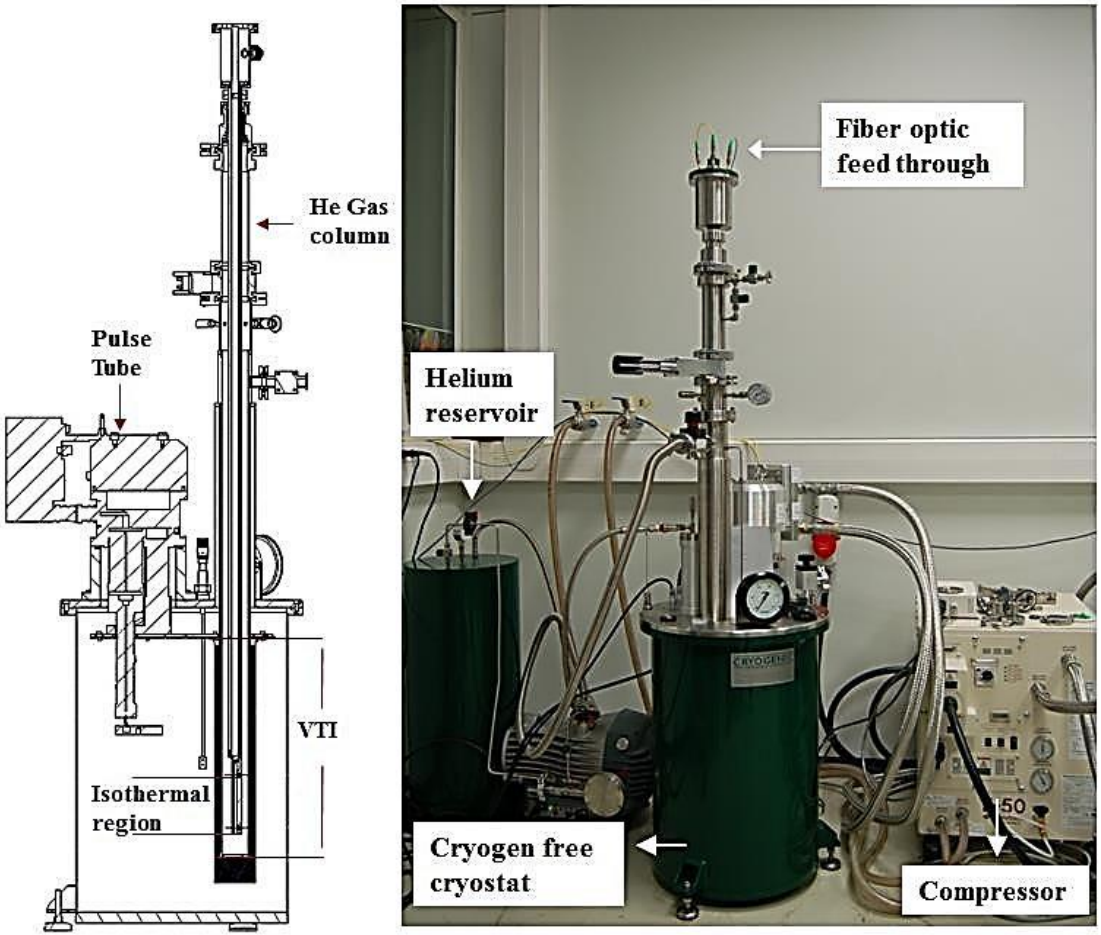





The simultaneous use of Metal-Dielectric Colloidal Crystals combines the localized surface plasmon resonance (LSPR) of noble metallic nanoparticles (Au) and the Photonic Bandgap from the colloidal assembly

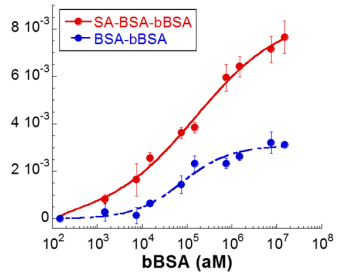


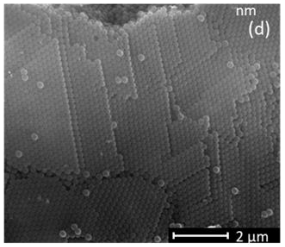
# Cryocooler testing of Colloidal Crystals fibre optic sensor @CERN

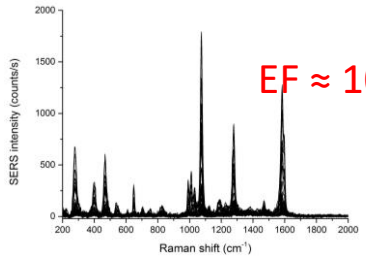


# Collaboration

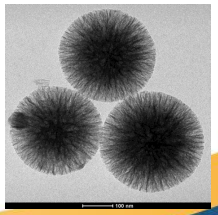
- Cryo temperature
- Biosensing
- Humidity sensing
- SERS probes




EF ≈ $10^5$



Working on Magnetic Responsive Photonic Crystals