The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

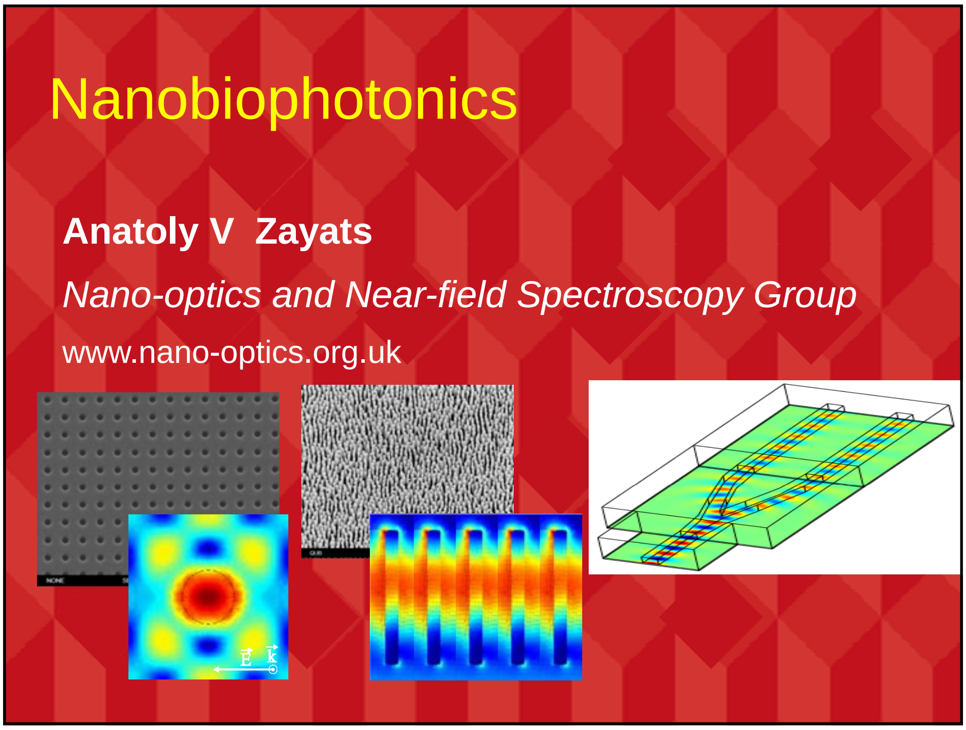
2328-20

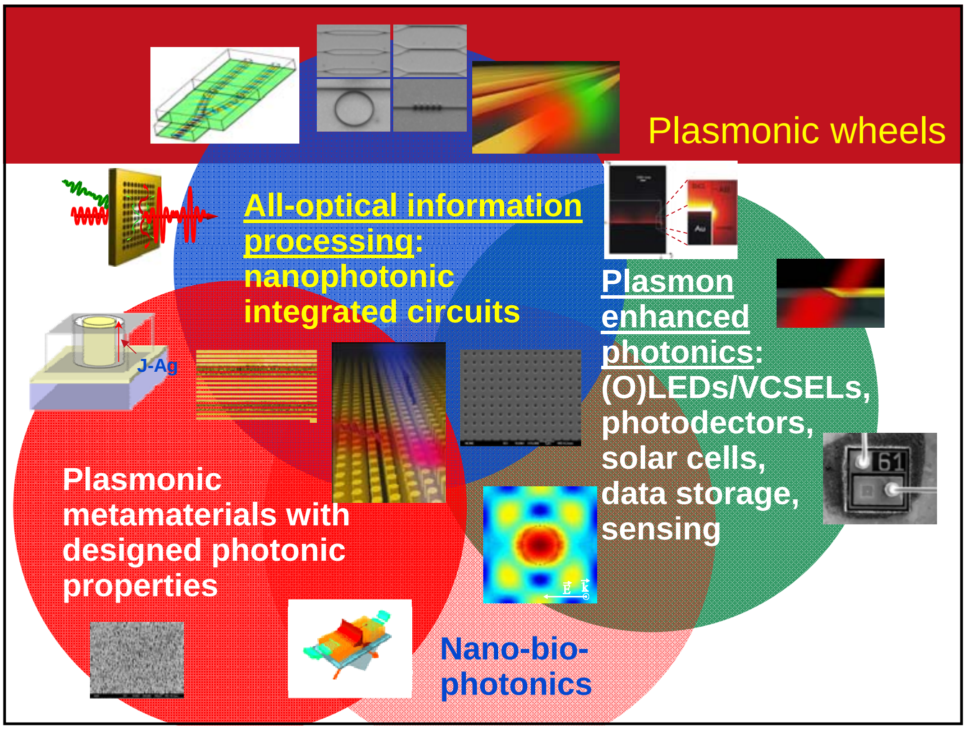
Preparatory School to the Winter College on Optics and the Winter College on Optics: Advances in Nano-Optics and Plasmonics

30 January - 17 February, 2012

Nanobiophotonics

A. Zayats
The Queen's University of Belfast
U.K.


Nanobiophotonics
Anatoly V Zayats
Nano-optics and Near-field Spectroscopy Group
www.nano-optics.org.uk


Plasmonic wheels
All-optical information processing:
nanophotonic integrated circuits
J-Ag
Plasmon enhanced photonics:
(O)LEDs/VCSELs,
photodetectors,
solar cells,
data storage,
sensing
Plasmonic metamaterials with designed photonic properties
Nano-bio-photonics

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Nanobiophotonics

Bio- and nano-imaging:
cell and protein imaging, Raman, SNOM, AFM, STORM, PALM, STED

Plasmonics and nanophotonics:
SPPC, waveguides, metamaterials: bio- , chemo sensing, photonic trapping and manipulation

Functional nanopraticles:
colloidal QDs, metal and polymer nanopartilcles, nanoemulsions

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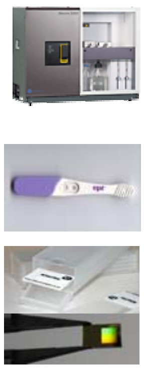
Nanophotonics and plasmonics in bio



YESTERDAY **TODAY** **TOMORROW**

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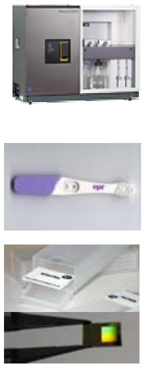
Nanophotonics and plasmonics in bio



Tricorder Gene I

YESTERDAY TODAY TOMORROW

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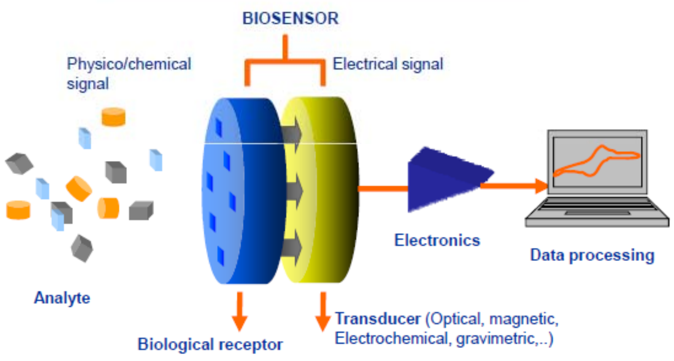
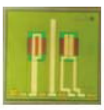
Nanophotonics and plasmonics in bio

- Plasmonic structures for image enhancement
- Metal nanostructures for label-free biosensing
- Metal nanostructures for optical manipulations (nanotweezers)
- Metal nanoparticles for photothermal cancer therapy
- Metal nanoparticles for targeted drug delivery
- Metal nanoparticles for acousto-optical imaging

Label-free photonic biosensing

BIOSENSOR DEVICE





- Biosensors are devices able to detect any subtance with a high sensitivity by using a specific and selective biomolecular recognition in real time and very fast (sc-min)
- Substances which can be detected: proteins, DNA, pathogens, virus, bacterias, toxic pollutants, chemical and biological warfare agents (aplications almost endless),

PHOTONIC BIOSENSORS

Binding event, $\Delta\Gamma$

↓

$\Delta RI \sim (dn/dc)_{vol}\ \Delta\Gamma$

↓

Change of refractive index, Δn

↓

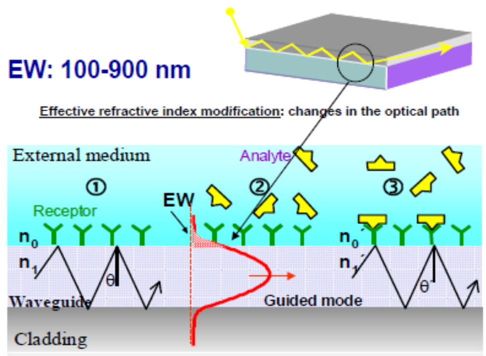
$\Delta p \sim \Delta\Gamma$

↓

Change of optical parameter, Δp

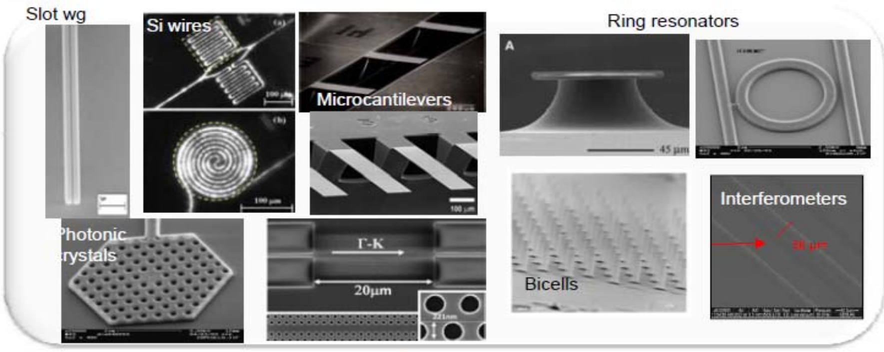
(Intensity, Phase, polarisation, resonant momentum,....)

Evanescent Wave Detection



- **High sensitivity**, specially at the surface
- Direct measurement without labelling of molecules (**LABEL-FREE**)
- Real-time (binding can be continuously monitoring). Small volumes
- Detection of selective biomolecular interactions. Generic technology

STATE-OF-THE-ART: PHOTONIC BIOSENSORS



OLD TRANSDUCERS	NEW TRANSDUCERS
SPR	Localised SPR
Optical fibers	Photonic crystals
Interferometers	Ring resonators
Resonant mirror	Microcantilevers
Grating couplers, RIfS	Slot and Si wire waveguides

NANO
More sensitive

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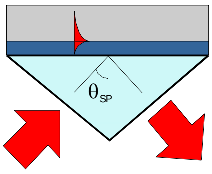
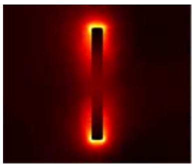
Label free biosensing

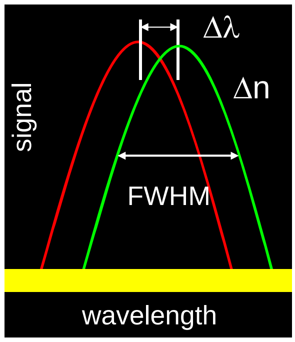




SPP and LSP resonances are extremely sensitive to refractive index

$$k_{SPP} = \frac{\omega}{c}\left(\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}\right)^{1/2}$$

$$\omega_{LSP} = f(a, \varepsilon_m, \varepsilon_d)$$



FOM = Δλ/ΔnFWHM

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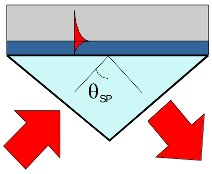
Label free biosensing

Label-free biosensing using surface plasmons

- SPR: based on SPP (propagating modes)
- **extremely high sensitivity: better than $\Delta n \sim 10^{-5}$**
- **FOM up to 20**
- **less sensitive to small molecular weight analytes**
- **no integration in nanoscale geometries**

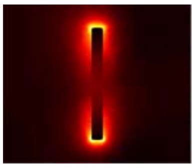
- LSPR: based on localised plasmon modes
- **FOM up to 8**
- **100 times smaller sensitivity than SPR**
- **10 times smaller penetration depth of probing field**

Label free biosensing

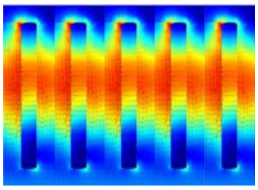


SPP and LSP resonances are extremely sensitive to refractive index

$$k_{SPP} = \frac{\omega}{c}\left(\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}\right)^{1/2}$$



$\omega_{LSP} = f(a, \varepsilon_m, \varepsilon_d)$



$\omega_{meta} = f(a, d, \varepsilon_m, \varepsilon_d)$

both LSP of individual particles are modified as well as interaction between them

Nanorod metamaterial as a transducer for refractive index sensing

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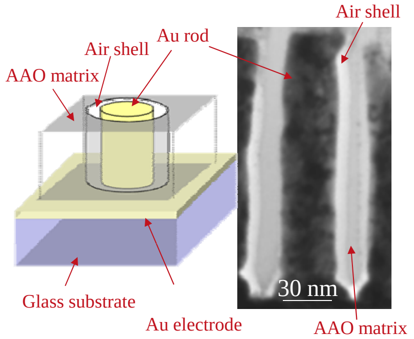
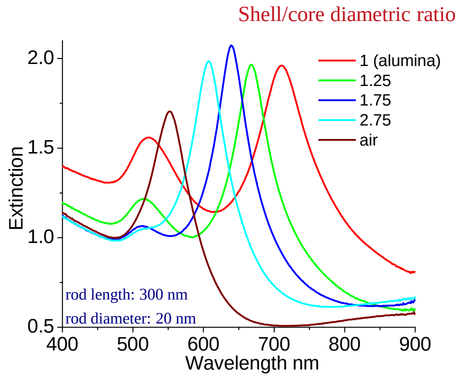
Plasmonic nanorod arrays





J Phys Chem C 111, 12522 (2007).

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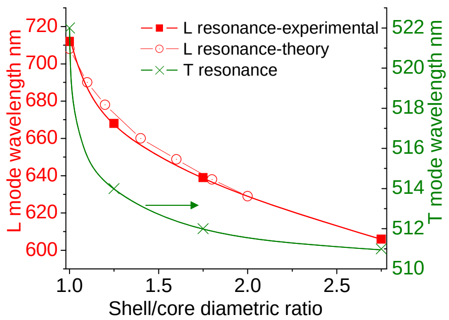
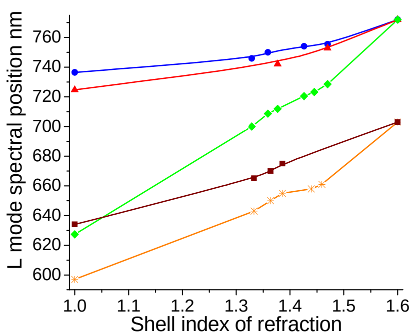
Plasmonic nanorod arrays

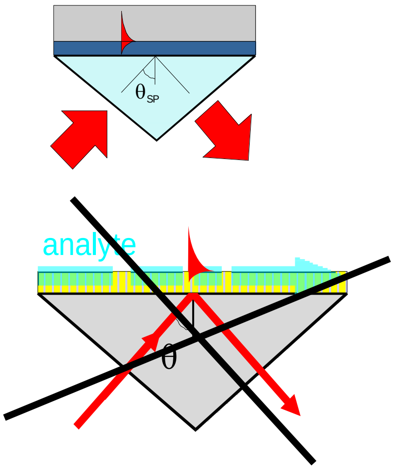




Sensitivity ~ 10^2 nm/RIU
Figure of merit ~ 1

J Phys Chem C 111, 12522 (2007).

Sensing geometry

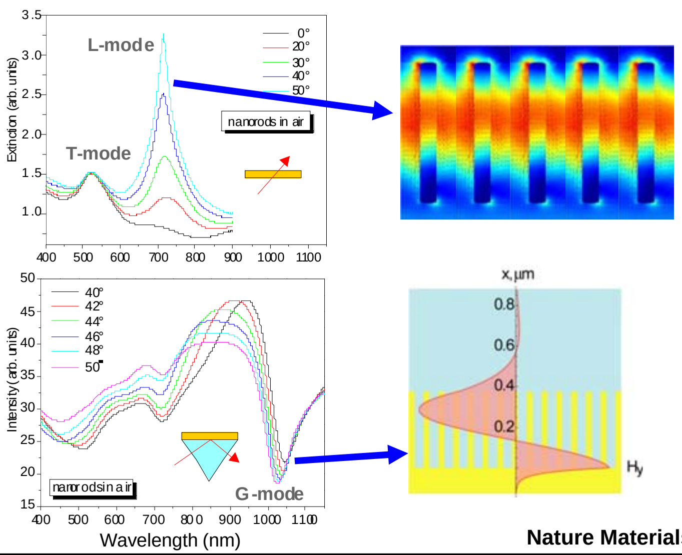


$$k_{SP} = \frac{\omega}{c}\left(\frac{\varepsilon_m \varepsilon_i}{\varepsilon_m + \varepsilon_i}\right)^{1/2}$$

$$k_{SP} = \frac{\omega}{c}\left(\frac{(\varepsilon_{xy} - \varepsilon_z)\varepsilon_i}{\varepsilon_{xz}\varepsilon_z + \varepsilon_i^2}\right)^{1/2}$$

uniaxial anisotropic medium:
ε_x, ε_{yz} < 0

Sensing geometry



Nature Materials 8, 867 (2009).

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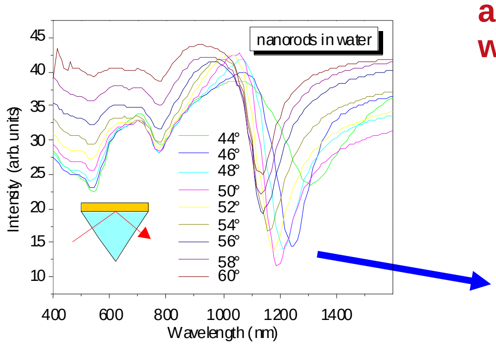
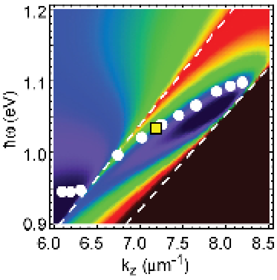
Sensing geometry



anisotropic metamaterial waveguide



Nature Materials 8, 867 (2009).

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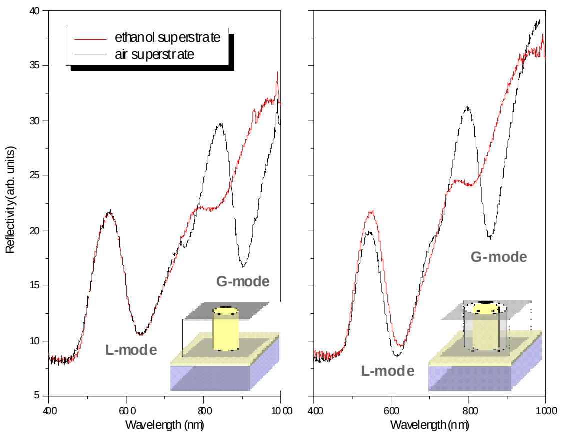
Sensing geometry



sensitivity and field distribution

Nature Materials 8, 867 (2009).

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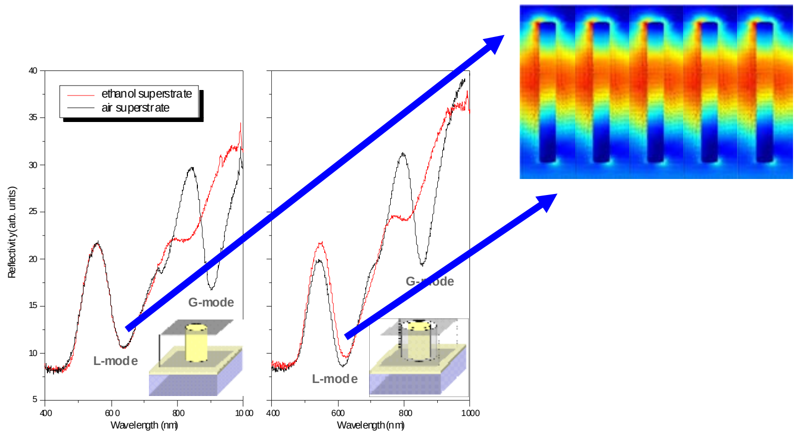
Sensing geometry



sensitivity and field distribution

Nature Materials 8, 867 (2009).

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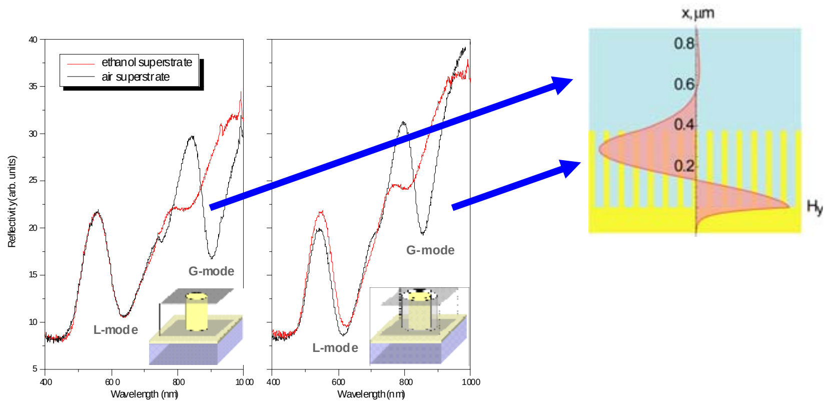
Sensing geometry



sensitivity and the field distribution

Nature Materials 8, 867 (2009).

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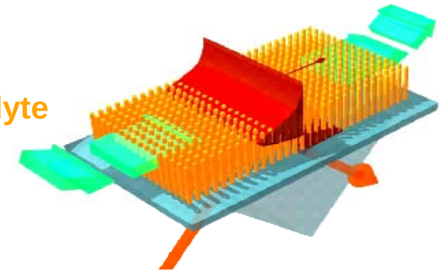
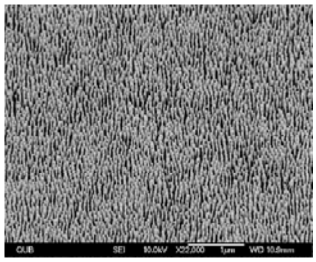
Sensing geometry

analyte



light



Transducer based on plasmonic nanorod array

Nature Materials 8, 867 (2009).

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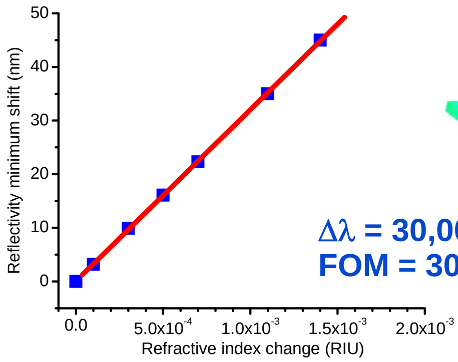
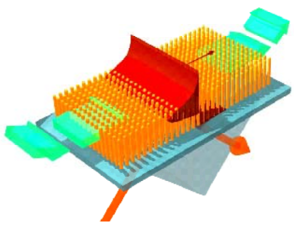
Sensing test



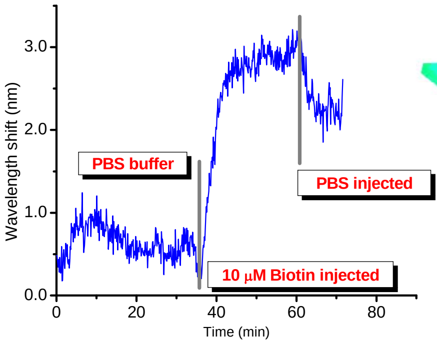


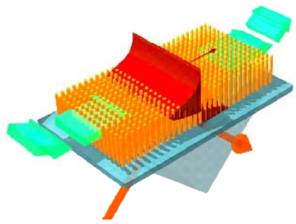
$\Delta\lambda$ = 30,000 nm per RIU
FOM = 300

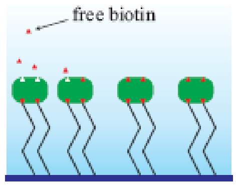
sensitivity test

Nature Materials 8, 867 (2009).

Sensing test





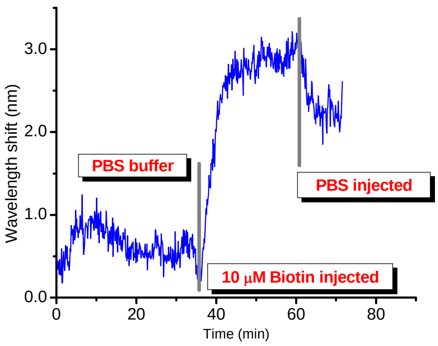


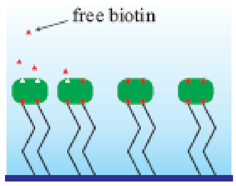
sensitivity test: biotin-streptavidin reaction

Nature Materials 8, 867 (2009).

Sensing test

Biotin: 250 Da
Detection limit: ca 500 nM
standard SPR - ca 50 μM





sensitivity test: biotin-streptavidin reaction

Nature Materials 8, 867 (2009).

Plasmonic nanotubes for biosensing

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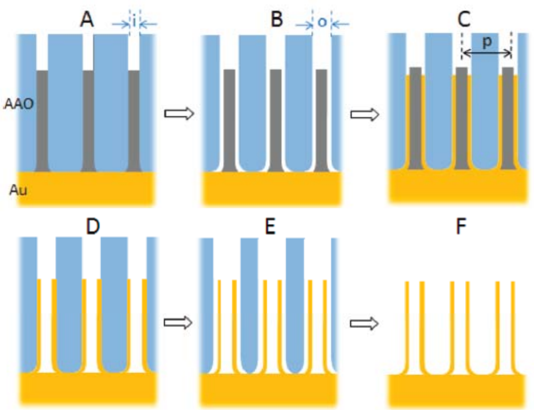
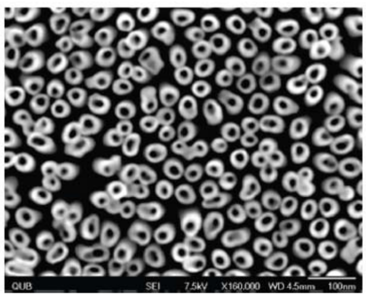
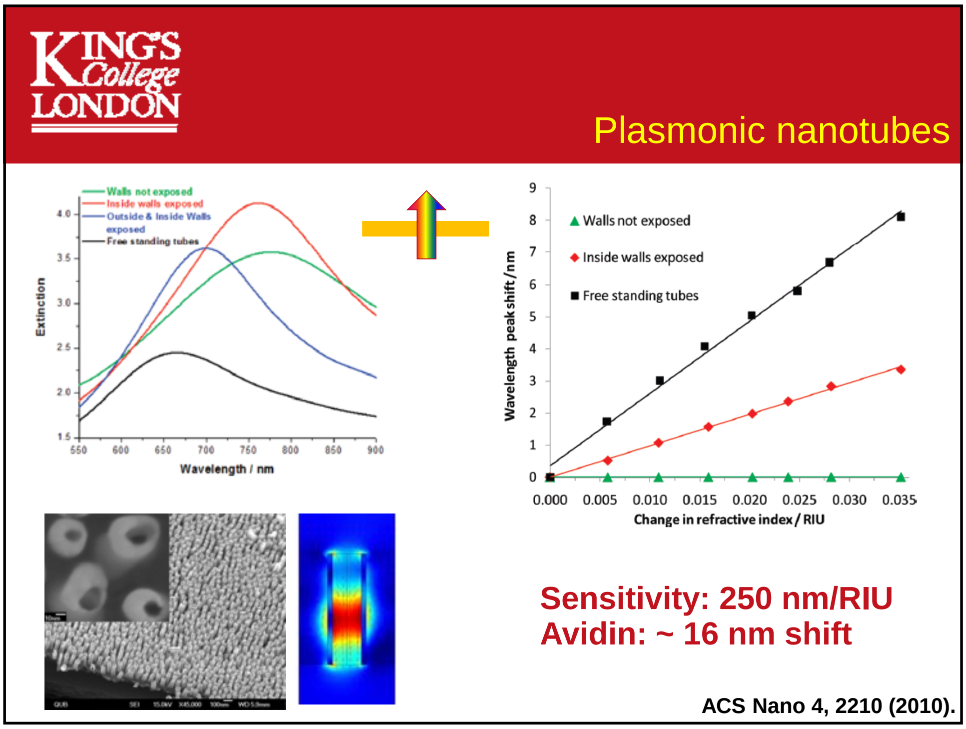
Plasmonic nanotubes





ACS Nano 4, 2210 (2010).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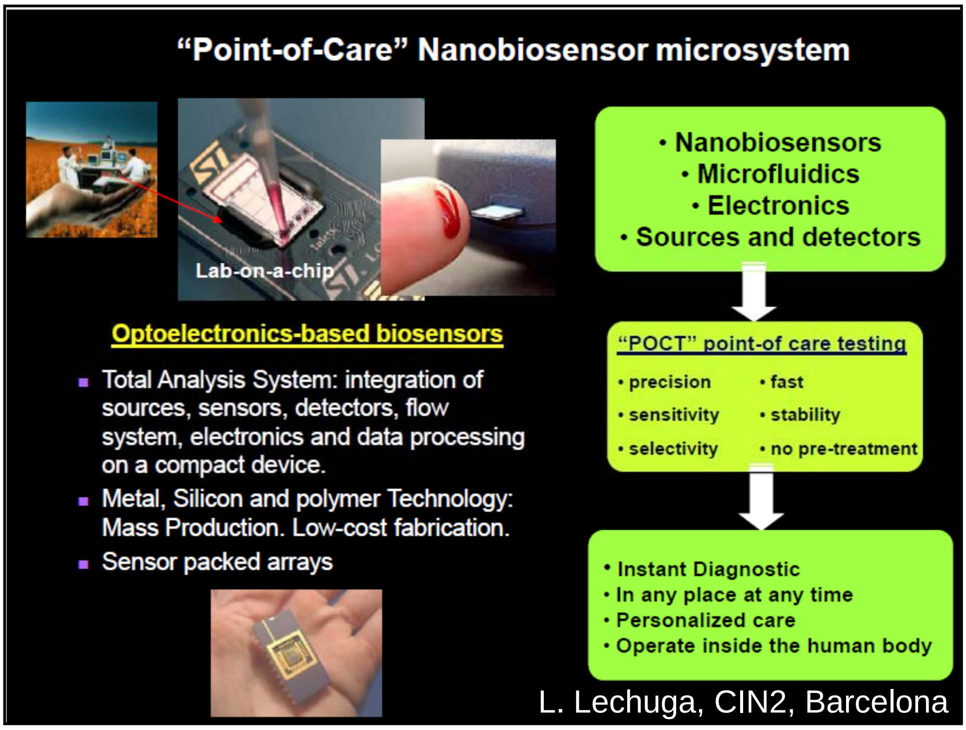
Plasmonic nanotubes
Walls not exposed
Inside walls exposed
Outside & Inside Walls exposed
Free standing tubes
Extinction
Wavelength / nm
Walls not exposed
Inside walls exposed
Free standing tubes
Wavelength peak shift / nm
Change in refractive index / RIU
Sensitivity: 250 nm/RIU
Avidin: ~ 16 nm shift
ACS Nano 4, 2210 (2010).


"Point-of-Care" Nanobiosensor microsystem
Lab-on-a-chip
• Nanobiosensors
• Microfluidics
• Electronics
• Sources and detectors
Optoelectronics-based biosensors
Total Analysis System: integration of sources, sensors, detectors, flow system, electronics and data processing on a compact device.
Metal, Silicon and polymer Technology: Mass Production. Low-cost fabrication.
Sensor packed arrays
"POCT" point-of care testing
• precision
• fast
• sensitivity
• stability
• selectivity
• no pre-treatment
• Instant Diagnostic
• In any place at any time
• Personalized care
• Operate inside the human body
L. Lechuga, CIN2, Barcelona

Theranostics

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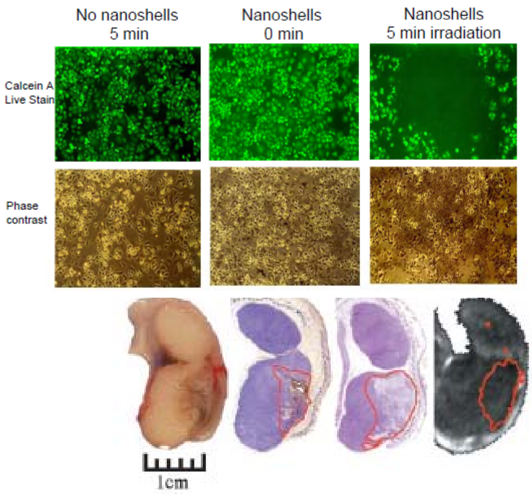
Theranostics

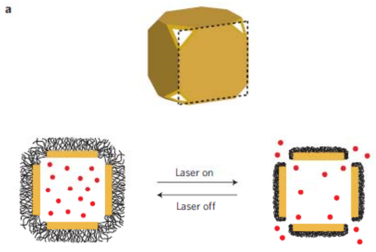
Photothermal cancer therapy



(Naomi Halas)

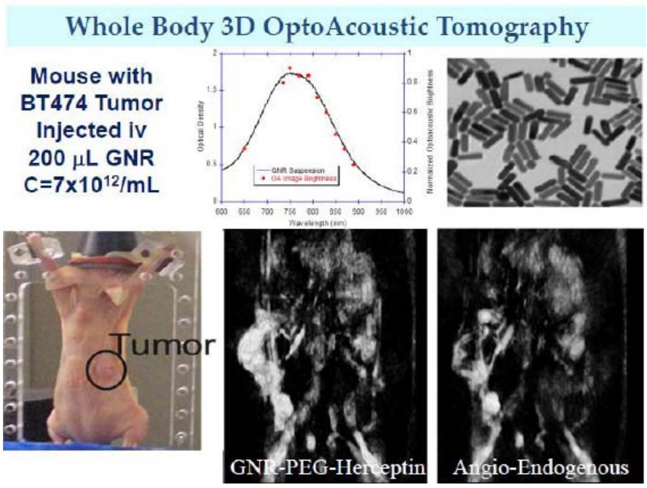
Theranostics

Photothermal drug release



M. S. Yavuz *et al*., Nature Mat. 8, 935 (2009)

Photoacoustic imaging



(Alexander Oraevsky)

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Conclusions

Tricorder Gene I

Tricorder Gene II

“super-smart” phones

Eco-sensor concept

With thanks to Laura Lechuga (CIN2 Barcelona), Roman Quidant (ICFO Barcelona), Naomi Halas (Rice), Boris Chichkov (LZH), Alexander Oraevsky.

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Photonics and medicine

(Boris Chichkov)