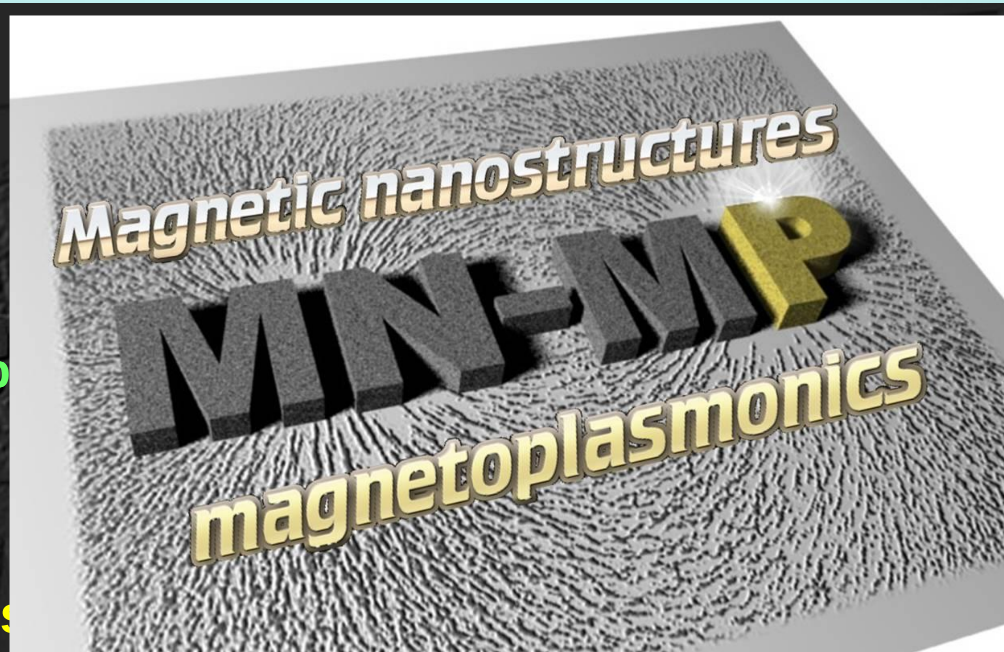
Antonio García-Martín



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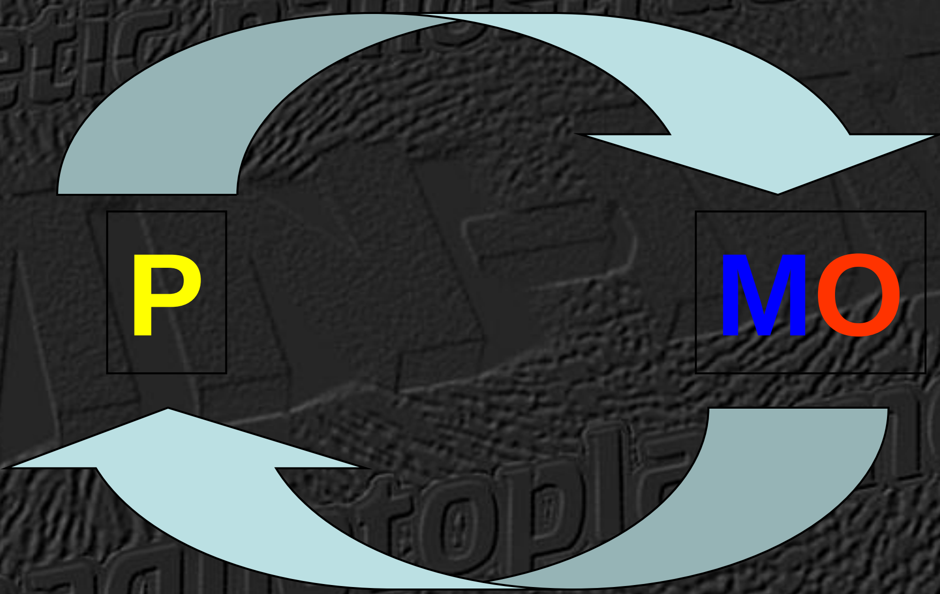
Cons ... icas

Magnetoplasmonics: fundamentals and applications

MAGNETO-PLASMONICS

Control of MO activity with plasmon excitation



Control plasmon properties with an external magnetic field

PLASMONICS

Active topic, but not so new …

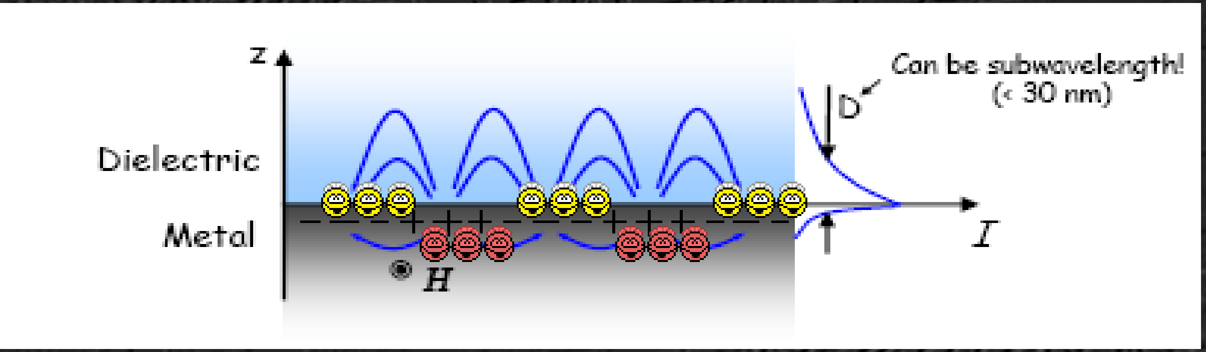
The Lycurgus cup
(British Museum. 4th Century)
When illuminated from outside the cup appears green, but turns into red when illuminated from inside.

"Labors of the Months"
(Norwich, England, ca. 1480)
The ruby color is probably due to embedded gold nanoparticles.

PLASMONICS

… based on …

"Electromagnetic excitation (TM polarized) localized at the interface between a media $\varepsilon_r < 0$ (metal) and a media $\varepsilon_r > 0$ (dielectric material) "

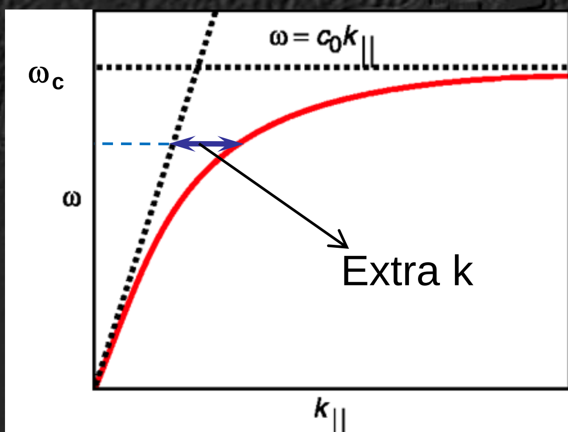


Main characteristics

- Strong localization of EM in subwavelength volumes: *Optical nanodevices*
- Very sensitive to metal dielectric interface: *Sensors*

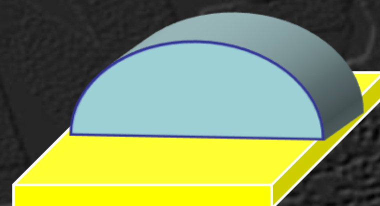
… that are excited if …

❖ both frequency and wavevector match those of the SPP (propagating plasmon)

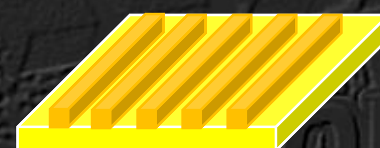


Ways to produce the extra k

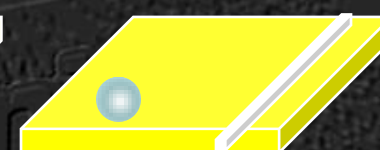
A prism



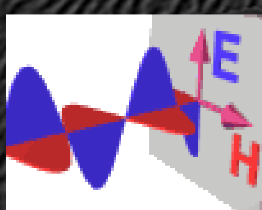
A grating

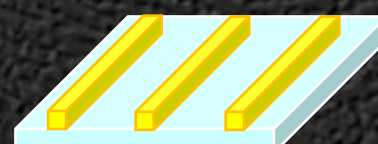


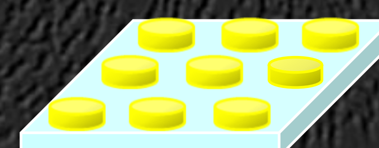
A defect



❖ the frequency matches that of the LSPP (localized plasmon)

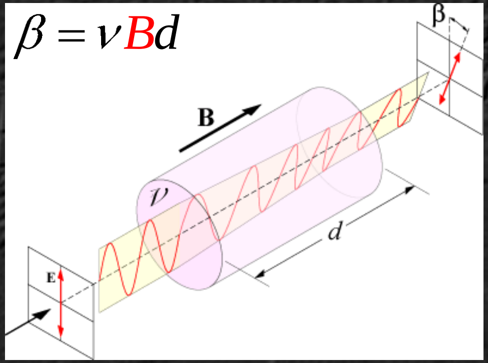




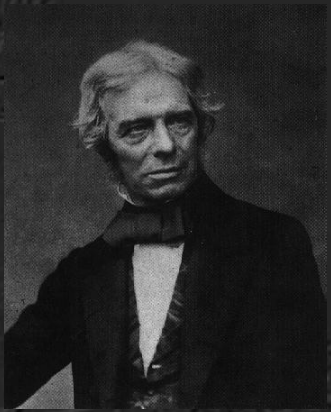


New effect …

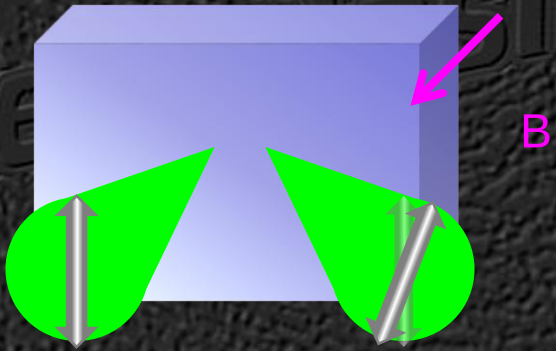
Faraday effect: 1845



1791-1867



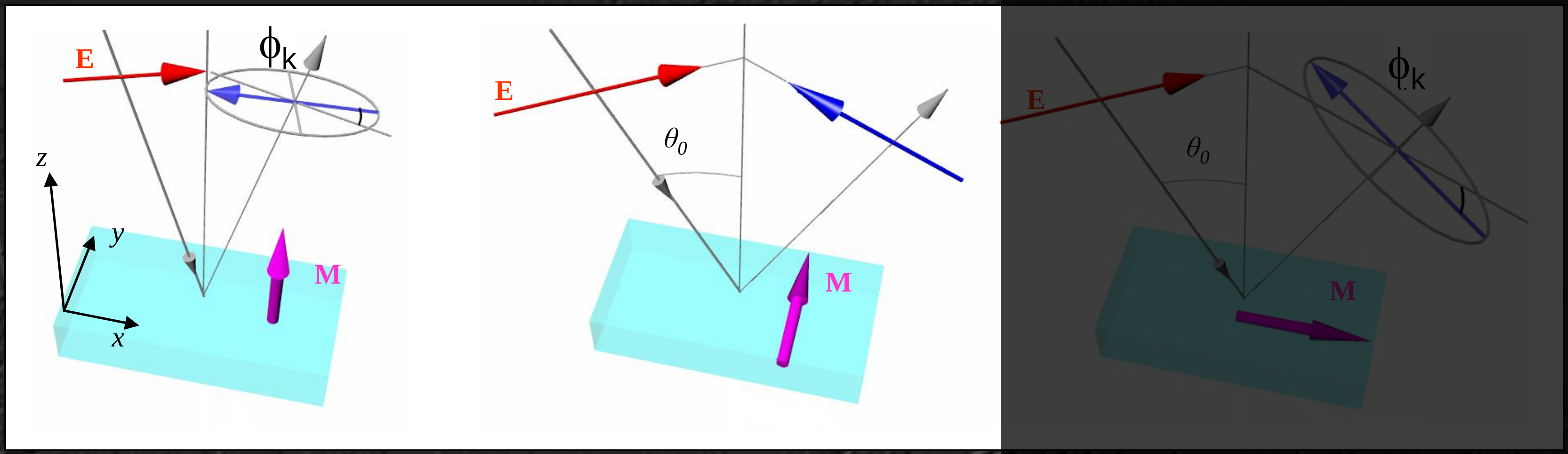
Kerr effect: 1876



1824-1907

MAGNETO-OPTICS
Kerr effect

… depends on relative orientation of B …



Polar	Transverse	Longitudinal
$\theta + i\phi = f(M_z)$	$R_{pp} = f(M_y)$	$\theta + i\phi = f(M_x)$

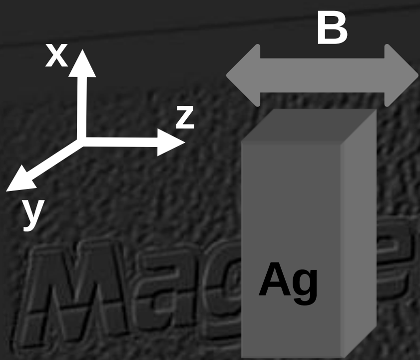
$$\begin{pmatrix} \varepsilon & aM_z & 0 \\ -aM_z & \varepsilon & 0 \\ 0 & 0 & \varepsilon \end{pmatrix}$$

$$\begin{pmatrix} \varepsilon & 0 & -aM_y \\ 0 & \varepsilon & 0 \\ aM_y & 0 & \varepsilon \end{pmatrix}$$

$$\begin{pmatrix} \varepsilon & 0 & 0 \\ 0 & \varepsilon & aM_x \\ 0 & -aM_x & \varepsilon \end{pmatrix}$$

MAGNETO-PLASMONICS

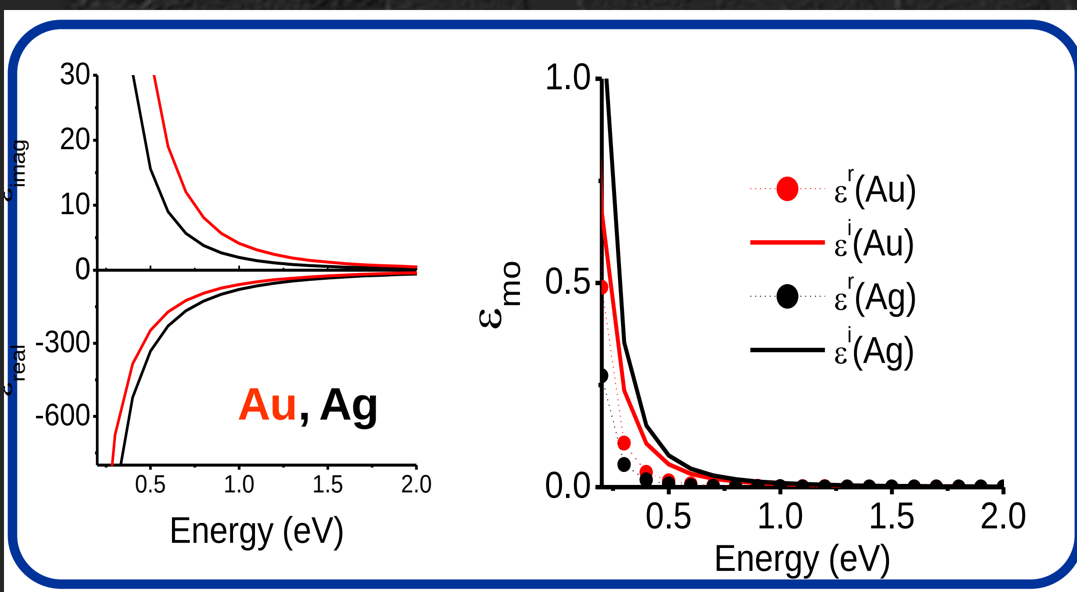
Effects of magnetic field on optical properties of metals (Drude):



$$\begin{pmatrix} \varepsilon & \pm\varepsilon_{mo} & 0 \\ \mp\varepsilon_{mo} & \varepsilon & 0 \\ 0 & 0 & \varepsilon \end{pmatrix}$$

$$\varepsilon = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2+\Gamma^2} + i\frac{\omega_p^2\Gamma}{\omega(\omega^2+\Gamma^2)}$$

$$\varepsilon_{mo} = -\left(\frac{2\omega_p^2\omega_c\Gamma}{\omega^2+\Gamma^2}^2 + i\frac{\omega_p^2\omega_c}{\omega(\omega^2+\Gamma^2)} \right)$$



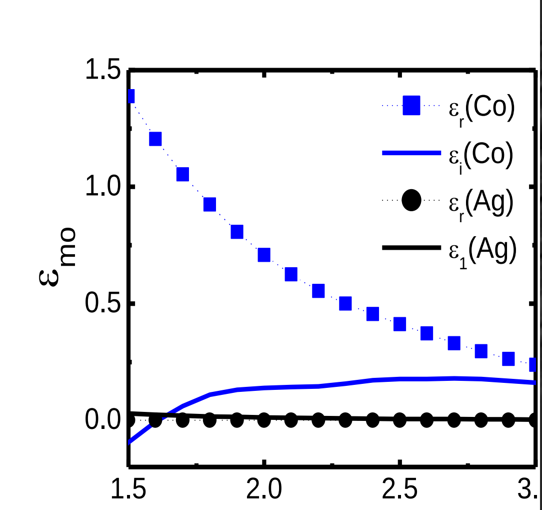
$$\omega_c = \frac{eB}{m^*}$$ ⇨ small for metals

$$\varepsilon_{mo} << \varepsilon$$

$\hbar\omega_c$= 0.115 meV (B=1 Tesla)

MAGNETO-PLASMONICS

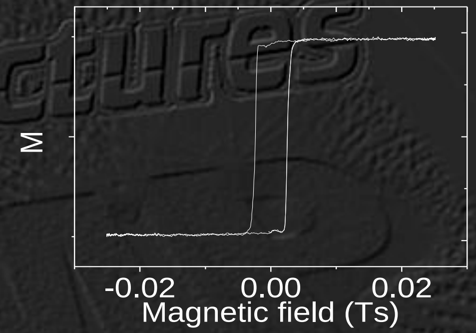
ε_{mo} in noble metals is very small → Solution: **ferromagnetic metals**



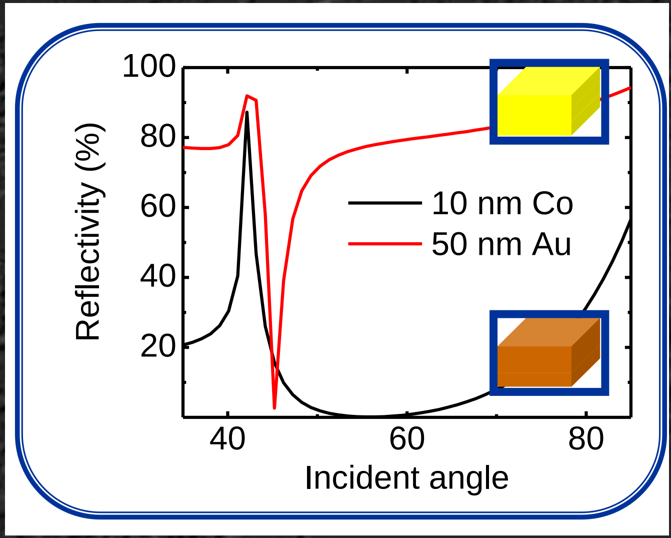
$$\varepsilon_{mo}(Co, Fe, Ni) \propto M$$

$$\pm M_{sat}(B \sim 0.005T)$$

$$\varepsilon_{mo}(Ag, Au) \propto B$$



Ferromagnetic metals are very absorbent → very broad plasmonic resonances

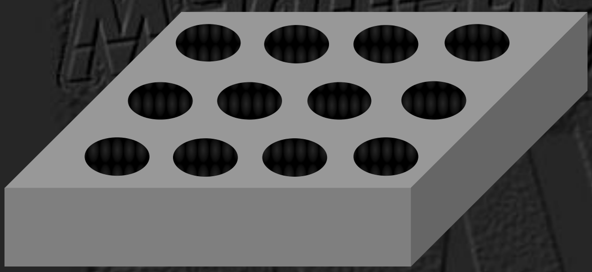


MAGNETO-PLASMONICS

ε_{mo} in noble metals is very small → Solution: **ferromagnetic metals**

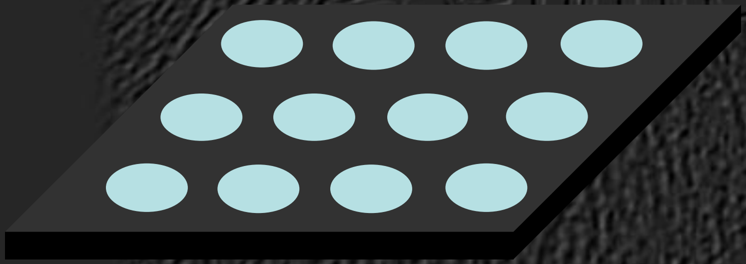
Ferromagnetic nanowires

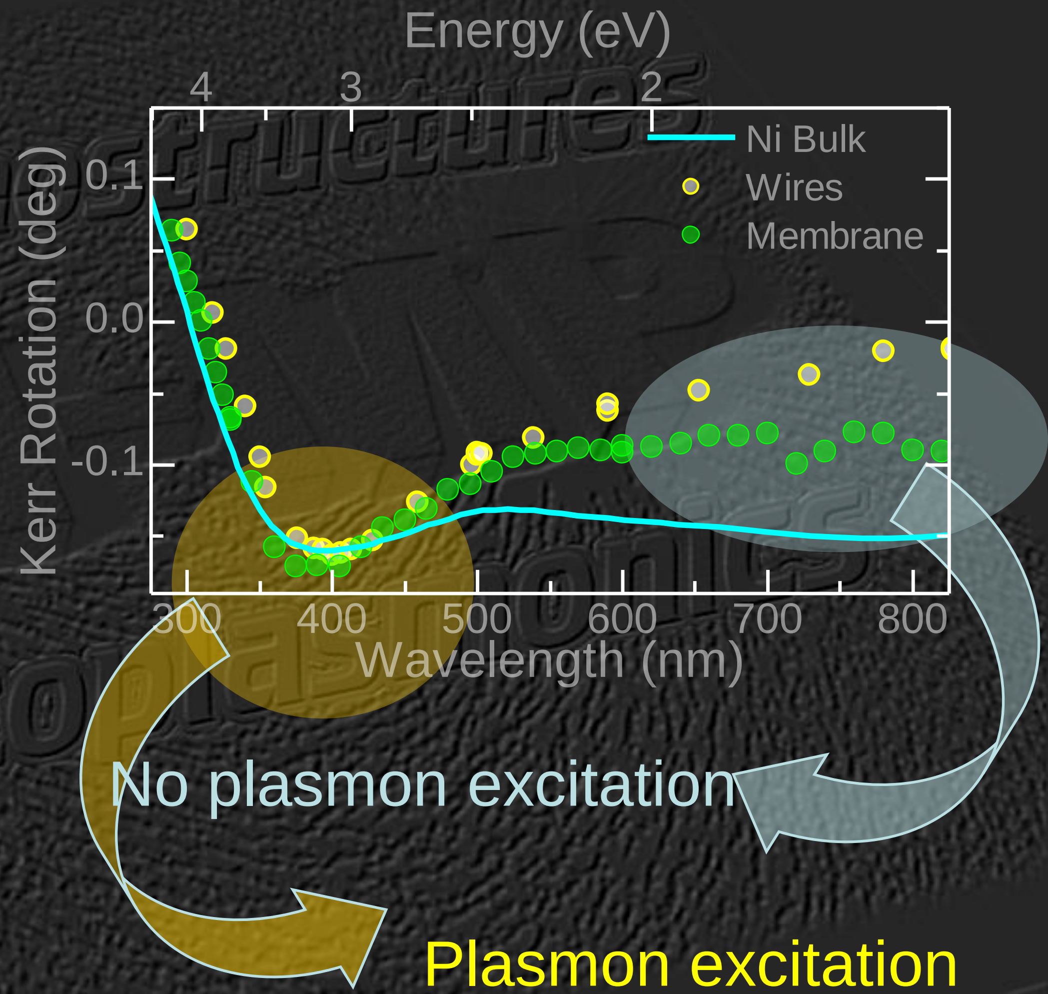
Adv. Mat. 19, 2643 (2007)



Ferromagnetic membranes

Appl. Phys. Lett. 94, 062502(2009)

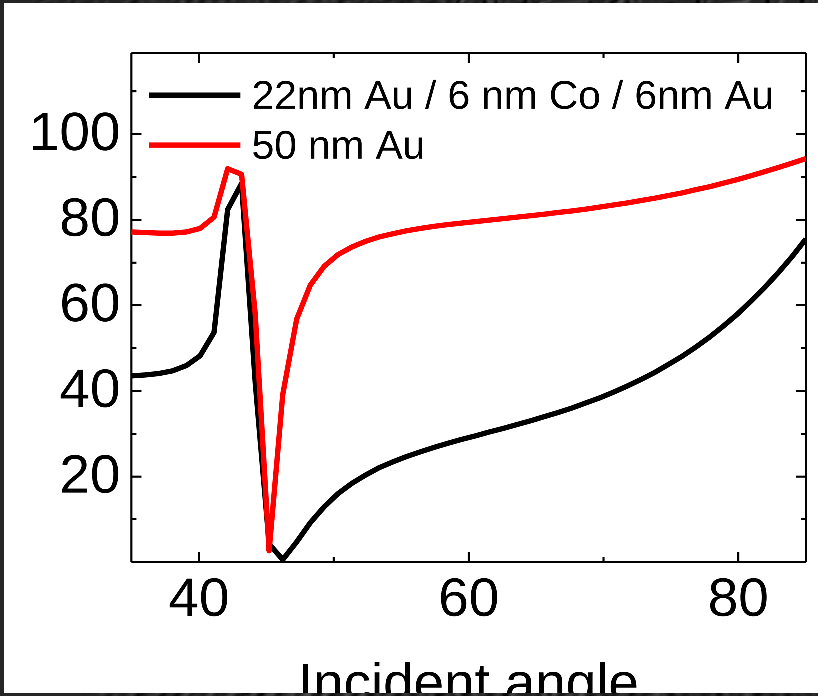


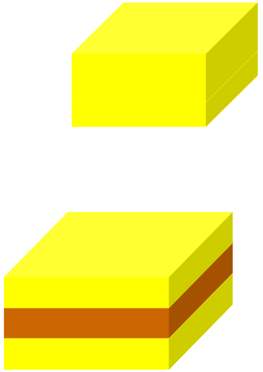


MAGNETO-PLASMONICS

Magnetoplasmonic materials:

Hybrid ferromagnetic – noble metal systems





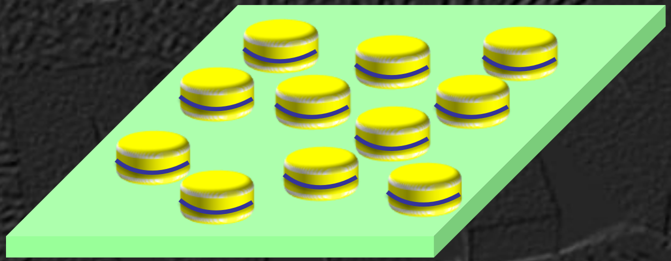
- Fair plasmonic modes
- Good MO activity

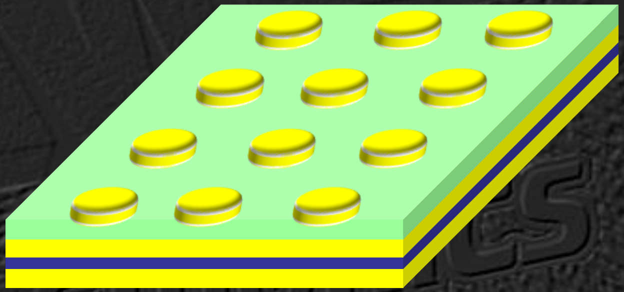
Plasmon effects on the
Kerr effect

… in nanostructured media…

Disordered Au/Co/Au nanosdiscs

Small (2008)

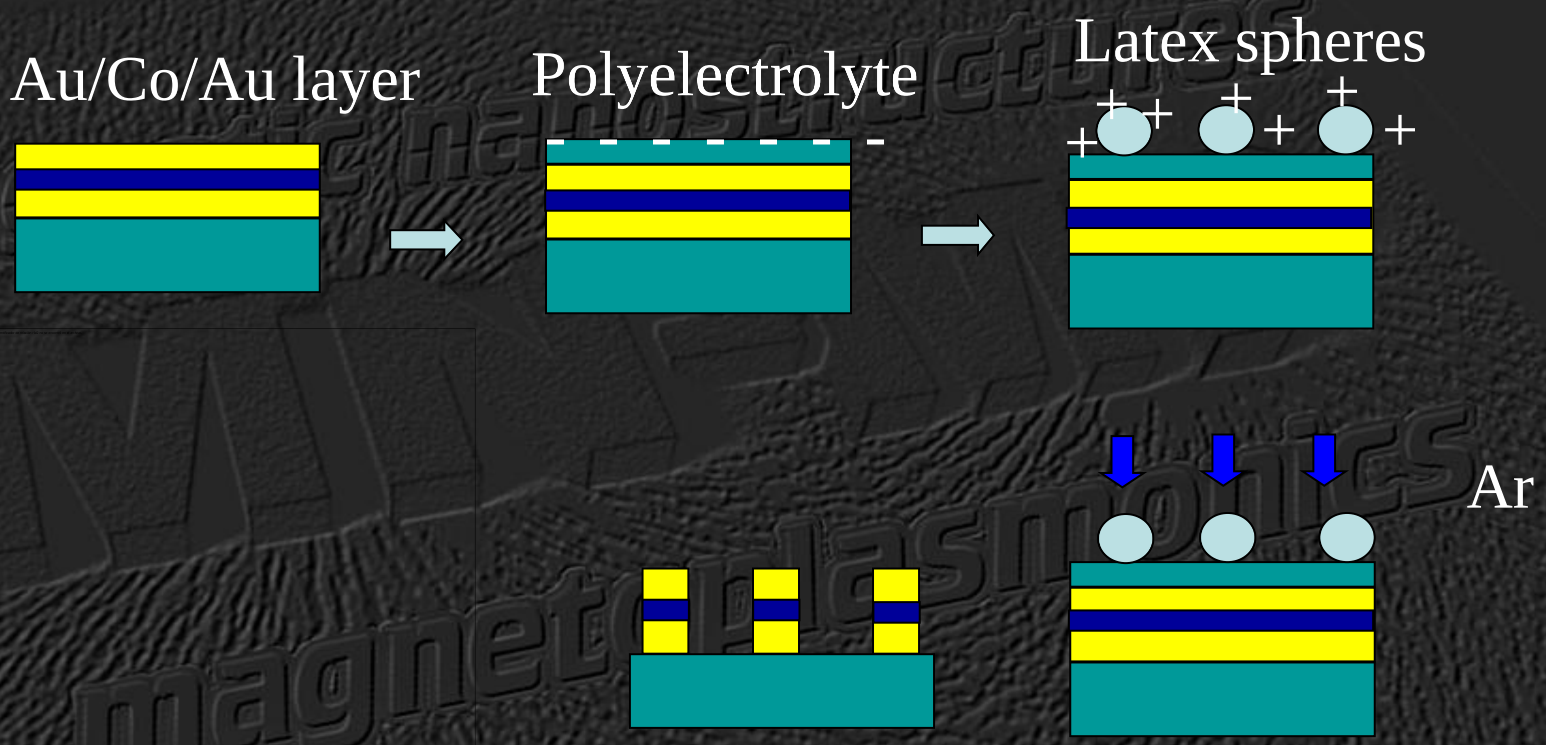




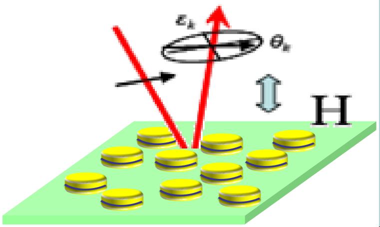
Au discs over Au/Co/Au film

Opt. Express (2008)

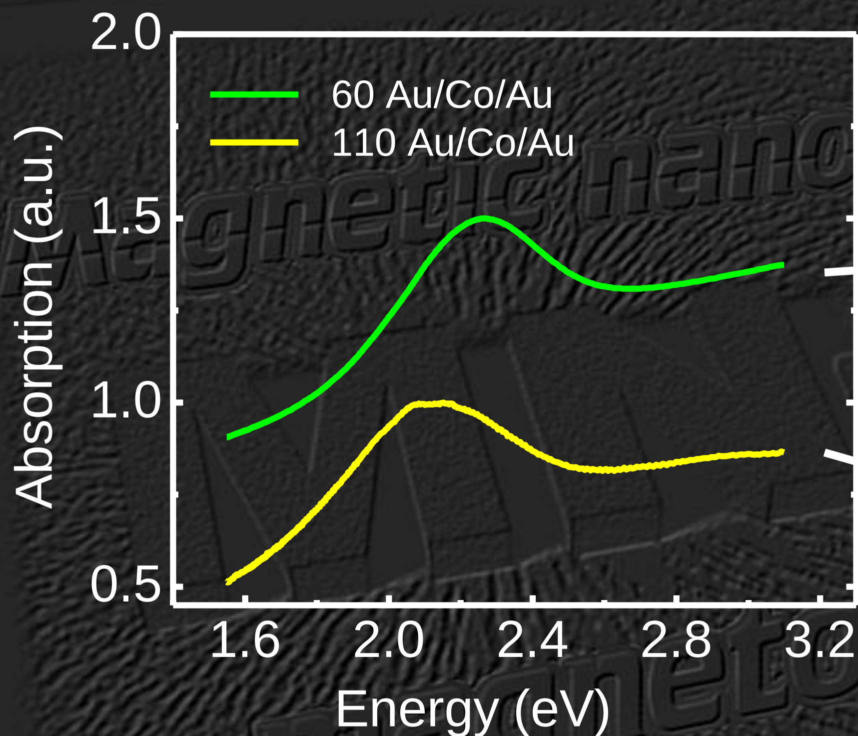
Fabrication method: Sputtering+ colloidal lithography

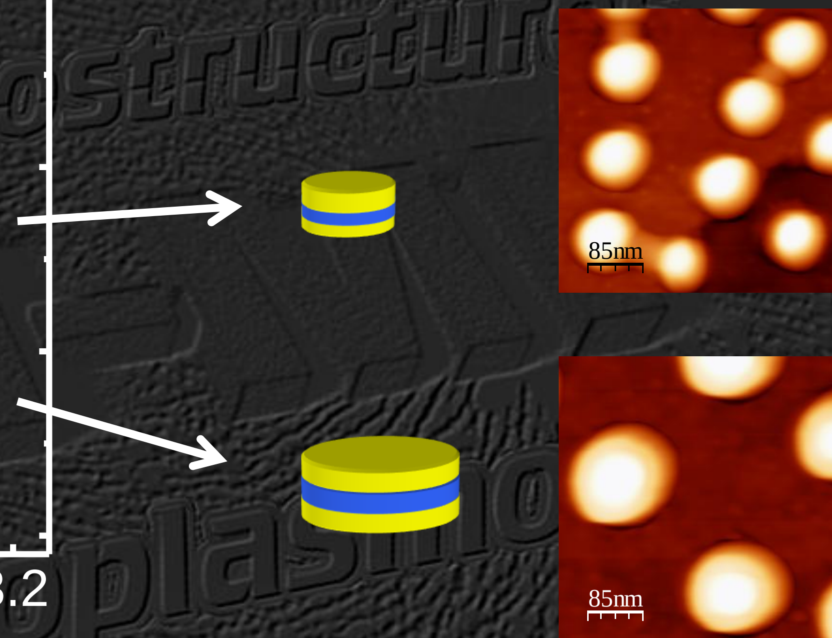


J.B. González et.al. Small 4,202 (2008)



Optical and magneto-optical analysis



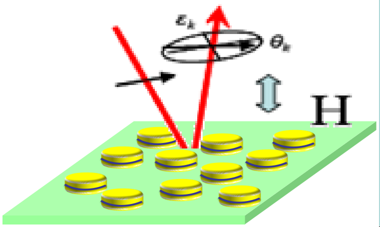


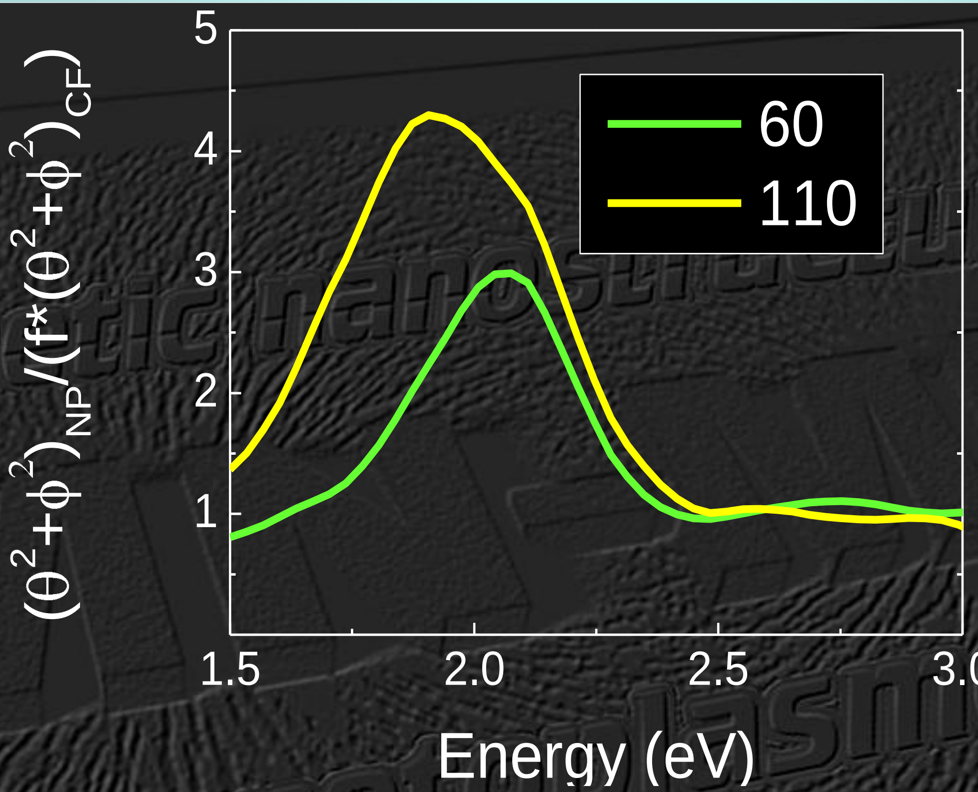
Peak in the LSPR spectral region

Shifts to lower energy as D/H increases

J.B. González et.al. Small 4,202 (2008)

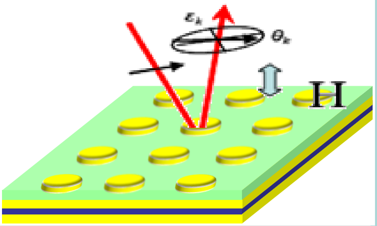
Optical and magneto-optical analysis





A large enhancement of the MO activity of the system is observed in the region corresponding to the excitation of the localized surface plasmon.

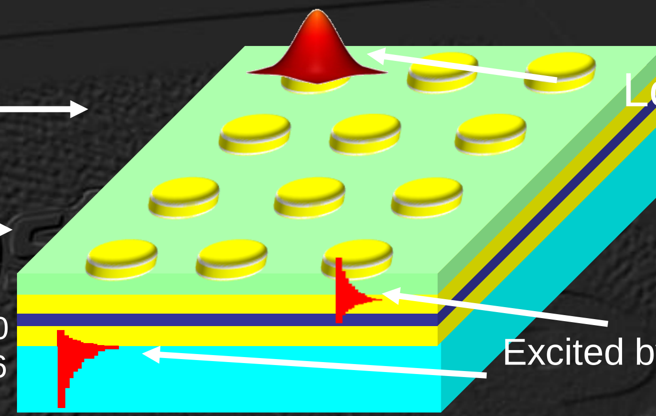
J.B. González et.al. Small 4,202 (2008)



Dots over Au/Co/Au

Square periodic array **Au nanodiscs**
(Grating)
(e-beam Φ:110nm,h 20nm,a:250-400nm)

SiO_2 (e-beam ev.) variable thickness



Localized SP

Au:6
Co:10
Au:16

SPP
Excited by periodic array

Glass

$$k_{sp} = k_{light}^{//} \pm G$$

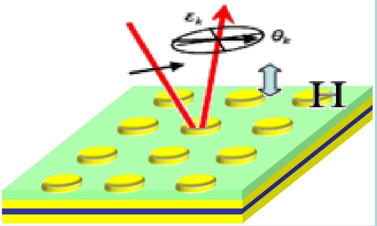
Plasmon excitation:

-Disc diameter: tunes LSP energetic position

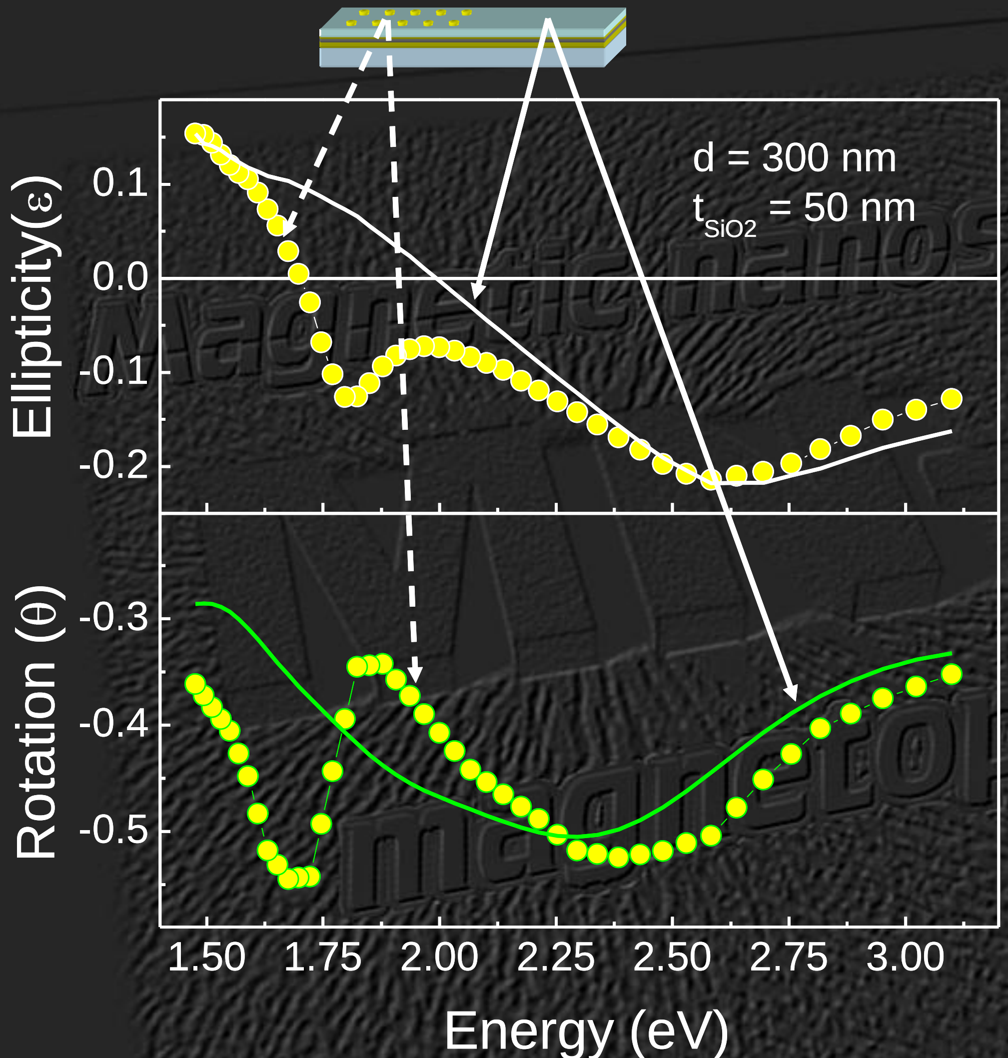
-Array periodicity (grating): tunes G vector and allows exciting SPP

-Spacer thickness: tunes LSP vs SPP overlapping/interaction

G. Armelles et. al. Opt. Express 16, 16104 (2008)

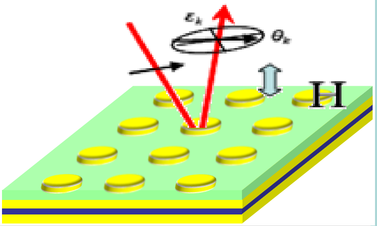


Dots over Au/Co/Au



The magneto-optical activity of the system is strongly modified in the region corresponding to the localized surface plasmon of the gold disc.

G. Armelles et. al. Opt. Express 16, 16104 (2008)

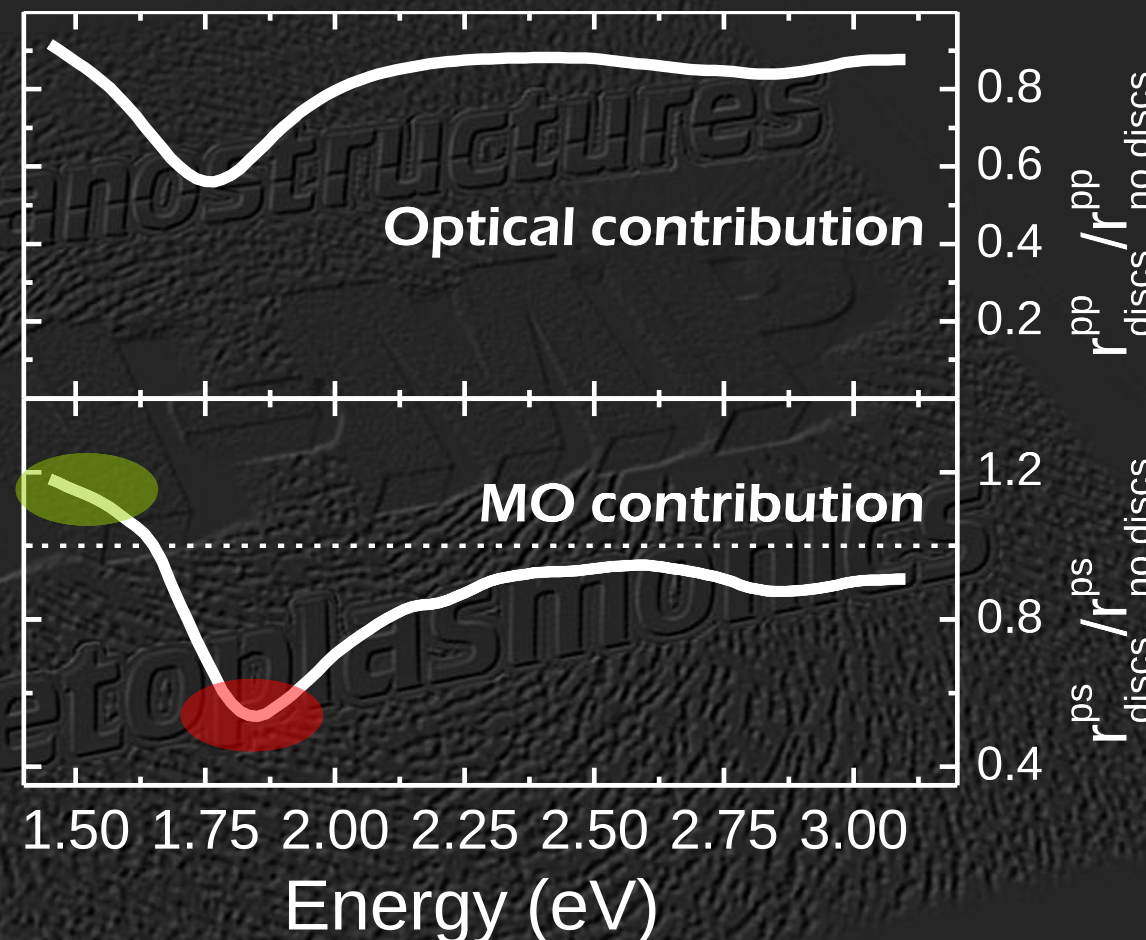


Dots over Au/Co/Au

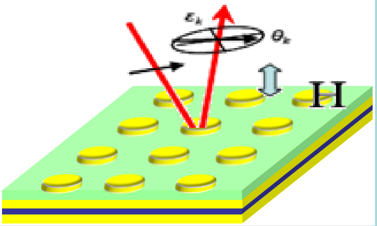
The purely optical component, r_{pp}, contributes to the magnetooptical activity enhancement due to the dip at the LSP position

The purely magnetooptical contribution, r_{ps}, is modified around the LSP position

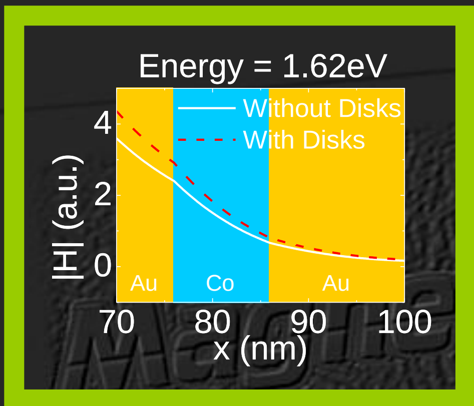
$$\theta_k + i\phi_k \approx \frac{r_{ps}}{r_{pp}}$$

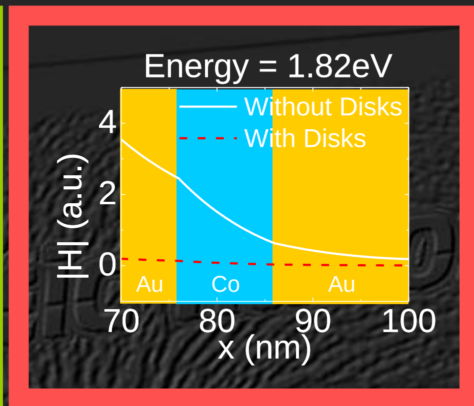


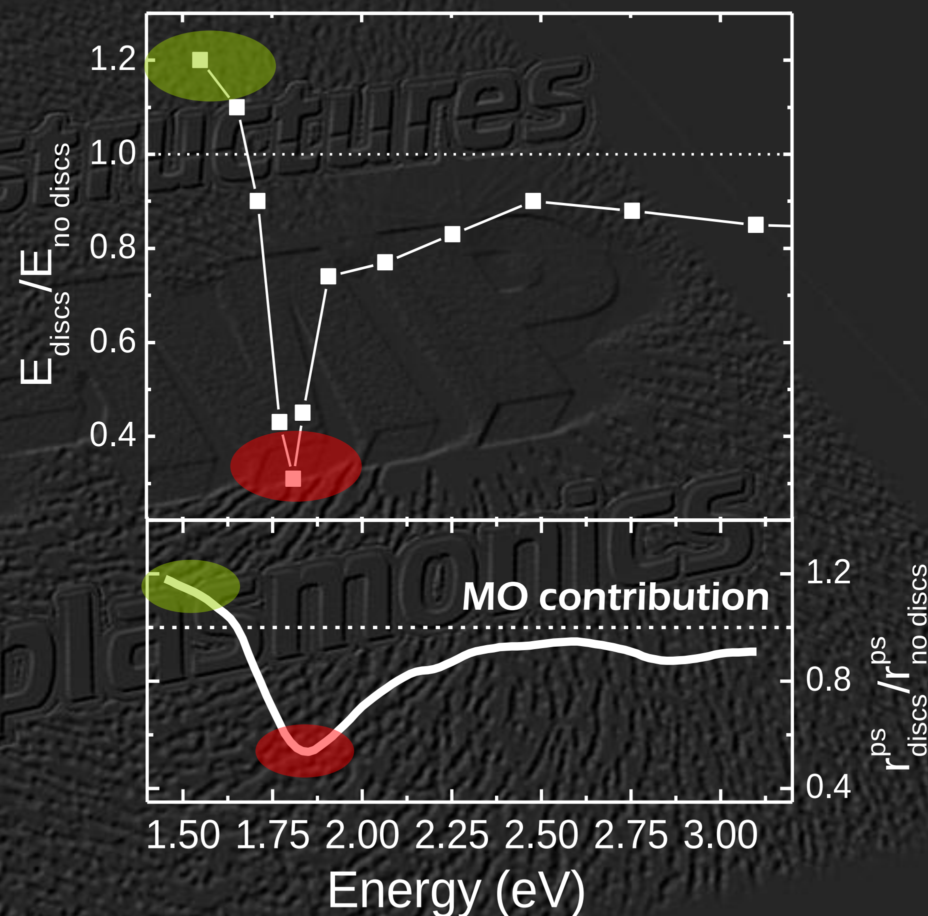
G. Armelles et. al. Opt. Express 16, 16104 (2008)



Dots over Au/Co/Au





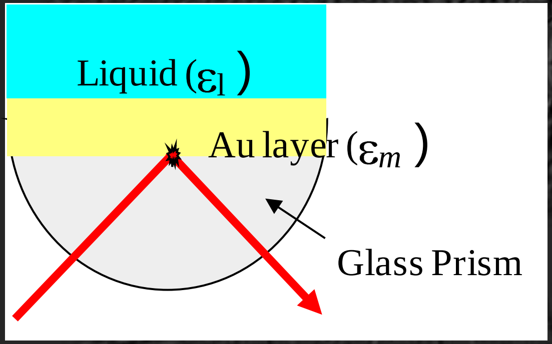


The purely magnetooptical contribution, r_{ps}, is related to the redistribution of the electromagnetic field inside the Co layer

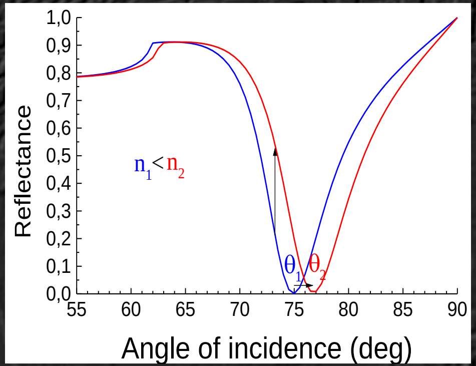
G. Armelles et. al. Opt. Express 16, 16104 (2008)

Operation Principle of Surface Plasmon Resonance sensor

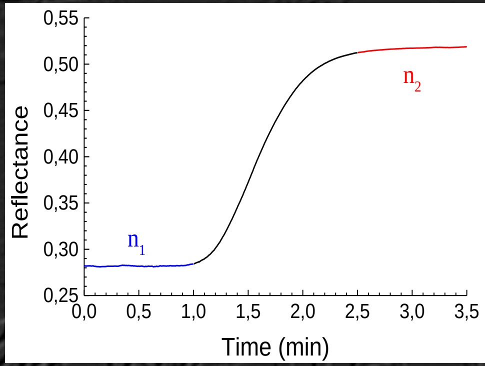
$$k_{SP} = k_0 \sqrt{\frac{\varepsilon_m \varepsilon_l}{\varepsilon_l + \varepsilon_m}}$$



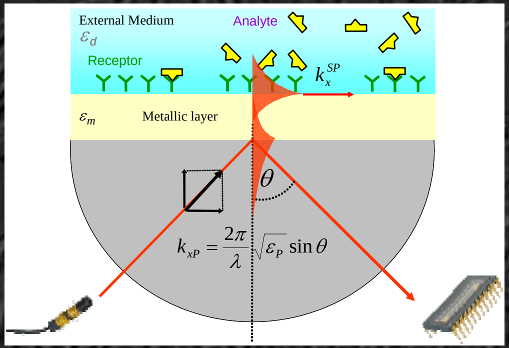
Resonant angle shift due to a change in the refractive index



Real time monitoring of the refractive index change at a fixed angle

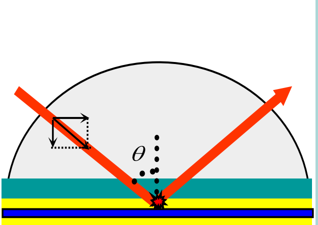


Sensor Device :



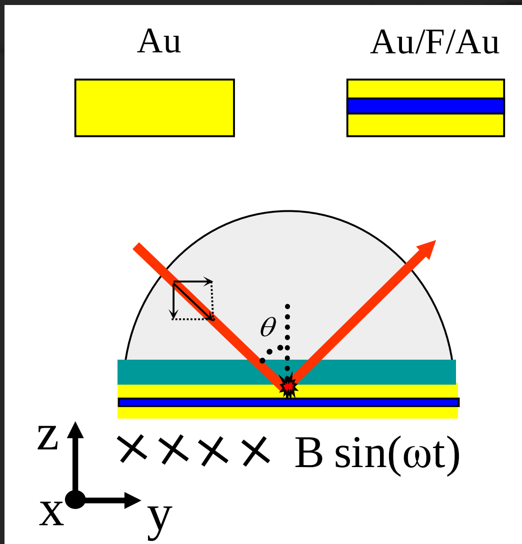
Evanescent Field detects changes in the local refractive index

Evanescent Field ~ 80 nm
(45 nm Au, λ= 632 nm)

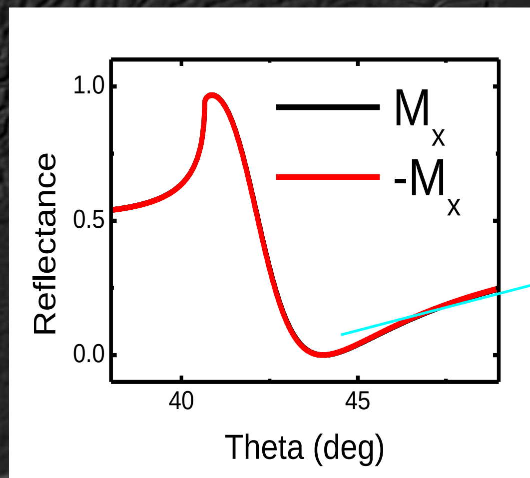


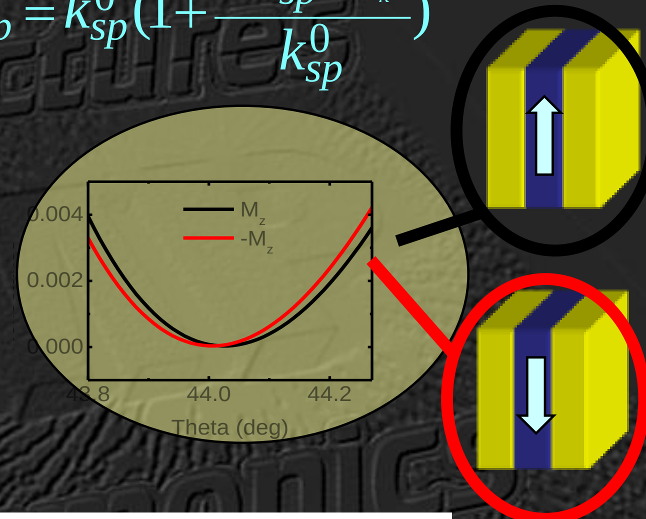
MOSPR: Angular derivative

Resonant angle depends on magnetization (M)

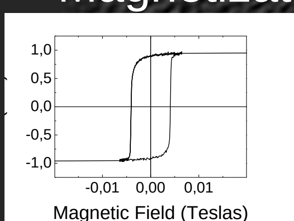


$$k_{//}^{light} = k_{sp} = k_{sp}^{0}\left(1 + \frac{\Delta k_{sp}\ M_x}{k_{sp}^{0}}\right)$$

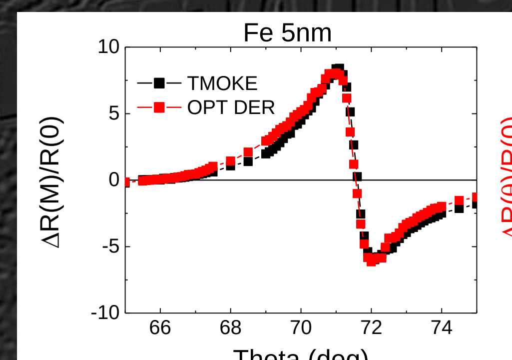




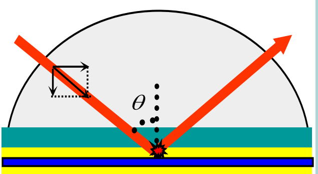
Magnetization switching ↔ angular derivative



$$R_{pp}(M) - R_{pp}(-M) \approx \frac{\partial R_{pp}(0)}{\partial \theta_{inc}}$$



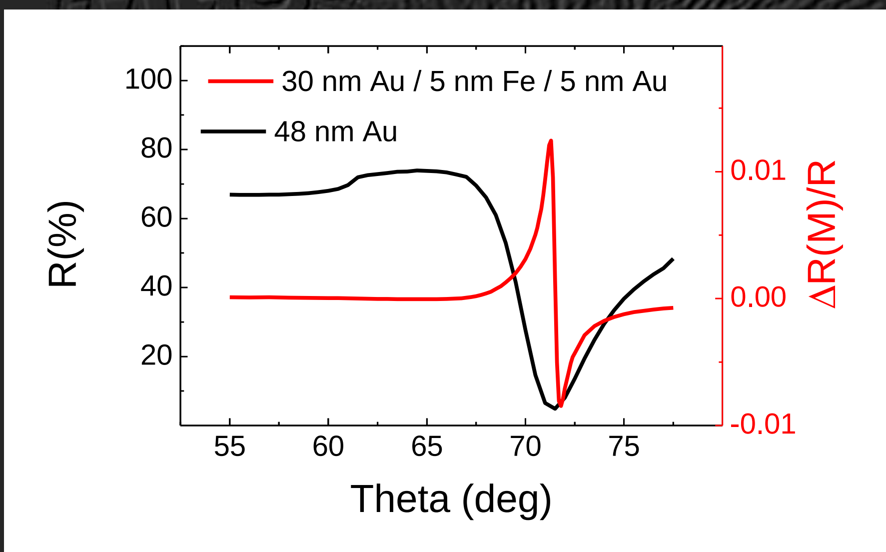
J.B. González-Diaz et.al. Phys. Rev B76, (2007)



MOSPR vs. SPR

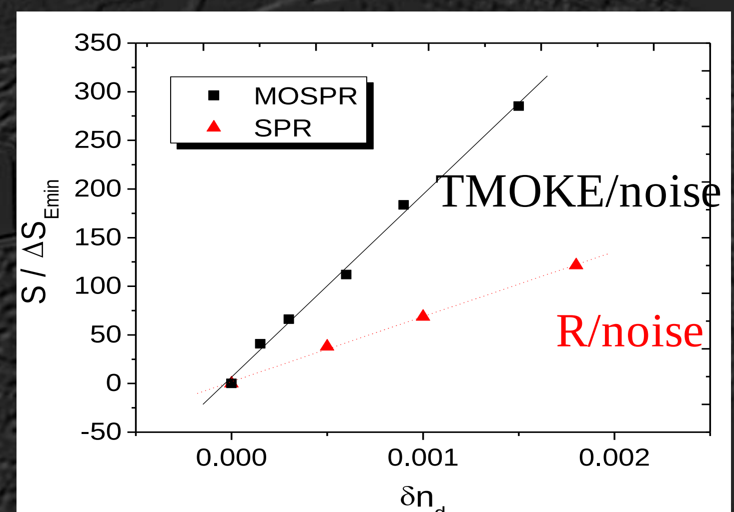
Sharper angular curves

(Angular derivative)



Higher sensitivity

	Δn_{Emin}
MOSPR	$5{\cdot}10^{6}$
SPR	1.510^{5}



B. Sepulveda et al., Optics Letters **31** (2006) 1085 + Patent.

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Instituto de Microelectrónica de Madrid

Conclusions

Magnetic Nanostructures MN-MP Magneto Plasmonics

Using materials exhibiting plasmonic and magneto optical activity simultaneously we have shown:

- *Enhancement of MO activity due to SPP-Light coupling*
- *Magnetic field modifies the SPP momentum*

Applications

Sensing

Novel scheme exploiting:

a) Electromagnetic field localization

b) External modulation via magnetic field

Optronics

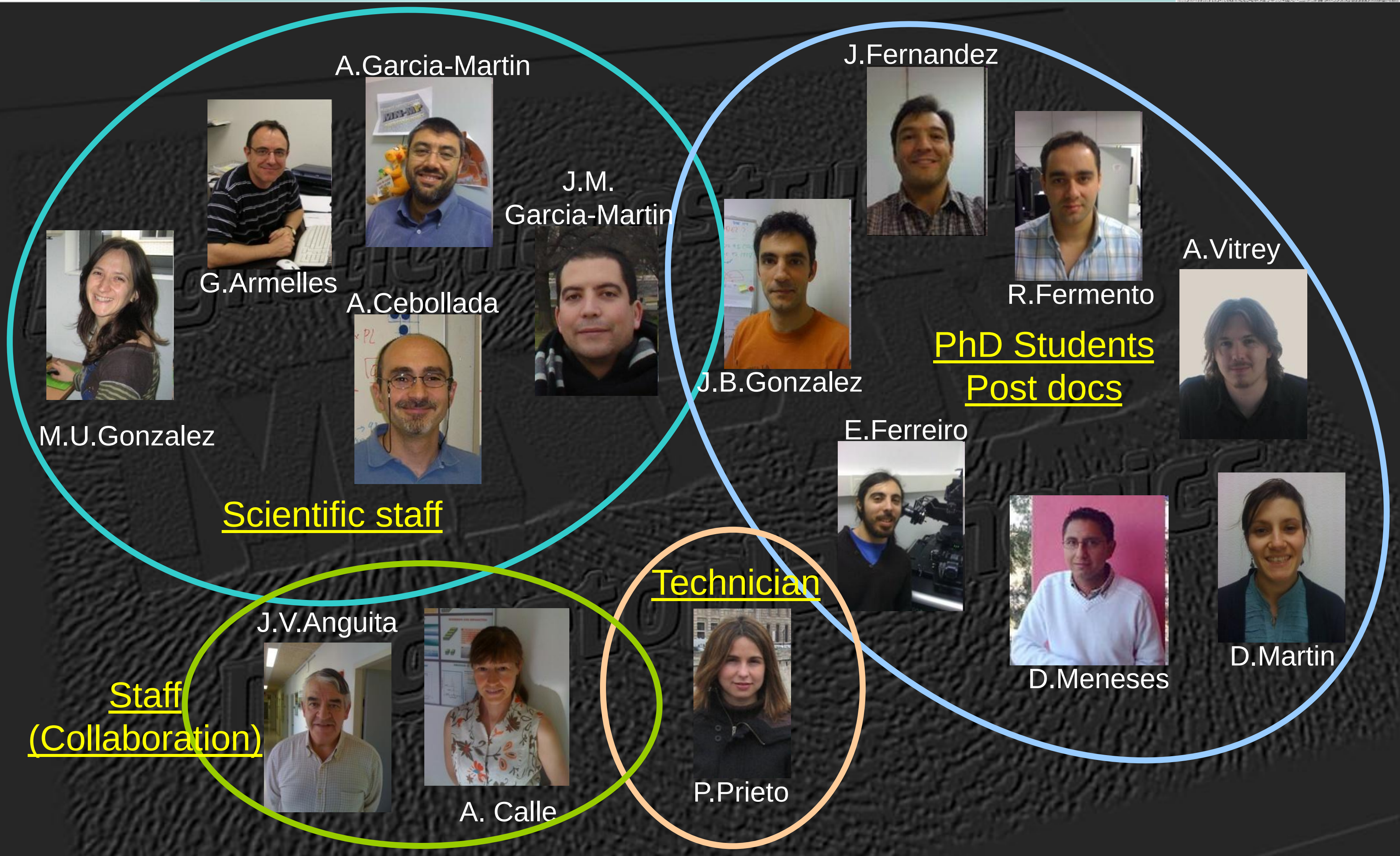
Communications: external control

Photonics on silicon:potential structure for dynamic behaviour of plasmonic components

Data storage: MO plasmon-mediated enhancement

Enhanced magneto-optical media & patterned MO media

Acknowledgments



Acknowledgments

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University of Toledo

ICFO

ICMM

CIN2

University of Michigan

Acknowledgments

EU

PhOREMOST

nanomagma
www.nanomagma.org

Regional (CAM)

Comunidad de Madrid

Microseres

Nanomagnet

National (MICINN,CSIC)

CSIC
Consejo Superior de Investigaciones Científicas

Programa ingenio 2010

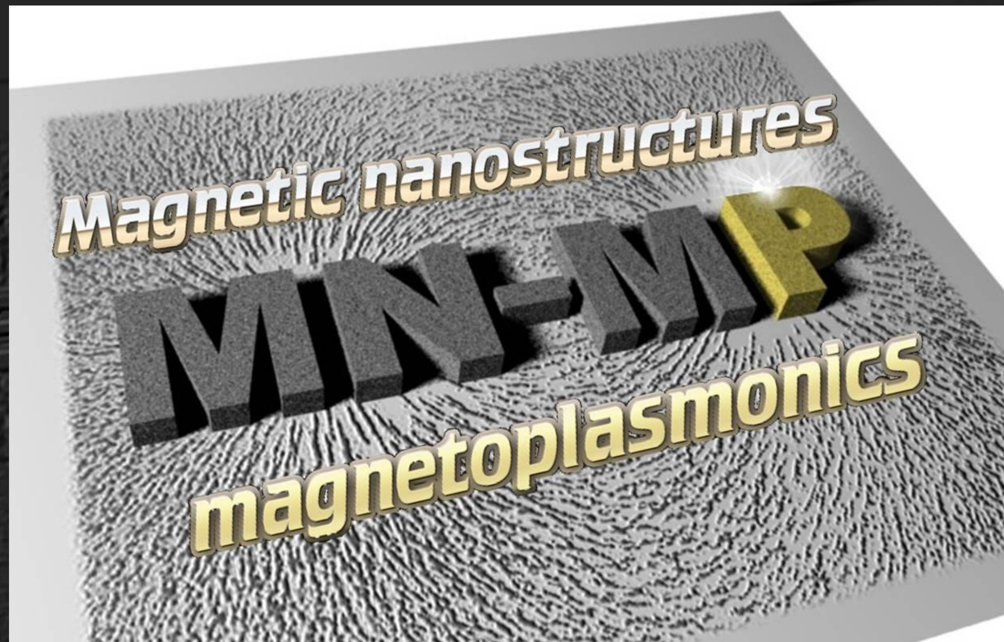
Gobierno de España
Ministerio de Ciencia e Innovación

Crimafot
Bioptomag

Funcoat

Magplas

Magnetoplasmonics: fundamentals and applications



http://www.imm-cnm.csic.es/magnetoplasmonics

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