Increasing the modulation depth in Au/Co/Au magnetoplasmonic interferometers

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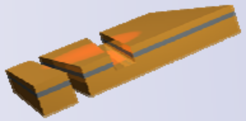
Outline

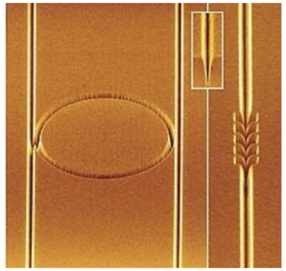
- Motivation
- Magnetic field effects
- Magnetoplasmonic interferometers
- Engineering Δk_{sp} → addition of a thin dielectric film
- Figure of merit
- Conclusions



Motivation

Plasmonics ➡ one path to develop nanophotonic devices

- Passive systems widely demonstrated

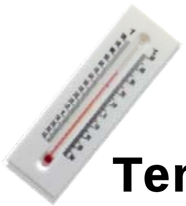


Groove based waveguides

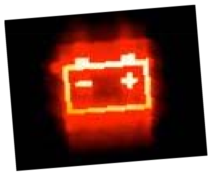
Nature **440**, 508 (2006)
Nano Lett. **7**, 880 (2007)

- **Active plasmonics** is needed to provide active components

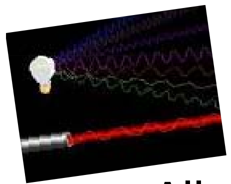
  ↳ Several proposed control agents:



Temperature
Thermo-optical materials



Voltage
PlasMOStor
Electro-optical materials

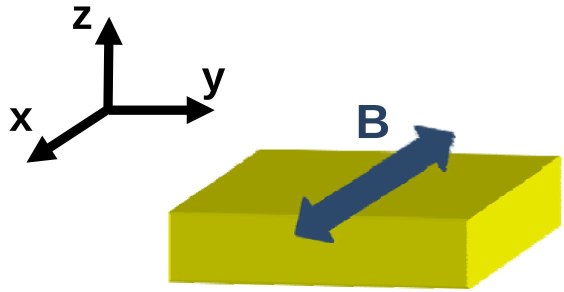


Light
All-optical modulation

- Our choice as external agent ➡ **magnetic field**

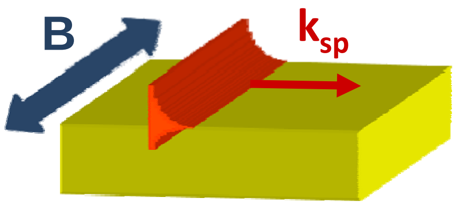
Magnetic field effects

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



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

Effects of magnetic field on surface plasmon polaritons (SPP):



$$k_{sp} \approx \frac{\omega}{c}\sqrt{\frac{\varepsilon}{\varepsilon+1}}\left(1 - \frac{i\varepsilon_{mo}}{(1+\varepsilon^2)\sqrt{-\varepsilon}}\right)$$

$$k_{sp}(B) = k_{sp}^{0} + \Delta k_{sp}(B)$$

SPP wavevector modulation

R.F. Wallis *et al.*, PRB **9**, 3424 (1974)

Magnetoplasmonics

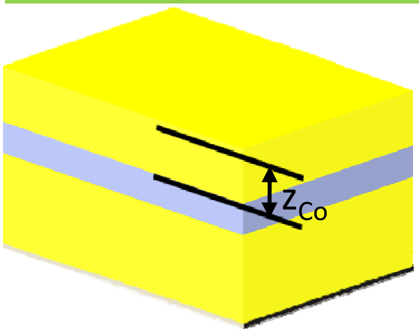
Which materials (metals) should we use?

Plasmonic metals (Au, Ag) → Very small ε_{mo} ($\propto$B):
Au/air, B = 1T, ($\Delta k/k_0$) ~1×10^{-6}

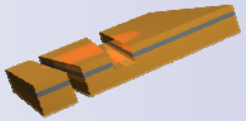
Ferromagnetic metals (Fe, Co, Ni) → Higher ε_{mo} ($\propto$M); M sat. at low B (mT):
Co/air, B = 10^{-3} T, ($\Delta k/k_0$) ~1×10^{-4}

High optical absorption

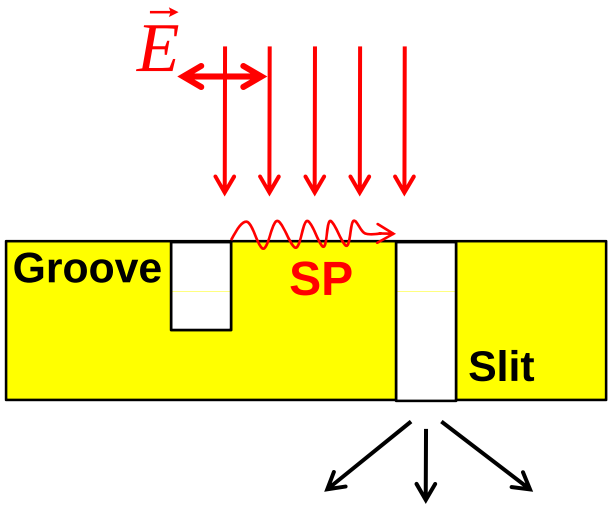
Magnetoplasmonic materials:
Hybrid ferromagnetic – noble metal systems



Glass+ 2Cr+Trilayers Au/6 nm Co/Au 200nm thick
Co depth, z_{Co}: 05/15/25/35/45/55 nm

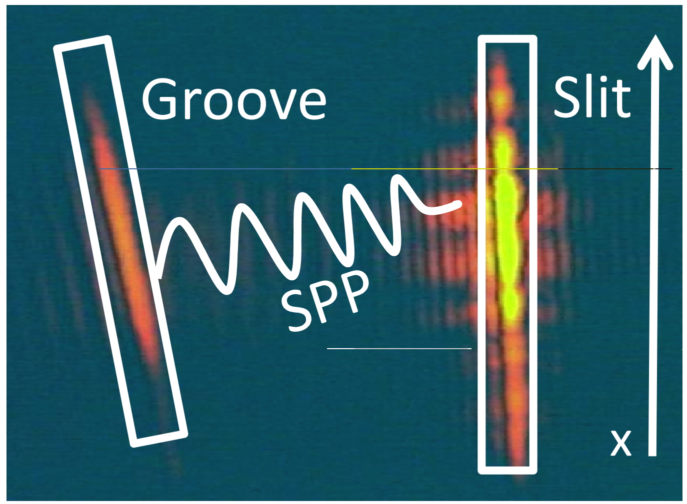


Plasmonic interferometer



$$I_T = I_{direct} + I_{SPP} + I_{interference}$$

Tilted groove

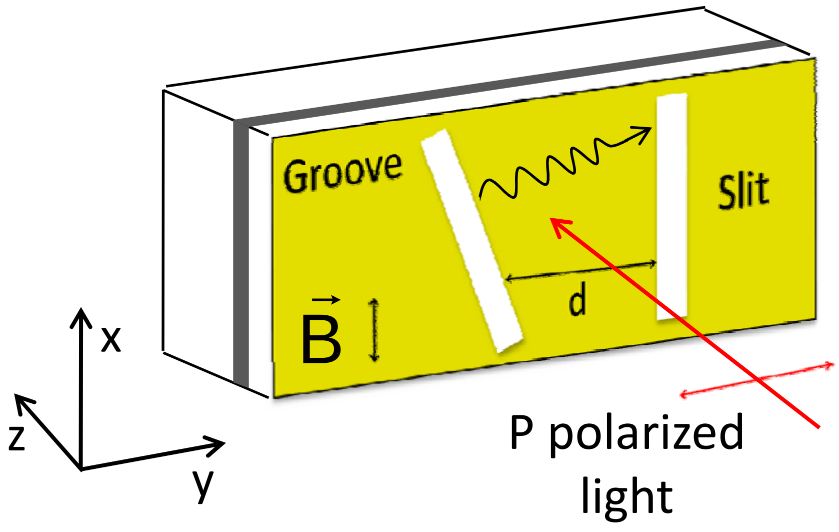


$$I = \underbrace{A_r^2}_{I_{direct}} + \underbrace{A_{sp}^2 e^{-2k_{sp}^i \cdot d}}_{I_{SPP}} + \underbrace{2 \cdot A_r A_{sp} \cdot e^{-k_{sp}^i \cdot d} \cdot \cos(k_{sp}^r \cdot d + \varphi)}_{\text{Interference term}}$$

V.V. Temnov *et al.*, Opt. Express **17**, 8423 (2009)

Magnetoplasmonic interferometer

Transversal configuration

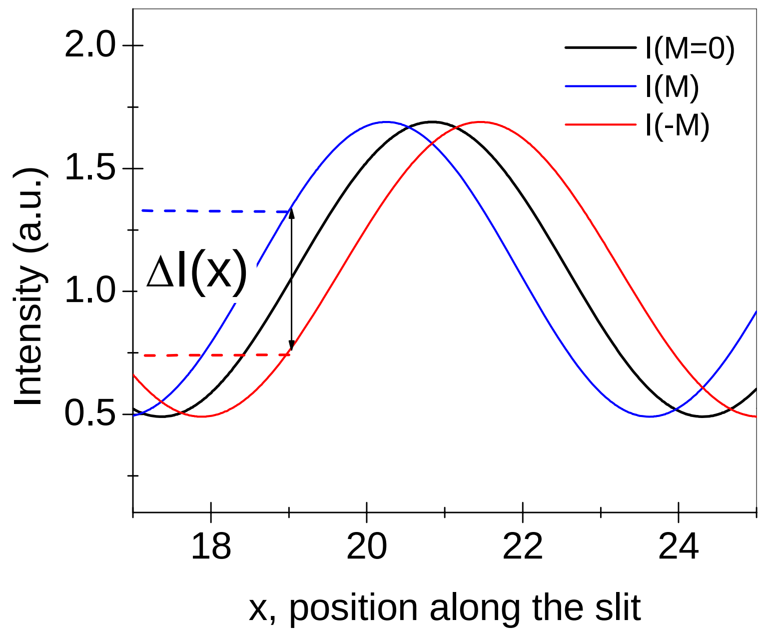


$$k_{sp}(M) = k_{sp}^{0} + \Delta k_{sp}(M)$$

$$\Delta k_{sp} = k_{sp}(M) - k_{sp}(0) \propto M$$

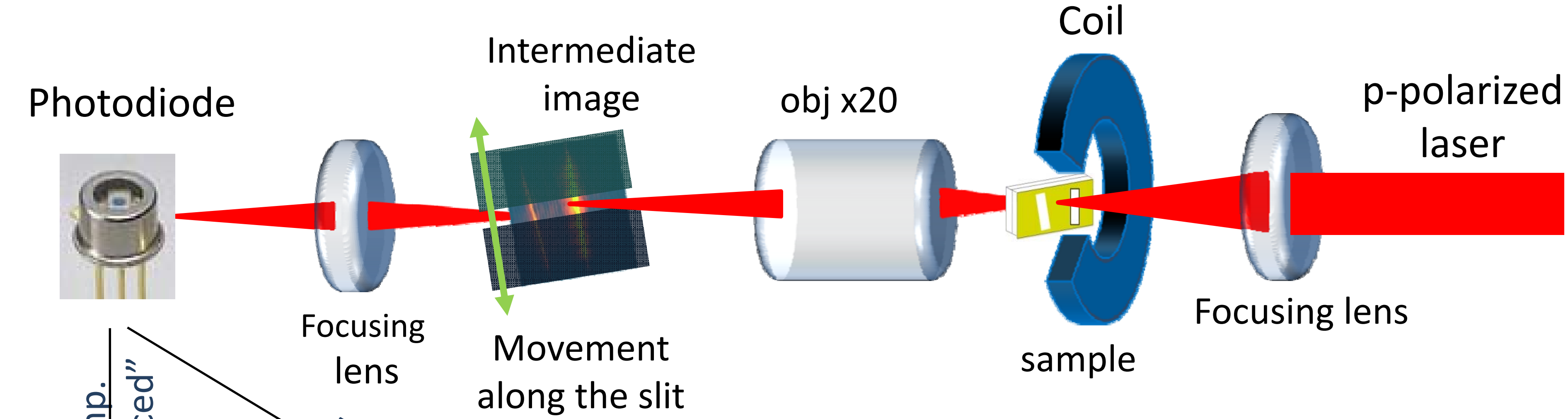
Δk_{sp}

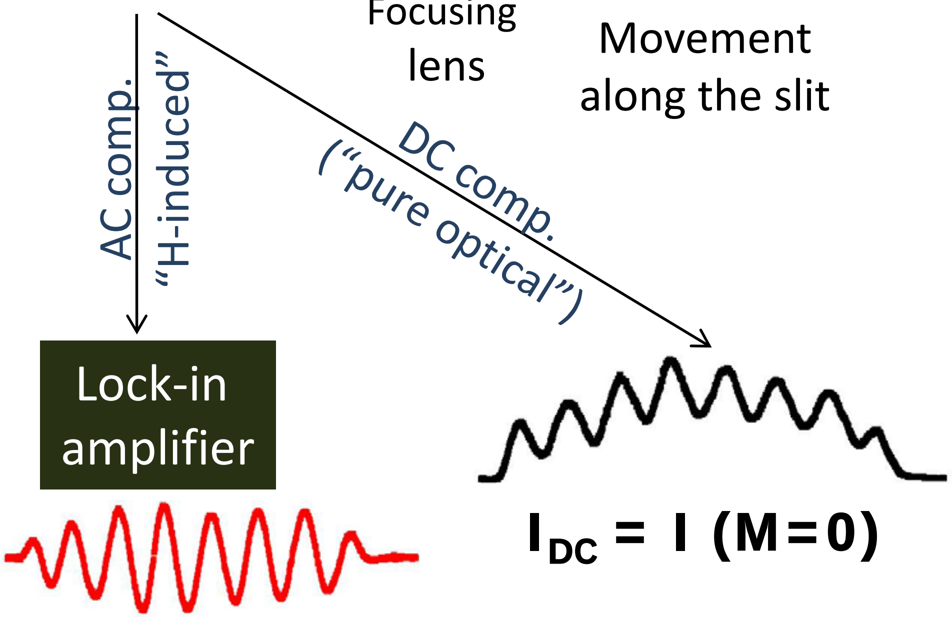
interference pattern shift



We modulate ΔI

Experimental setup



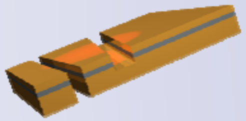


$I_{DC} = I\ (M=0)$

$I_{MP} = \Delta I(M) = I(M) - I(-M)$

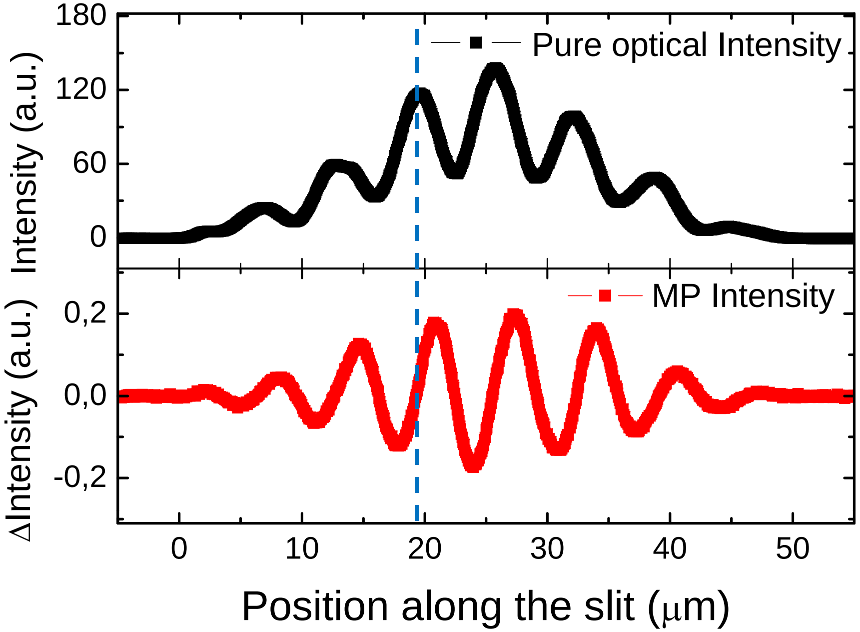
Lasers: λ=633 nm, P =30 mW

Applied magnetic field:
B= 19 mT; f=1400 Hz

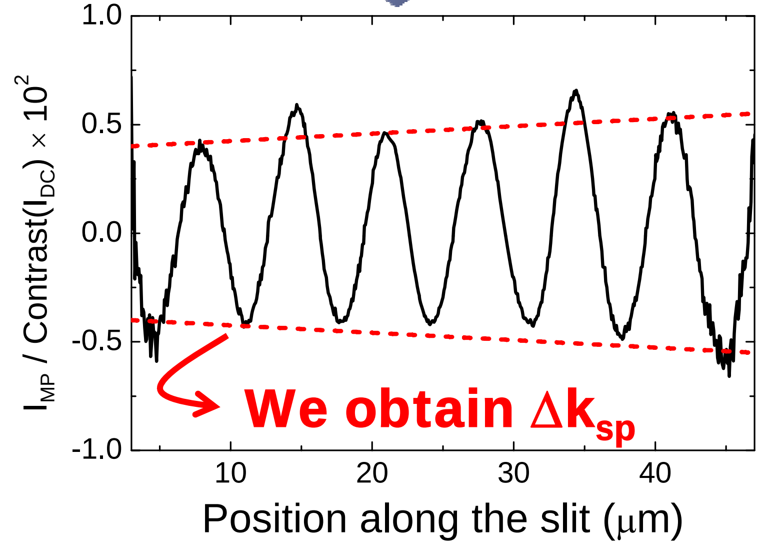


Magnetoplasmonic interferogram

$$I_{DC} = A_r^2 + A_{sp}^2 e^{-2k_{sp}^i \cdot d} + 2A_r A_{sp} e^{-k_{sp}^i \cdot d} \cos(k_{sp}^0 \cdot d + \varphi)$$



$$\frac{I_{MP}}{Contrast\left(I_{DC}\right)} \propto \Delta k_{sp} \cdot d$$

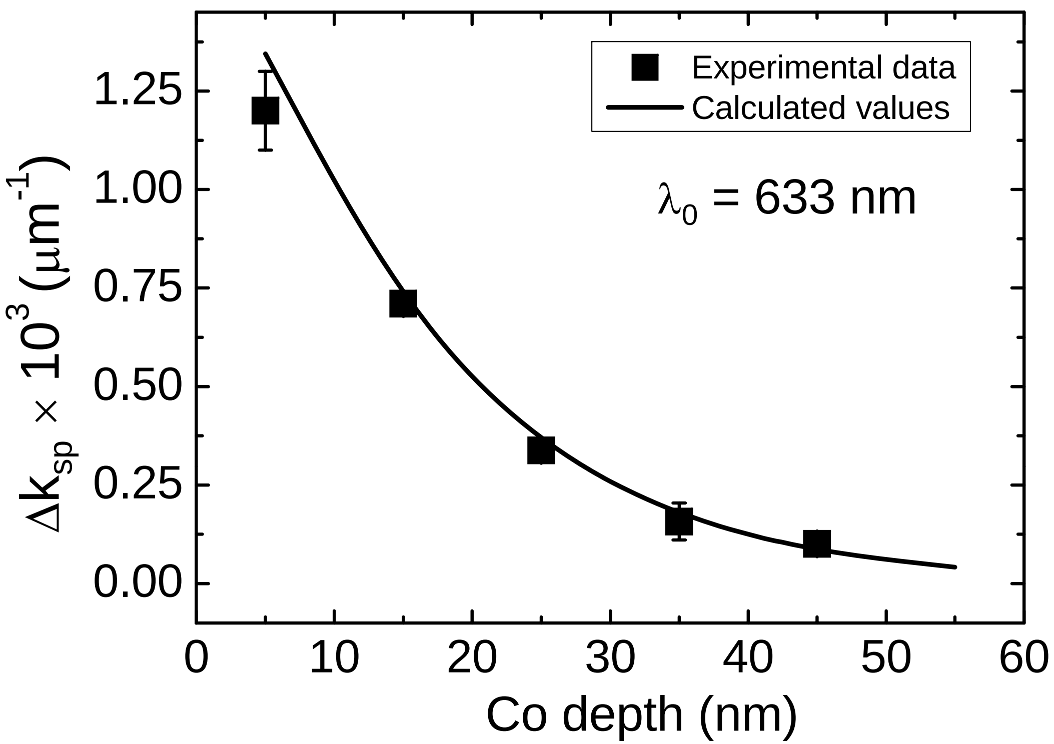


$$I_{MP} = -2A_r A_{sp} e^{-k_{sp}^i \cdot d} \Delta k_{sp} d \sin(k_{sp}^0 \cdot d + \varphi)$$

V. V. Temnov, G. Armelles *et al.,* Nat. Photonics **4**, 107 (2010)

Magnetoplasmonic modulation

Evolution of Δk_{sp} with Co depth



$$\Delta k_{sp} \approx \frac{2t_{Co}k_0^2\varepsilon_d^2}{-\varepsilon_{Au}^2}\frac{i\varepsilon_{mo}^{Co}}{\varepsilon_{Co}}e^{-2z_{Co}k_z^{Au}}$$

k_{sp} modulation depends on the SPP field penetration

Modulation depth:

$\Delta k_{sp} \times d \sim 4\%$

How to increase Δk_{sp}?

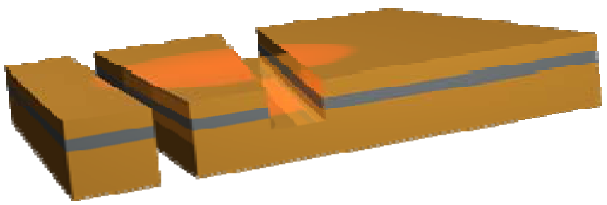
Engineering Δk_{sp}

How to increase Δk_{SP}?

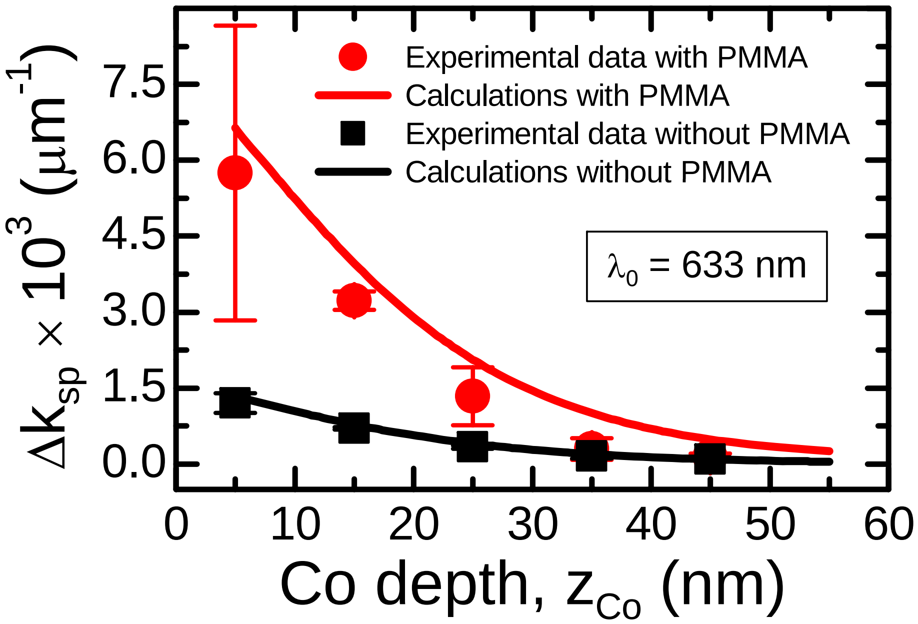
$$\Delta k_{sp} \approx \frac{2t_{Co}k_0^2\varepsilon_d^2}{-\varepsilon_{Au}^2}\frac{i\varepsilon_{mo}^{Co}}{\varepsilon_{Co}}e^{-2z_{Co}k_z^{Au}}$$

We can use a dielectric with a higher ε

we add a thin dielectric overlayer



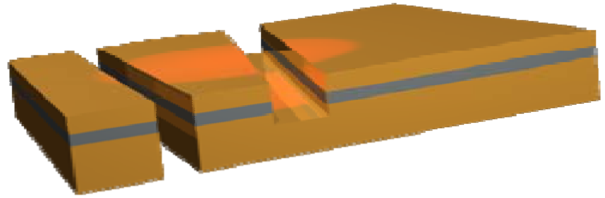
60 nm PMMA overlayer

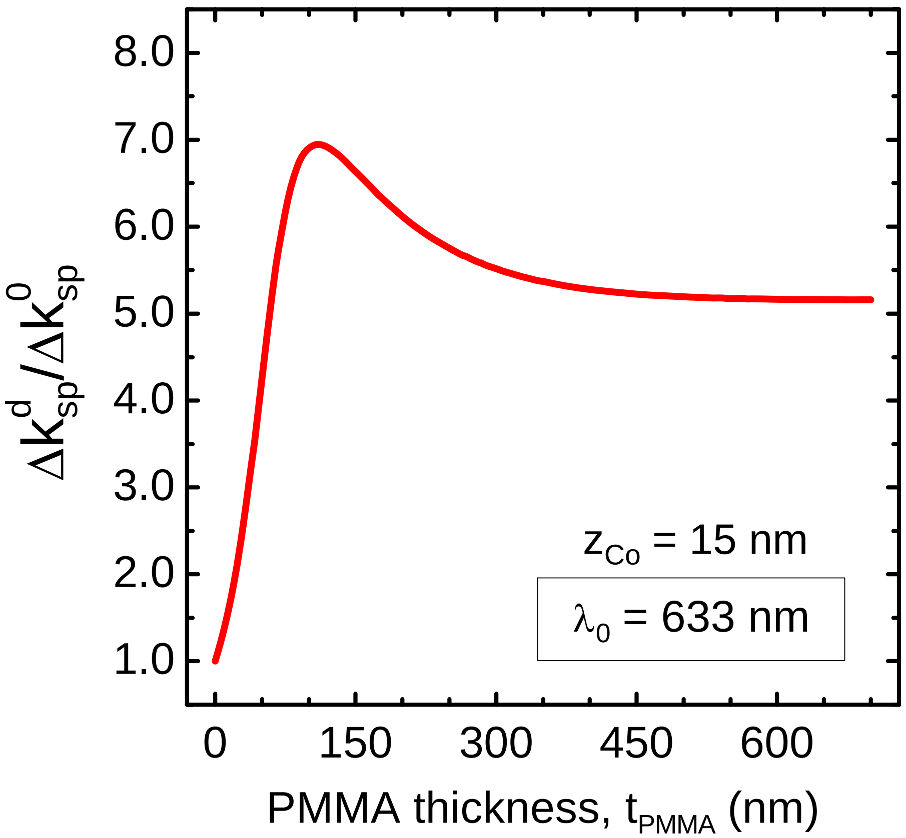


Enhancement factor = $\Delta k_{sp}^d \,/\, \Delta k_{sp}^0$

Engineering Δk_{sp}

Evolution with the dielectric thickness



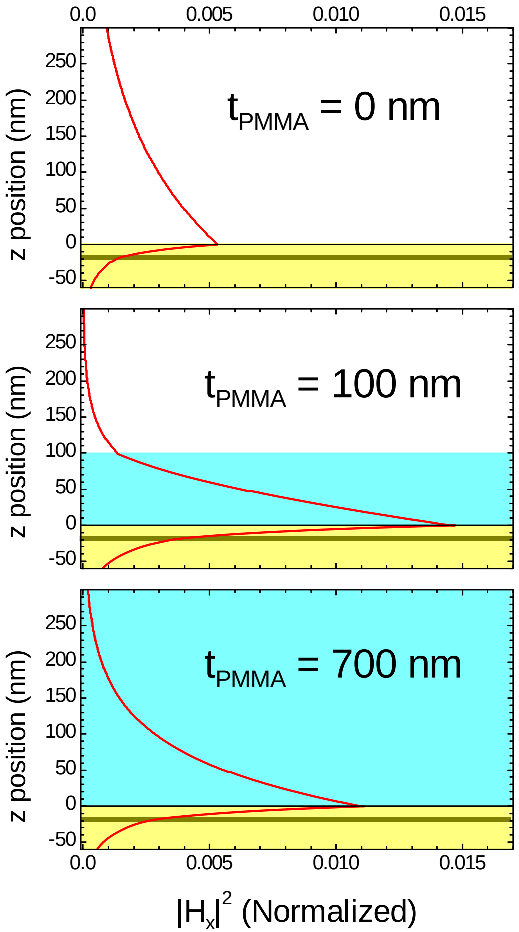


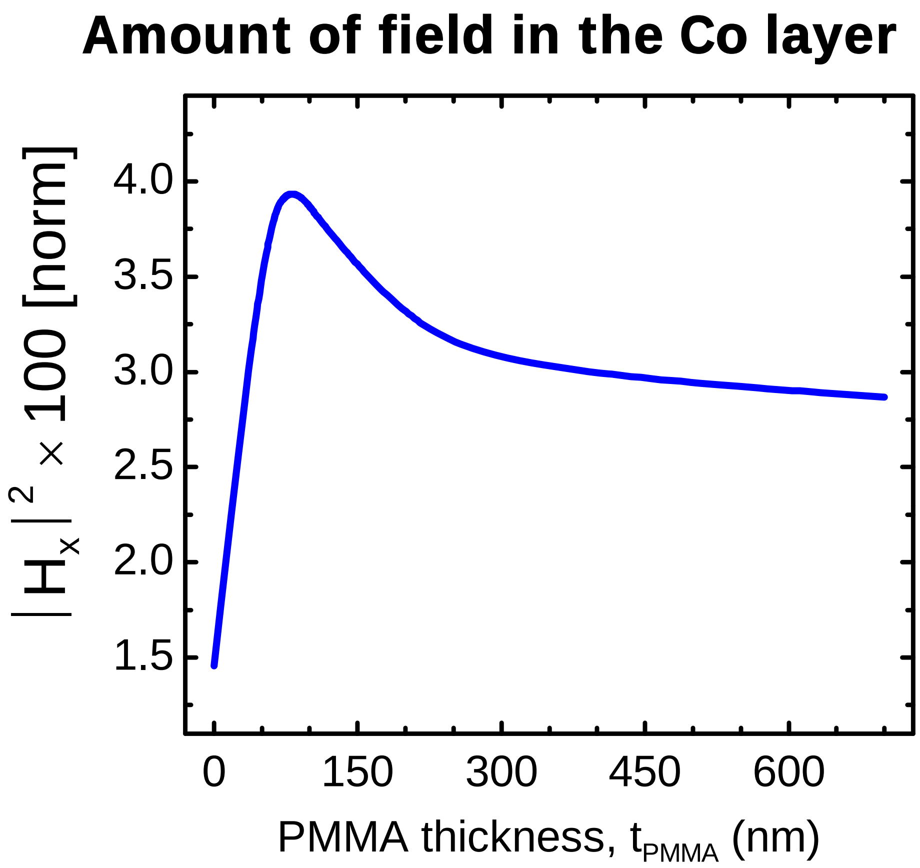
7-fold enhancement of the SPP wavevector modulation

Why this non-monotonous behaviour of the enhancement factor?

Engineering Δk_{sp}

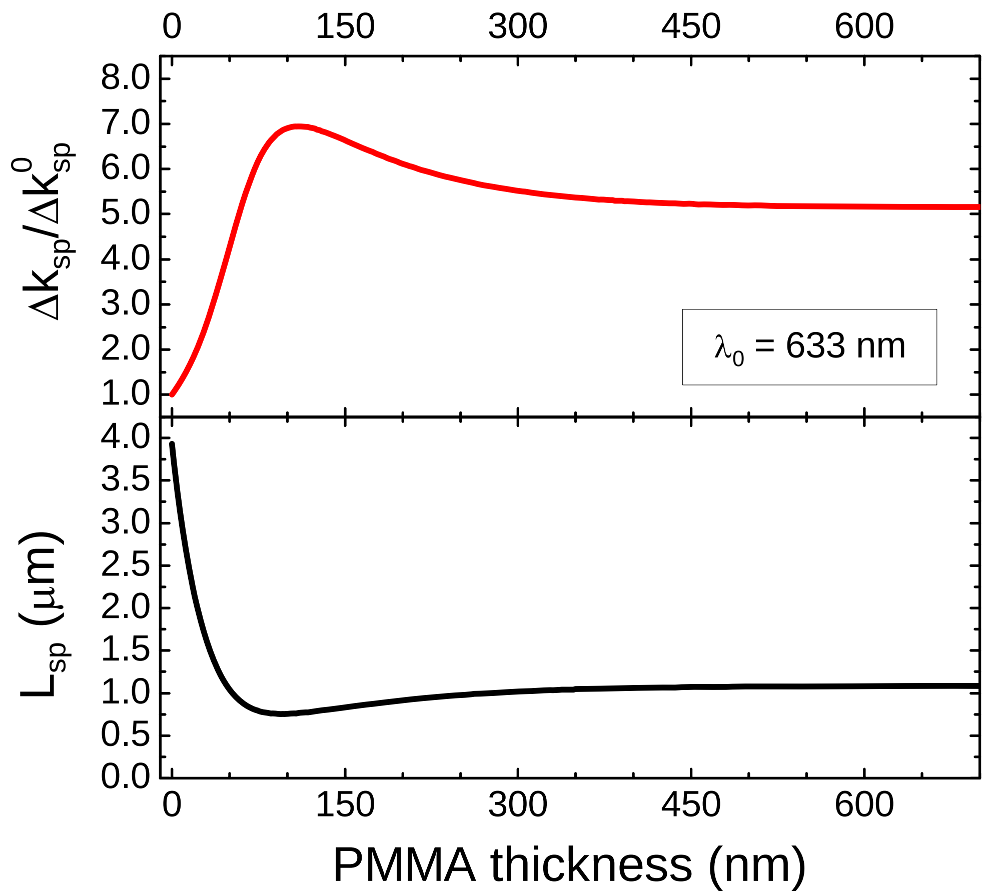
Redistribution of the fields with the addition of the dielectric film

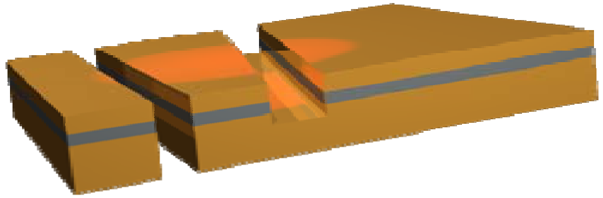




Engineering Δk_{sp}

Evolution with the dielectric thickness

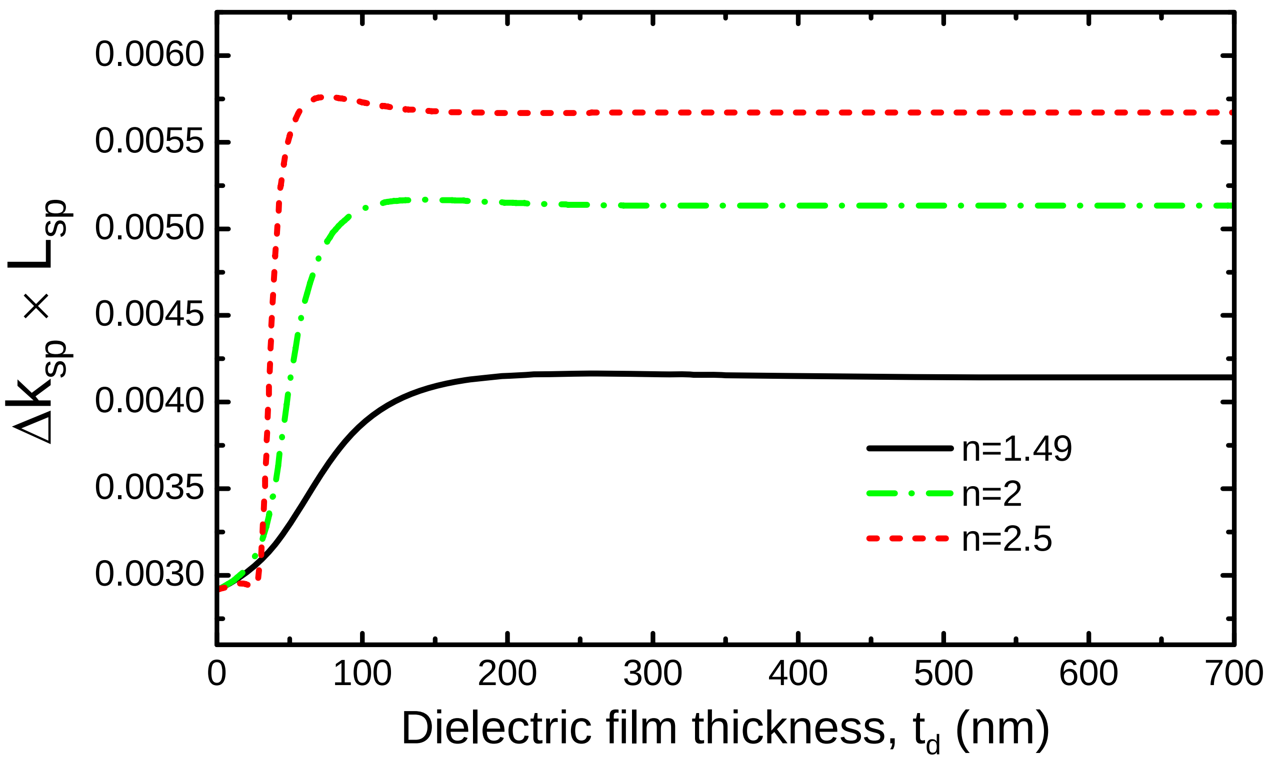




Reduction of the SPP propagation distance

Engineering Δk_{sp}

Figure of merit: Δk_{sp} x L_{SP}



Conclusions

- A magnetic field induces a measurable modulation on the surface plasmon wavevector in magnetoplasmonic systems

  ➡ Development of active plasmonic interferometers

- k_{sp} modulation can be increased up to 7 times by adding a thin dielectric overlayer, keeping a favourable figure of merit Δk_{sp} x L_{sp}

- Δk_{sp} can provide information on the plasmon field distribution

Thank you very much!

Funding

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