Wavelength dependence of the SPP wavevector magnetic modulation in Au/Co/Au films

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Motivation

- SPP are very interesting since their properties make them promising for optoelectronic applications: Plasmon circuitry, sensing, etc.

- Problem: how can one control/modify the plasmon properties? We need active control over the device performance

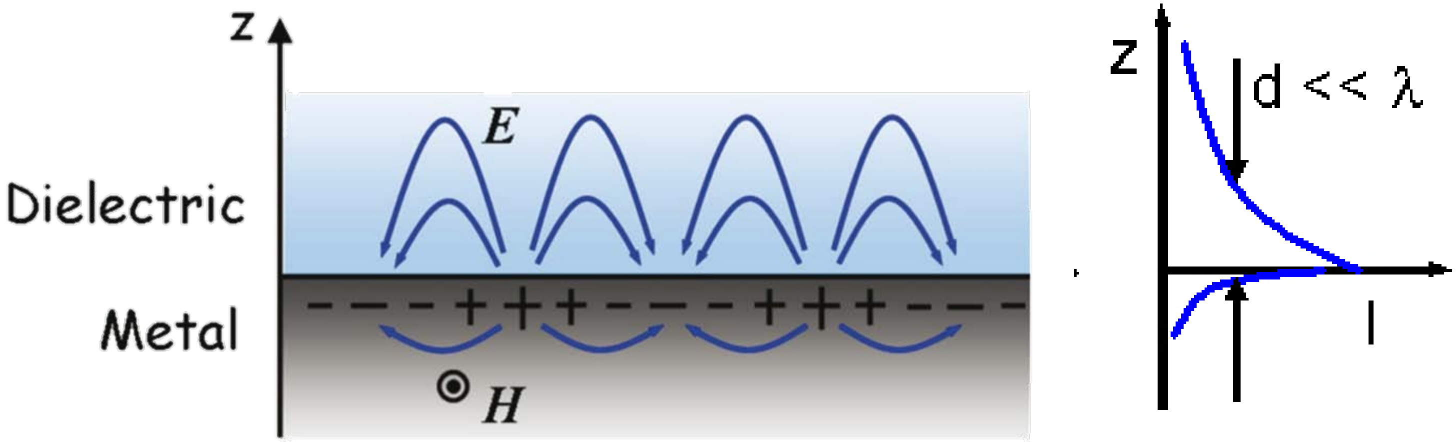
- "Active" plasmonic devices, we control the SPP properties with an external agent; our choice: magnetic field ⇨ wavevector modulation

- Demonstrative device ⇨ interferometer

Plasmons

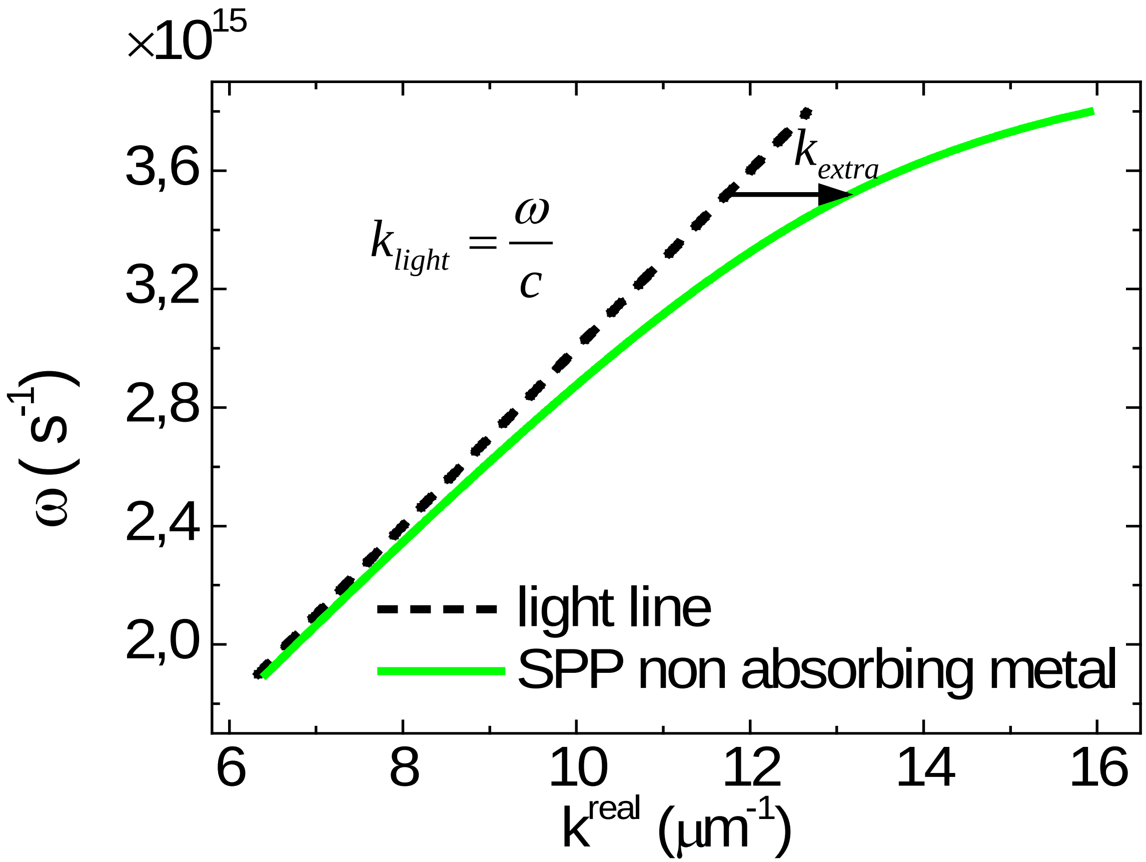
Surface Plamons

Surface Plasmon Polaritons (SPPs) are electromagnetic waves that propagate along a metal-dielectric interface and are coupled to the free electrons in the metal.



- *EM field confined to the metal-dielectric interface.*
- *Very sensitive to the materials*

Surface Plamons



ε_m =dielectric constant of the metal

ε_{diel} =dielectric constant of the dielectric

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

$k_{SP} >> k_{light}$

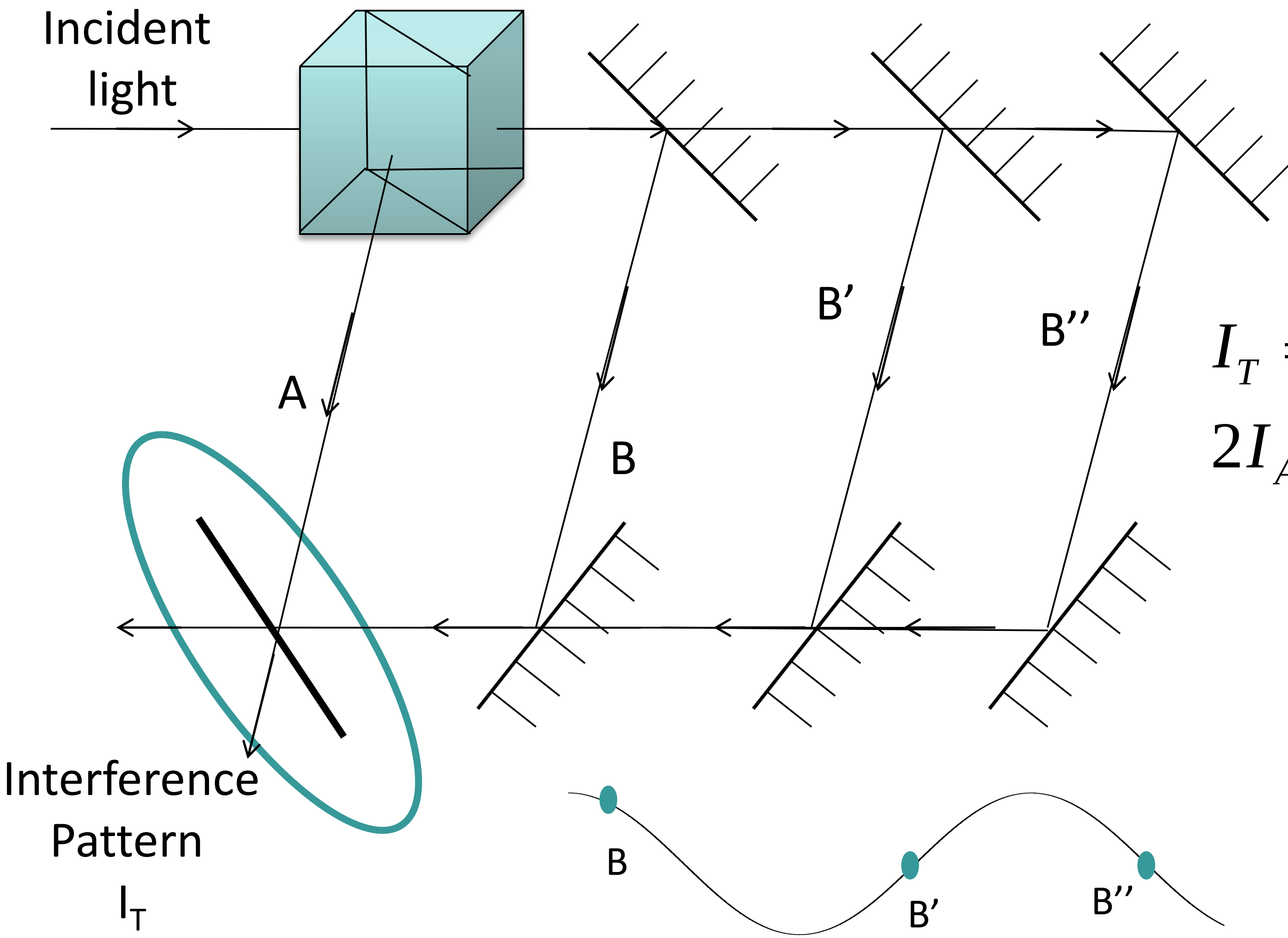
We need "something" that provides that "extra" momentum

↓

a "defect" on our metal surface

Interferometer

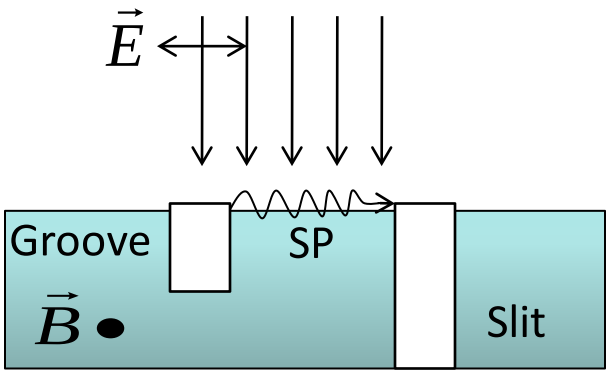
Classic Interferometer



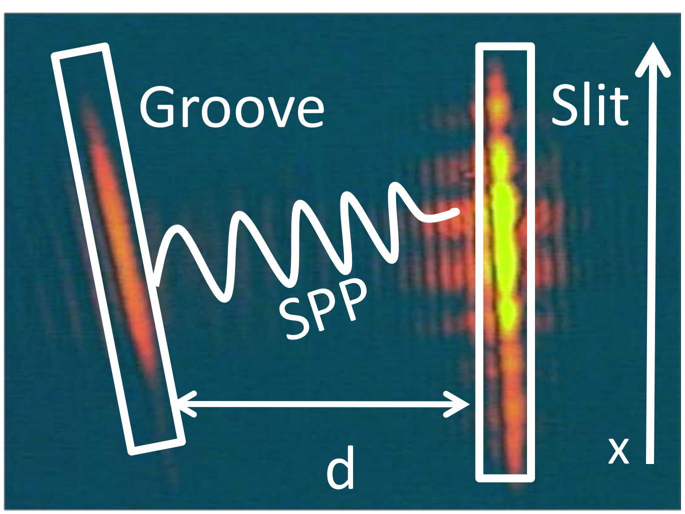
$$I_T = I_A + I_B + 2 I_A I_B Cos(A - B)$$

A. A. Michelson, E. Morely. 1887

Plasmon Interferometer



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



Laser → At the groove, plasmon generation

Plasmons travelling perpendicularly to the groove

↓

Plasmon decoupling into light at the slit

↓

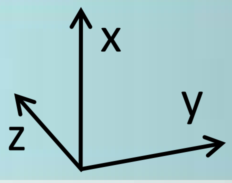
Interference pattern at the slit

↓

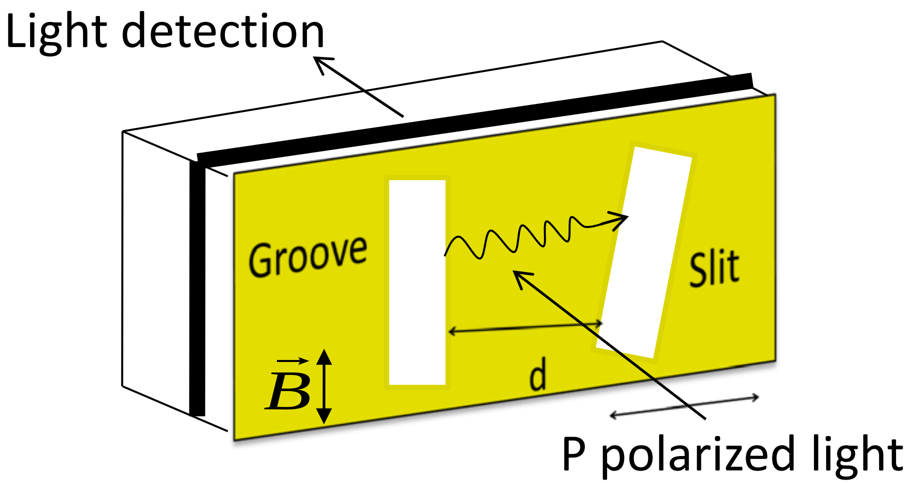
Plasmon travelled different paths at each point of the slit due to the slit to groove angle

V. V Temnov et al. , *Opt. Express,* **17**, 8423-8432 (2009)

Magnetic Field



Magnetic field



B ⟹ ε becomes non-diagonal

$$\varepsilon \approx \begin{pmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{xx} & \varepsilon_{yz} \\ 0 & -\varepsilon_{yz} & \varepsilon_{xx} \end{pmatrix}$$

MO constants

Au → B → low MO, Plasmonic material

Co → M → high MO, Magnetic material

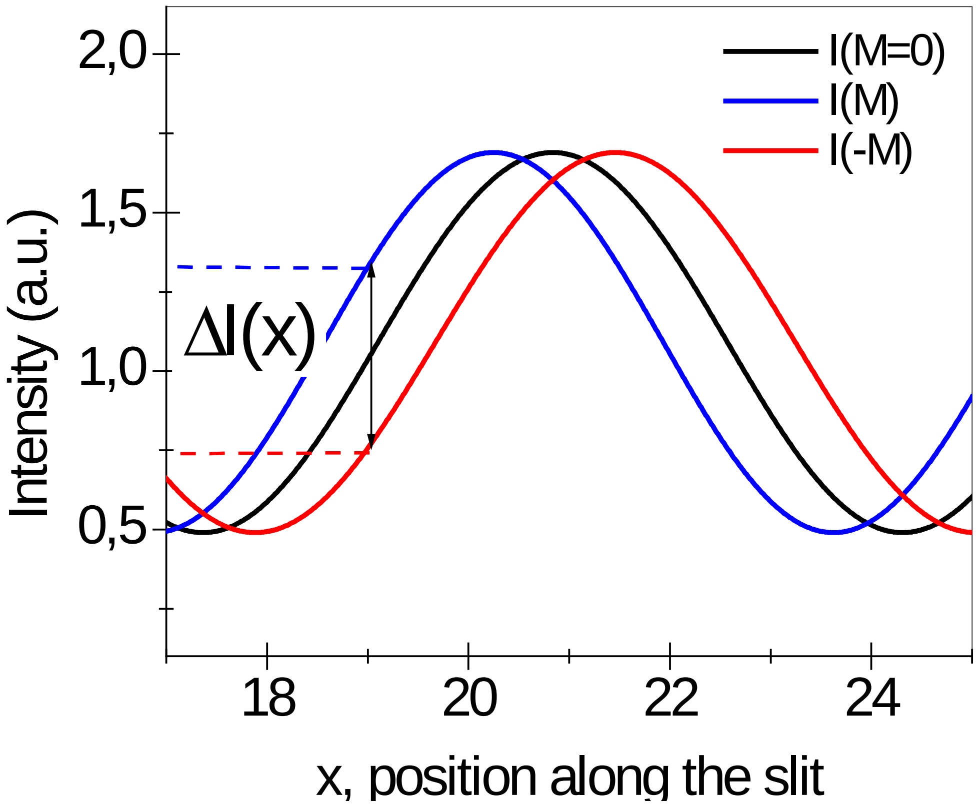
⟹ Trilayer Au/Co/Au

Transversal configuration. Magnetization is on the sample plane, and it’s perpendicular to the incidence plane. M is perpendicular to k_{sp}

Plasmon Interference + Interferometer

$$k_{sp}(M) = k_{sp_0} + \frac{1}{2}\Delta k_{sp}$$

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



Transversal configuration. No conventional Kerr effect (normal incidence)

⇩

We modify k_{sp}!!

⇩

We shift the interference pattern right-left

⇩

$\Delta I(x)$!! = I_{MP}

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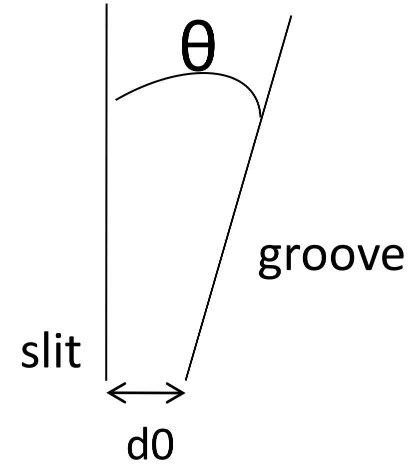
Experimental Setup

Samples

Glass+ 2Cr+Trilayers **Au/6Co/15Au** 200nm thick

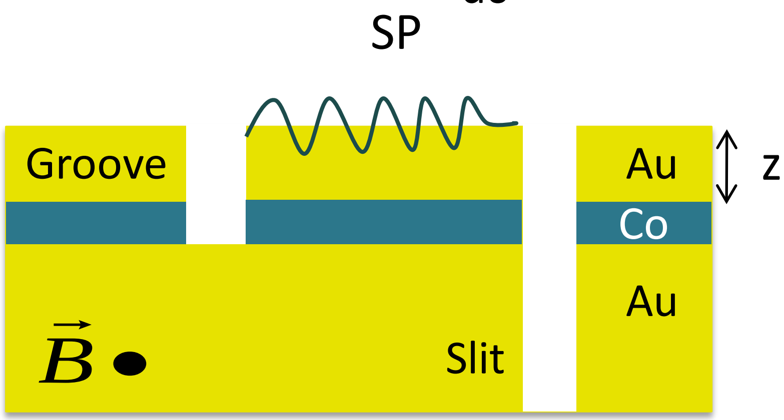
Sputtering



Slit: 100 nm width

Groove: 200 nm width, 100nm depth

FIB



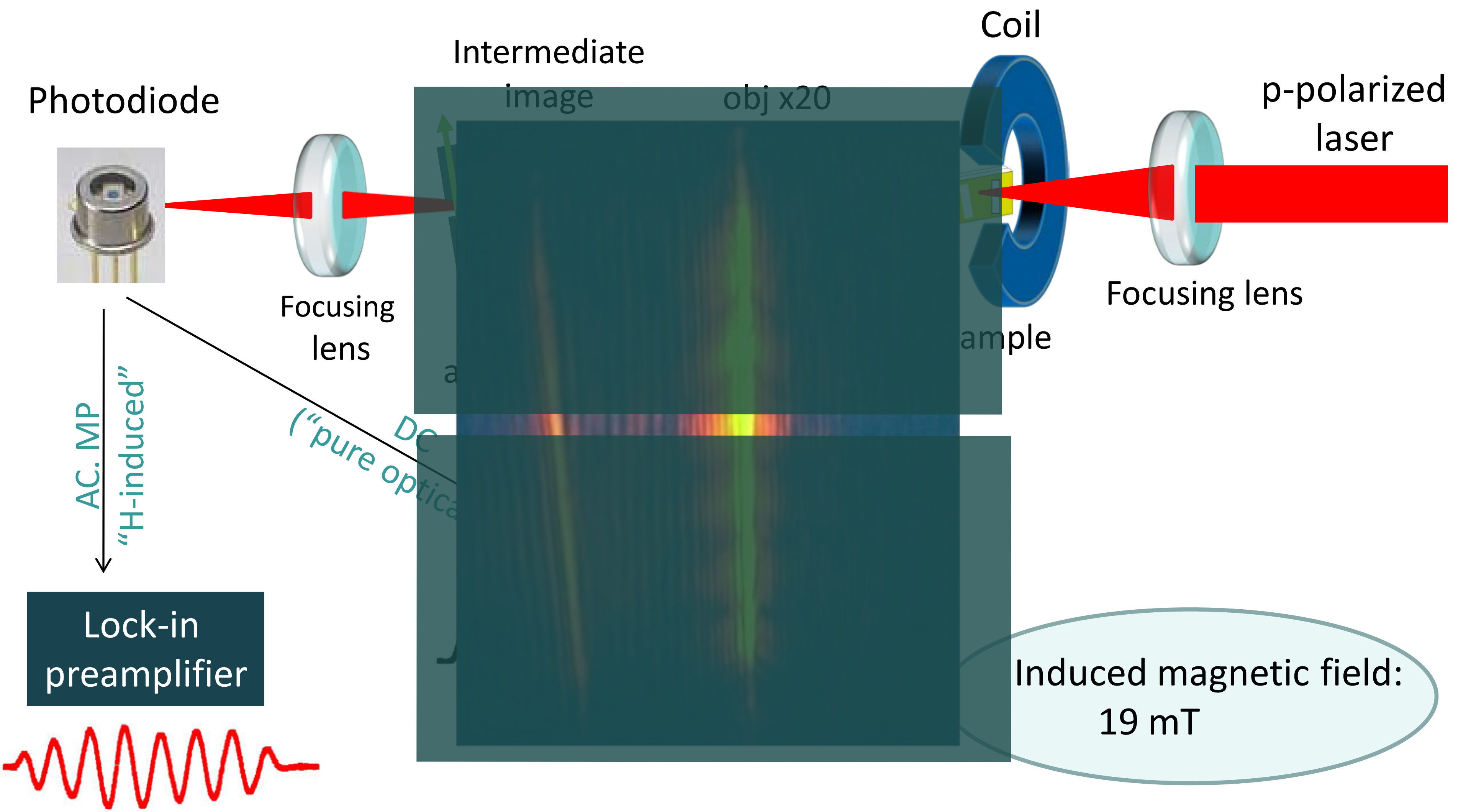
<u>Motives:</u> slit & groove : 50µm long

Θ=5-10º, d_0 =0,10 and 20 µm

6 interferometers per sample

Lasers: 532, 633, 690, 785, 860, 890 nm

Setup


Photodiode
Focusing lens
Intermediate image
obj x20
Coil
p-polarized laser
Focusing lens
AC. MP
“H-induced”
DC
Lock-in preamplifier
Induced magnetic field:
19 mT

Mathematics of the experiment

Maths

$$I_{DC} = I_r + I_{SP} e^{-2k^i_{SP} d} + \sqrt{I_r}\sqrt{I_{SP}} e^{-k^i_{SP} d} \cdot \cos(k_{sp0}{}^r \cdot d + \varphi_0)$$ **DC**

I_r: $I_{direct.}$; $I_{SP} e^{-2k^i_{SP} d}$: I_{SPP}; $\sqrt{I_r}\sqrt{I_{SP}} e^{-k^i_{SP} d} \cdot \cos(k_{sp0}{}^r \cdot d + \varphi_0)$: $I_{Interference}$

$k_{sp}(M)$ →

$k^{i,r}{}_{SP}(\pm M) = k^{i,r}{}_{SP0} \pm (1/2) \cdot \Delta k^{i,r}{}_{SP}$

$\Delta k^{i,r}{}_{SP} = k^{i,r}{}_{SP}(+M) - k^{i,r}{}_{SP}(-M)$

$I_{MP} = \Delta I(M) = I(M) - I(-M)$, First order aproximation:

$$I_{MP} \approx (-2\Delta k_{sp}{}^r \cdot d)\sqrt{I_{SP}}\sqrt{I_r}\left[Sin(k_{sp0}{}^r \cdot d + \varphi_0 + \Phi)\right]$$ **AC**

$$\tan\Phi = \frac{\Delta k^i_{sp}}{\Delta k^r_{sp}}$$

We obtain both Δk^r and $\Phi(\Delta k^i)$

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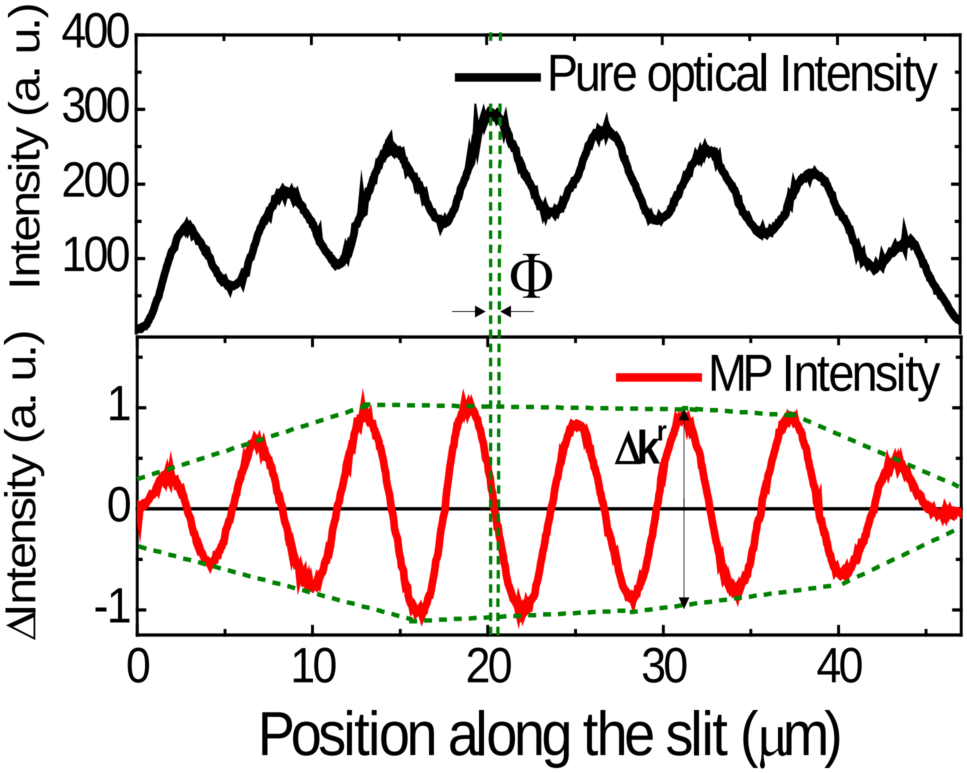
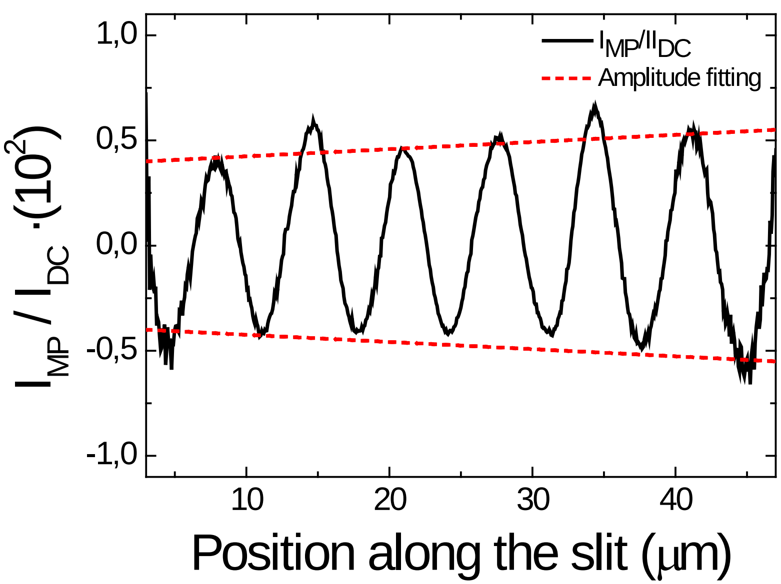
Example of a measurement: Δk^r and Φ (Δk^i)

$$I_{DC} = I_r + I_{SP} e^{-2k_{SP}d} + \sqrt{I_r}\sqrt{I_{SP}} e^{-k_{SP}d} \cdot \cos(k^r{}_{SP0} \cdot d + \varphi_0)$$



$$\tan \Phi = \frac{\Delta k^i_{sp}}{\Delta k^r_{sp}}$$

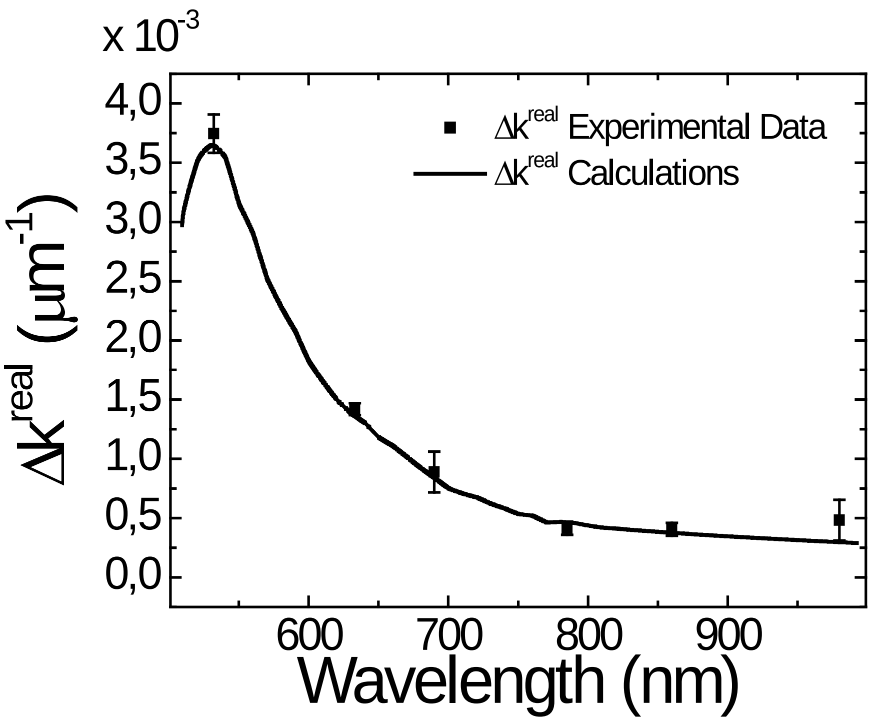
$$\frac{I_{MPContrast}}{I_{DCContrast}} \approx \Delta k^r{}_{sp} \cdot d$$

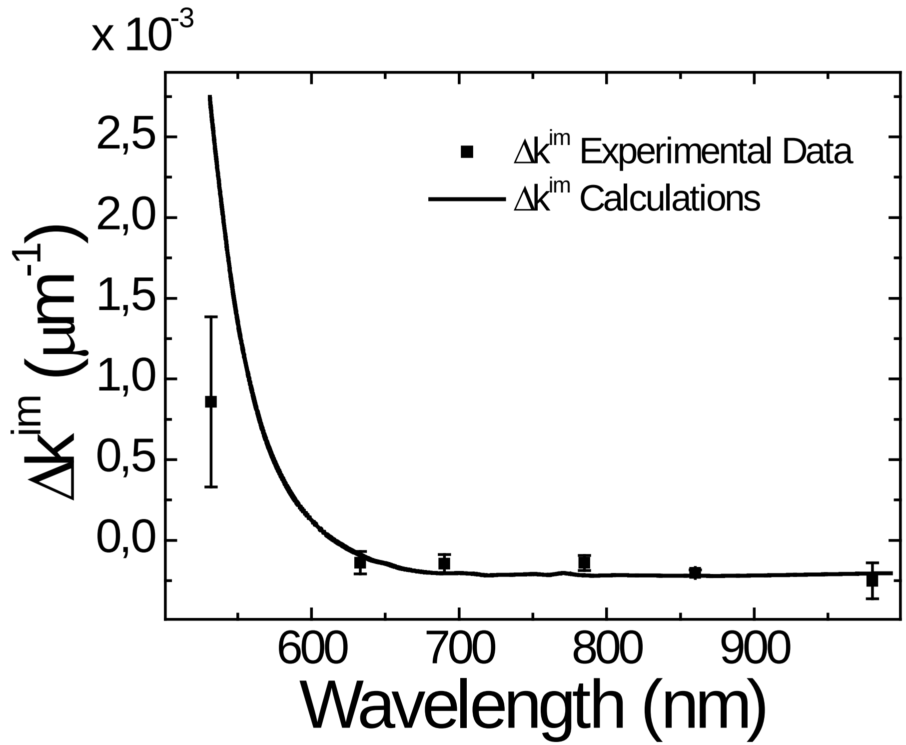


$$I_{MP} \approx -2 \cdot \Delta k_{sp}{}^r \cdot d \cdot \sqrt{I_{sp}}\sqrt{I_{np}} \sin(k_{sp0}{}^r \cdot d + \varphi + \Phi)$$

Wavelength dependece of Δk^{real} and Δk^{im}

Results: Δk^{real} and Δk^{im}

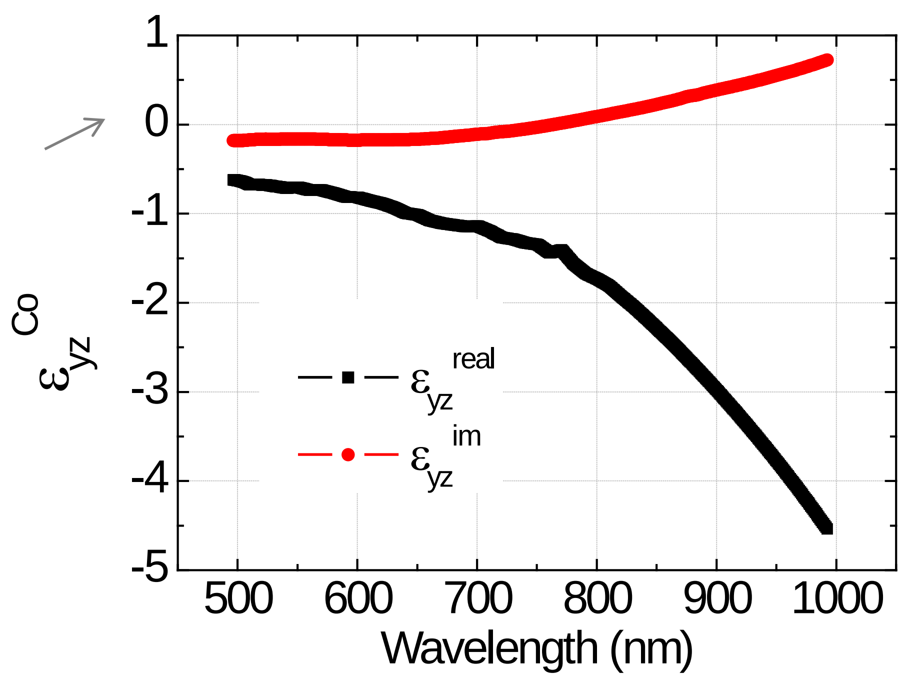




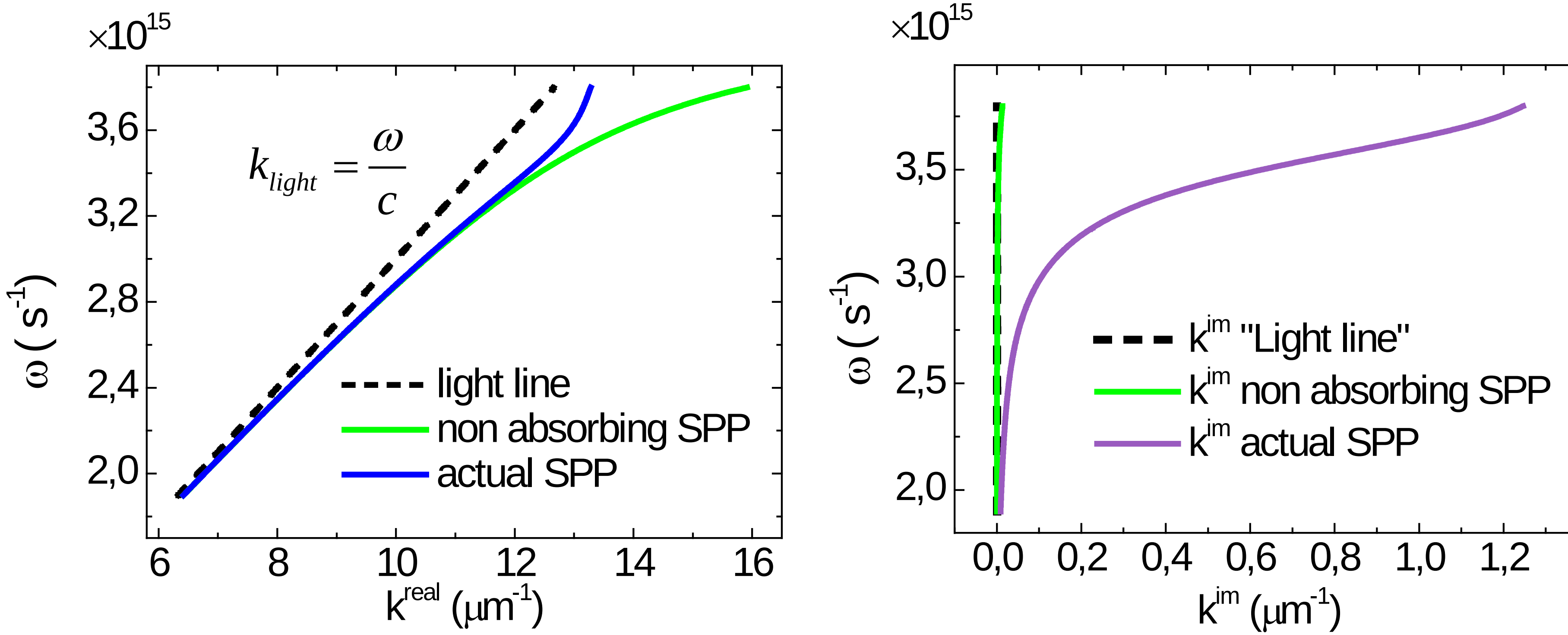
Δk_{SP} and MO constants

Analytical expression for air and gold infinite. Co layer extremely thin.
Continuity conditions of the fields and no waves incoming to the system.

$$\Delta k_{sp} \approx \frac{4iz_{Co}\cdot(k_0\varepsilon_{air}\varepsilon_{Au})^2}{(\varepsilon_{air}+\varepsilon_{Au})\cdot(\varepsilon^2_{air}-\varepsilon^2_{Au})}\left(\frac{\varepsilon_{yz}}{\varepsilon_{xx}}\right)_{Co} M_x\cdot e^{-2k_{zAu}\cdot z} \approx$$



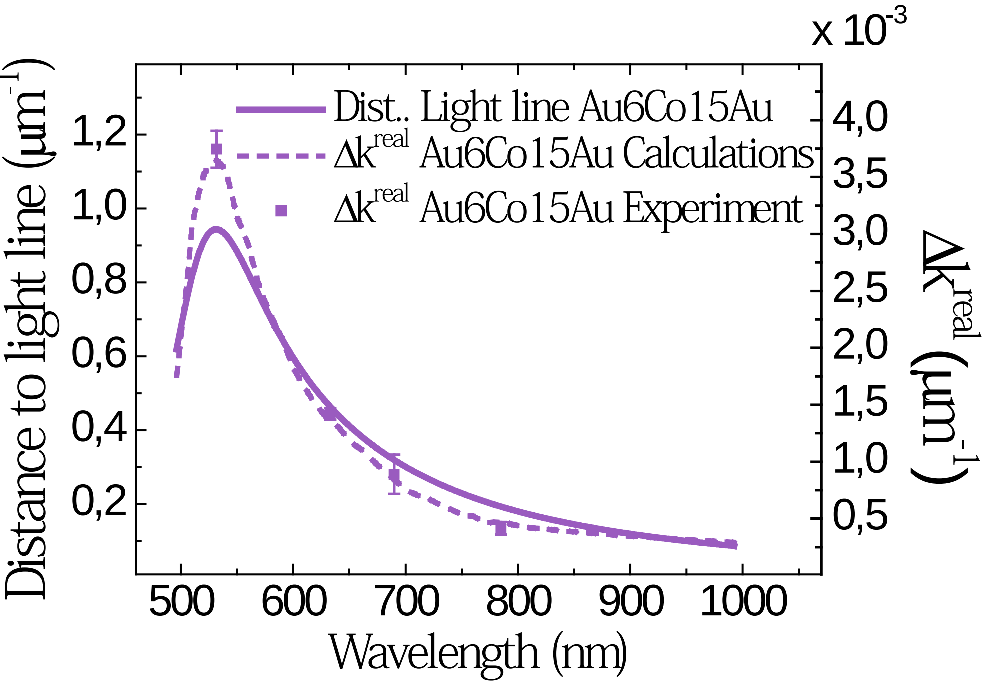
Dispersion Relation: k^{real} and k^{im}



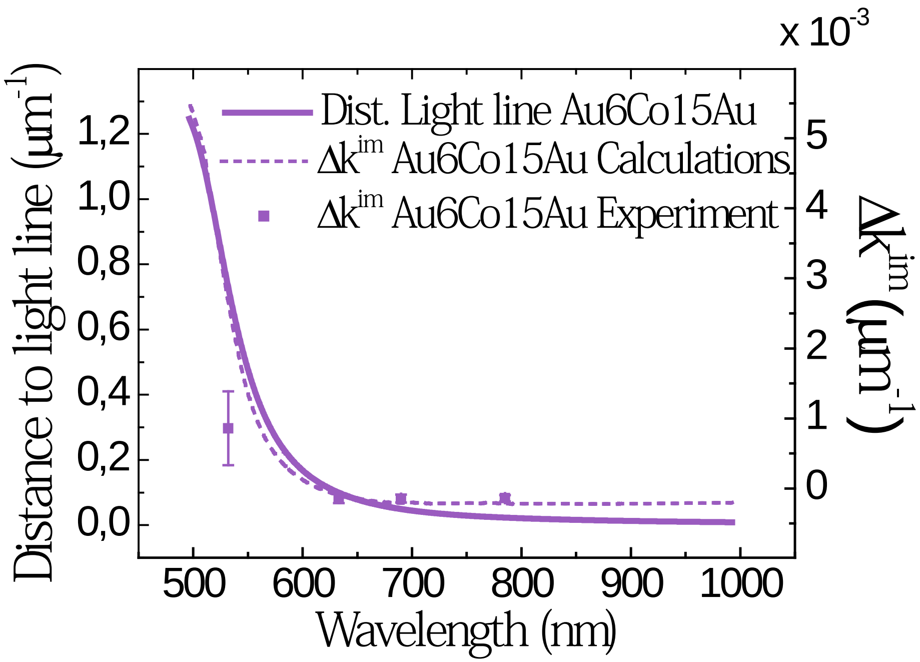
At $3{,}5 \cdot 10^{15}\ s^{-1}$ the actual plasmon is "more metallic" than at other frequencies

Dispersion Relation Vs Modulation of k_{SP}^{real}

Δk^{real}_{SP}



Δk^{im}_{SP}



Shape of Spectral evolution of Δk^{r}_{SP} and Δk^{im}_{SP} is mainly determined by SPP dispersion relation!

Conclusions

Conclusions

- Magnetic field induces a modulation on $k_{SP.}$
- Active device: Interferometer
- Spectral evolution of Δk_{SP} is mainly determined by the dispersion relation of the SPP

Thank you very much!!

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Magplas