



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

Lecture 13: Plasmons- IV

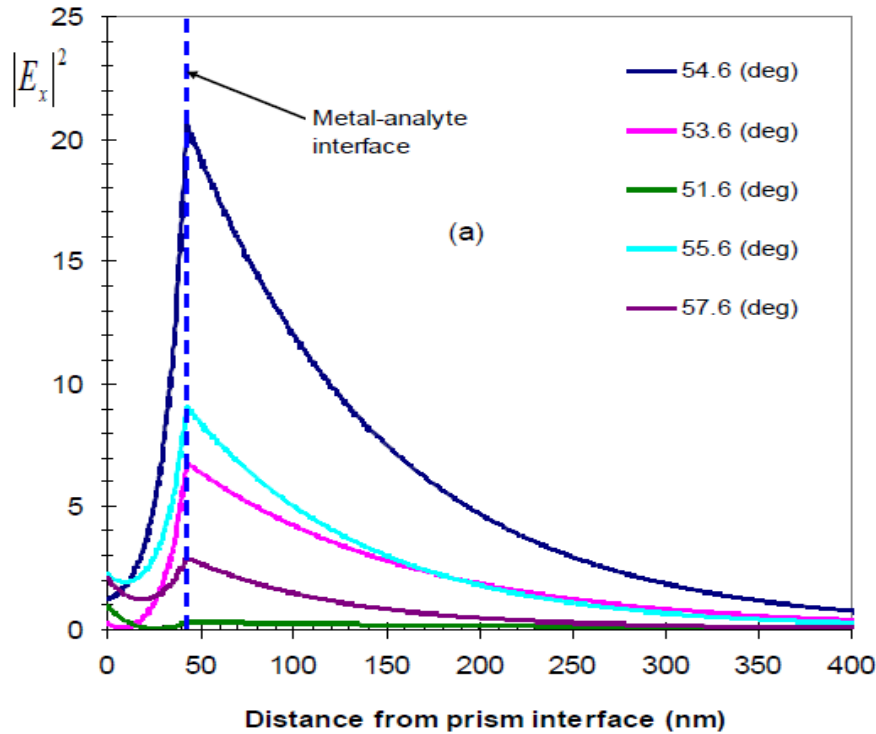
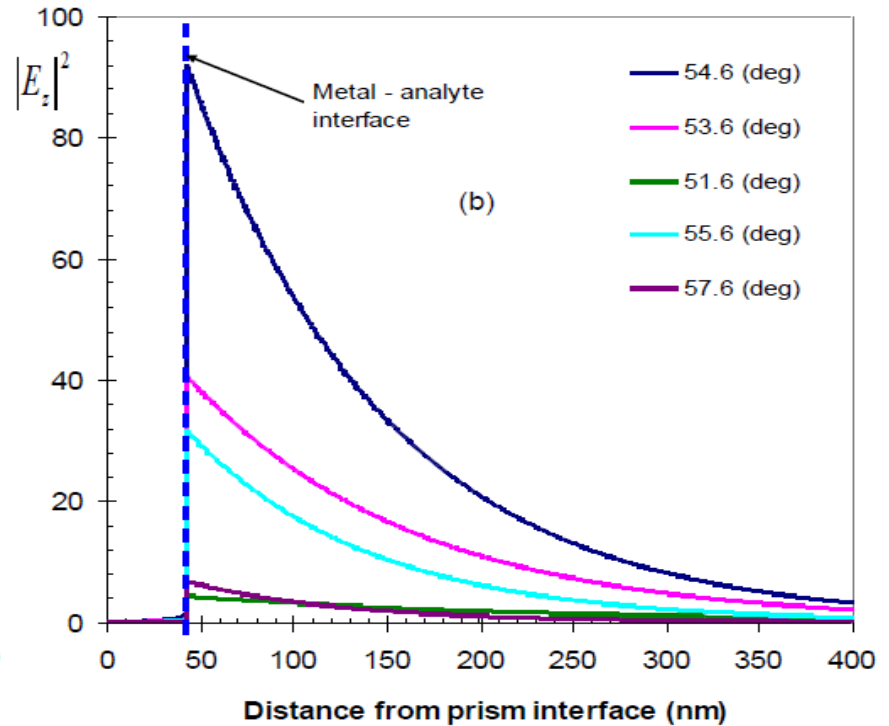
Surface Plasmon: Field enhancement, SPR Sensors, Sensitivity, Extra-ordinary Transmission

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Department of Physics



Field Enhancement

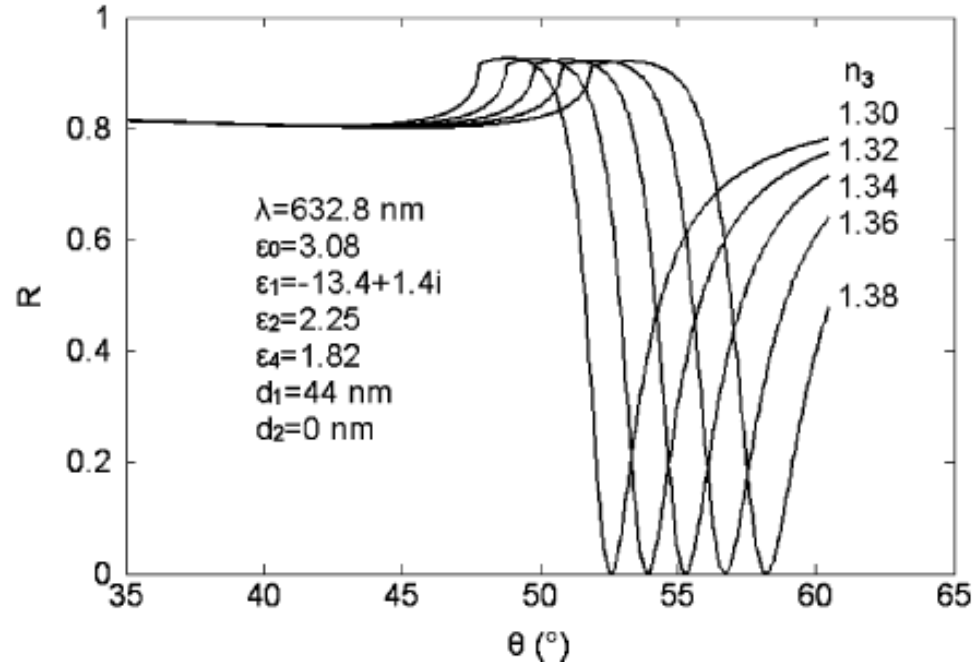


Ag Thickness = 43 nm, $n_p = 1.732$, $n_a = 1.33$, $\lambda = 633$ nm, $\vartheta_{\text{SPR}} = 64.61^\circ$

Sensing with SPR

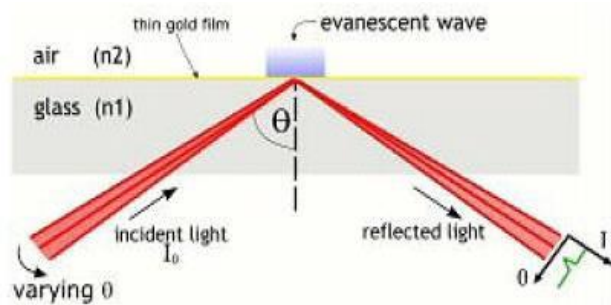
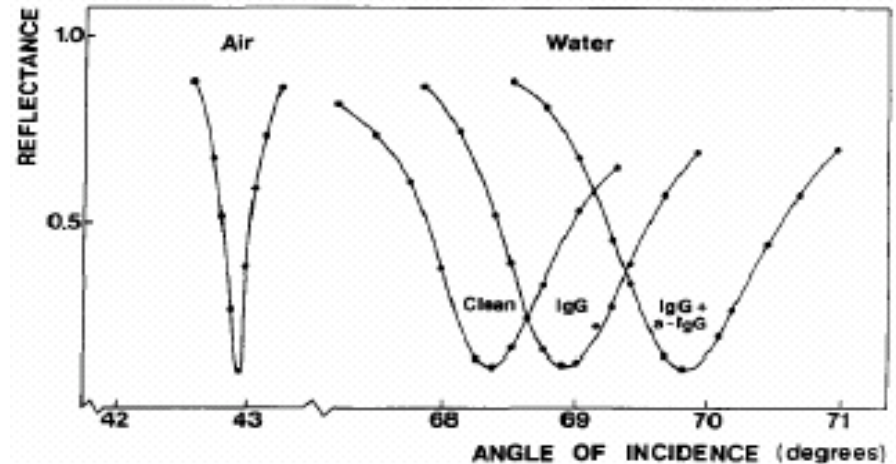
Example for Index Variation Effect

$$\frac{\omega_o}{c} n_p \sin \theta_1 = \frac{\omega_o}{c} \left(\frac{\varepsilon_m n^2}{\varepsilon_m + n^2} \right)^{1/2}$$
$$\Rightarrow n_p \sin \theta_1 = \left(\frac{\varepsilon_m n^2}{\varepsilon_m + n^2} \right)^{1/2}$$



SPR Biosensor

First experiments on biosensing using SPR method



Liedberg et al, 1983

SPR Sensitivity with Prism Coupling

From

$$n_p \sin \theta_1 = \left(\frac{\epsilon_m n_a^2}{\epsilon_m + n_a^2} \right)^{1/2}$$

- Angular Sensitivity:

$$S_\theta = \frac{\partial \theta_{dip}}{\partial n_a} = \frac{\epsilon_{mr} \sqrt{-\epsilon_{mr}}}{(\epsilon_{mr} + n_a^2) \sqrt{\epsilon_{mr} (n_a^2 - n_p^2) - n_p^2 n_a^2}}$$

~100-200 deg/RIU

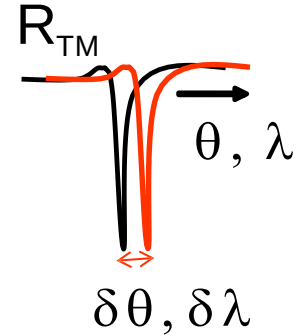


$\delta n \sim 10^{-7}$ RIU (1pg/mm²)

- Spectral sensitivity:

$$S_\lambda = \frac{\partial \lambda}{\partial n_a} = \frac{\epsilon_{mr}^2}{\frac{n_a^3}{\lambda} \left| \frac{d\epsilon_{mr}}{d\lambda} \right| + (n_a^2 + \epsilon_{mr}) \epsilon_{mr} \frac{dn_p}{d\lambda} \frac{n_a}{n_p}}$$

~1000-30000nm/RIU



J. Homola, Sens.Actuators B 41, 207-211 (1997)

Sensitivity enhancement over the years

- **Long range SPs: sensitivity improvement by factor of 7 found**

G.G. Neninger et.al., Sens.Actua. B 145-151 (2001)

D. Sarid, Long-range surface-plasma waves in very thin metal films, Phys. Rev. Lett. 47 (1981) 1927–1930.

- **Prism index: lower index yields larger penetration depth of the evanescent field (factor of 1.5-2)**

Yuk et.al., Eur. Biophys J., 35, 469-476 (2006)

- **Phase sensitivity:**

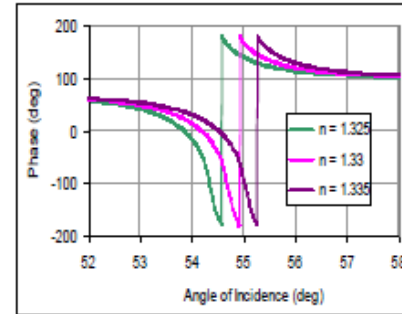
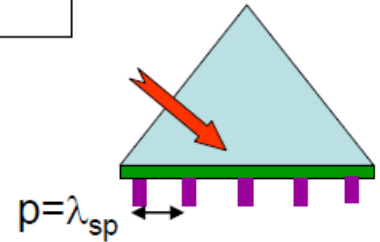
$$\delta n \sim 10^{-8} \text{ RIU}$$

Wu et.al. Opt. Lett., 29, 2378-2380, 2004

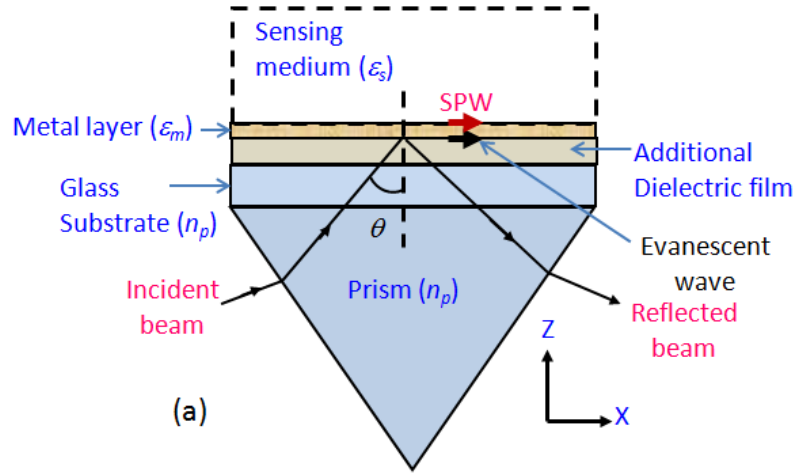
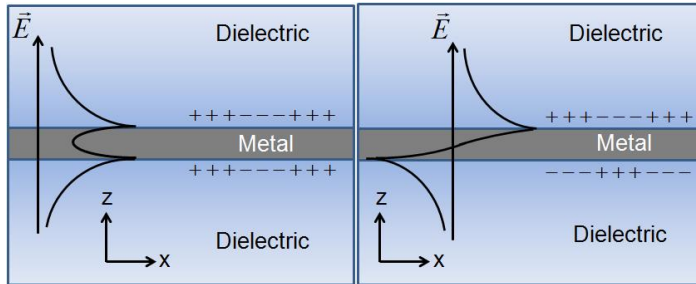
- **Prism and grating coupling**

When $p = \lambda_{sp}$, a band gap is obtained for the SP. Enhancement by factor 6 was predicted near the bandgap

Alleyne, et al., Opt.Exp.15, 8163-8169 (2007).

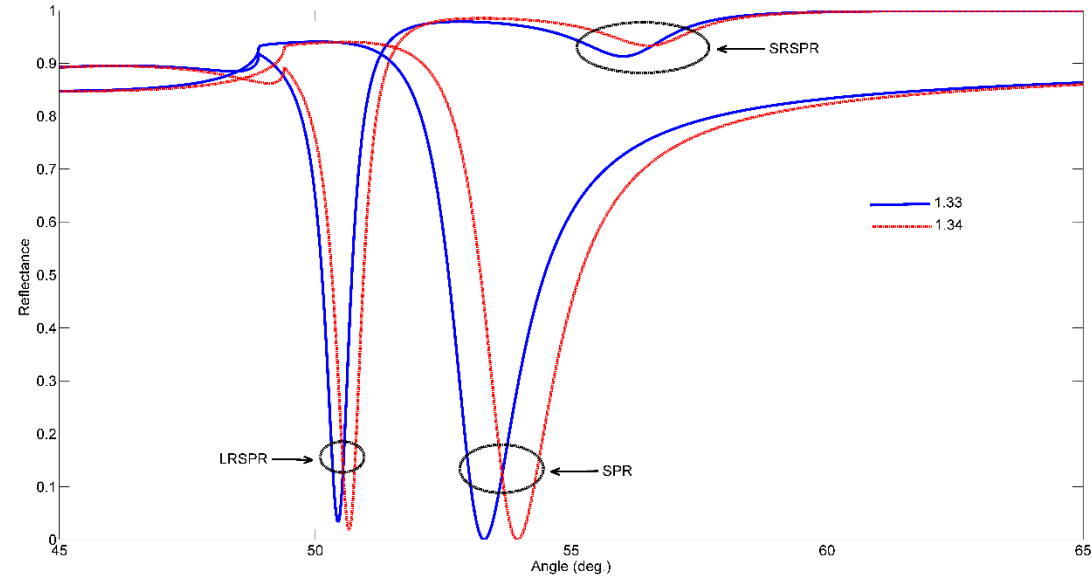


Long Range SPR

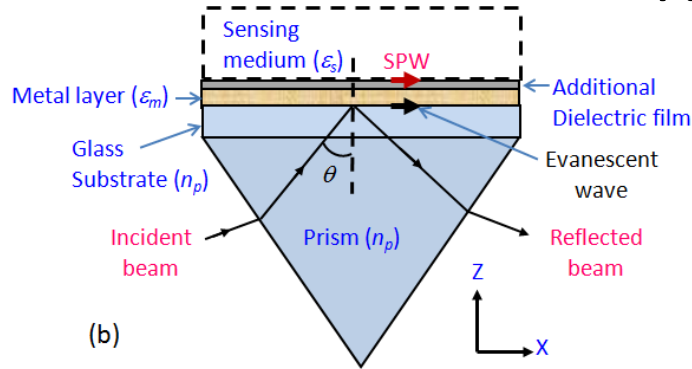
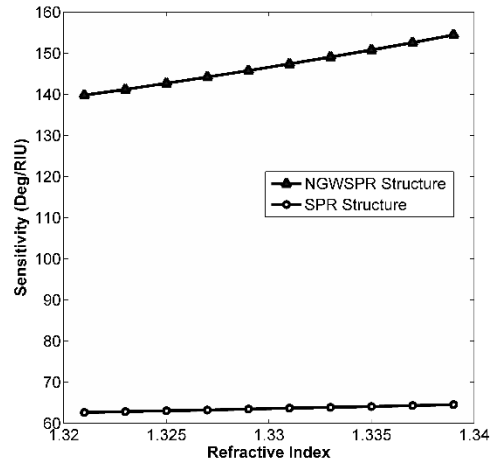
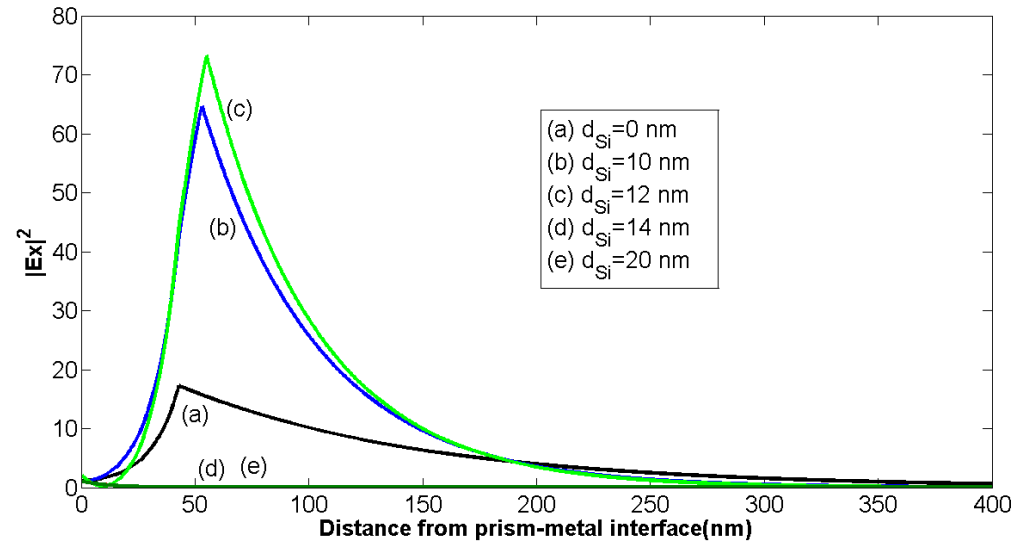


(a) Symmetric Plasmon Mode

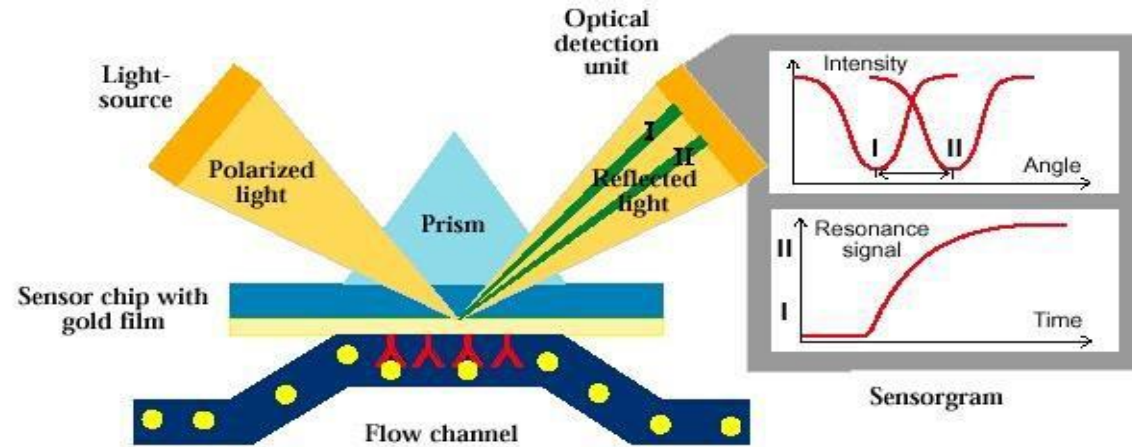
(b) Anti-symmetric Plasmon Mode



Nearly Guided Wave SPR



Commercial SPR Biosensor



The most popular company producing SPR instruments is [Biacore \(GE\)](#)

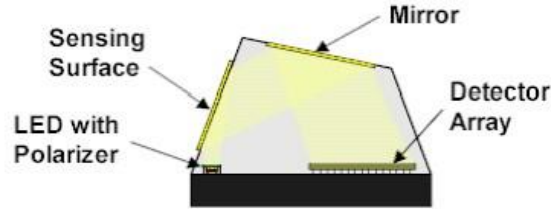
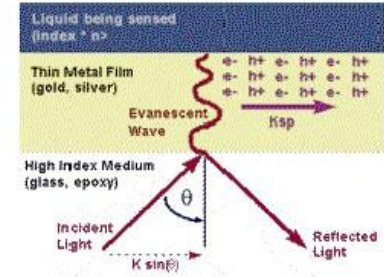
Commercial SPR Biosensor



Surface Plasmon Resonance Spectrometer BIO-SUPLAR 2 ([Analytical m-Systems](http://www.analytical-m-systems.com), Germany) is based on the Kretschmann type prism and GaAs solid-state laser ($\lambda = 670 \text{ nm}$). However, the most popular company producing SPR instruments is [Biacore](http://www.biocore.com)

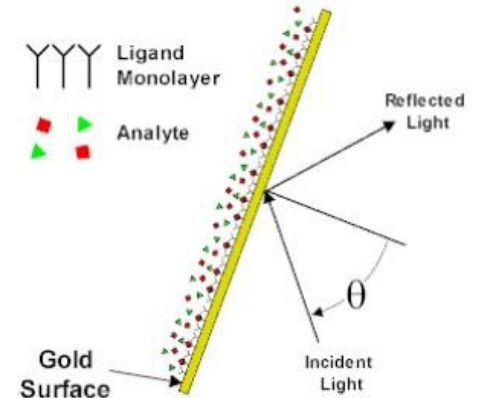
Commercial SPR Devices

Surface Plasmon Resonance Biosensor *Spreeta* from **NOMADICS**
Texas Instruments



SPR based sensor

Beverages
Medical Diagnostics
Food Safety
National Defense
Water Quality
Research



www.nomadics.com

Commercial SPR Biosensor



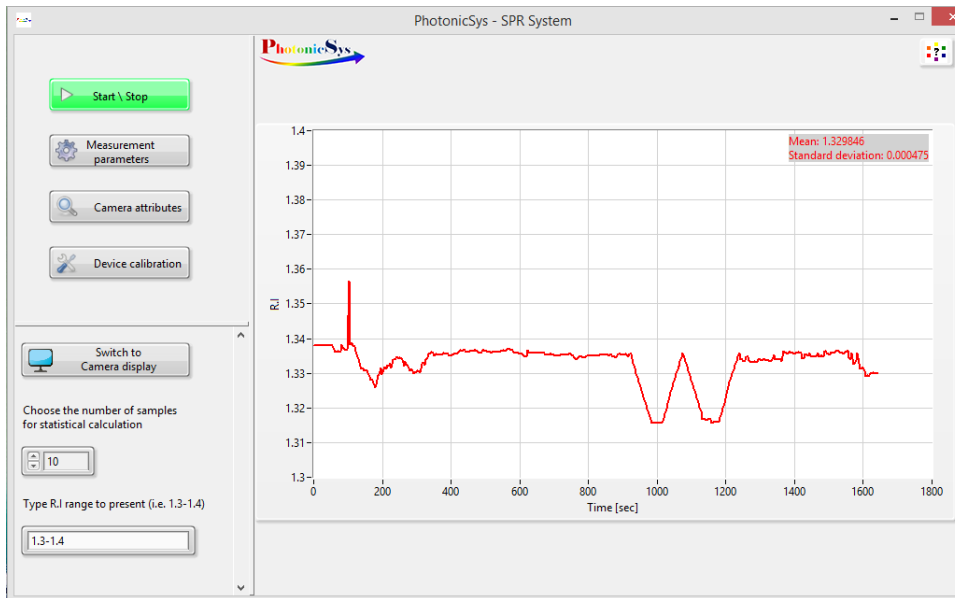
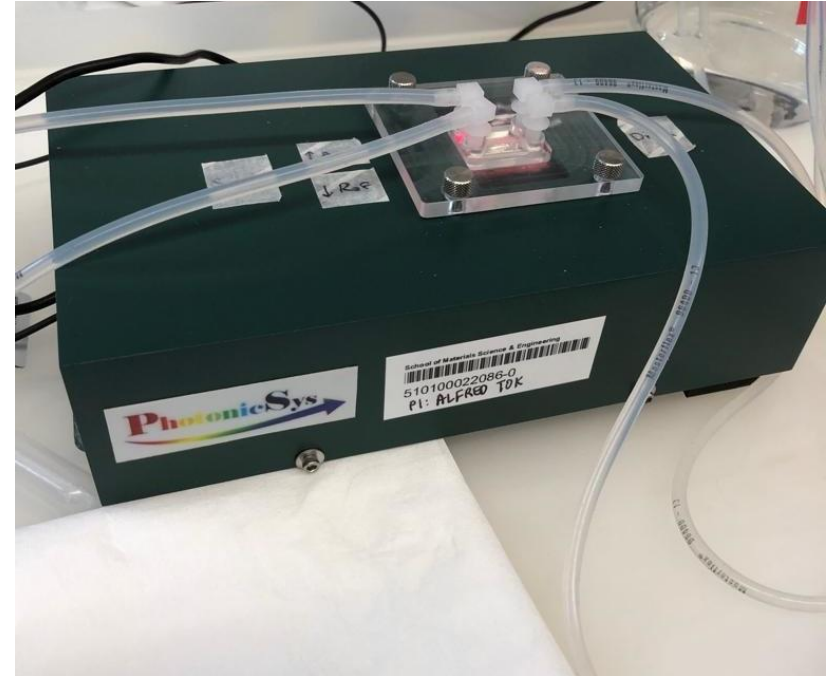
**Immobilized by (bio)chemical binding?
Determine interactions without labelling!**

AUTOLAB

www.ecochemie.nl/spr

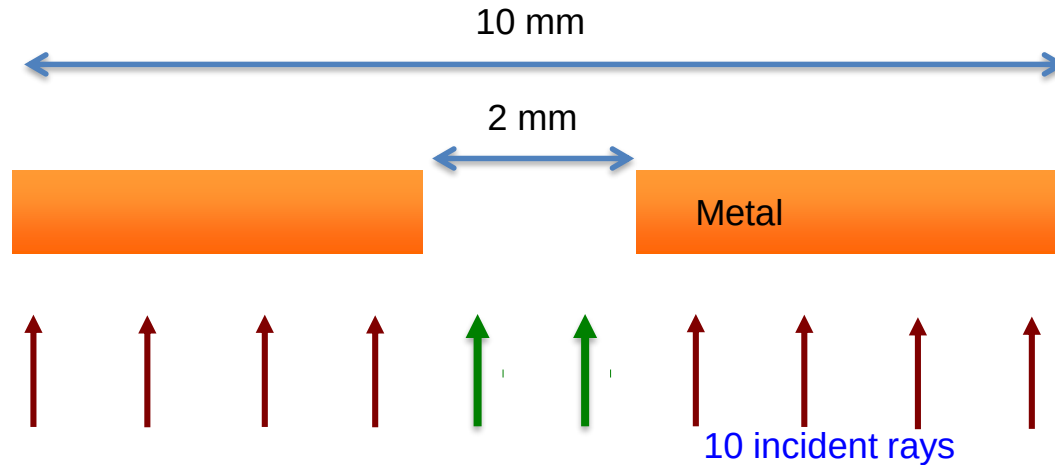
spr@ecochemie.nl

Commercial SPR Biosensor



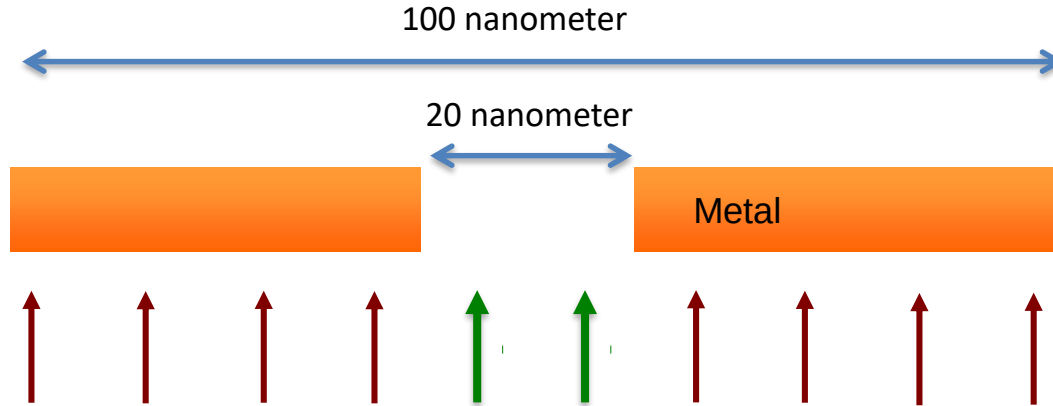
Cost-effective System

How much light is transmitted by a small aperture in a metal plate?



- 20 % of the metal plate is open, so only 2 out of 10 rays can pass through. The others are either reflected or absorbed.
- Geometrical optics predicts a transmission of 20%.

What about nano-holes?



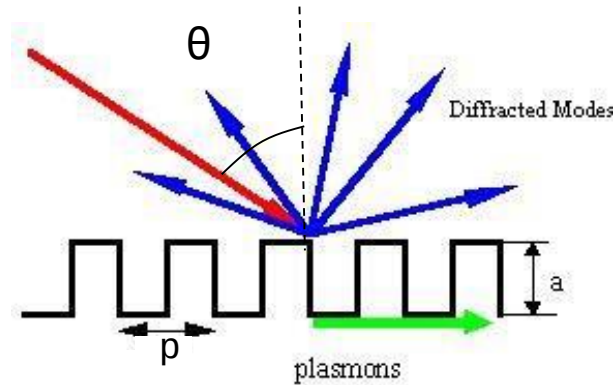
- For holes *smaller* than the wavelength geometrical optics is no longer valid.
- *So what happens to the transmission? Is it still 20%?*

Bethe Theory (1944)

$$\text{Transmission Efficiency} = \frac{64}{27\pi^2} (kr)^4 \sim \left(\frac{r}{\lambda}\right)^4$$

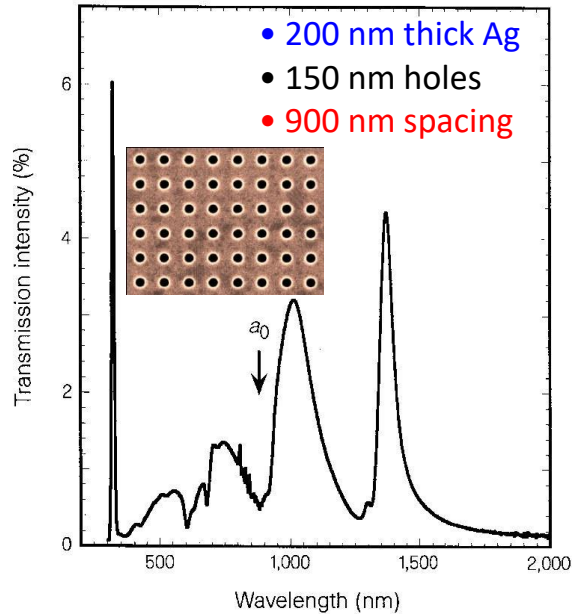
Revisiting Grating Coupling for SPR

The evanescent modes couple to Surface Plasmons (green), which run along the interface between the grating and the ambient medium.



The grating could be dielectric on metal surface and the analyte above or the grating itself could be metallic on substrate and the analyte above!

Extraordinary Optical Transmission



$$\text{Transmission Efficiency} = \frac{\text{Fraction of light transmitted}}{\text{Fraction of surface hole area}} = 2$$

□ More than twice the light that impinges on the holes is transmitted through the film!

How is this *extraordinary transmission* possible?

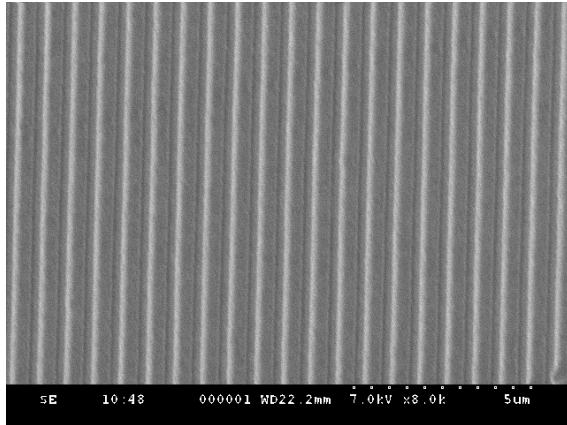
Possible mechanisms?

- ❖ Surface plasmons
- ❖ Cavity /guided modes

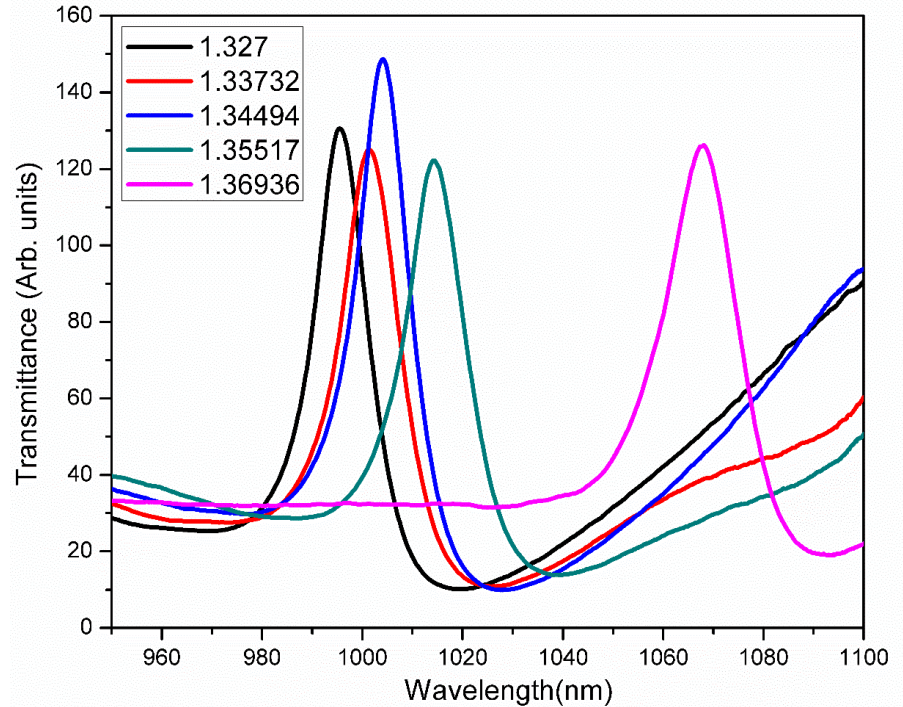
- ❖ In thin metallic films (~ 20- 300 nm), the transmission is explained via plasmons
- ❖ In thick films (~ 1 micron), the transmission is due to cavity effects

Ebbesen *et al.*, Nature 391, 1998.

Metallic nanogratings based sensing in NIR



Sensitivity: 2250 nm/RIU



Summary

1. Expression for propagation length and penetration depth were obtained and discussed
2. Dispersion curve of SPs was studied and the issues with excitation of SPs were discussed.
3. Methods to overcome such issues and excite SPs were presented and the use of SPs for sensing in various modes of operation was discussed.

Thank You

