On correction of the resonance condition in the effect of surface plasmon resonance

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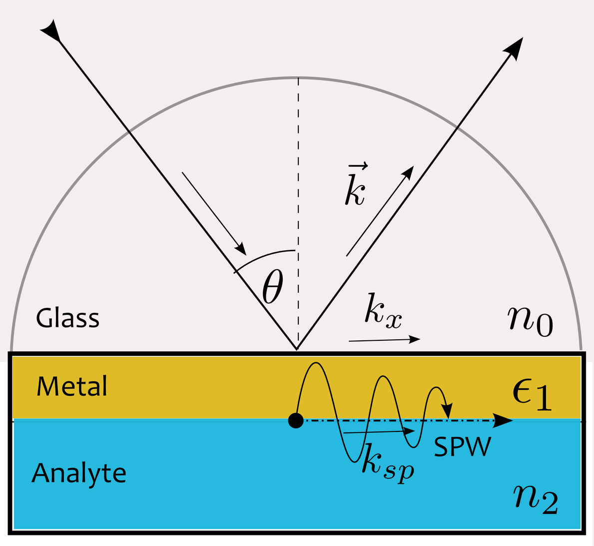
Abstract: Surface plasmon resonance has emerged as a powerful optical detection technique. Among others, one can find its applications in sensors, material characterization or detection of molecules and their interactions. The existence of surface plasmons can be identified in a setup consisting of a glass prism, thin metallic layer and analyte. This effect manifests itself as a plasmon wave propagating on a boundary between two layers, which are metal and analyte, and its detection can be performed via reflectivity of the incident light. Excitation of a plasmon wave corresponds to a minimum of the reflected light. This situation occurs if certain resonance condition is fulfilled. Nevertheless, this resonance condition works well only under certain circumstances.

I Introduction and model

Surface plasmons are electron oscillations taking place at the interface of two layers. For instance, illumination of a setup given by a glass prism, metallic layer and analyte might excite surface plasmon wave if certain resonance condition is met.



Schematic configuration of a system exciting surface plasmon wave (SPW)

Here, Kretschmann configuration is assumed [1].

Plasmon wave arises at the interface of metal and analyte assuming that the wave vector component k_x is sufficiently large to excite plasmon wave.

It is: $k_x = k_{sp}$

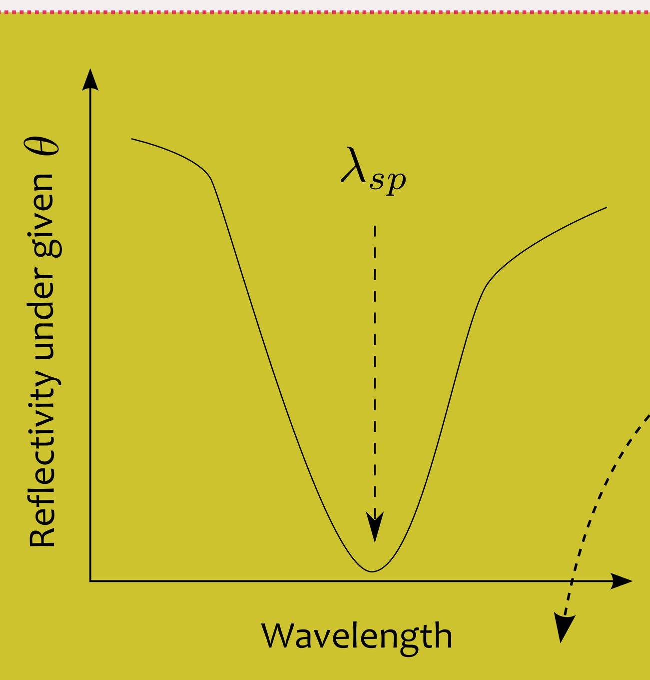
where $k_x = \frac{2\pi}{\lambda} n_0 \sin\theta$ and $k_{sp} = \frac{2\pi}{\lambda}\sqrt{\frac{\epsilon_1 n_2^2}{\epsilon_1 + n_2^2}}$ give rise to

a resonance condition of the form $n_0 \sin\theta = \Re\left\{\sqrt{\frac{\epsilon_1 n_2^2}{\epsilon_1 + n_2^2}}\right\}$ (1)

Note that refractive index and dielectric constant depend on a wavelength:

$$n_0 = n_0(\lambda), \epsilon_1 = \epsilon_1(\lambda), n_2 = n_2(\lambda)$$

If the angle of incidence θ is known, the resonance condition provides us with a resonance (plasmonic) wavelength λ_{sp}.



Reflectivity R:

$$R = |r_{012}|^2 = \left|\frac{r_{01}^p + r_{12}^p e^{2ik_{z1}d}}{1 + r_{01}^p r_{12}^p e^{2ik_{z1}d}}\right|^2$$

where $r_{ij}^p = \frac{\frac{k_{zi}}{\epsilon_i} - \frac{k_{zj}}{\epsilon_j}}{\frac{k_{zi}}{\epsilon_i} + \frac{k_{zj}}{\epsilon_j}}$, $\sqrt{\epsilon_i} = n_i$

$$k_{zi} = \sqrt{\epsilon_i \left(\frac{2\pi}{\lambda}\right)^2 - k_x^2},\ i = 0, 1, 2$$

and upper index p stands for p-polarized wave for which SPR effect occurs. Parameter d is thickness of the metallic layer in the setup.

II Outline of the problem

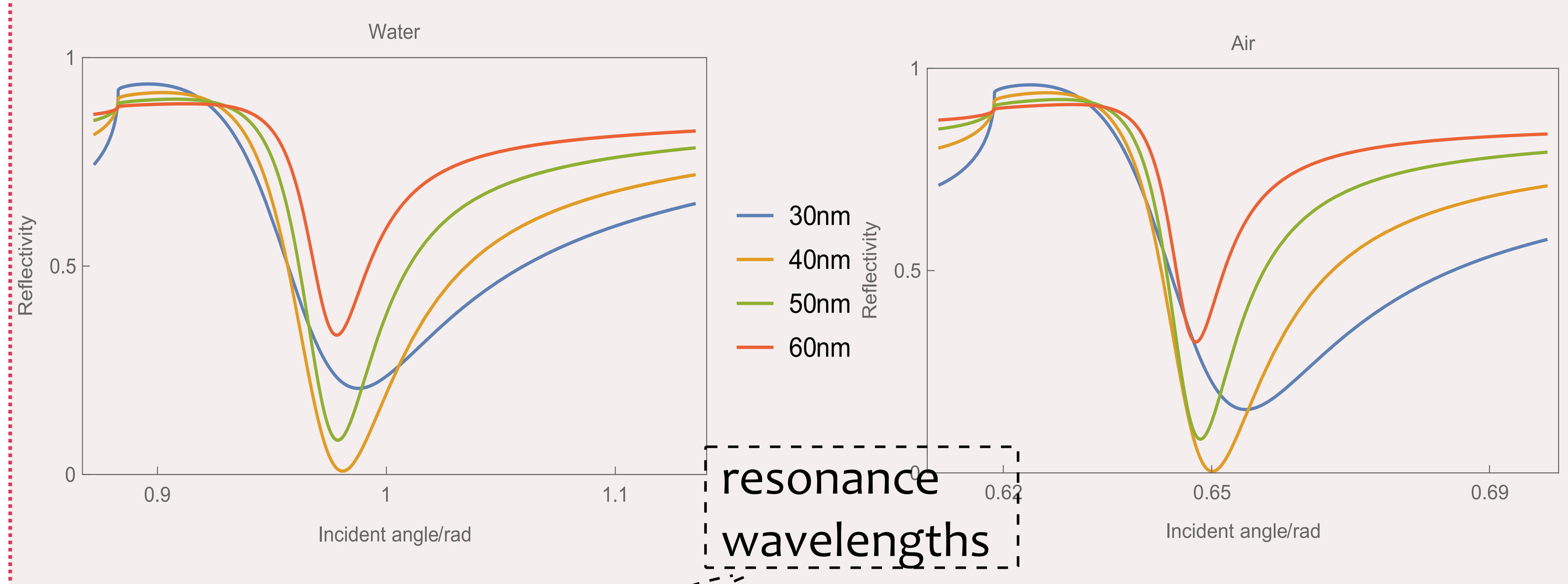
The resonance condition, Eq. (1) and the reflectivity R are supposed to give the same relation between resonant wavelengths λ_{sp} and the corresponding angle of incidence θ.

- This correspondence cannot be true since Eq. (1) does not consider thickness of the metallic layer.

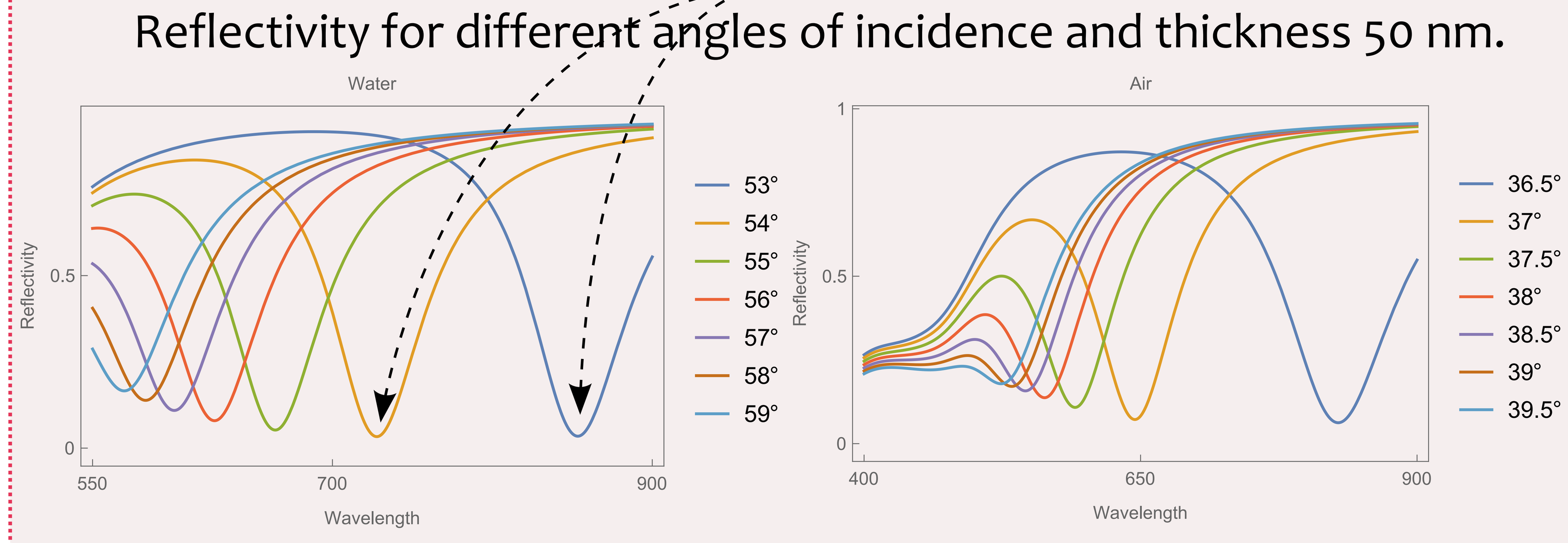
We show, how these two relations differ and that the thickness of the metallic layer is an important parameter that cannot be easily neglected.

III Dependence on the metal thickness

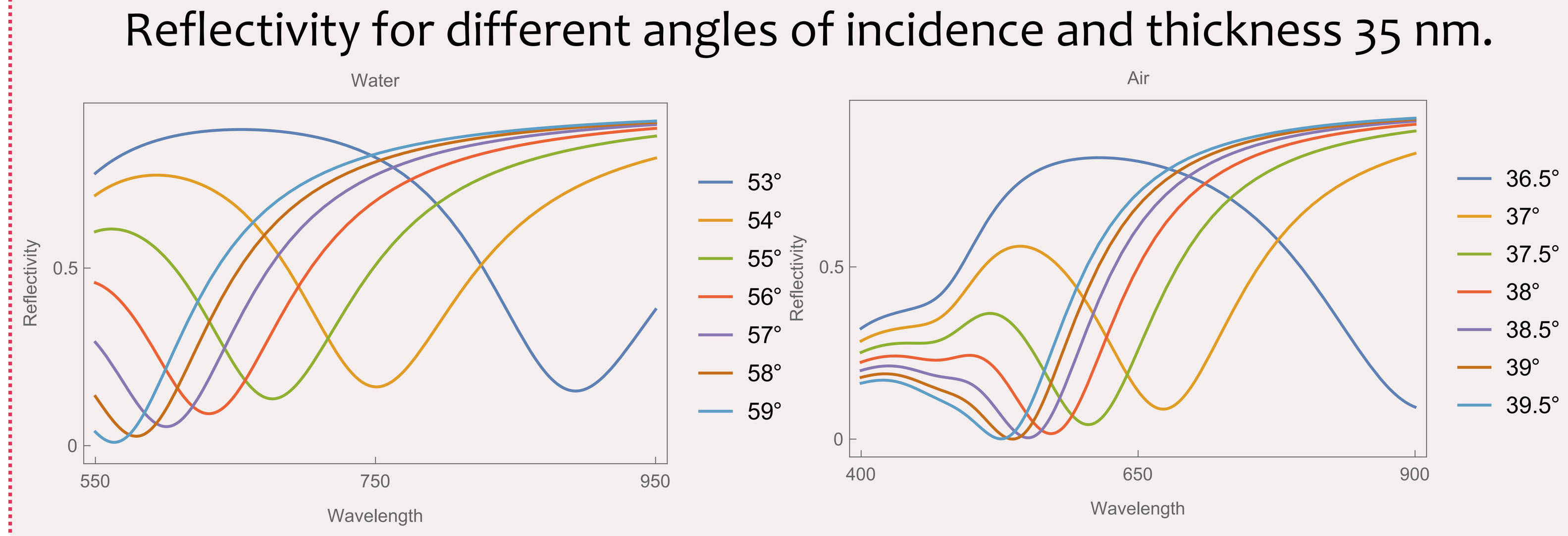
Reflectivity for different thicknesses and wavelength of 623 nm.



Reflectivity for different angles of incidence and thickness 50 nm.



Reflectivity for different angles of incidence and thickness 35 nm.



IV Comparison with the resonant condition

Water:			
d=50 nm:		d=35 nm:	
θ	θ from (1)	θ	θ from (1)
53°	52.93°	53°	52.74°
54°	53.89°	54°	53.65°
55°	54.84°	55°	54.61°
56°	55.76°	56°	55.62°
57°	56.65°	57°	56.67°
58°	57.48°	58°	57.69°
59°	58.25°	59°	58.66°

Air:			
d=50 nm:		d=35 nm:	
θ	θ from (1)	θ	θ from (1)
36.5°	36.47°	36.5°	36.41°
37°	36.91°	37°	36.78°
37.5°	37.30°	37.5°	37.17°
38°	37.63°	38°	37.52°
38.5°	37.90°	38.5°	37.82°
39°	38.08°	39°	38.04°
39.5°	38.20°	39.5°	38.17°

The corresponding wavelengths are obtained as minima in the figures above.

IV Conclusion

We have shown that the thickness of the metallic layer significantly affects validity of the resonance condition.
There exist several ways dealing with the thickness, for instance [1,2] providing correction to k_{sp} or [3] which study metal permittivity ϵ_1. Nevertheless there are some limitation.
Our aim is to provide relation between the incident angle and the resonant wavelength that would exclude some of these limitations.

References:
[1] E. Kretschmann, Z. Phys. 241, 313-324 (1971).
[2] H. Reather, Surface plasmons on smooth and rough surfaces, Springer-Verlag, Berlin (1988).
[3] Z. Yang, D. Gu, Y. Gao, Opt. Commun. 329, 180-183 (2014).

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