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NPTEL ONLINE CERTIFICATION COURSE

Lecture 7: Basic Optics for Optical Sensing-V

Total Internal Reflection - Sensors

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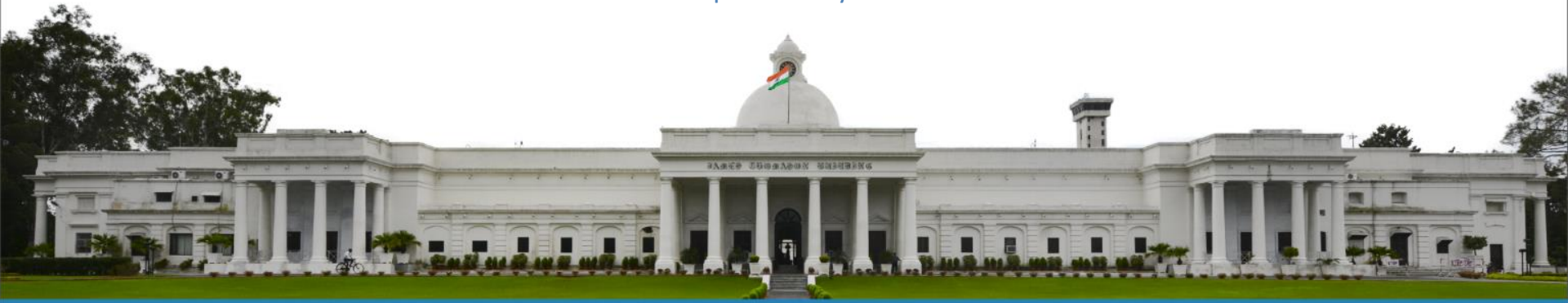
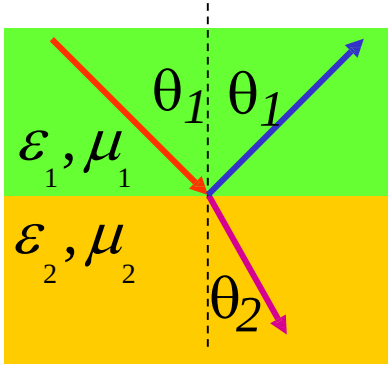
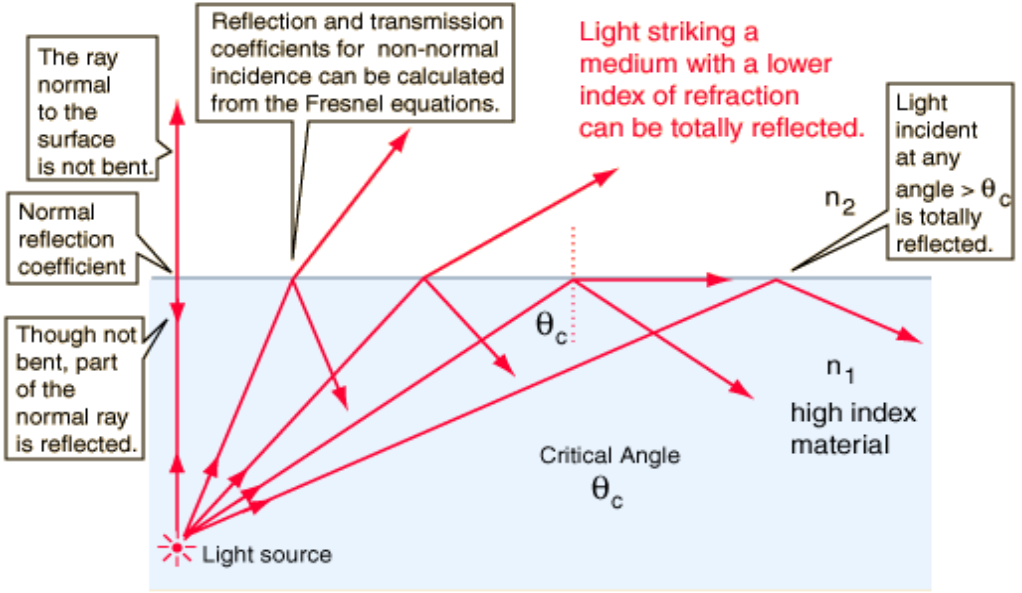


Total Internal Reflection-TIR



Snell's law:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

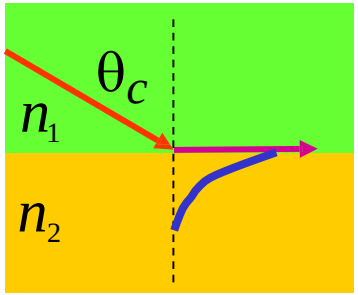


When $n_1 > n_2$ then at certain incidence angle we get: $\theta_2 = 90^\circ$

The critical angle: $\sin\theta_c = \frac{n_2}{n_1}$

For $\theta_1 > \theta_c$ the refraction angle is imaginary

$$\cos\theta_2 = \sqrt{\left[\frac{n_1 \sin\theta_1}{n_2}\right]^2 - 1}$$



We get a decaying wave across the surface

Evanescent Wave! $E \propto \exp(-z/\mathrm{d})$

Penetration Depth $\mathrm{d} = \lambda_0 / (2\pi\sqrt{n_1^2 \sin^2\theta_1 - n_2^2})$

Fresnel Equations at Total Internal Reflection

Using Fresnel formulae we get:

$$r_p = \frac{n_{12}^2 \cos\theta_1 - i\sqrt{\sin^2\theta_1 - n_{12}^2}}{n_{12}^2 \cos\theta_1 + i\sqrt{\sin^2\theta_1 - n_{12}^2}} \qquad r_s = \frac{\cos\theta_1 - i\sqrt{\sin^2\theta_1 - n_{12}^2}}{\cos\theta_1 + i\sqrt{\sin^2\theta_1 - n_{12}^2}}$$

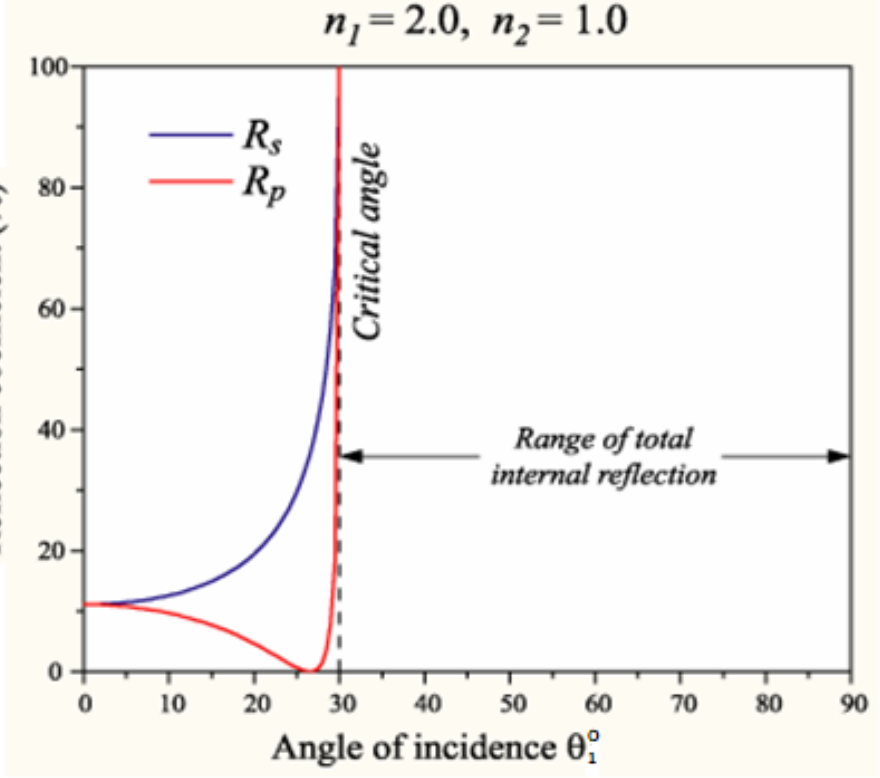
The phase:

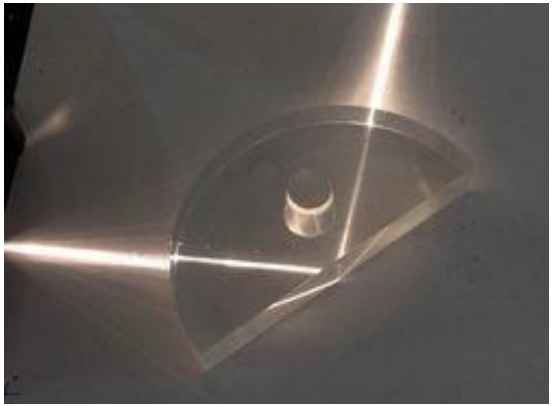
$$\tan\frac{\delta_p}{2} = -\frac{\sqrt{\sin^2\theta_1 - n_{12}^2}}{n_{12}^2\cos\theta_1}$$

$$\tan\frac{\delta_s}{2} = -\frac{\sqrt{\sin^2\theta_1 - n_{12}^2}}{\cos\theta_1}$$

$$\tan\frac{\delta_p - \delta_s}{2} = \frac{\cos\theta_1\sqrt{\sin^2\theta_1 - n_{12}^2}}{\sin^2\theta_1}$$

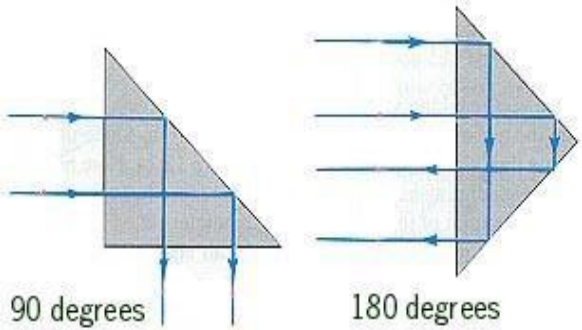
TIR - Example


$n_1 = 2.0,\ n_2 = 1.0$
Reflection coefficient (%)
100
80
60
40
20
0
R_s
R_p
Critical angle
Range of total internal reflection
0
10
20
30
40
50
60
70
80
90
Angle of incidence θ_1°



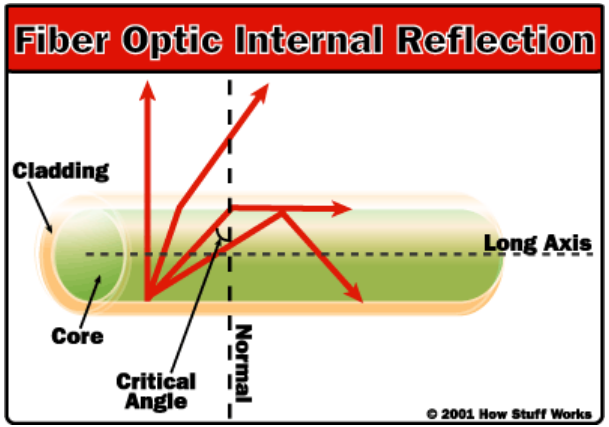
TIR or ATR

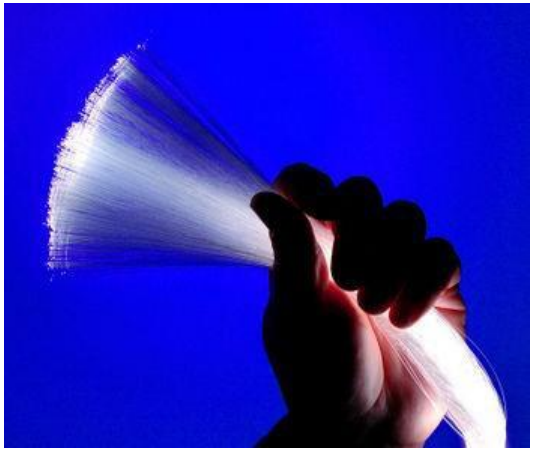
Prisms as Mirrors



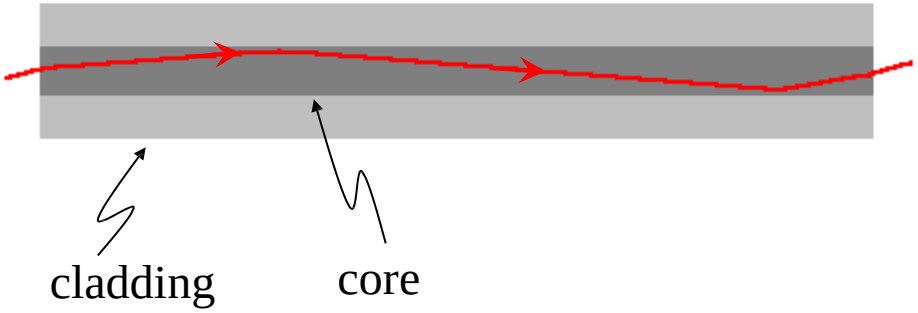
In water streams

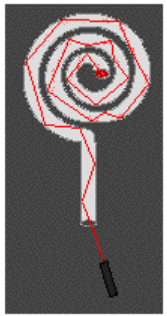
TIR in Optical Fibers



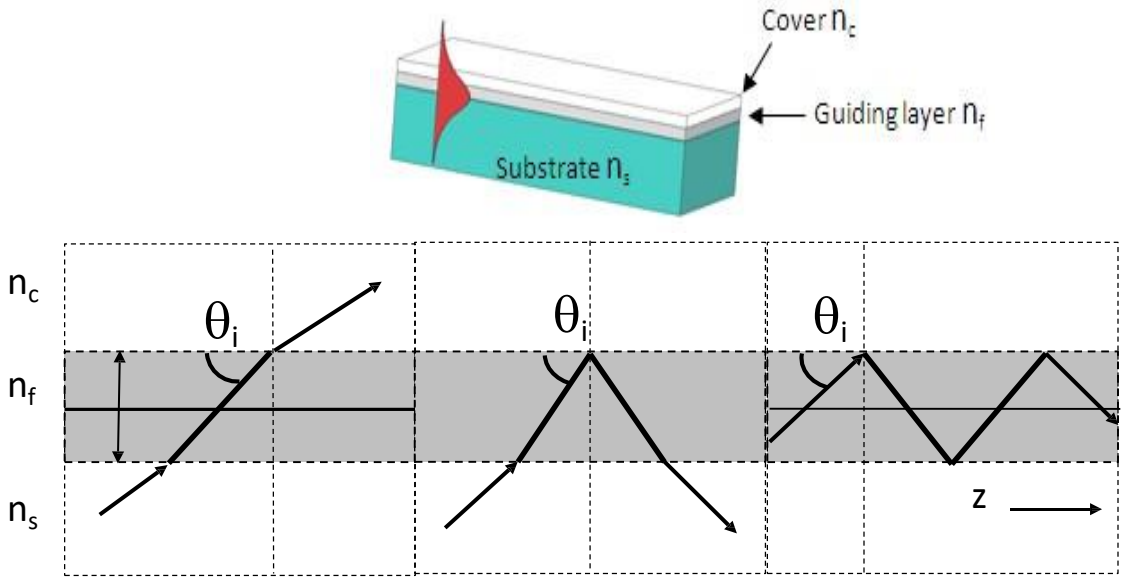


$n_{core} > n_{cladding}$





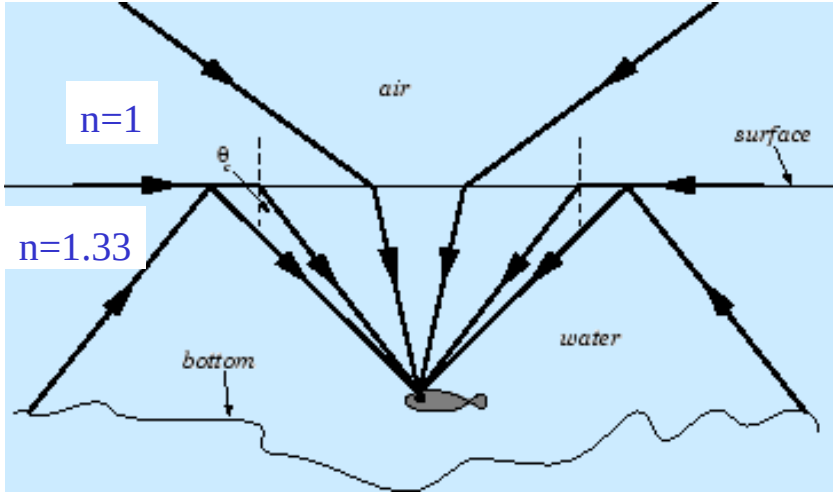
Planar Waveguides



(a) Radiation mode (b) Substrate mode (c) Guided mode

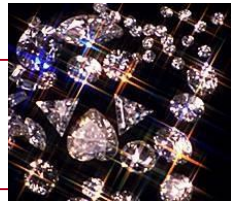
Ray patterns of (a) a radiation mode, (b) a substrate mode, and (c) a guided mode in a PW, where $n_f > n_s \geq n_c$.

TIR, Fish Vision and Diamonds Brilliance



The fish sees the sky if it looks upwards but seem the bottom of the bond if it looks at angle larger than 48.8 degs.

Question: explain the brilliance of diamond in air knowing that for diamond n=2.42 and explain why it is less shiny when it is in water?

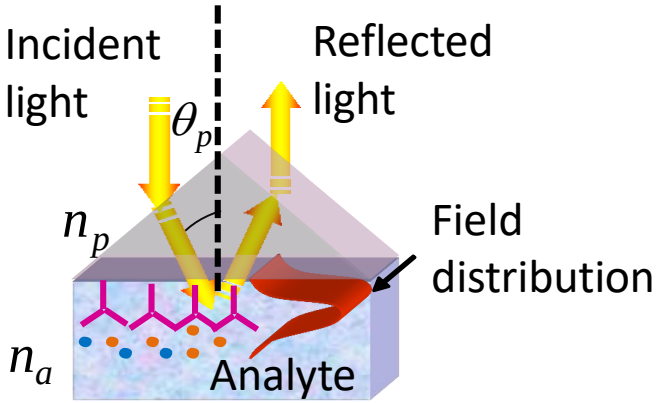


Can we do Sensing using TIR?

$$\sin\theta_c = \frac{n_a}{n_p}$$

Use: $\frac{d\sin x}{dx} = \cos x$

$$\frac{d\sin\theta_c}{dn_a} = \cos\theta_c \frac{d\theta_c}{dn_a} = \frac{1}{n_p} \Rightarrow$$



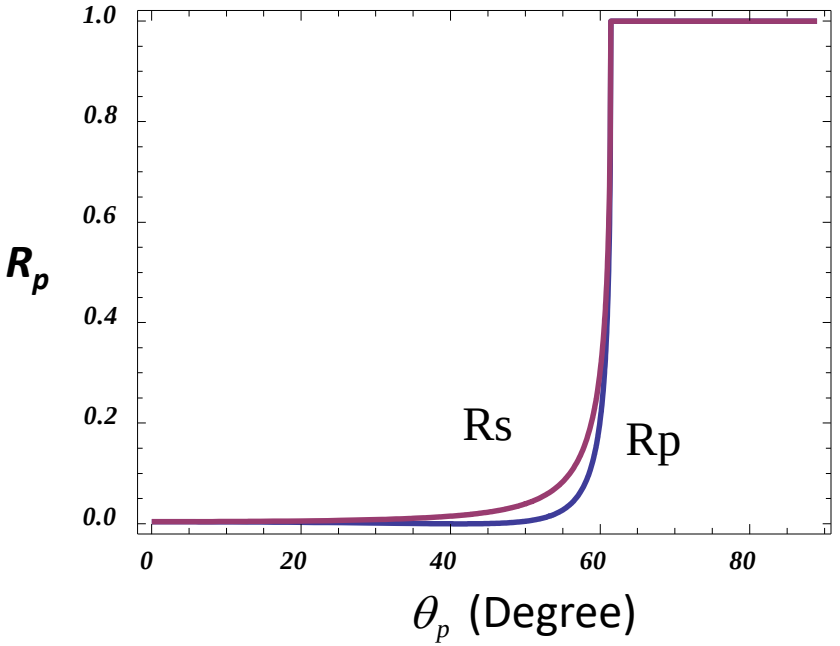
$$S = \frac{d\theta_c}{dn_a} = \frac{1}{n_p\cos\theta_c} = \frac{1}{n_p\sqrt{1-\sin^2\theta_c}} = \frac{1}{n_p\sqrt{1-n_a^2/n_p^2}} = \frac{1}{\sqrt{n_p^2-n_a^2}}$$

Example: BK7 prism and water analyte:

$$S = \frac{1}{\sqrt{n_p^2 - n_a^2}} = \frac{1}{\sqrt{1.515^2 - 1.33^2}}$$

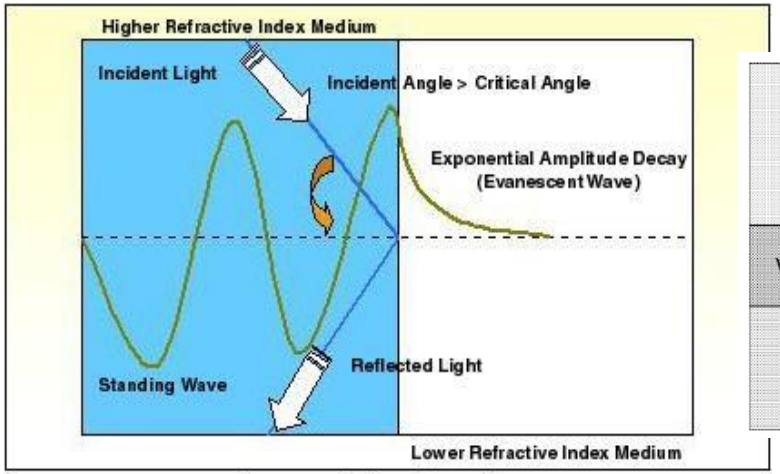
$$\approx 1.38\, rad / RIU = 78.97\, \text{deg}/\ RIU$$

High sensitivity and sharp response Curve!

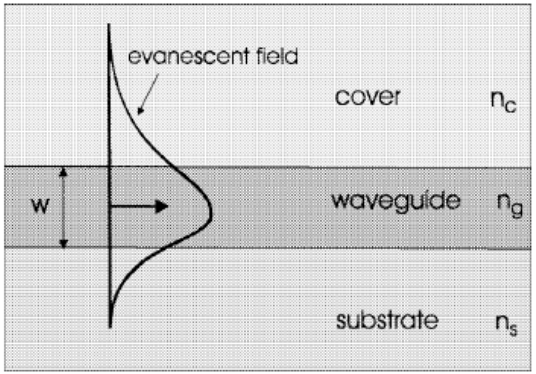


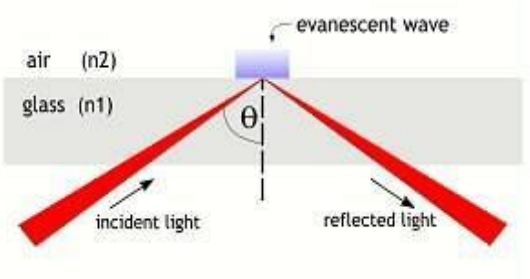
Evanescent Wave Sensors

The sensing is performed by the evanescent tail of the modal field in the cover medium. This sensing operation consists of measuring the change of the effective index of a propagating mode when a change of the refractive index takes place in the waveguide cover. Or due to absorption!



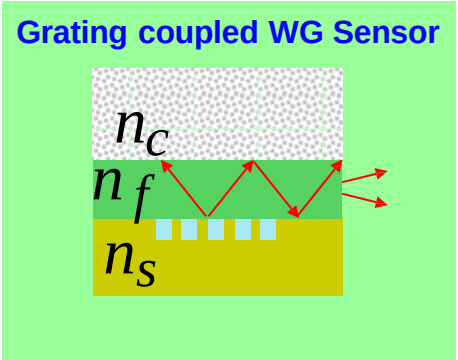
Evanescent Wave Generation

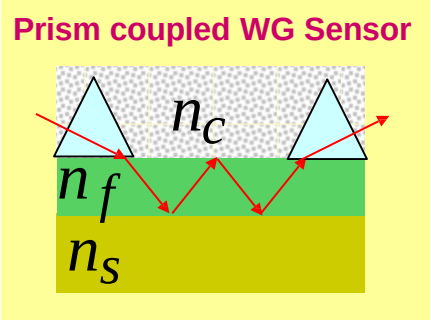


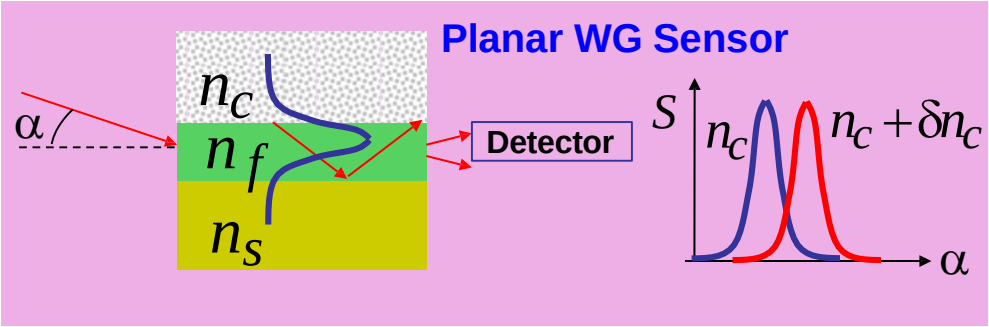


Evanescent wave sensor configurations

Wave guide geometries

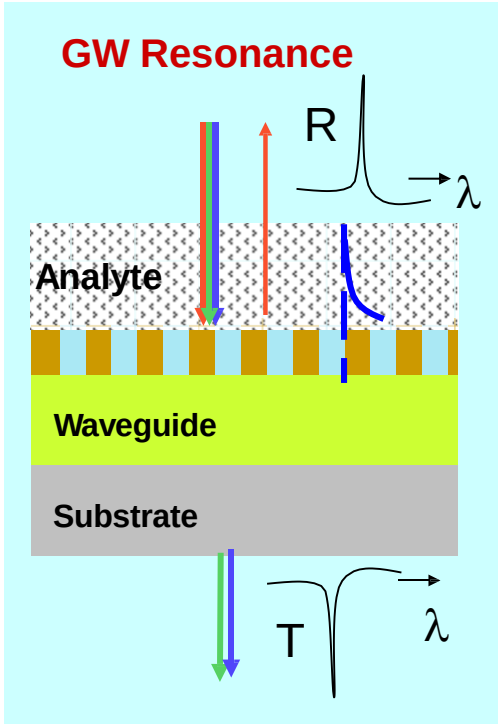


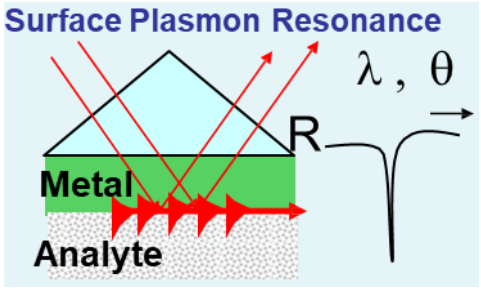


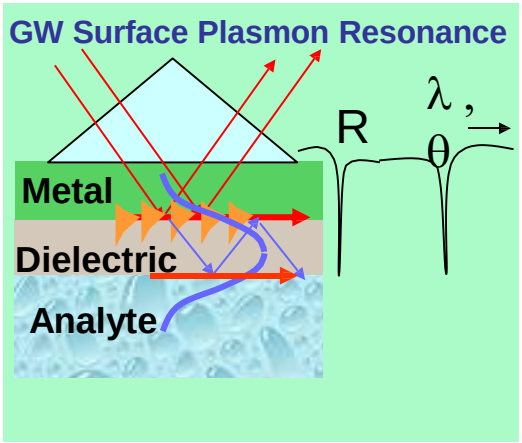


Evanescent wave sensor configurations

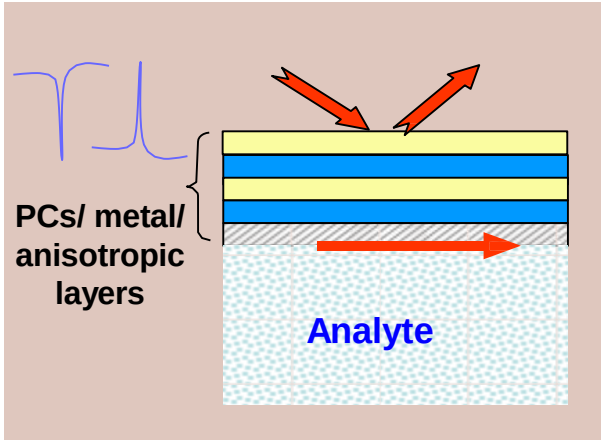
Plasmonic sensors



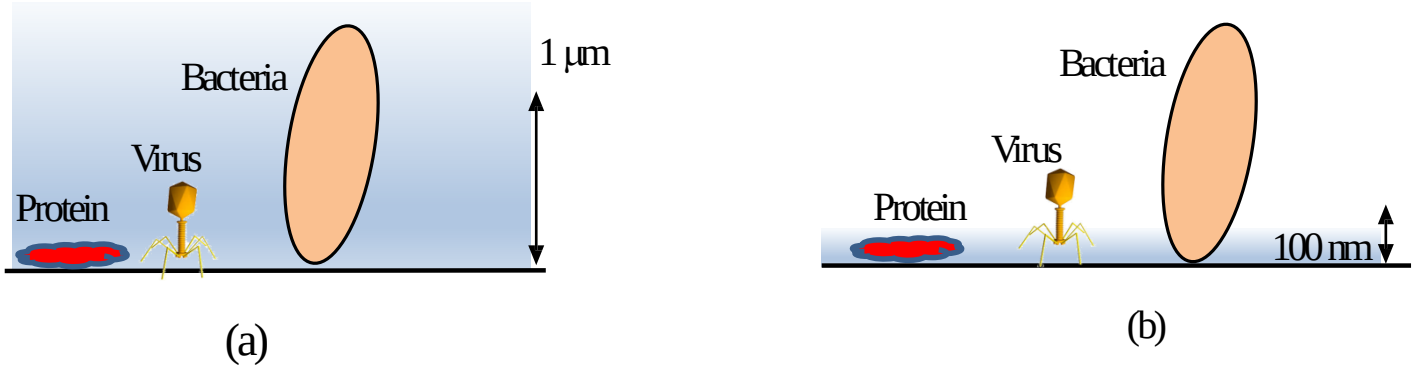




SEW from PCs & anisotropic films



The importance of the Penetration Depth



Schematics of (a) the evanescent field of a conventional evanescent-field sensor of 100-nm penetration depth and (b) a long-range evanescent field, in comparison to biologically significant targets to be sensed.

Summary

1. Total internal reflection for angles $\theta_1 > \theta_c$ was discussed and the expression for penetration depth of evanescent waves was obtained.
2. Use of TIR for sensing was discussed.
3. Various configurations for evanescent wave based sensors were presented

Thank You