Solar Cell Operation, Performance and Design Rules

Light Trapping II - Anti-Reflection and Trapping Methods

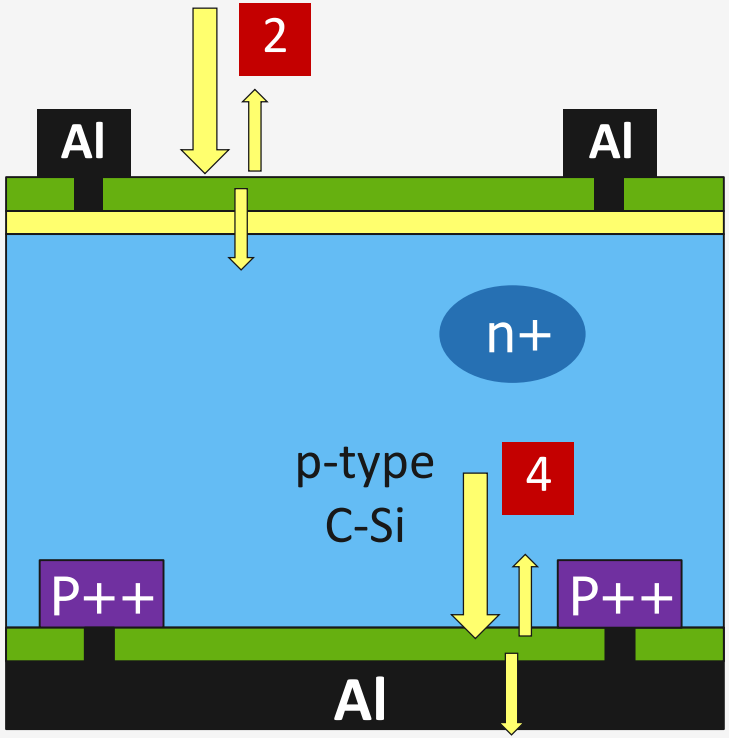
Week 3.3.5

Arno Smets

Parasitic losses = outside absorbing layers

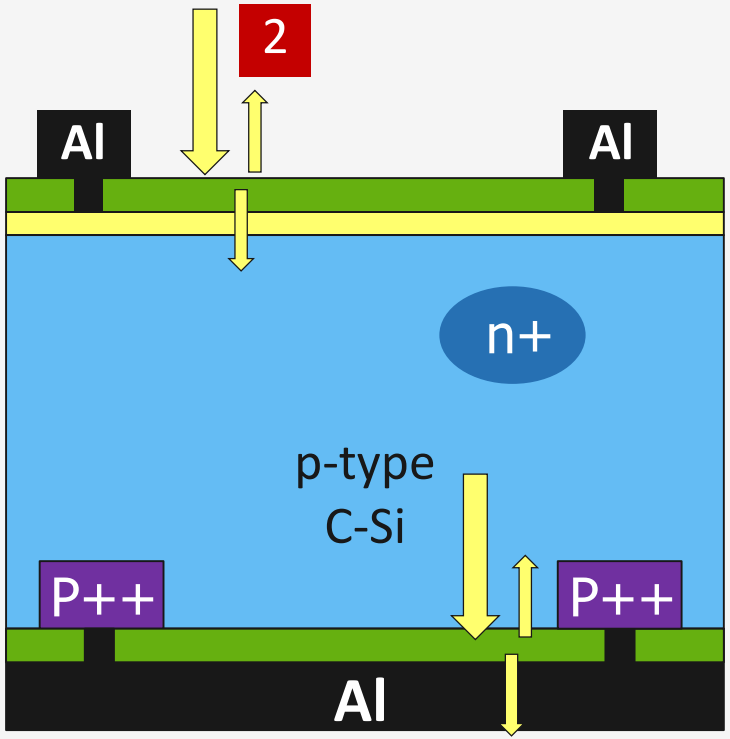
2 Reflection

4 Transmission



Parasitic losses = outside absorbing layers

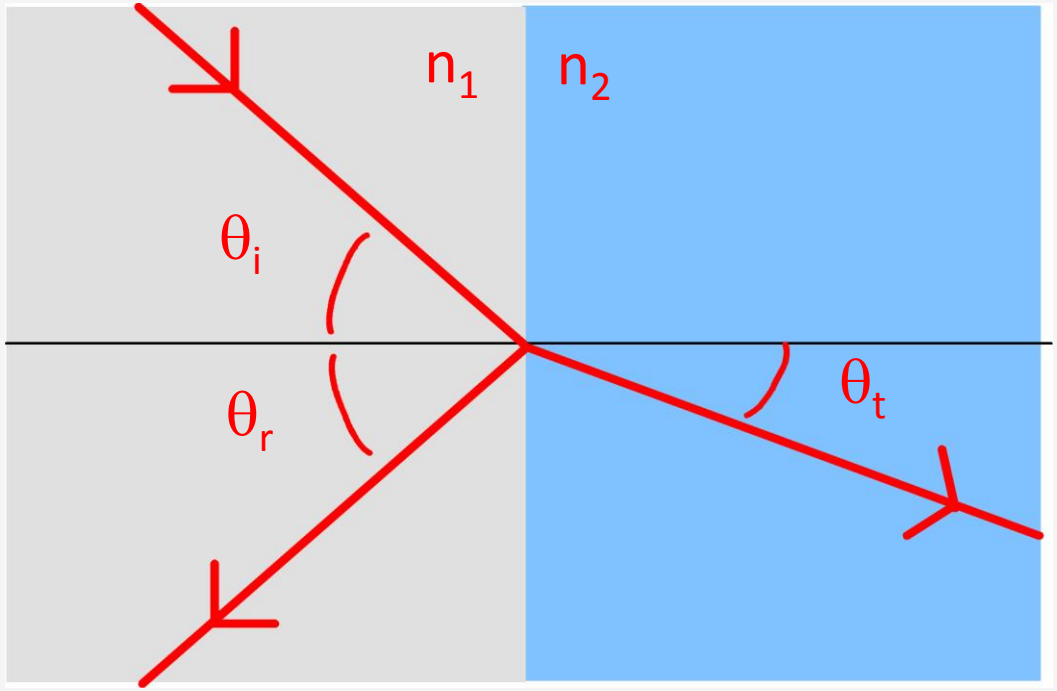
2 Reflection



Snell's Law

$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

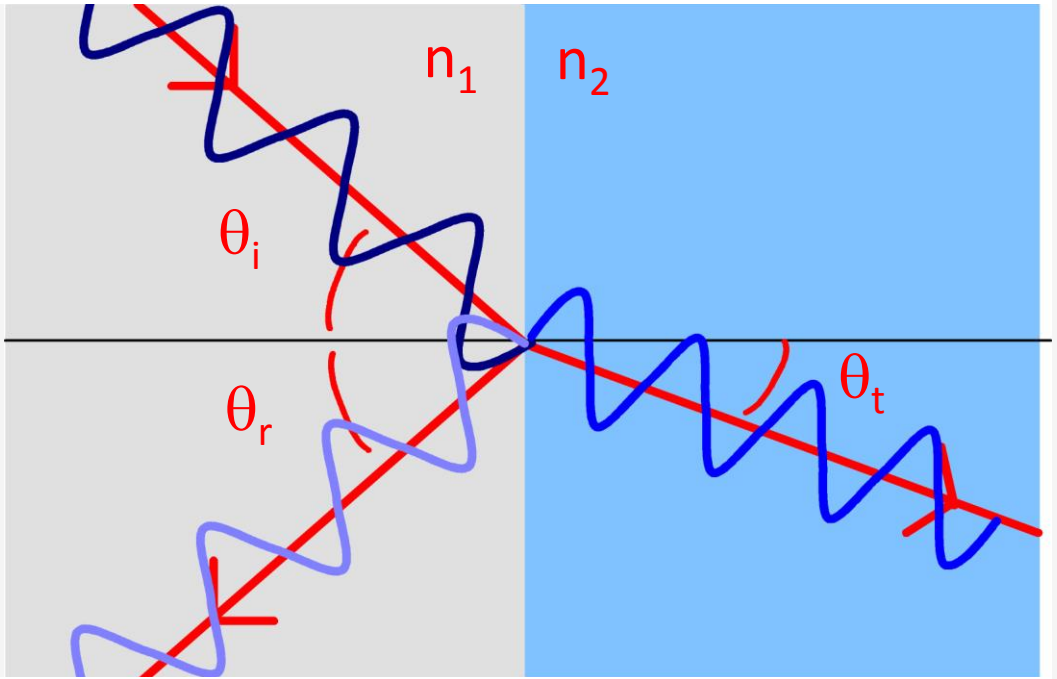
$$\theta_i = \theta_r$$



The Fresnel equation

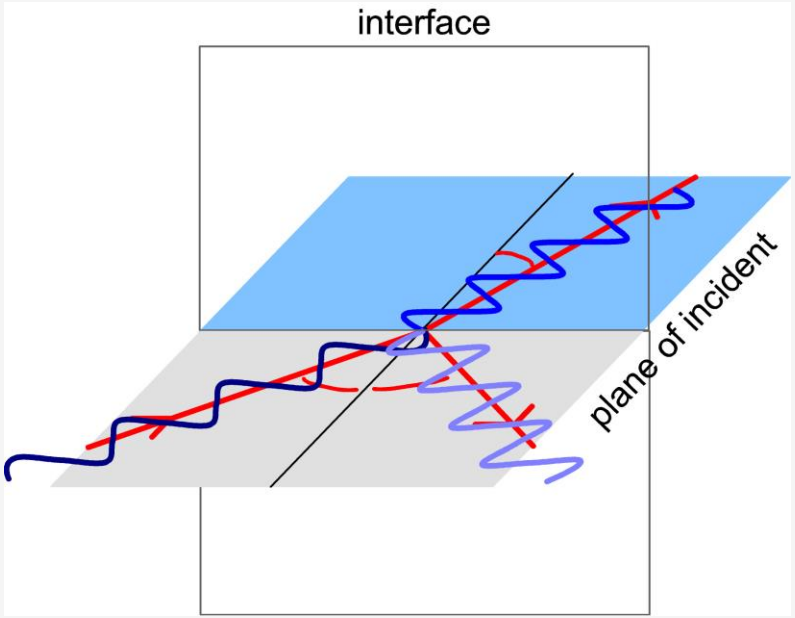
$$n_1 \sin\theta_i = n_2 \sin\theta_t$$

$$\theta_i = \theta_r$$

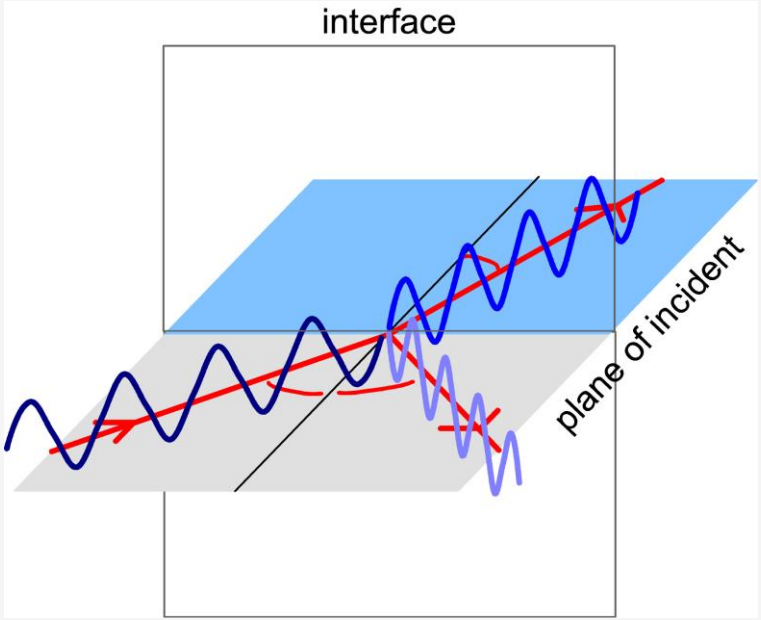


P- and S- polarization

P-polarization



S-polarization



Fresnel coefficients

P-polarization

$$R_p = \left(\frac{n_1 \cos(\theta_t) - n_2 \cos(\theta_i)}{n_1 \cos(\theta_t) + n_2 \cos(\theta_i)} \right)^2$$

$$T_p = 1 - R_p$$

S-polarization

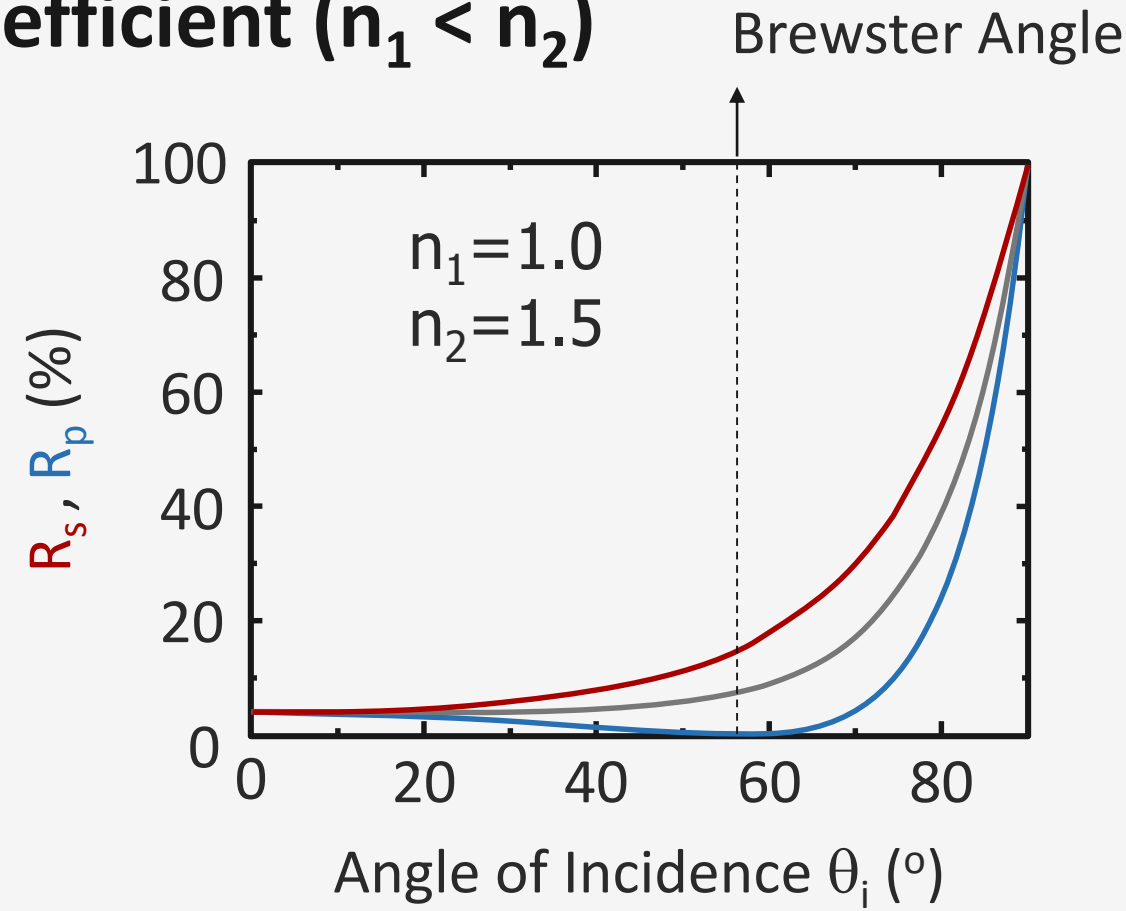
$$R_S = \left(\frac{n_1 \cos(\theta_i) - n_2 \cos(\theta_t)}{n_1 \cos(\theta_i) + n_2 \cos(\theta_t)} \right)^2$$

$$T_S = 1 - R_s$$

Reflection coefficient ($n_1 < n_2$)

P-polarization

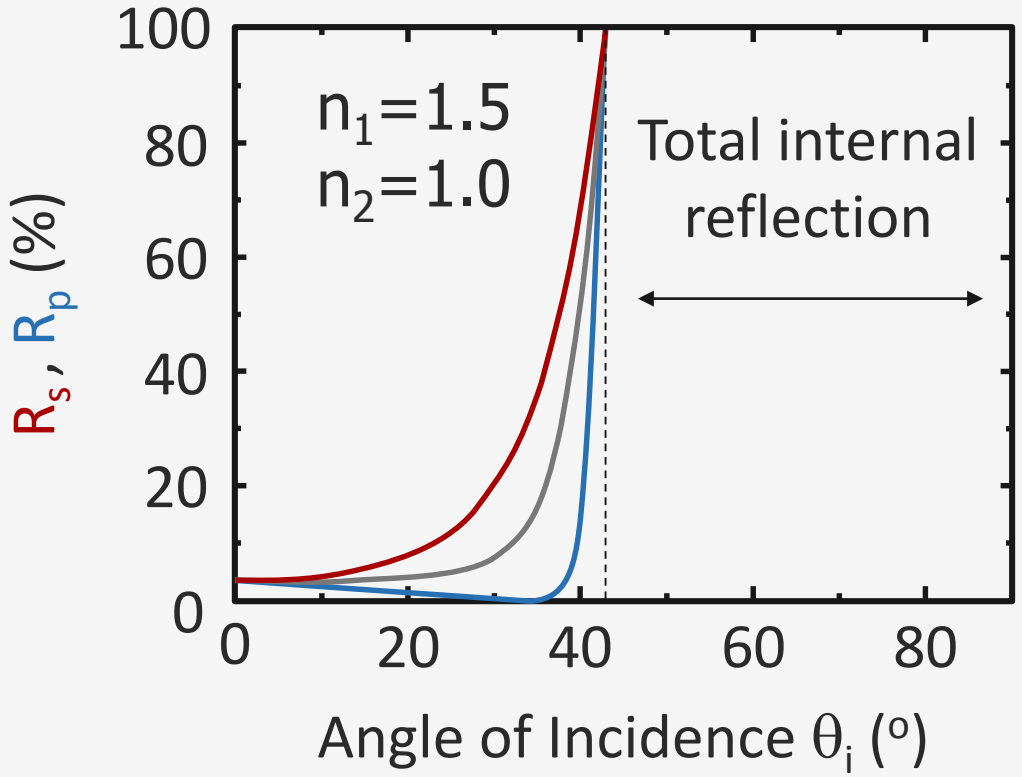
S-polarization



Reflection coefficient ($n_1 > n_2$)

P-polarization

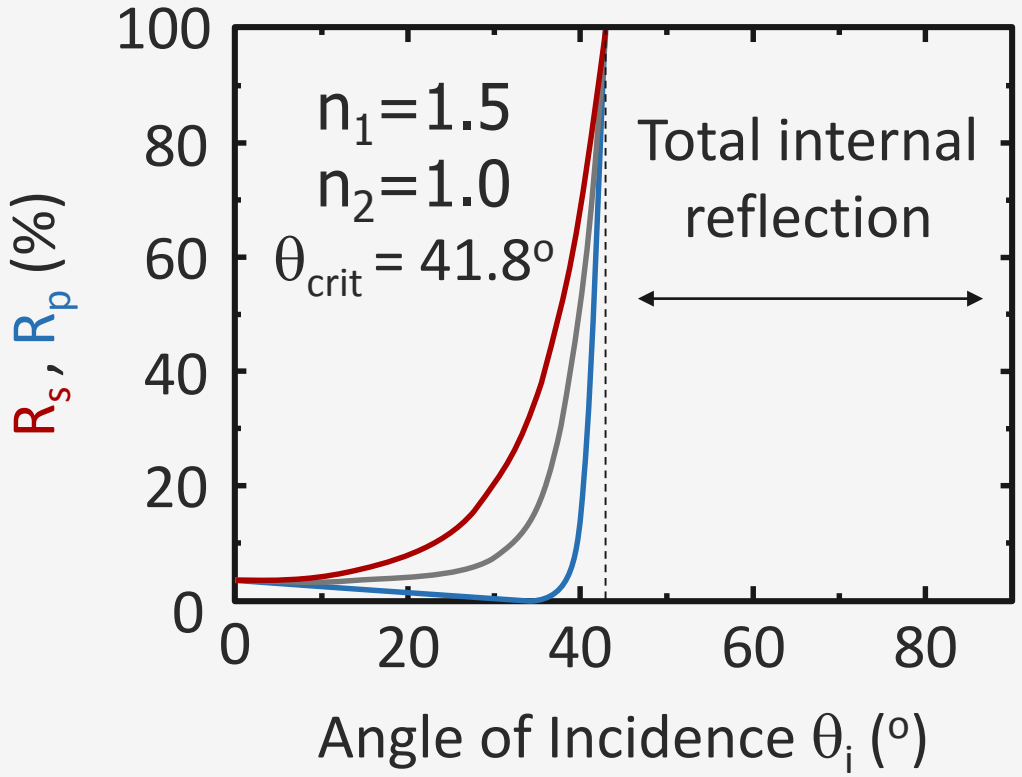
S-polarization



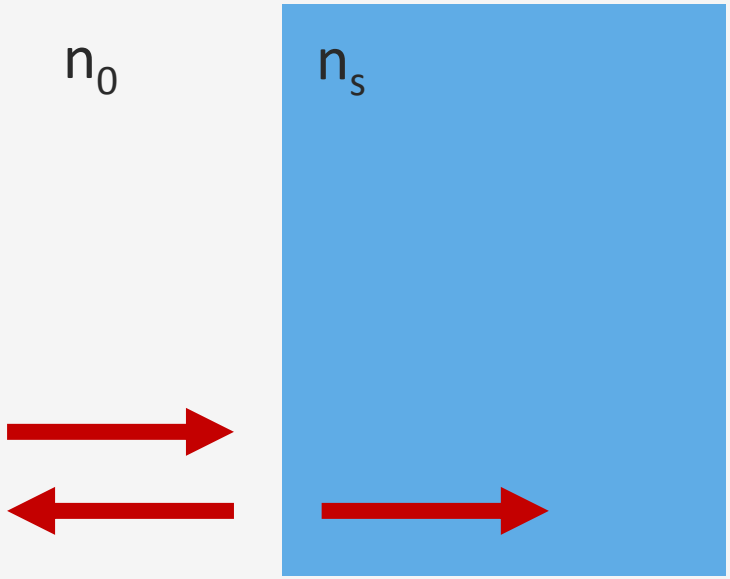
Reflection coefficient ($n_1 > n_2$)

P-polarization

S-polarization

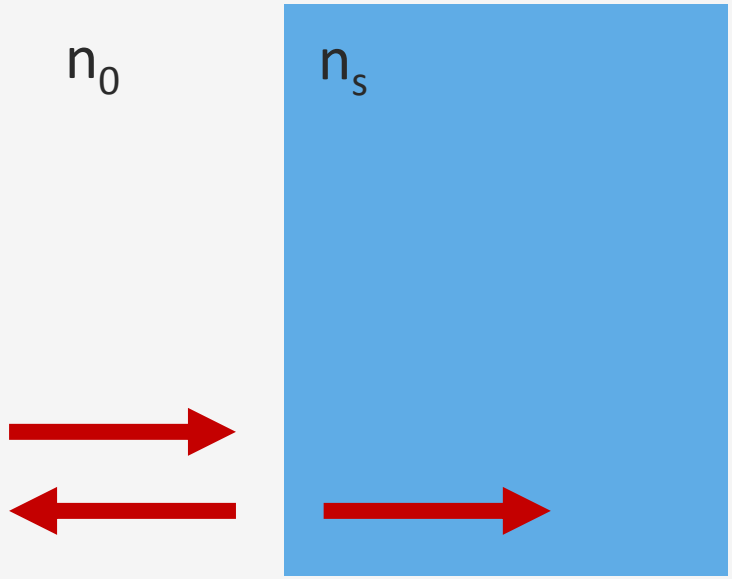


Reduction Front Reflection:



$$R_{0s} = \frac{(n_0 - n_s)^2}{(n_0 + n_s)^2} \qquad T_{0s} = \frac{4n_0 n_s}{(n_0 + n_s)^2}$$

Reduction Front Reflection:

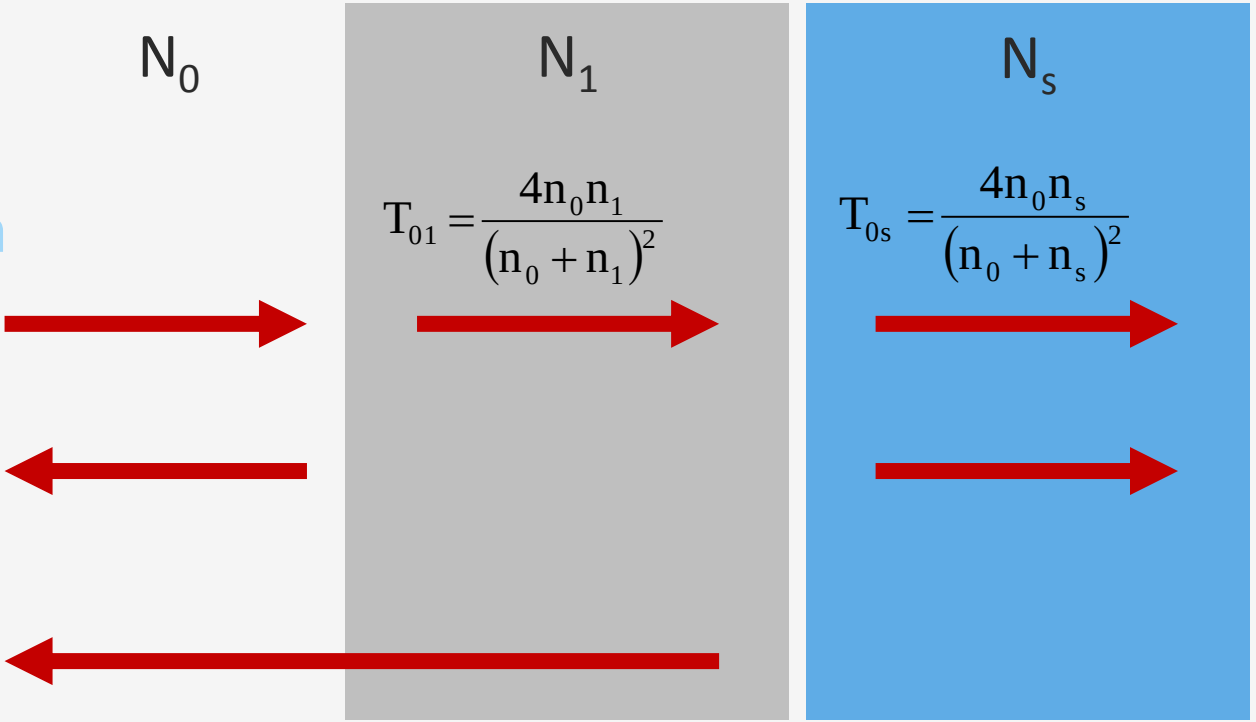


$R_{0s} = 0.388$

$T_{0s} = 0.612$

Rayleigh film

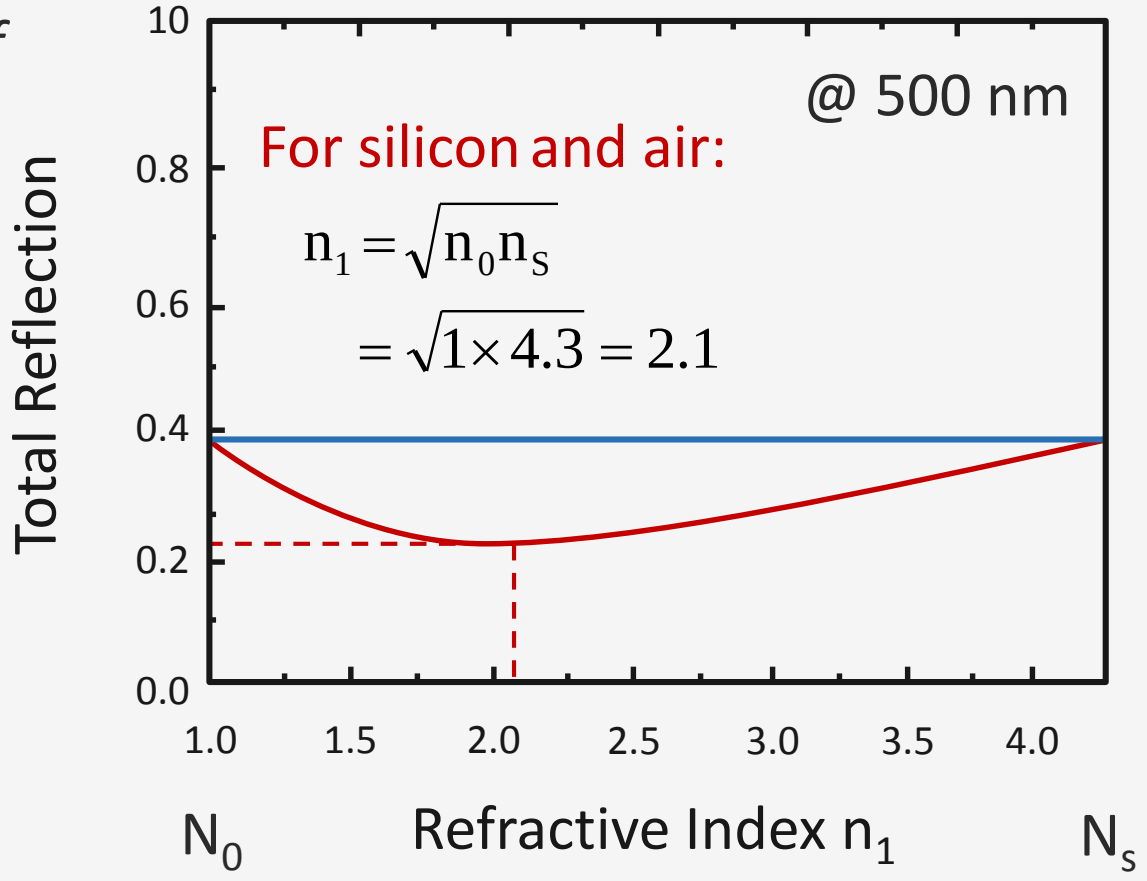
First order approximation

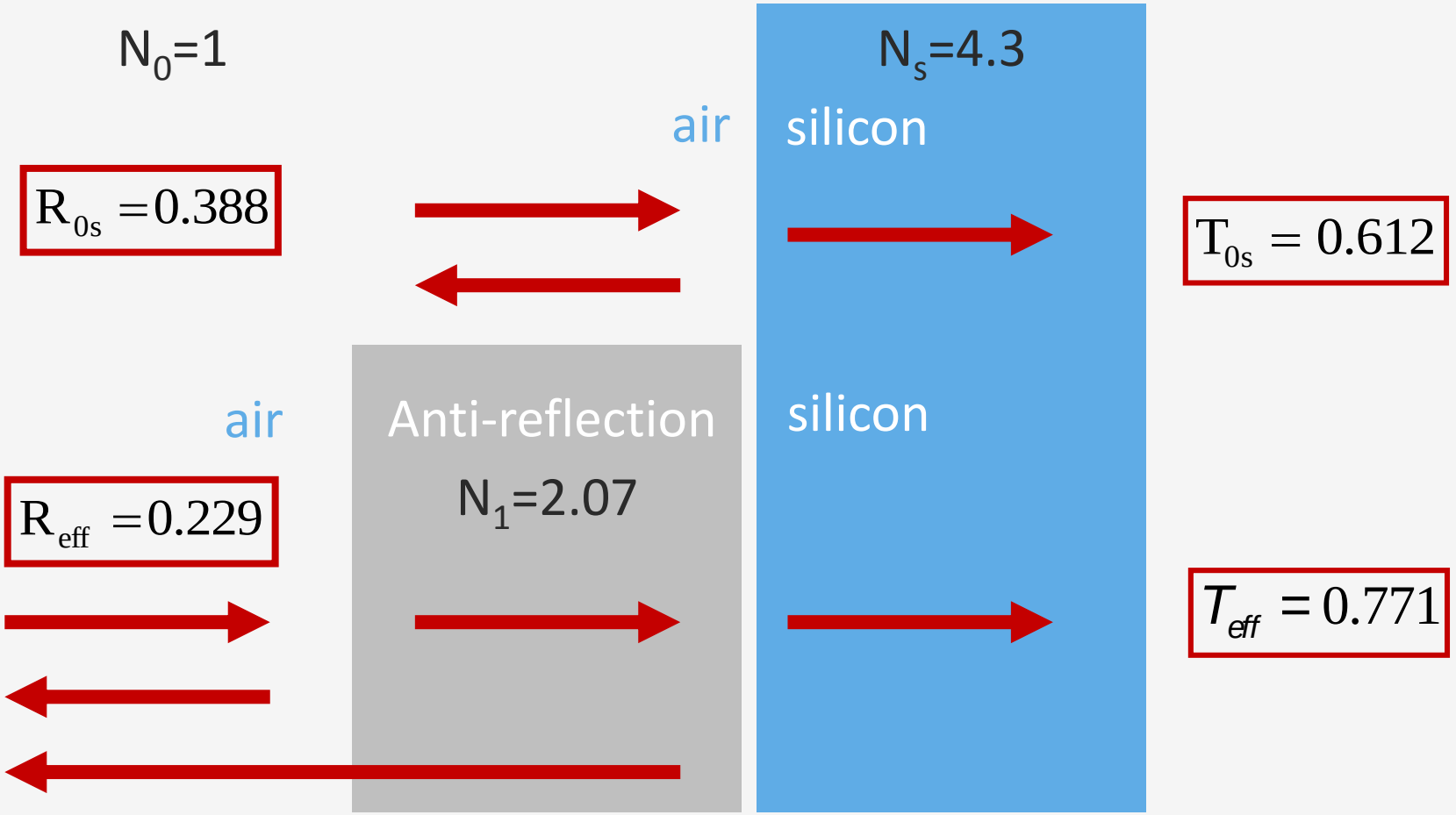


$$R_{01} = \frac{(n_0 - n_1)^2}{(n_0 + n_1)^2}$$

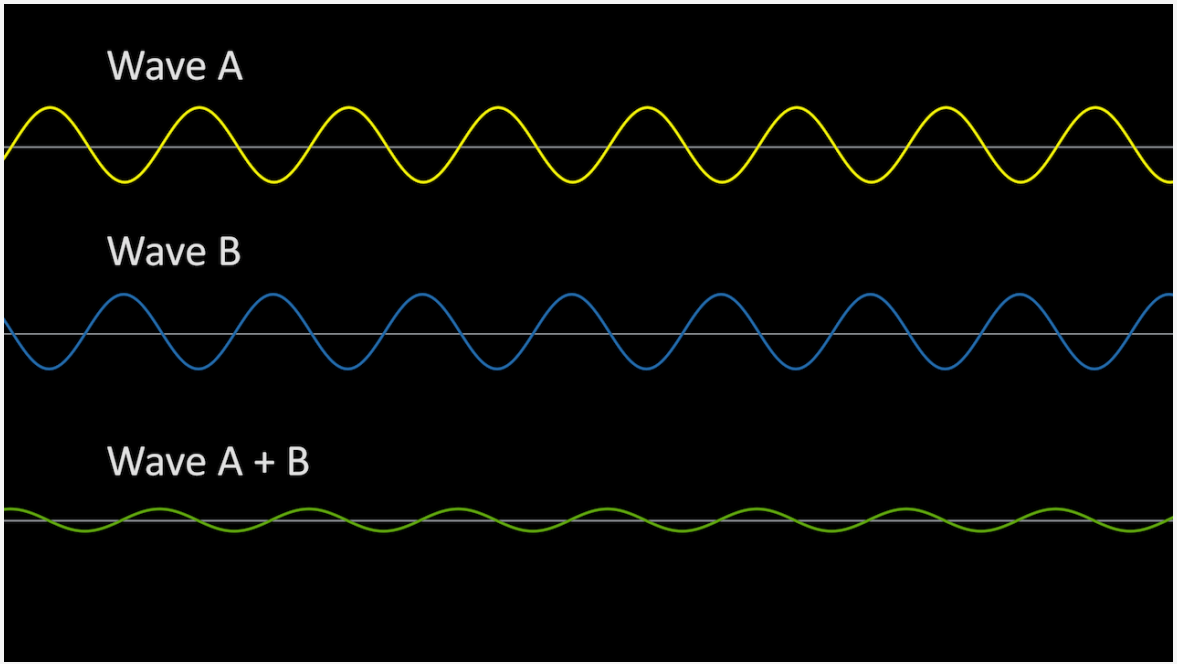
$$R_{1s} = \frac{(n_1 - n_s)^2}{(n_1 + n_s)^2}$$

Lower reflection coeff

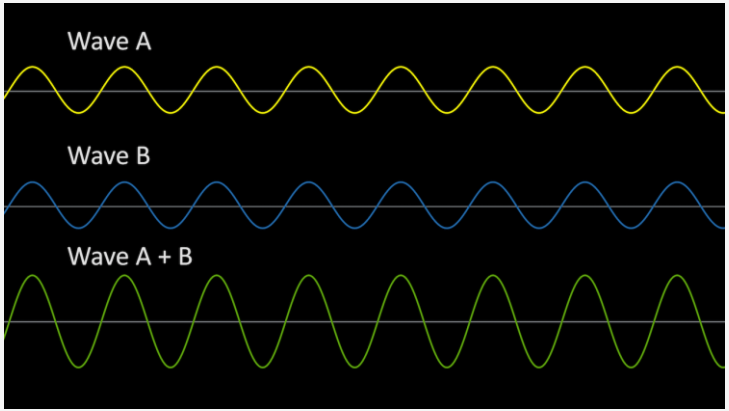



N_0=1
N_s=4.3
air
silicon
R_{0s} =0.388
T_{0s} = 0.612
air
Anti-reflection
N_1=2.07
silicon
R_{eff} =0.229
T_{eff} = 0.771

Interference:

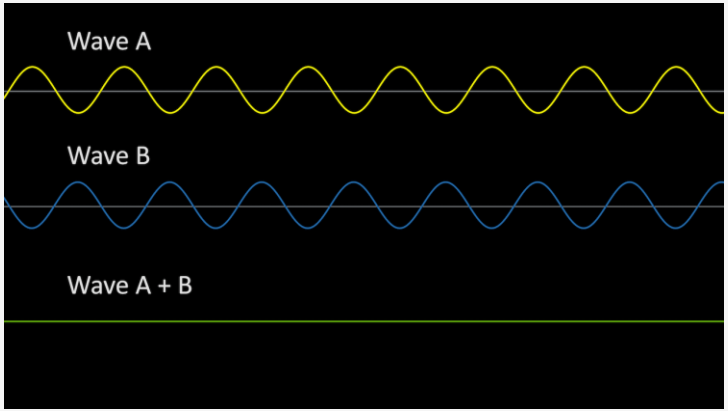


Interference:



constructive Interference

□□=0



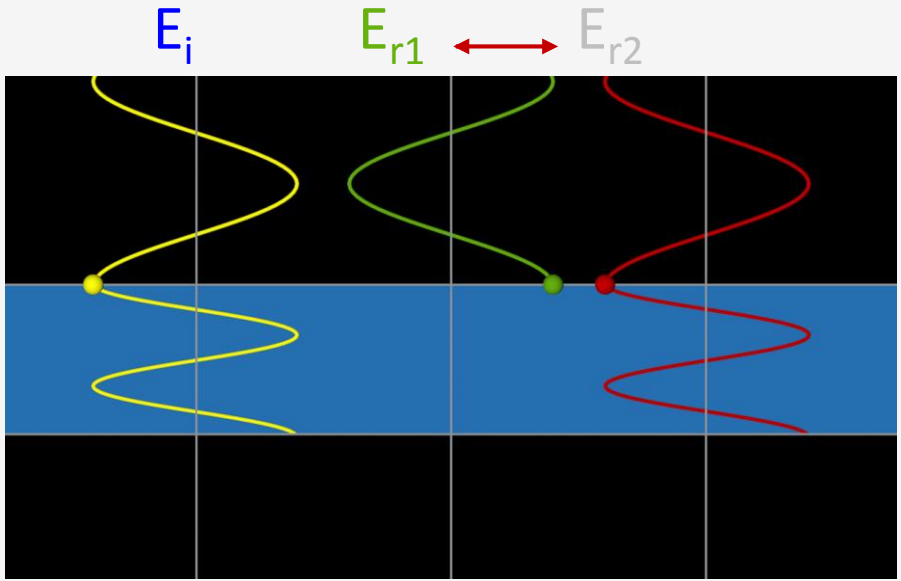
destructive Interference

□□=□

Interference: the anti-reflection coating

Destructive interference

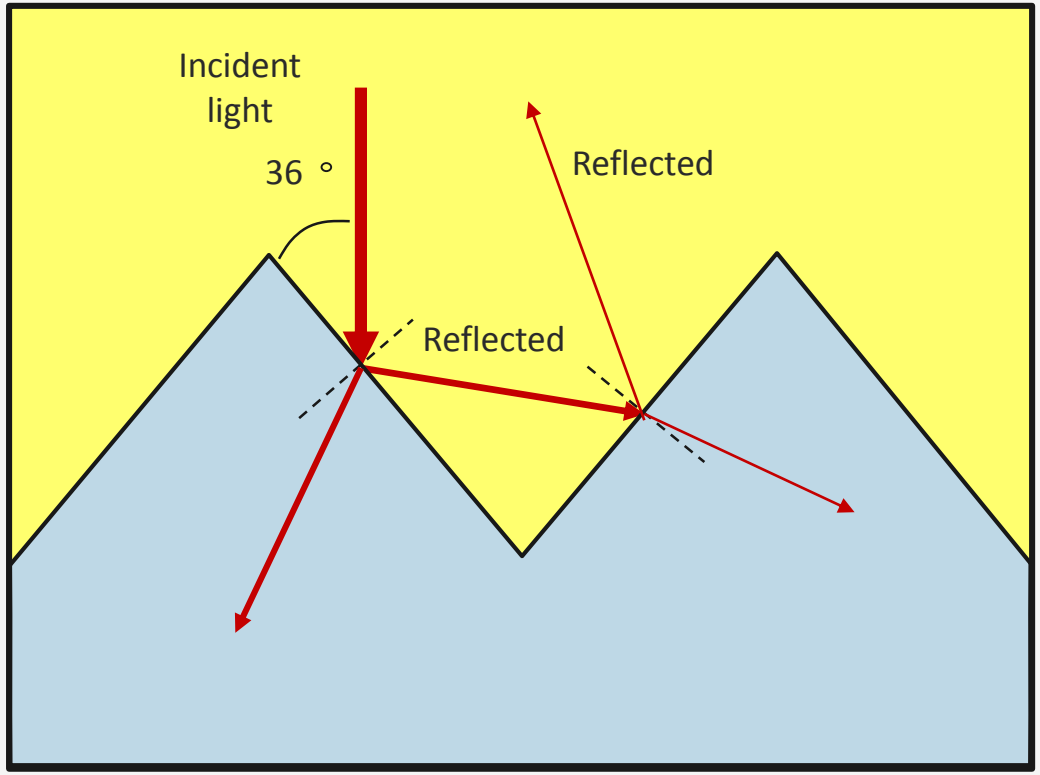
$\Delta\phi=\pi$



$$d = \frac{\lambda}{4n_2}$$

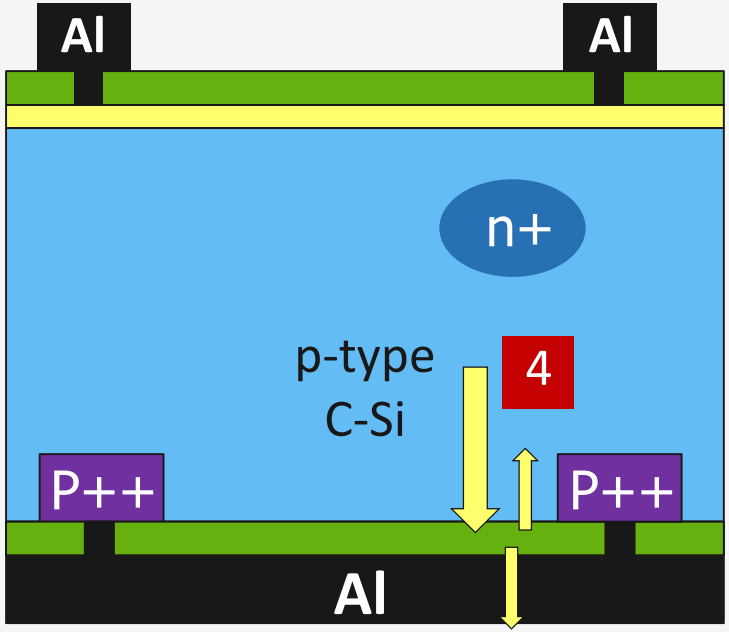
Macroscopic roughness (d>>λ)

Path of light rays
Are determined
By refraction.

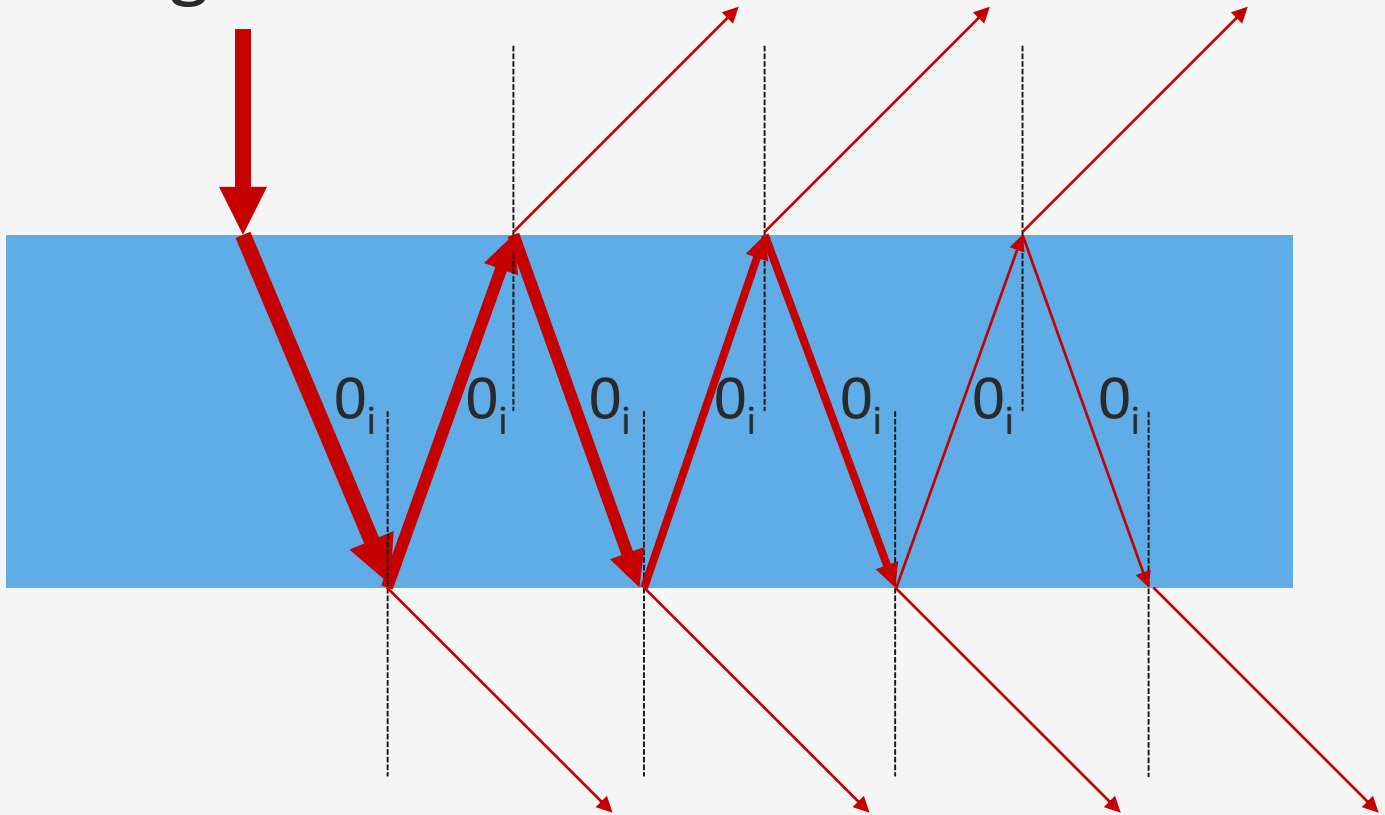


Parasitic losses = outside absorbing layers

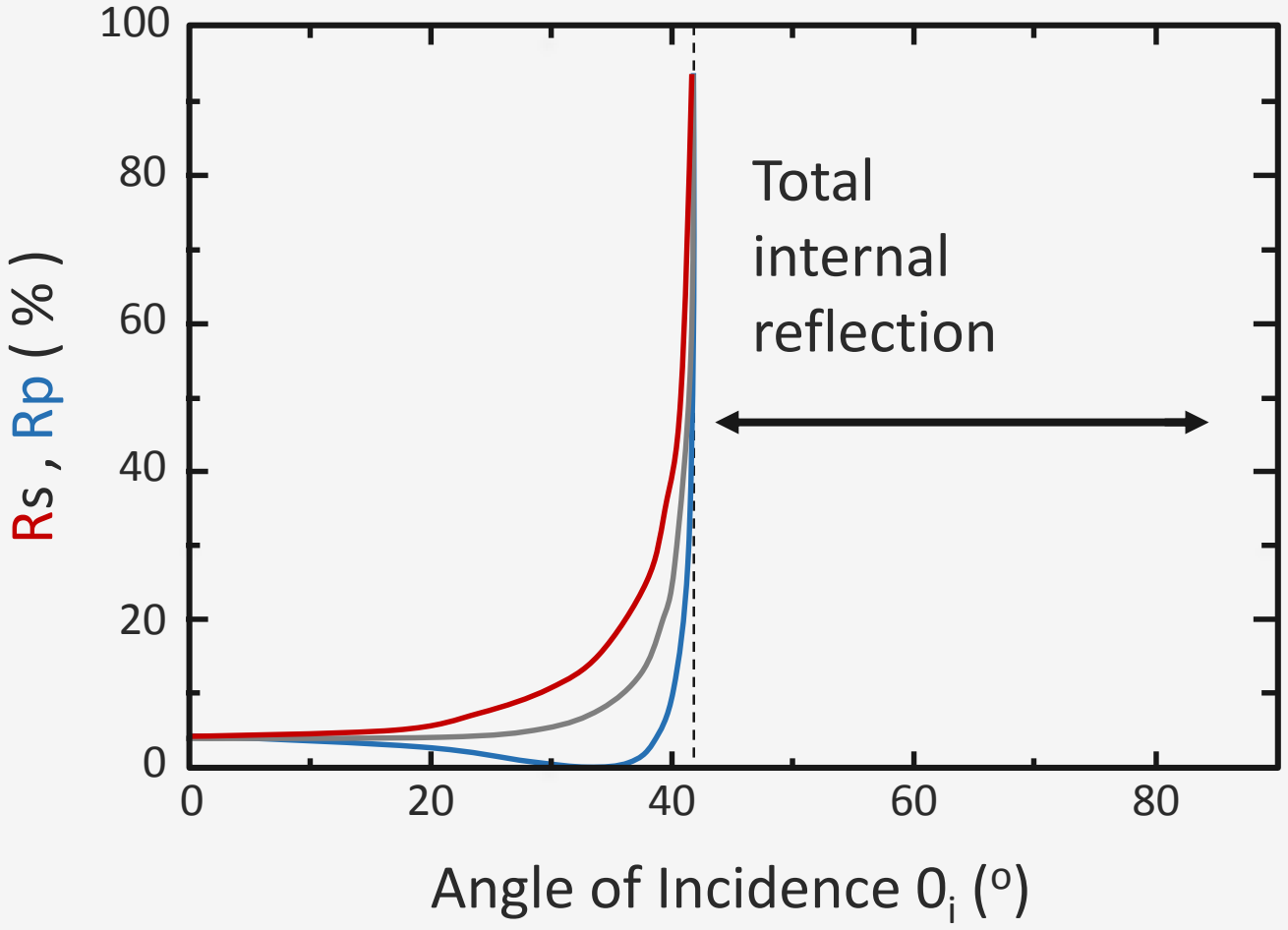
4 Transmission



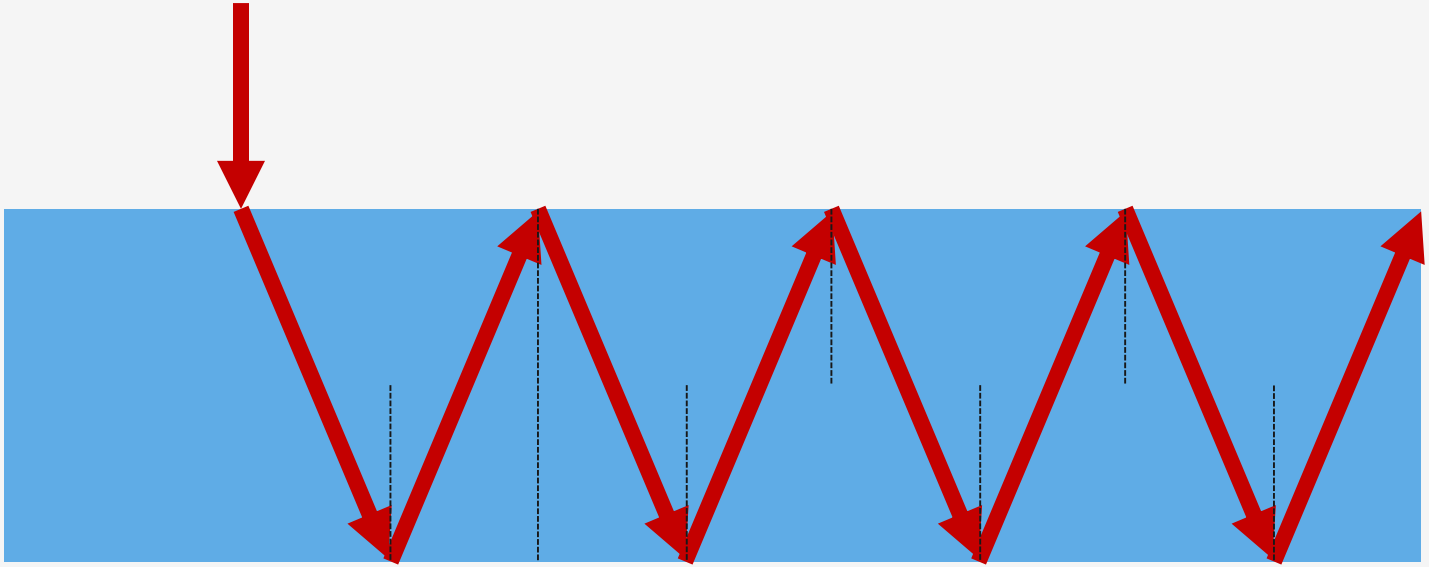
Enhancement of Absorption path length in Thin Film Solar cells



$\theta_i < \theta_{critical}$

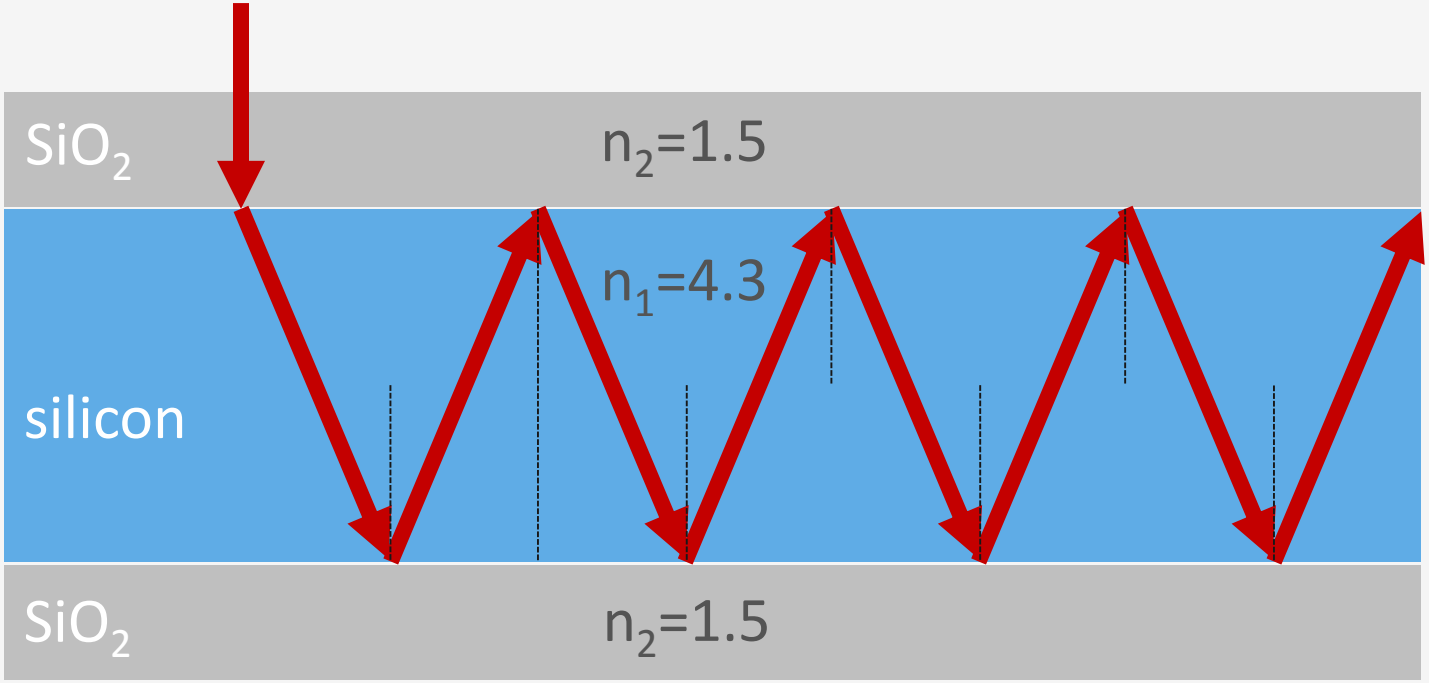

100
80
60
40
20
0
Rs , Rp (%)
0
20
40
60
80
Angle of Incidence 0i (o)
Total
internal
reflection

Enhancement of Absorption path length in Thin Film Solar cells

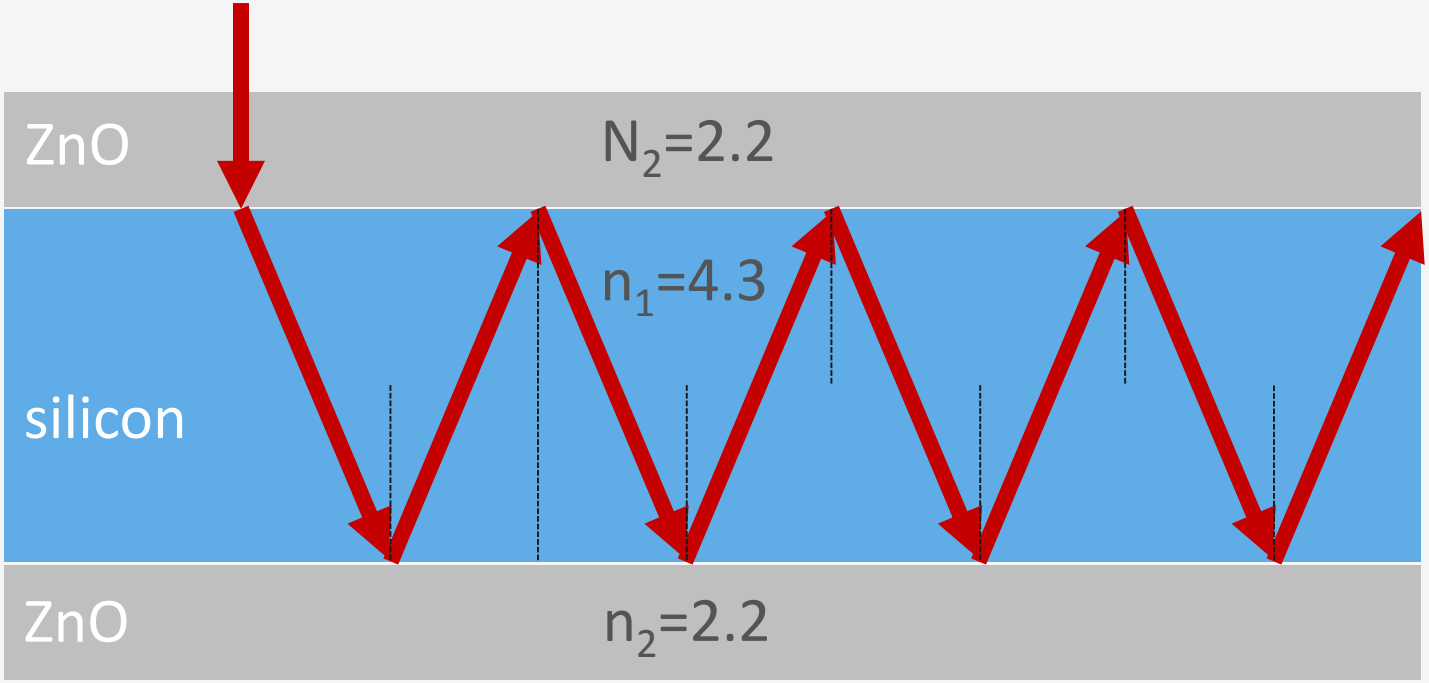


$\theta_i < \theta_{critical}$

Enhancement of Absorption path length in Thin Film Solar cells

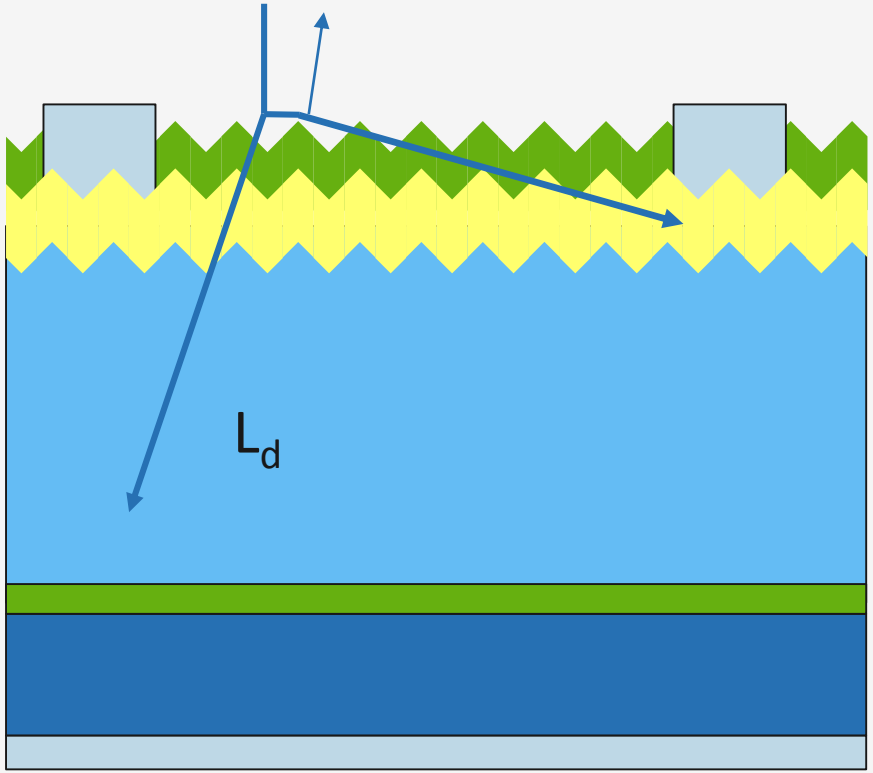


Enhancement of Absorption path length in Thin Film Solar cells



Light management in solar cells

Increasing the absorption path length



Thank you for your attention!

Enhancement absorption pathlength