Multilayer coatings for Solar Absorber

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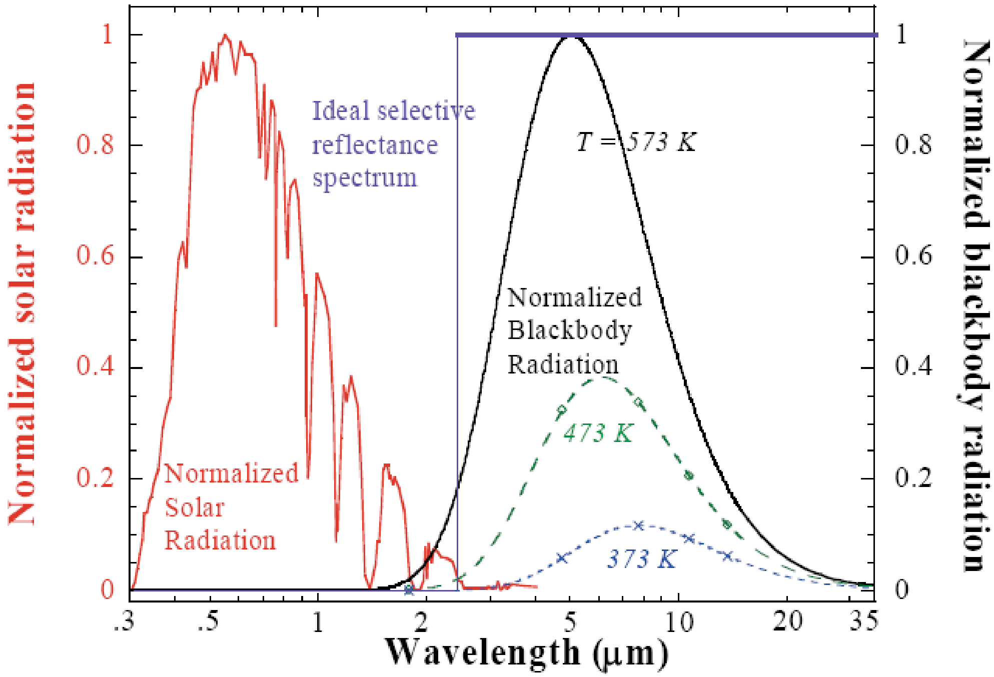
Plan

- Solar Absorber Physical Fundamentals
- Multilayer Solar Absorber Optical Design
- Results

Physical fundamentals



The wavelength distribution of radiation emitted by a blackbody

$$I_b(\lambda,T)=\frac{2\,\pi\,h\,c^2}{\lambda^5\left[\exp\left(\frac{h\,c}{\lambda\,k_B\,T}\right)-1\right]}$$

h is Plank's constant
k is Boltzman's constant
c is the speed of the light

$$R(\lambda)+\underbrace{T(\lambda)}_{0\,(\text{Opaque})}+A(\lambda)=1$$

According to Kirschoff's law

$$\text{Emittance}(\lambda)=A(\lambda)=1-R(\lambda)$$

Ideal absorber:

- R = 0; Emittance = 1 in solar spectrum
- R = 1;Emittance = 0 in thermal spectrum

Solar Absorbance and thermal Emittance

$$\alpha_{sol} = \frac{\int_{0.3}^{2.5} I_s(\lambda)(1 - R(\lambda))\, d\lambda}{\int_{0.3}^{2.5} I_{sol}(\lambda)\, d\lambda}$$

$$\varepsilon_t = \frac{\int_{2.5}^{20} I_b(\lambda, T)(1 - R(\lambda))\, d\lambda}{\int_{2.5}^{20} I_b(\lambda, T)\, d\lambda}$$

Different designs of solar absorber

•Intrinsic Materials

•Optical trapping surfaces-textured surfaces

•Tandem Absorbers:

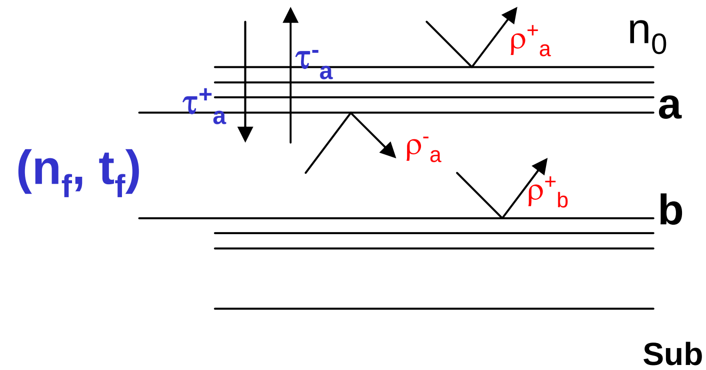
Absorber-Reflector tandems: High absorbance coating at solar wavelength deposited on highly IR-reflecting metal substrate (Copper).

Metal-dielectric composite coating consists of very fine metal particles embedded in a dielectric host (*cermet coating*). Optically are highly absorbent in the solar absorbing spectral range and good transparency in the IR.

In this work we are using the Ti-TiN_xO_y cermet coatings.

The resultant amplitude reflection coefficient :

$$\rho^+ = \rho_a^+ + \frac{\rho_b^+ \, \tau_a^+ \, \tau_a^- \exp(-2\,\mathrm{i}\,\delta)}{1 - \rho_b^+ \, \rho_a^- \exp(-2\,\mathrm{i}\,\delta)}$$



The phase thickness:

$$\delta = \frac{2\pi}{\lambda} \underbrace{(n - \mathrm{i}\,k)}_{n_f} t_f = \alpha - \mathrm{i}\,\beta$$

$$R = R_a^+ + \frac{R_b^+ \, T^2 \exp(-4\beta) \dfrac{|n_f|^2}{\mathrm{Re}(n_f)^2} + \overbrace{2\exp(-2\beta)\,\mathrm{Re}\left[\rho_a^+ \, \overline{\rho_b^+ \, \tau_a^+ \, \tau_a^-} \left(\exp(2\,\mathrm{i}\,\alpha) - \rho_a^- \, \rho_b^+ \exp(-2\beta)\right)\right]}^{***}}{\left(1 - \sqrt{R_a^- \, R_b^+} \exp(-2\beta)\right)^2 \left[1 - \dfrac{4\exp(-2\beta)\sqrt{R_a^- \, R_b^+}}{\left(1 - \sqrt{R_a^- \, R_b^+}\exp(-2\beta)\right)^2} \sin^2\left(\dfrac{\varphi_a + \varphi_b}{2} - \alpha\right)\right]}$$

where $\rho_a^- = |\rho_a^-| \exp(\mathrm{i}\,\varphi_a)$ and $\rho_b^+ = |\rho_b^+| \exp(\mathrm{i}\,\varphi_b)$

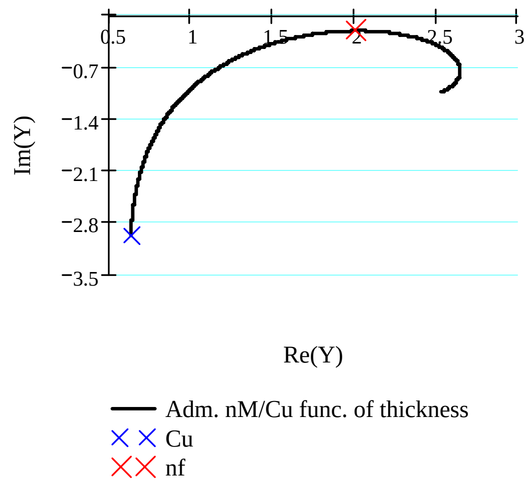
Particular case: $\rho_b^+ = 0 \quad \Rightarrow \quad R = R_a^+ \left(\forall\, t_f\right)$

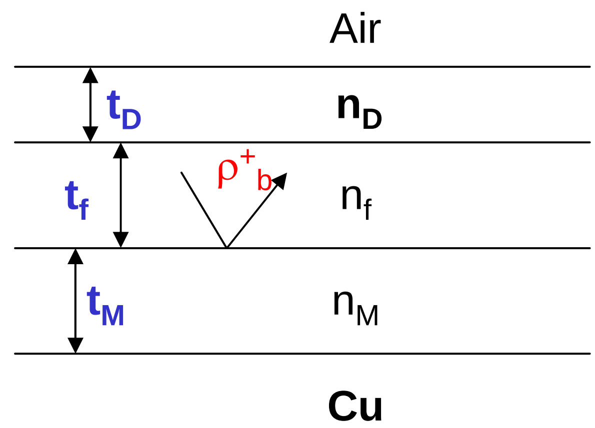
$\lambda \equiv \lambda_0 = 550\ \text{nm}$

1. Admittance matching between n_M-n_f

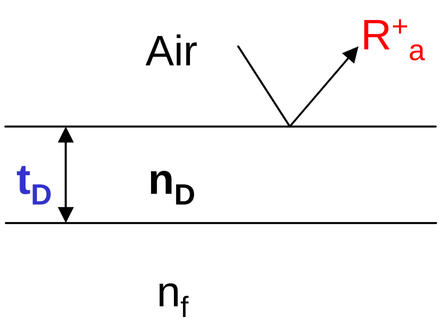
$$\rho_b^+ = \frac{n_f - Y_{n_M/Cu}}{n_f + Y_{n_M/Cu}}$$

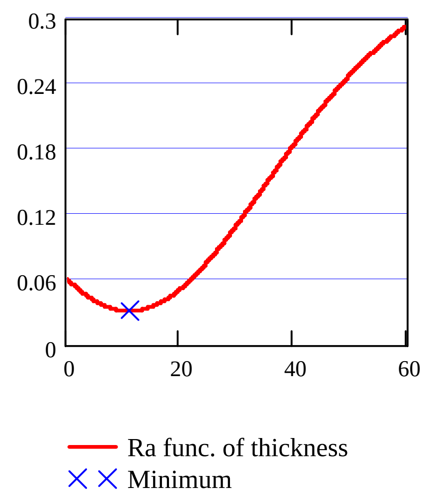
$$\rho_b^+ = 0 \rightarrow n_f \equiv Y_{n_M/Cu}$$

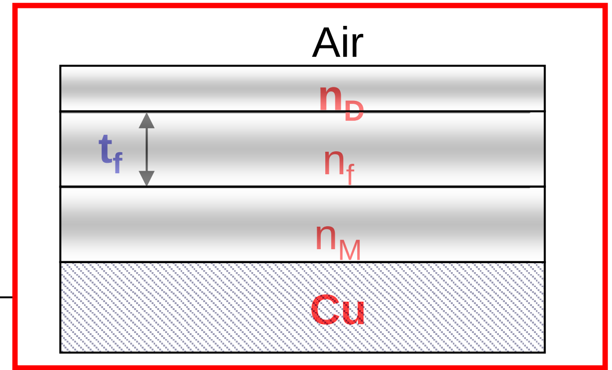




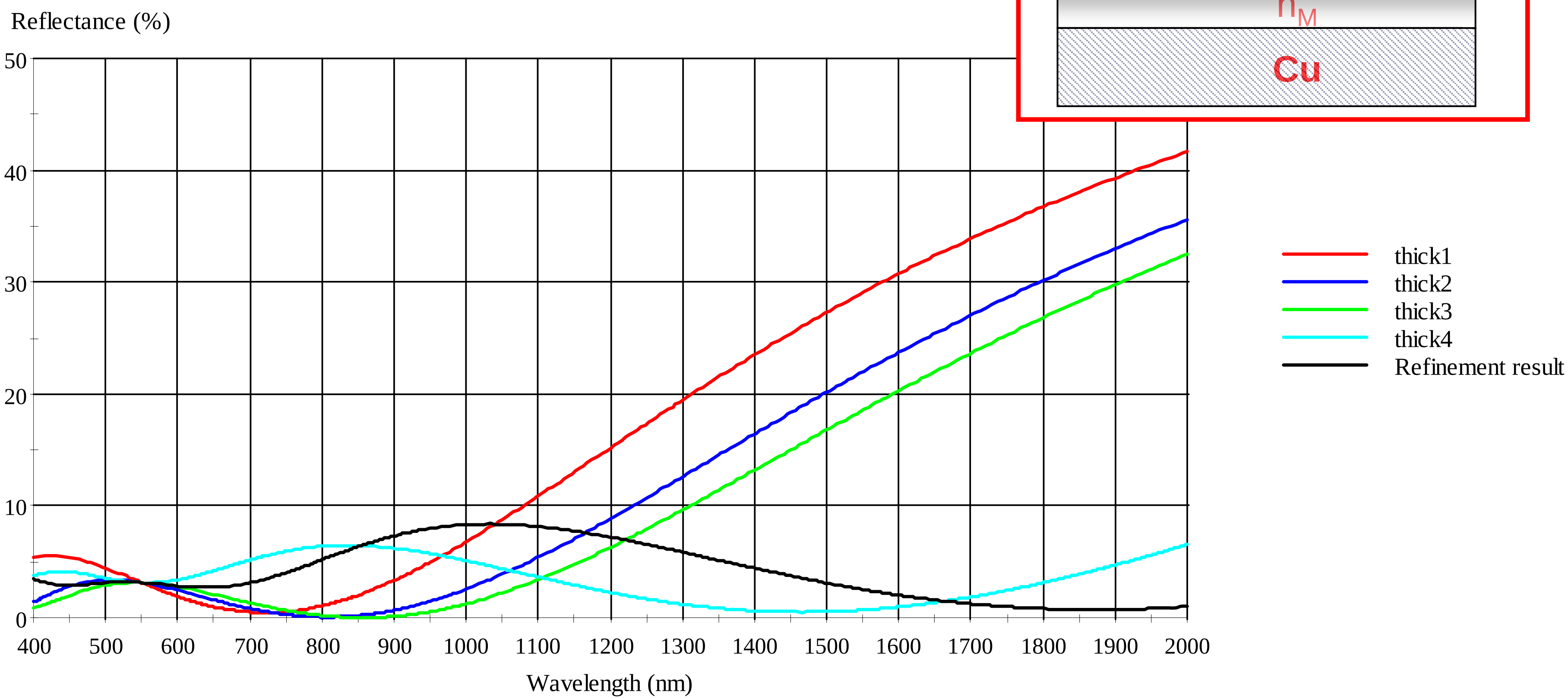
2. Minimize the reflection







3 layer solar absorber Reflectance, different nf thickness
+ Refinement result spectral curve



Could we have $R = 0$ **?**

$\lambda \equiv \lambda_0 = 550\ \text{nm}$

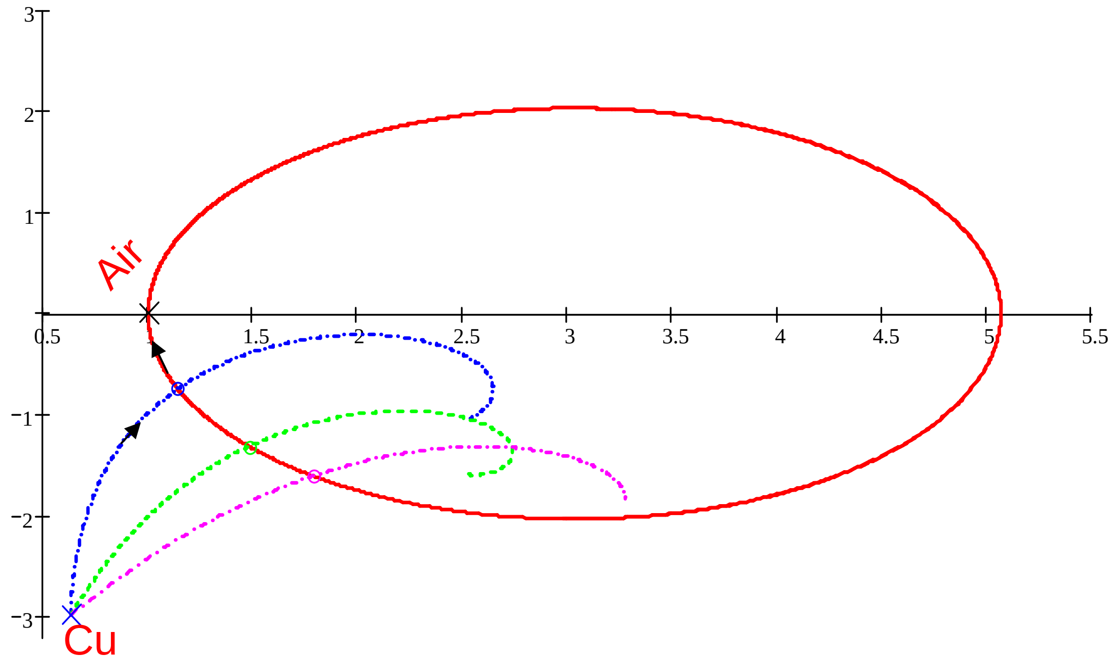
Input: substrate Cu and the top dielectric (anti-reflection) layer optical indexes

1. Calculating the (optical) admittance of n_D *thin film on Air* function of the layer thickness t_D

2. Calculating the admittance of n_M *thin film/Cu* function of the layer thickness t_M

3. The intersection gives the indexes n_f also the thicknesses of the two surrounded layers.

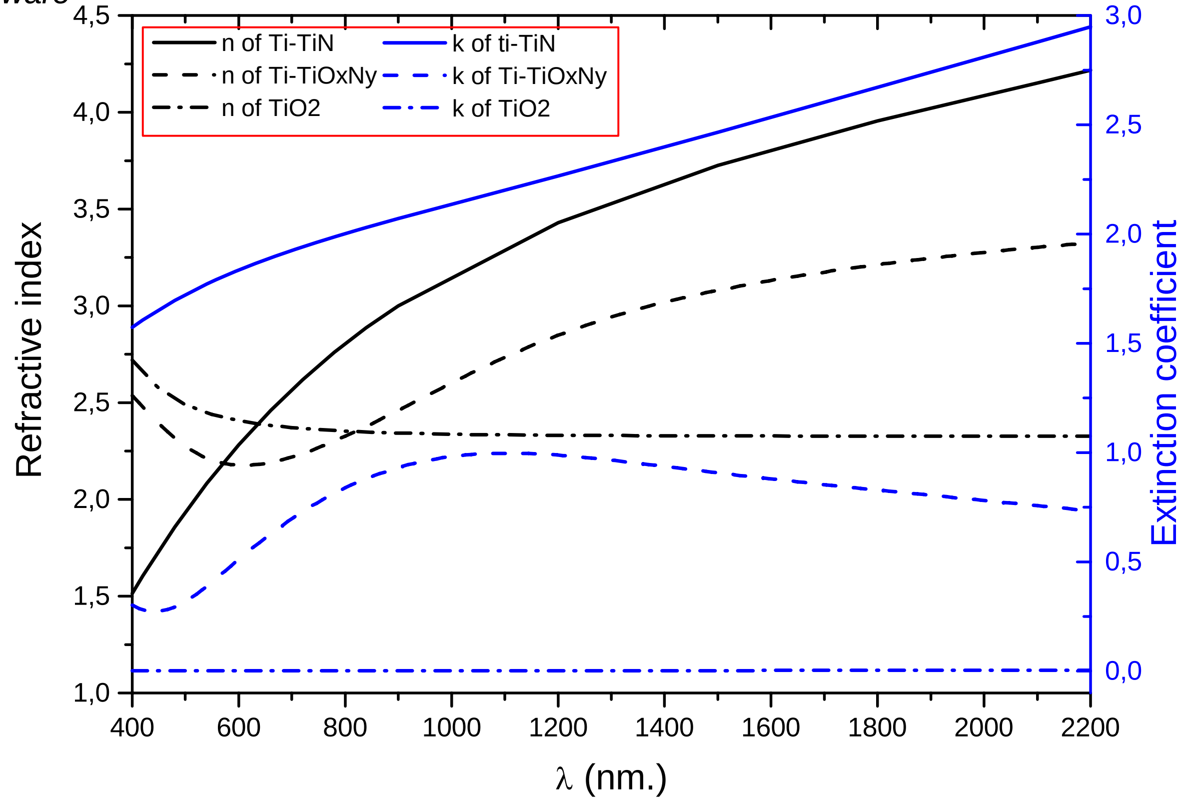
4. The admittance of the n_f layer is a single (intersection) point.



Materials database:

The refractive index n and the extinction coefficient k of individual (cermet) layer of the solar absorber were extracted from the spectral R% and T% data in the wavelength range of 380-2200 nm. The optical indexes spectral dependence follows a model that combine combination of terms representing both metallic (Drude Model) and dielectric properties (Lorentzian model). The thickness of the layer (AFM step measurement) is an additional input parameter.

"METAL n AND k script, Essential Macleod software"



Optical constants for composite (Effective Medium Theory):

The optical indexes of an inhomogeneous composite medium, consisting of small metallic particles embedded in a dielectric matrix, can be derived from optical indexes of the homogeneous constituents.

We are using here the Bruggeman model (a randomly intermixed particles of dielectric and metal *aggregate structure*) to carry out these indexes calculation.

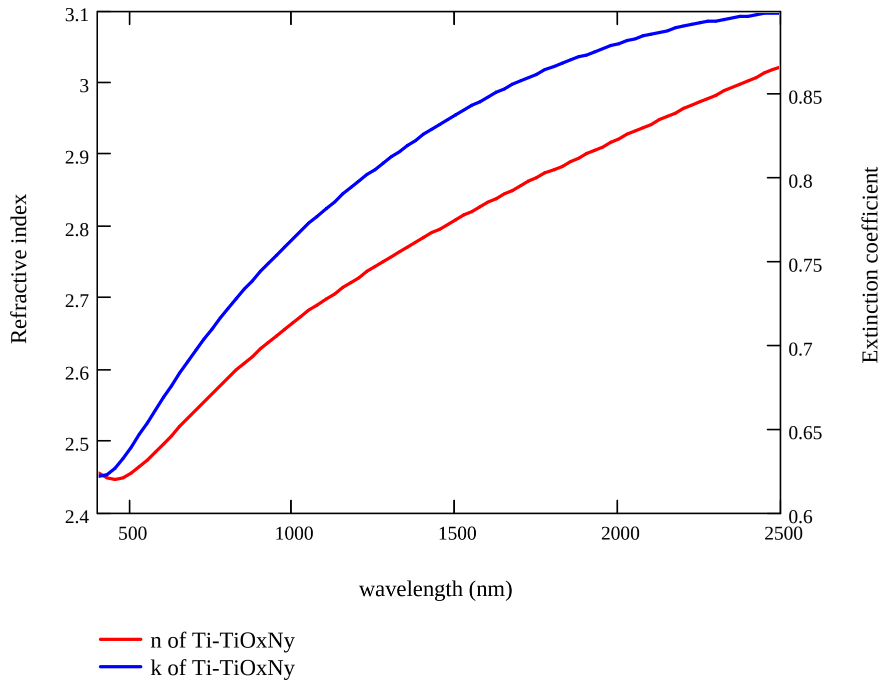
$$f_M \frac{\varepsilon_M - \varepsilon_{BR}}{\varepsilon_M + 2\varepsilon_{BR}} + (1 - f_M)\frac{\varepsilon_D - \varepsilon_{BR}}{\varepsilon_D + 2\varepsilon_{BR}} = 0$$

where

f_M is the volume fraction of metallic component

ε is dielectric function of

M metal, ***D*** dielectric and ***BR*** (Bruggeman) metallic-dielectric composite.



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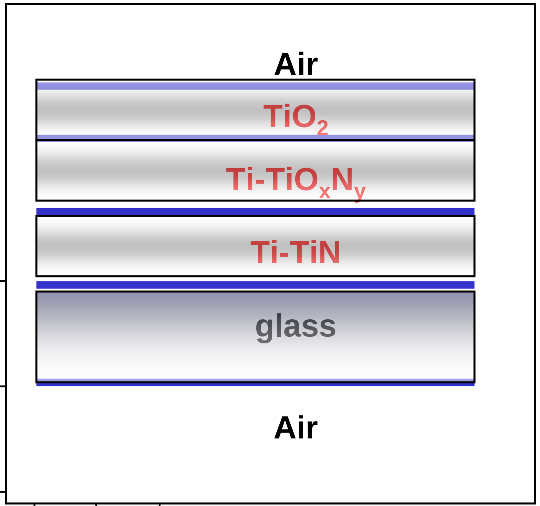
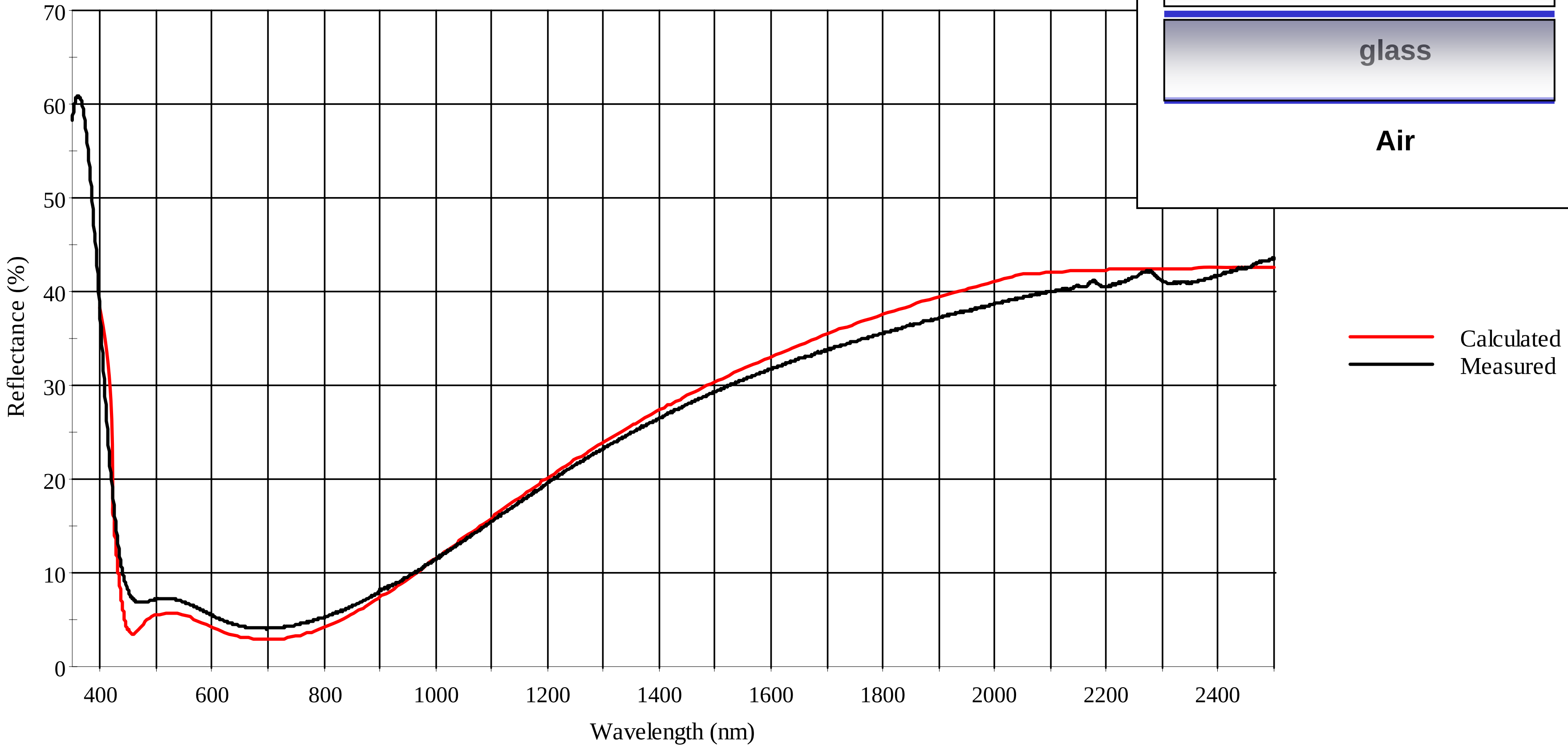
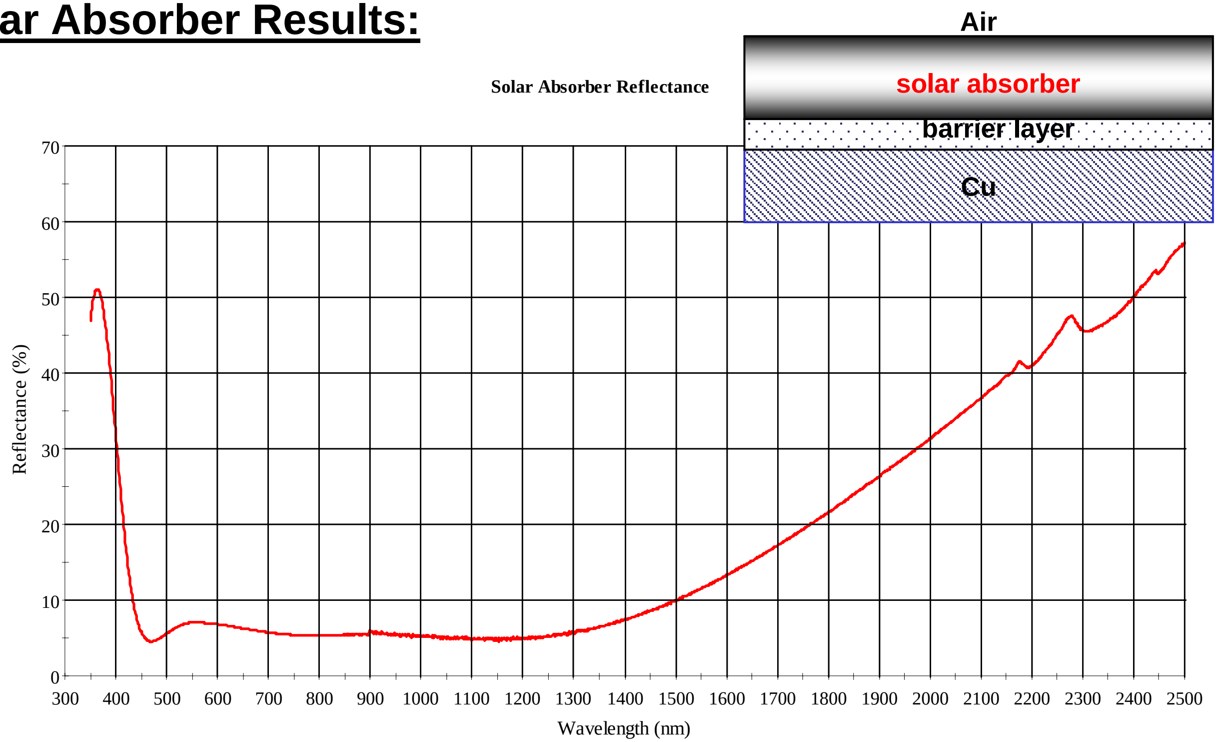




Solar Absorber Results:



α_{sol} = 91%

ε_t = 6 - 7 %

Still to do (challenges) :

Service lifetime of absorber coating during at least 25 years with the performance criterion:

$$-\Delta\alpha_{sol} + 0.25\Delta\varepsilon_t \leq 5\%$$

Accelerated aging tests & Thermal stability : 250° C during 200 hours (we aren't there yet)

References:

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