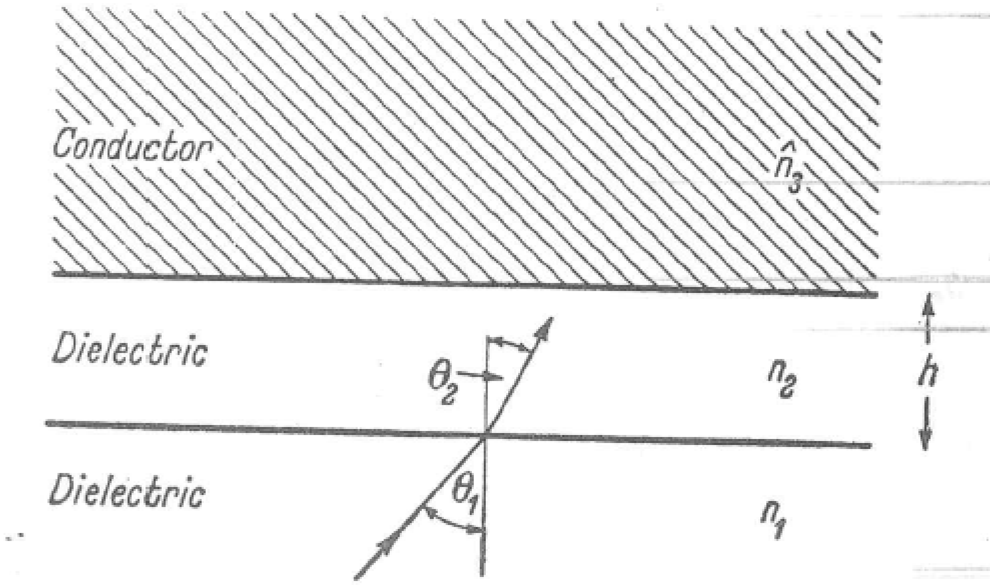
Fresnel Analysis of AR Coating on Stainless Steel
7/23/13



Useful index of refraction data can be found at RefractiveIndex.INFO

vacuum wavelength, m $\quad \lambda_0 := 1.064 \cdot 10^{-6}$

photon energy, eV $\quad E_{ev} := \frac{6.63 \cdot 10^{-34} \cdot 3 \cdot 10^{8}}{1.602 \cdot 10^{-19}} \cdot \frac{1}{\lambda_0}$

$E_{ev} = 1.167$

index of vacuum $\quad n_1 := 1$

index of SS substrate $\quad n_{ss} := 2.5 + 4.1i$

$n_3 := n_{ss}$

index of DLC AR coating $\quad n_{dlc} := 2.4 + 0.04i$

index of AR coating $n_2 := n_{dlc}$

power absorption coefficient, m^-1 $\alpha(n_2) := \frac{4\cdot\pi}{\lambda_0}\cdot\left|\mathrm{Im}(n_2)\right|$

relative index of AR coating, external $n_{2R}(n_2) := \frac{n_2}{n_1}$

relative index of SS substrate $n_{3R}(n_2, n_3) := \frac{n_3}{n_2}$

Si absorption coefficient, m^-1 $\alpha_{si} := 1000$

imaginary index of refraction
(extinction coeff.) $n_{Isi} := \alpha_{si}\cdot\frac{\lambda_0}{4\cdot\pi}$

$n_{Isi} = 8.467 \times 10^{-5}$

index of Si AR coating $n_{si} := 3.45 + i n_{Isi}$

$n_{si} = 3.45 + 8.467i \times 10^{-5}$

rel index of Si AR coating $n_{Rsi} := \frac{n_{si}}{n_1}$

index of InSb AR coating $n_{insb} := 4.2 + 0.325i$

index of AlInP AR coating $n_{alinp} := 2.7 + 0.073i$

index of CdZnTe AR coating $n_{cdznte} := 2.8 + 0.031i$

incidence angle, rad $\theta_1 := 57\cdot\frac{\pi}{180}$

incidence angle, deg $\theta_{1deg}(\theta_1) := \theta_1\cdot\frac{180}{\pi}$

angle inside AR coating, rad

$$\theta_2(\theta_1, n_1, n_2) := \operatorname{asin}\left(\frac{n_1}{n_2}\cdot\sin(\theta_1)\right)$$

$$\theta_2(\theta_1, n_1, n_2) = 0.357 - 6.214i \times 10^{-3}$$

angle inside SS, rad

$$\theta_3(\theta_1, n_1, n_2, n_3) := \operatorname{asin}\left(\frac{n_2}{n_3}\cdot\sin(\theta_2(\theta_1, n_1, n_2))\right)$$

$$\theta_3(\theta_1, n_1, n_2, n_3) = 0.09 - 0.149i$$

Reflectivity, P Polarization (TM field)

external reflection coefficient for surface 1-2

input angle, rad $\theta_1 := 0.995$

$$\theta_{1deg}(0.995) = 57.009$$

Takahashi formula

$$r_{1Tp}(\theta_1, n_1, n_2) := \frac{n_1\cdot\cos(\theta_2(\theta_1, n_1, n_2)) - n_2\cdot\cos(\theta_1)}{n_1\cdot\cos(\theta_2(\theta_1, n_1, n_2)) + n_2\cdot\cos(\theta_1)}$$

$$r_{1Tp}(\theta_1, n_1, n_2) = -0.165 - 6.979i \times 10^{-3}$$

Pedrotti complex formula

$$r_{1Pp}(\theta_1, n_1) := \frac{n_{2R}(n_2)^2\cdot\cos(\theta_1) - \sqrt{n_{2R}(n_2)^2 - \sin(\theta_1)^2}}{n_{2R}(n_2)^2\cdot\cos(\theta_1) + \sqrt{n_{2R}(n_2)^2 - \sin(\theta_1)^2}}$$

$$r_{1Pp}(\theta_1, n_2) = 0.165 + 6.979i \times 10^{-3}$$

Reflectance from uncoated SS surface

Takahashi formula

$$r_{1Tp}(\theta_1, n_1, n_{ss}) := \frac{n_1 \cdot \cos(\theta_2(\theta_1, n_1, n_{ss})) - n_{ss} \cdot \cos(\theta_1)}{n_1 \cdot \cos(\theta_2(\theta_1, n_1, n_{ss})) + n_{ss} \cdot \cos(\theta_1)}$$

$$r_{1Tp}(\theta_1, n_1, n_{ss}) = -0.547 - 0.419i$$

$$R_{ssTp}(\theta_1, n_1, n_{ss}) := \left| r_{1Tp}(\theta_1, n_1, n_{ss})^2 \right|$$

$$R_{ssTp}(\theta_1, n_1, n_{ss}) = 0.474$$

Pedrotti formula

external reflection coefficient for surface 1

$$r_{1Pp}(\theta_1, n_{ss}) := \frac{n_{2R}(n_{ss})^2 \cdot \cos(\theta_1) - \sqrt{n_{2R}(n_{ss})^2 - \sin(\theta_1)^2}}{n_{2R}(n_{ss})^2 \cdot \cos(\theta_1) + \sqrt{n_{2R}(n_{ss})^2 - \sin(\theta_1)^2}}$$

$$r_{1Pp}(\theta_1, n_2) = 0.165 + 6.979i \times 10^{-3}$$

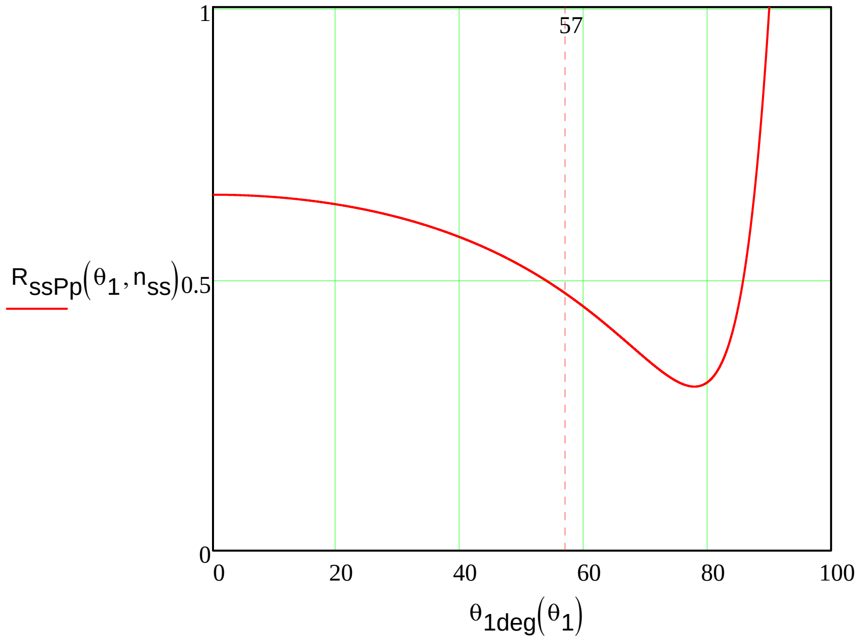
Reflectance from uncoated SS surface

$$R_{ssPp}(\theta_1, n_{ss}) := \left| r_{1Pp}(\theta_1, n_{ss})^2 \right|$$

$$R_{ssPp}(\theta_1, n_{ss}) = 0.474$$

$$\theta_{1deg}(\theta_1) := \theta_1 \cdot \frac{180}{\pi}$$

$$\theta_1 := 0, 0.0001 .. 1.571$$



$\theta_1 := .7$

Takahashi Results with DLC film

P-polarization

AR film thickness, m $\qquad h := 1.016 \times 10^{-6}$

Note: Takahashi uses the negative index convention

$$\overline{n_2} = 2.4 - 0.04i$$

$$\overline{n_3} = 2.5 - 4.1i$$

external reflection coefficient for surface 1-2

Takahashi formula

$$\theta_2(\theta_1, n_1, n_2) := \mathrm{asin}\left(\frac{n_1}{n_2}\cdot\sin(\theta_1)\right)$$

$$r_{1Tp}(\theta_1, n_1, n_2) := \frac{n_1\cdot\cos(\theta_2(\theta_1, n_1, n_2)) - n_2\cdot\cos(\theta_1)}{n_1\cdot\cos(\theta_2(\theta_1, n_1, n_2)) + n_2\cdot\cos(\theta_1)}$$

$$r_{1Tp}(\theta_1, n_1, n_2) = -0.312 - 6.939i \times 10^{-3}$$

Pedrotti complex formula

$$r_{1Pp}(\theta_1, n_2) := \frac{n_2{}^2\cdot\cos(\theta_1) - \sqrt{n_2{}^2 - \sin(\theta_1)^2}}{n_2{}^2\cdot\cos(\theta_1) + \sqrt{n_2{}^2 - \sin(\theta_1)^2}}$$

$$r_{1Pp}(\theta_1, n_2) = 0.312 + 6.939i \times 10^{-3}$$

reflection coefficient for surface 2

$$r_{2Tp}(\theta_1, n_1, n_2, n_3) := \frac{n_2\cdot\cos(\theta_3(\theta_1, n_1, n_2, n_3)) - n_3\cdot\cos(\theta_2(\theta_1, n_1, n_2))}{n_2\cdot\cos(\theta_3(\theta_1, n_1, n_2, n_3)) + n_3\cdot\cos(\theta_2(\theta_1, n_1, n_2))}$$

$$r_{2Tp}(\theta_1, n_1, n_2, n_3) = -0.397 - 0.478i$$

additional round trip phase shift between first surface reflection and internally reflected beam, rad

$$n_2 = 2.4 + 0.04i$$

$$\delta_T(\theta_1, n_1, n_2, h) := \frac{2\cdot 2\cdot\pi}{\lambda_0}\cdot n_2\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h$$

$$\delta_T(\theta_1, n_1, n_2, h) = 27.742 + 0.498i$$

$$e^{-i\cdot\delta_T(\theta_1, n_1, n_2, h)} = -1.418 - 0.835i$$

$$r_{1Tpeff}(\theta_1, n_1, n_2, n_3, h) := \frac{r_{1Tp}(\theta_1, n_1, n_2) + r_{2Tp}(\theta_1, n_1, n_2, n_3)\cdot e^{-i\cdot\delta_T(\theta_1, n_1, n_2, h)}}{1 + r_{1Tp}(\theta_1, n_1, n_2)\cdot r_{2Tp}(\theta_1, n_1, n_2, n_3)\cdot e^{-i\cdot\delta_T(\theta_1, n_1, n_2, h)}}$$

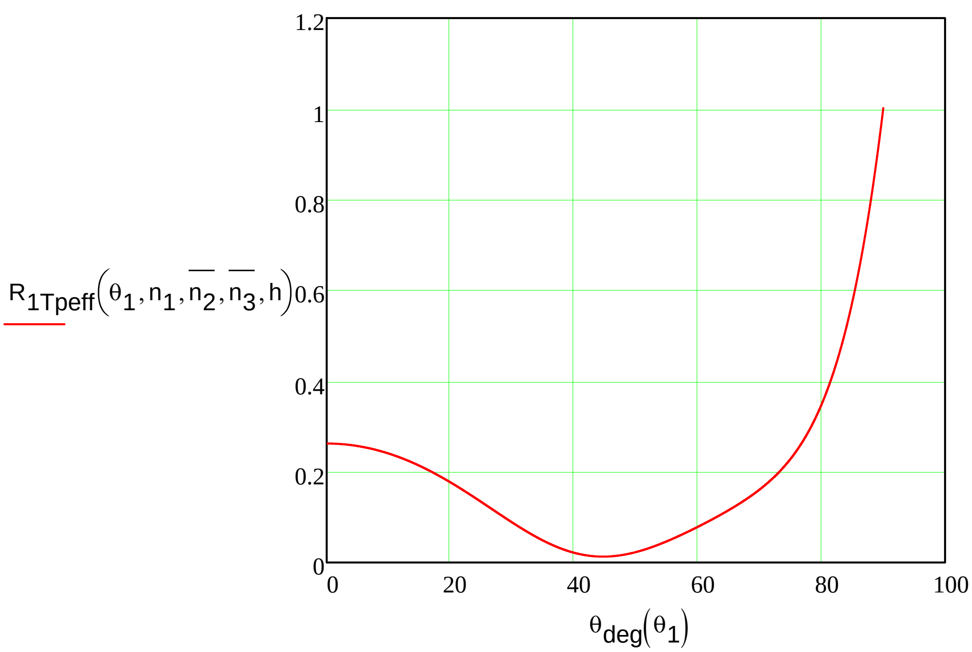
$$r_{1Tpeff}(\theta_1, n_1, n_2, n_3, h) = -0.452 + 0.9i$$

$$R_{1Tpeff}(\theta_1, n_1, n_2, n_3, h) := \left| r_{1Tpeff}(\theta_1, n_1, n_2, n_3, h)^2 \right|$$

$$R_{1Tpeff}(\theta_1, n_1, \overline{n_2}, \overline{n_3}, h) = 0.021$$

$$\theta_1 := 0, 0.0001 .. 1.571$$

$$\theta_{deg}(\theta_1) := \theta_1 \cdot \frac{180}{\pi}$$



$$\theta_1 := .7$$

Check Pedrotti equations, p-pol

Note: Pedrotti uses relative index

Pedrotti complex formula

reflection coefficient for surface 1

$$r_{1Pp}(\theta_1, n_2) := \frac{n_{2R}(n_2)^2 \cdot \cos(\theta_1) - \sqrt{n_{2R}(n_2)^2 - \sin(\theta_1)^2}}{n_{2R}(n_2)^2 \cdot \cos(\theta_1) + \sqrt{n_{2R}(n_2)^2 - \sin(\theta_1)^2}}$$

$$r_{1Pp}(\theta_1, n_2) = 0.312 + 6.939i \times 10^{-3}$$

compare with Takahashi

$$r_{1Tp}(\theta_1, n_1, \overline{n_2}) = -0.312 + 6.939i \times 10^{-3}$$

reflection coefficient for surface 2

$$r_{2Pp}(\theta_1, n_1, n_2, n_3) := \frac{n_{3R}(n_2, n_3)^2 \cdot \cos(\theta_2(\theta_1, n_1, n_2)) - \sqrt{n_{3R}(n_2, n_3)^2 - \sin(\theta_2(\theta_1, n_1, n_2))^2}}{n_{3R}(n_2, n_3)^2 \cdot \cos(\theta_2(\theta_1, n_1, n_2)) + \sqrt{n_{3R}(n_2, n_3)^2 - \sin(\theta_2(\theta_1, n_1, n_2))^2}}$$

$$r_{2Pp}(\theta_1, n_1, n_2, n_3) = 0.397 + 0.478i$$

compare with Takahashi

$$r_{2Tp}(\theta_1, n_1, \overline{n_2}, \overline{n_3}) = -0.397 + 0.478i$$

additional round trip phase difference between first surface reflection and internally reflected beam, rad

use complex index of refraction

$$\delta_P(\theta_1, n_1, n_2, h) := \frac{4\cdot\pi}{\lambda_0}\cdot \mathrm{Re}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h + \frac{i\cdot 4\cdot\pi}{\lambda_0}\cdot \mathrm{Im}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h$$

$$\delta_P(\theta_1, n_1, n_2, h) = 27.742 + 0.498i$$

introduce the power absorption coefficient

$$\alpha(n_2) := \frac{4\cdot\pi}{\lambda_0}\cdot\left|\mathrm{Im}(n_2)\right|$$

$$\delta_P(\theta_1, n_1, n_2, h) := \frac{4\cdot\pi}{\lambda_0}\cdot \mathrm{Re}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h + i\cdot\alpha(n_2)\cdot(\cos(\theta_2(\theta_1, n_1, n_2))\cdot h)$$

$$\delta_P(\theta_1, n_1, n_2, h) = 27.742 + 0.498i$$

$$e^{i\cdot\frac{4\cdot\pi}{\lambda_0}\cdot \mathrm{Re}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h}\cdot e^{-\alpha(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h} = -0.524 + 0.308i$$

compare with Takahashi

$$\delta_T(\theta_1, n_1, \overline{n_2}, h) = 27.742 - 0.498i$$

$$e^{-i\cdot\delta_T(\theta_1, n_1, \overline{n_2}, h)} = -0.524 - 0.308i$$

effective reflection coefficient for surface 1 with infinite sum of multiple internal reflections

$$r_{1Ppeff}(\theta_1, n_1, n_2, n_3, h) := \frac{r_{1Pp}(\theta_1, n_2) + r_{2Pp}(\theta_1, n_1, n_2, n_3)\cdot e^{i\cdot\frac{4\cdot\pi}{\lambda_0}\cdot \mathrm{Re}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))}}{1 + r_{1Pp}(\theta_1, n_2)\cdot r_{2Pp}(\theta_1, n_1, n_2, n_3)\cdot e^{i\cdot\frac{4\cdot\pi}{\lambda_0}\cdot \mathrm{Re}(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2)}}$$

$$r_{1Ppeff}(\theta_1, n_1, n_2, n_3, h) = -0.042 - 0.138i$$

effective reflectance of AR coated SS

$$R_{1Ppeff}(\theta_1, n_1, n_2, n_3, h) := \left|\left(r_{1Ppeff}(\theta_1, n_1, n_2, n_3, h)\right)^2\right|$$

$$R_{1Ppeff}(\theta_1, n_1, n_2, n_3, h) = 0.021$$

compare with Takahashi

$$R_{1Tpeff}(\theta_1, n_1, \overline{n_2}, \overline{n_3}, h) = 0.021$$

Takahashi DLC sample measured by Smith & fit to theoretical curve

Reflectivity of DLC Coating on SS, P-pol

$$R_{dlc} := \begin{pmatrix} 5\cdot\frac{\pi}{180} & 0.0048 & R_{1Ppeff}\left(5\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 10\cdot\frac{\pi}{180} & 0.0053 & R_{1Ppeff}\left(10\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 15\cdot\frac{\pi}{180} & 0.008 & R_{1Ppeff}\left(15\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 20\cdot\frac{\pi}{180} & .0127 & R_{1Ppeff}\left(20\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 30\cdot\frac{\pi}{180} & 0.037 & R_{1Ppeff}\left(30\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 40\cdot\frac{\pi}{180} & 0.066 & R_{1Ppeff}\left(40\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 50\cdot\frac{\pi}{180} & 0.11 & R_{1Ppeff}\left(50\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 57\cdot\frac{\pi}{180} & 0.11 & R_{1Ppeff}\left(57\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 60\cdot\frac{\pi}{180} & 0.13 & R_{1Ppeff}\left(60\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 70\cdot\frac{\pi}{180} & 0.16 & R_{1Ppeff}\left(70\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \\ 80\cdot\frac{\pi}{180} & 0.31 & R_{1Ppeff}\left(80\cdot\frac{\pi}{180}, n_1, n_2, n_3, h\right) \end{pmatrix}$$

least squares fit of thickness

$j := 0$

measured reflectivity $R_{dlc_{j,1}} = 4.8 \times 10^{-3}$

incident angle, deg $\theta_j := R_{dlc_{j,0}}$

theoretical reflectivity $R_{dlctheo}(n_1, n_2, n_3, h) := R_{1Ppeff}(\theta_j, n_1, n_2, n_3, h)$

$R_{dlctheo}(n_1, n_2, n_3, h) = 0.256$

Reflectivity error $\Delta_j(n_1, n_2, n_3, h) := R_{dlc_{j,1}} - R_{dlctheo}(n_1, n_2, n_3, h)$

$\Delta_j(n_1, n_2, n_3, h) = -0.252$

First Iteration $h := 0.99 \cdot 10^{-6}$

Second Iteration $h := 9.739 \times 10^{-7}$

$j := 0, 1 .. 10$

$$\sum_j \Delta_j(n_1, n_2, n_3, h)^2 = 2.918 \times 10^{-9}$$

$$\sqrt{\sum_j \Delta_j(n_1, n_2, n_3, h)^2} = 5.402 \times 10^{-5}$$

least squares analysis

Given

$n_1 = 1$

$n_2 = 2.4 + 0.04i$

$n_3 = 2.5 + 4.1i$

$$\sqrt{\sum_j \Delta_j(n_1, n_2, n_3, h)^2} = 0$$

Results

$$\begin{pmatrix} n_{1eval} \\ n_{2eval} \\ n_{3eval} \\ h_{evalcpx} \end{pmatrix} := \mathrm{Find}(n_1, n_2, n_3, h)$$

$n_{1eval} = 1$

$n_{2eval} = 2.4 + 0.04i$

$n_{3eval} = 2.5 + 4.1i$

$h_{evalcpx} = 9.73892 \times 10^{-7} - 7.93593i \times 10^{-12}$

$h_{eval} := \mathrm{Re}(h_{evalcpx})$

$h_{eval} = 9.739 \times 10^{-7}$

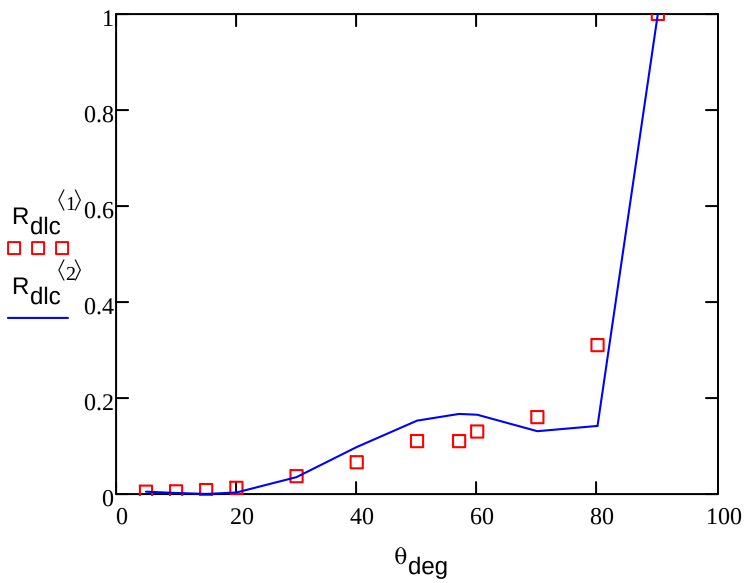
$$\sqrt{\sum_j \Delta_j(n_{1eval}, n_{2eval}, n_{3eval}, h_{eval})^2} = 3.826 \times 10^{-6}$$

Plot the results

$$R_{dlc} := \begin{pmatrix} 5\cdot\frac{\pi}{180} & 0.0048 & R_{1Ppeff}\left(5\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(5\cdot\frac{\pi}{180}, n_{1eva} \right. \\ 10\cdot\frac{\pi}{180} & 0.0053 & R_{1Ppeff}\left(10\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(10\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 15\cdot\frac{\pi}{180} & 0.008 & R_{1Ppeff}\left(15\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(15\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 20\cdot\frac{\pi}{180} & .0127 & R_{1Ppeff}\left(20\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(20\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 30\cdot\frac{\pi}{180} & 0.037 & R_{1Ppeff}\left(30\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(30\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 40\cdot\frac{\pi}{180} & 0.066 & R_{1Ppeff}\left(40\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(40\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 50\cdot\frac{\pi}{180} & 0.11 & R_{1Ppeff}\left(50\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(50\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 57\cdot\frac{\pi}{180} & 0.11 & R_{1Ppeff}\left(57\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(57\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 60\cdot\frac{\pi}{180} & 0.13 & R_{1Ppeff}\left(60\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(60\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 70\cdot\frac{\pi}{180} & 0.16 & R_{1Ppeff}\left(70\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(70\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 80\cdot\frac{\pi}{180} & 0.31 & R_{1Ppeff}\left(80\cdot\frac{\pi}{180}, n_{1eval}, n_{2eval}, n_{3eval}, h_{eval}\right) & R_{1Ppeff}\left(80\cdot\frac{\pi}{180}, n_{1ev} \right. \\ 90\cdot\frac{\pi}{180} & 1 & 1 & \end{pmatrix}$$

$$\theta_{deg} := R_{dlc}^{\langle 0 \rangle}\cdot\frac{180}{\pi}$$

$$h_{eval} = 9.739 \times 10^{-7}$$



DLC design thickness for lowest reflectivity @ 57 deg

Takahashi

$$R_{1Tpeff}\left(\theta_1, n_1, \overline{n_{dlc}}, \overline{n_3}, h\right)$$

Pedrotti

$$\theta_1 := 57 \cdot \frac{\pi}{180} \qquad \theta_1 = 0.995$$

$$R_{1Ppeff}\left(\theta_1, n_1, n_{dlc}, n_3, 2.689 \cdot 10^{-6}\right) = 6.525 \times 10^{-5}$$

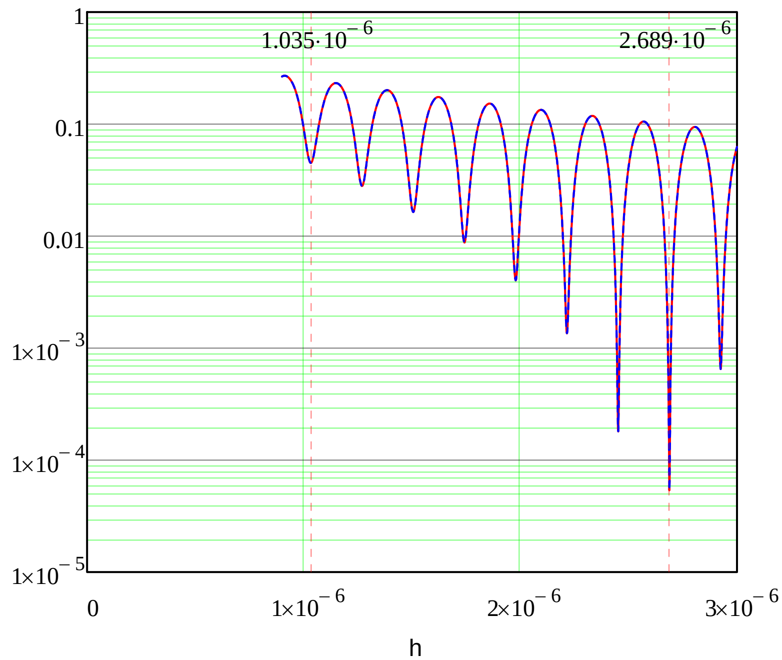
$$R_{1Ppeff}\left(\theta_1, n_1, n_{dlc}, n_3, 2.823 \cdot 10^{-6}\right) = 0.089$$

$$R_{1Ppeff}\left(\theta_1, n_1, n_{dlc}, n_3, 2.555 \cdot 10^{-6}\right) = 0.102$$

$$h := 9 \cdot 10^{-7}, 9.01 \cdot 10^{-7} .. 3 \cdot 10^{-6}$$

$R_{1Ppeff}(\theta_1, n_1, n_{dlc}, n_3, h)$

$R_{1Tpeff}(\theta_1, n_1, \overline{n_{dlc}}, \overline{n_3}, h)$

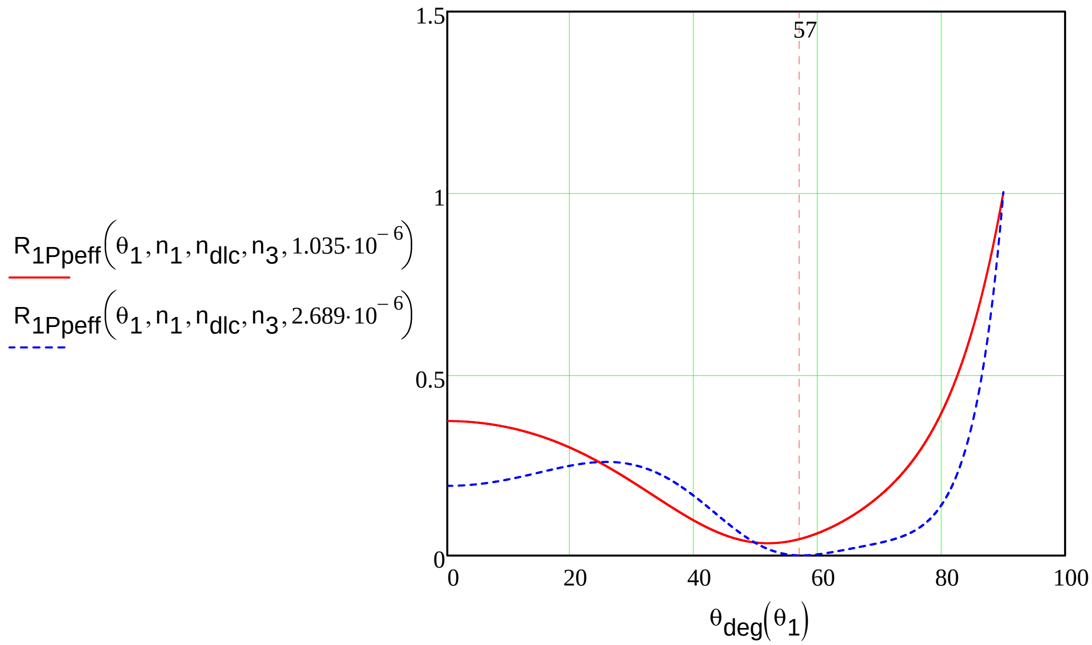


best-fit thickness, m

$h := 2.689 \cdot 10^{-6}$

$\theta_1 := 0, 0.0001 .. 1.571$

$\theta_{deg}(\theta_1) := \theta_1 \cdot \frac{180}{\pi}$



Silicon AR coating for lowest reflectivity @ 57 deg

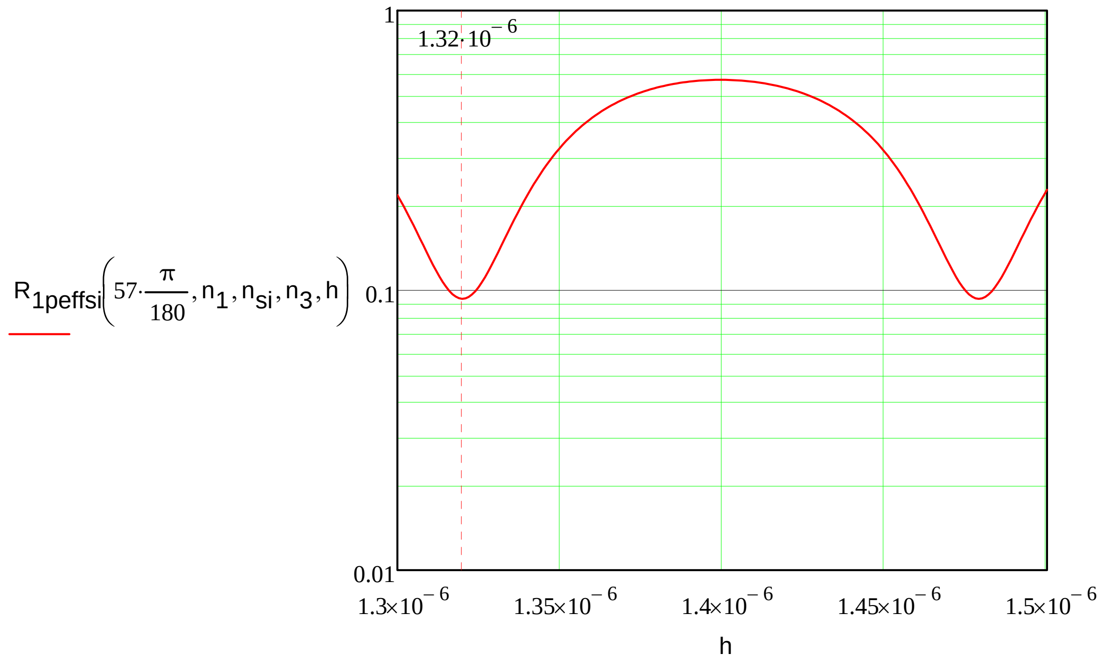
index of Si AR coating $n_{si} = 3.45 + 8.467i \times 10^{-5}$

incidence angle, rad $\theta_1 := 57 \cdot \frac{\pi}{180}$

reflectivity @ 57 deg incidence

$$R_{1peffsi}(\theta_1, n_1, n_{si}, n_3, h) := R_{1Ppeff}(\theta_1, n_1, n_{si}, n_3, h)$$

$h := 1.3 \cdot 10^{-6}, 1.301 \cdot 10^{-6} .. 1.5 \cdot 10^{-6}$



best-fit thickness, m $\quad h := 1.32\cdot10^{-6}$

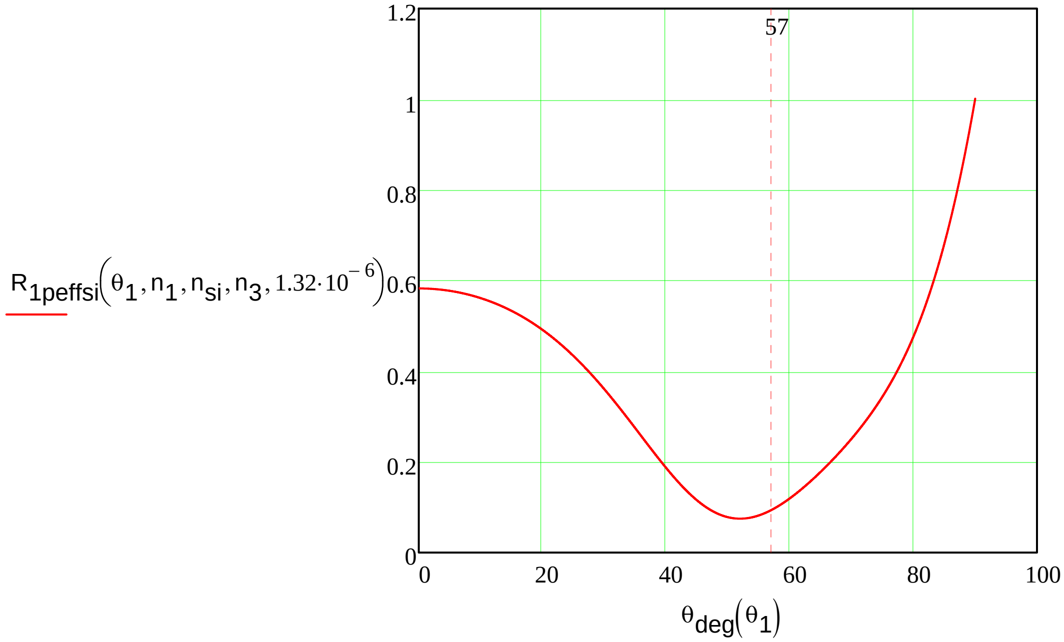
reflectivity @ 57 deg incidence $\quad R_{1peffsi}\left(57\cdot\frac{\pi}{180}, n_1, n_{si}, n_3, 1.386\cdot10^{-6}\right) = 0.548$

$$R_{1peffsi}\left(57\cdot\frac{\pi}{180}, n_1, n_{si}, n_3, 1.32\cdot10^{-6}\right) = 0.093$$

$$R_{1peffsi}\left(57\cdot\frac{\pi}{180}, n_1, n_{si}, n_3, 1.254\cdot10^{-6}\right) = 0.549$$

$$\theta_1 := 0, 0.0001 .. 1.571$$

$$\theta_{deg}(\theta_1) := \theta_1\cdot\frac{180}{\pi}$$



$$\theta_{deg}(\theta_1) := 57\cdot\frac{180}{\pi}$$

InSb AR coating for lowest reflectivity @ 57 deg

index of InSb $n_{insb} = 4.2 + 0.325i$

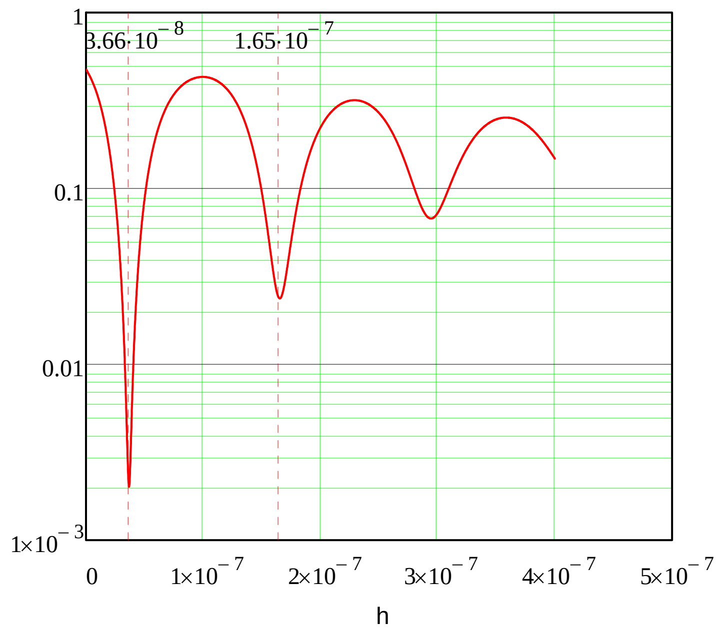
incidence angle, rad $\theta_1 := 57\cdot\frac{\pi}{180}$

reflectivity @ 57 deg incidence

$$R_{1peffinsb}\left(\theta_1, n_1, n_{insb}, n_3, h\right) := R_{1Ppeff}\left(\theta_1, n_1, n_{insb}, n_3, h\right)$$

$$h := 0, 0.001\cdot 10^{-7} .. 4\cdot 10^{-7}$$

$R_{1peffinsb}\left(57\cdot\frac{\pi}{180}, n_1, n_{insb}, n_3, h\right)$



best-fit thickness, m $h := 3.66\cdot10^{-8}$

reflectivity @ 57 deg incidence

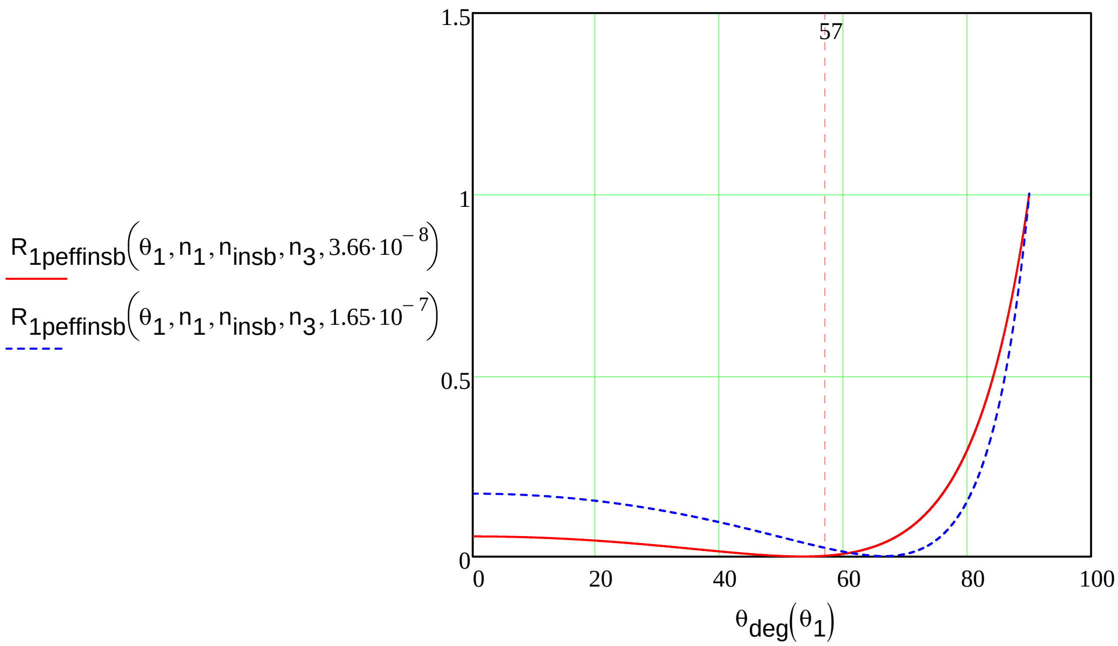
$$R_{1peffinsb}\left(57\cdot\frac{\pi}{180}, n_1, n_{insb}, n_3, 3.86\cdot10^{-8}\right) = 4.173\times10^{-3}$$

$$R_{1peffinsb}\left(57\cdot\frac{\pi}{180}, n_1, n_{insb}, n_3, 3.66\cdot10^{-8}\right) = 2.015\times10^{-3}$$

$$R_{1peffinsb}\left(57\cdot\frac{\pi}{180}, n_1, n_{insb}, n_3, 3.46\cdot10^{-8}\right) = 4.795\times10^{-3}$$

$\theta_1 := 0, 0.0001 .. 1.571$

$$\theta_{deg}(\theta_1) := \theta_1\cdot\frac{180}{\pi}$$



AlInP AR coating for lowest reflectivity @ 57 deg

index of AlInP $n_{alinp} = 2.7 + 0.073i$

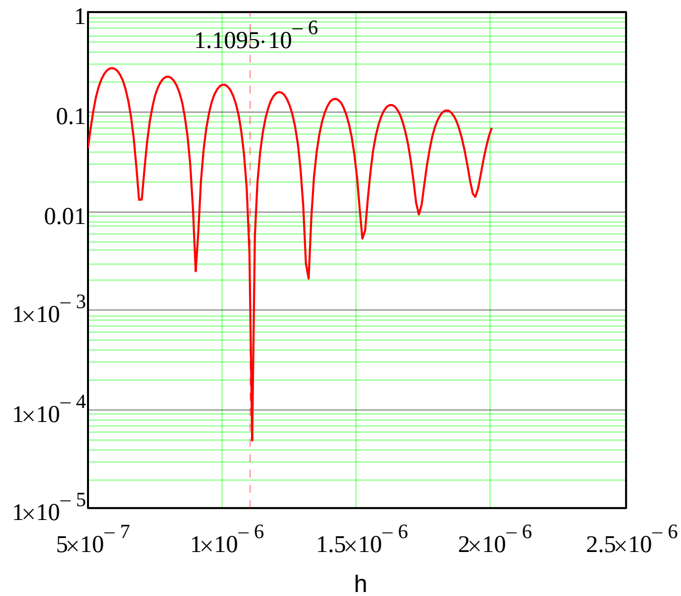
incidence angle, rad $\theta_1 := 57 \cdot \frac{\pi}{180}$

reflectivity @ 57 deg incidence

$$R_{1peffalinp}(\theta_1, n_1, n_{alinp}, n_3, h) := R_{1Ppeff}(\theta_1, n_1, n_{alinp}, n_3, h)$$

$$h := 0.5 \cdot 10^{-6}, 0.51 \cdot 10^{-6} .. 2 \cdot 10^{-6}$$

$R_{1peffalinp}\left(57\cdot\frac{\pi}{180}, n_1, n_{alinp}, n_3, h\right)$



best-fit thickness, m $h := 1.1095\cdot 10^{-6}$

reflectivity @ 57 deg incidence $R_{1peffalinp}\left(57\cdot\frac{\pi}{180}, n_1, n_{alinp}, n_3, 1.15\cdot 10^{-6}\right) = 0.062$

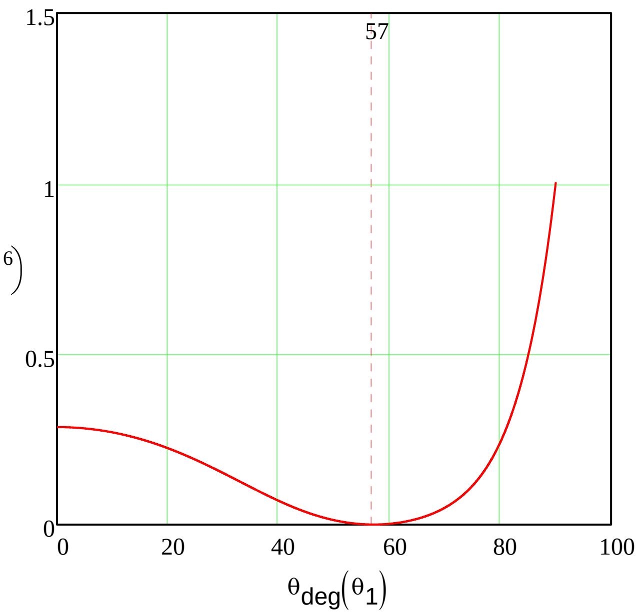
$R_{1peffalinp}\left(57\cdot\frac{\pi}{180}, n_1, n_{alinp}, n_3, 1.1095\cdot 10^{-6}\right) = 1.219\times 10^{-}$

$R_{1peffalinp}\left(57\cdot\frac{\pi}{180}, n_1, n_{alinp}, n_3, 1.06\cdot 10^{-6}\right) = 0.09$

$\theta_1 := 0, 0.0001 .. 1.571$

$\theta_{deg}(\theta_1) := \theta_1\cdot\frac{180}{\pi}$

$R_{1peffalinp}\left(\theta_1, n_1, n_{alinp}, n_3, 1.1095\cdot 10^{-6}\right)$



CdZnTe AR coating for lowest reflectivity @ 57 deg

index of CdZnTe $n_{cdznte} = 2.8 + 0.031i$

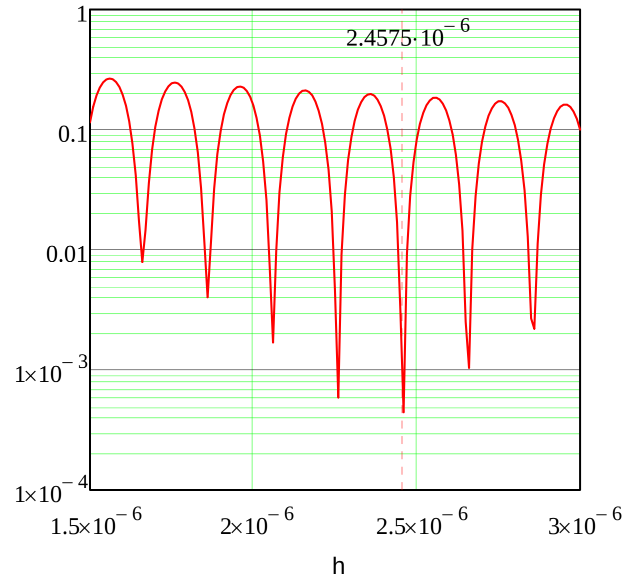
incidence angle, rad $\theta_1 := 57\cdot\frac{\pi}{180}$

reflectivity @ 57 deg incidence

$$R_{1peffcdznte}(\theta_1, n_1, n_{cdznte}, n_3, h) := R_{1Ppeff}(\theta_1, n_1, n_{cdznte}, n_3, h)$$

$$h := 1.5 \cdot 10^{-6}, 1.51 \cdot 10^{-6} .. 3 \cdot 10^{-6}$$

$$R_{1peffcdznte}\left(57 \cdot \frac{\pi}{180}, n_1, n_{cdznte}, n_3, h\right)$$



best-fit thickness, m $h := 2.1575 \cdot 10^{-6}$

reflectivity @ 57 deg incidence

$$R_{1peffcdznte}\left(57 \cdot \frac{\pi}{180}, n_1, n_{cdznte}, n_3, 2.55 \cdot 10^{-6}\right) = 0.183$$

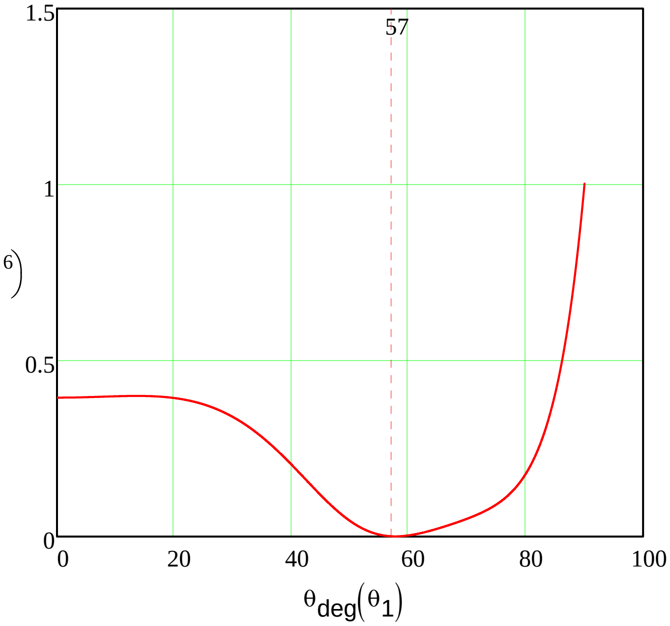
$$R_{1peffcdznte}\left(57 \cdot \frac{\pi}{180}, n_1, n_{cdznte}, n_3, 2.4575 \cdot 10^{-6}\right) = 3.594 \times 10^{-6}$$

$$R_{1peffcdznte}\left(57 \cdot \frac{\pi}{180}, n_1, n_{cdznte}, n_3, 2.3 \cdot 10^{-6}\right) = 0.087$$

$$\theta_1 := 0, 0.0001 .. 1.571$$

$$\theta_{deg}(\theta_1) := \theta_1 \cdot \frac{180}{\pi}$$

$$R_{1peffcdznte}\left(\theta_1, n_1, n_{cdznte}, n_3, 2.46 \cdot 10^{-6}\right)$$



$$\frac{\cdot h \; \cdot e^{-\alpha(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h}}{))\cdot h \; \cdot e^{-\alpha(n_2)\cdot\cos(\theta_2(\theta_1, n_1, n_2))\cdot h}}$$

$$
\left.\begin{array}{l}
\text{al}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
\text{val}, n_{2eval}, n_{3eval}, h_{eval}\Big) \\
1
\end{array}\right)
$$