Incoherent Propagation of Light in Coherent Models

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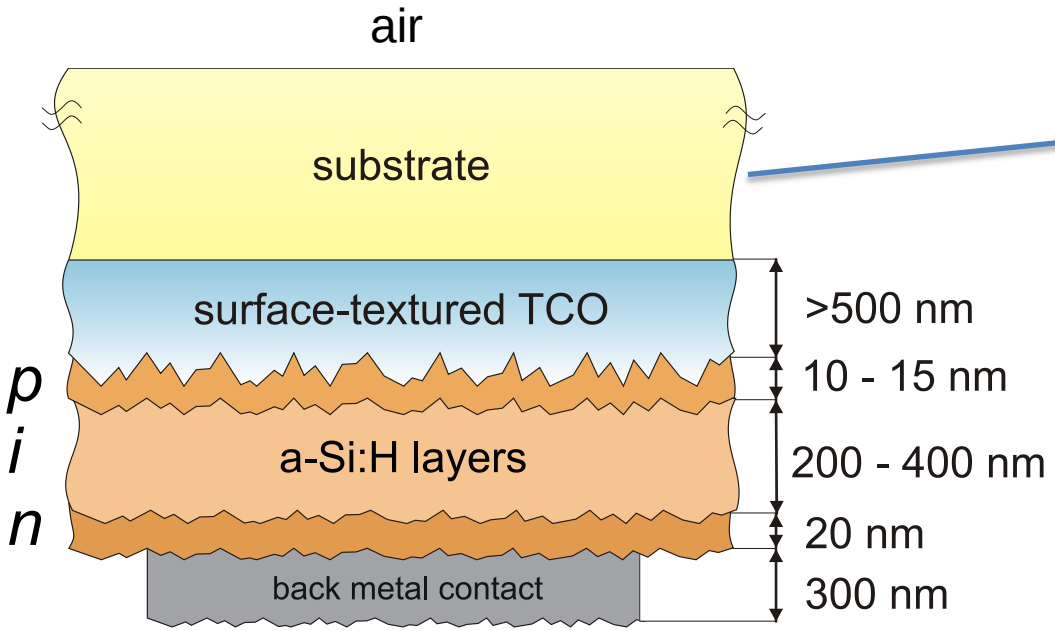
Outline

- Introduction
- Incoherent propagation of light
- Thinning down the incoherent layer
- Model
- Results
- Conclusions

Example of a-Si thin-film solar cell structure



1. Incoherent propagation of light
2. Thining down of thick glass layer
   - mm range to nm range!

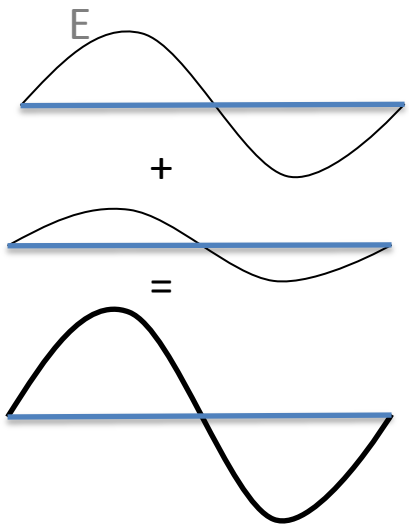
Incoherent propagation of light

In many optical cases light loses coherence:

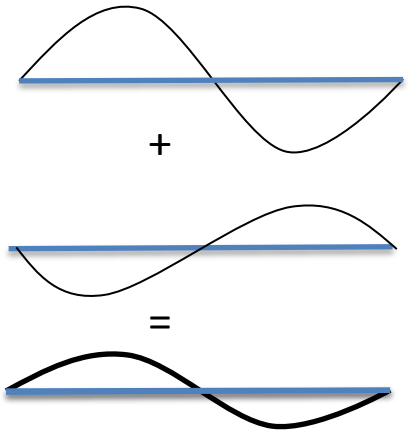
1. Spatial incoherence
2. Spectral incoherence
3. Temporal incoherence

→ Incoherent light does not interfere, we have to eliminate constructive and destructive interference in coherent models

Constructive interference



Destructive interference



Incoherent propagation of light

In rigorous simulations interference term of Poynting vector has to be eliminated

$$\mathbf{E}\mathbf{E}^* = (\mathbf{E}_0 e^{jk\mathbf{r}} + \mathbf{E}_1 e^{jk\mathbf{r} - jk2d - j\varphi}) \cdot (\mathbf{E}_0 e^{jk\mathbf{r}} + \mathbf{E}_1 e^{jk\mathbf{r} - jk2d - j\varphi})^*$$

$$= |\mathbf{E}_0^2| + |\mathbf{E}_1^2| e^{\mathrm{Re}[-jk]4d} + |\mathbf{E}_0\mathbf{E}_1^*| e^{-jk2d - j\varphi} + |\mathbf{E}_0\mathbf{E}_1^*| e^{jk2d + j\varphi}$$

Interference term

Correcting the thickness by very small value

Incoherent propagation of light

Two approaches:

a) Phase matching method
- the structure needs to be well defined to find the phase shift of the reflected wave

interference term = 0

$$d' = Re[\frac{\frac{\pi}{2} + m\pi - \varphi}{2k}], \qquad \mathrm{m} = 0, \pm 1, \pm 2, \ldots$$

a) Phase elimination approach
- the phase is eliminated by two simulation runs
- more appropriate for structure that are not well defined

interference term (d) − interference term (d') = 0

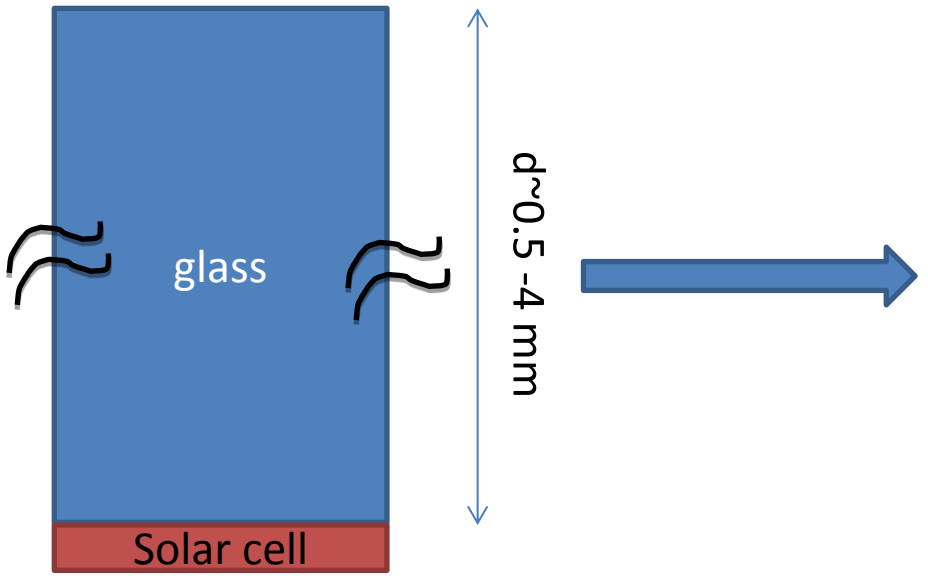
$$d' = d - Re[\frac{\lambda}{4N(\lambda)}]$$

*A. Campa et al., "Two approaches for incoherent propagation of light in rigorous numerical simulations," Progress In Electromagnetics Research, Vol. 137, 187-202, 2013.

Thinning down the incoherent layer

$$\mathbf{E}\mathbf{E}^* = \left|\mathbf{E}_0^2\right| + \left|\mathbf{E}_1^2\right| e^{\mathrm{Re}[-jk]4d}$$

$$k^*(\lambda) = k(\lambda)\frac{d}{d^*}$$

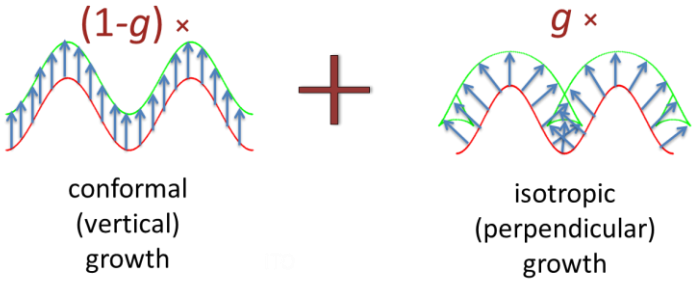


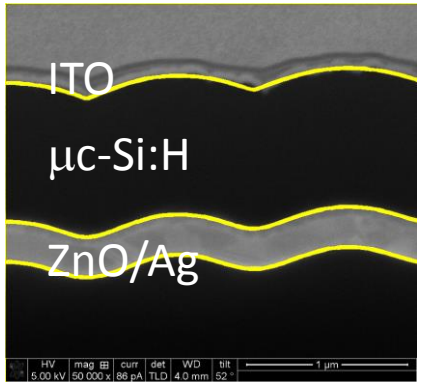
d~500 nm + Δd(λ)

*A. Campa et al., "Two approaches for incoherent propagation of light in rigorous numerical simulations," Progress In Electromagnetics Research, Vol. 137, 187-202, 2013.

Model

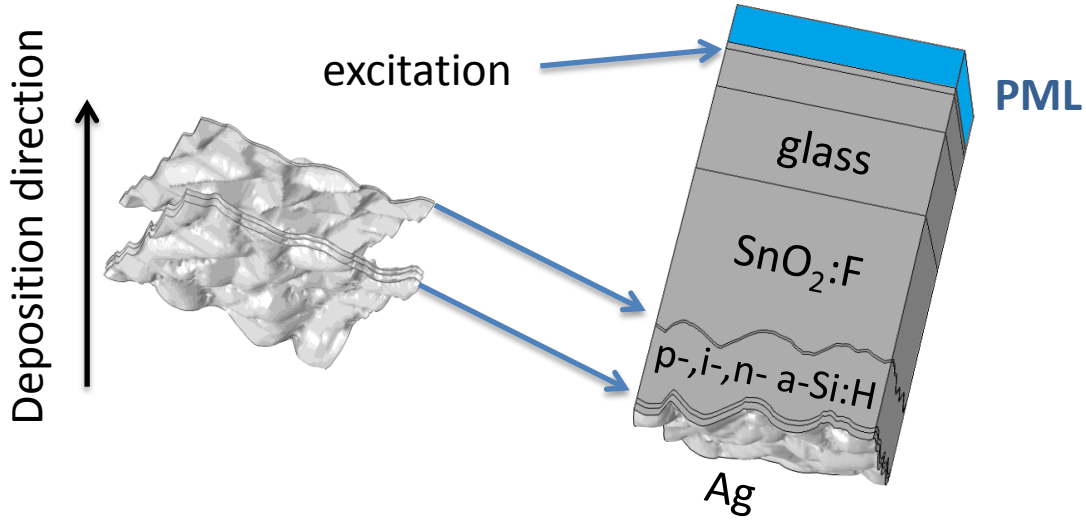
Non-conformal growth model





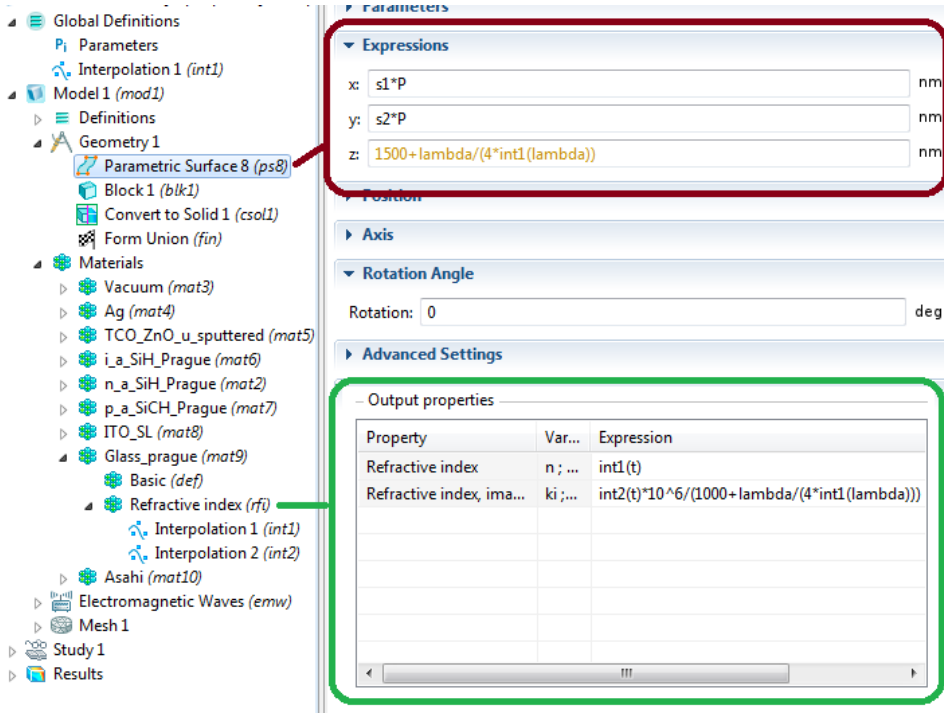
$g_{\mu c\text{-}Si:H} = 0.3$

$g_{Ag,\ ZnO} = 0.2$



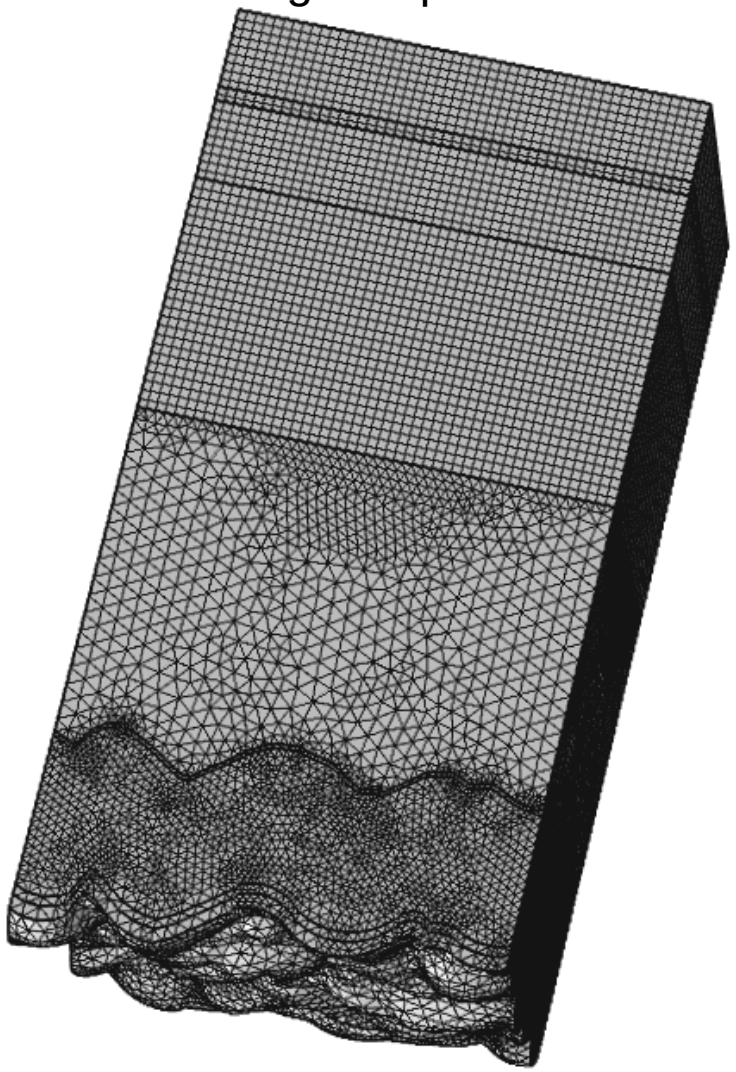
*M. Sever et. al., Combined model of non-conformal layer growth for accurate optical simulation of thin-film silicon solar cells, Sol. energy mater. sol. cells., Vol. 119, 59-66 (2013)

Model

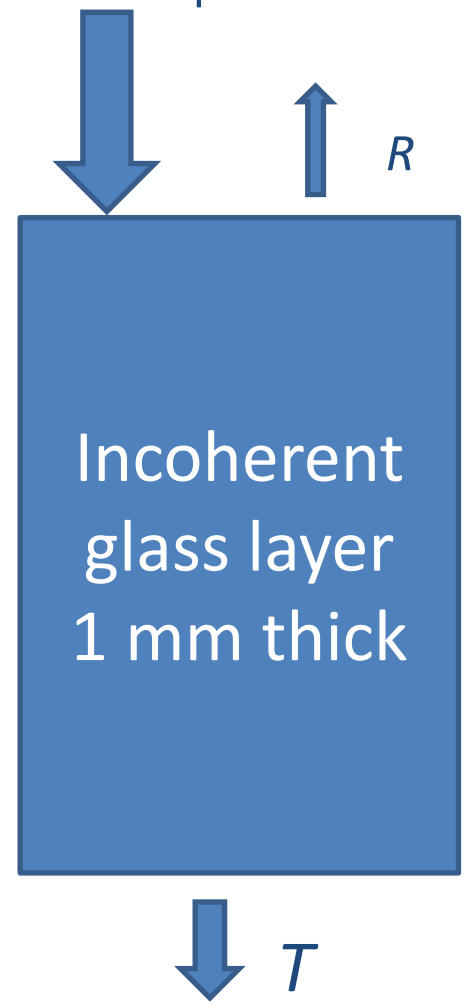


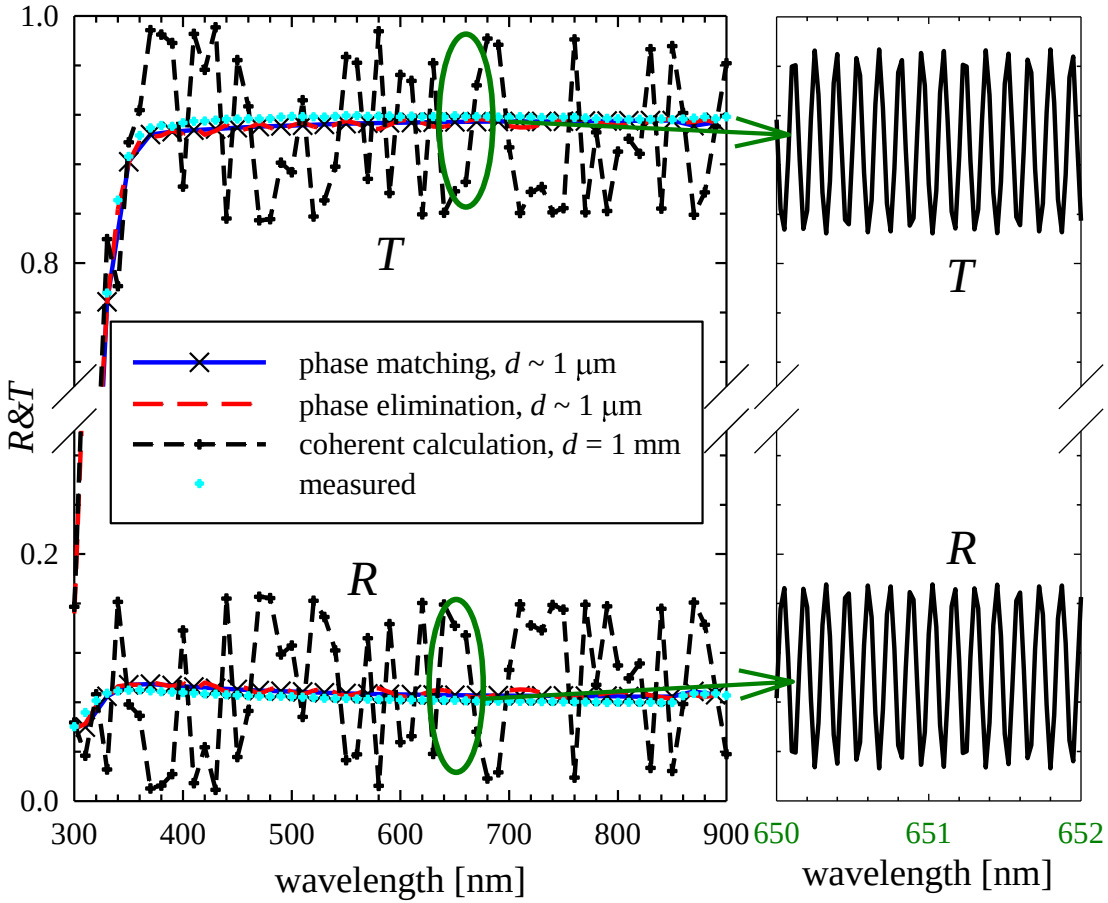
Realistic optical constants (layers)

Wavelength dependent mesh

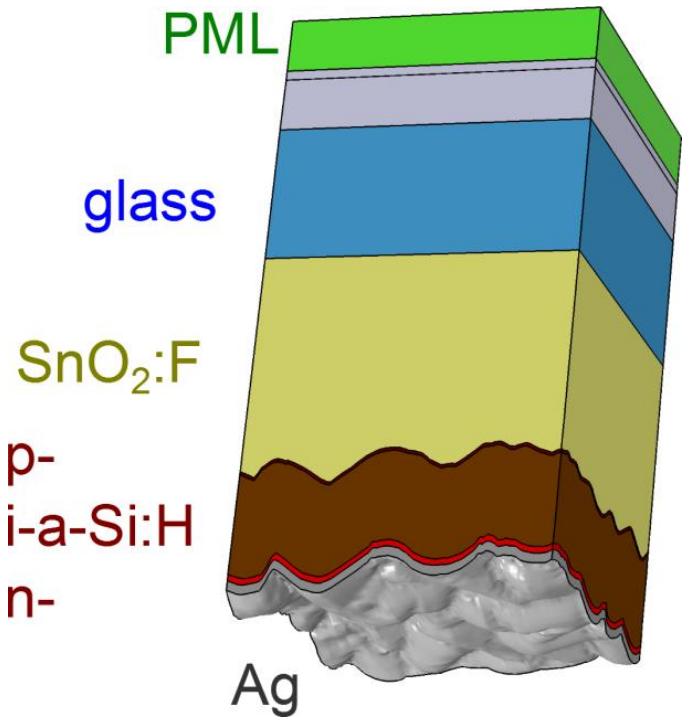


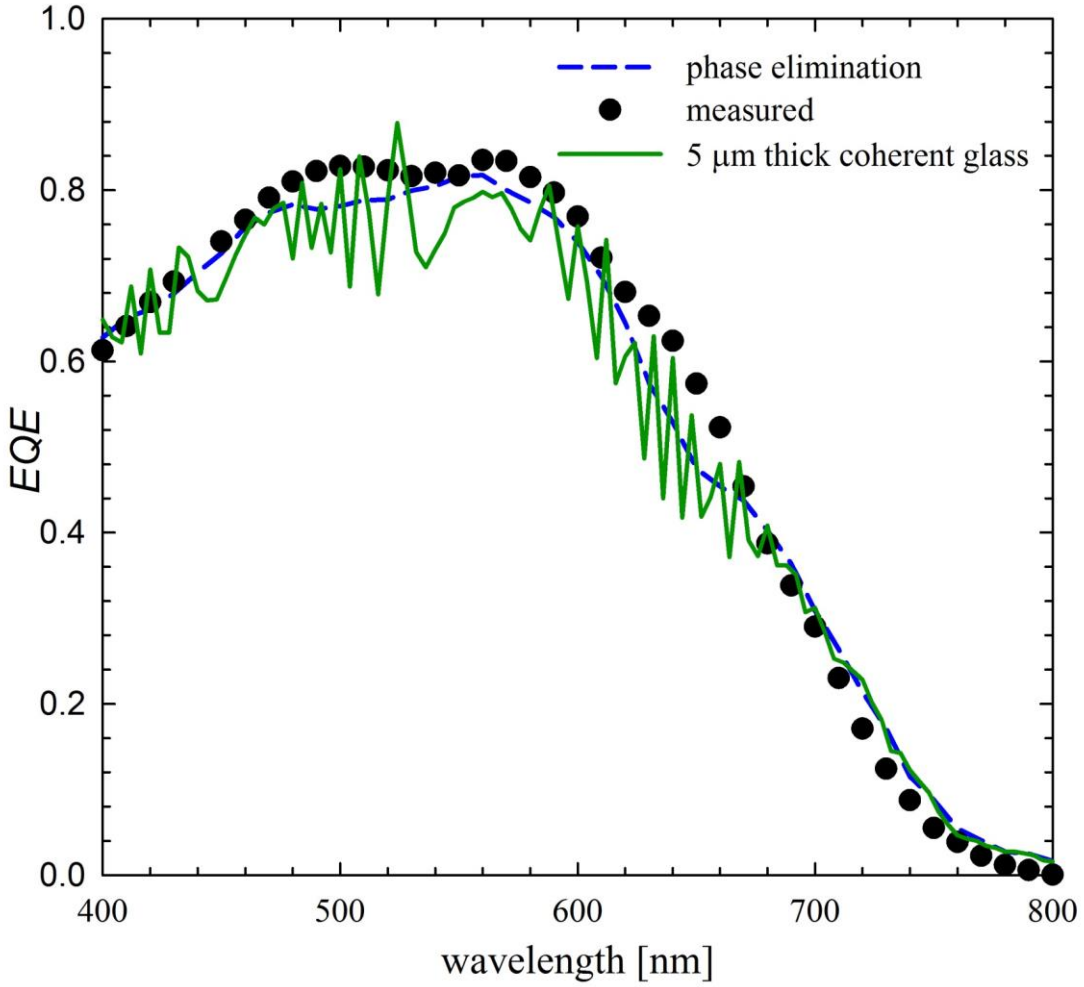
Results – thick glass layer



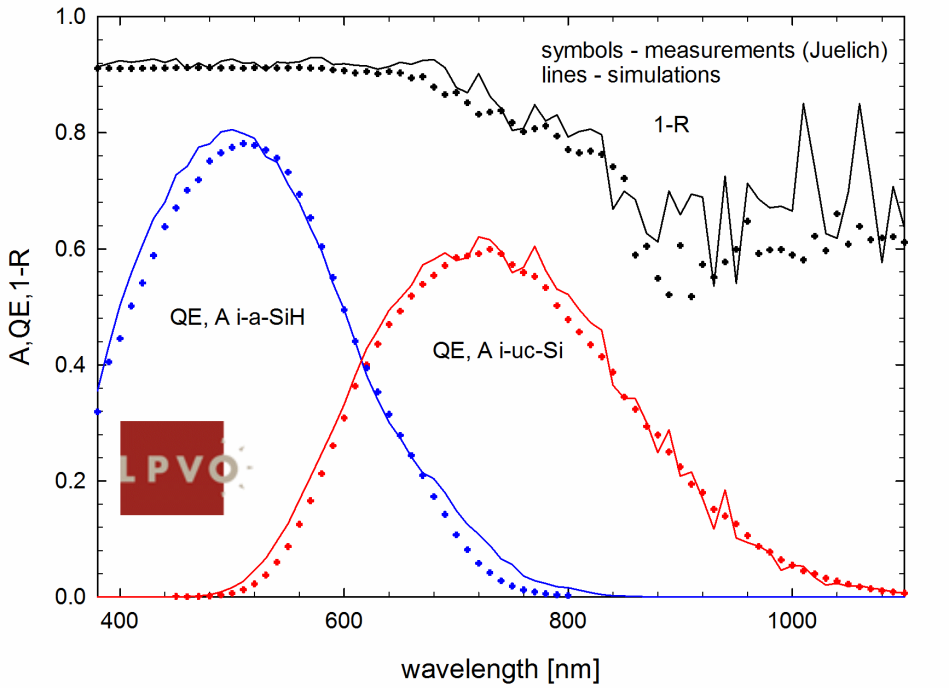


Results thin-film amorphous silicon solar cell



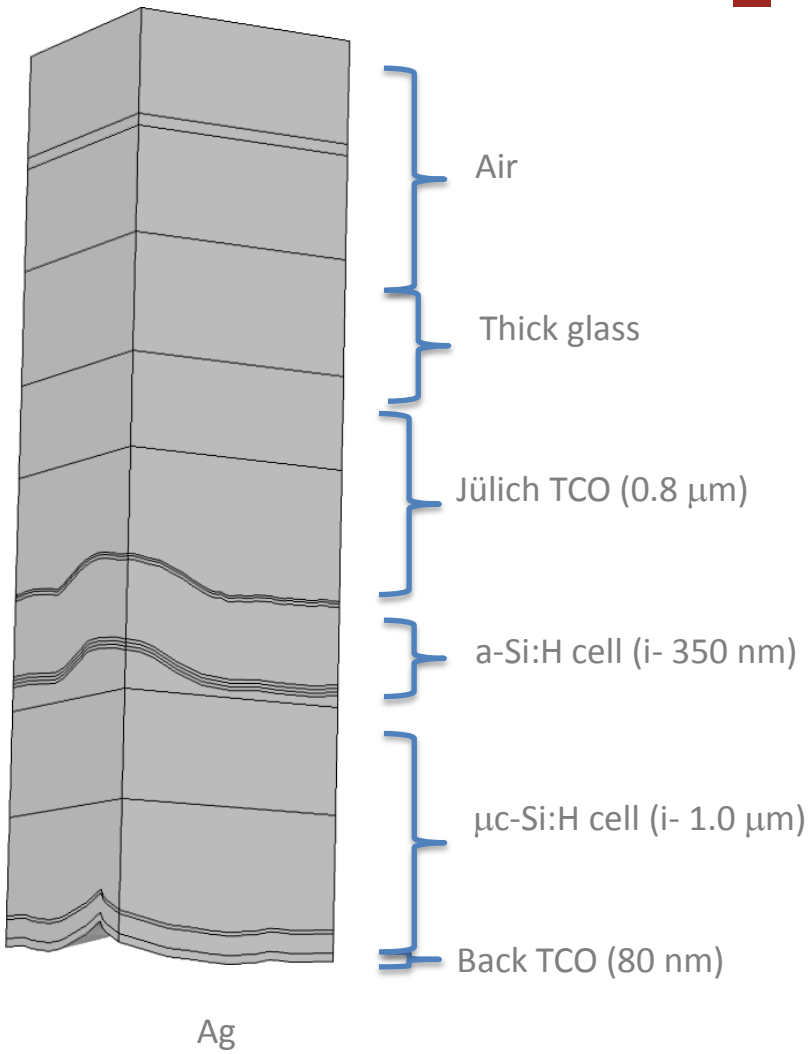


Results

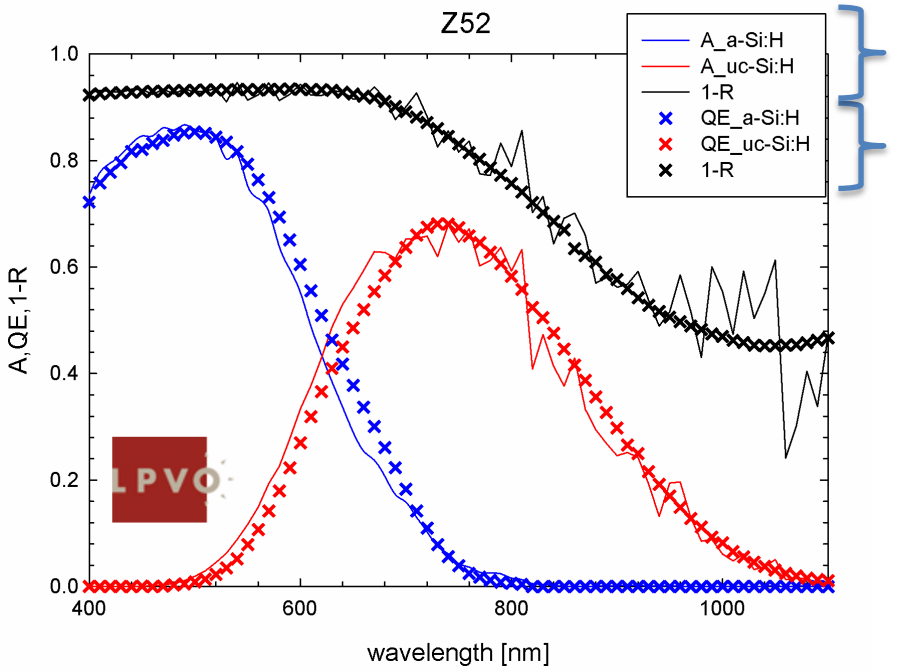


Fast Track

Cell made and measured at Inst. of Energy Research (IEK-5) – Photovoltaics, FZJ



Results

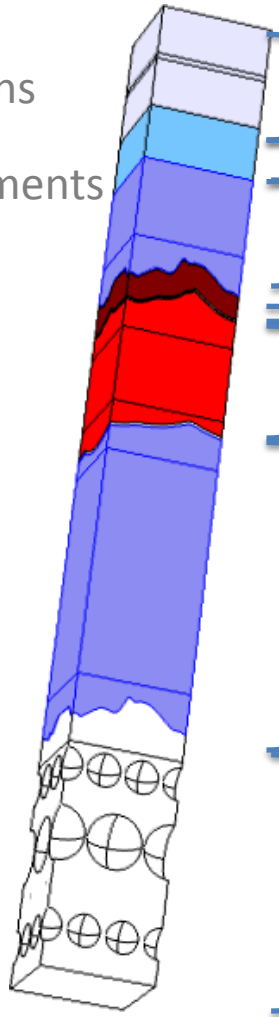


simulations

measurements

Cell made and measured at École Polytechnique Fédérale de Lausanne - EPFL

Fast Track



Air

Thick glass

B52 (2.5 μm)

a-Si:H cell (i- 250 nm)

μc-Si:H cell (i- 1.2 μm)

B52 (2.5 μm)

White paint

Conclusions

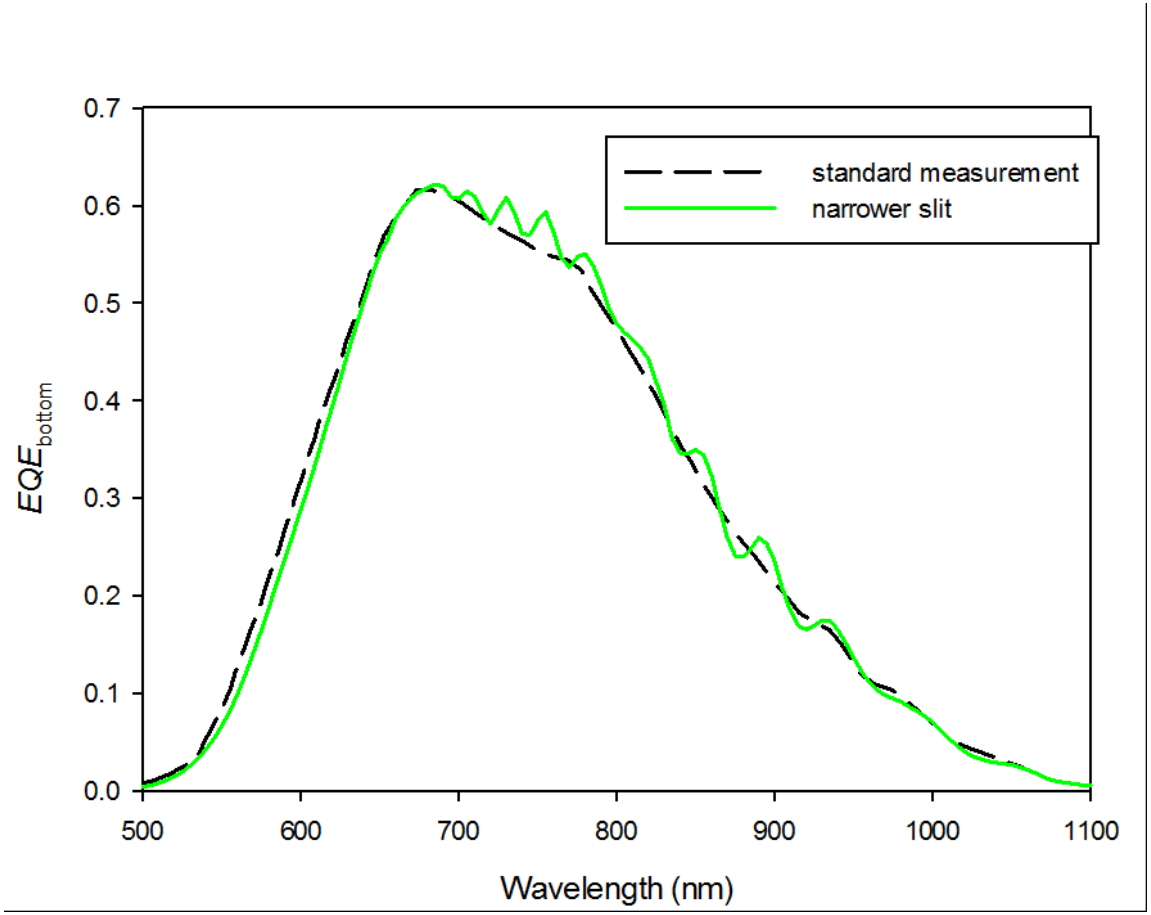
- Optical simulations including thick incoherent layer were shown
  - a) using phase matching method
  - b) using phase elimination method
  - c) thinning down thick layer
- Results of simulations compared with realized cells of different institutes

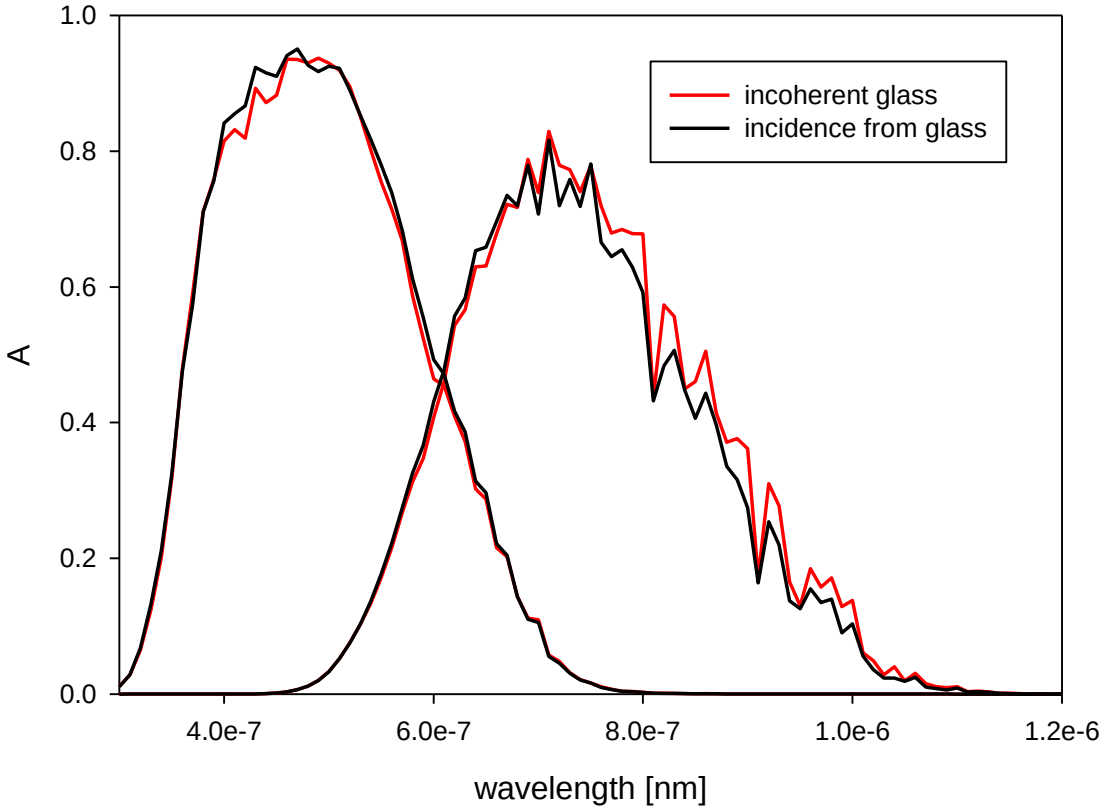
Acknowledgments

- FP7 Fast Track project (GA No.: 283501)
  Accelerated development and prototyping of nano-technology-based high-efficiency thin-film silicon solar modules

- Slovenian Research Agency - ARRS

Thank you for your attention


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
EQE bottom
500
600
700
800
900
1000
1100
Wavelength (nm)
standard measurement
narrower slit


1.0
0.8
0.6
0.4
0.2
0.0
A
4.0e-7
6.0e-7
8.0e-7
1.0e-6
1.2e-6
wavelength [nm]
incoherent glass
incidence from glass