Laboratory of Photovoltaics and Optoelectronics

Incoherent Propagation of Light in Coherent Models

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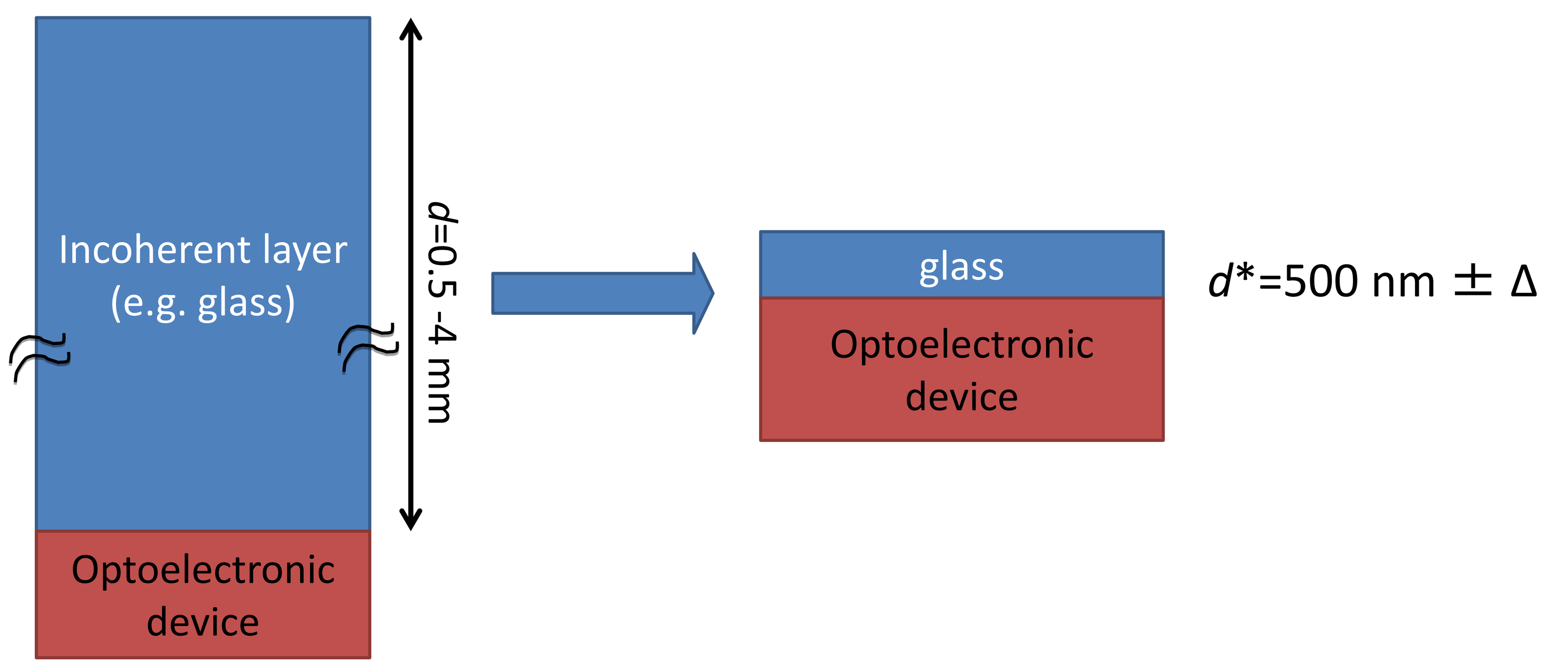
Introduction: In the finite element based modeling and simulation only the coherent propagation of light is considered. However, in reality when light passes a thick layer it loses the phase information and its coherent nature.



Original and modified structure after applying incoherent propagation of light and thining down of layers

Theory: Main term of the Poynting vector for forward and backward propagating wave in arbitrary isotropic media

$$\mathbf{EE}^* = \left(\mathbf{E_0}e^{jk\mathbf{r}} + \mathbf{E_1}e^{jk\mathbf{r}-\mathrm{j}k2\mathrm{d}-\mathrm{j}\varphi}\right)\left(\mathbf{E_0}e^{jk\mathbf{r}} + \mathbf{E_1}e^{jk\mathbf{r}-\mathrm{j}k2\mathrm{d}-\mathrm{j}\varphi}\right)^* = \left|\mathbf{E}_0^2\right| + \left|\mathbf{E}_1^2\right|e^{Re[-jk]4d} + \underbrace{\left|\mathbf{E_0}\mathbf{E}_1^*\right|e^{-jk2d-j\varphi} + \left|\mathbf{E_0}\mathbf{E}_1^*\right|e^{jk2d+j\varphi}}_{interference\ term}$$

Interference term has to be eliminated to reproduce the incoherent propagation of light

1) Phase Matching Approach: In this approach the interference term is directly eliminated in **one simulation run**, first by finding the phase shift φ of the common electric field of reflected waves (in this approach it is assumed φ is known) and then to adjust the thickness to nullify the interference term.

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

where k is a wavenumber

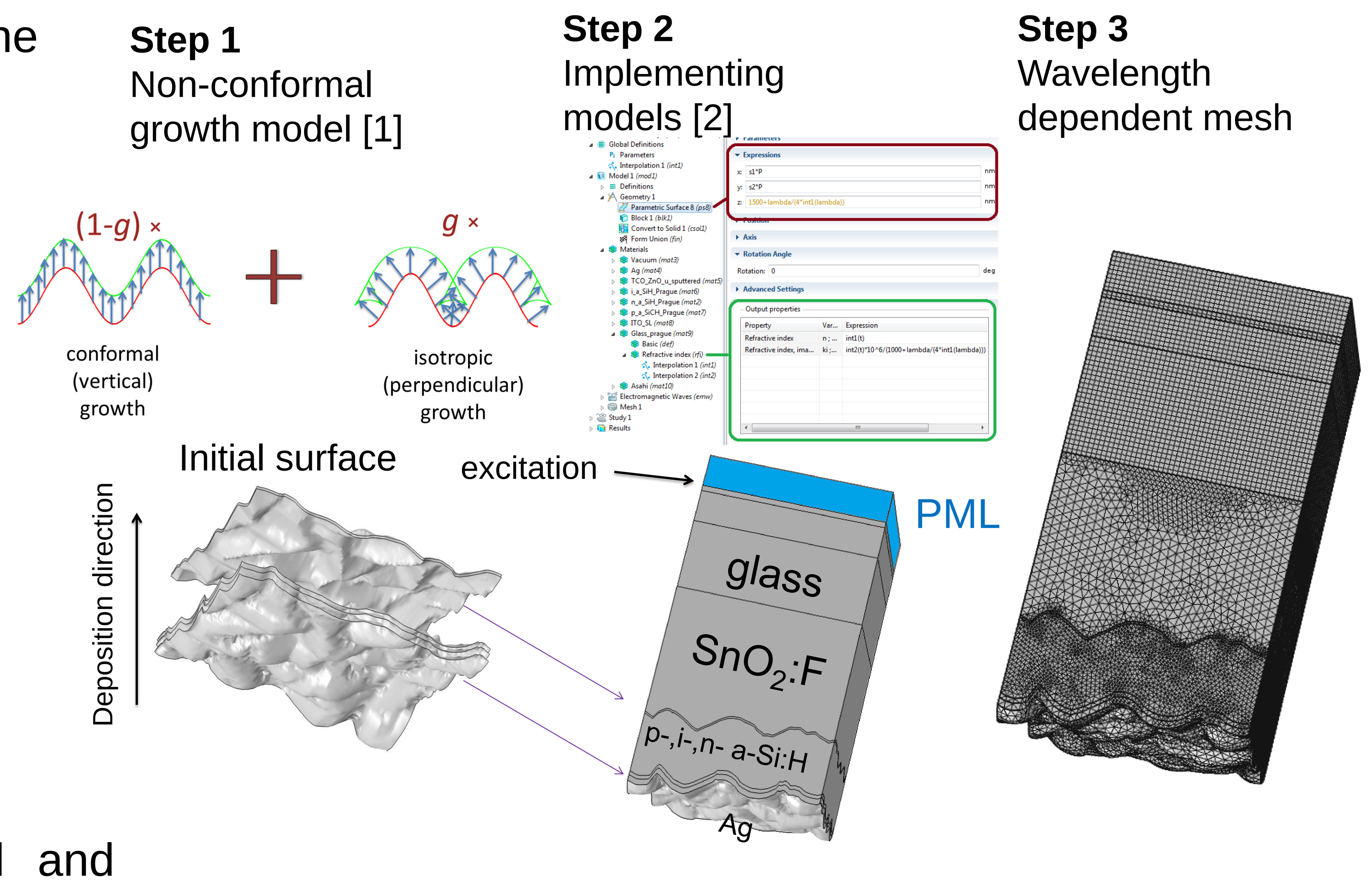
2) Phase Elimination Approach: In this approach we do not need to know the phase of backward propagating wave, thus it is much easier to implement this method to **complex structure** (e.g. random textures at interfaces of thin-film solar cells). This approach is also suitable for **rough interfaces of incoherent layer**. **Two simulation runs** one at original thickness d and another at d'

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

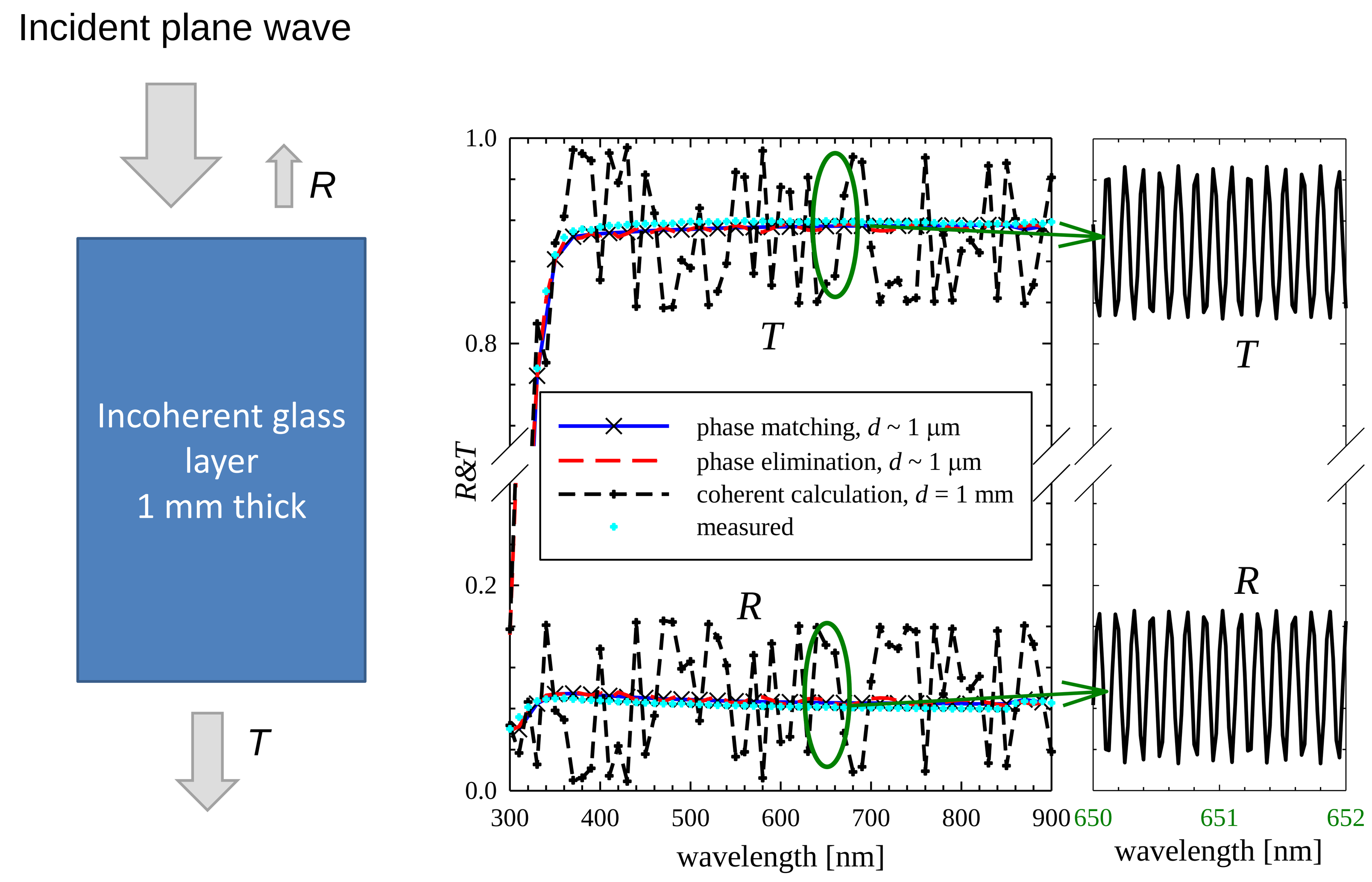
3) Thinning down the incoherent layer: Only propagation term is left thus by reducing the thickness of layer the extinction coefficient κ* needs to be modified

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

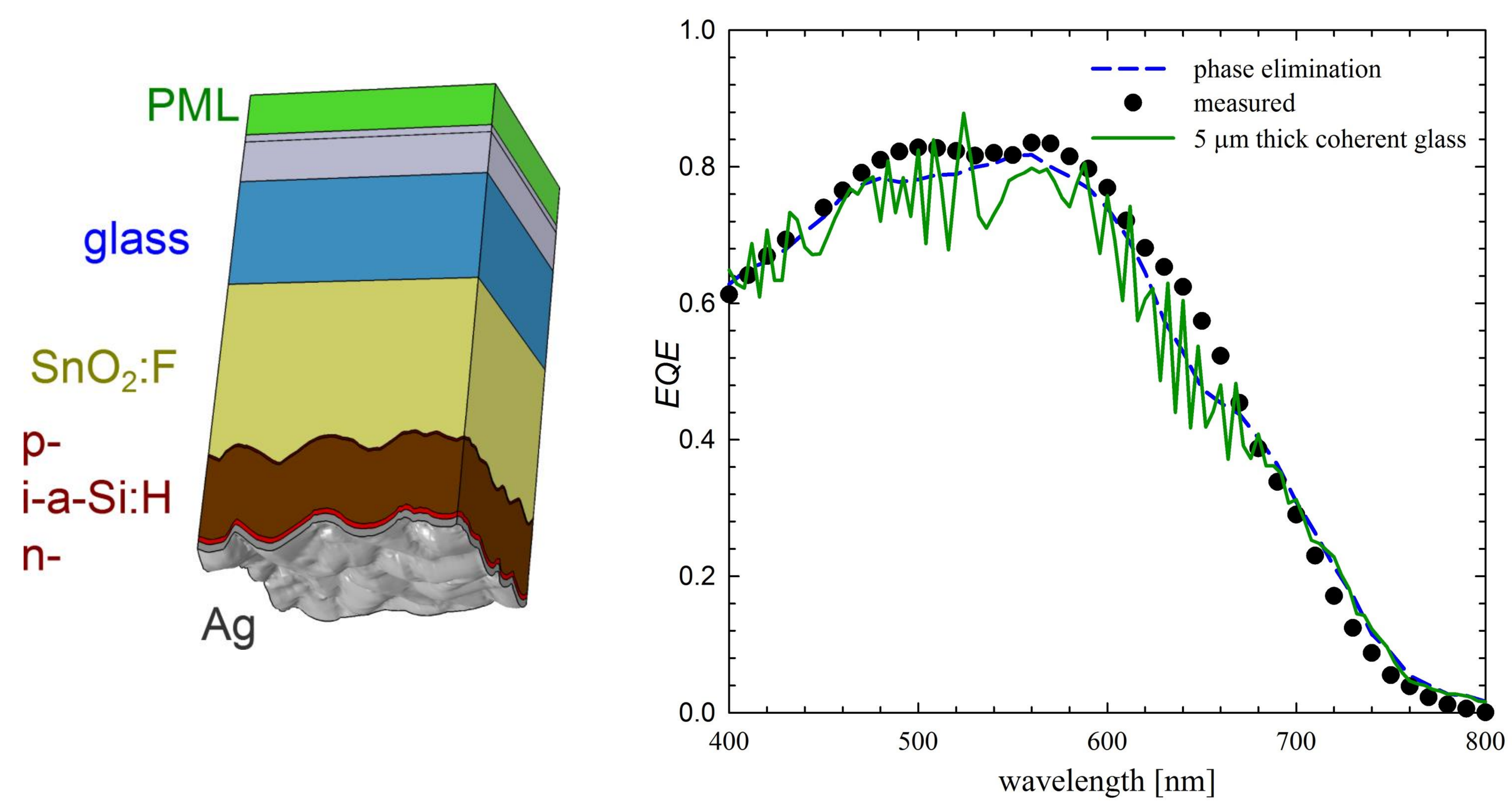
Numerical model: COMSOL RF or Wave Optics module



Results: a) thick glass layer



Results: b) thin-film amorphous silicon solar cell



Conclusions: All methods showed to be crucial to accurately simulate complete optoelectronic devices.

References:

1. 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)
2. A. Čampa, J. Krč, M. Topič, Two approaches for incoherent propagation of light in rigorous numerical simulations, *Progress In Electromagnetics Research*, Vol. 137, 187-202 (2013)