Incoherent Propagation of Light in Coherent Models

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Abstract

Introduction
In thin-film silicon solar cells in superstrate configuration the glass layer is usually the carrier during the deposition process and also the first incident layer from the optical point of view. Since the glass layer is very thick (in the range of millimeters) the propagation of the light through the layer is hard to calculate with FEM based simulators. Meshing and solving such system is almost impossible with standard methods, and also calculating the incoherent layer in the coherent model would produce lots of interference fringes which are not expected and observed in measurements. Due to the light nature, finite spectral width, the light losses its coherency nature in thick layers.

In this paper, we present new and numerically very efficient methods for taking into account the incoherent layers. In this way we were able to accurately simulate the complete thin-film solar cell with almost no additional computational resources required. The thick layer is modeled by a thin film layer using the newly developed algorithm. Two approaches will be shown: a) phase matching method and b) phase elimination method.

In the first approach the phase of the propagating and reflected wave is regulated by the small variation of the reduced thickness of the thick layer, in this way the interference effect is nullified. However, sometimes the phase information of the reflected wave is hard to obtain, thus second approach is used in which the phase is eliminated by two simulations. One at fixed reduced thickness (d1) and the second at the thickness:

$$d_2(\lambda)=d_1-\mathrm{Re}[\lambda/(4N\cos(\varphi))],$$

where N is the complex refractive index of the incoherent layer and φ is the propagation angle of the wave. All solutions are wavelength dependent (λ) and the thickness and refractive index varies with the wavelength in both approaches. The mentioned reduction of the thickness (from thick (mm) to thin (nm)) of incoherent layer will be shown.

The use of COMSOL Multiphysics®
The model was built using the COMSOL Multiphysics® simulation software version 4.3b with Wave Optics Module (the RF module can be used instead of the Wave Optics Module). The model was tested on realistic amorphous thin-film solar cell with random rough interfaces, Figure 1.

Looking from the incidence of the light, the solar cell is composed of the following layers: 1 mm thick incoherent glass layer, SnO2:F transparent conductive oxide (650 nm), p-a-Si:H (10 nm), i-a-Si:H (300 nm), n-a-Si:H (20 nm) and opaque Ag layer as a back contact. The texture of the interfaces between materials are defined by the deposition of SnO2:F layer.

The simulation results show very good agreement between measured and simulated external quantum efficiency (EQE), Figure 2, by applying the new approaches (results are presented for the second approach). The model advantages and approaches will be discussed in detail in order to improve time and resource demanding simulations.

Figures used in the abstract

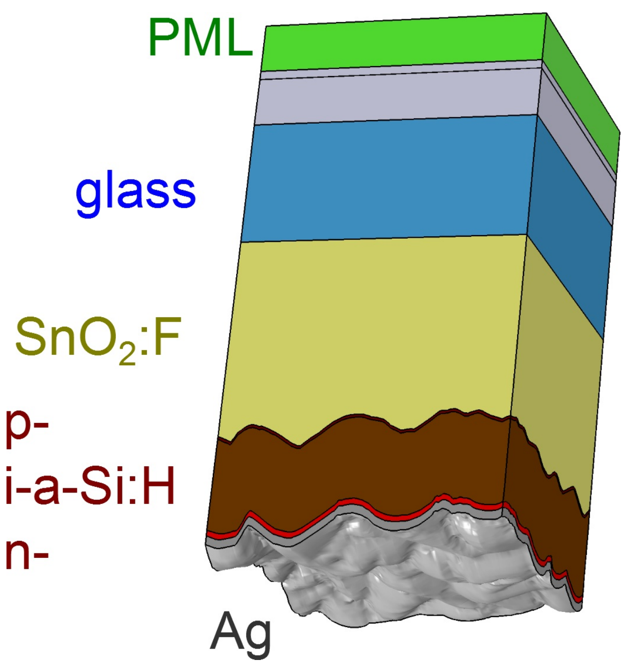

Figure 1: Realistic thin-film solar cell modeled in COMSOL.

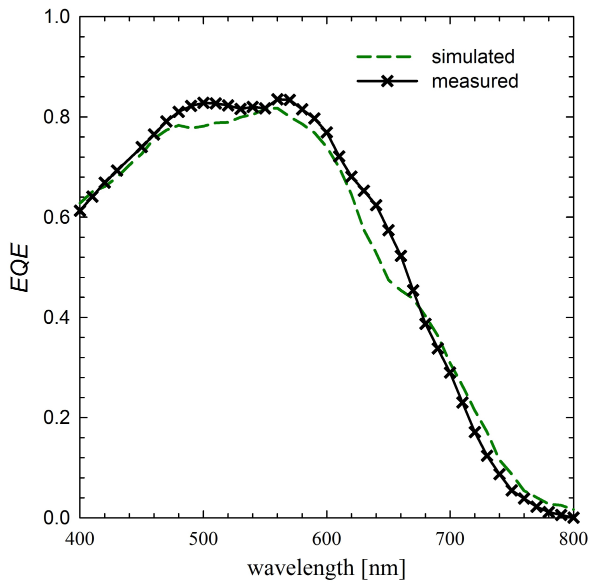

Figure 2: Measured and simulated EQE.