Optical modeling of luminous flux propagation at the front of photovoltaic modules

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During their life cycle, photovoltaic modules are exposed to different sources of degradation: humidity, UV irradiation, dust and thermal cycling. It is necessary to evaluate their impact on light transmission, through the various protective layers (glass and encapsulant) until the cell, in order to estimate the yield losses they generate over the module's lifespan. The aim of this study is to develop an evaluation protocol including physical measurements and analyses using optical models to describe light transmission through protective layers and observe the impact of the various degradations on the light transmission.

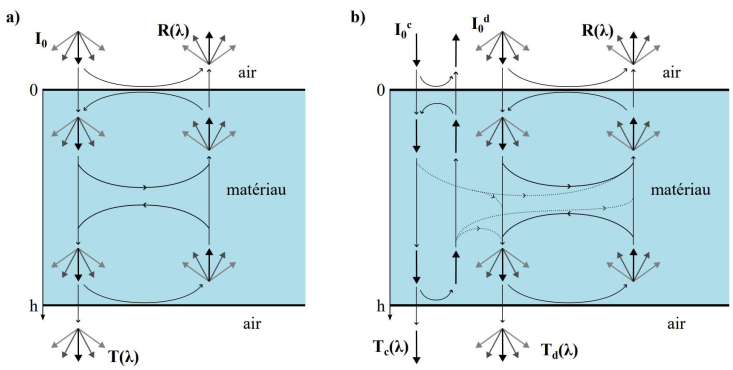

Figure 1 : Propagation of luminous fluxes considered by 2-flux (a) and 4-flux (b) models.

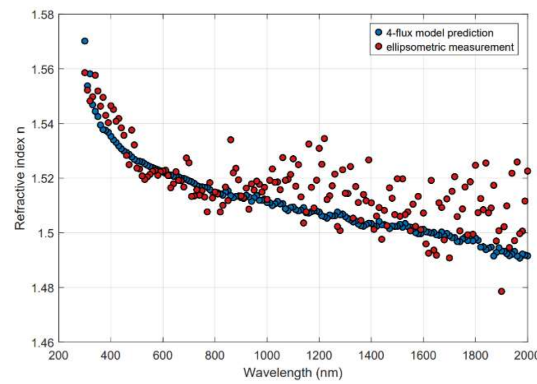

Figure 2 : measured and predicted refractive index of solar glass.

So-called 2-flux and 4-flux models are photometric models that describe the propagation of luminous fluxes within a material or a multilayer object, taking into account scattering and absorption by the material layers. Coupled with spectrophotometric reflectance and transmittance measurements, they can be used to predict the intrinsic parameters of the material of interest. The optical properties of a material are described in particular by its refractive index n, its extinction coefficient k or its scattering coefficient s. The measurements required to determine these properties can be performed with relatively affordable equipment that tolerates a wide variety of sample types. The 2-flux model [1], [2] assumes the propagation of perfectly diffuse fluxes within the material (Figure 1a), which is the case for highly diffusing materials. The more complex 4-flux model [3] can handle a wider range of behaviors by considering both diffuse and collimated fluxes (Figure 1b). These general models are easily adaptable to the numerous encapsulants and glasses used in the photovoltaic industry, enabling their application to a wide variety of PV modules.

The relevance of the 4-flux model has previously been established for predicting the optical coefficients of thermoplastic polyolefin (TPO) encapsulants [4]. Preliminary results allow the extension of the validity domain of this model to the prediction of refractive index of a solar glass (Figure 2). By comparing the values obtained after applying the 4-flux model to reflectance and transmittance measurements and its direct ellipsometric measurement, an RMS error of less than 3.5% is observed over the 300–2000 nm spectral range. As the noise of direct measurement of refractive index remains significant (especially in the infrared), adjustments are needed to optimize the ellipsometric measurement. This model still needs to be validated on other optical parameters.

The aim of the current project is to validate this model on other solar glasses and encapsulants of various compositions, and then to extend it to multilayer materials that have undergone various types of degradation.

References:

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