Team #50: Development of a software tool for the design and optimization of thin-film solar cells

Khoa Duong, Jay Karasiuk, Eric Rodriguez

Project Objective

Develop a software tool to calculate the total optical absorption efficiency of a thin-film solar cell through a graphical user interface.

Enable the user to optimize the design of their thin-film solar cell.

Background

Thin-film solar cells are a 2nd generation photovoltaic (PV) technology for the conversion of light energy to electrical power. They are more flexible and cheaper to produce than 1st generation crystalline silicon solar cells; however, thin-film solar cells are less efficient.

The three most common types of thin-film solar cells are cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si).

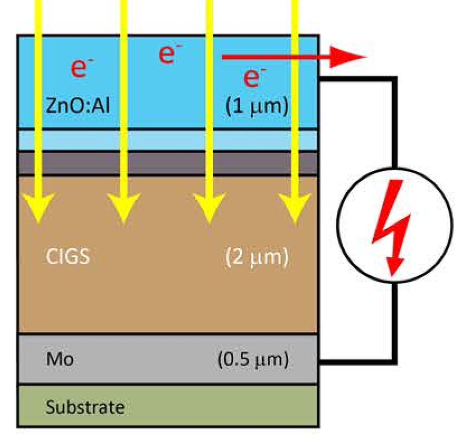
Simulation Parameters

Material Layer properties: parameters referring to the individual material per layer in the solar cell stack

- Thickness (nm)
- Stack order/position
- Optical constants
  - Set of tabulated values that define the optical qualities of a given material

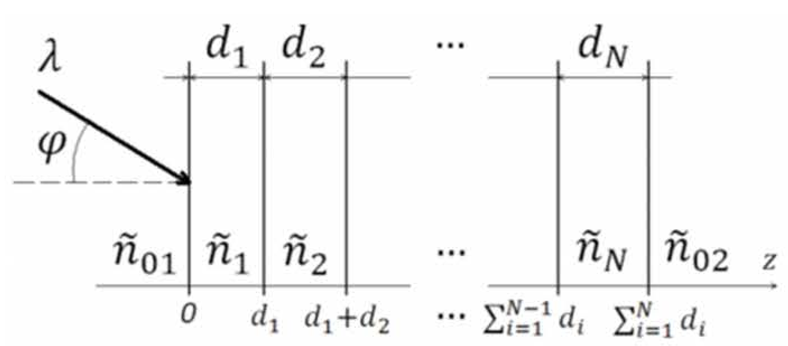
Wave vector properties: parameters referring to the light wave incident to the solar cell stack

- Wavelength range
- Angle of incident
- Polarization
  - TE (or s) - electric field is perpendicular to the plane of incidence
  - TM (or p) - magnetic field is normal to the plane of incidence



Depiction of a solar cell stack

Calculations


Visualization of a solar cell stack with N layers with wave vector λ at angle of incident φ, where each layer n has distance d_n and each interface has a sum of n distances

Transfer Matrix Method: calculation of two sets of 2x2 matrices using material layer and wave vector parameters

The interface matrix describes the propagation of the wave vector incident to an interface between two layers.

The propagation matrix describes the absorption and phase shift for a wave propagating through a layer.

Interface Matrix

$$I(z_k) = \frac{1}{t_k}\begin{pmatrix} 1 & r_k \\ r_k & 1 \end{pmatrix}$$

Propagation Matrix

$$P(z_k, z_{k+1}) = \begin{pmatrix} e^{jb_k} & 0 \\ 0 & e^{-jb_k} \end{pmatrix}$$

Matrix multiply each layer matrix for the Total Transfer Matrix.

$$T^{tot} = I(z_0)P(z_0,z_1)I(z_1)P(z_1,z_2)I(z_2)\ldots I(z_{N-1})P(z_{N-1},z_N)I(z_N)$$

Reduce the Total Transfer Matrix to its key components: Reflection and Transmission.

$$R = \left|\frac{T_{21}^{tot}}{T_{11}^{tot}}\right|^2 \qquad T = \left|\frac{\tilde{n}_{02}}{\tilde{n}_{01}} \cdot \frac{1}{T_{11}^{tot}}\right|^2$$

Solve for the Absorption Efficiency.

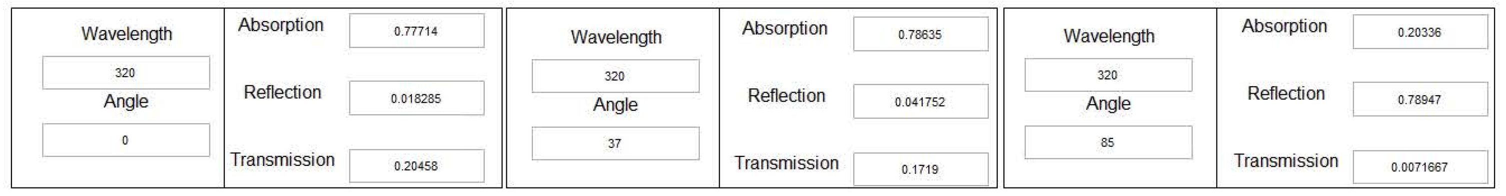
A = 1 - R - T

Testing

Test by incrementing or decrementing the incidence angle (0 to 90°) as well as the active layer's optical constant. Absorption, reflection, and transmission should fluctuate consistently and approximately match expected values.

After development, experimental results for a solar cell stack will be simulated with the same configuration parameters.

Further testing accomplished by integrating multiple transfer matrix methods to check for consistency at the final output stage.

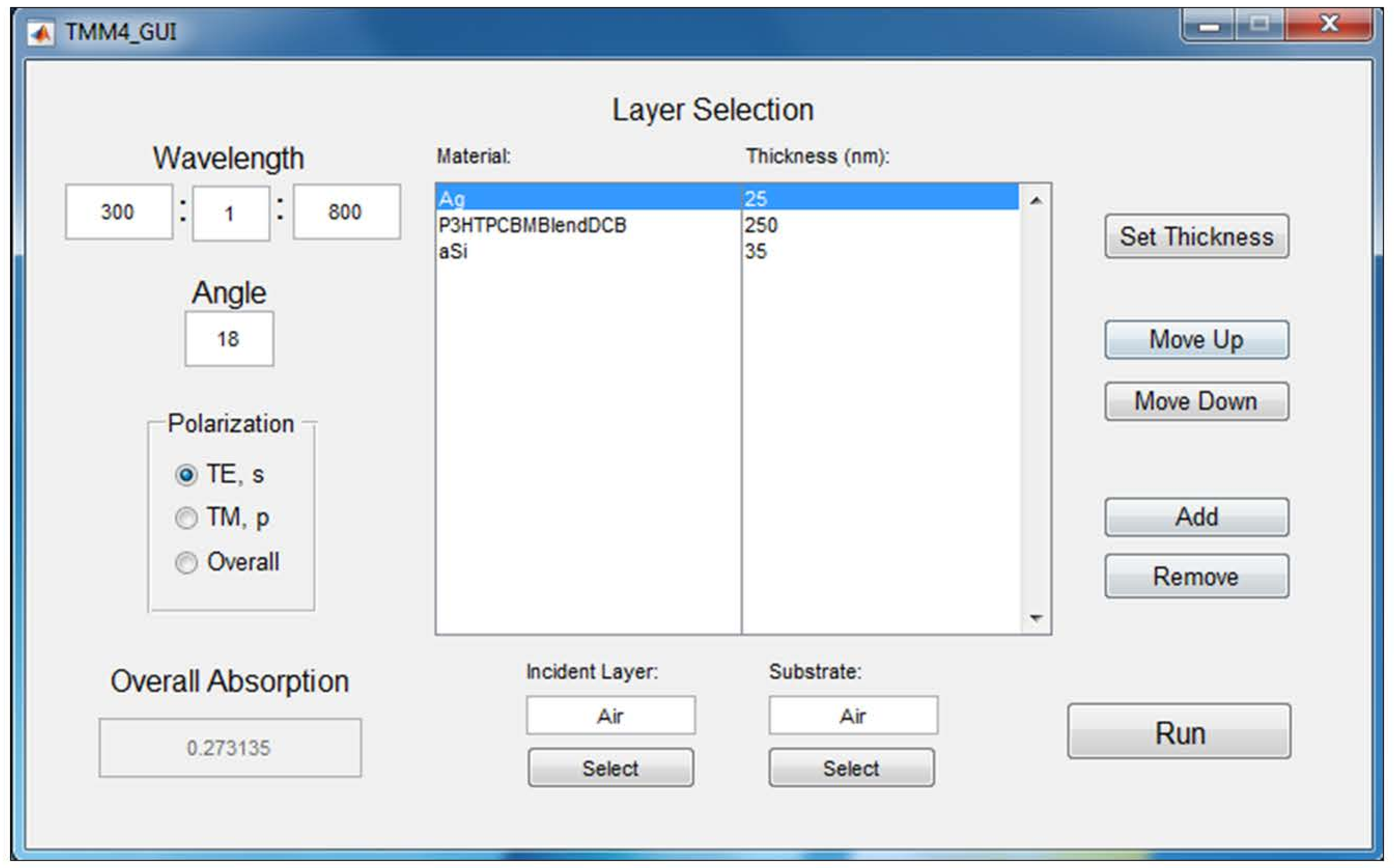


Results from incrementing the incident angle

Graphical User Interface

The GUI reads all user parameters and calculates the reflection, transmission, and absorption of a solar cell design.

Results are shown by wavelength or by the incidence angle in a graphical representation.



Current GUI in development

Sponsor: Georgios Veronis

Adviser: Georgios Veronis