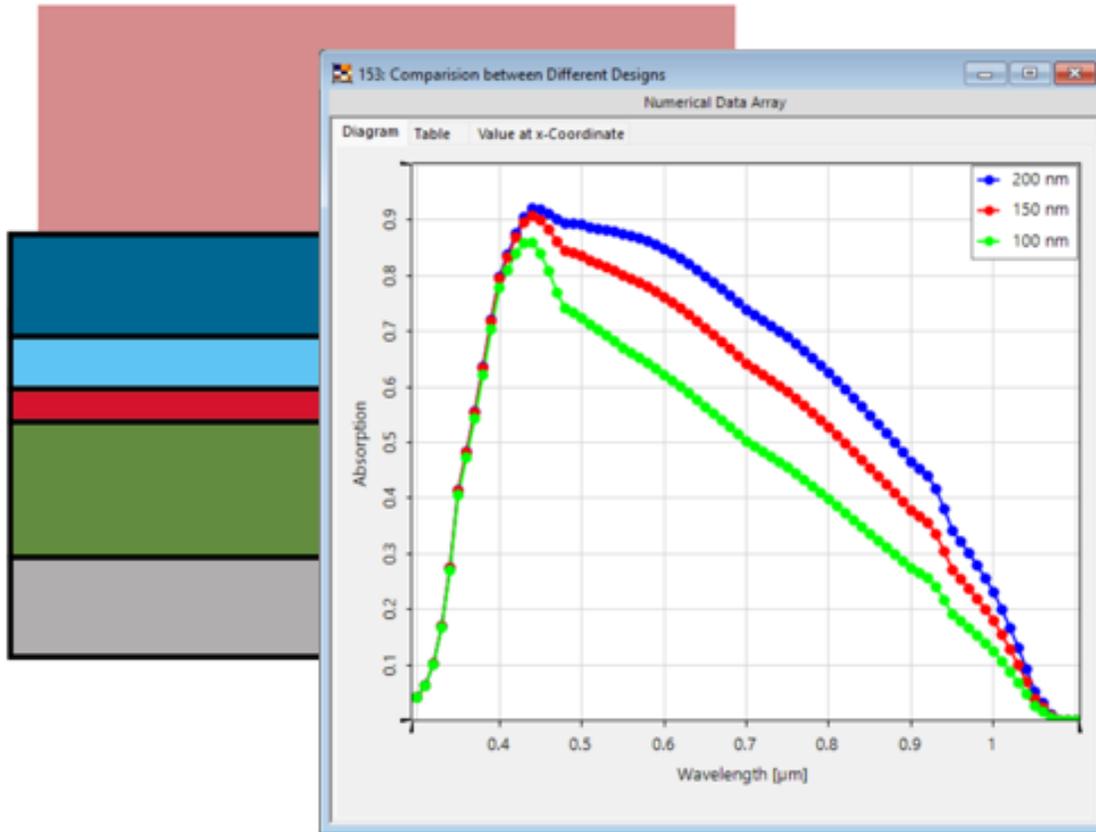


Absorption in a CIGS Solar Cell

Abstract



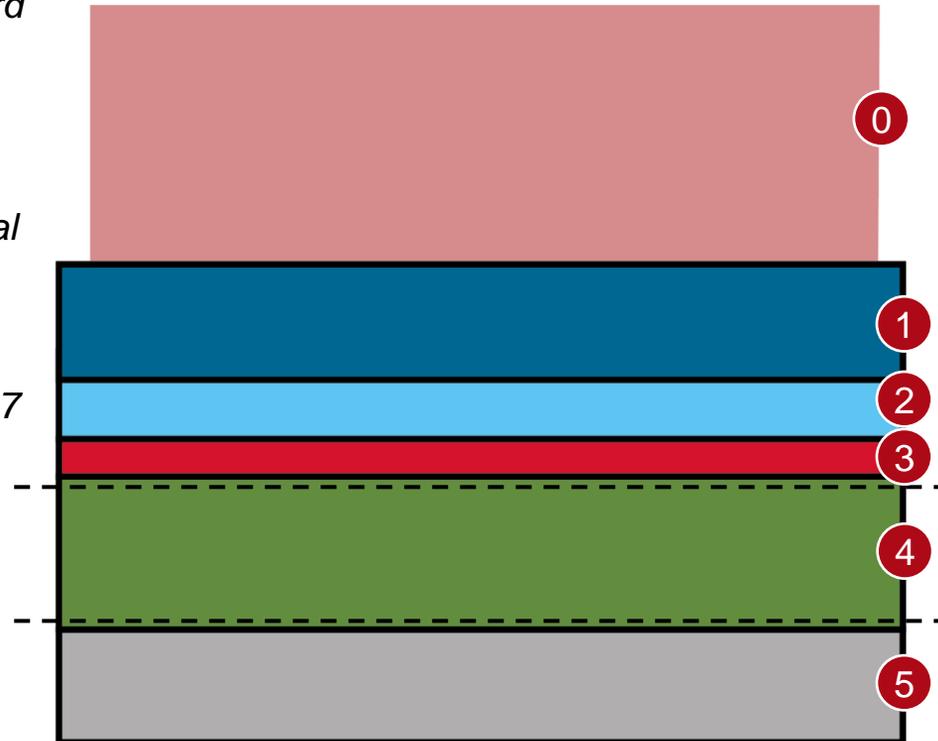
Solar cells are a fundamental technology in the field of renewable energy. To optimize efficiency, most common designs use thin-layer structures and media with high absorption coefficients – as it is precisely this absorbed optical energy what will eventually be transformed into an electric current. Solar cells based on copper indium gallium selenide (CIGS) have become quite common as they can be made much thinner without losing absorption efficiency, compared with cells based on other materials.

Modeling Task

plane wave

homogeneous spectrum from 300nm to 1100nm

System from: J. Goffard et al., "Light Trapping in Ultrathin CIGS Solar Cells with Nanostructured Back Mirrors," in *IEEE Journal of Photovoltaics*, vol. 7, no. 5, pp. 1433-1441, Sept. 2017, doi: 10.1109/JPHOTOV.2017.2726566.



detectors

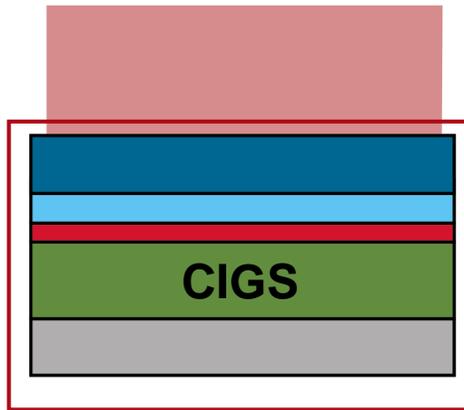
power (absorbed power will be calculated as the difference between the power readings of both detectors)

solar cell

nr.	Material	thickness
0	fused silica*	-
1	ZnO:Al	100nm
2	i-ZnO	70nm
3	ZnS	50nm
4	CIGS	100/150/200nm
5	molybdenum	substrate

* we assume that the solar cell is protected by a layer of fused silica with anti-reflection coating.

System Building Blocks – Stratified Media Component



For the coated mirrors we employ the *Stratified Media Component*, since it provides a fast and rigorous solution for x, y-invariant layer stacks.

The screenshot shows the 'Edit Stratified Media Component' software interface. The main window displays the 'Edit Parameters of Coating' dialog box, which is used to define the properties of the coating layers. The dialog box is divided into two tabs: 'Layer Definition' and 'Process Data'. The 'Layer Definition' tab is active, showing a diagram of the coating layers and a table of their properties.

The 'Edit Parameters of Coating' dialog box shows the following parameters:

- Component Size: 20 mm x 20 mm
- Reference Surface (all Channels): Plane Surface
- Aperture: Yes No
- Coating Name: Standard Coating
- Coating Orientation: Front Side Application
- Homogeneous Medium Behind Surface: CIGS in Homogeneous Medium

The 'Layer Definition' tab shows a diagram of the coating layers and a table of their properties:

Index	Thickness	Distance	Material
1	50 nm	50 nm	ZnS
2	70 nm	120 nm	i-ZnO
3	100 nm	220 nm	ZnO:Al

The 'Process Data' tab shows the 'Wavelength Range of Materials' parameters:

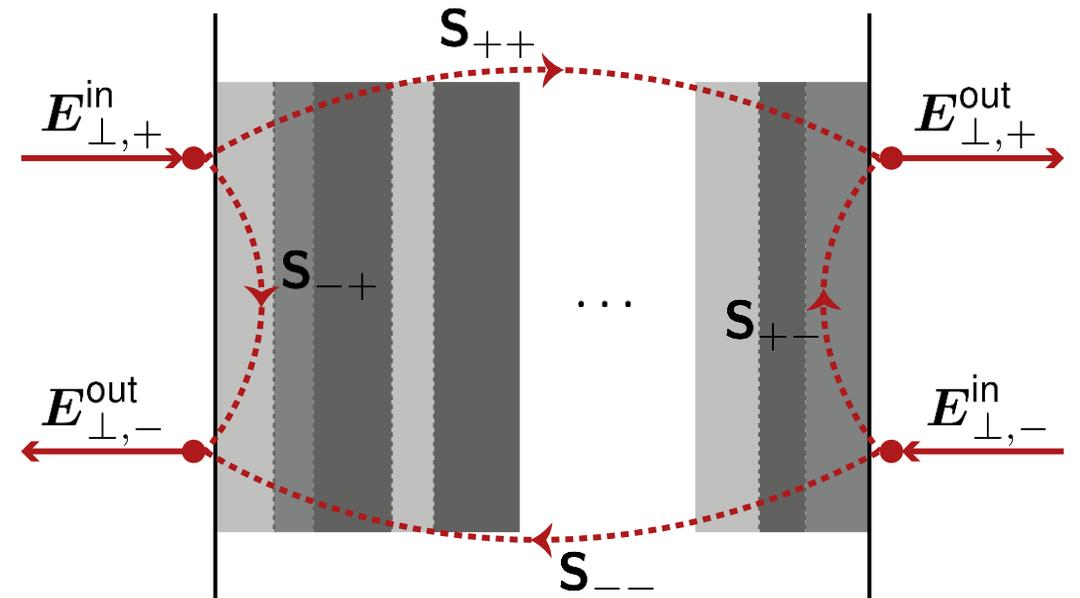
- Minimum Wavelength: 300 nm
- Maximum Wavelength: 1.125 μm

System Building Blocks – Layer Matrix Solver

The *Stratified Media Component* uses the layer matrix electromagnetic field solver. This solver works in the spatial frequency domain (**k-domain**). It consists of

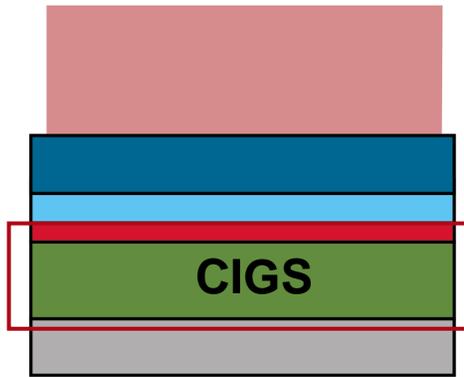
1. an eigenmode solver for each homogeneous layer and
2. an S-matrix for matching the boundary conditions at all the interfaces.

The eigenmode solver computes the field solution in the k-domain for the homogeneous medium in each layer. The S-matrix algorithm calculates the response of the whole layer system by matching the boundary conditions in a recursive manner. This is a method well-known for its unconditional numerical stability since, unlike the traditional transfer matrix, it avoids the exponentially growing functions in the calculation steps.



For further information:
[Layer Matrix \[S-Matrix\]](#)

System Building Blocks – Sampled Media



VirtualLab Fusion offers a comprehensive catalogue of different materials that can, among other things, be used for coatings. But it is also possible to import material data from measurements.

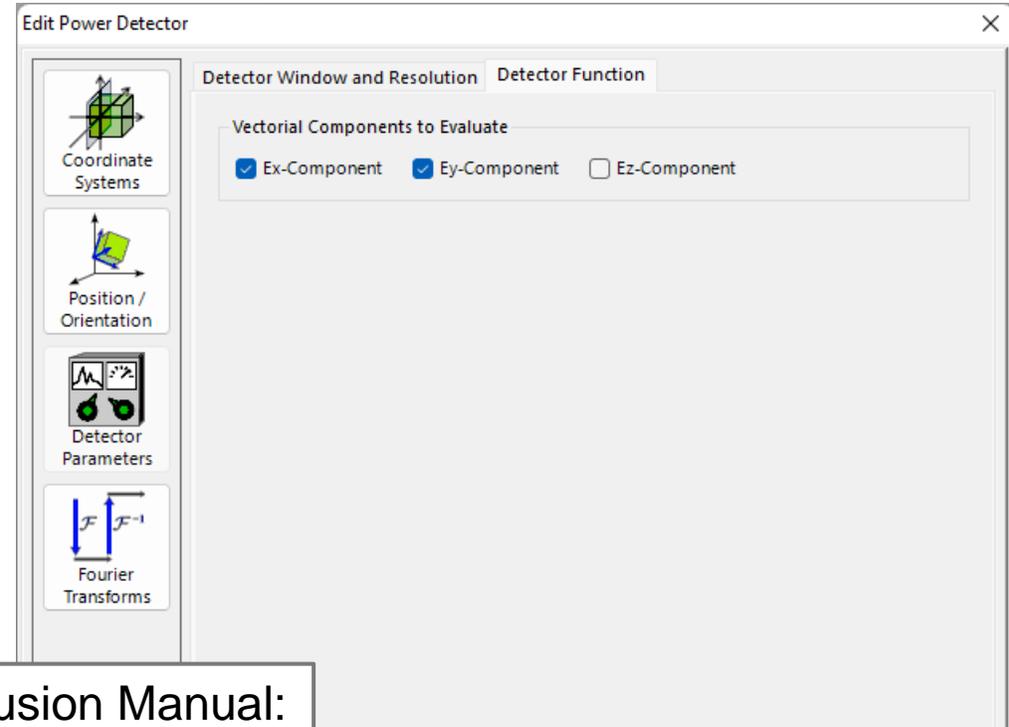
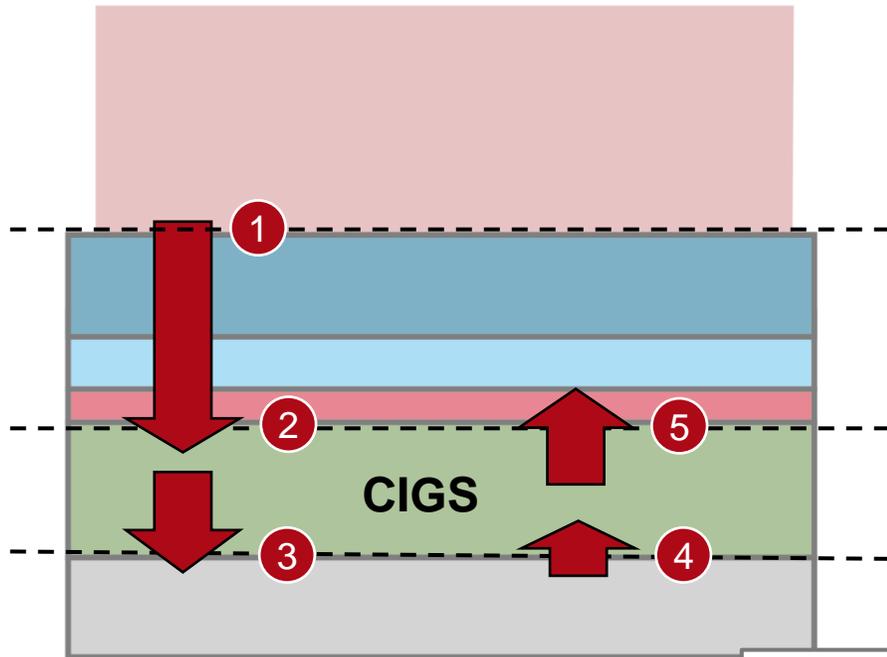
The screenshot displays the 'Materials Catalog' window on the left, showing a tree view of materials under 'Photovoltaic' with 'CIGS' selected. The main window shows the 'CIGS' material properties, including a graph of 'Relative Refractive Index n' (blue line) and 'Absorption Coefficient α ' (red line) versus 'Vacuum Wavelength' (nm). The graph shows the refractive index decreasing from approximately 3.1 at 0.3 nm to 2.7 at 0.7 nm, and the absorption coefficient peaking at about 0.45 nm.

The 'Edit Material Data' window is open on the right, showing the 'CIGS' material name and the 'Refractive Index' tab. The 'Define Refractive Index by' section has 'Sampled Dispersion' selected. The 'Data' section shows a table of sampled dispersion data:

Wavelength	Real Refractive Index
636 nm	2.96
652 nm	2.96
670 nm	2.95
689 nm	2.96
708 nm	2.96
729 nm	2.96
751 nm	2.97
775 nm	2.97
800 nm	2.98
827 nm	2.99
855 nm	2.98
886 nm	2.98

The 'Domain of Definition' section shows the 'Vacuum Wavelength Range' set from 636 nm to 945 nm. The 'Usable Vacuum Wavelength Range' is shown as 636 nm to 925 nm. The 'Interpolation Method' is set to 'Linear Interpolation'.

System Building Blocks – Detection



From VirtualLab Fusion Manual:

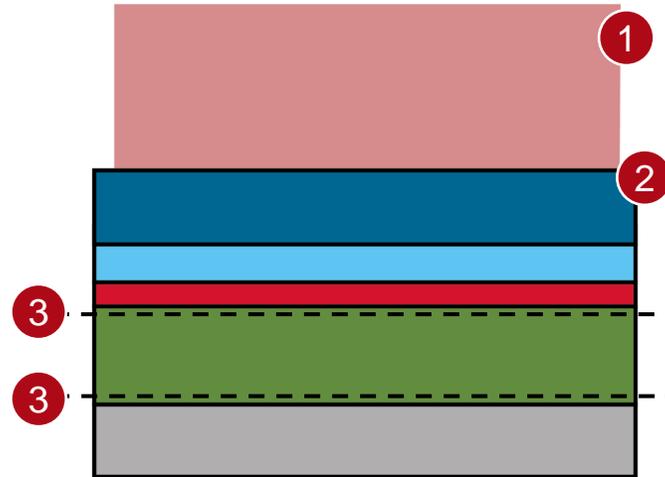
This detector calculates the power P in watts, either for the complete field in the detector plane or for a region of it. It is calculated via

$$P = n \frac{\epsilon_0}{2} c \sum_i \Delta_i \cdot A_i^2.$$

n is the refractive index derived from the embedding medium of the field, ϵ_0 is the dielectric constant and c is the vacuum speed of light. A_i is the squared amplitude of the data point i and Δ_i is the area this data point occupies (sampling distance in x-direction times sampling distance in y-direction for equidistant data).

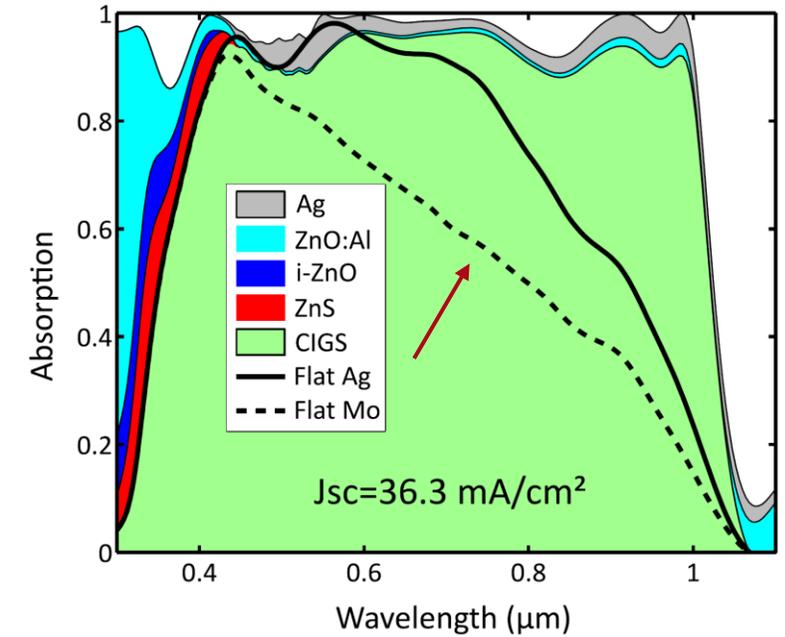
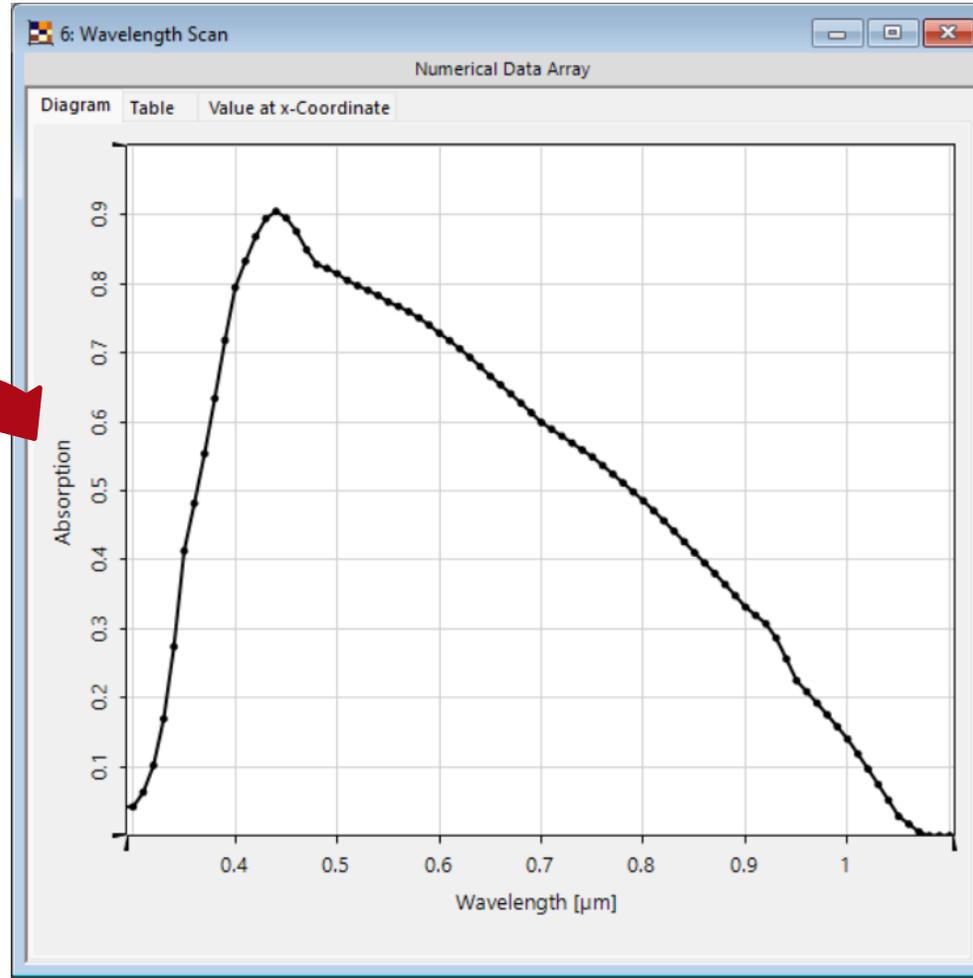
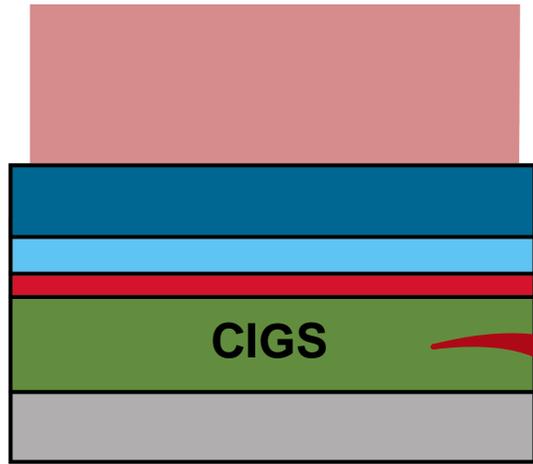
$$\text{Abs. Power} = \frac{P_2 - P_3 + P_4 - P_5}{P_1}$$

Summary – Components...



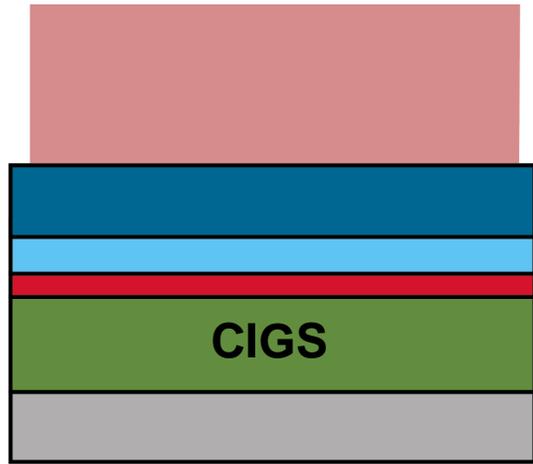
... of Optical System	... in VirtualLab Fusion	Model/Solver/Detected Value
1. source	<i>Plane Wave (with Homogeneous Power Spectrum)</i>	truncated Ideal Plane Wave (with homogeneous spectrum)
2. solar cell	<i>Stratified Media Component</i>	S-Matrix
3. detector	<i>Power Detector</i>	energy density integration

Absorption for Different Thicknesses of the CIGS Layer



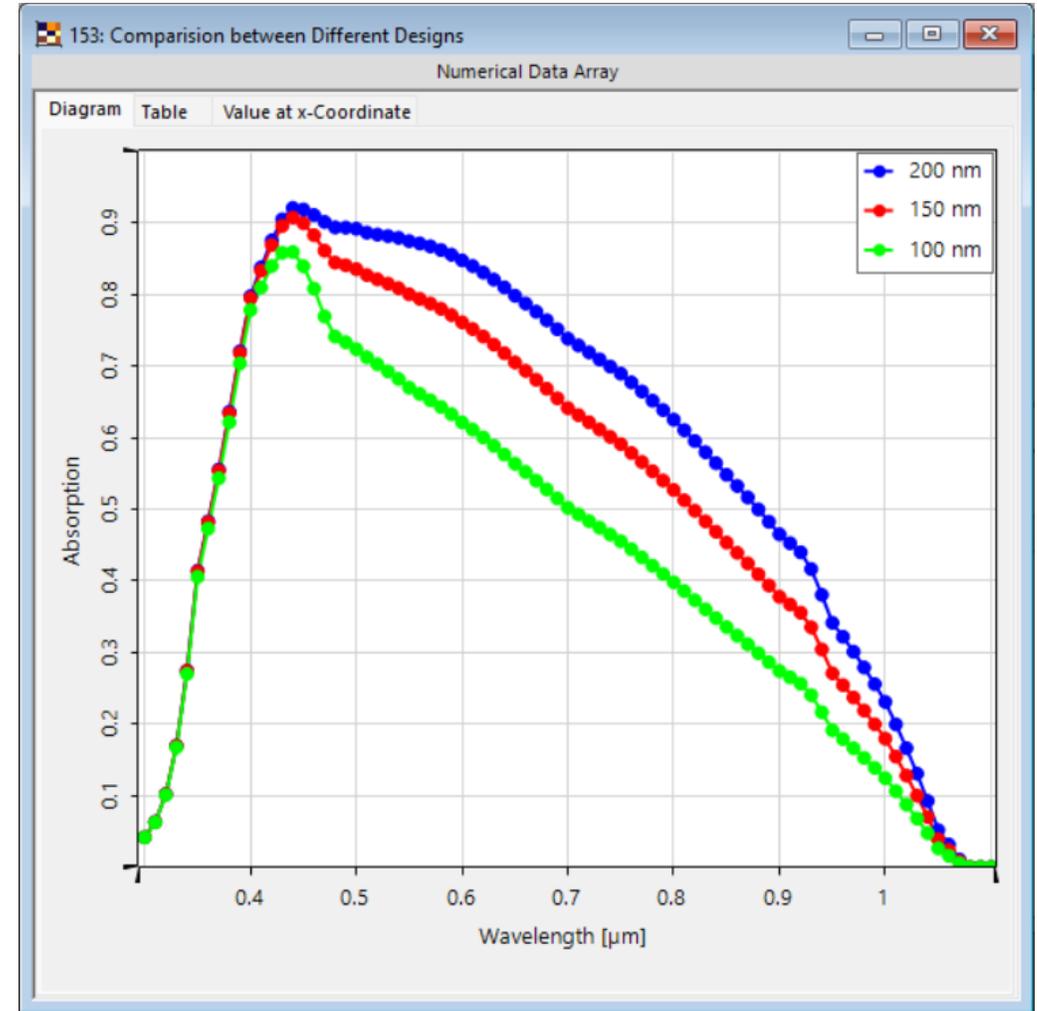
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Absorption for Different Thicknesses of the CIGS Layer



variation of thickness
of CIGS layer:
100/150/200 nm

Thickness of the absorbing material is one of the most important factors influencing the overall efficiency of the cell.



Document Information

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document version	1.0
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