Modeling and Simulation of Ultraviolet Downshifting and Infrared Reflective Encapsulants for Photovoltaic Modules

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Motivations & goals

Motivations [1]

- Improve power conversion efficiency
- Enhance lifetime stability

Target solar module

- Solar cell: c-Si n-type TOPCon
- Configuration: bifacial (glass-glass)
- Efficiency: 23%

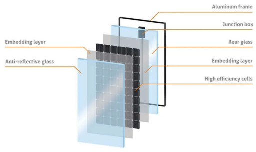

Figure 1 Structure of bifacial PV module

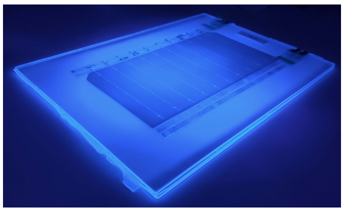

Figure 2 Photo of a mini-module with UVDS layer under artificial UV light

New layers

- Ultraviolet downshifting front encapsulant (UVDS)
- Infrared reflective back encapsulant (IR-reflective)

Goals

Propose experimental, analytical, simulation methods to characterize the impact of such layers on the PV module's performance.

Theory & Methods

Working principles

UV downshifting front encapsulant (UVDS):

- absorbs harmful UV photons ➡ protects from UV degradation
- re-emits blue spectral range photons ➡ generates more electricity

IR reflective back encapsulant (IR-reflective):

- redirects IR light back toward the cell ➡ generates more electricity

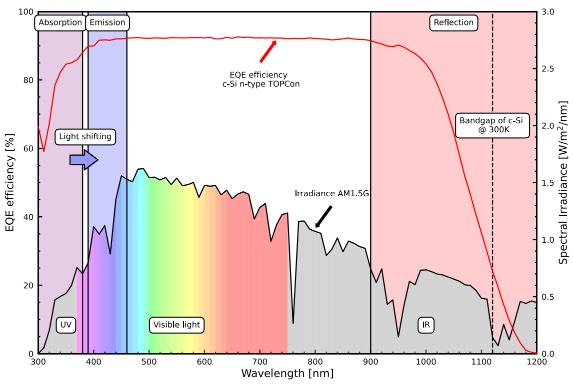

Figure 3 Scheme of UVDS and IR-reflective layers effects on the solar cell's performance

Experimental method

EQE measurements

IV-curve measurements

Spectrophotometry measurements

Analytical method

Simulate UVDS effect [2,3]

One-diode electrical model

Shockley-Queisser thermal model [4]

Simulation method CROWM

UVDS and IR-reflective effects simulation

Combined Ray Optics/Wave optics Model

New version developed on CROWM [5]

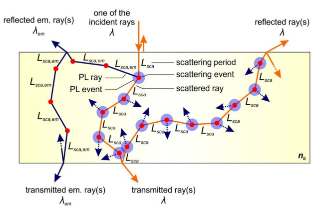

Figure 4 Photoluminescence path scheme

Results

Impact on electrical performance

KPI: short-circuit current density J_{sc}

Optimisation at standard test conditions (STC)

<u>UVDS layer</u>:

Comparison with UV blocker layer

Modification of properties:

- Absorbance scaling factor Λ_{abs}
- Conversion efficiency η_{LDS}

Maximum of +2.6% relative increase

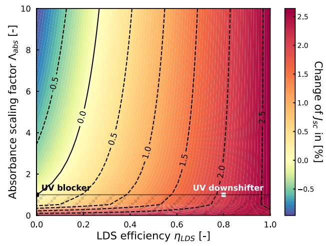

Figure 5 Optimisation color plot for UVDS layer

<u>IR-reflective layer</u>:

Comparison with clear matrix layer

Mitigated results

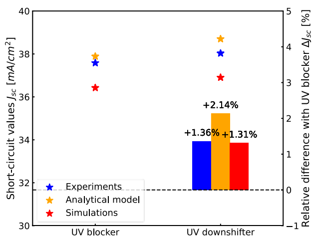

Figure 6 Jsc results for UVDS layer

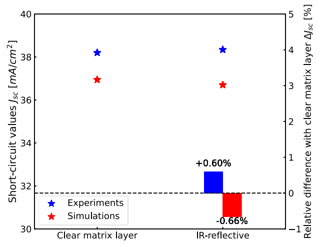

Figure 7 Jsc results for IR-reflective layer

Impact on energy yield

Different weather conditions days for UVDS layer

- Clear sky summer day
- Cloudy sky summer day
- Clear sky winter day
- Cloudy sky winter day

Yearly increase: **+2.18%**

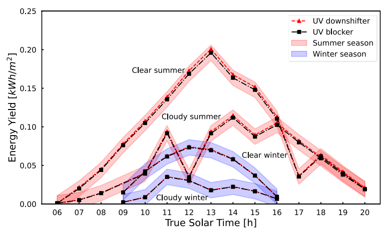

Figure 8 Energy yield estimation per hours

Day	Clear summer	Cloudy summer	Clear winter	Cloudy winter	Year
Absolute gain [Wh/m²]	+34.74	+21.16	+3.69	+1.44	**+2'804**
Relative gain [%]	+2.62%	+2.73%	+1.01%	+1.03%	**+2.18%**

Figure 9 Energy yield results with UVDS layer

Conclusion & perspectives

- UV downshifting front encapsulant can enhance the energy yield by +2%.
- IR-reflective back encapsulant shows mitigated results.
- New version of CROWM with photoluminescence incorporation.
- Broader applications could benefit from the UV downshifting effect.

Acknowledgements

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