End-to-End Approach in Photovoltaics : Technology-Agnostic Compact Models

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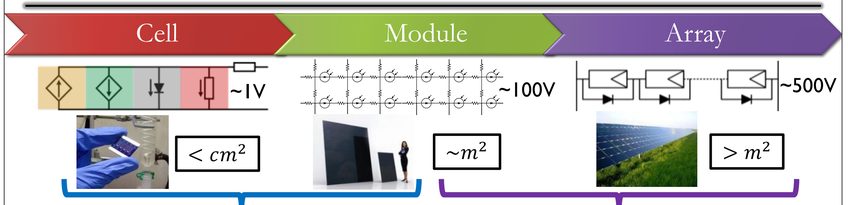
NEEDS

An End-to-End Approach for PV



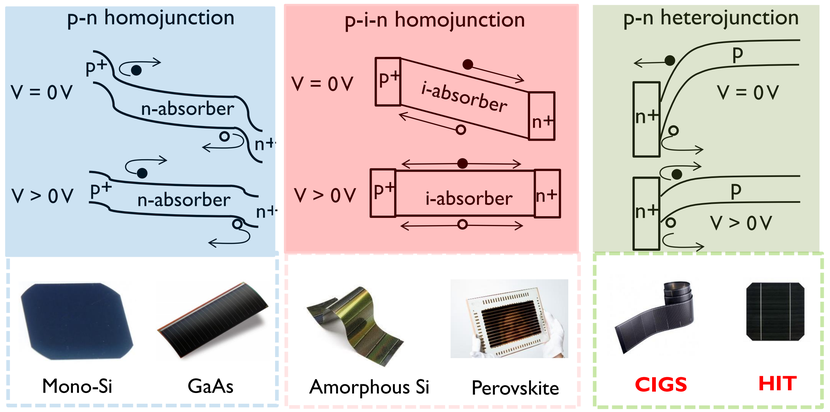
Shunt leakage and its effect on module efficiency

Partial shading, PID, Hot Spot, Corrosion related loss

Compact models connects micro-scale cells to macro-scale arrays.

1

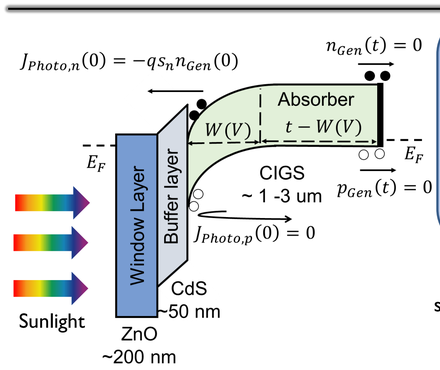
Only Three Configurations of Solar Cells



Develop compact models for all three classes of solar cells.

2

Compact model for heterojunction CIGS Cells



A typical CIGS solar cell

electron and hole continuity equations

$$D\frac{\partial^2 n(x)}{\partial x^2} + \mu E(x)\frac{\partial n(x)}{\partial x} + G(x) - R(x) = 0$$

$$D\frac{\partial^2 p(x)}{\partial x^2} - \mu E(x)\frac{\partial p(x)}{\partial x} + G(x) - R(x) = 0$$

Poisson's equation

$$\nabla \cdot E(x) = \rho(x)/\epsilon$$

solve non-linear coupled equations analytically

$$J_{Photo} = \frac{J_{SC}}{1 + \alpha_C \exp(\beta \frac{q(V - V_{bi})}{k_B T})}$$

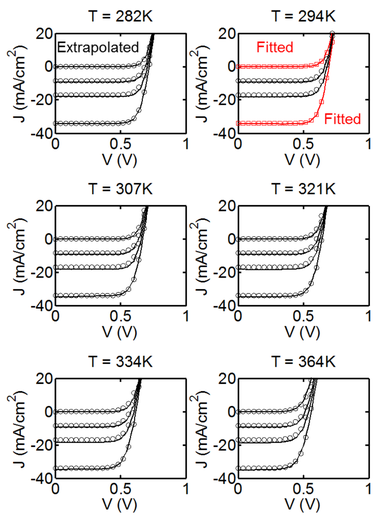
$$J_{Diode} = J_0(\exp\left(\frac{qV}{AkT}\right) - 1)$$

$$J_{light} = J_{Diode} + J_{photo}$$

Photocurrent obtained analytically by solving the drift-diffusion equations, with approximations validated by numerical simulations.

3

The CIGS Model Anticipates Temperature- and Illumination-Dependent IV



Validation Steps:

Fit the model to the dark and light IV at one sun and room temperature — Step 1: Calibration

Extrapolate the parameter from Step 1 to other temperatures & irradiances — Step 2: Prediction

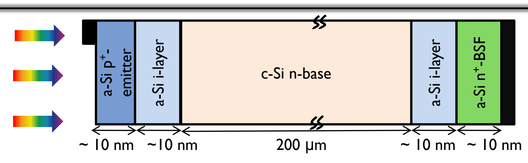
The model is compared to measurements using the extrapolated parameters — Step 3:Validation

The model predicts temperature- and illumination-dependent IV without performing the measurement.

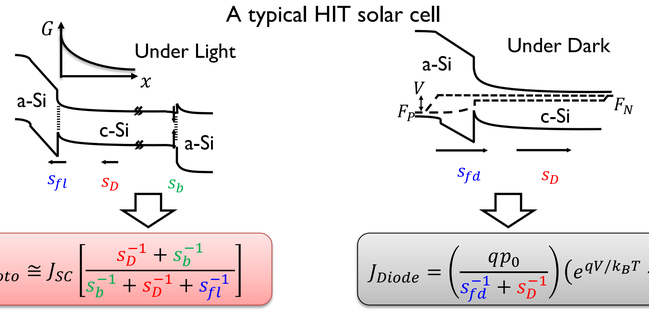
Sun, JPV., 2016. (Submitted)

4

Compact Model for heterojunction HIT Cells



A typical HIT solar cell



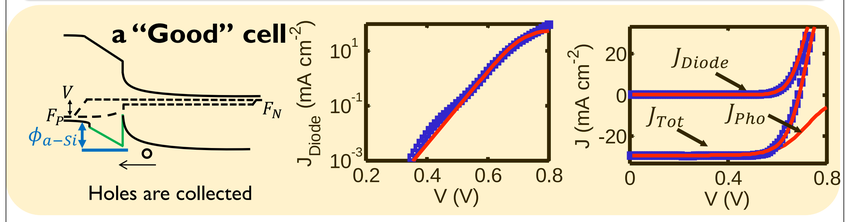
$$J_{Photo} \cong J_{SC}\left[\frac{s_D^{-1} + s_b^{-1}}{s_b^{-1} + s_D^{-1} + s_{fl}^{-1}}\right]$$

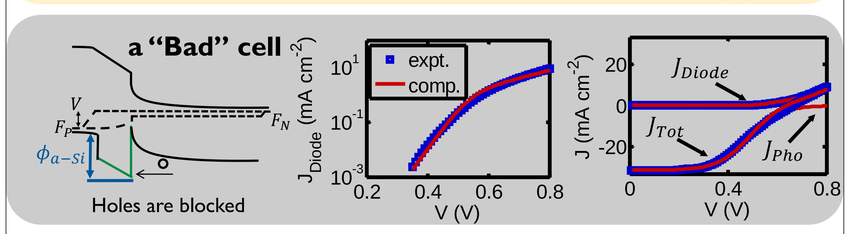
$$J_{Diode} = \left(\frac{qp_0}{s_{fd}^{-1} + s_D^{-1}}\right)\left(e^{qV/k_BT} - 1\right)$$

We have analytically solved photocurrent and diode current in HIT cells.

5

First HIT Model to Capture Process Variations



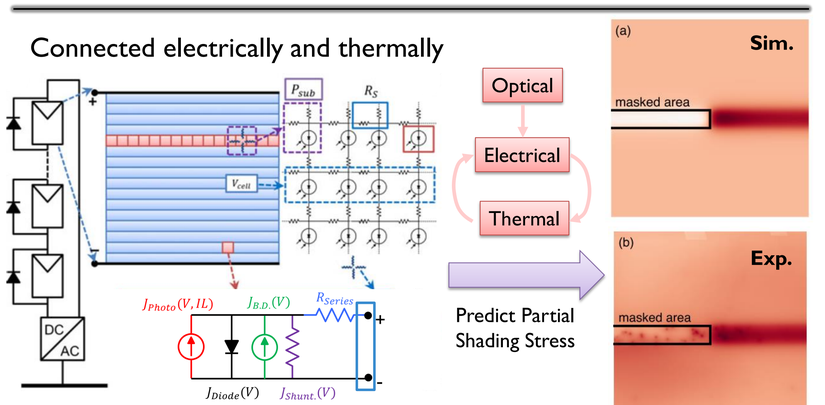


The compact model connects the a-Si film properties to I-V characteristics.

6

The Opto-Electro-Thermal Coupled Simulation Framework for CIGS Modules

Connected electrically and thermally



Optical

Electrical

Thermal

Predict Partial Shading Stress

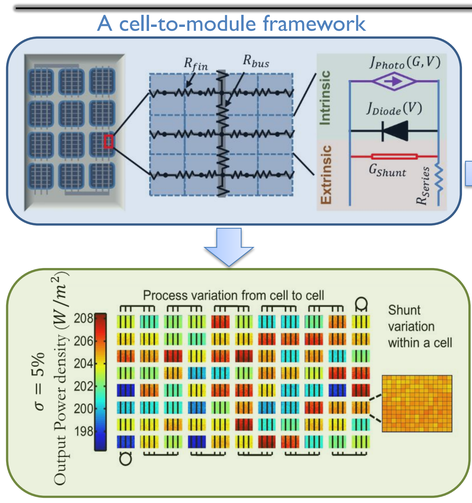
Silverman, JPV., 2015.

The panel simulation framework has ben used to predict the industrial-standard shading-stress test.

7

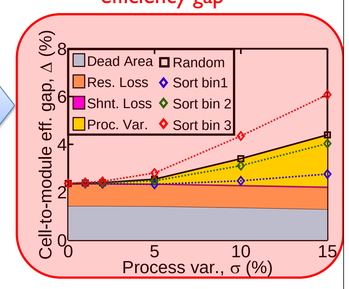
Impact of Process Variation at the Module level

A cell-to-module framework



Performance variation within a module

Variation-induced cell-to-module efficiency gap

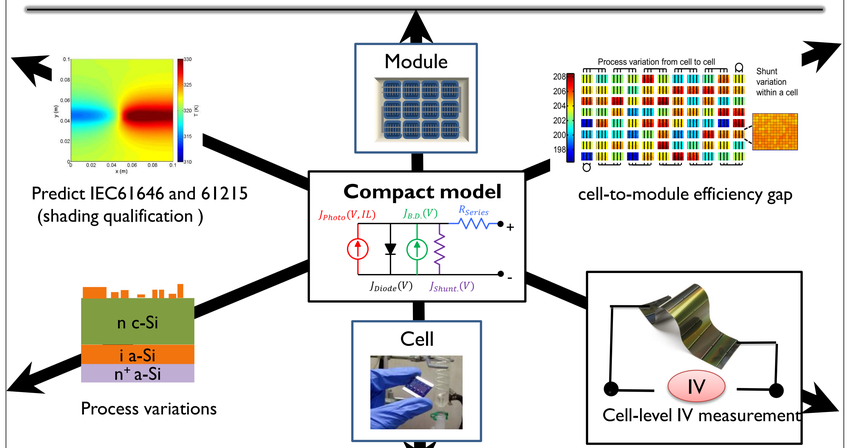


Chavali, JPV., 2016.

Connects cell-level variations to panel-level performance.

8

Conclusions and Plans



The model package v2.0.0 will be available on NEEDS website 08/16

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Xingshu Sun, *et al.*, A physics-based compact model for CIGS and CdTe solar cells: from voltage-dependent carrier collection to light-enhanced reverse breakdown, Photovoltaic Specialist Conference (PVSC), 2015 IEEE 41th, 14-19 June 2015.
Xingshu Sun, et al., "A Physics-Based Analytical Model for Perovskite Solar Cells," IEEE J. Photovoltaics, vol. 5, no. 5, pp. 1389–1394, Sep. 2015.
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Xingshu Sun, et al., "An Illumination- and Temperature-Dependent Analytical Model for Copper Indium Gallium Diselenide (CIGS) Solar Cells," IEEE J. Photovoltaics, 2016. (submitted)

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