Loss Analysis of a Perovskite/Perovskite/Silicon Solar Cell

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Motivation

- Perovskite/perovskite/silicon triple-junction is a promising candidate for high-efficiency low-cost solar cells
- Simulations can analyze specific parameters or aspects of a device that may be difficult to access experimentally
- Simulations can provide guidelines for development of multi-junction solar cells

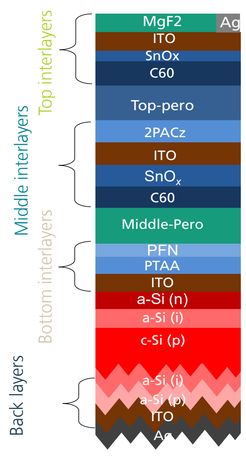
General Approach

- The simulation consists of two parts:
  - Optical simulation that yields an absorption profile
  - Electrical simulation which provides band diagrams and *iV*-curves
- The simulation is conducted with Sentaurus TCAD

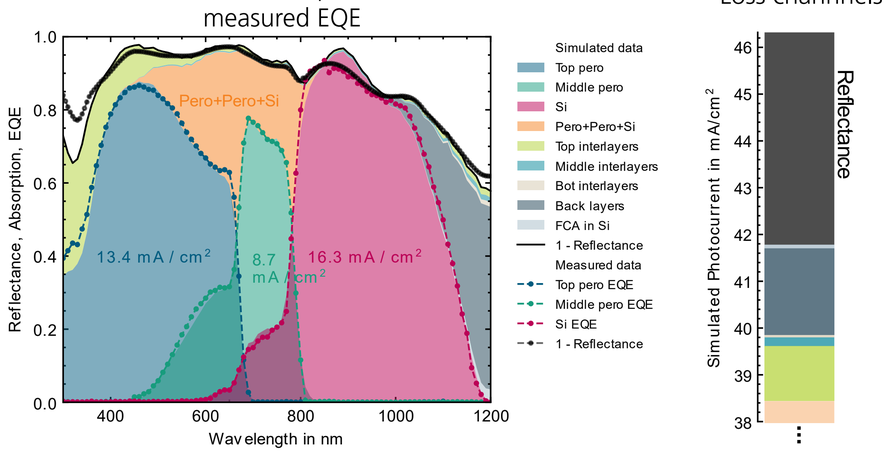
Optical Analysis

- The optical simulation calculates **reflection**, **transmission** and **absorption** of the individual layers using **transfer-matrix method** and **raytracing**
- The simulation is compared against original lab cell's measured values. Based on this comparison, an **optical roadmap** [1] is conducted

Layerstack



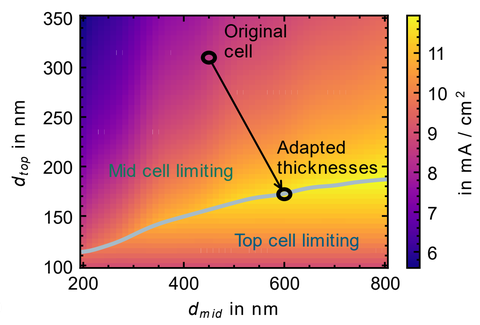
Simulated absorption and measured EQE



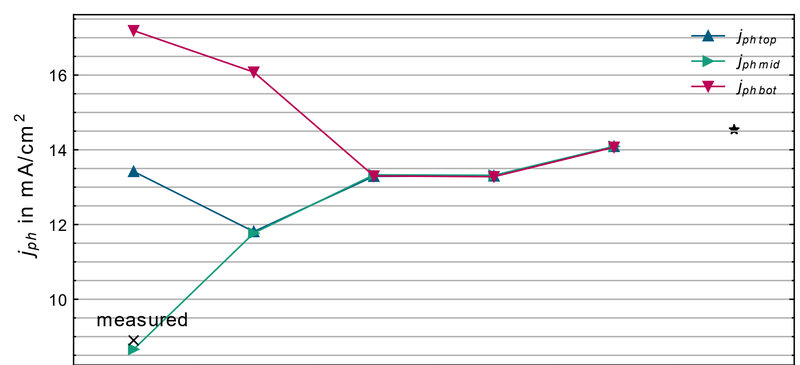
Loss channnels

- The scenarios considered here are:
  1. Adjusted perovskite thicknesses
  2. Adjusted perovskite bandgaps
  3. Adding front side texture

Adjusted absorber thicknesses
Photocurrent of 3J cell



Photocurrent roadmap

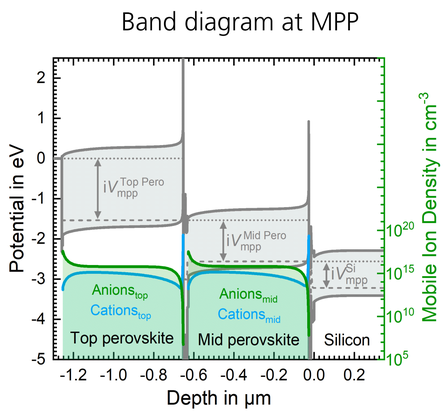


	Current 3J cell	+ Adjusted thicknesses	+ Adjusted $E_{g,mid}$	+ Adjusted $E_{g,top}$	+ Front textured	Radiative limit
$E_{g,top}$ in eV	1.84	1.84	1.84	1.98	1.97	2.01
$E_{g,mid}$ in eV	1.57	1.57	1.47	1.47	1.46	1.5
d_{top} in nm	270	167	235	600	600	-
d_{mid} in nm	450	600	600	600	600	-

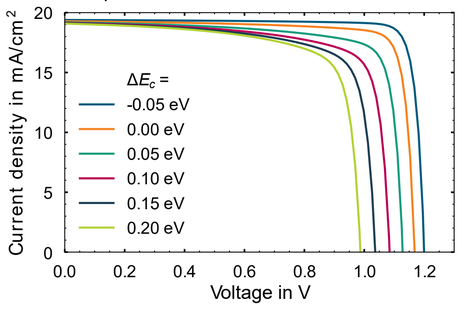
Electrical Analysis

- Simulation is based on **drift-diffusion** and **Poisson equation** of electrons, holes, and mobile ions
- Includes **Radiative**, **Shockley-Read-Hall**, and **Auger recombination**
- Yields ***iV*-curves** and **band diagrams** of the device
- Simulations adapted electrical parameters from [2]

Band diagram at MPP

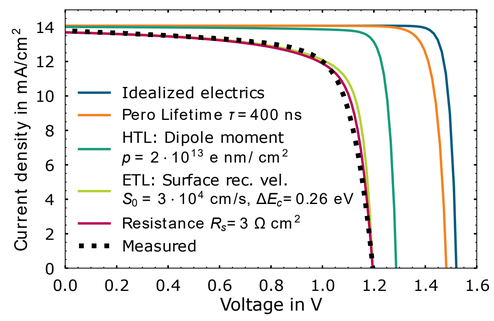


Variation of conduction band alignment at ETL/perovskite interface in middle cell

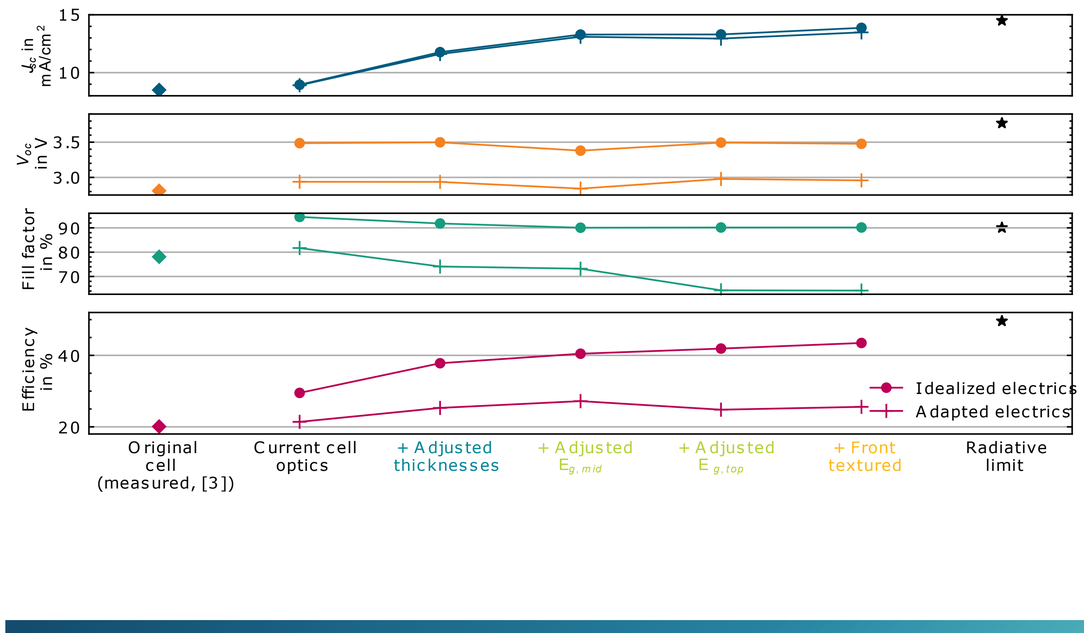


- Band diagram shows e.g. in detail where iVoc/Voc losses occur
- Impact of individual parameters can be analysed
- Losses of different sources are quantized

iV-curves *t*opcell, from idealized electrics to measurement (with electrical parameters from [2])



Roadmap with adapted electrics



Summary

- An opto-electrical model for perovskite/perovskite/silicon triple junction solar cells was built showing a practical efficiency potential of 44.3%
- Short-circuit current density can be improved from 8.7 mA/cm² to 13.3 mA/cm² with perovskite thickness and bandgap adjustments
- Electrical simulation is needed to understand losses at interfaces and guide development of interface engineering

1 L. Restat et al, Solar RRL 2024, DOI: 10.1002/solr.202300887

2 O. Er-raji et al, Solar RRL 2023, DOI: 10.1002/solr.202300659

3 M. Heydarian, ACS Energy Letters, DOI: 10.1021/acsenergylett.3c01391

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