Zentrum für Sonnenenergie- und Wasserstoff-
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Open-Circuit Voltage Losses in Perovskite/Cu(In,Ga)Se_2 Tandem Partners

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Objective

- To analyse the recombination in perovskite and Cu(In,Ga)Se_2 (CIGS) solar cells individually and together in a tandem structure
- To evaluate the impact of individual layer properties on device performance

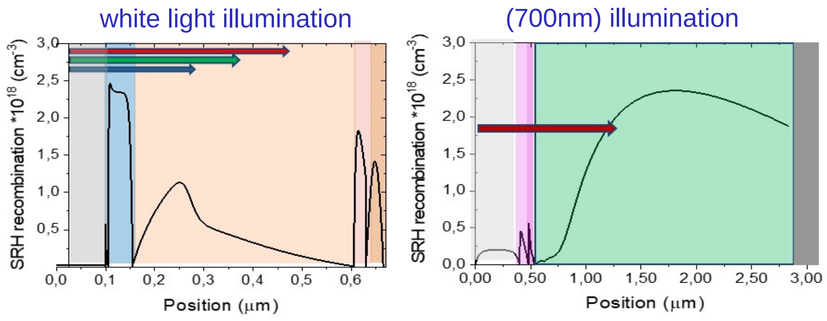
Location of SRH Recombination

- In the perovskite cell, most recombination happens in the transport layers
- In the CIGS under perovskite, the recombination is mostly in the absorber

Simulated SRH recombination rate as a function of position in:

Perovskite cell under white light illumination

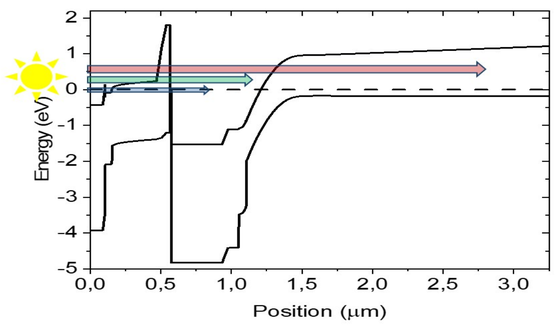
CIGS cell under filtered (700nm) illumination



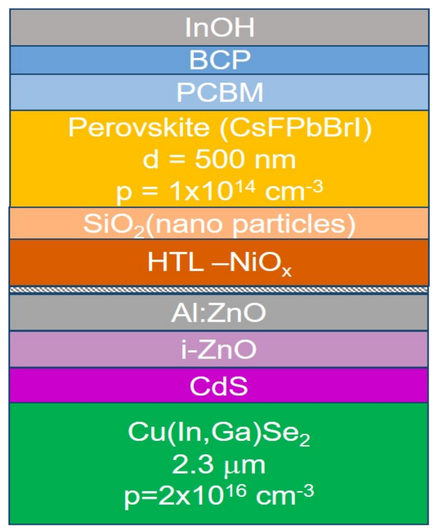
Introduction

- Perovskite and CIGS are good tandem candidates due their favorable optoelectronic properties
- Nonradiative recombination is the dominant loss mechanism in both devices
- We show numerical simulations to understand the dominant contributors of Shockley–Read–Hall (SRH) recombination
- The individual cells are simulated with SCAPS 1D and the tandem structure with Silvaco TCAD software

A simulated equilibrium band diagram of the tandem structure



A schematic of the Perovskite / CIGS structure used in simulations

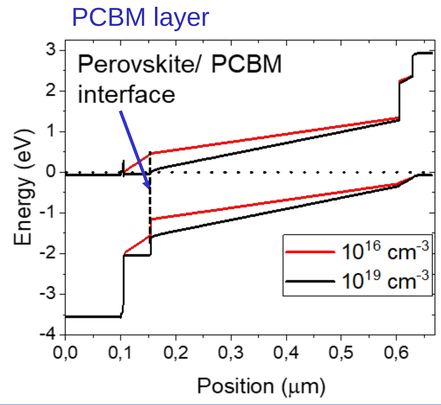


Impact of Carrier Density in the Electron Transport Layer

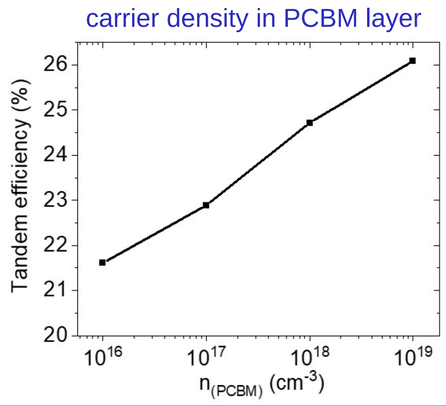
Increased carrier density in the PCBM layer:

- flattens the bands in PCBM and decreases the supply of holes available for recombination
- decreases the sensitivity of performance to interface defects
- can improve tandem conversion efficiency by > 4% absolute
- reduces the overall SRH recombination rate

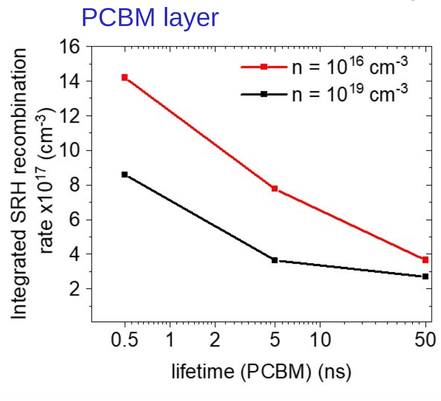
Equilibrium band diagram for two carrier densities in the PCBM layer



Efficiency of tandem structure as a function of carrier density in PCBM layer

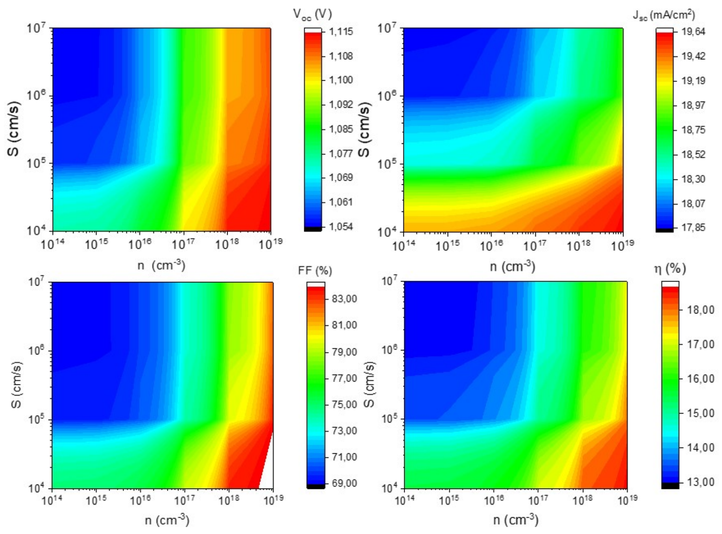


Integrated SRH recombination as a function of defect density in PCBM layer



PCBM / Perovskite Interface Recombination

Contour plot showing the simulated combined impact of carrier density in PCBM layer and interface recombination at the Perovskite / PCBM interface

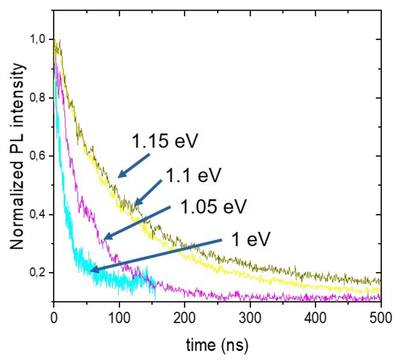


- Impact of interface recombination is strongly dependent on the band bending in transport layers
- Low carrier density in the transport layer and a defective interface can decrease the efficiency by 5% absolute

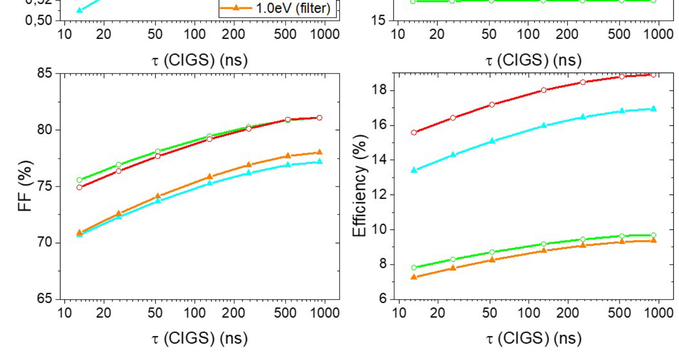
CIGS Bottom Cell

- Comparing standard band gap (min band gap at the notch =1.1 eV) and low band gap CIGS (1 eV)
- Measured low band gap CIGS shows significantly lower minority-carrier lifetime
- Under a 700 nm filter, the efficiencies are comparable

Time-resolved photoluminescence measurements for different CIGS band gaps



Calculated solar cell parameters as a function of defect density in the CIGS absorber for low band gap (1eV at the notch) and 'standard' CIGS (1.1 eV at the notch)



Conclusions

- The dominant nonradiative recombination in the perovskite is in transport layers and interfaces, while for CIGS it is in the absorber
- Higher carrier density in ETL layer increases the tolerance to defects in the ETL layer and at the interface
- While a bottom cell with a low band gap provides a more favorable current, the filtered efficiency and minority carrier lifetimes slightly favor a moderately higher band gap

Acknowledgements

- The authors acknowledge German Federal Ministry for Economic Affairs and Energy under Project Number 03EE1078 (ODINCIGS).
- The authors acknowledge the VIPERLAB project financed by European Union's Horizon 2020 (grant agreement N°101006715).
- The single junction simulation reported in this work were performed with the use of SCAPS-1D program developed at the University of Gent, while the tandem simulations used Silvaco TCAD software package.