Funded by
the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

TERASUN

Understanding the electron transport mechanisms in MoO_x-based layer stack for application in simplified IBC-SHJ solar cells

K. Kovačević, Y. Zhao, P. Procel, L. Cao, L. Mazzarella, O. Isabella

4th of December 2024

Delft, The Netherlands

BCworkshop 2024

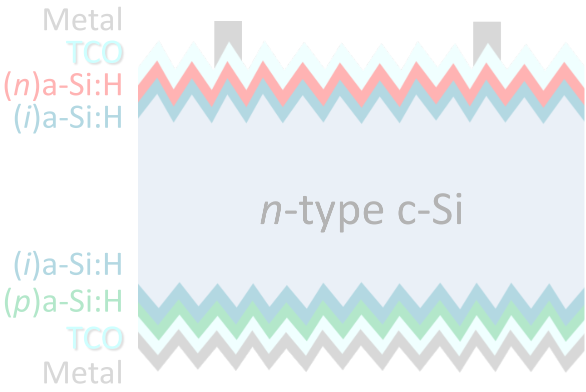
PVMD
Delft University of Technology

TU Delft

Silicon heterojunction (SHJ) solar cells

Front/back-contacted (FBC)

η = 26.81% [1]



V_{OC} > 750 mV [1]

Limited potential for J_{SC}

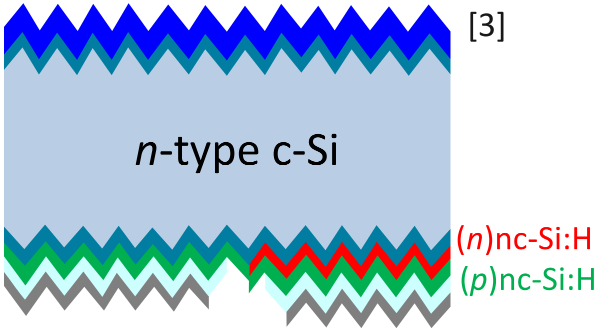
Interdigitated-back-contacted (IBC)

η = 27.3% [2]

Optimized front side

Complex fabrication

η = 25.4% [4]



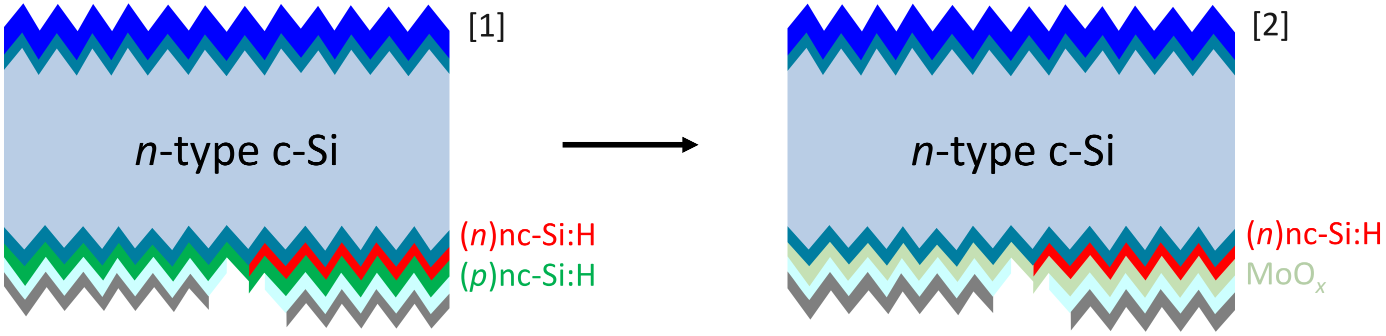
Reduced complexity

Challenge to control high shunt resistance[4]

Simple processing and controlable high shunt resistance?

[1] H. Lin, et al., *Nat. Energy*, **8**, 789 (2023)
[2] H. Wu, et al., *Nature*, **635**, 604 (2024)
[3] A. Tomasi, et al., *Nat. Energy*, **2**, 17062 (2017)
[4] D. Lachenal, bifiPV Workshop, Zhuhai, China (2024)

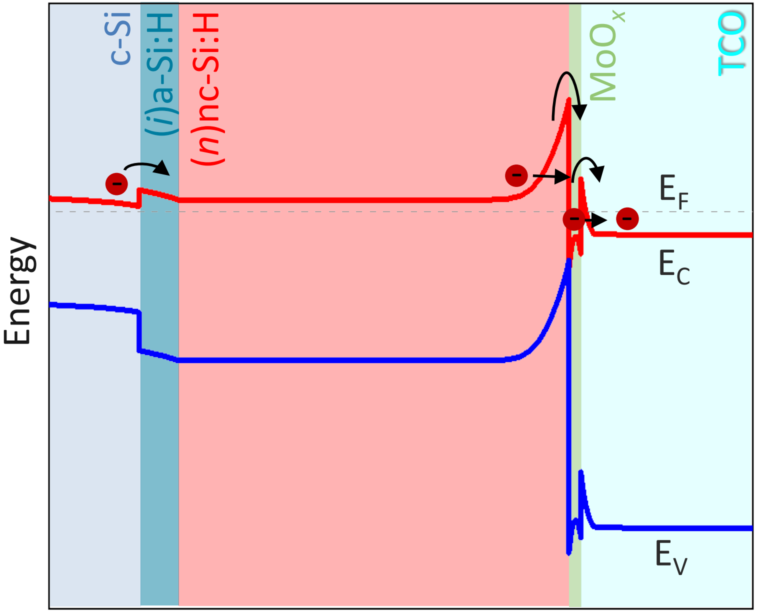
Alternative material choice

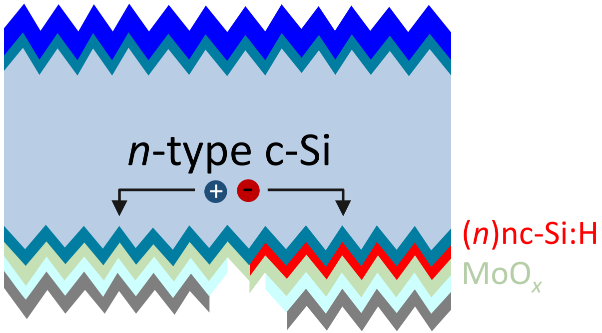


- Low lateral conductivity of MoO_x [3]
- η = 23.83% FBC-SHJ solar cell with ~2 nm MoO_x as HTL [4]
- Potentially faster processing of blanket layer
- Novel ETL with (*n*)nc-Si:H and MoO_x [2, 5]

[1] A. Tomasi, et al., *Nat. Energy*, **2**, 17062 (2017)
[2] K. Kovačević, et al., *Prog. Photovolt. Res. Appl*, (2024)
[3] L. Gerling, et al., *Sol. Energ. Mater. Sol. Cells*, **145**, 109 (2016)
[4] L. Cao, et al., *Prog. Photovolt. Res. Appl*, **31**, 1245 (2022)
[5] K. Kovačević, et al., *To be submitted*

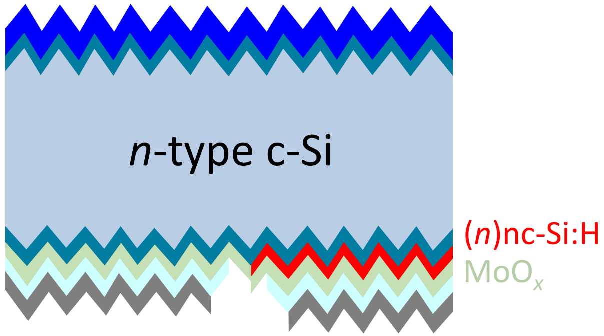
Working principle of the electron transport layer (ETL) stack





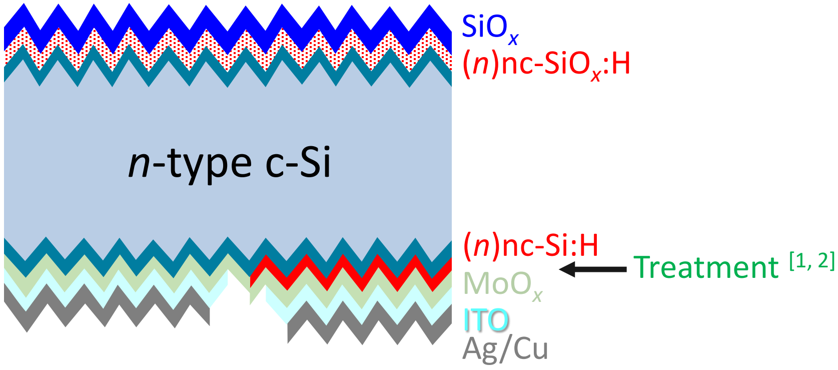
➡ Charge transfer in conduction band and no recombination junction

IBC-SHJ solar cells with MoO_x blanket layer



IBC-SHJ solar cells with MoO_x blanket layer

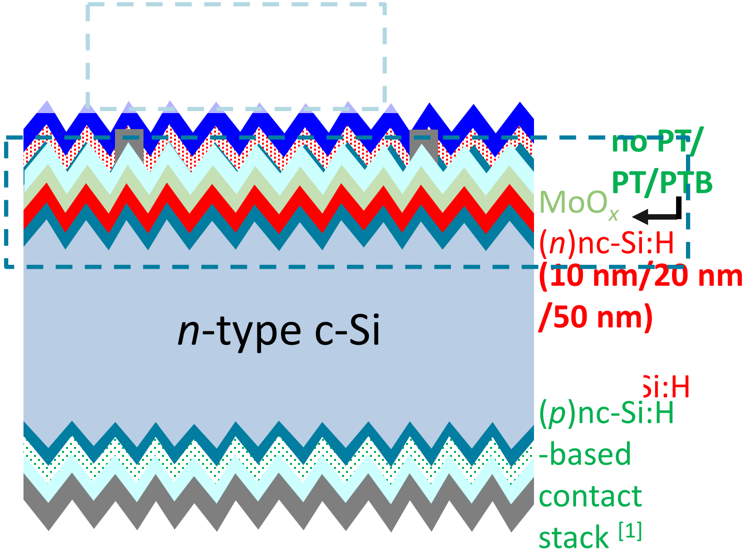
- Optimization of electron transport layer (ETL) stack
- Understanding of charge carrier collection
  - Effect of temperature
  - Interface analysis



$\eta > 23\%$

[1] L. Mazzarella, et al., *Prog. Photovolt. Res. Appl*, **29**, 391 (2020)
[2] L. Cao, et al., *Prog. Photovolt. Res. Appl*, **31**, 1245 (2022)

ETL contact stack evaluation



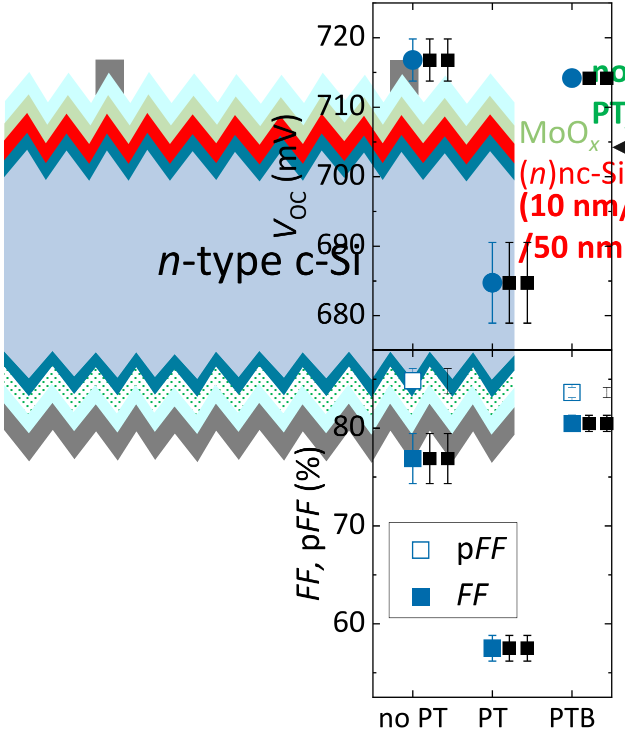
Experimental evaluation of passivation and transport

- Plasma treatment (PT)
  SiH_4, H_2, CO_2 [2]
  and plasma treatment with boron (PTB)
  SiH_4, H_2, CO_2, B_2H_6 [2, 3]
- (*n*)nc-Si:H thickness

[1] Y. Zhao, et al., *Sol. Energ. Mater. Sol. Cells*, **219**, 110779 (2021)
[2] L. Cao, et al., *Prog. Photovolt. Res. Appl*, **31**, 1245 (2022)
[3] L. Mazzarella, et al., *Prog. Photovolt. Res. Appl*, **29**, 391 (2020)

 All FBC-SHJ solar cells feature ITO TCO and screen-printed Ag contact

ETL contact stack evaluation

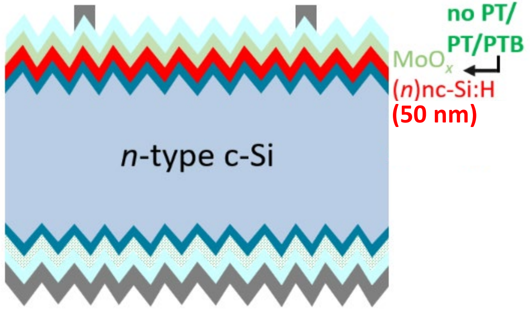


➡ Comparable V_{OC} and p*FF*

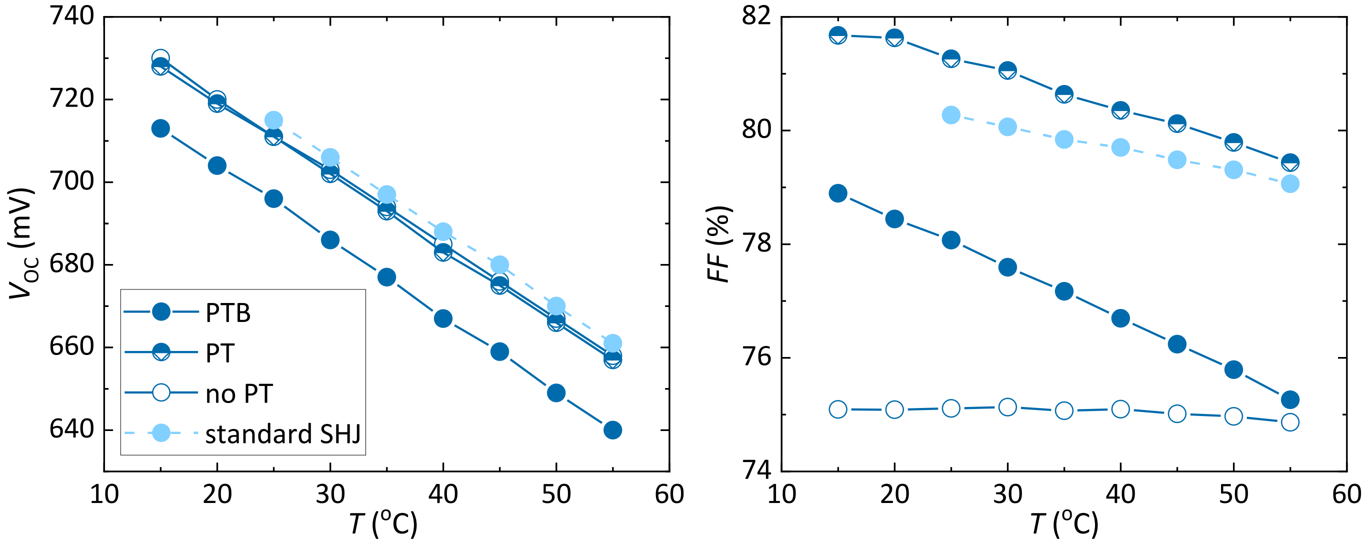
➡ Improved *FF* from (*n*)nc-Si:H/MoO$_x$

➡ **Overall improvement with PTB and lower sensitivity to (*n*)nc-Si:H thickness**

Effect of temperature



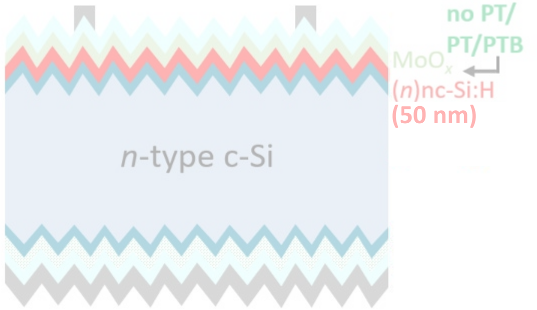
Temperature ↑ → ***Recombination*** ↑ → V_{OC} ↓ & *FF* ↓ [1, 2]

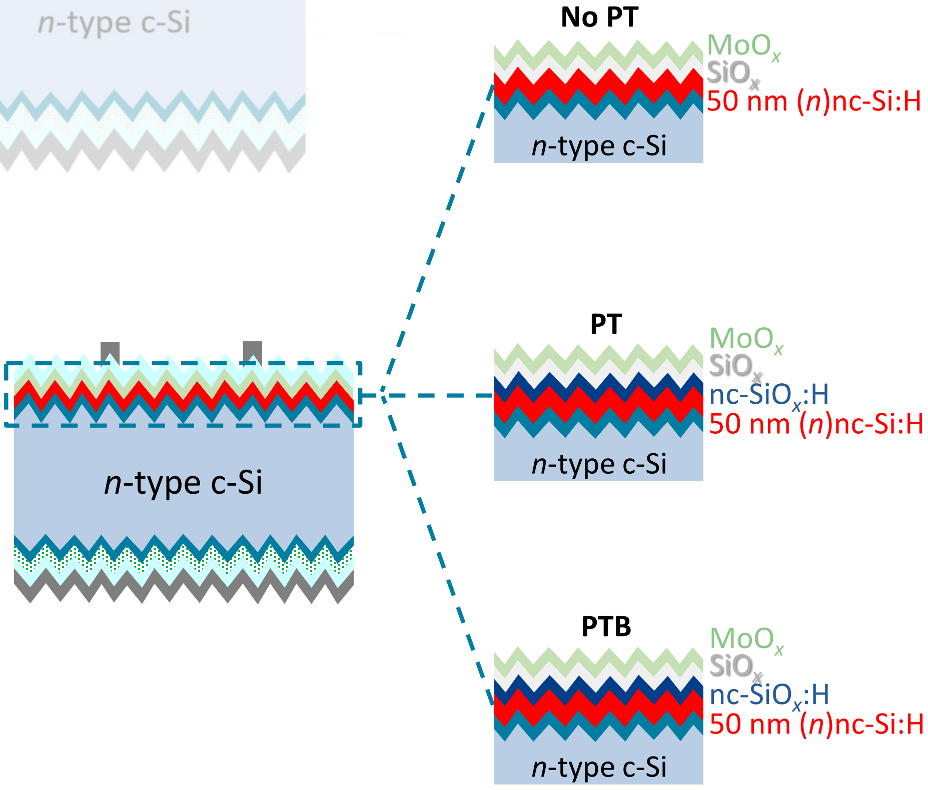


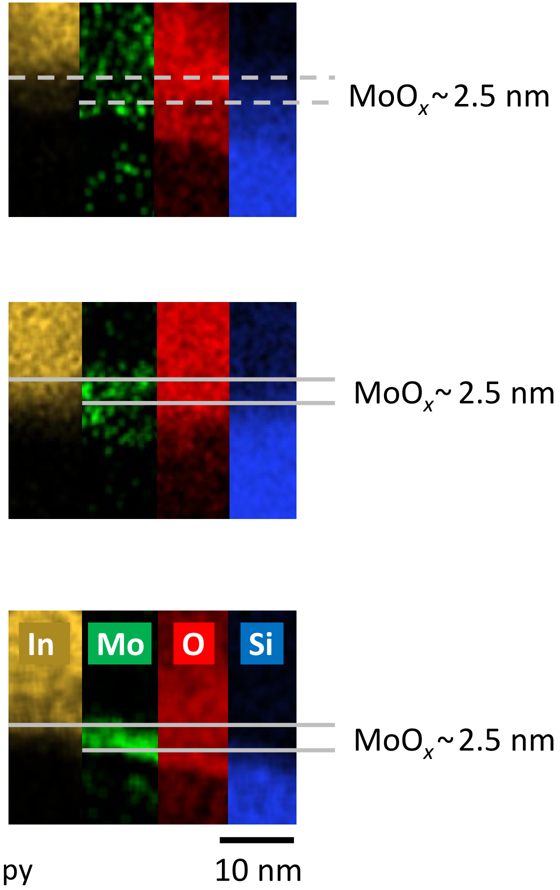
➡ Transport based on direct energy transitions enabled by PT and PTB [3]

[1] R. N. Hall, *Phys Rev*, **87**, 387 (1952)
[2] W. Shockley and W. T. Read, *Phys Rev*, **87**, 835 (1952)
[3] L. Mazzarella, et al., *Prog. in Photovolt. Res. Appl*, **29**, 391 (2020)

Interface and elemental analysis*

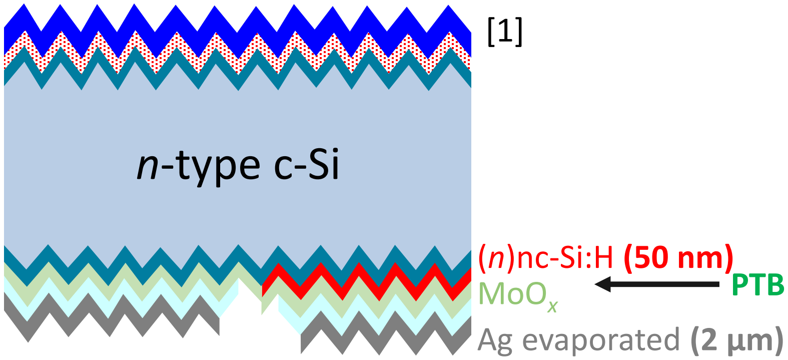


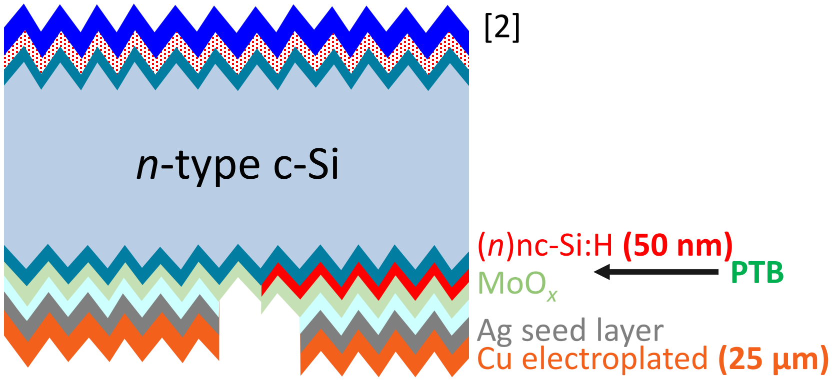


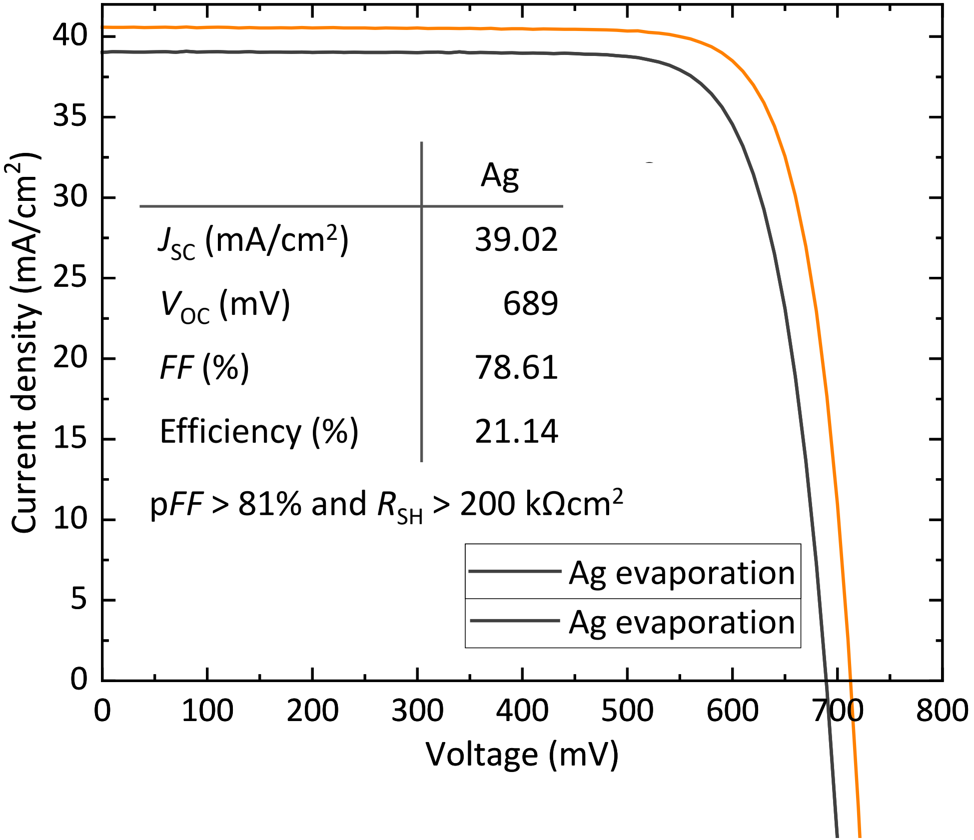


*Based on results of high-resolution transmission electron microscopy (HR-TEM) and energy-dispersive X-ray spectroscopy (EDX) analysis

IBC-SHJ solar cells with MoO_x blanket layer

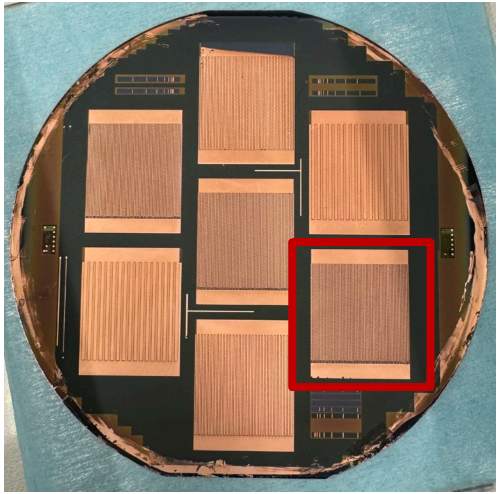


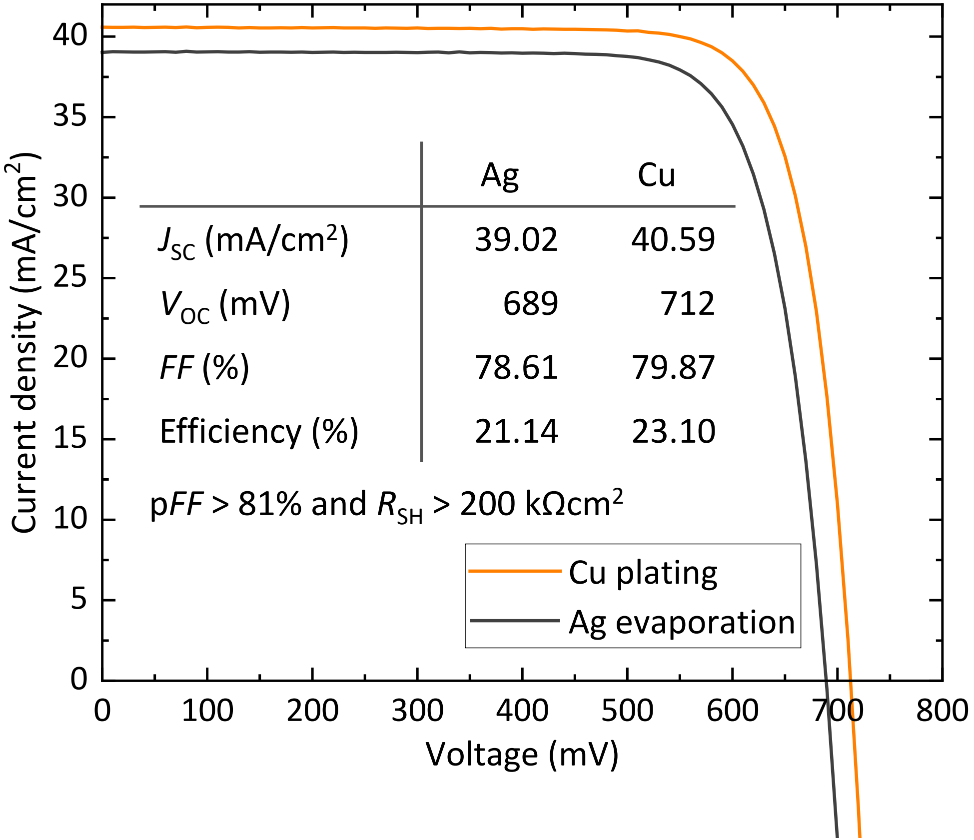




[1] K. Kovačević, et al., *Prog. Photovolt. Res. Appl*, (2024)
[2] K. Kovačević, et al., *To be submitted*

IBC-SHJ solar cells with MoO_x blanket layer

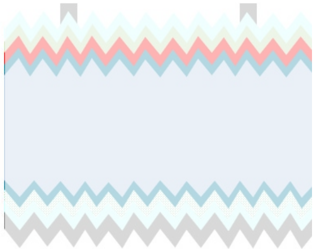


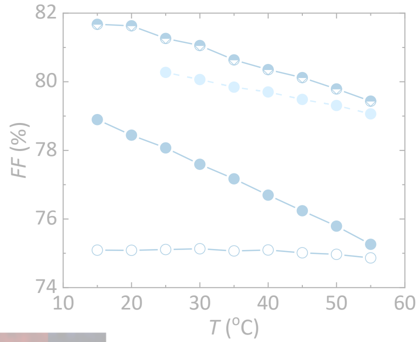


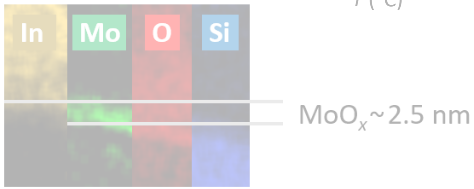
Future optimization towards $\eta > 24\%$

- Passivation enhancement
- (*n*)nc-Si:H improvement
- Double layer anti-reflection coating
- Metal grid redesign for higher bifaciality

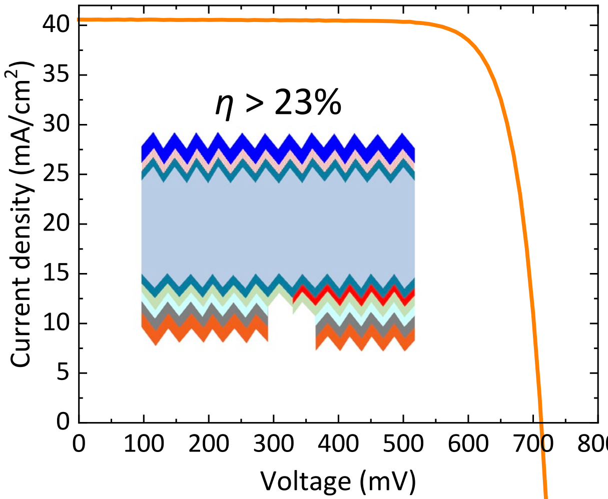
Conclusion







- Optimization of electron transport layer (ETL) stack
- Understanding of charge carrier collection
    - Effect of temperature
    - Interface analysis



Thank you for your attention!

TU Delft Institutes

Urban Energy

e-Refinery

AgTech

TU Delft Climate Action Programme

TERASUN

PVMD funding

Rijksdienst voor Ondernemend Nederland

URBAN EUROPE

HORIZON 2020

cet Partnership

Horizon Europe

NWO

HyET Solar
Flexible light weight solar modules

Contact

K.Kovacevic@tudelft.nl

Request your trial version of ASA7: **http://asa.ewi.tudelft.nl/**

PVMD web-lab: **www.tudelft.nl/dutchpvportal**

International PV Systems Summer School: **www.tudelft.nl/pvsss**

Scan the QR-code to reach our online courses hub

IBC-SHJ solar cells with MoO_x blanket layer