From Silicon Heterojunction to Transparent Passivating Contacts

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History of SHJ at JÜLICH

2007 – Started research on SHJ solar cells

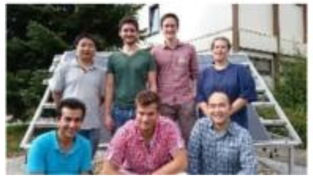
2012 – η=18.5%,0.67 cm^2 SHJ

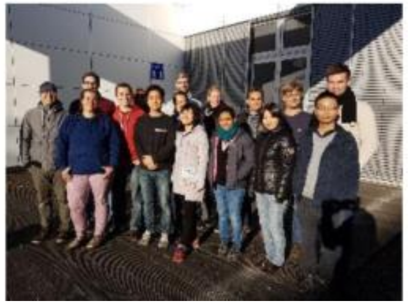
2016 – η=20.4%, 4 cm^2 SHJ

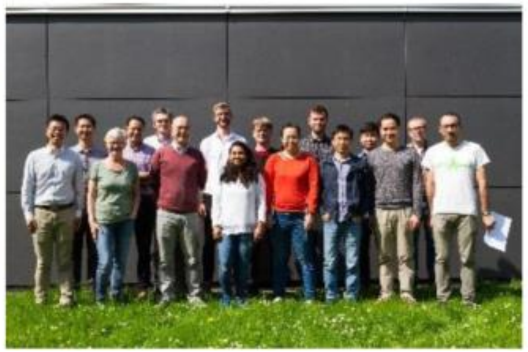
2017 – Establishing the SHJ-Baseline

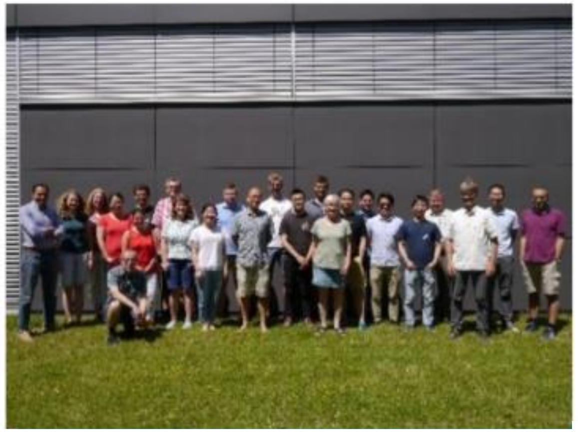
2019 – η=23.77%, M2, 0BB

2020 – η=24.55%, M2, 0BB

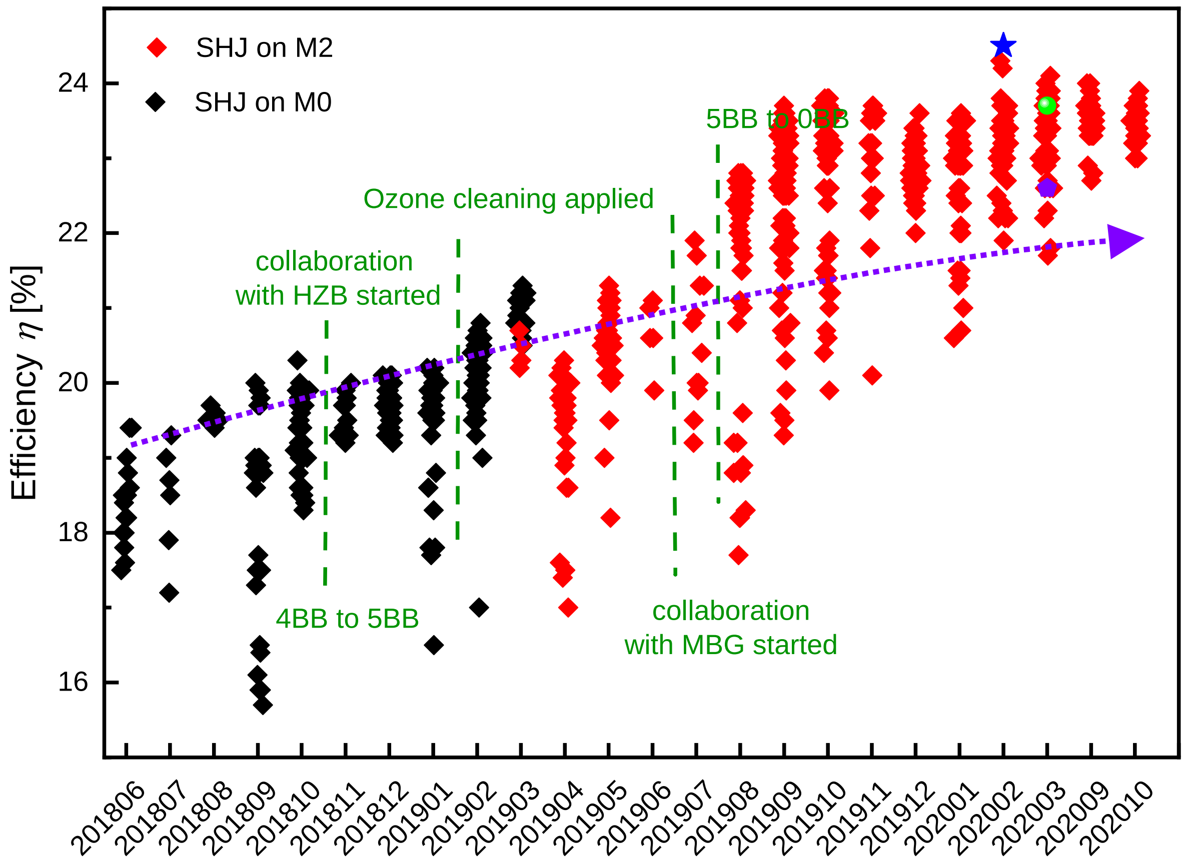








Cell progress of SHJ at JÜLICH



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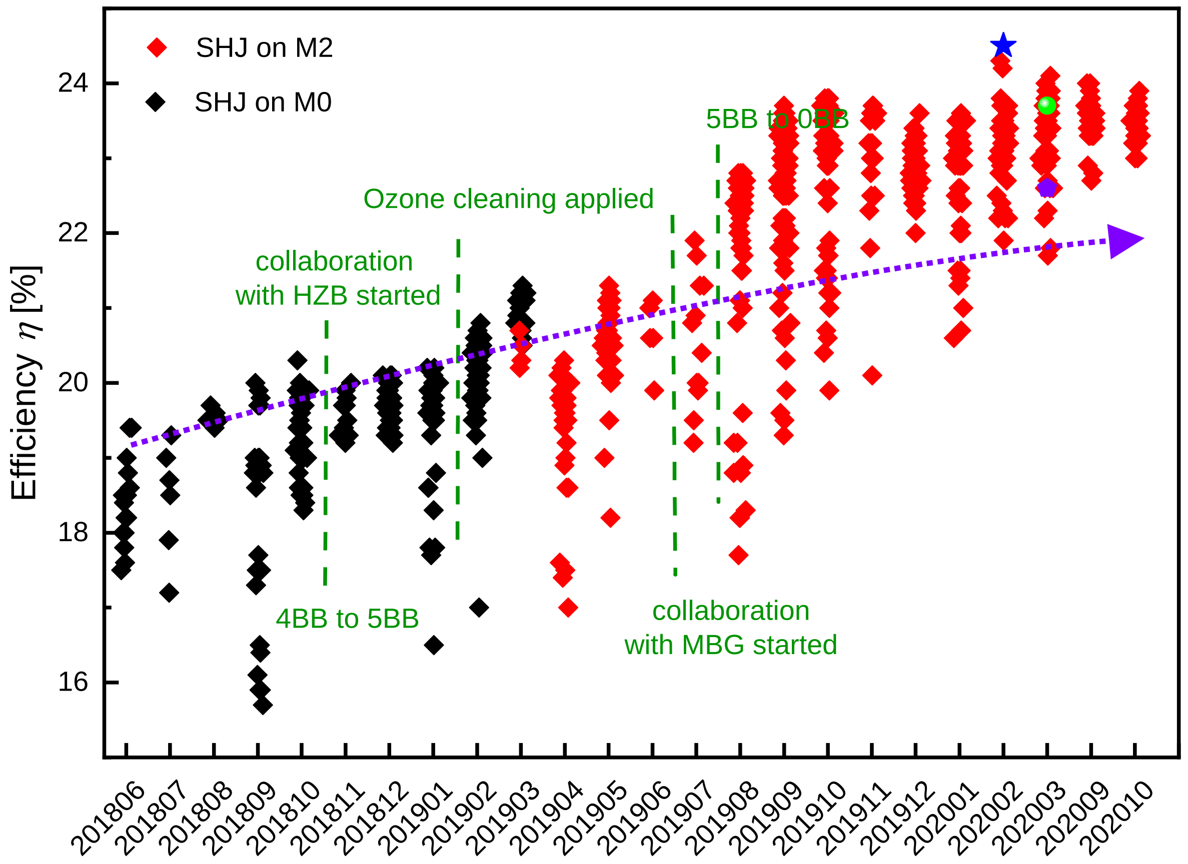


House measured champion

V_{oc}= 747 mV

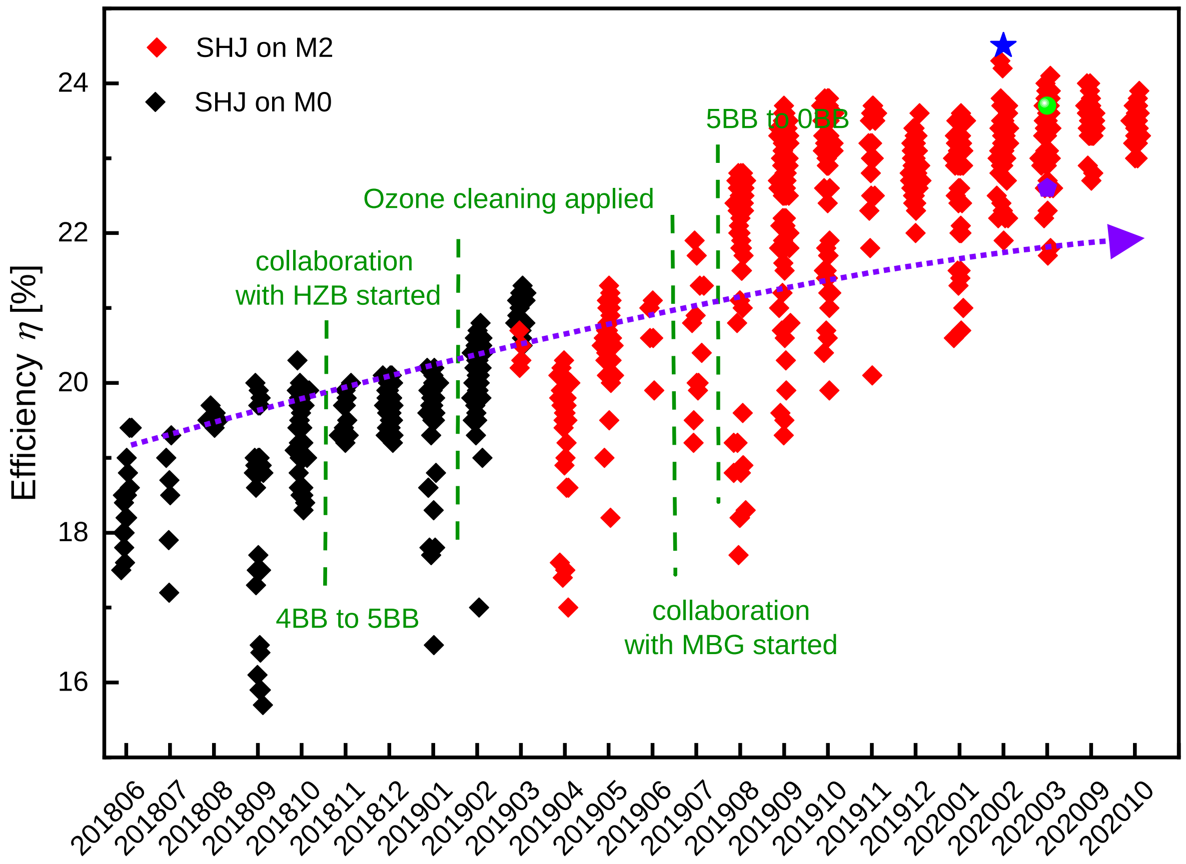
J_{sc}= 40.05 mA/cm^2

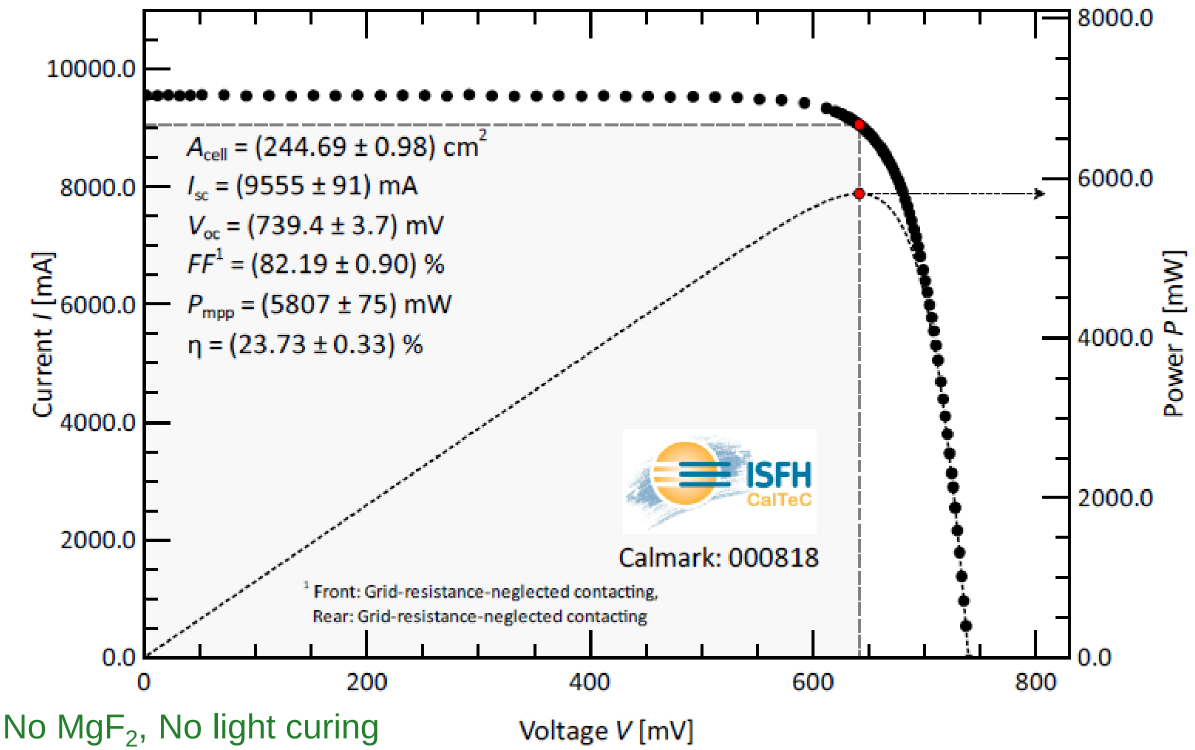
FF= 82%

Eff= 24.5%

+MgF_2 DARC, + Ag BR, +light curing

Cell progress of SHJ at JÜLICH





No MgF_2, No light curing

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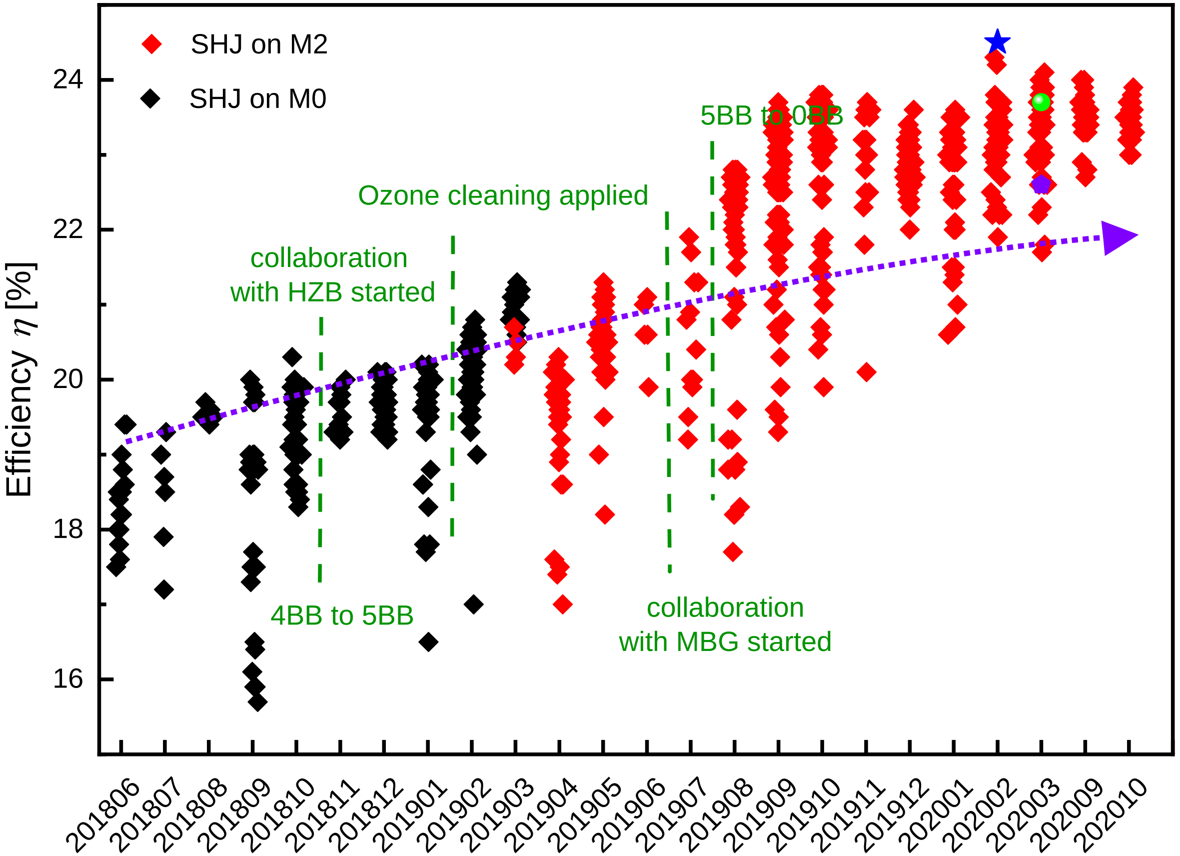
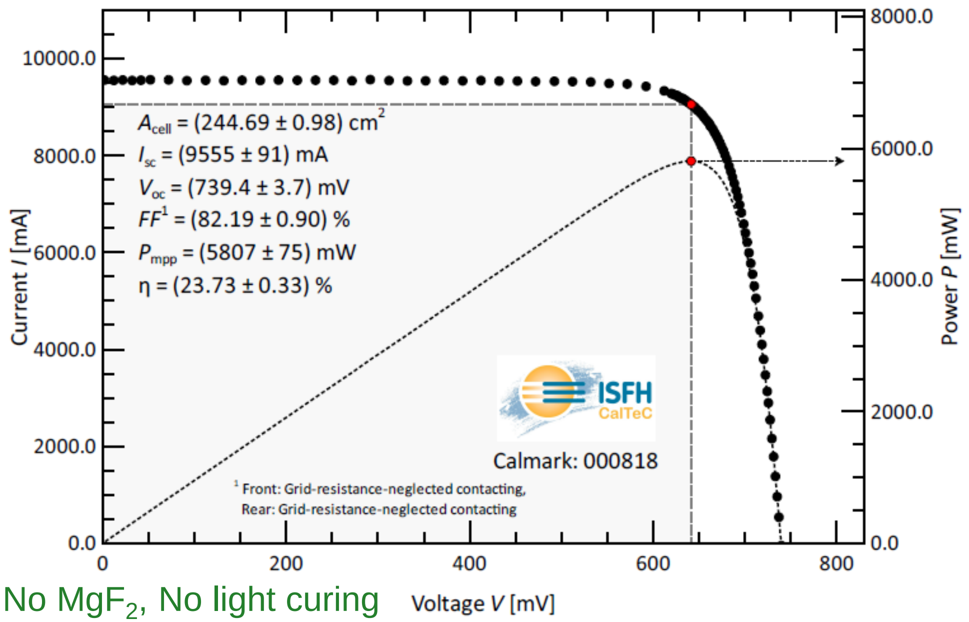
Cell progress of SHJ at JÜLICH





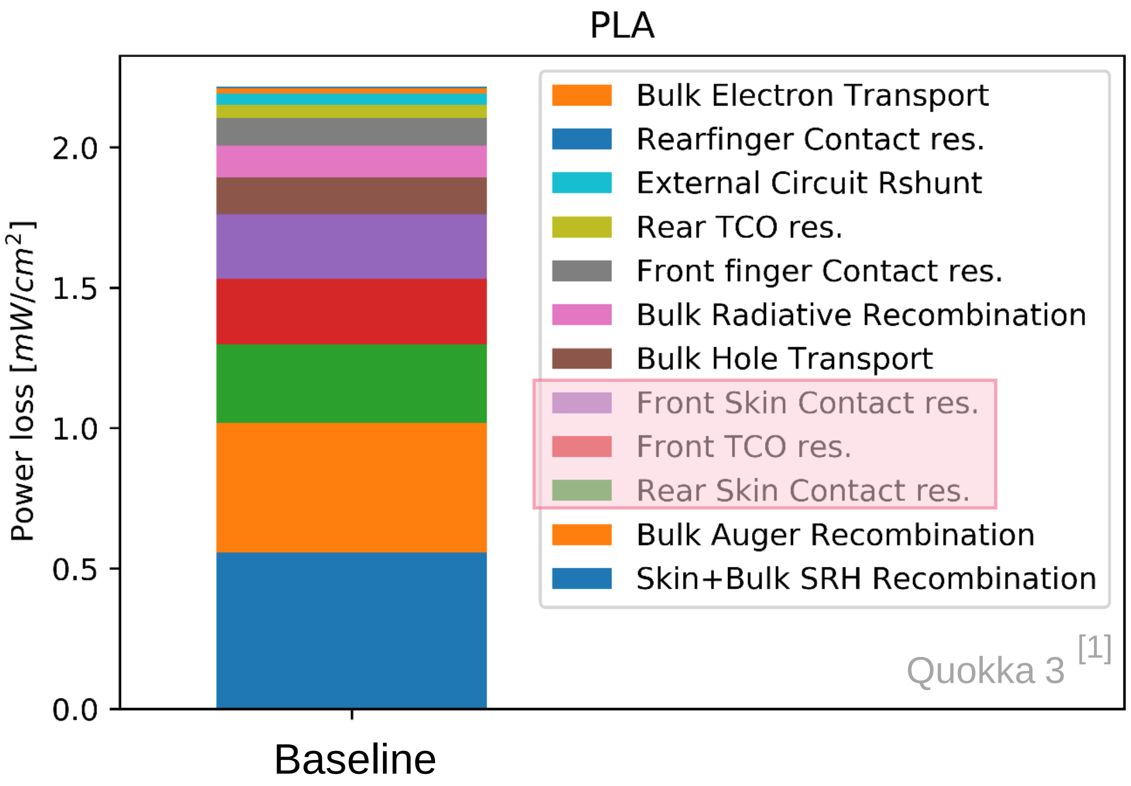
No MgF_2, No light curing

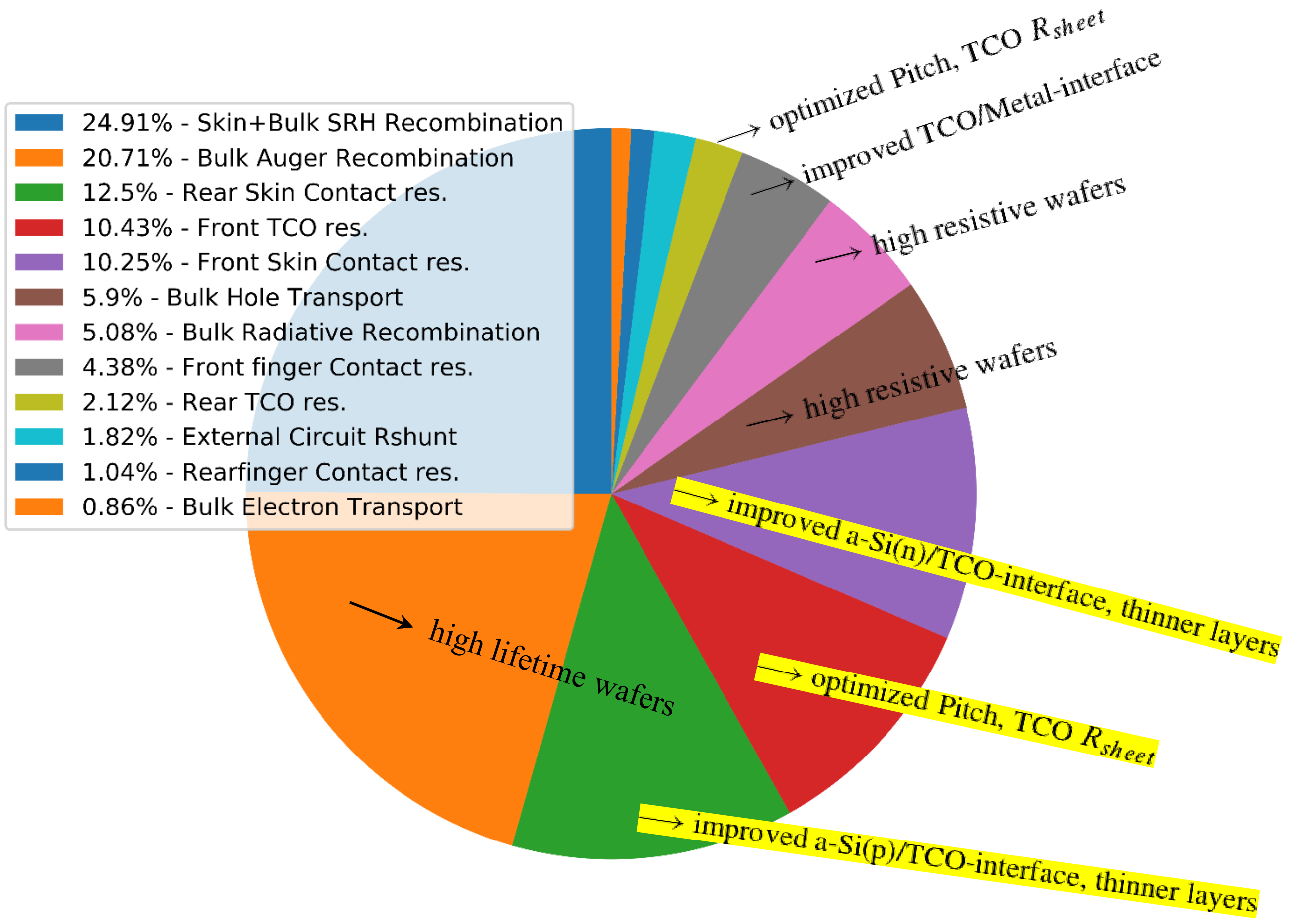
V_{oc} [mV]	743.1	747.0	-0.5%
J_{sc} [mA/cm²]	40.09	39.55	1.4%
***FF* [%]**	82.42	84.98	-3.0%
Eta [%]	24.55	25.11	-2.3%
P_{max} [W]	5.96	6.14	-3.0%

(Hanergy)

Roadmap of SHJ beyond 25%

➤ Power loss analysis

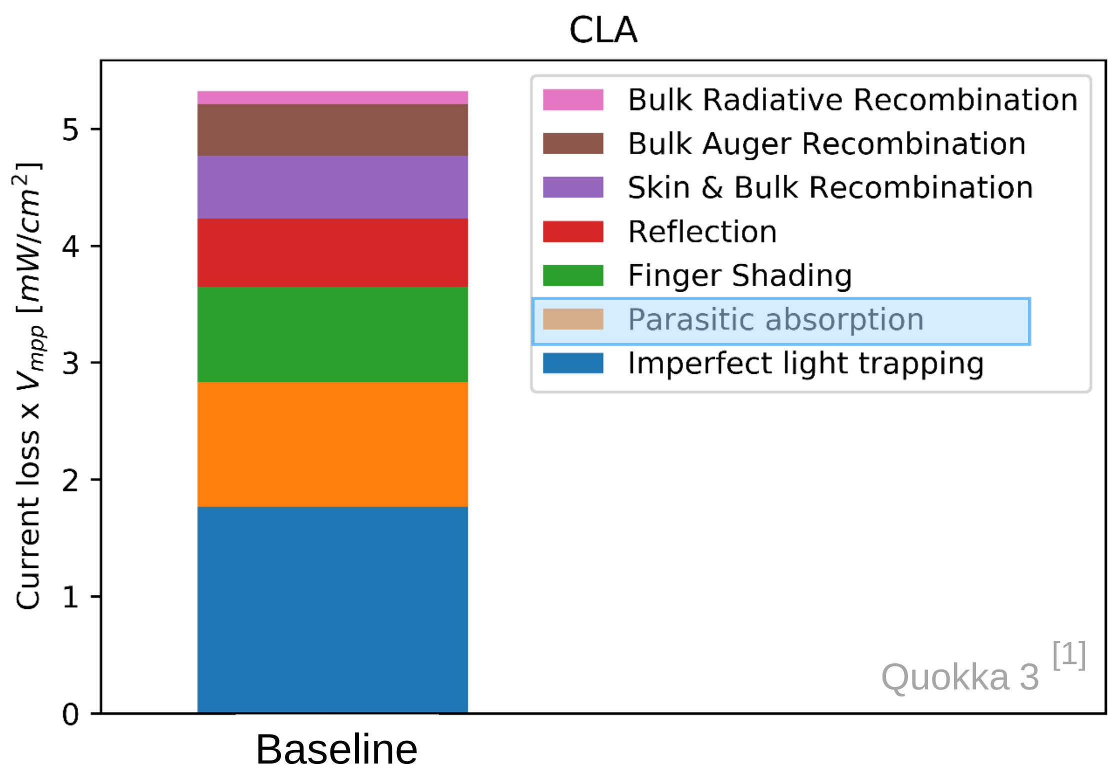


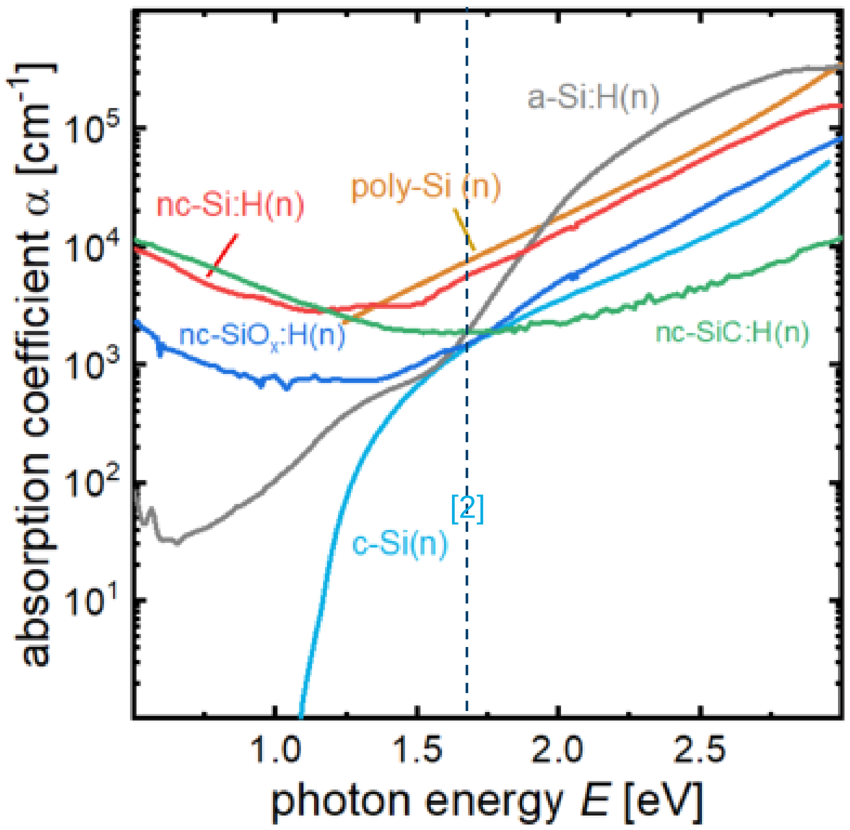


[1]. *Andreas Fell et.al., Solar Energy Materials and Solar Cells 173 (2017). pp. 128–133*

From SHJ to Transparent Passivating Contacts (TPC)

➢ Current loss analysis





[1]. *Andreas Fell et.al., Solar Energy Materials and Solar Cells 173 (2017), pp.128–133*

[2]. *Martin Green, Solar Energy Materials and Solar Cells 92 (2008), pp.1305-1310*

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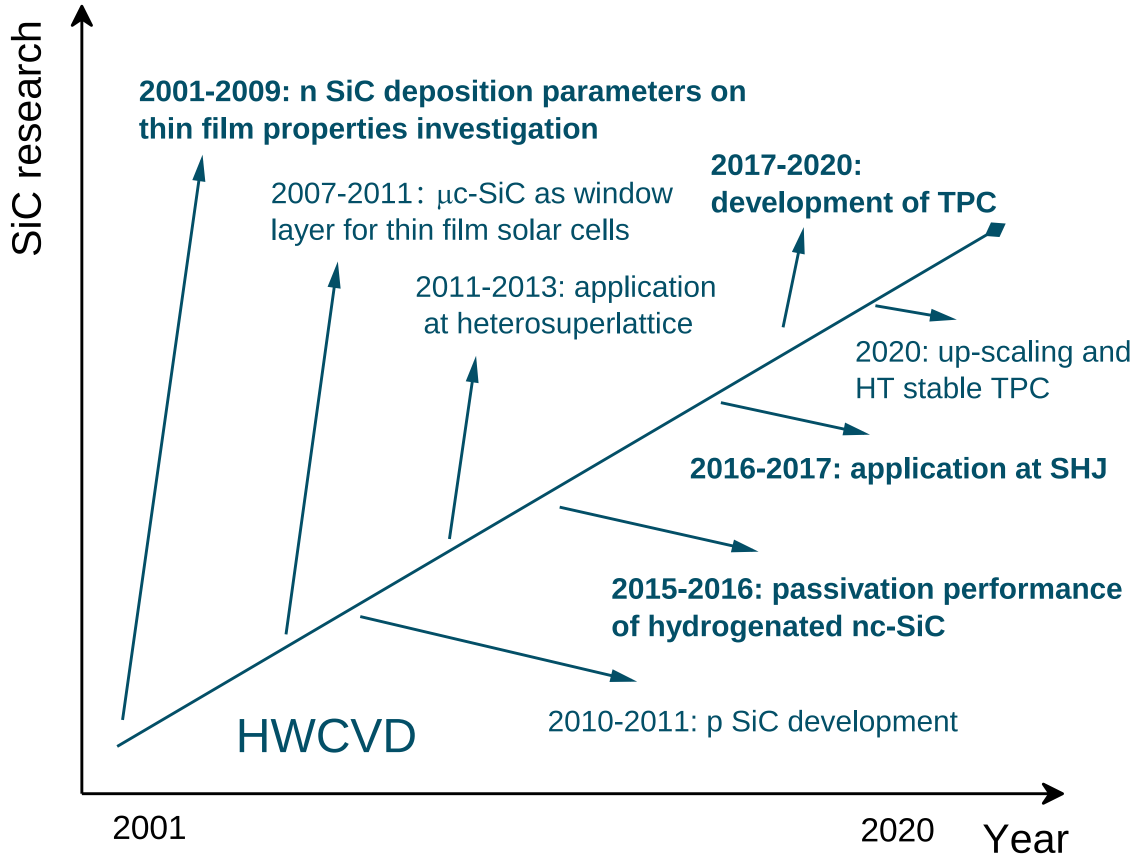
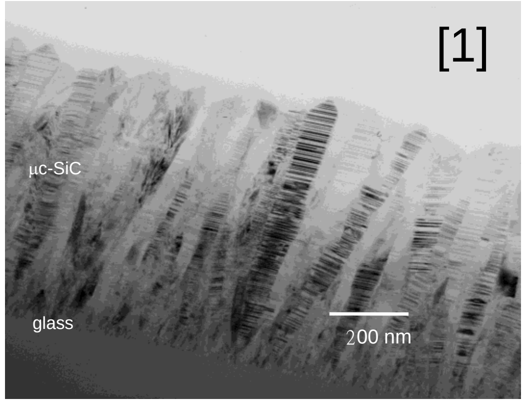
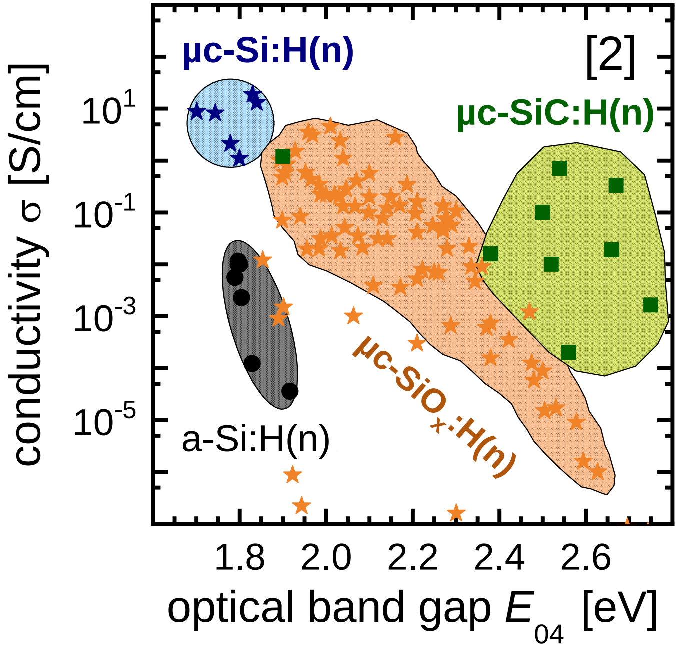
Transparent passivating contacts

➢ Unique nc-SiC:H developed at JÜLICH



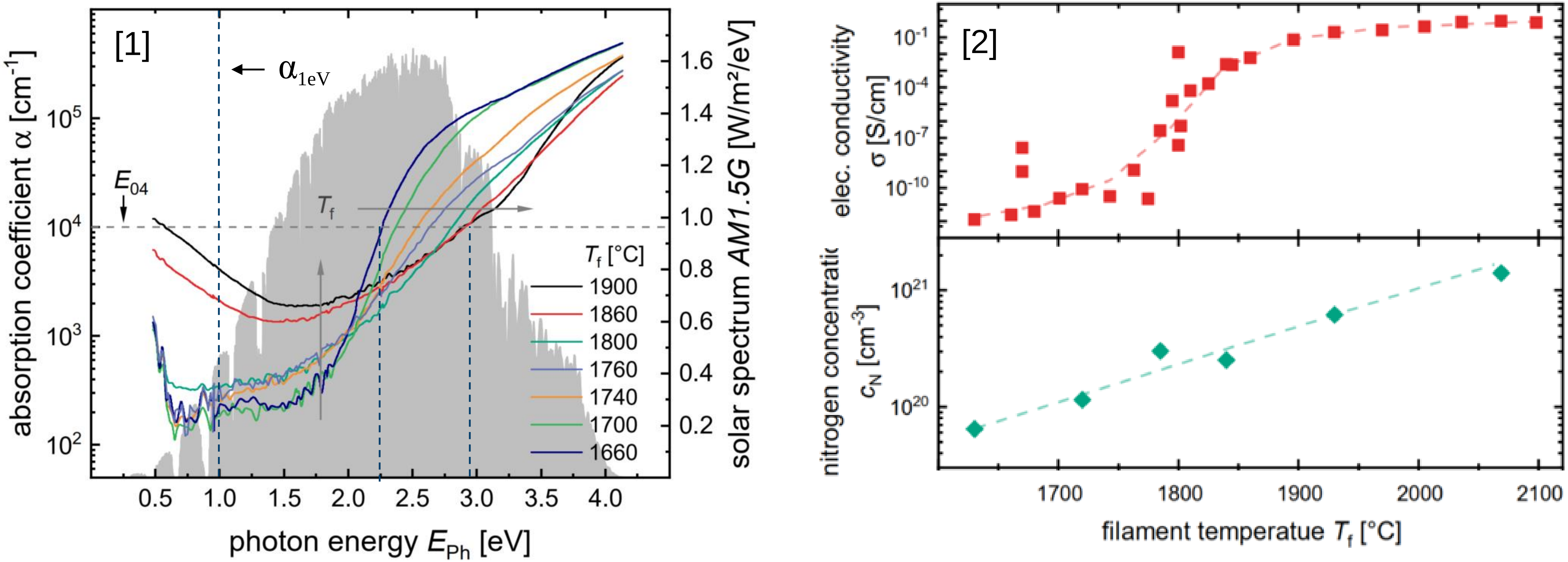




[1]. *F. Finger et al. Thin Solid Films 517 (2009) 3507-3512*
[2]. *T. Chen et al. Jpn. J. Appl. Phys. 53 (2014), 05FM04*

Layer properties of nc-SiC:H

➢ Optical and electrical properties

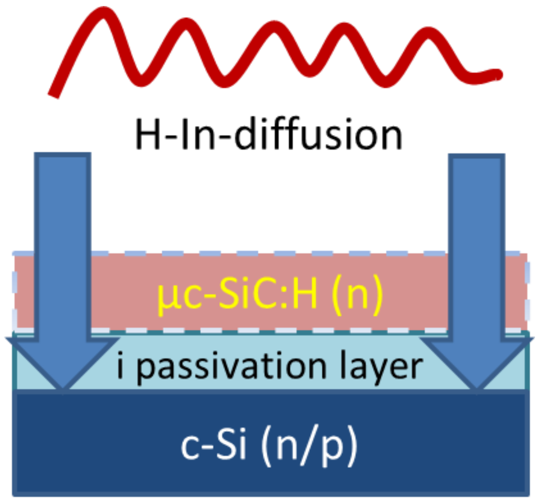


[1]. *Malte Köhler et,al., IEEE 7th WCPEC, 2018, June, 3468-3472*

[2]. *Malte Köhler et,al., IEEE JPV, 2019,10, 1, 46-53.*

Choice of the interface passivation layer

➢ a-SiO_x:H(i), a-SiC:H(i) , a-Si:H(i) or SiO_2



- nc-SiC:H(n) promising to avoid parasitic absorption.
- Growth process conditions deteriorate interface passivation.
- Passivation layer has to fulfill:
  1. Etch resistivity
  2. Thermal stability
  3. Allow H-in-diffusion

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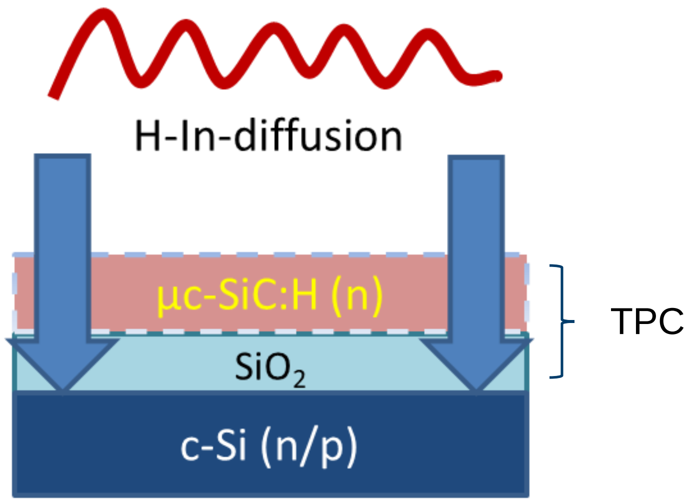

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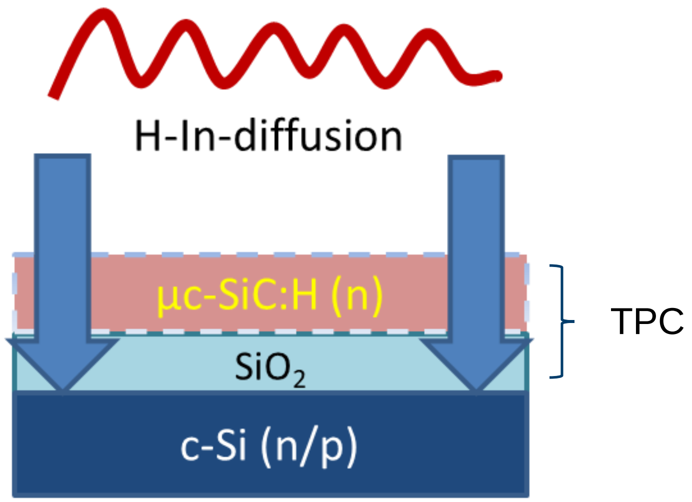

Piranha oxide!

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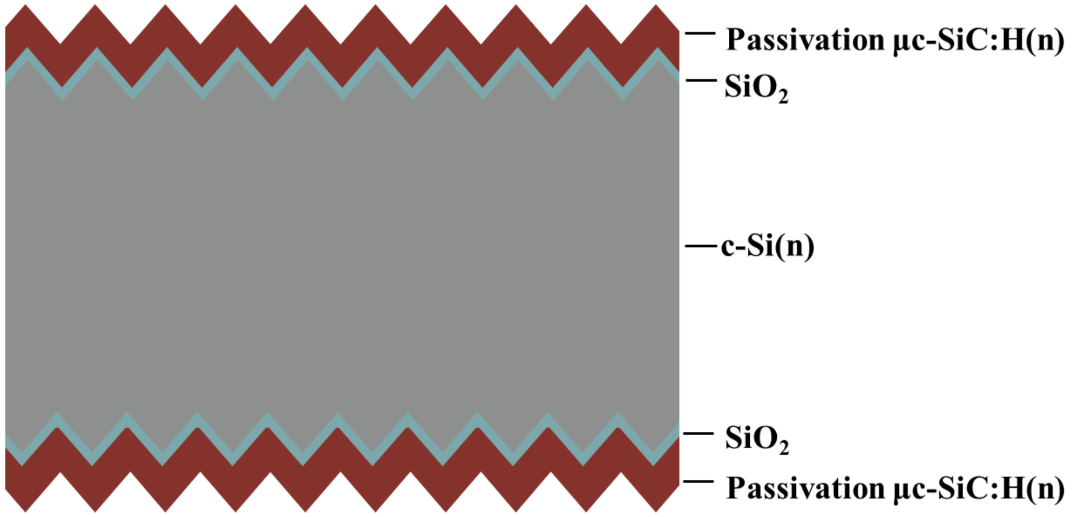
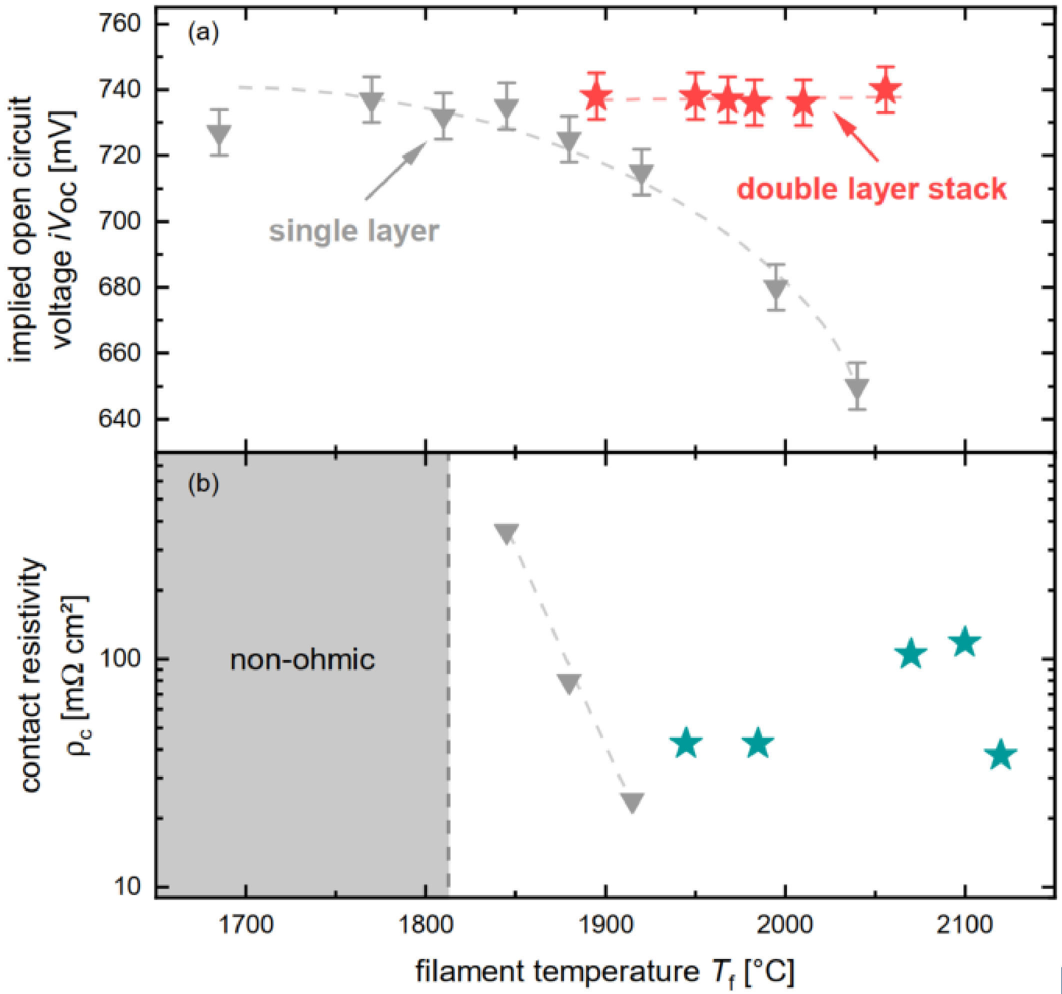
Selectivity of TPC stack

- Passivation quality and contact resistivity





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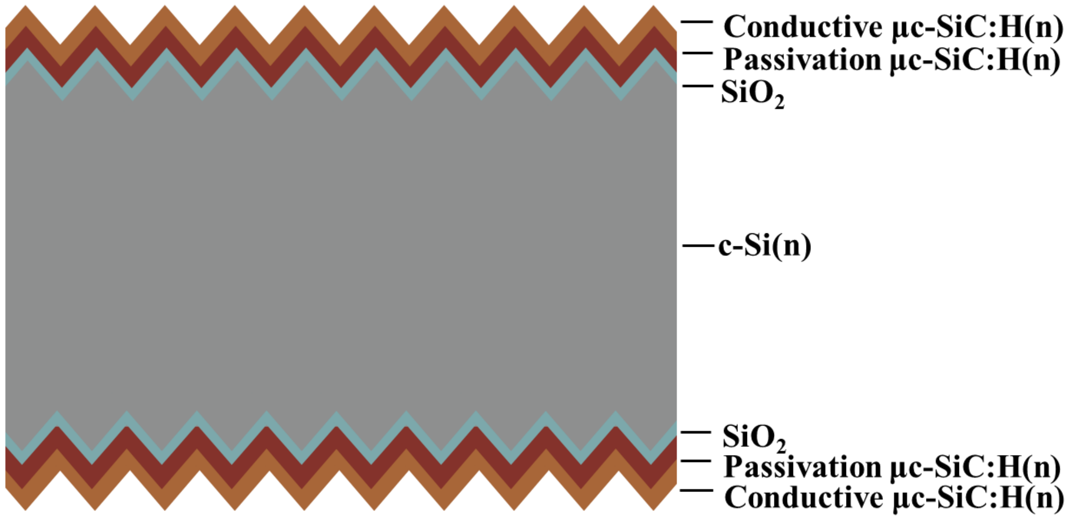
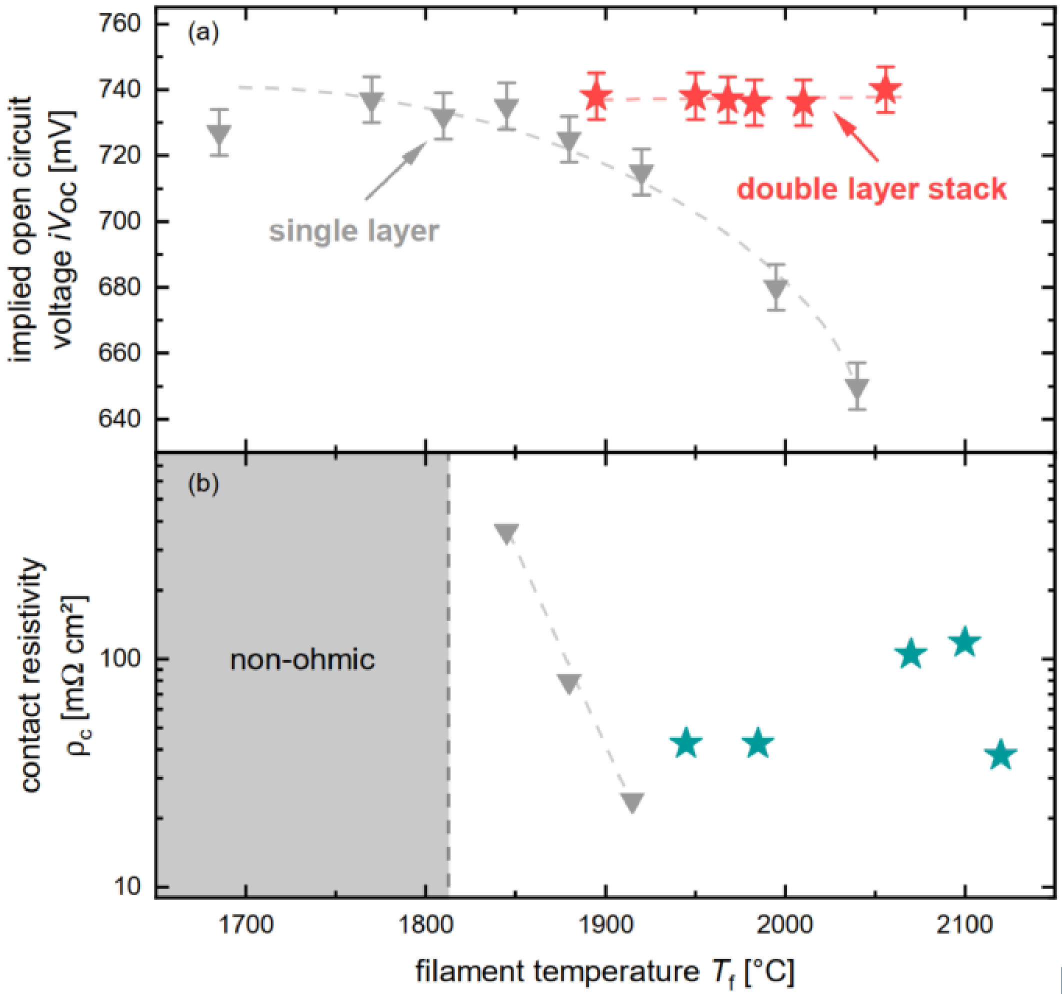
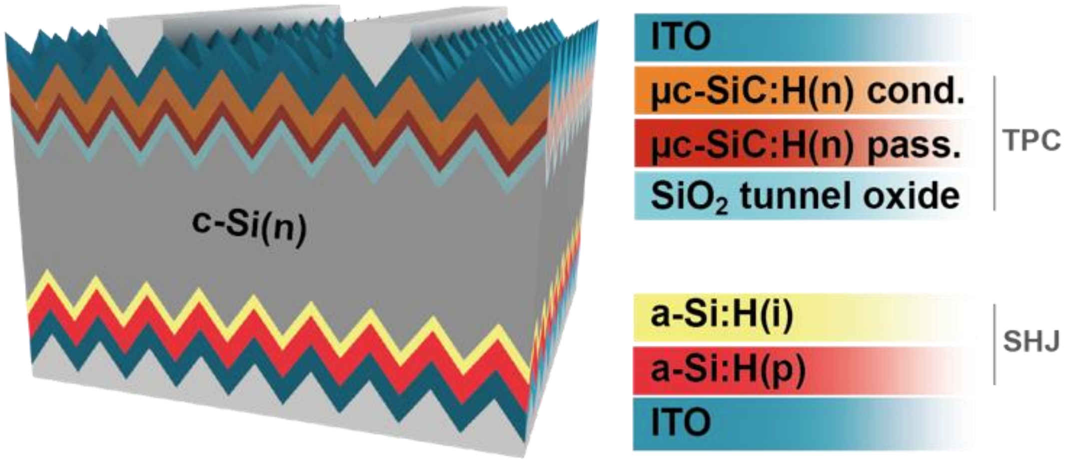




Application of TPC on solar cells

➢ Device performance of TPC



	Eta [%]	V_{oc} [mV]	J_{sc} [mA/cm^2]	FF [%]	iV_{oc}-V_{oc} [mV]
Single layer	21.6	709	39.5	77.1	22

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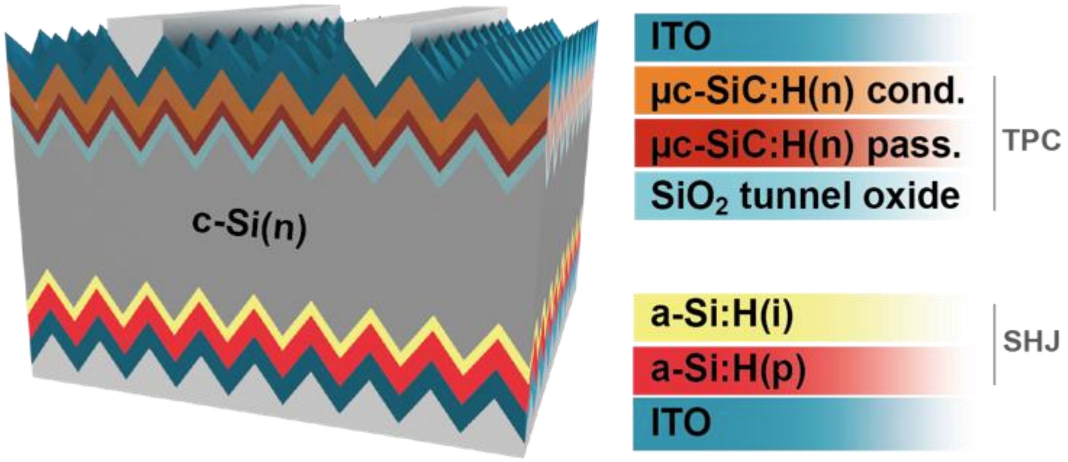

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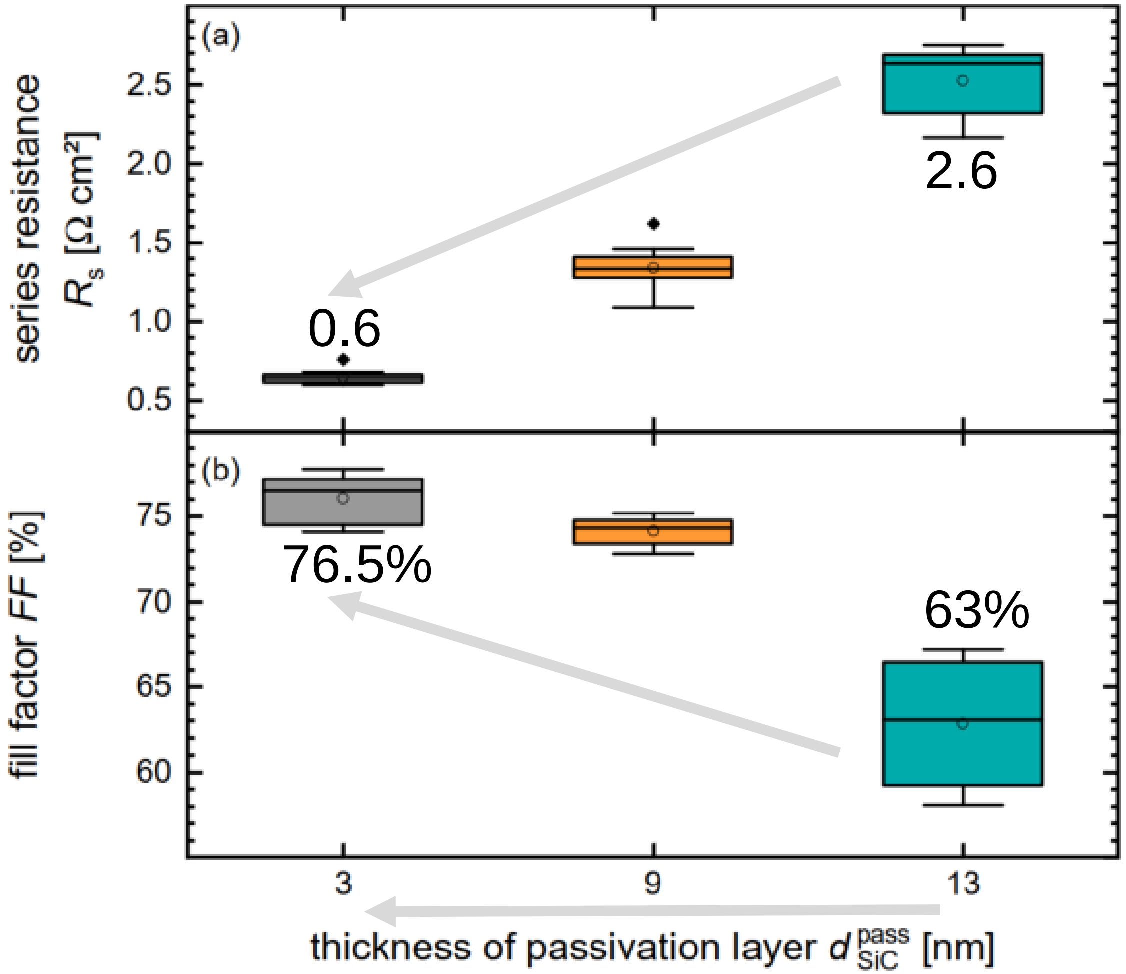

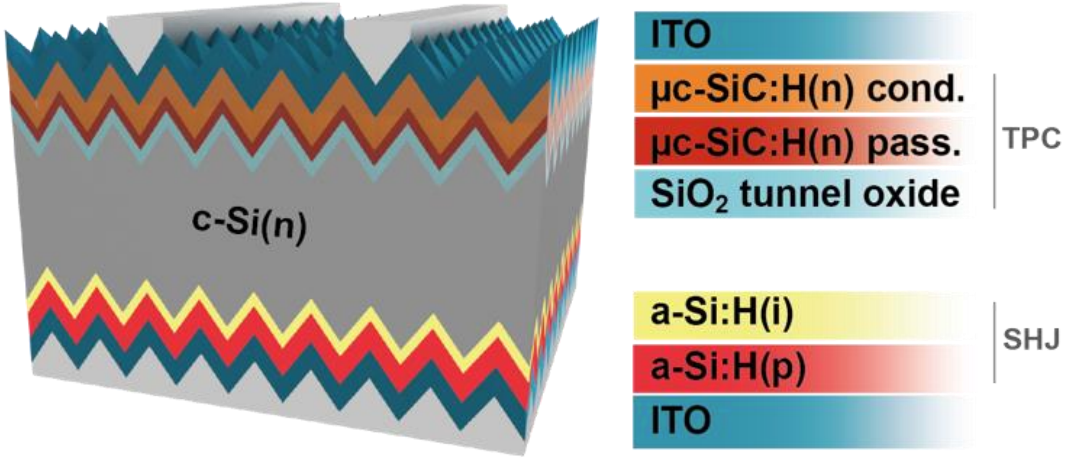

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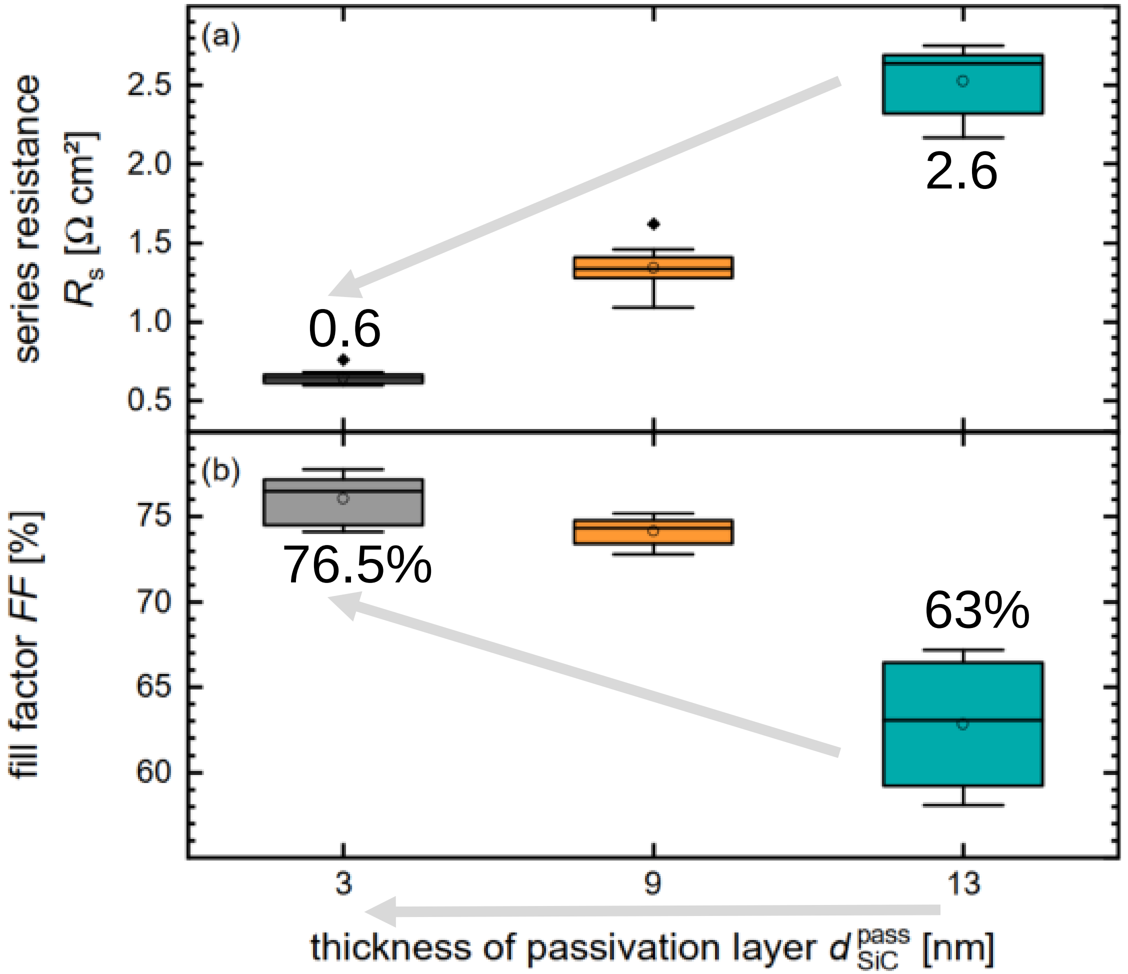

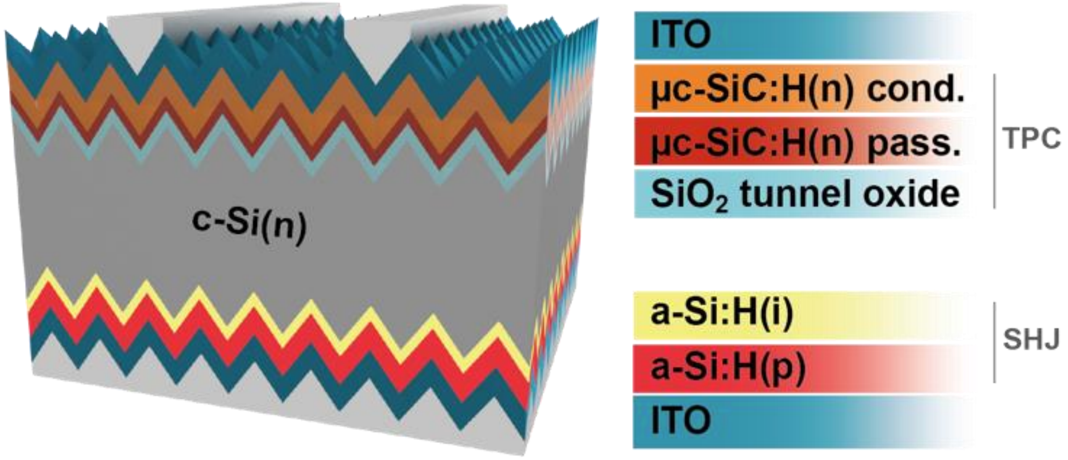

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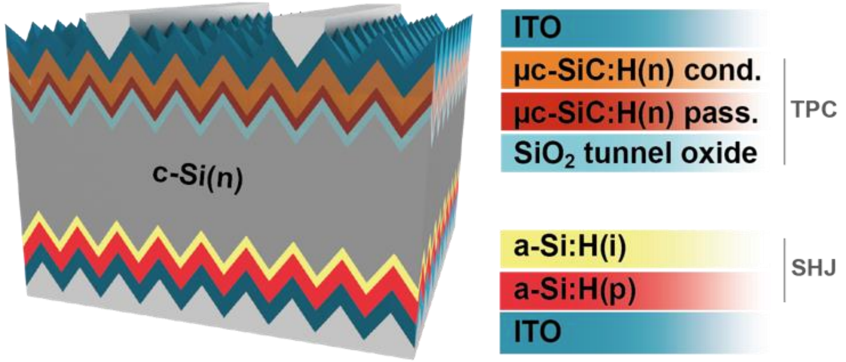
Application of TPC on solar cells

- TCO improvement for TPC



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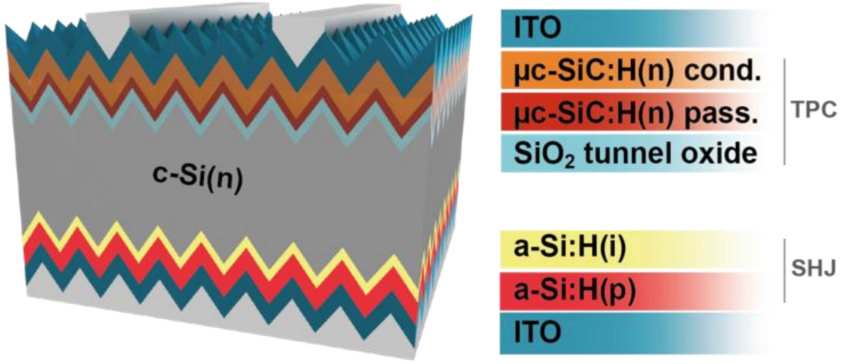

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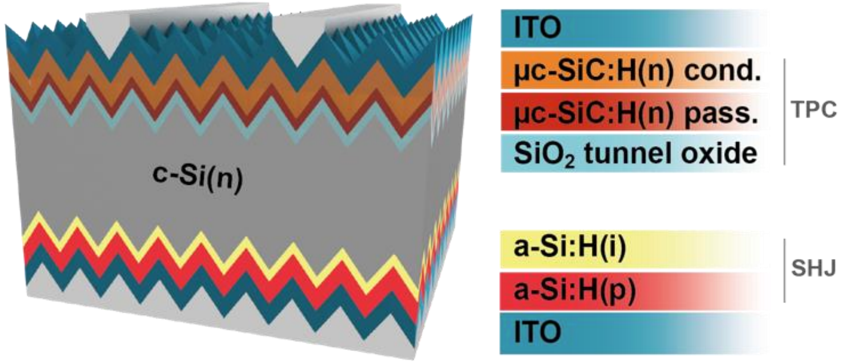

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ANN.	23.8	725	40.3	81.3	7

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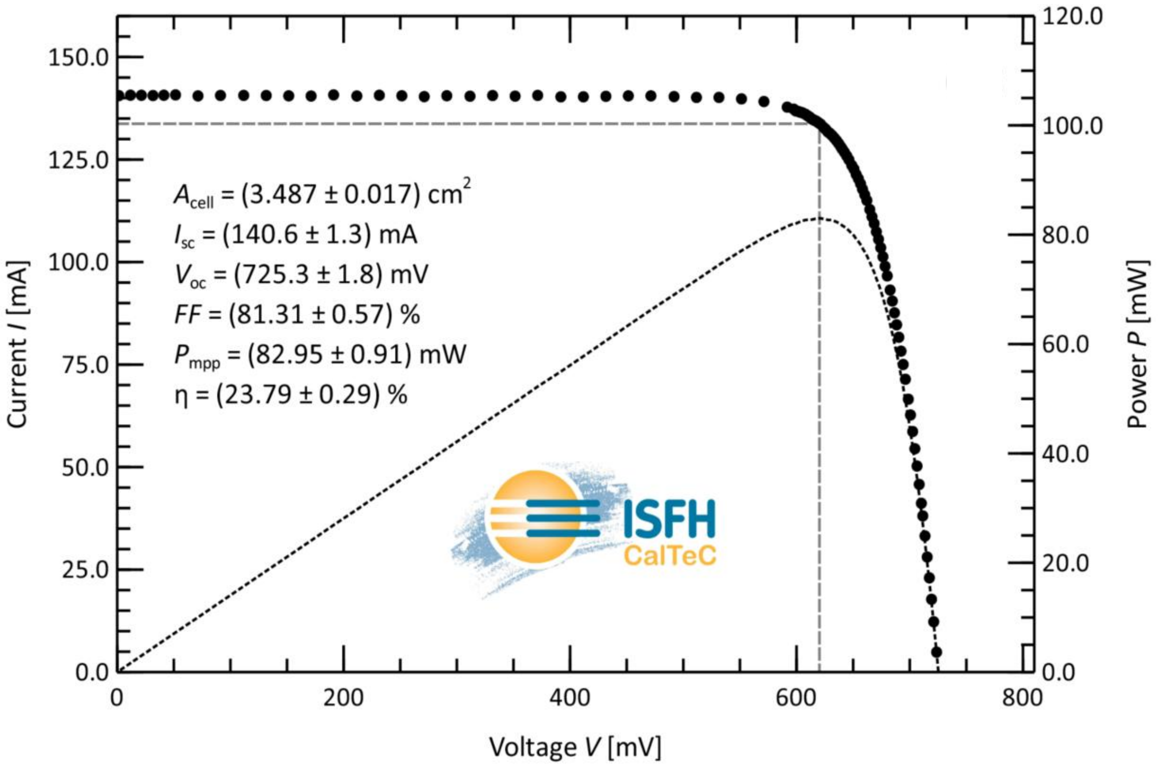

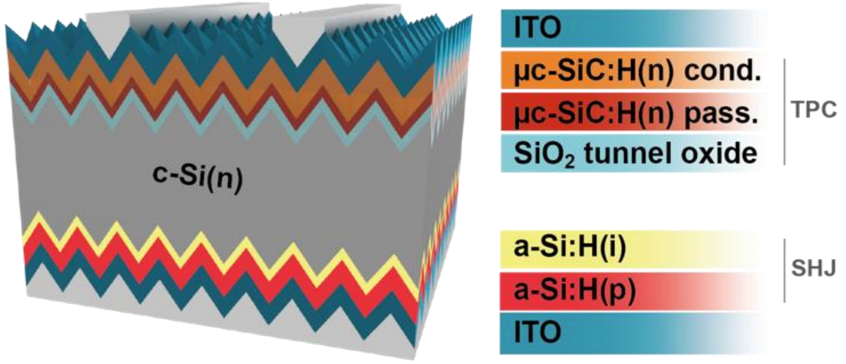

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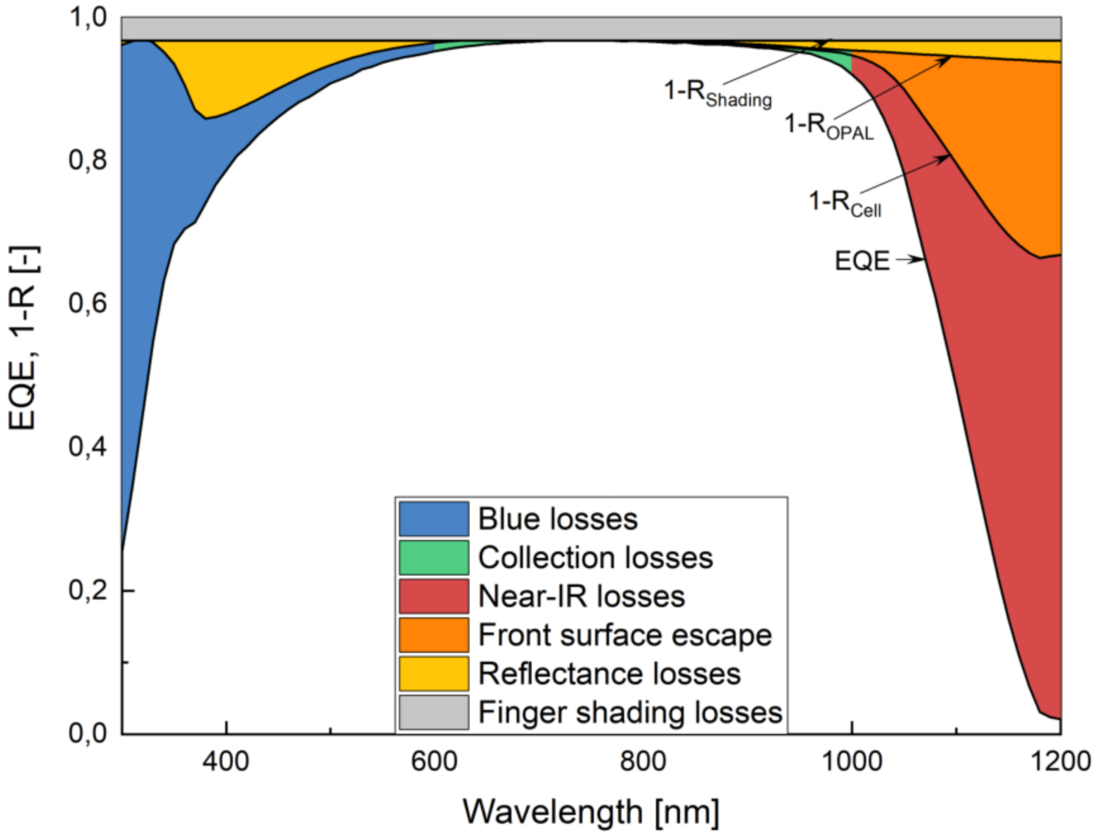
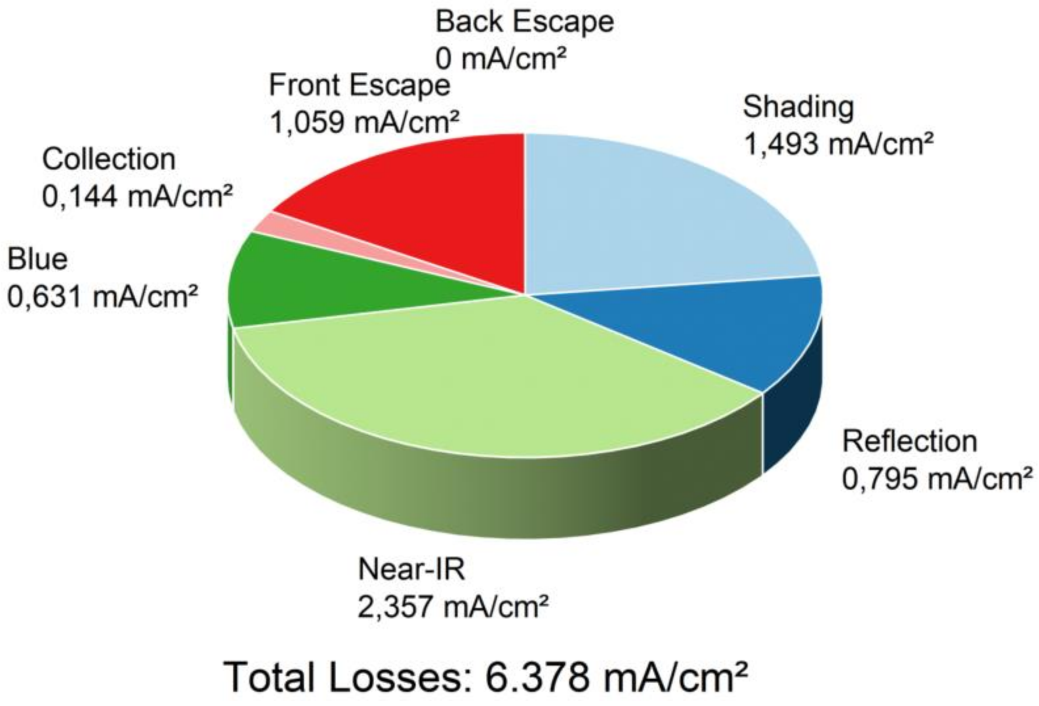
Application of TPC on solar cells

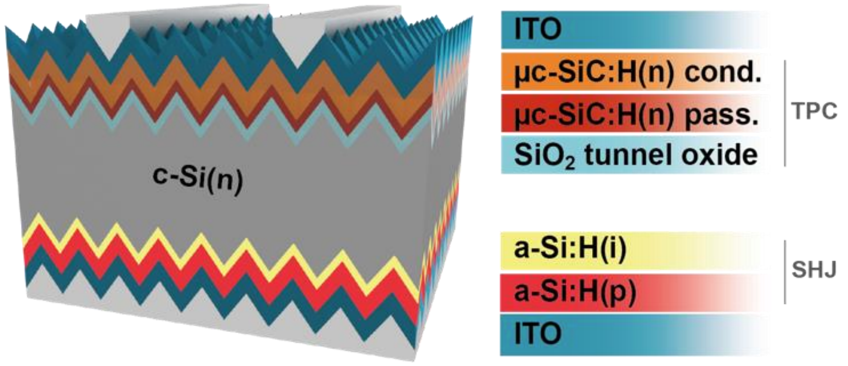
- Optical loss of analysis





Application of TPC on solar cells

- Optical improvement



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Application of TPC on solar cells

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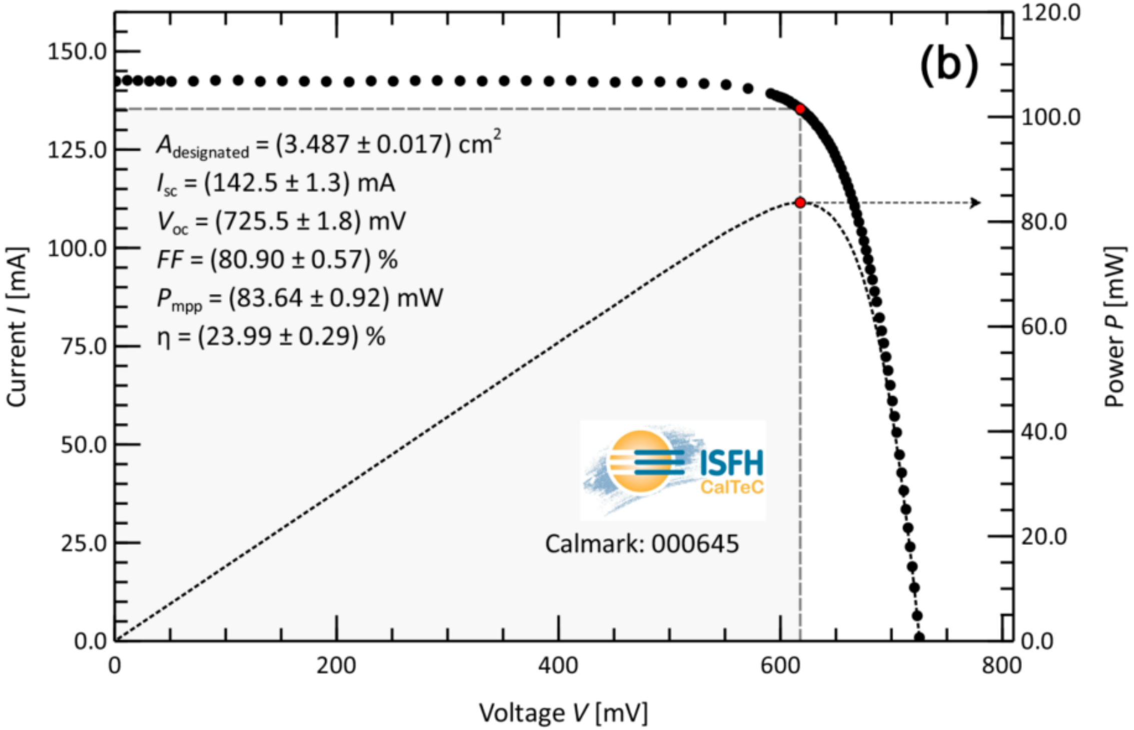

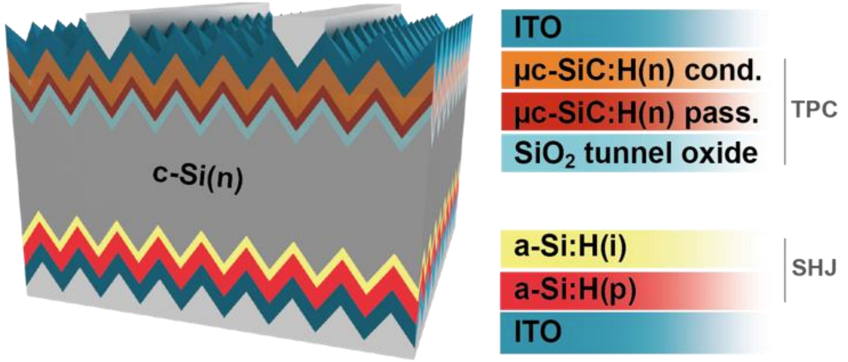

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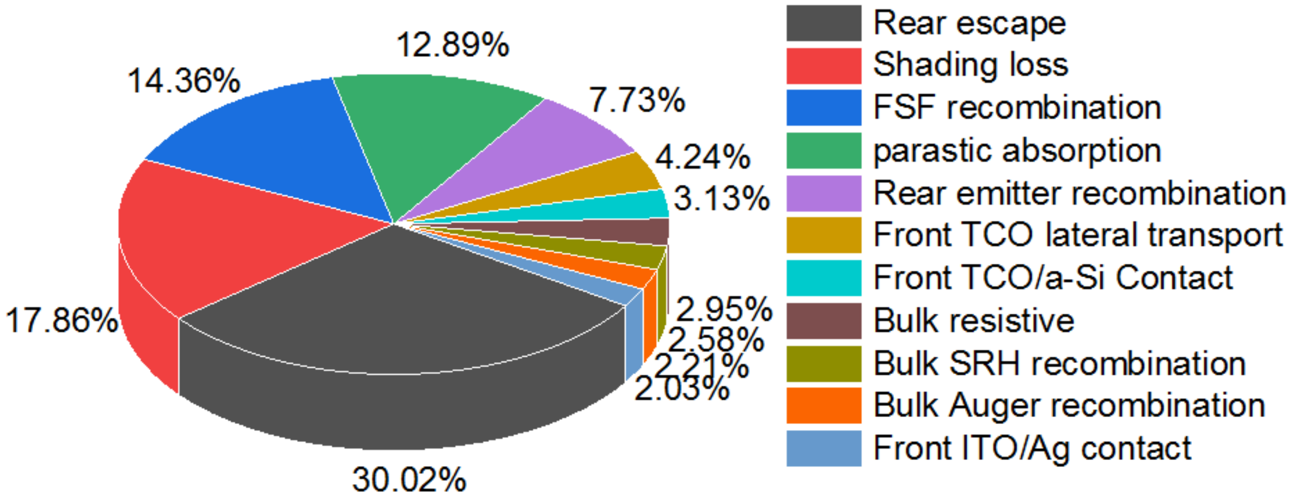
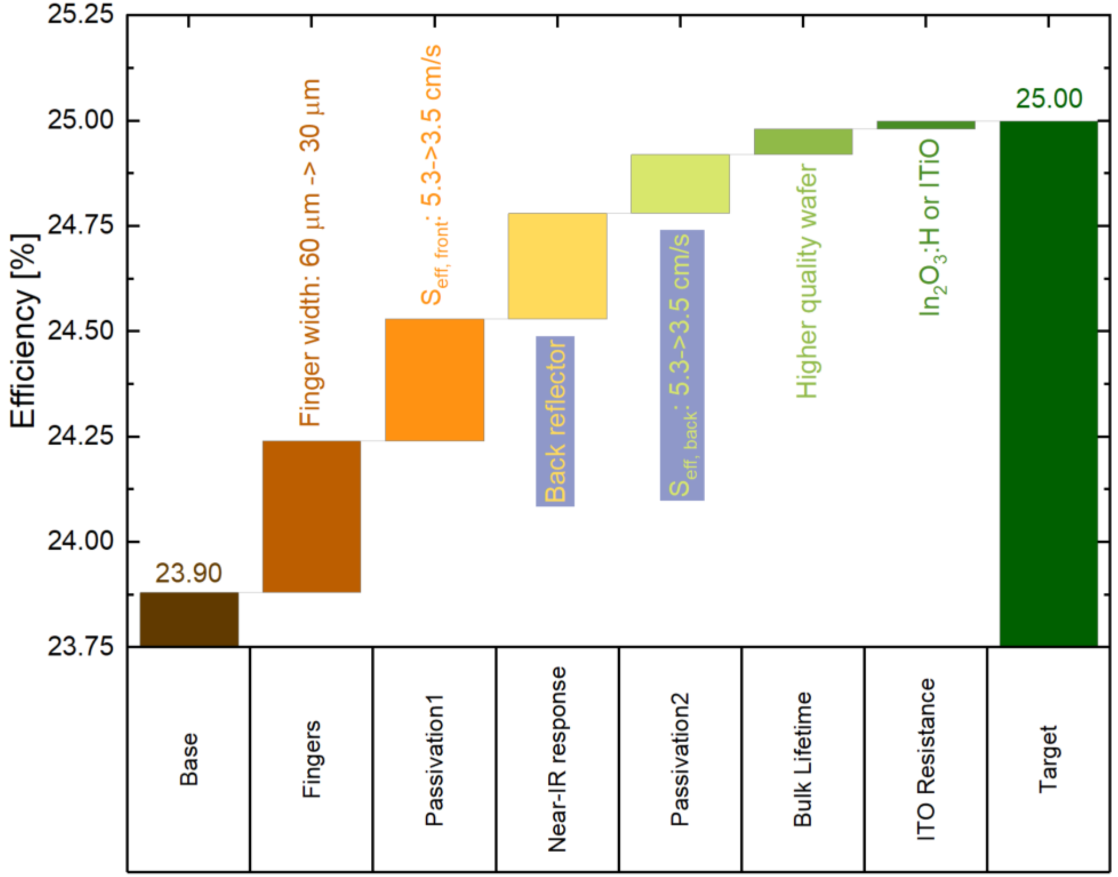
What to do next?

- Roadmap of TPC beyond 25%





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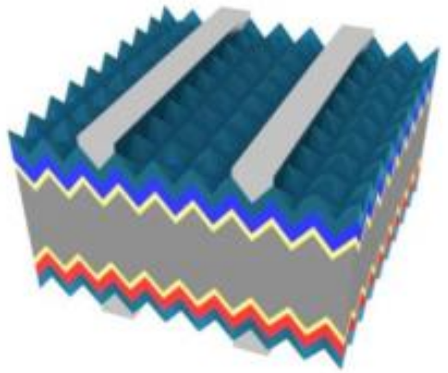
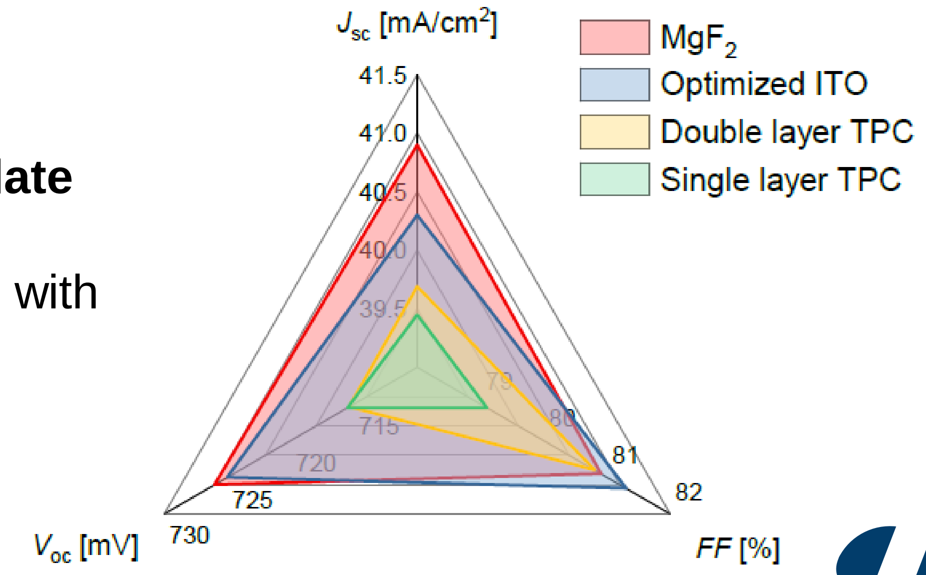
Conclusion

- **24.55% SHJ** solar cells is achieved, and roadmap to 25% is proposed;
- A TPC for the front side of c-Si solar cells must fulfill three basic requirements: (i) **transparent**, (ii) **passivating** and (iii) **conductive**.
- **Piranha oxide** fits best with the TPC and the first passivation layer is critical to the TPC solar cells.
- **Double layer of SiC**, **ITO optimization** and **hot plate annealing**, **MgF_2 coating** enable a TPC solar cells with efficiency of 24%

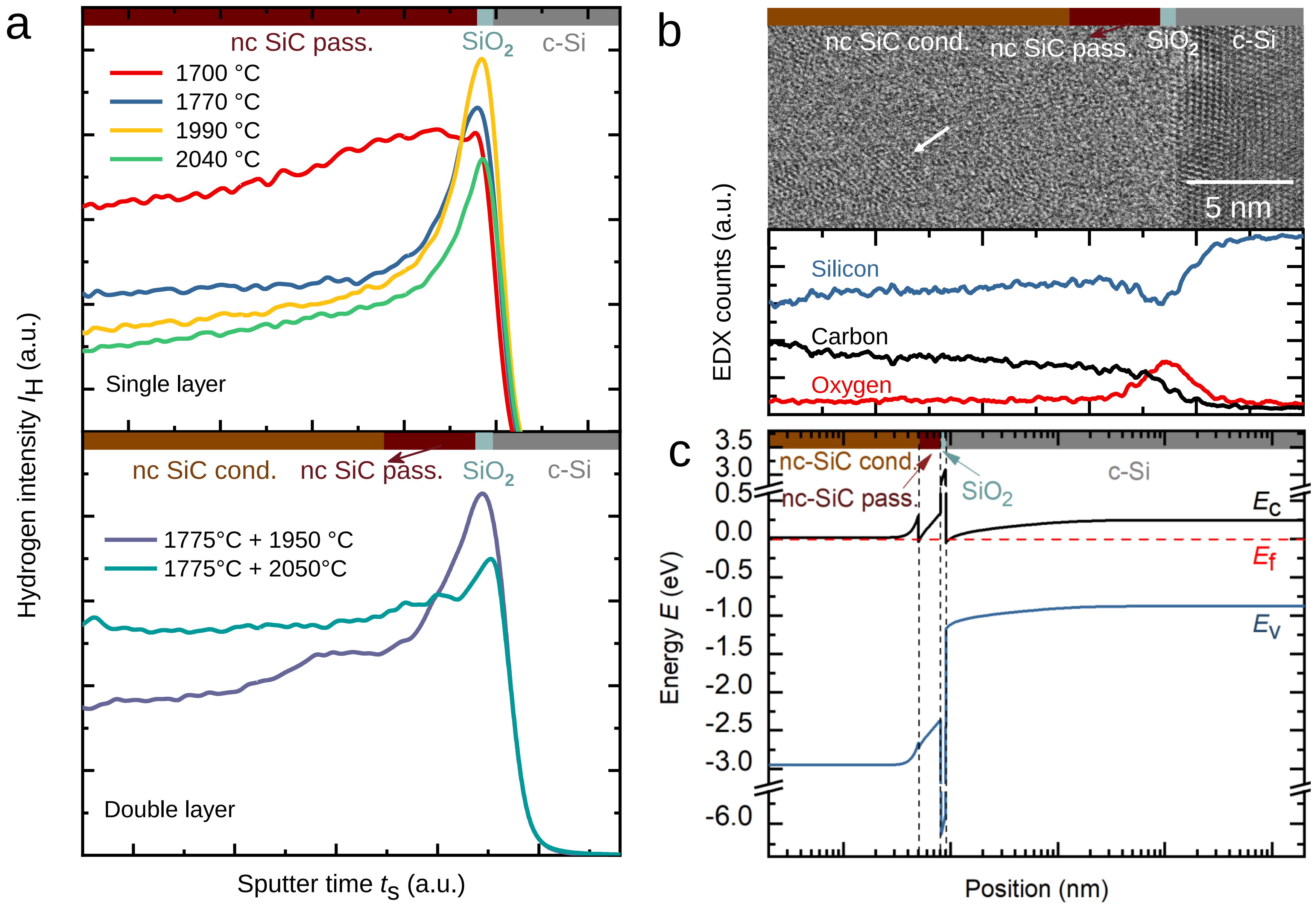




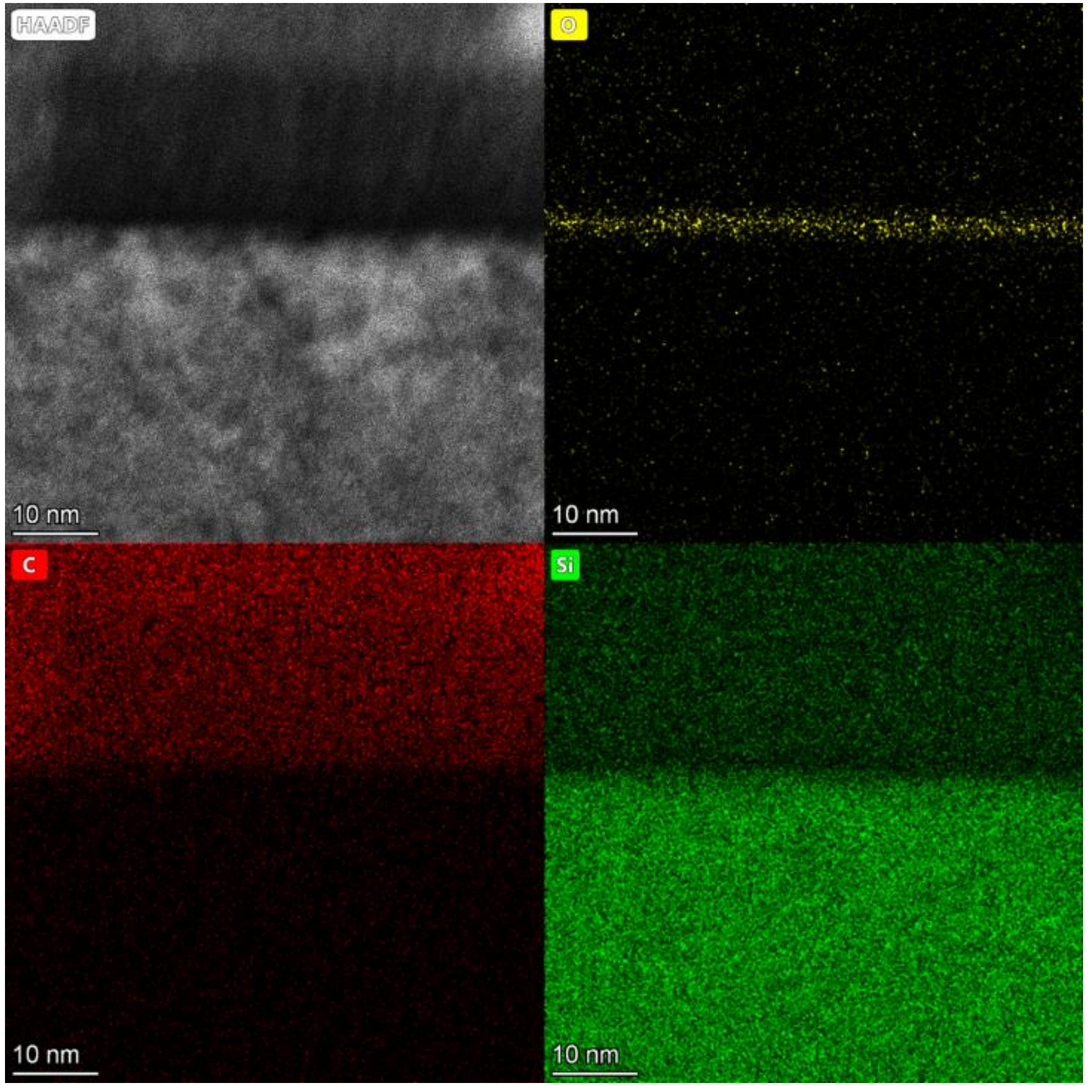
THANK YOU FOR YOUR ATTENTION
QUESTIONS?

Federal Ministry
for Economic Affairs
and Energy

k.qiu@fz-juelich.de



a
nc SiC pass.
SiO2
c-Si
1700 °C
1770 °C
1990 °C
2040 °C
Single layer
nc SiC cond.
nc SiC pass.
SiO2
c-Si
1775°C + 1950 °C
1775°C + 2050°C
Double layer
Hydrogen intensity I_H (a.u.)
Sputter time t_S (a.u.)
b
nc SiC cond.
nc SiC pass.
SiO2
c-Si
5 nm
EDX counts (a.u.)
Silicon
Carbon
Oxygen
c
nc-SiC cond.
nc-SiC pass.
SiO2
c-Si
E_C
E_f
E_V
Energy E (eV)
3.5
3.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-6.0
Position (nm)


HAADF
10 nm
O
10 nm
C
10 nm
Si
10 nm