Barrier Properties of TCOs against Metallization and Interconnection materials for Thermal Stability of Perovskite Solar Cells

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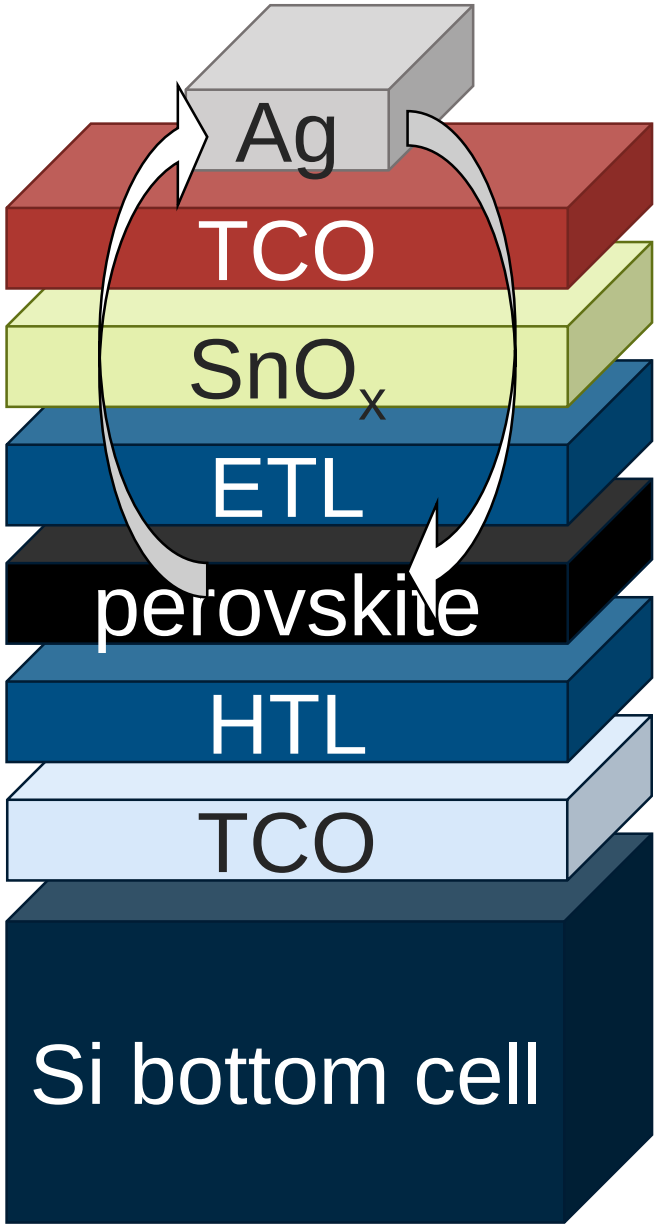
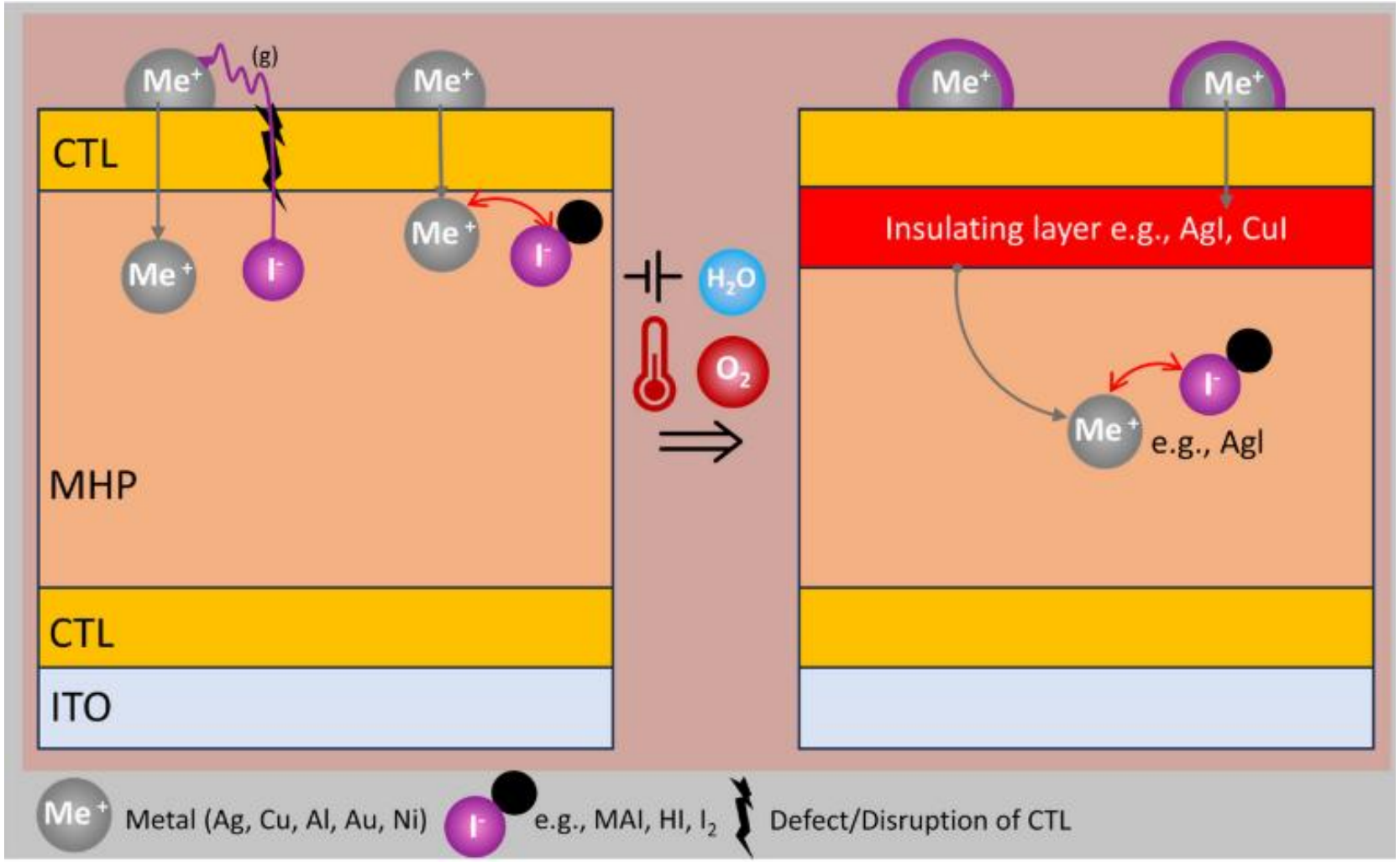
Baumann S et al. *Energy Environ Sci*. doi:10.1039/d4ee01898b

MOTIVATION





HZB Helmholtz Zentrum Berlin

Baumann S et al. *Energy Environ Sci*. doi:10.1039/d4ee01898b

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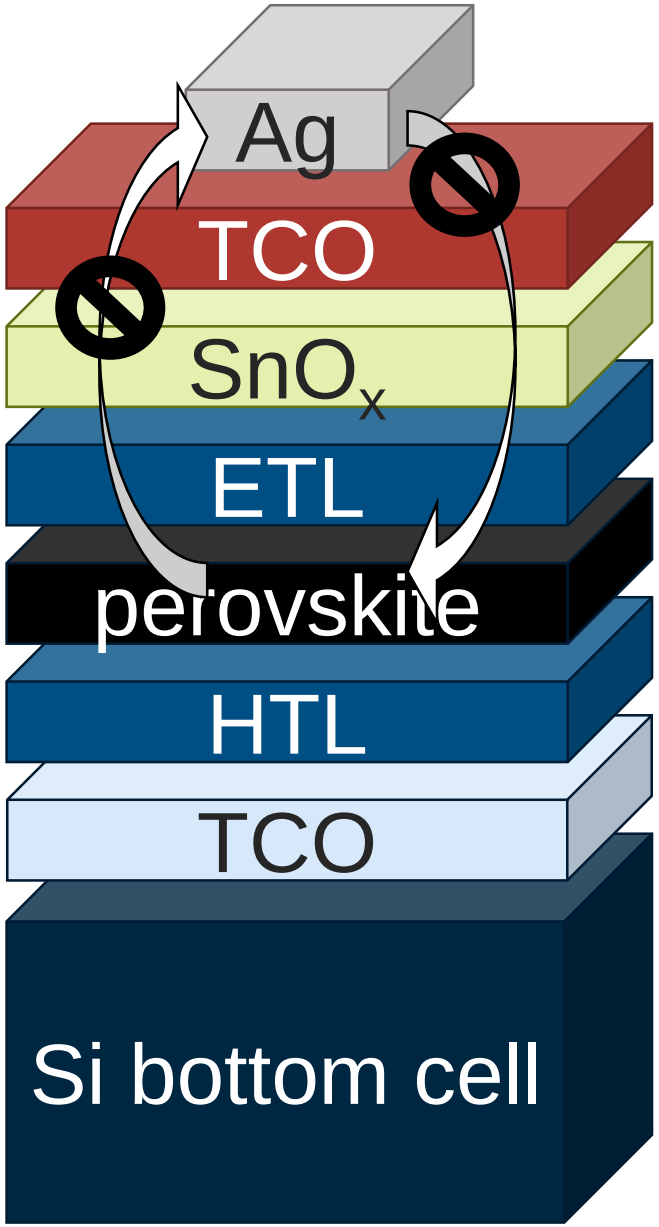

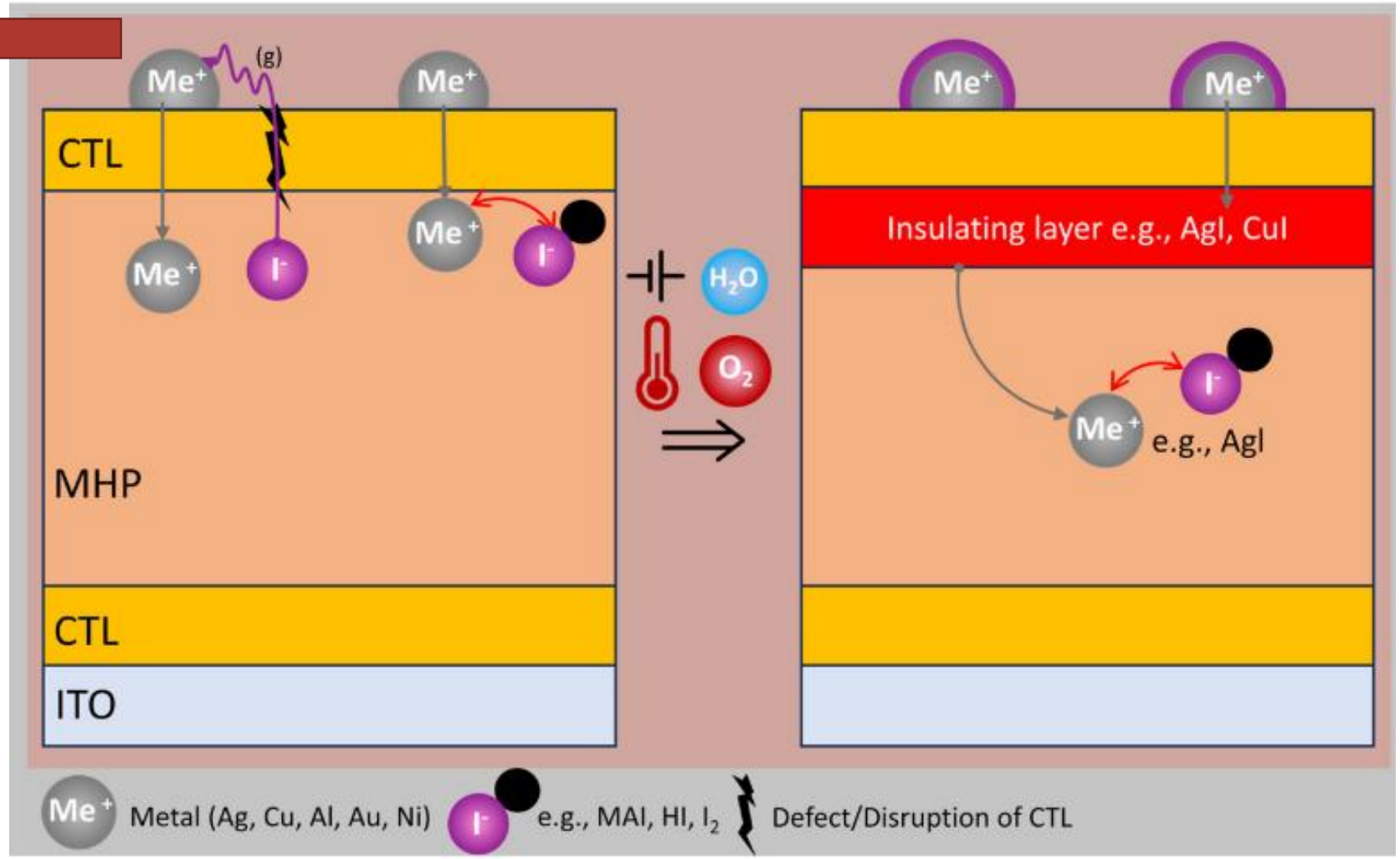

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AIM AND OBJECTIVES

Quiterie Emery
Poster B-12

Investigate how **degradation** related to **sp-Ag** can be reduced by optimisation of **top-contact TCO**.

1. Test TCOs in unencapsulated **in-house 1 cm² single-junction perovskite** solar cells.

2. Test TCOs in encapsulated **industrial M6 silicon/perovskite tandem** solar cells.

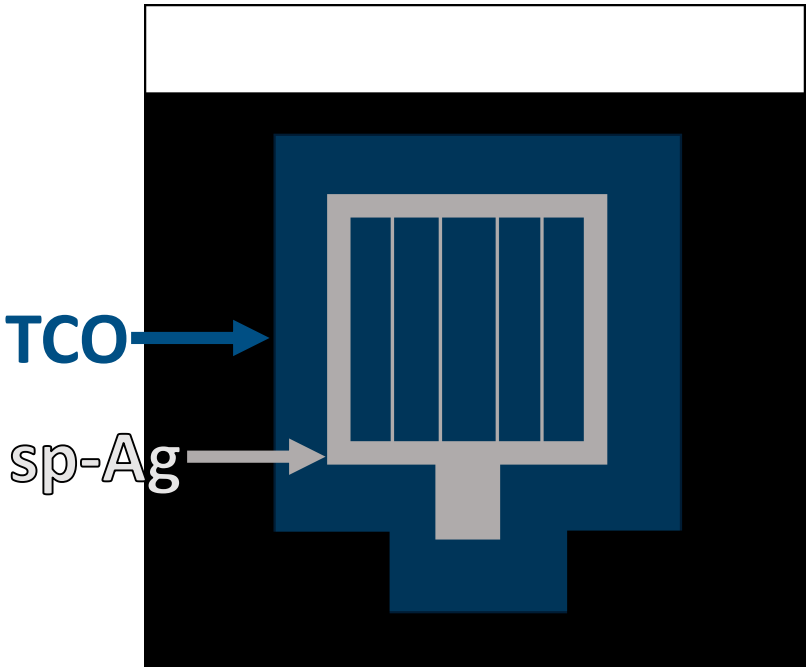
1. Test TCOs in unencapsulated in-house 1 cm^2 single-junction perovskite solar cells.

EXPERIMENT DESIGN

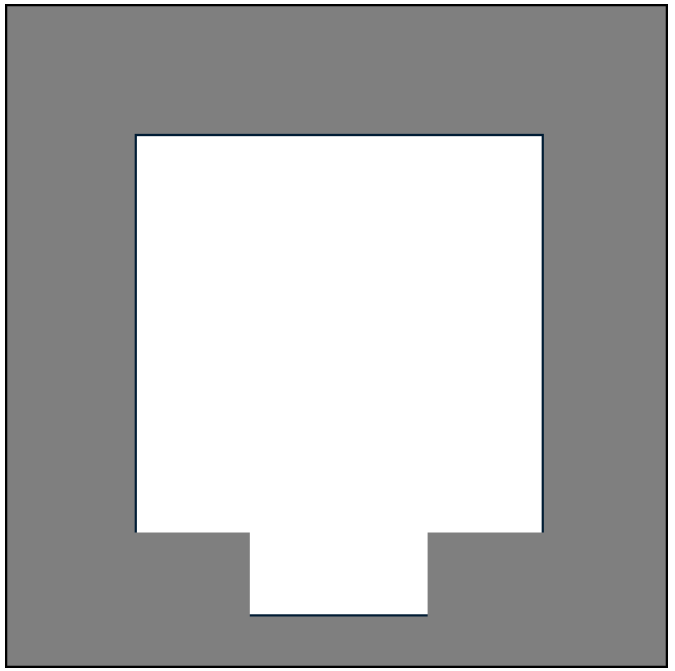
Dr. Philippe Holzhey

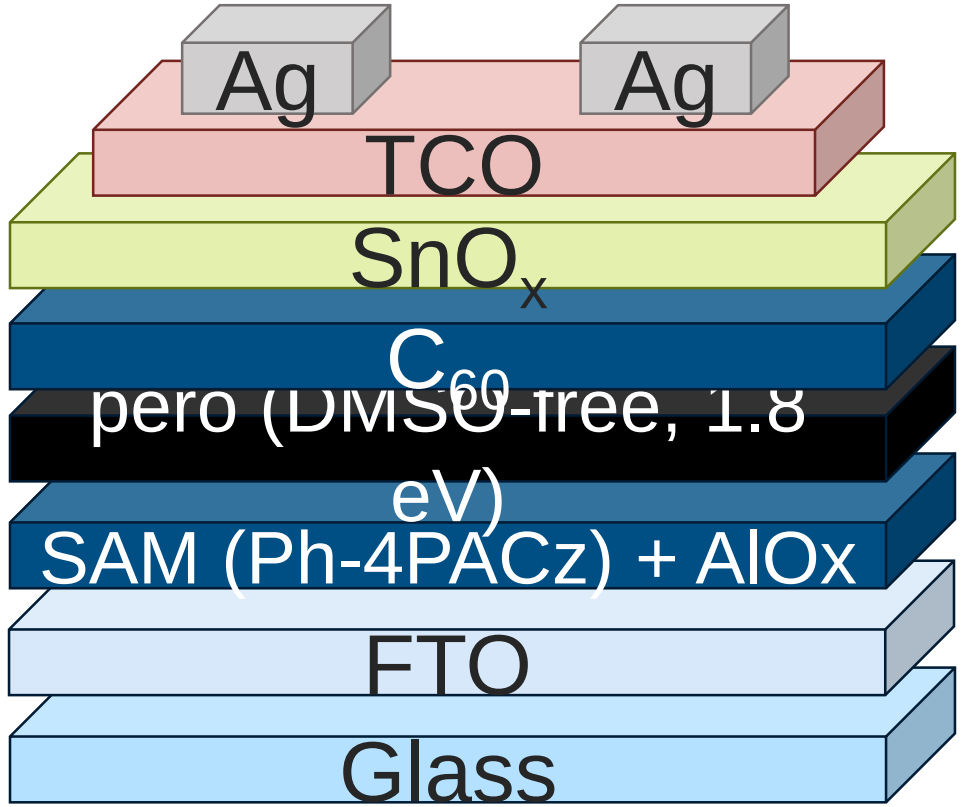
Objective:
Test barrier properties of TCOs against **sp-Ag**

1 cm² device



TCO mask design





EXPERIMENT DESIGN

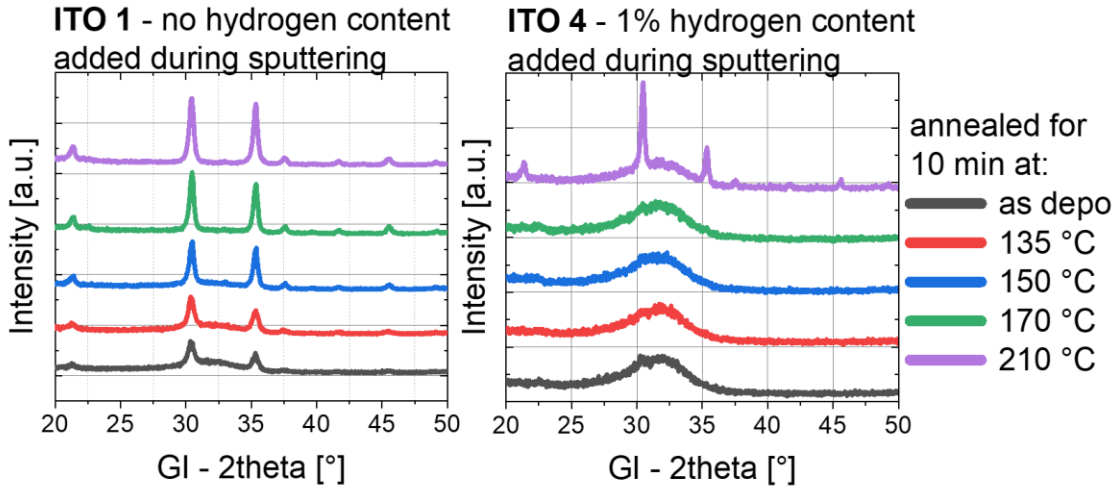
Jannik Kleesiek
Poster B-03

	TCO	Thickness
1	IZO 5 µbar	40 nm
2	IZO 14 µbar	
3	a-ITO	
4	c-ITO	

- ITO → industry standard
- IZO → silicon-perovskite community standard

- Low-T ITO developed at HZB
- Crystallinity varied, no performance reduction

XRD-results



EXPERIMENT DESIGN

Jannik Kleesiek
Poster B-03

	TCO	Thickness
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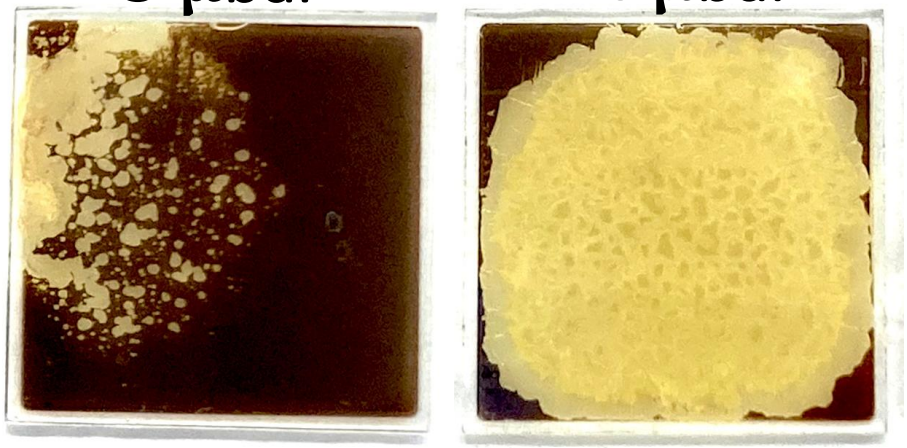
- ITO → industry standard
- IZO → silicon-perovskite community standard

- Low-T ITO developed at HZB
- Crystallinity varied, no performance reduction

- IZO: sputter pressure varied
- High pressure → poor barrier

5 µbar **14 µbar**



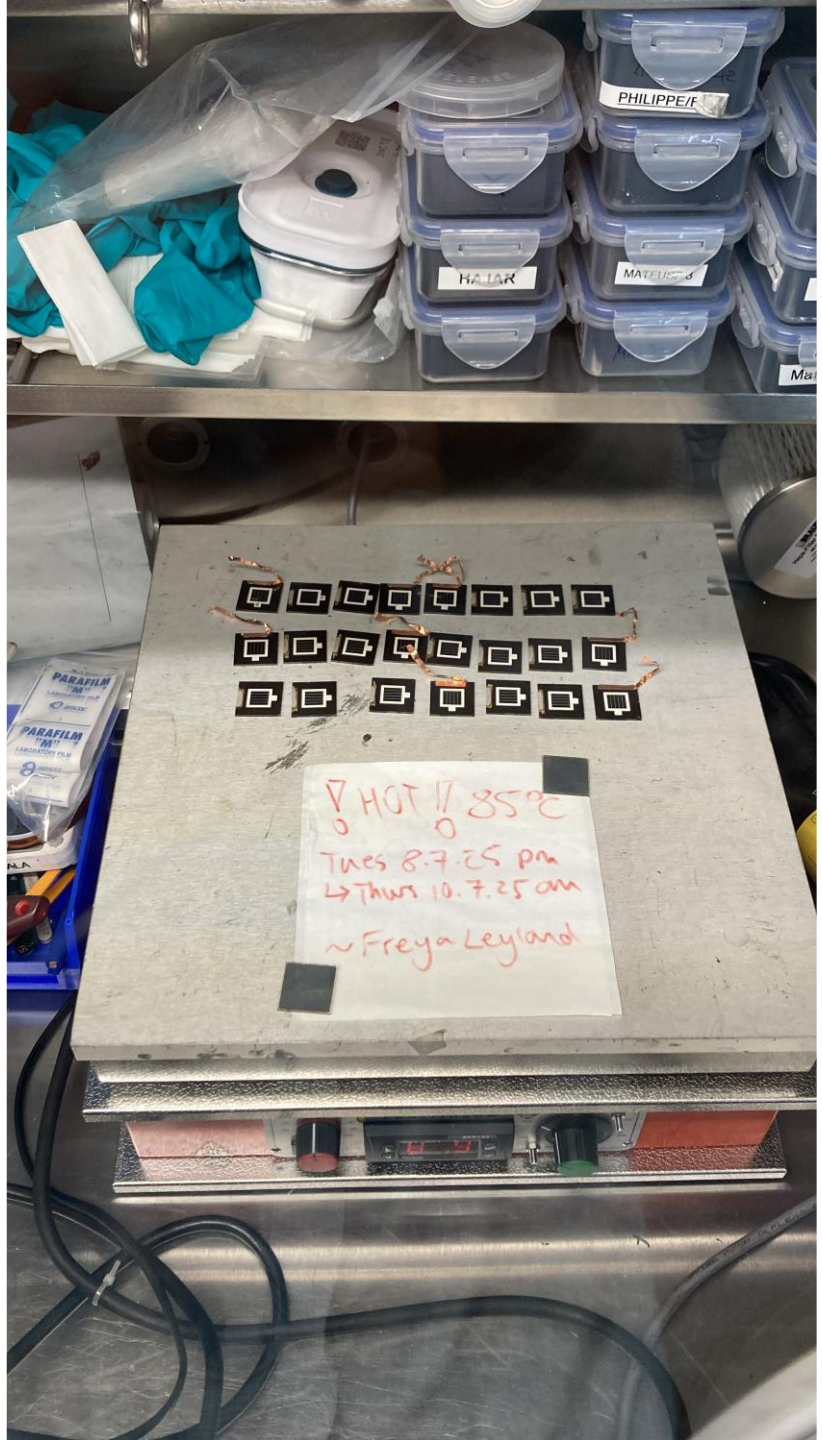
EXPERIMENT DESIGN

	TCO	Thickness
1	IZO 5 µbar	40 nm
2	IZO 14 µbar	
3	a-ITO	
4	c-ITO	
5	IZO 5 µbar	100 nm
6	a-ITO	
7	c-ITO	

- Thickness varied
- Thicker → better barrier
- Trade off with reduced transparency

EXPERIMENT DESIGN

	TCO	Thickness
1	IZO 5 µbar	40 nm
2	IZO 14 µbar	
3	a-ITO	
4	c-ITO	
5	IZO 5 µbar	100 nm
6	a-ITO	
7	c-ITO	



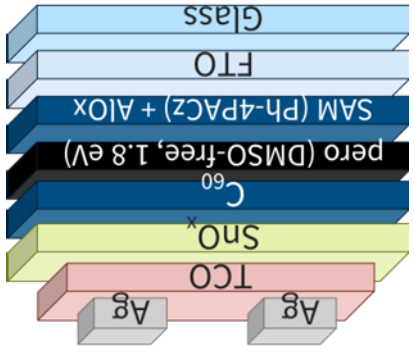
Ageing:

- 85 °C
- Hotplate
- Glovebox - N_2 atmosphere
- Dark(ish)
- **41 hours**

PHOTOGRAPHS FROM BACKSIDE

Aged at 85 °C, dark

From rear side through glass

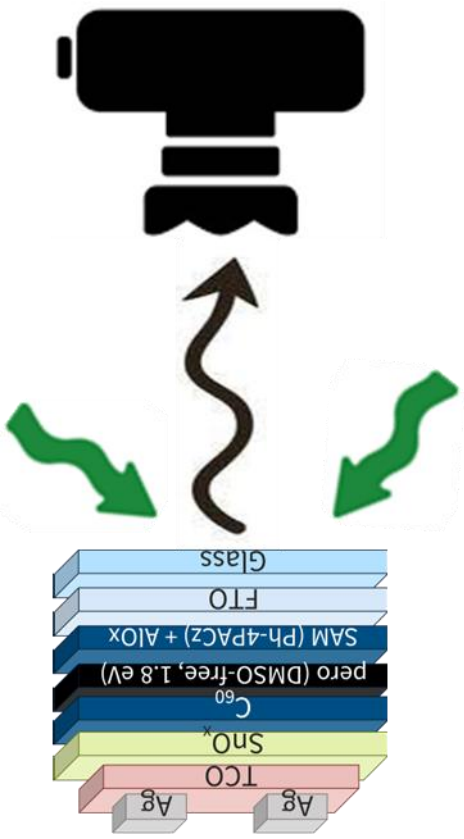


IZO		a-ITO	c-ITO
5 ubar	*14 ubar*		
			

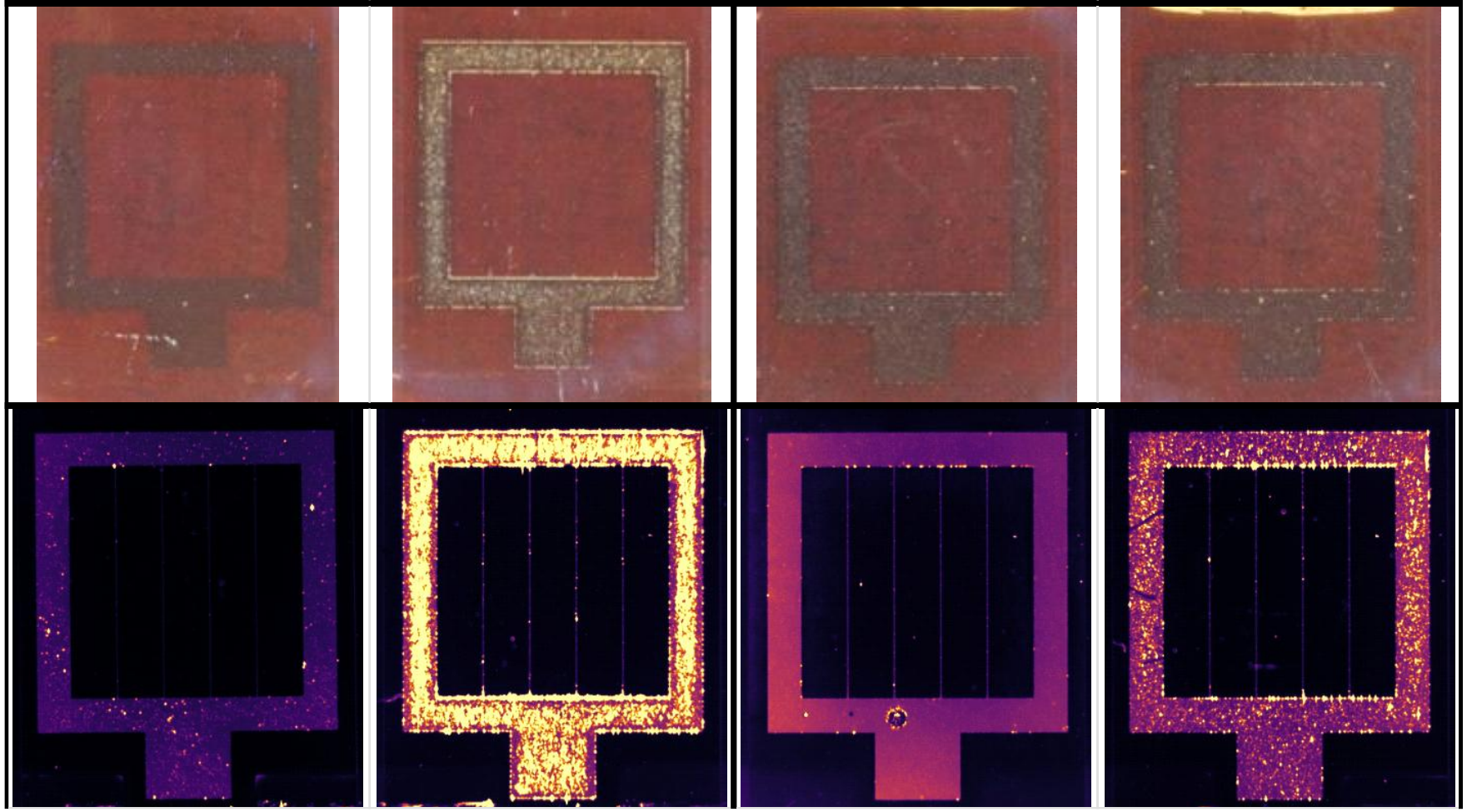
PL FROM BACKSIDE

Aged at 85 °C, dark

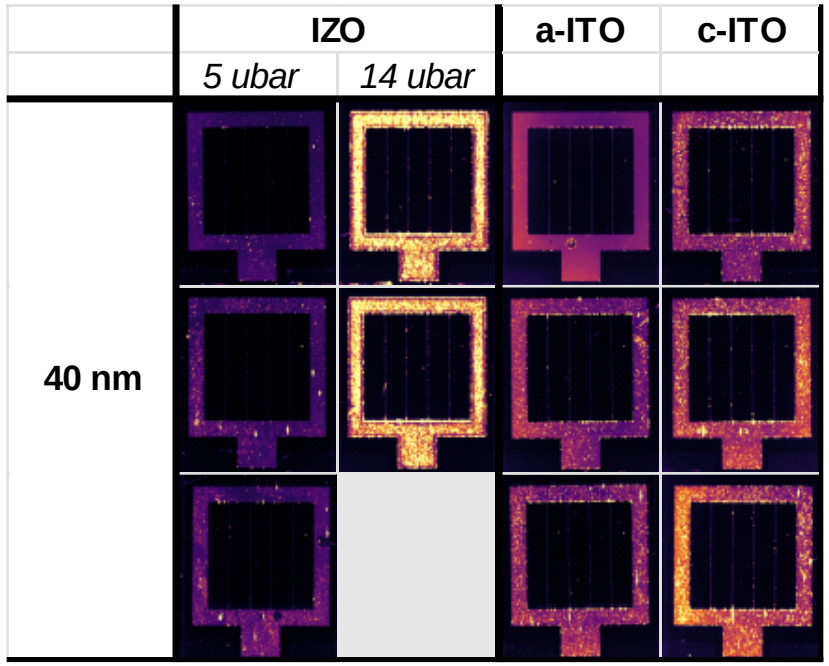
From rear side through glass

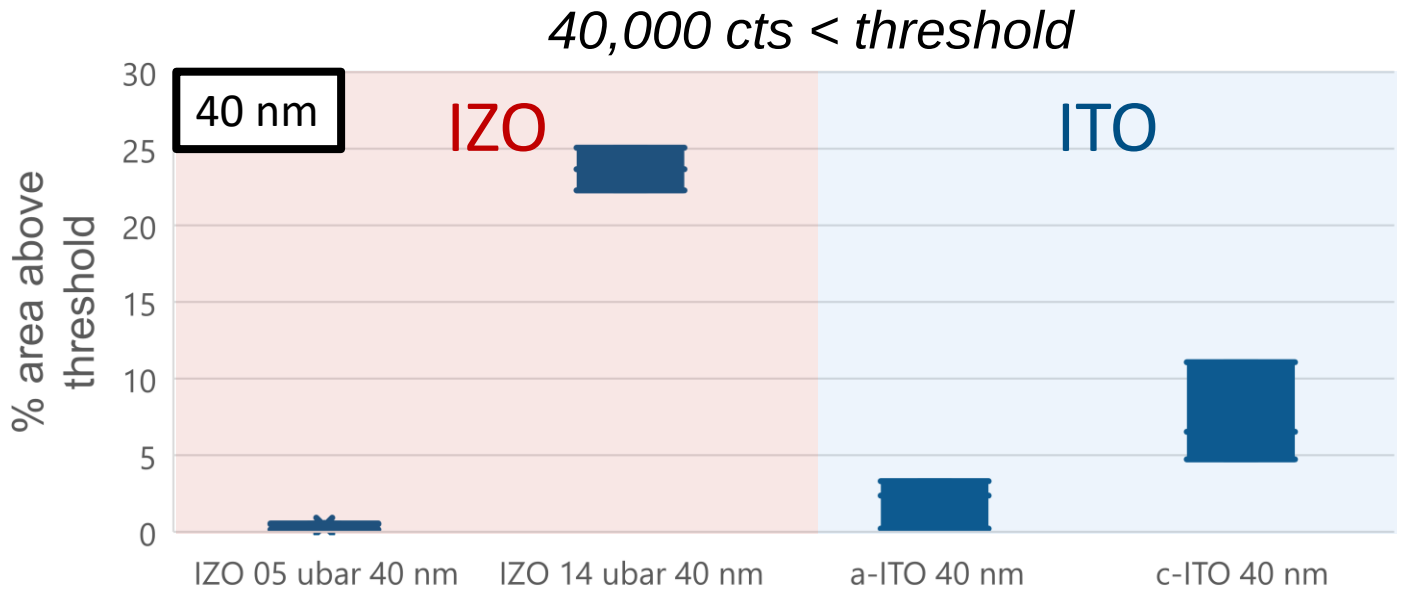


IZO		a-ITO	c-ITO
5 ubar	*14 ubar*		



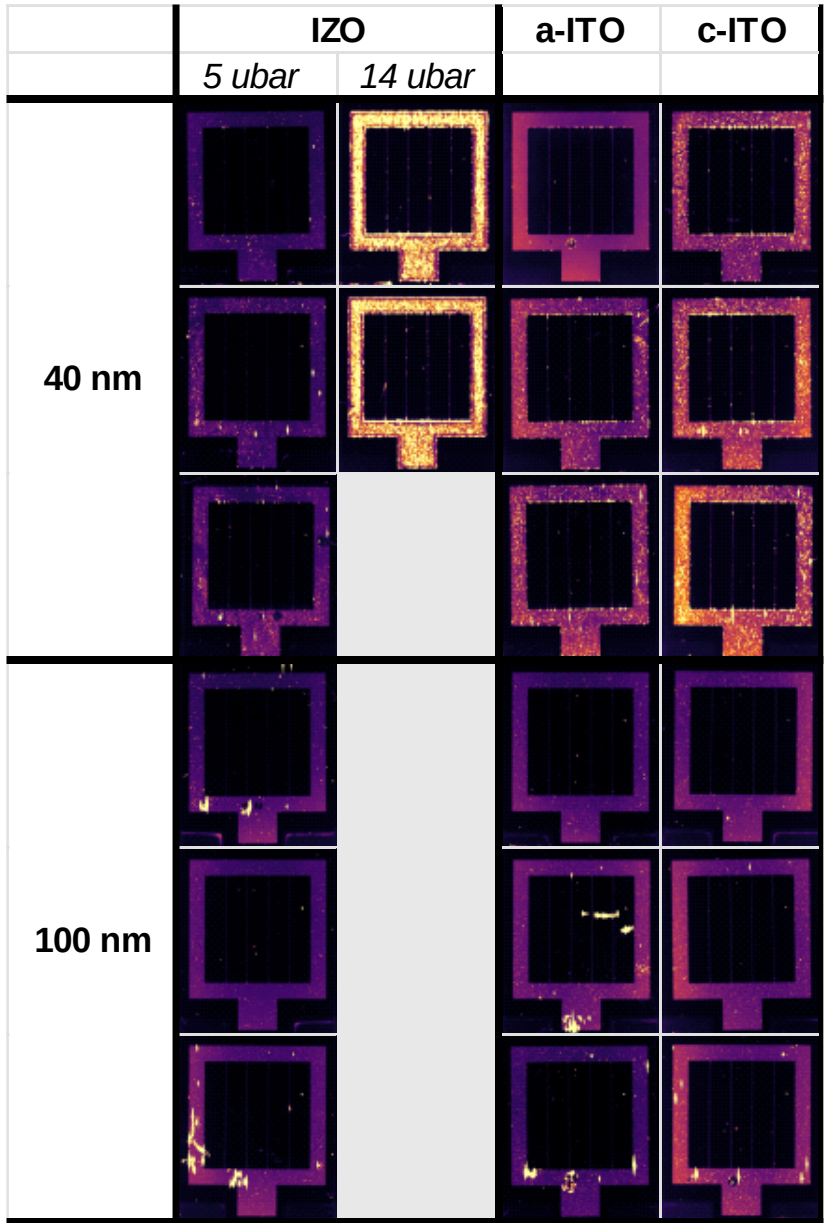
PL FROM BACKSIDE



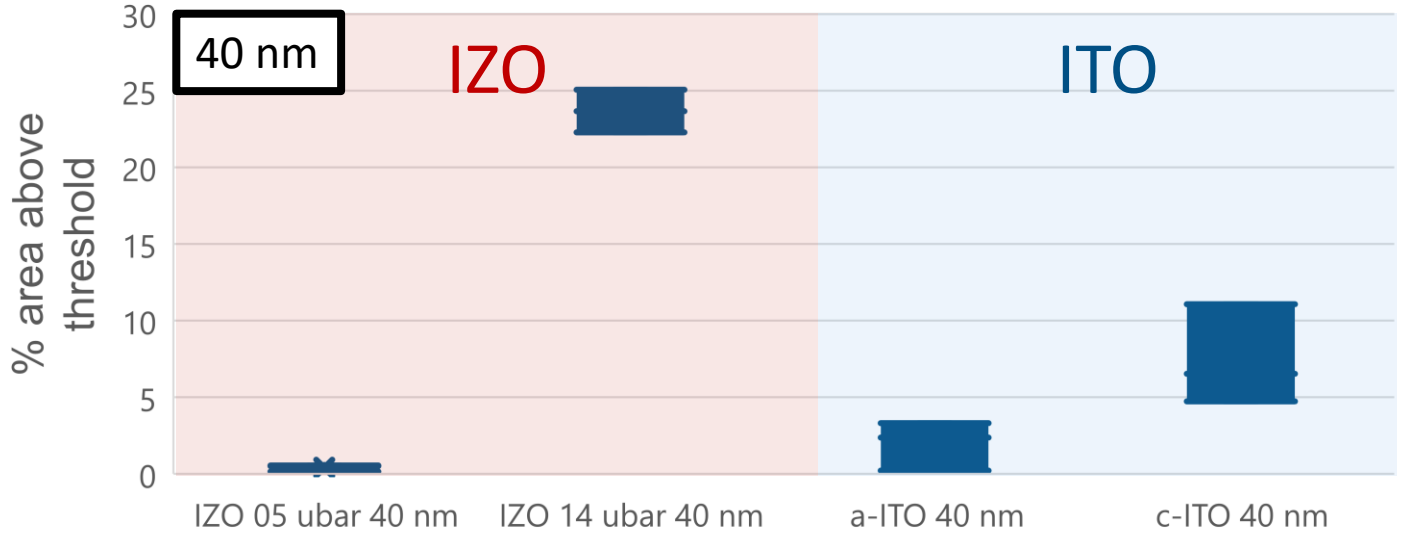


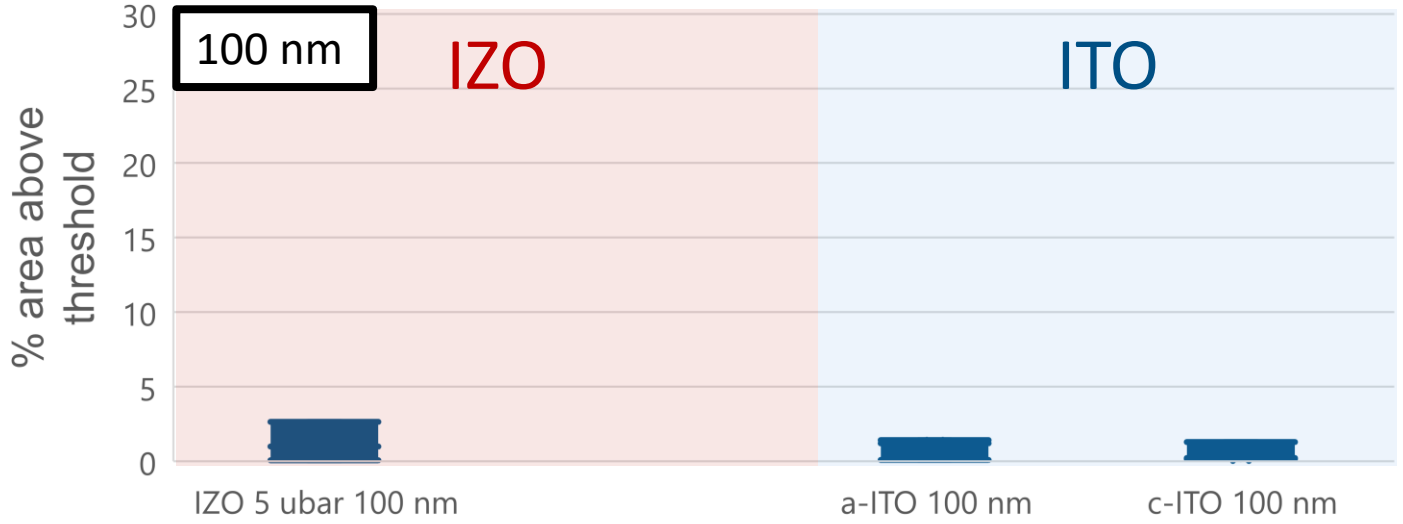
- IZO 5 μbar > a-ITO > c-ITO > IZO 14 μbar

PL FROM BACKSIDE



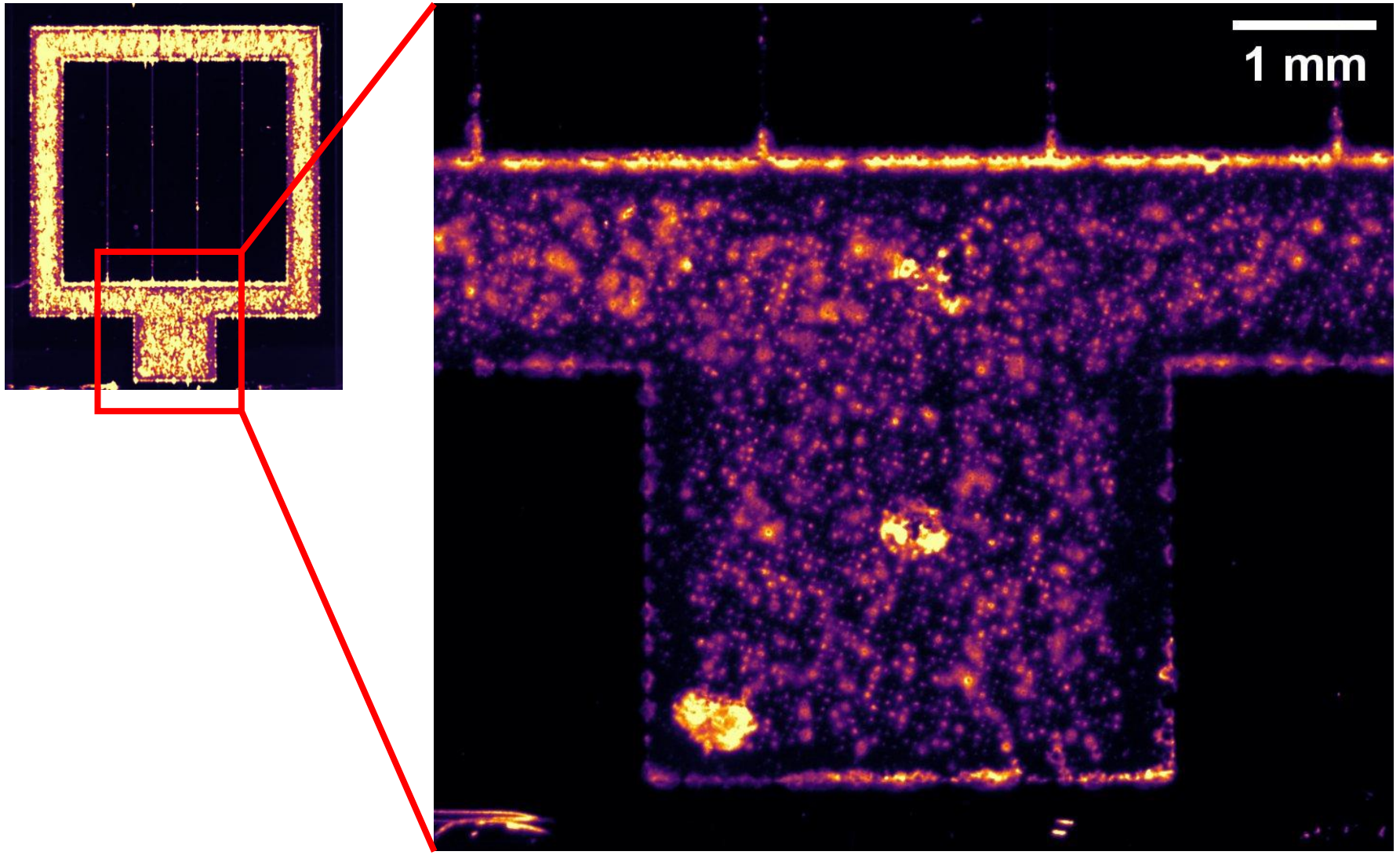
40,000 cts < threshold





- IZO 5 μbar > a-ITO > c-ITO > IZO 14 μbar
- Increasing thickness improves barrier

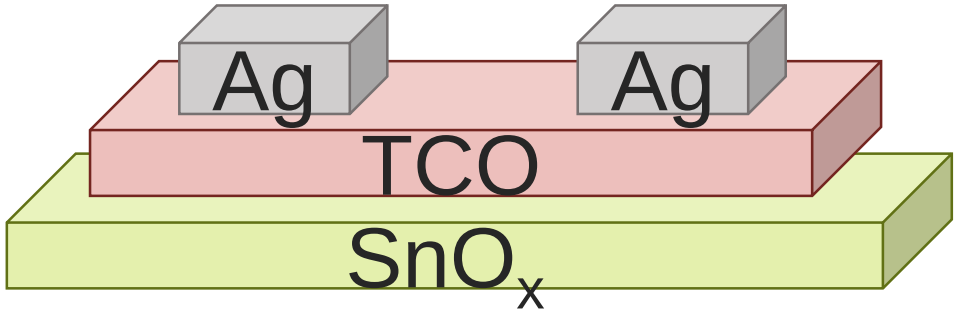
SCREEN-PRINTING GRID MESH



- Grid observed
- Spacing = **0.7 µm**
- Screen printing mesh grid spacing = **0.7 µm**
- Pressure points allow Ag diffusion.

XPS – SILVER INGRESS TO C60 INTERFACE

Dr. Fengshuo Zu



XPS – SILVER INGRESS TO C60 INTERFACE

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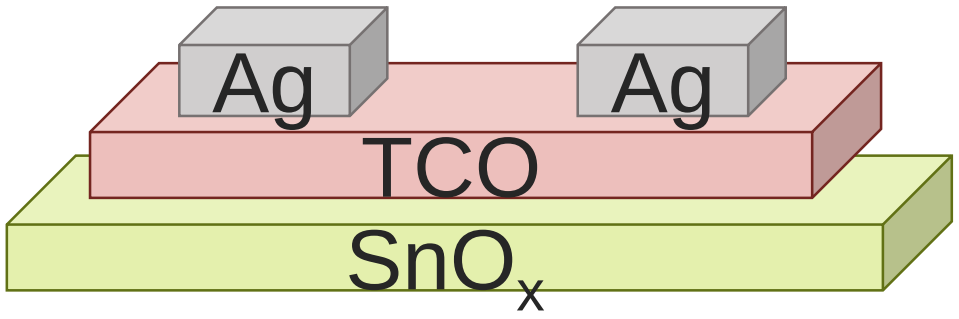
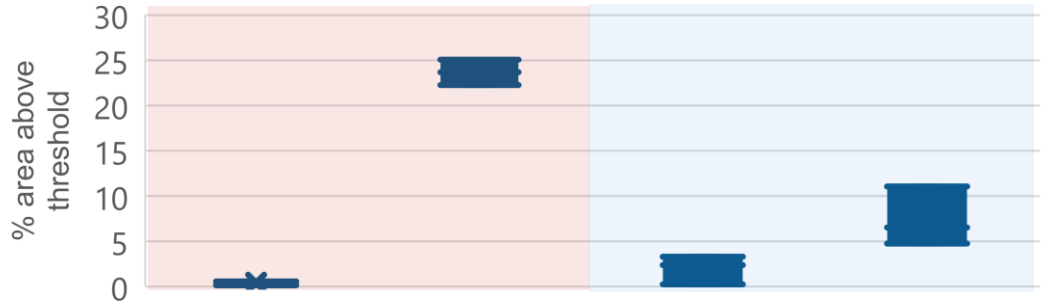
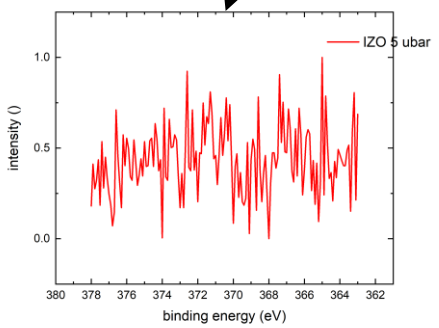
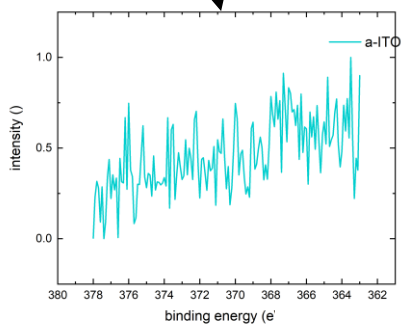
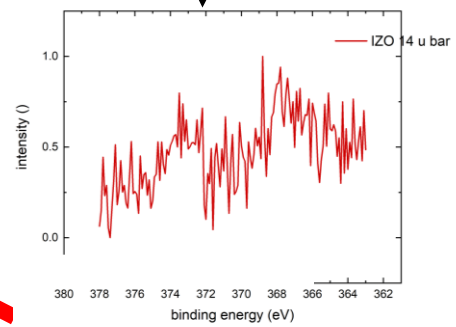


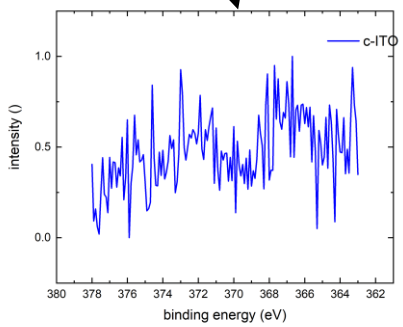


	IZO 5 μbar	IZO 14 μbar	a-ITO	c-ITO
Ag detected?	X	✓	X	✓



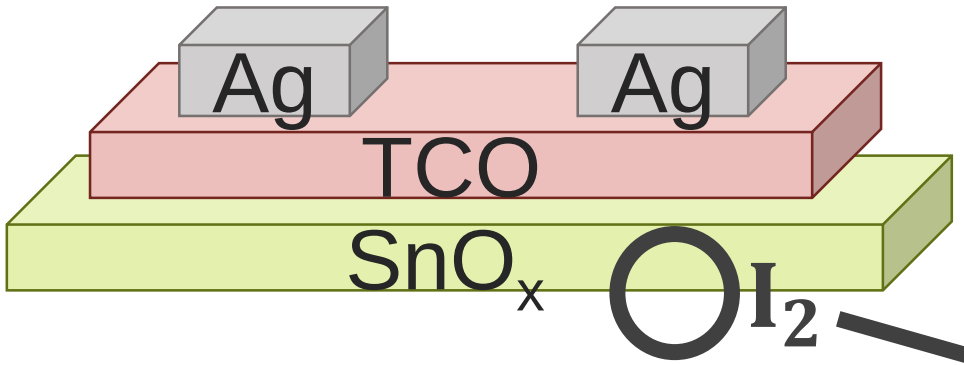




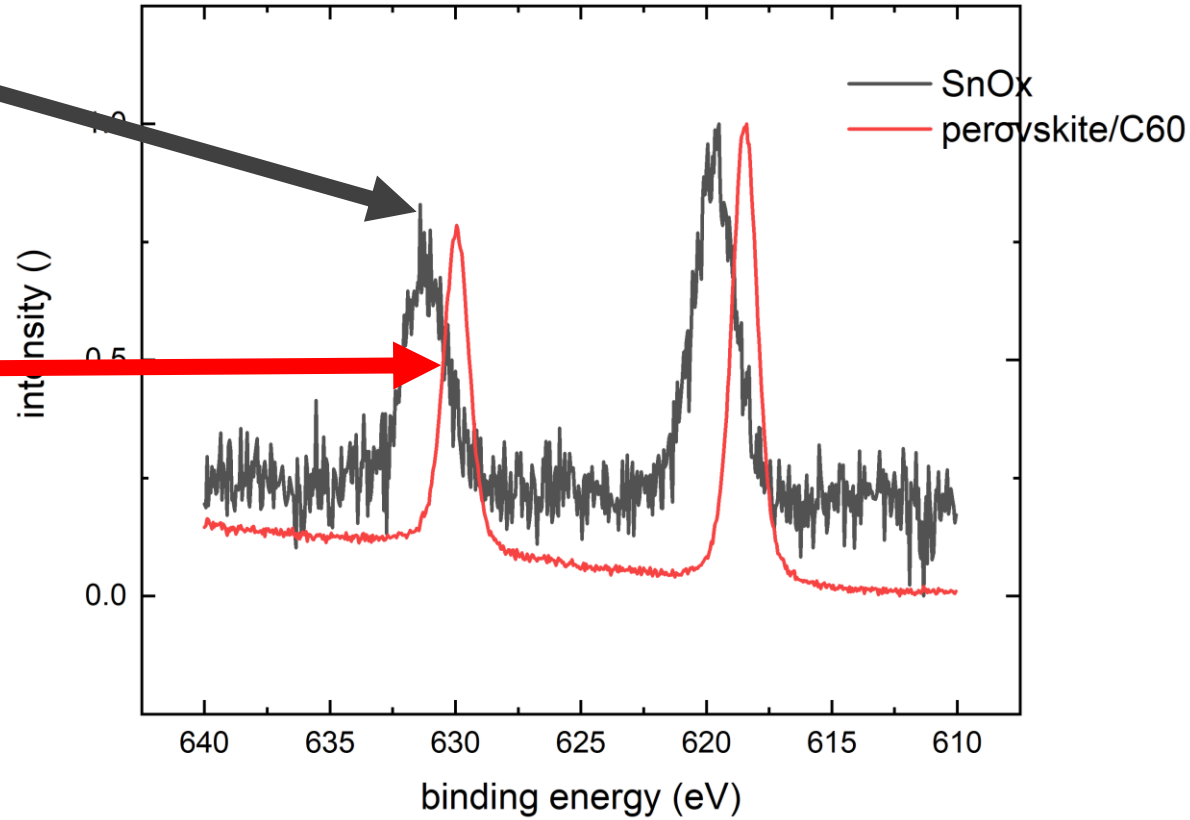


XPS – IODINE BONDING ENVIRONMENT

Dr. Fengshuo Zu



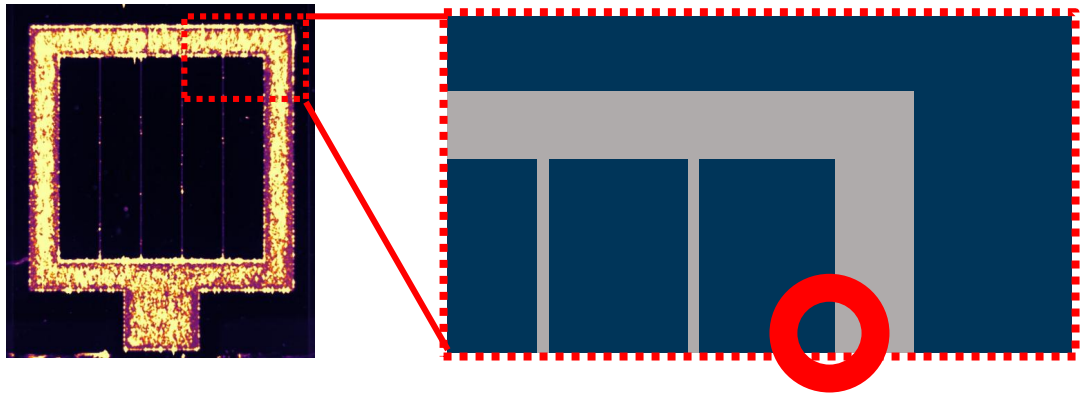
- Iodine 3d peak shifted by 1.5 eV depending on location indicates different bonding environments.
- I_2 diffuses from perovskite up towards Ag contacts.



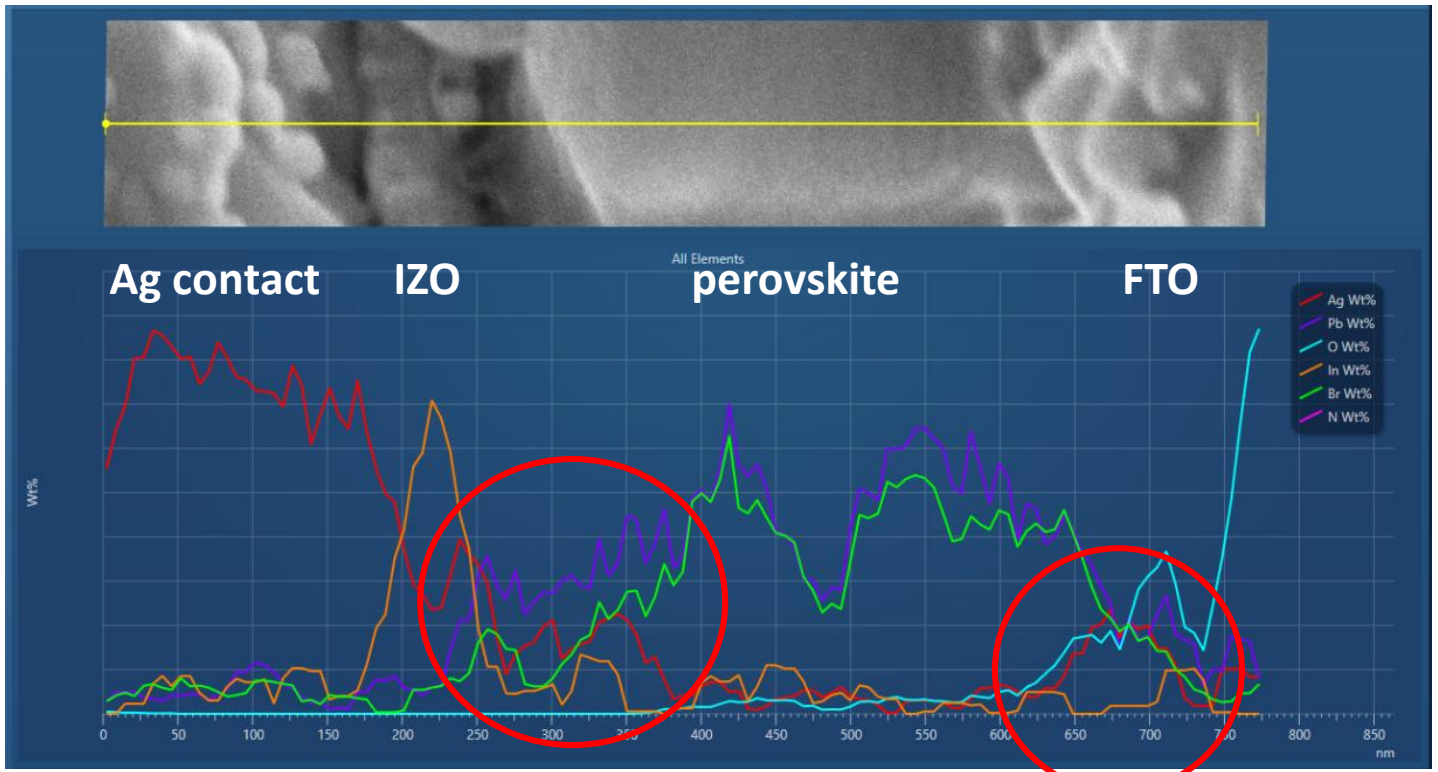
Dr. Guillermo Farias Basulto

CROSS-SECTION SEM-EDX

14 µbar IZO (high pressure, poor barrier)



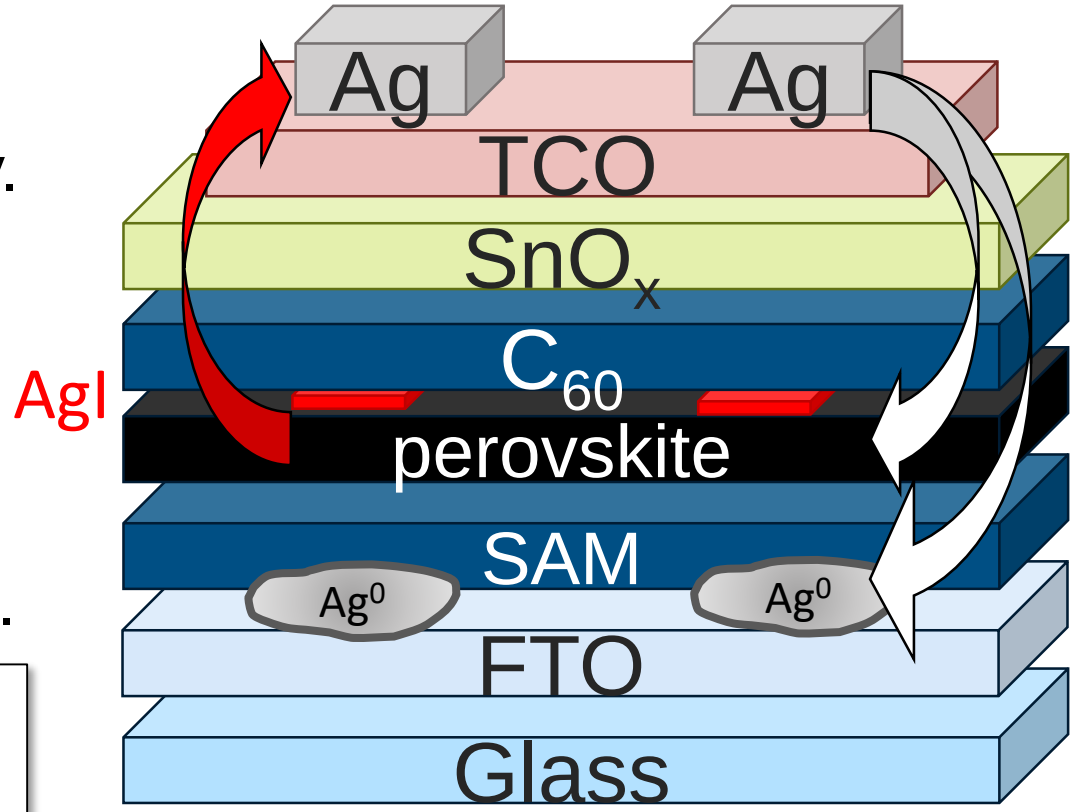
- Ag diffusion
- Accumulation at FTO surface – Ag^0 plating?
- Accumulation at perovskite/C60 interface – AgI?



CONCLUSIONS

- IZO *(5 µbar)* > a-ITO > c-ITO > IZO *(15 µbar).*
- Increasing thickness improves barrier quality.
- Silver diffuses down and iodine diffuses up.
- Silver accumulates at perovskite and FTO surfaces.
- Speculative: formation of AgI and Ag^0 plating.

Outlook:
- Directly measure Ag^0 at FTO surface.
- Understand why TCOs have differing barrier properties.



2. Test TCOs in encapsulated industrial M6 silicon/perovskite tandem solar cells.

WORKFLOW

Key: Oxford PV / HZB

Tandem fabrication

TCO

Metallisation
ECA interconnection
Encapsulation

Characterisation

Aging
85 °C, dark,
ambient, 1000 h

Characterisation

	TCO	Thickness
1	IZO 5 µbar	40 nm
2	a-ITO	
3	c-ITO	

WORKFLOW

Key: Oxford PV | HZB

Tandem fabrication

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85 °C, **dark**,
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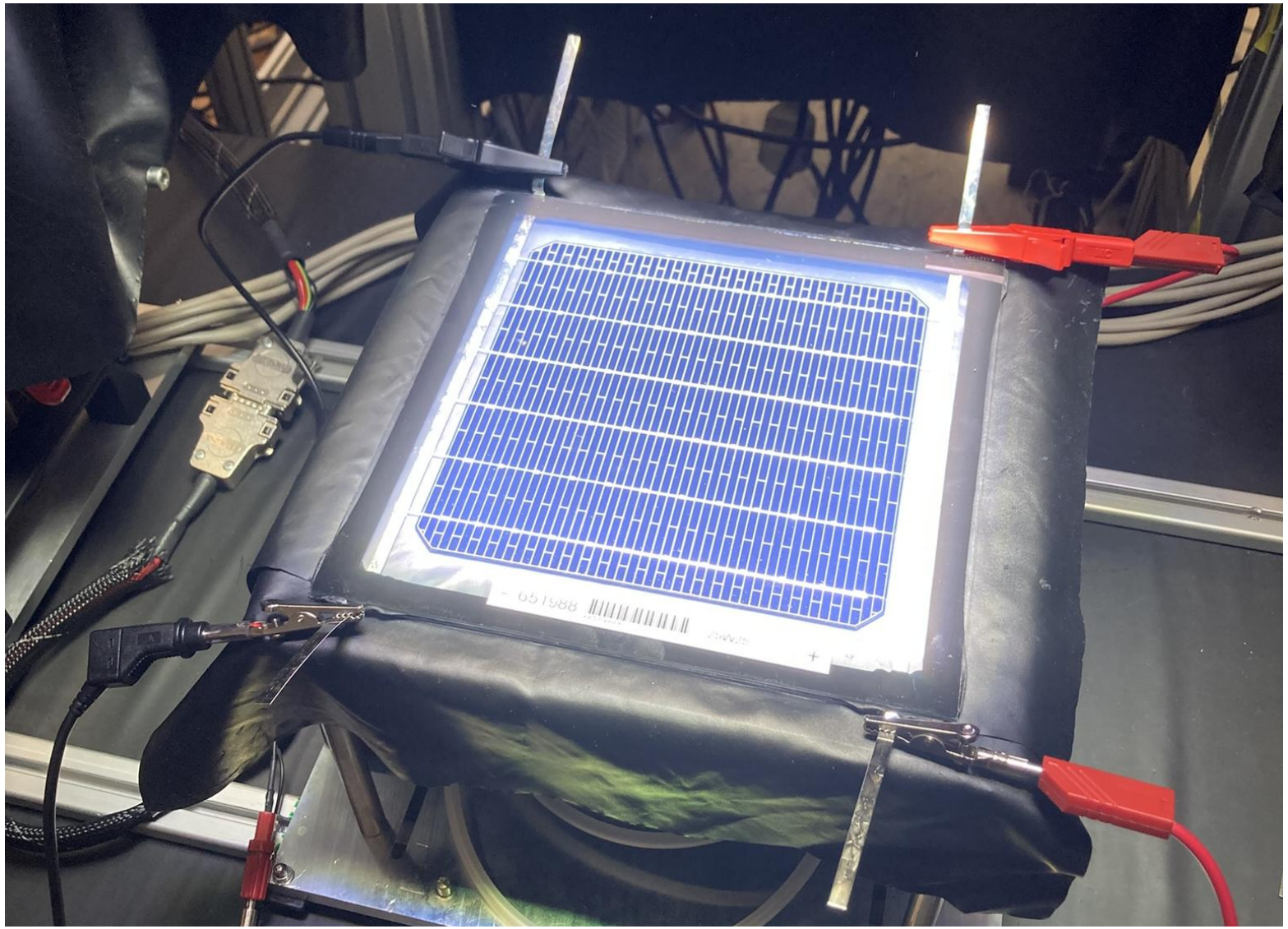
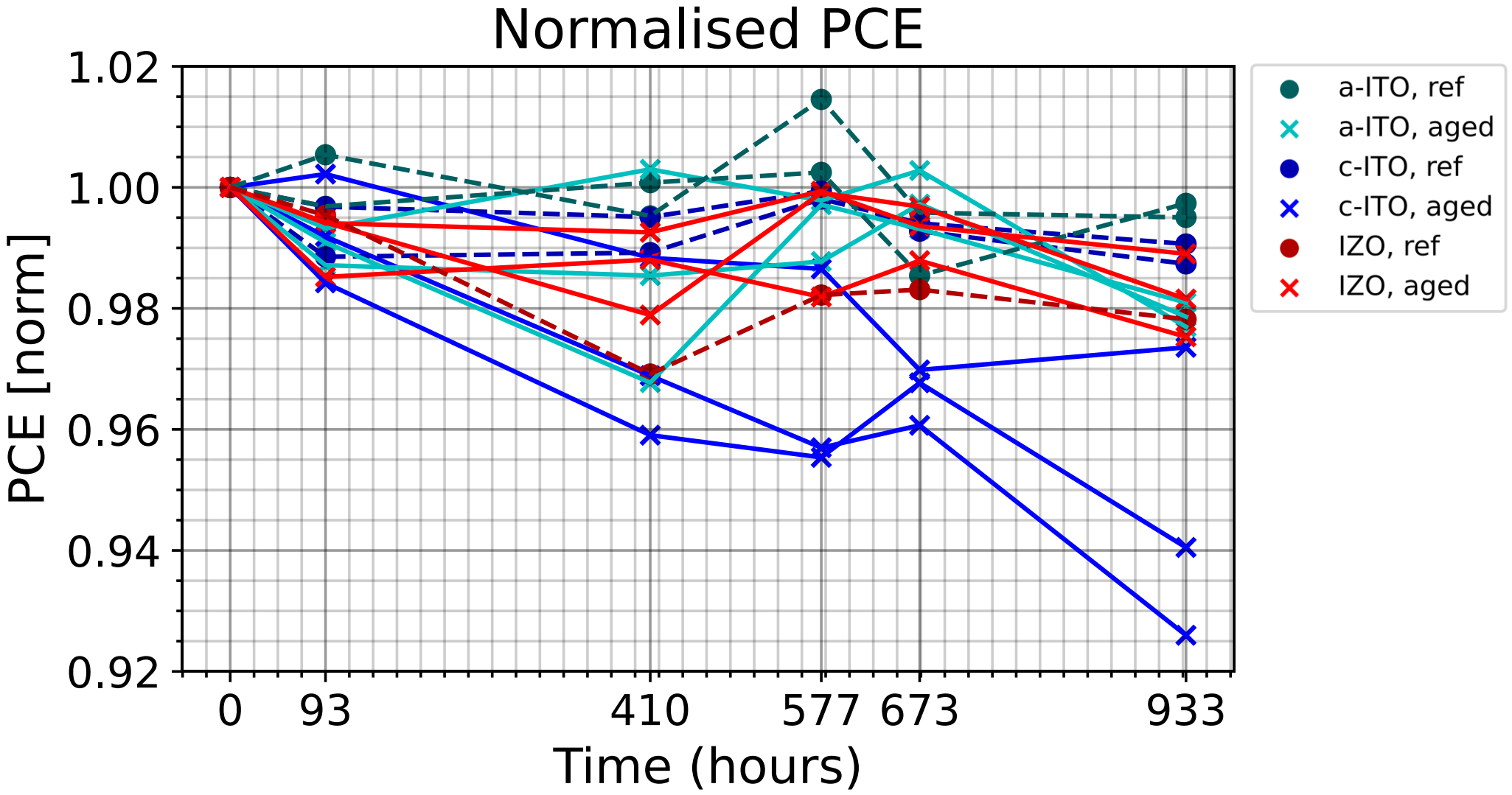


JV – PCE

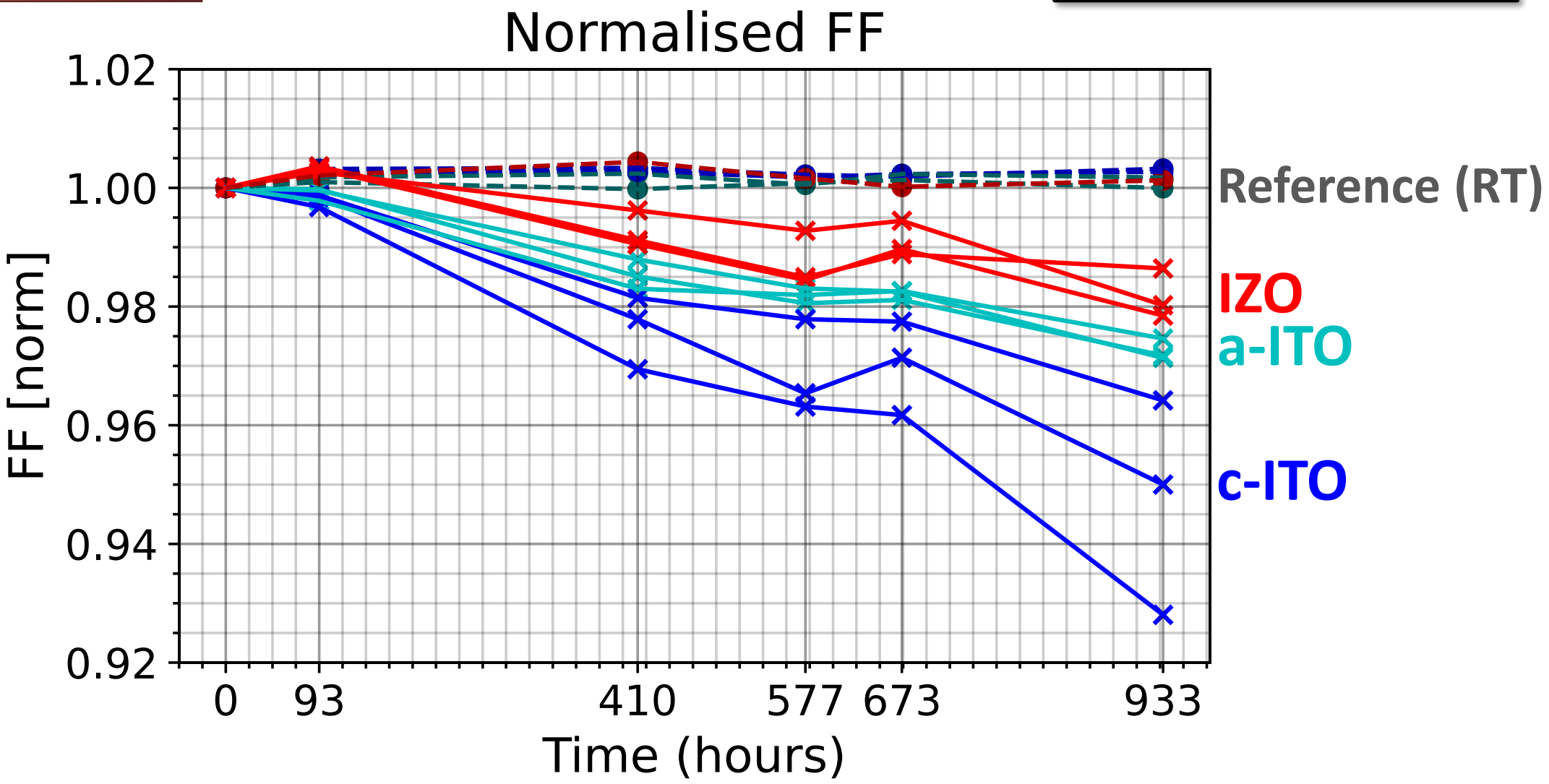
Aged at 85 °C, dark



JV – FF

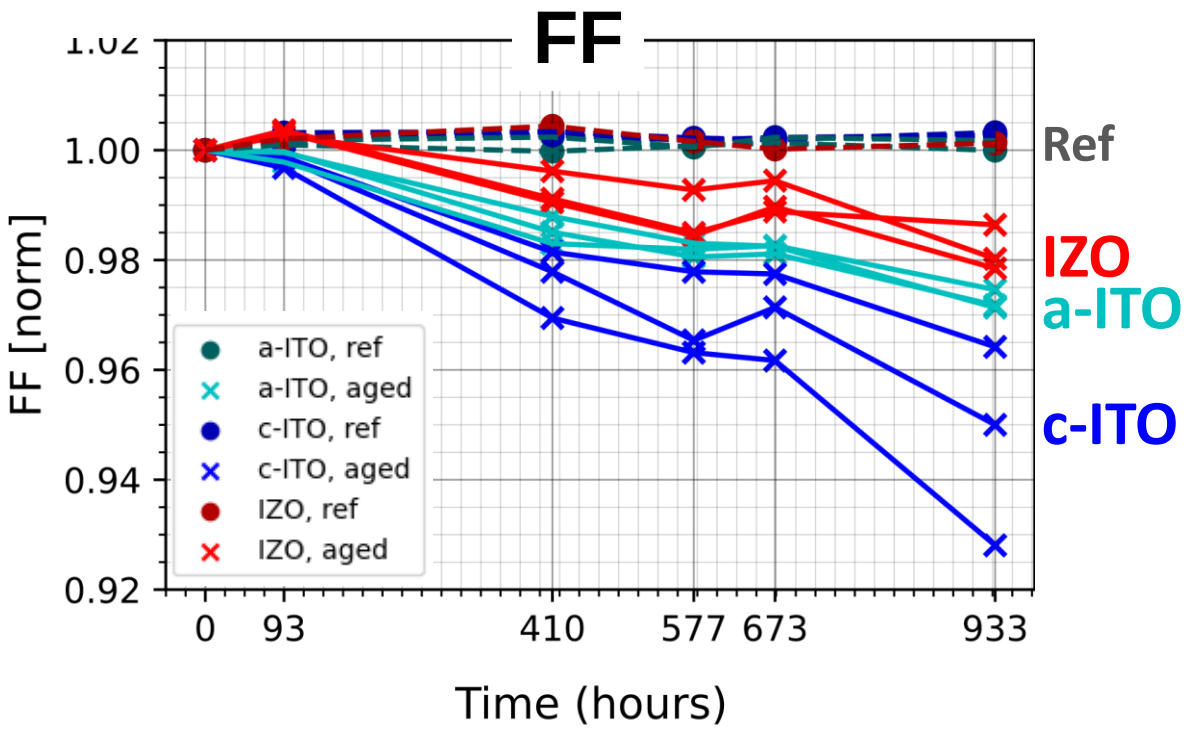
Aged at 85 °C, dark

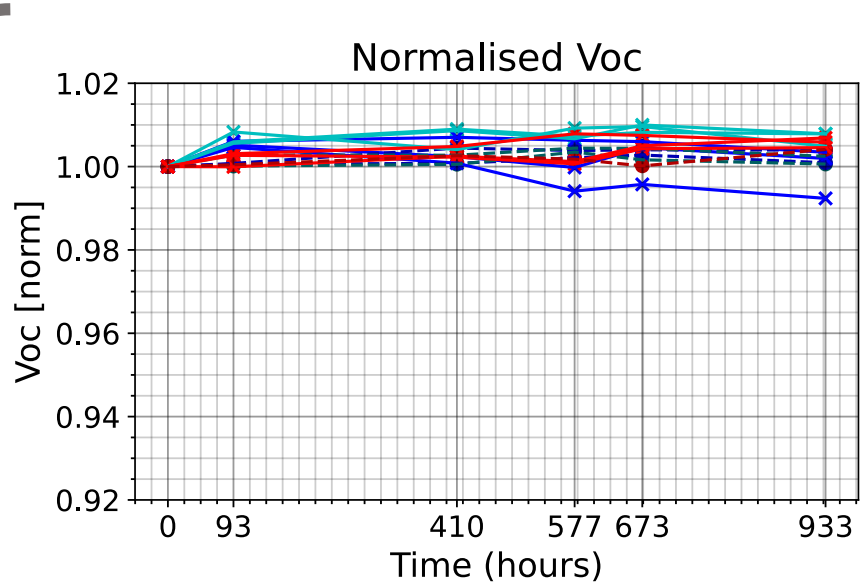
IZO > a-ITO > c-ITO

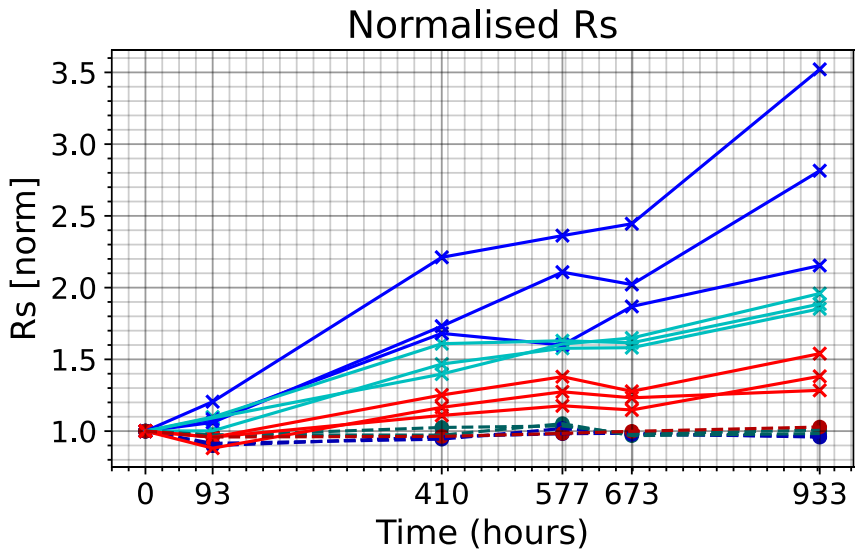


RS AND VOC

Aged at 85 °C, dark



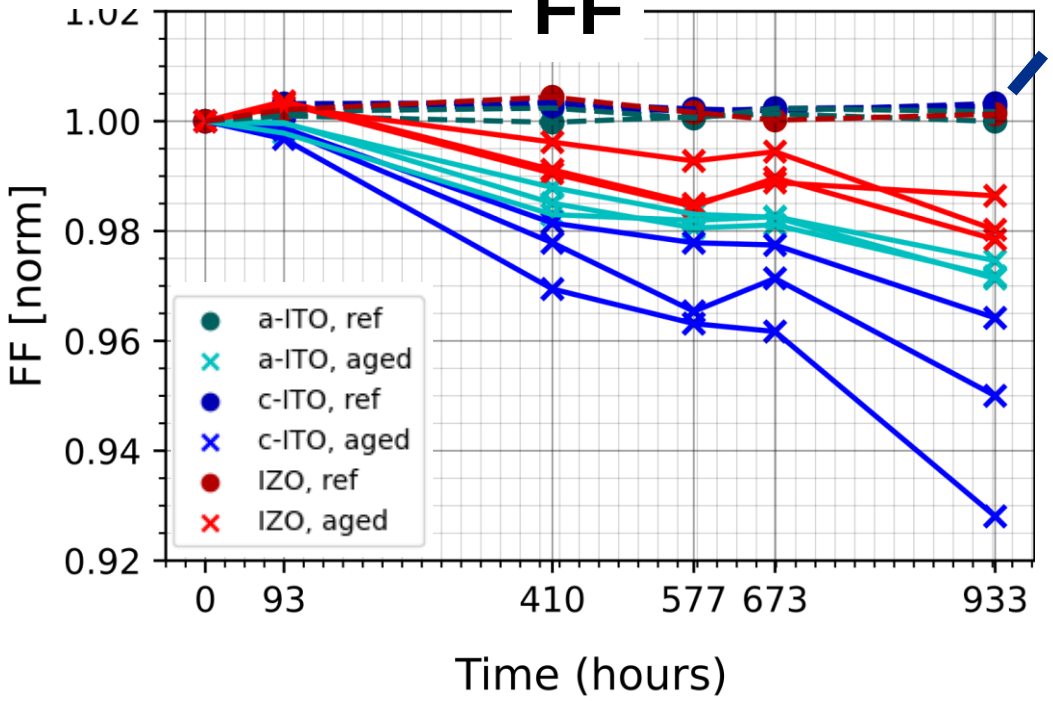


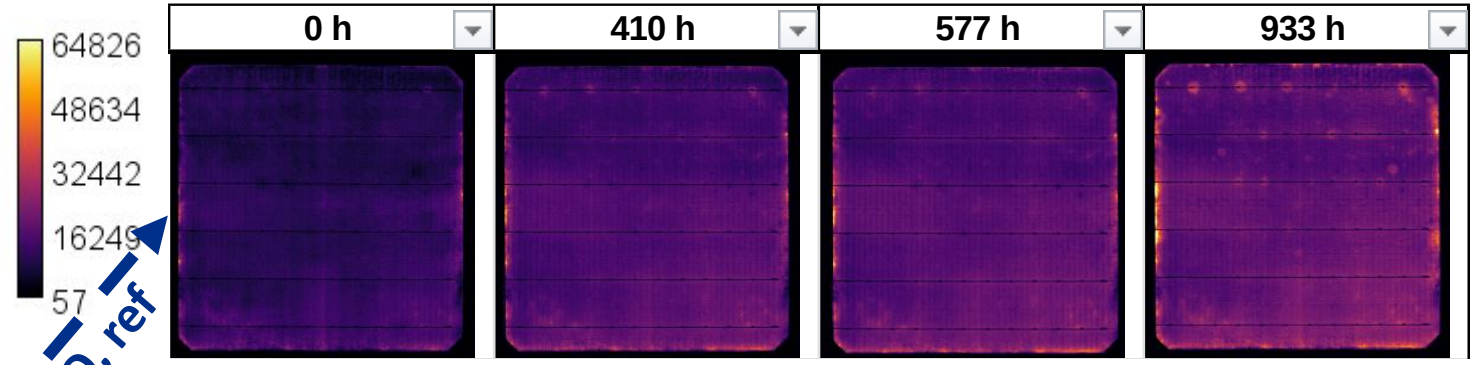


- No change in Voc
- Increased Rs → drop in FF
- Degradation due to metal corrosion

EL IMAGING

Aged at 85 °C, dark





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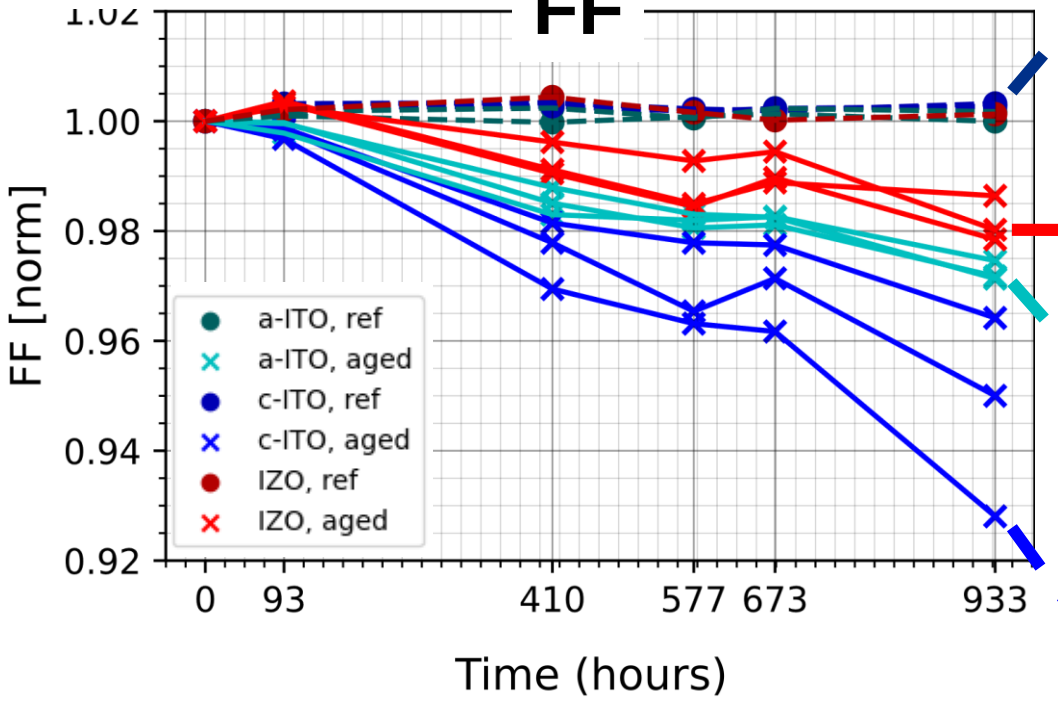
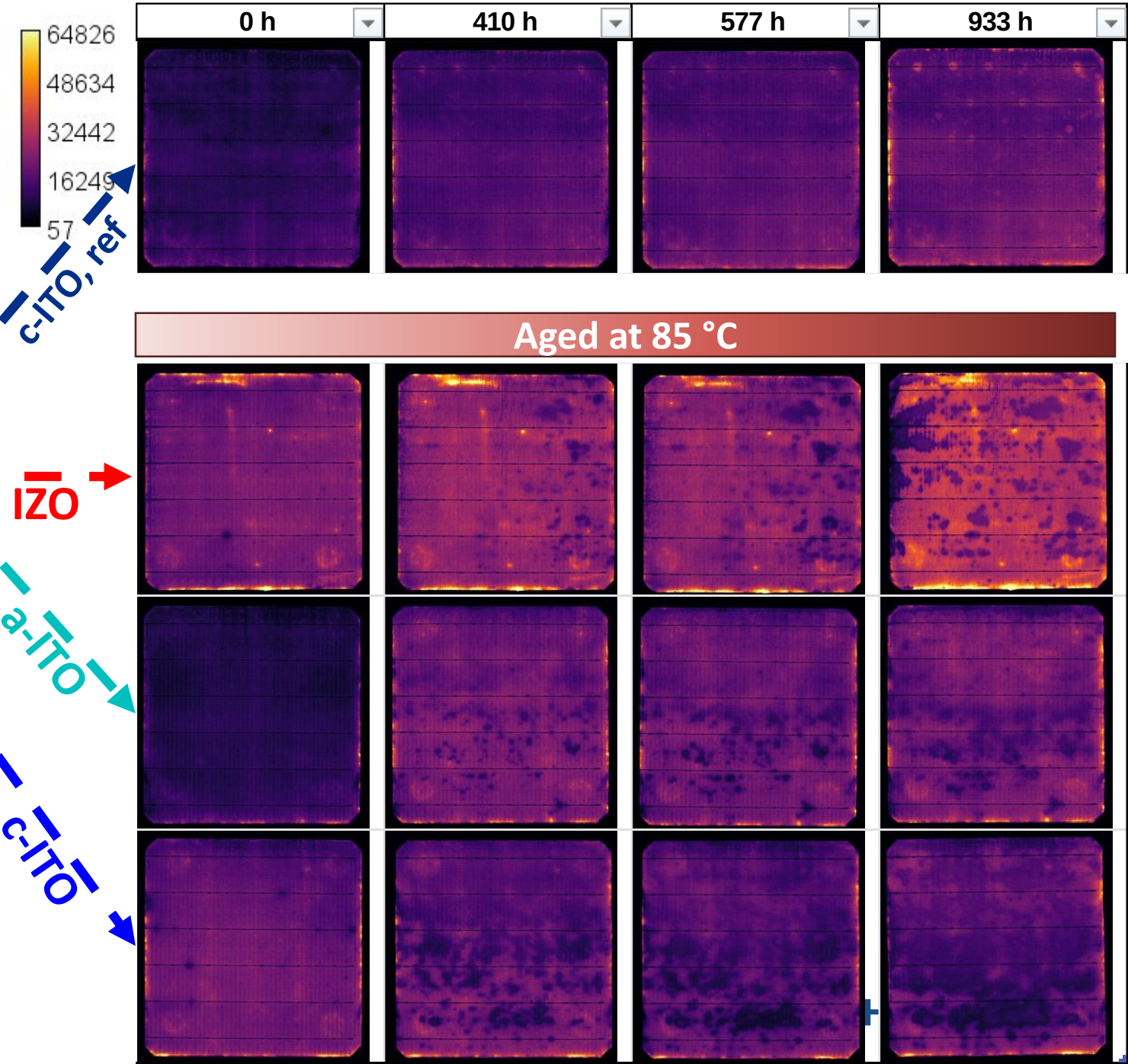
EL IMAGING

Aged at 85 °C, dark





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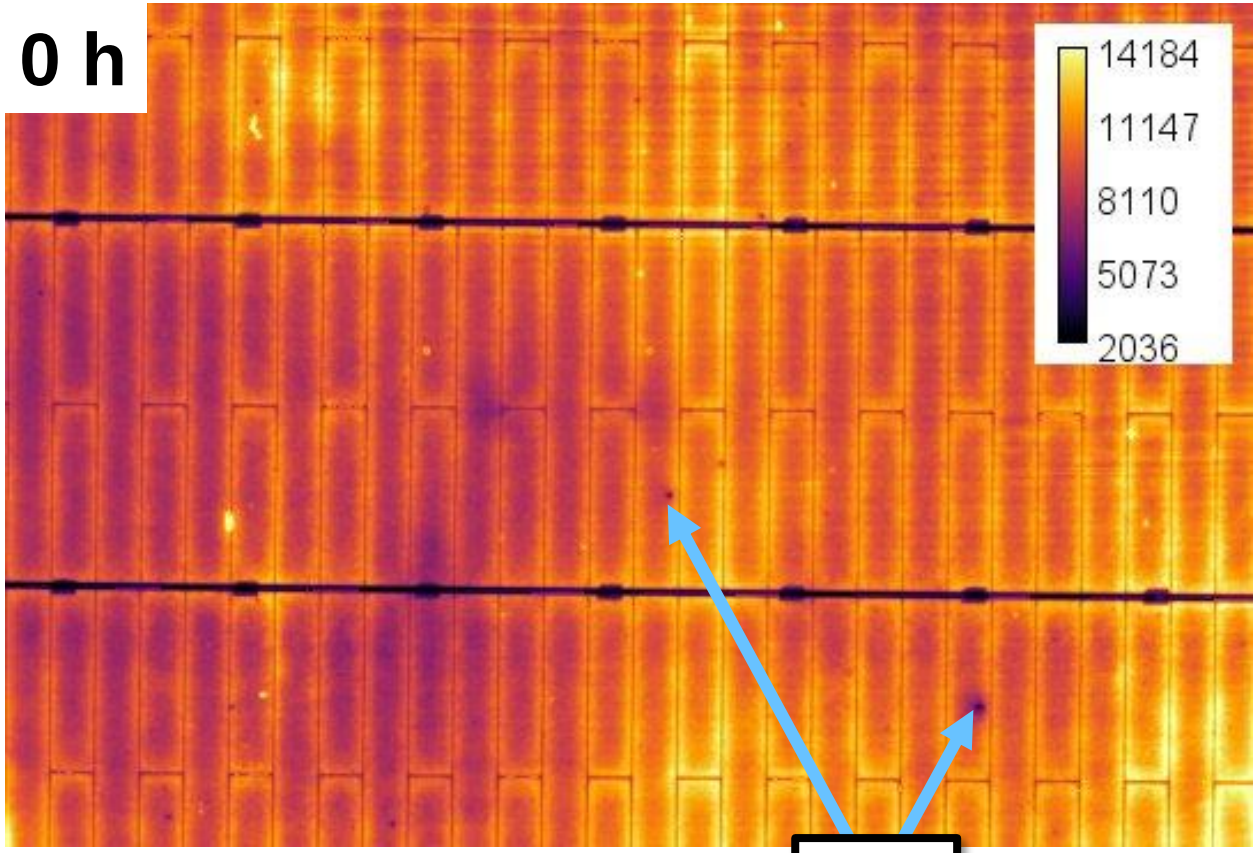
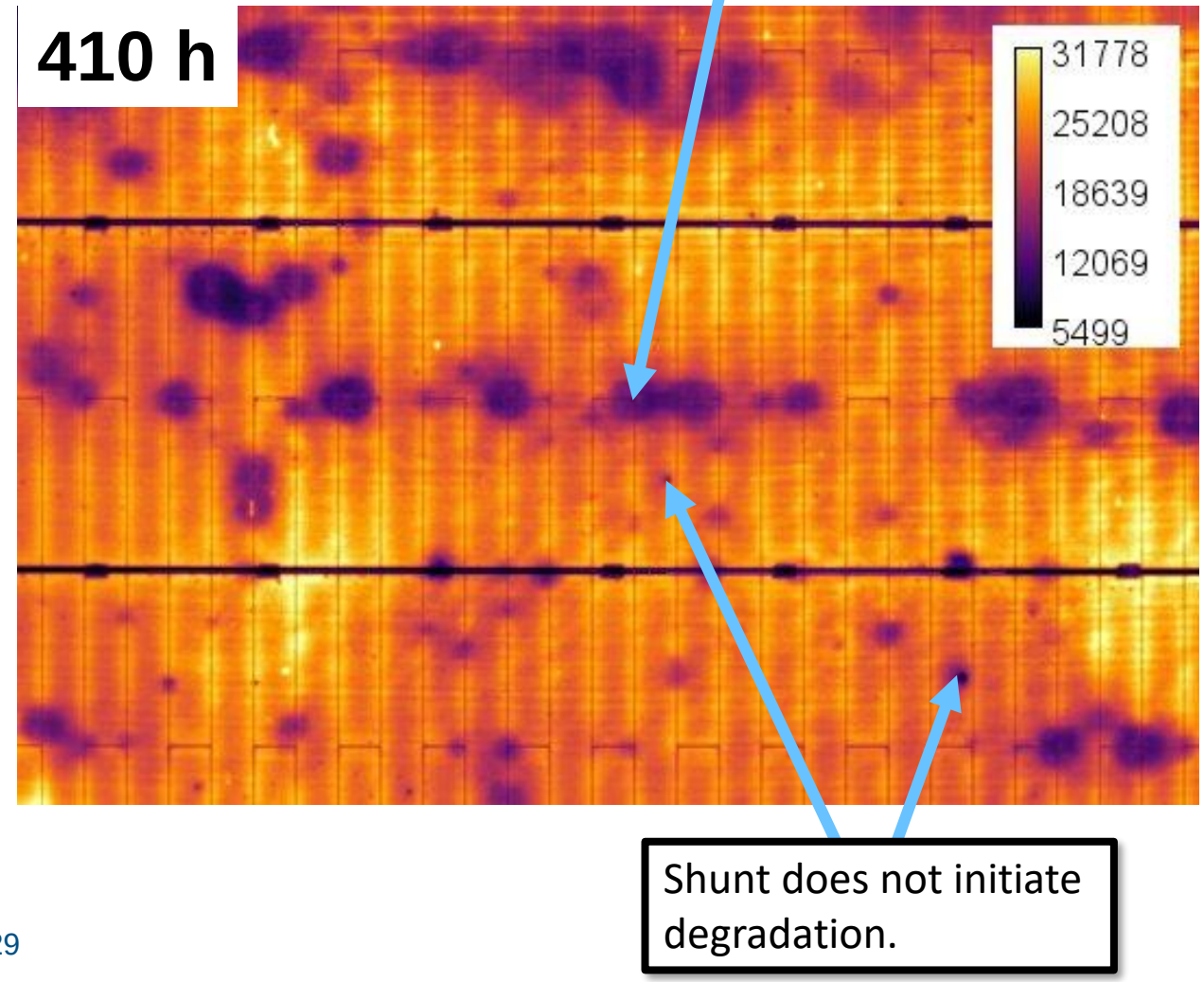
EL – CLOSER LOOK (a-ITO)

Aged at 85 °C, dark



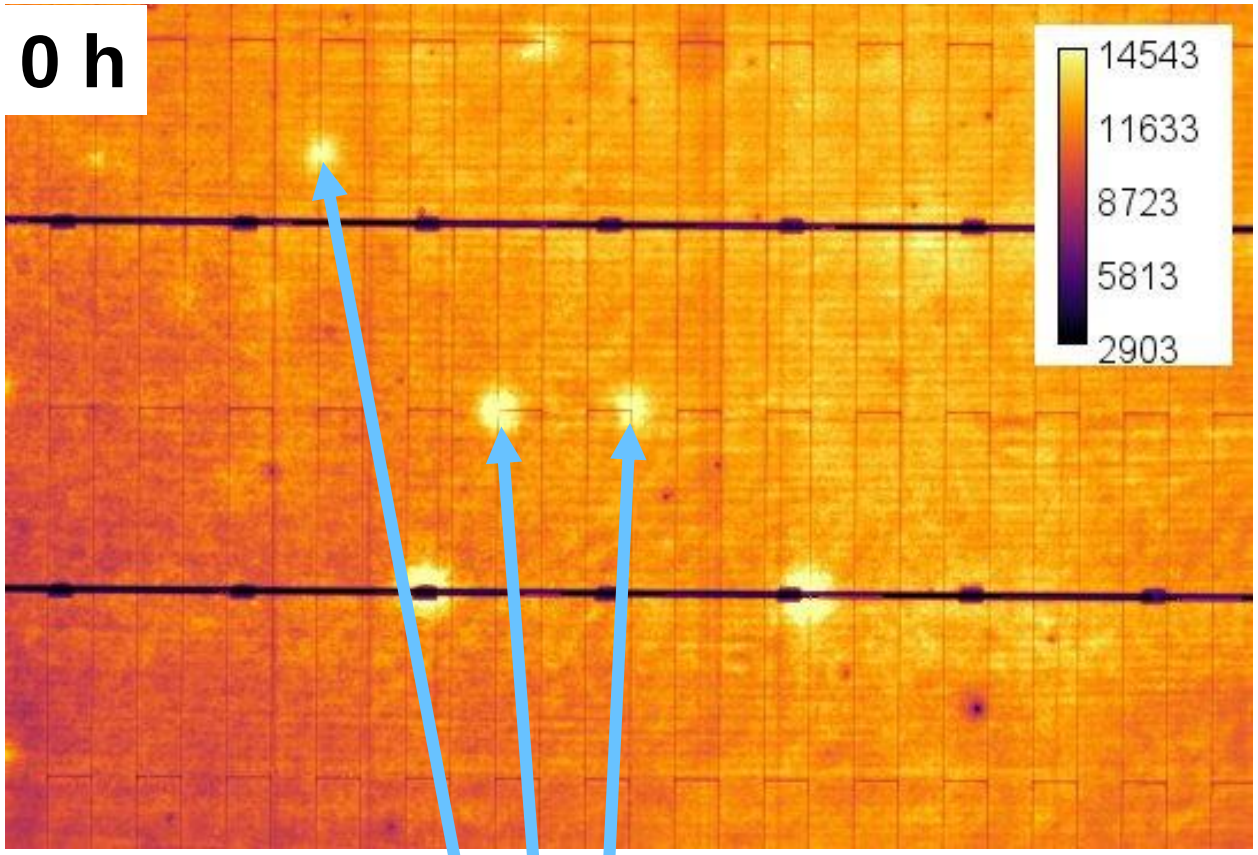


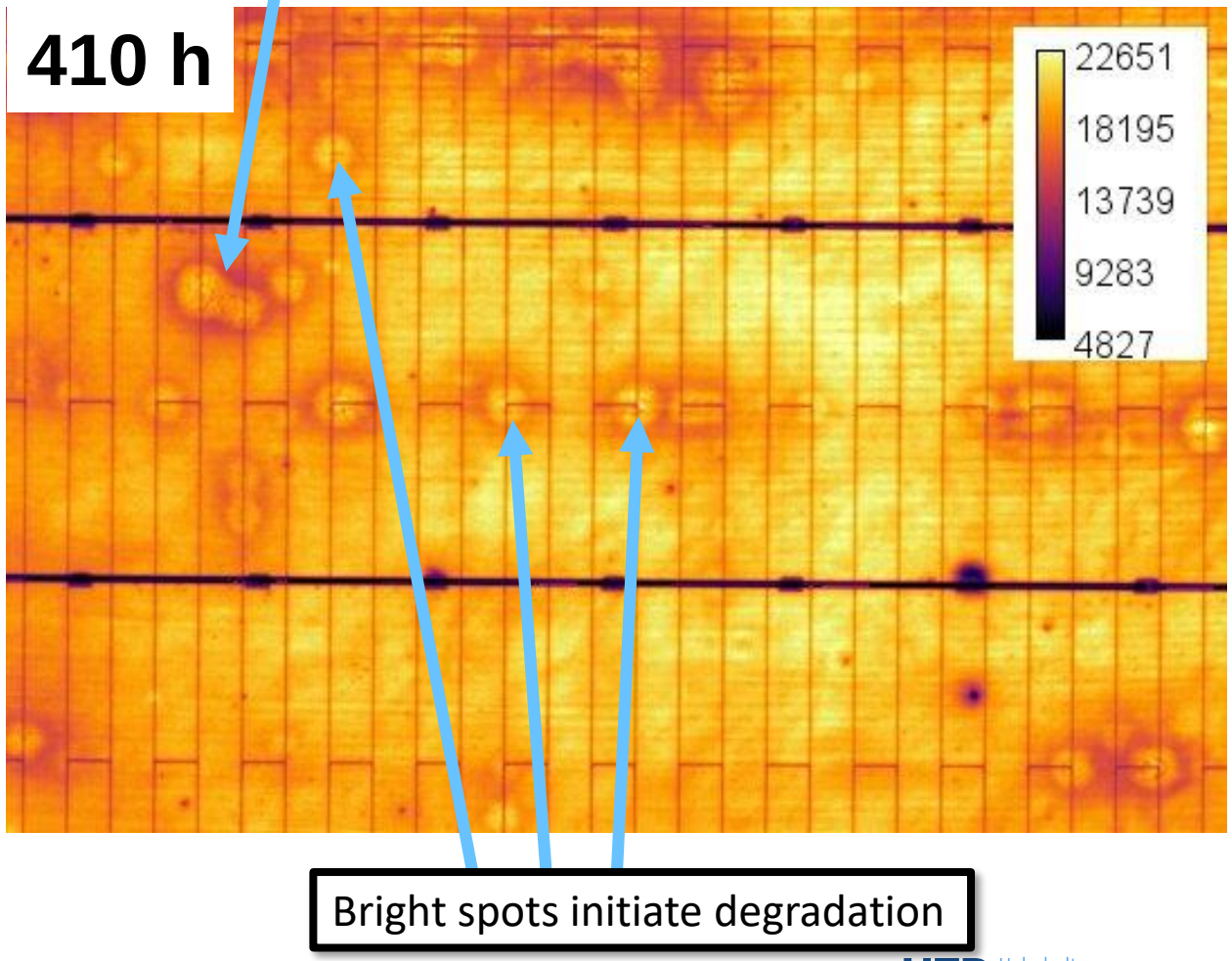
PL – CLOSER LOOK (a-ITO)

Aged at 85 °C, dark

Bright core surrounded by a dark ring, lines up with EL dark spots.

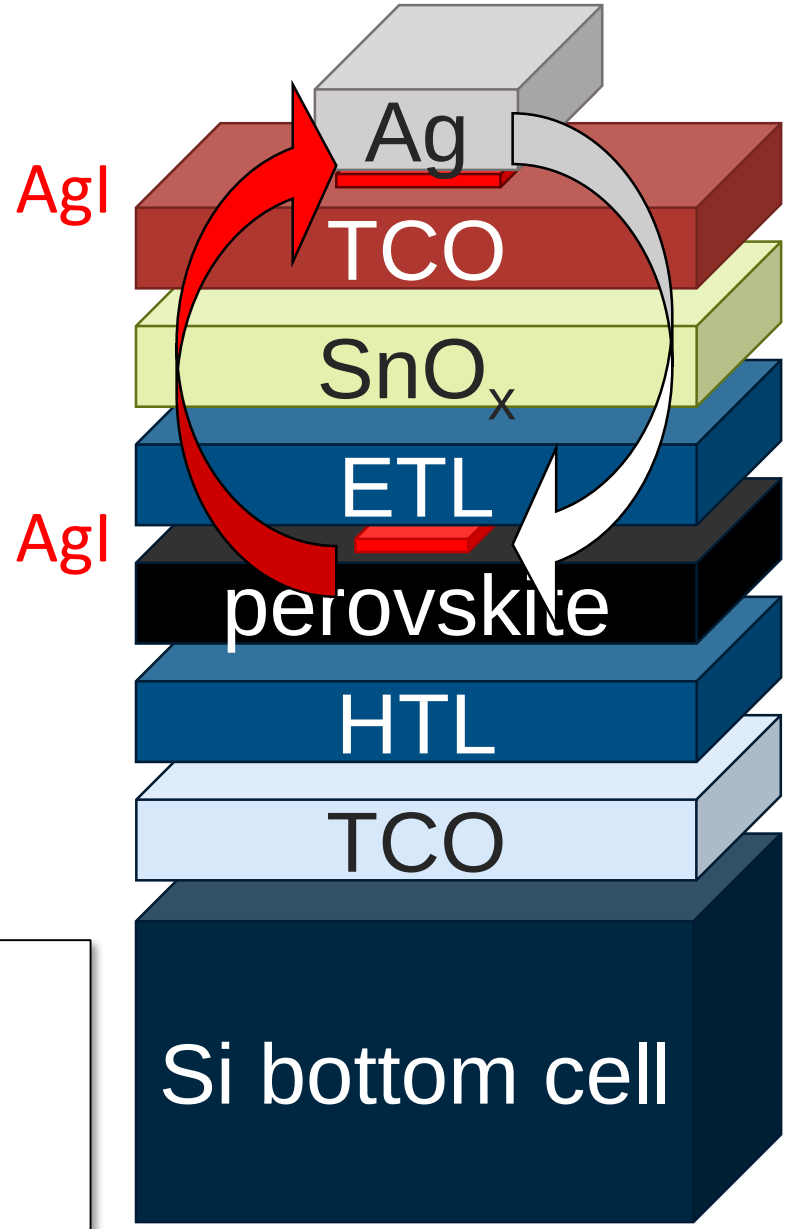
Degradation in charge transport layer, not perovskite.





CONCLUSIONS

- IZO > a-ITO > c-ITO
- All cells have PCE > 92 % after 933 h.
- Metal corrosion → drop in FF.
- Dark spots in EL + bright spots in PL → CTL damage.
- Dark EL spots always centred on Ag fingers: silver-related.

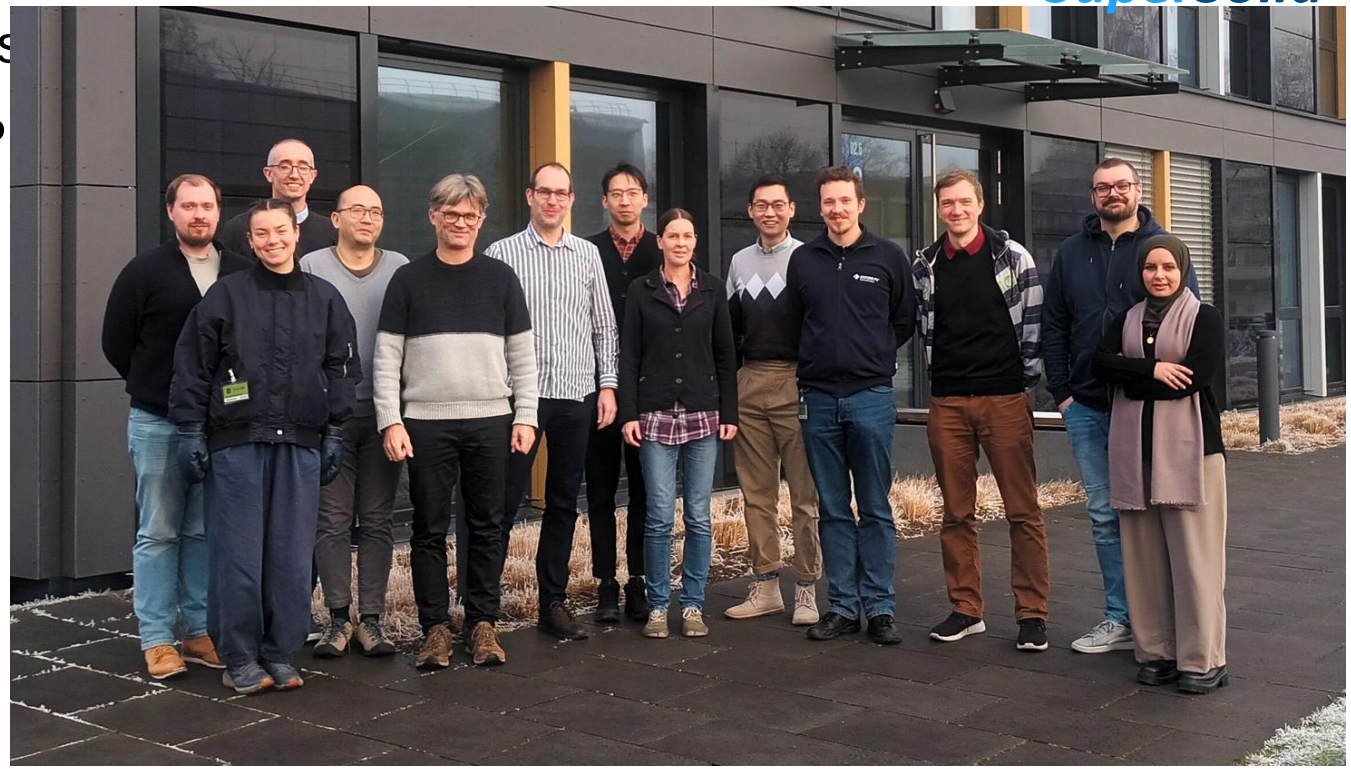


Outlook:
- Compare sp-Ag vs. evap-Ag vs. sp solvents.
- Compare sp-Ag to sp-Cu/Ag.
- Can Ag^0 plating occur in tandems?

THANK YOU! ☺

- Co-authors.
- Oxford PV for tandem cells.
- Katja Mayer-Stillrich, Manuel Hartig and Denise Debrassine for TCO depositions.
- Dr. Guillermo Farias Basulto for SEM-EDX.
- Dr. Fengshuo Zu for XPS measurements.
- Dr. Philippe Holzhey for single-junction cells
- Dr. Arman Mahboubi Soufiani for ELI and P

SuperSolid



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