ALD as an enabling technology for new crystalline silicon solar cell concepts

ALD4PV workshop
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Sjoerd Smit
Bart Macco

PMP
plasma & materials processing

TU/e Technische Universiteit Eindhoven University of Technology

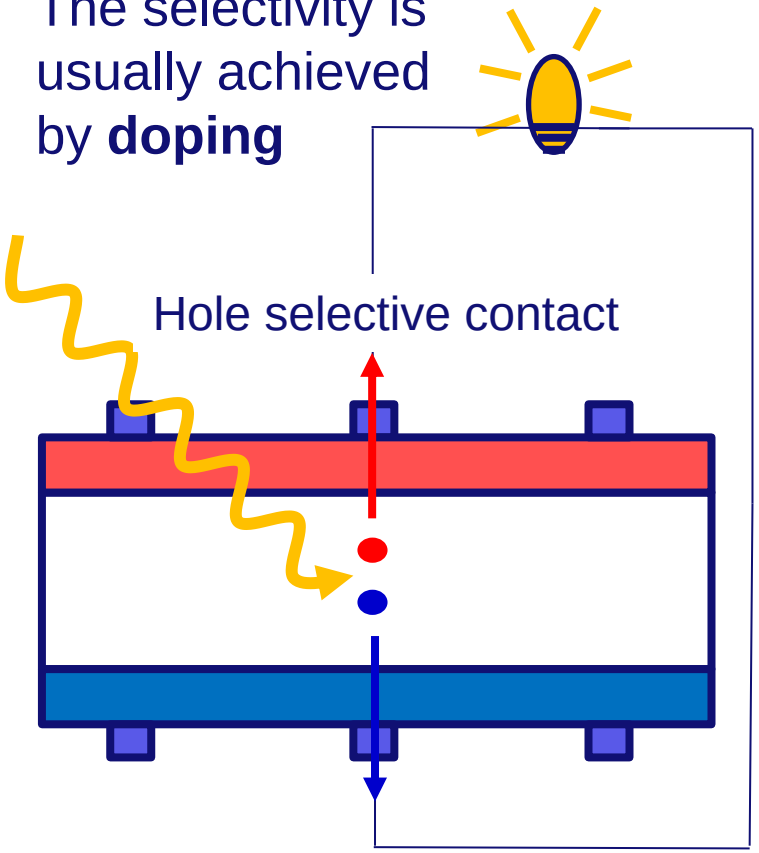
Where innovation starts

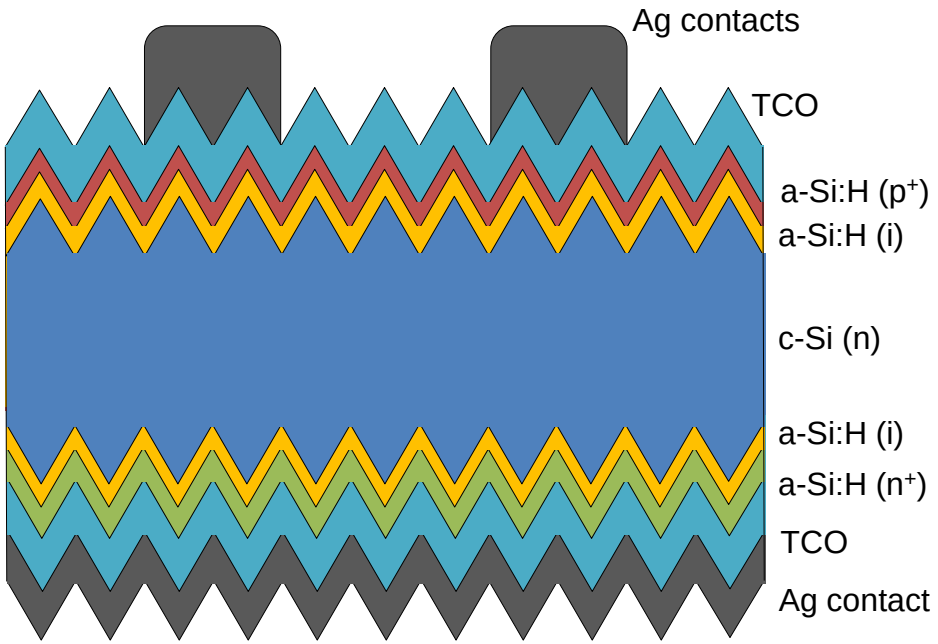
In this presentation

- ALD 4 silicon heterojunction solar (SHJ) cells
  - Reduction of deposition damage
  - Precise and graded doping of TCOs
- ALD 4 novel solar cell concepts
  - Charge inversion cells
  - Outlook: clever use of band structure

ALD 4 SHJ solar cells
Solar cell basics

The selectivity is usually achieved by **doping**





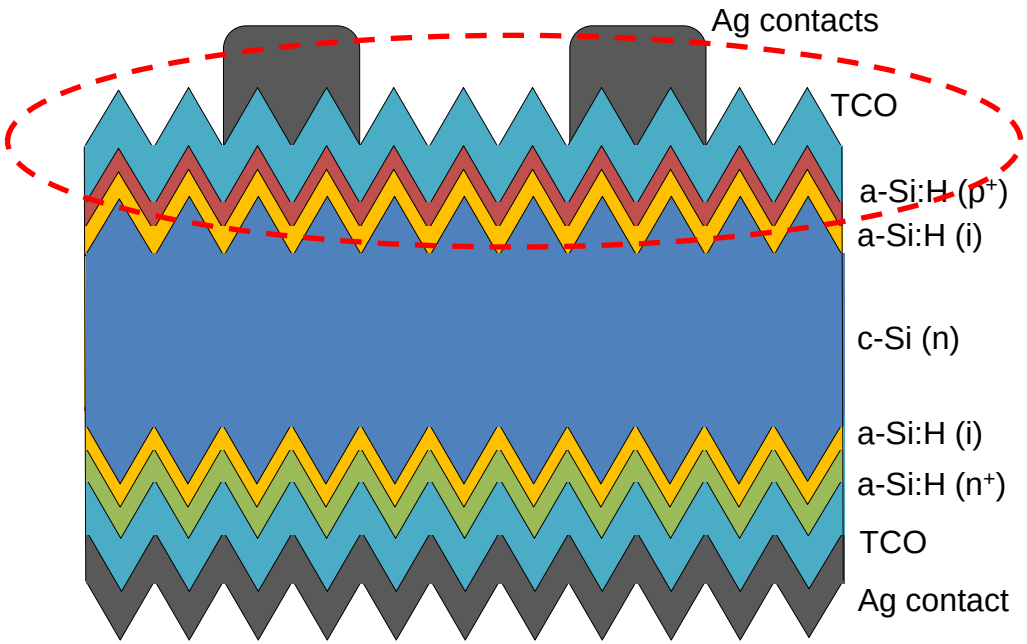
Silicon heterojunction (SHJ) solar cell
a.k.a. HIT solar cell

ALD 4 SHJ solar cells

Two spots where ALD can improve SHJ solar cells:

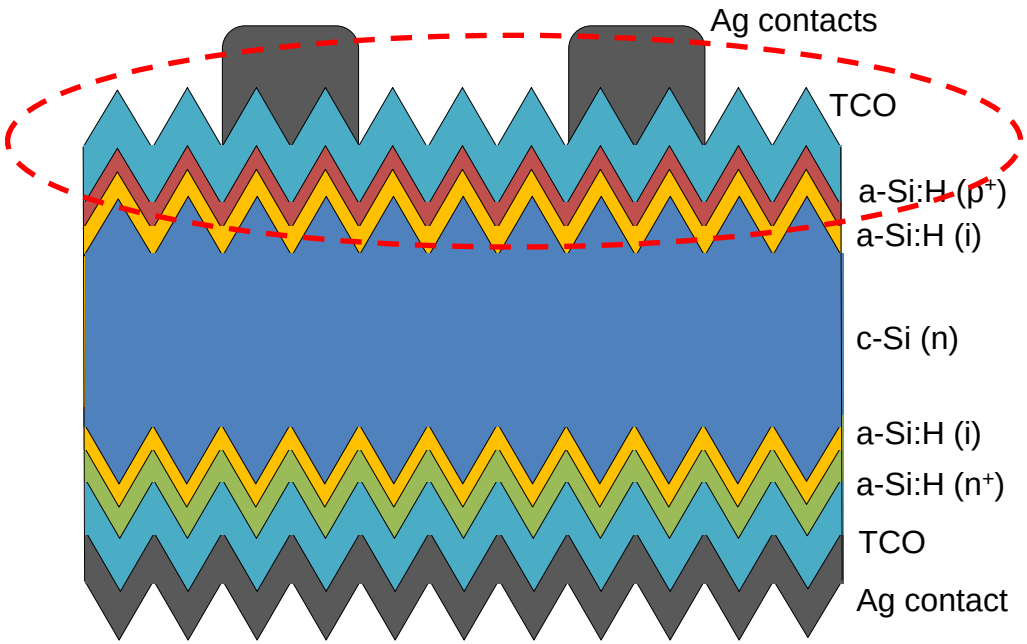
1: Top TCO layer
- Lateral conductivity
- Anti reflective coating

2: Backside reflector (BSR)
- Reflect light into silicon again
- Prevent light absorption in Ag back contact



ALD 4 SHJ solar cells: The frontside TCO

Top TCO layer **Important aspects:**	Can ALD provide this?
High transparency	✓
Low sheet resistance	✓
Light incoupling into silicon (ARC)	✓✓
Industrial potential	+/-
Effect on passivation of the cell	✓✓



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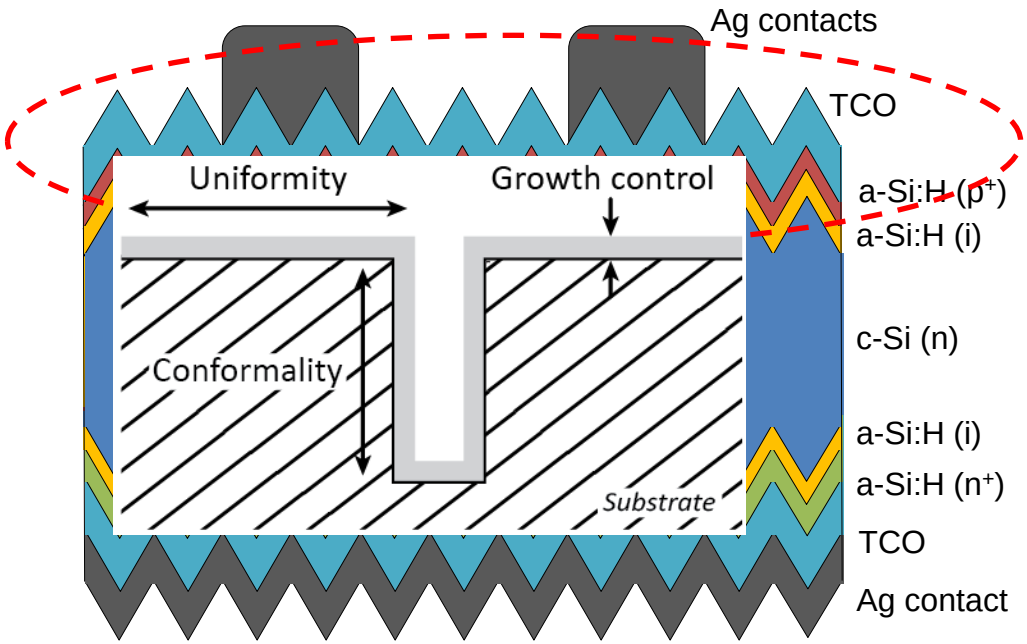

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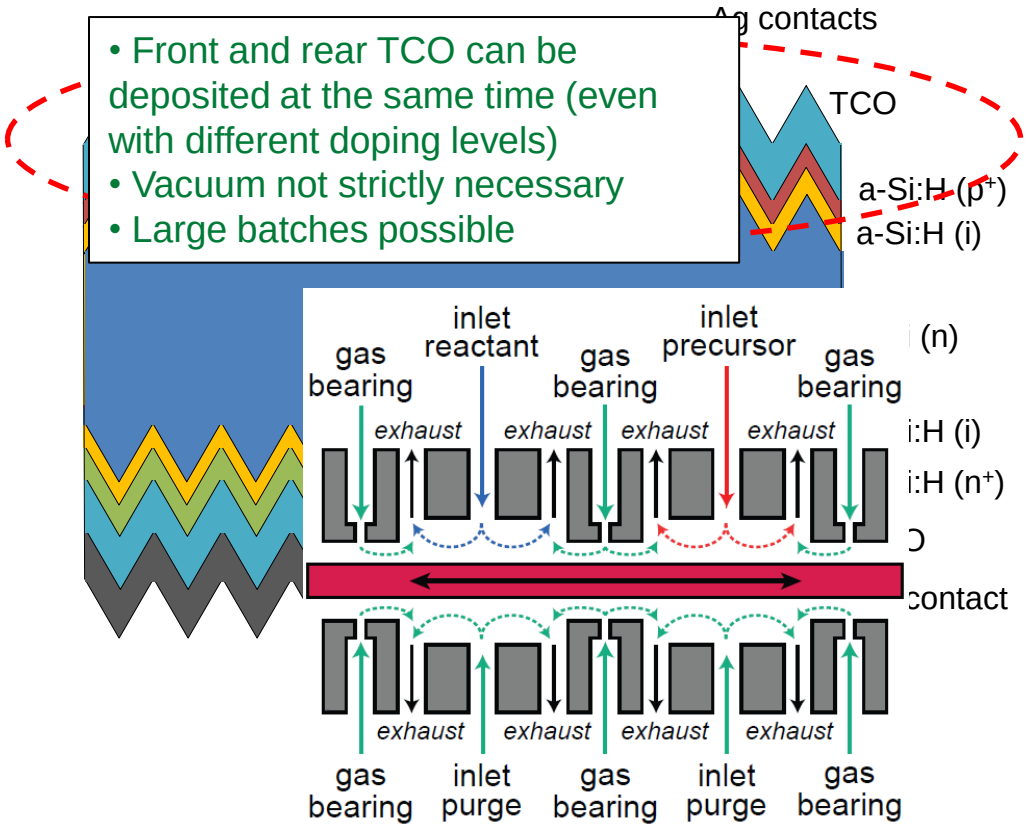
- Front and rear TCO can be deposited at the same time (even with different doping levels)
- Vacuum not strictly necessary
- Large batches possible



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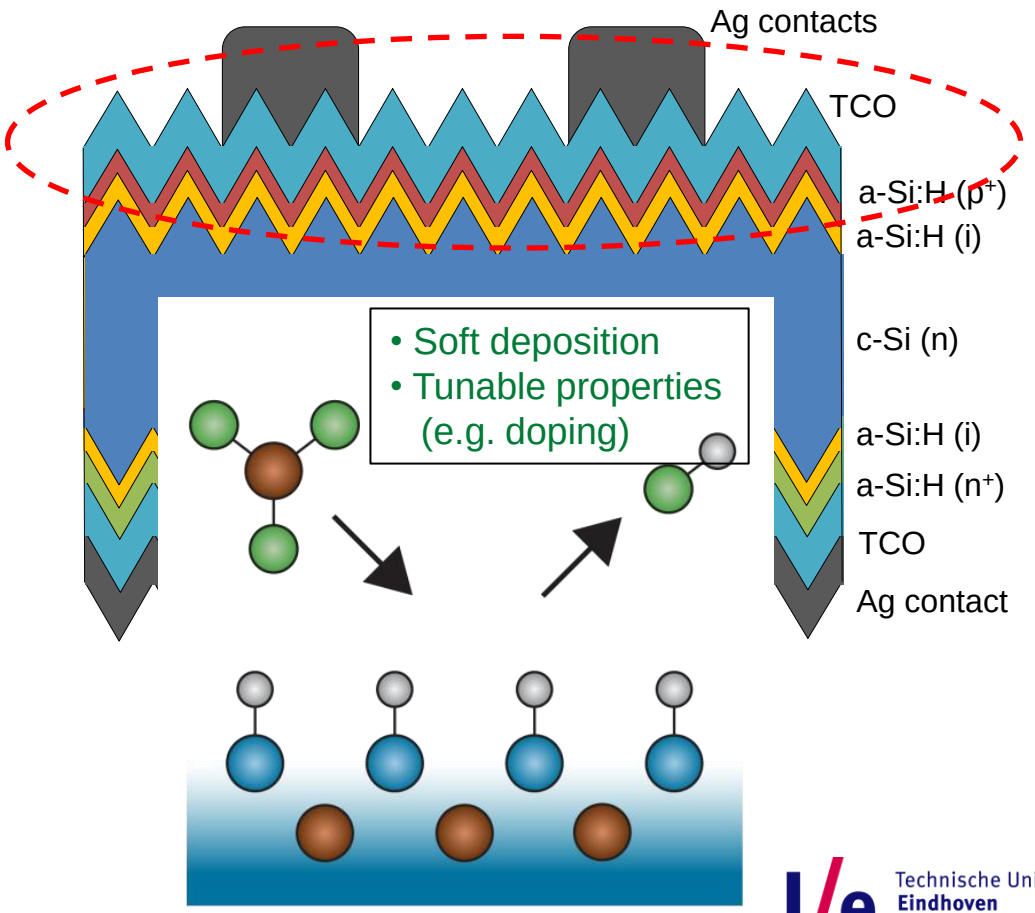
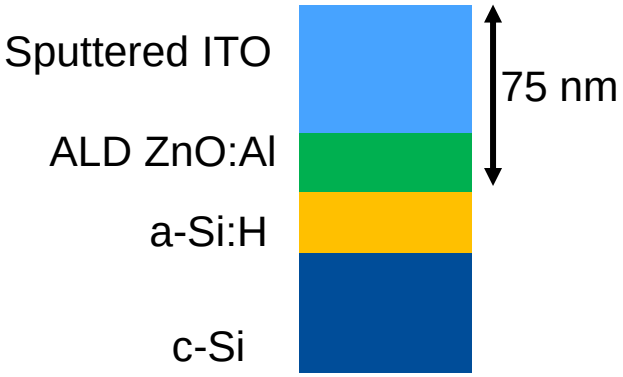


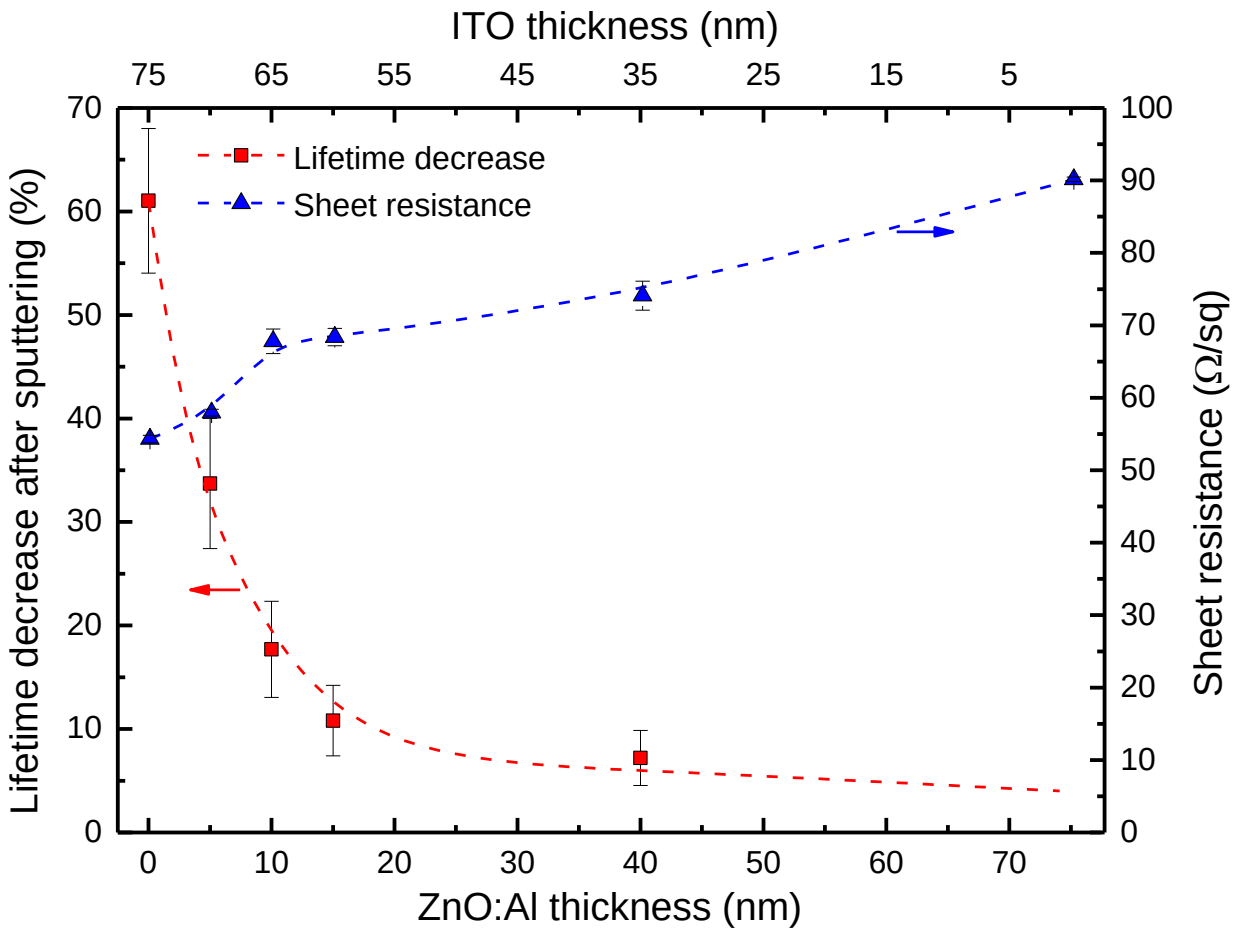
ALD 4 SHJ solar cells: The frontside TCO: Effect on passivation

Front TCO has pronounced influence on the carrier lifetime of the solar cell.

Causes:

- **Sputtering damage**. Can be prevented by using ALD





E.g.: B. Demaurex (APL 2012): DOI: 10.1063/1.4764529
Figure: B. Macco (APL, submitted for publication)

ALD 4 SHJ solar cells: The frontside TCO: Effect on passivation

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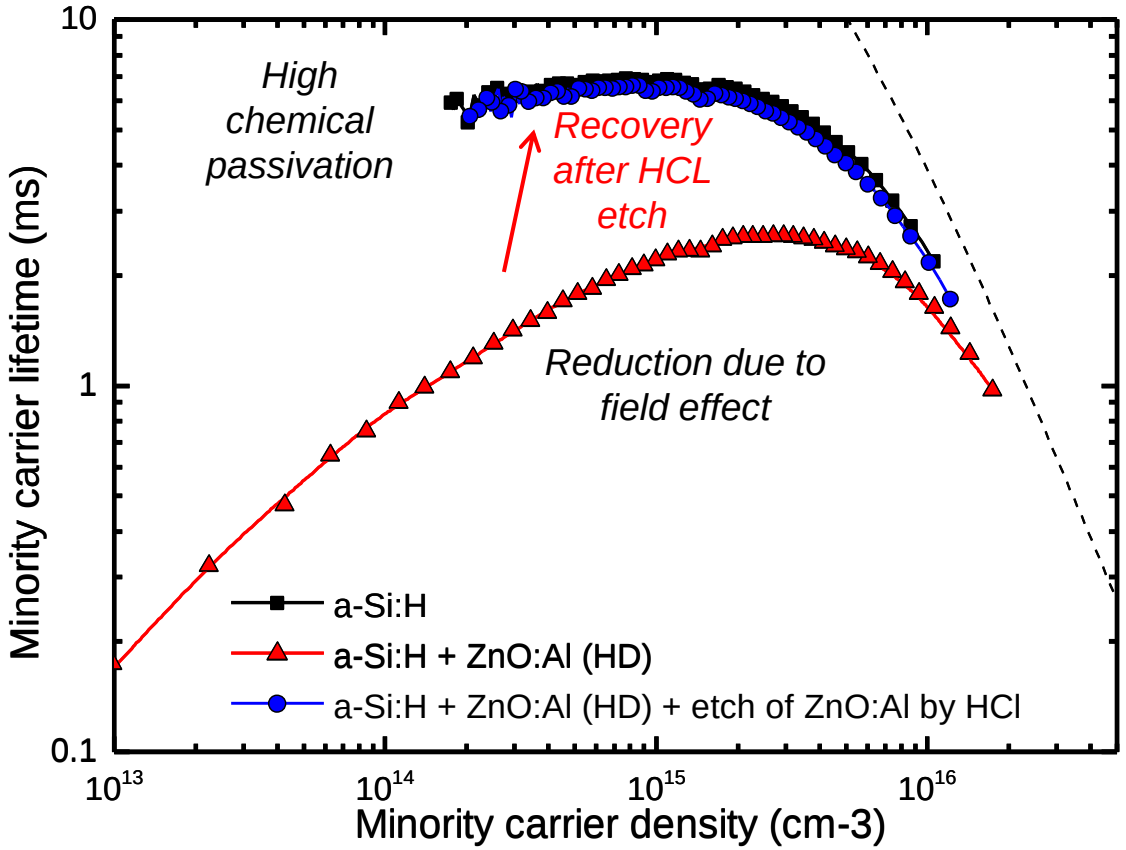

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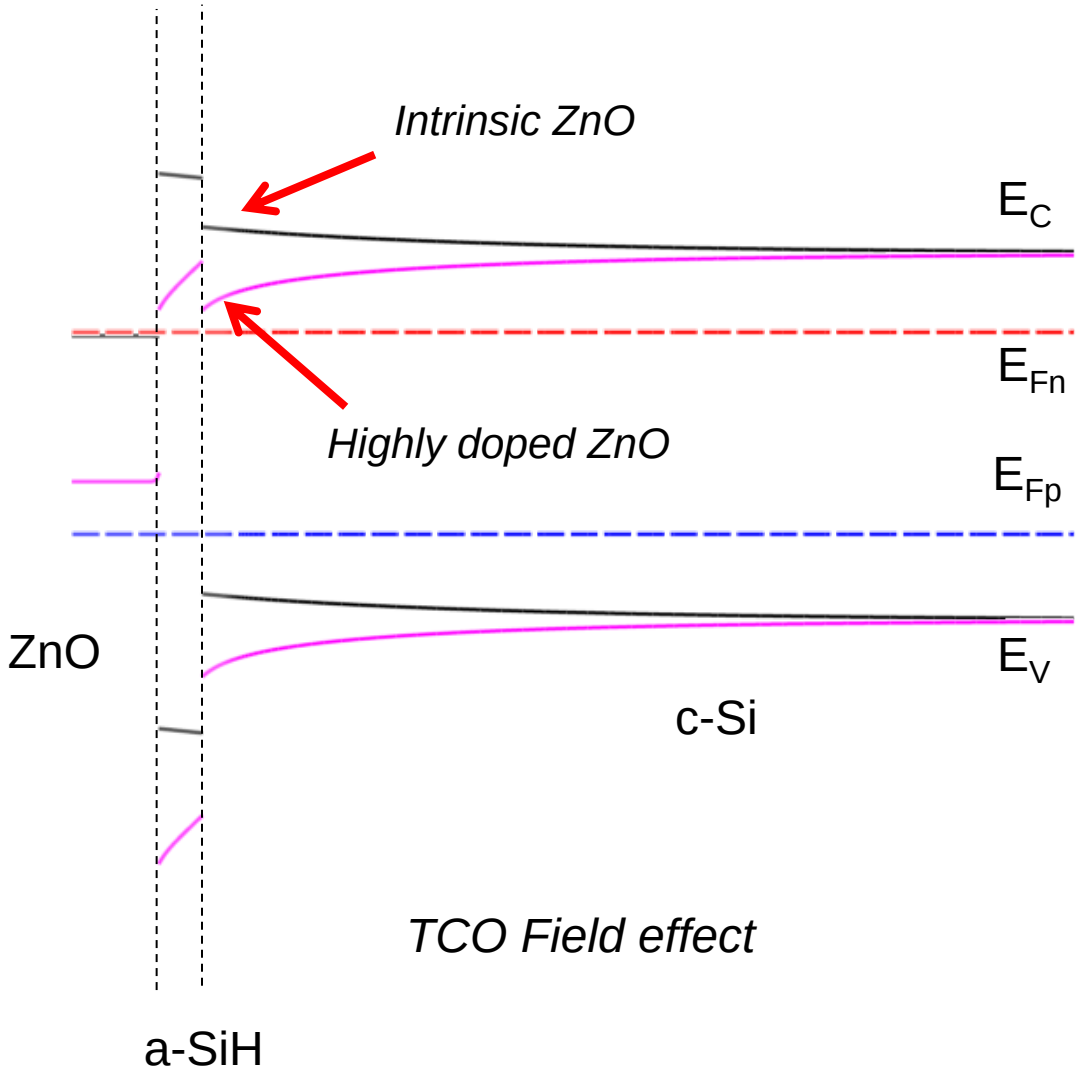

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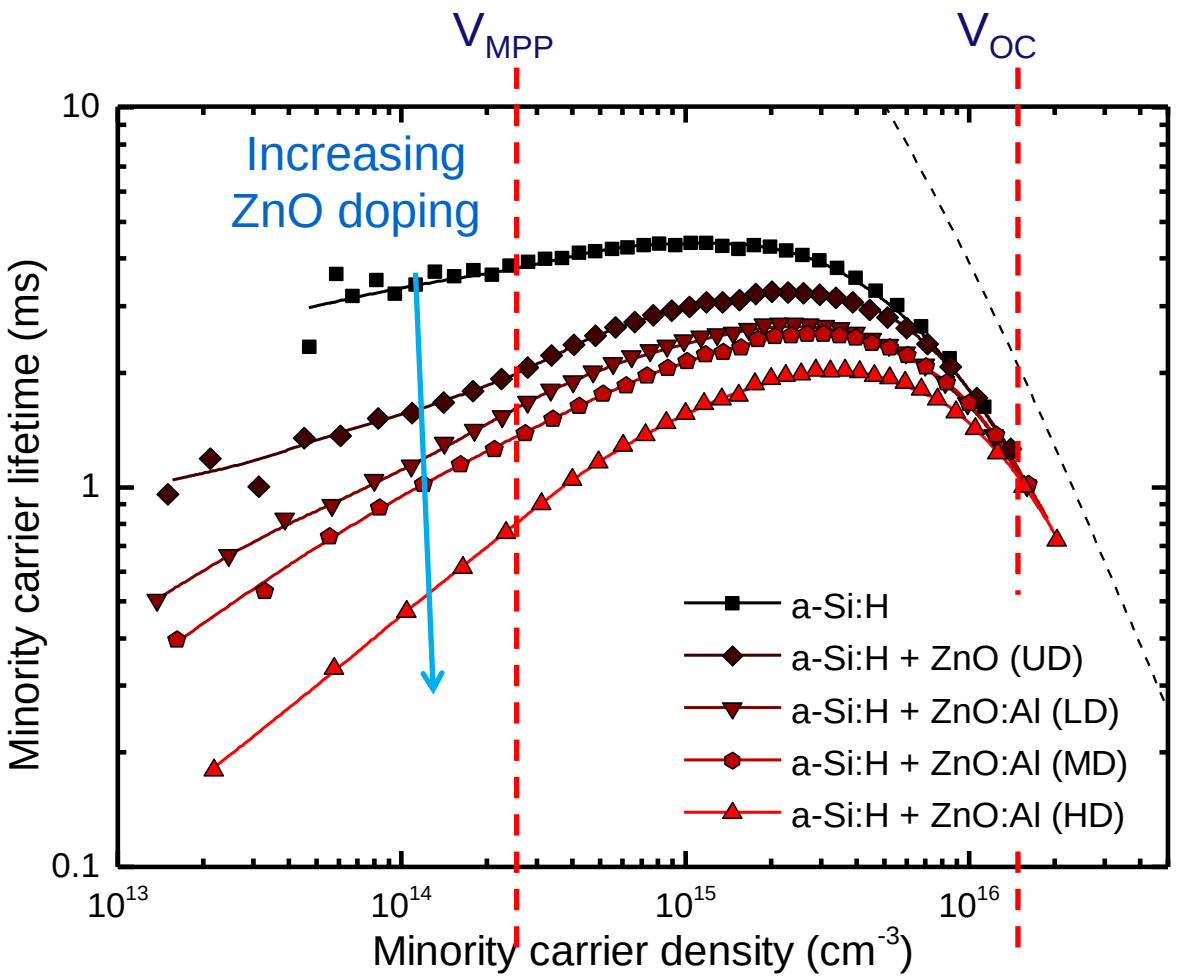
ALD 4 SHJ solar cells: The frontside TCO: Effect on passivation

Front TCO has pronounced influence on the lifetime of the solar cell.

Causes:

- Sputtering damage. Can be prevented by using ALD
- Influence TCO field effect. **Doping can be accurately tuned by using ALD**



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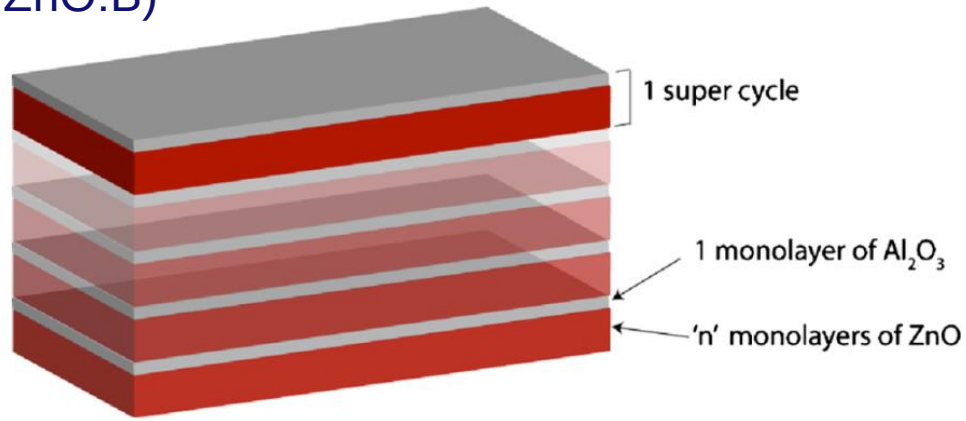
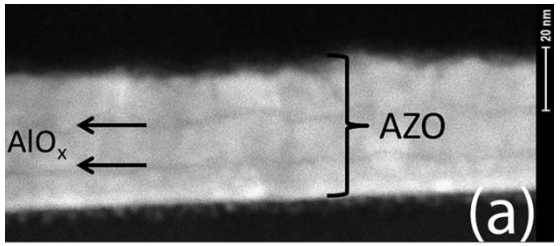
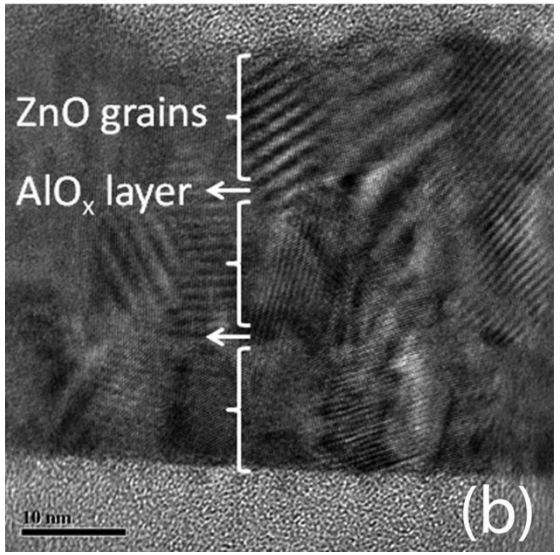
ALD 4 SHJ solar cells: The frontside TCO: Controlling the doping

Example: Al doped ZnO

- Al content can be varied by tuning cycle ratio *n*
- Doping efficiency also depends on doping precursor (E.g. TMA vs DMAI)
- Other dopants also possible (e.g ZnO:B)







More in Dr. Knoops' presentation

Y. Wu (JAP 2013): DOI 10.1063/1.4813136
Y. Wu (Chem. of Mater. 2013): DOI 10.1021/cm402974j

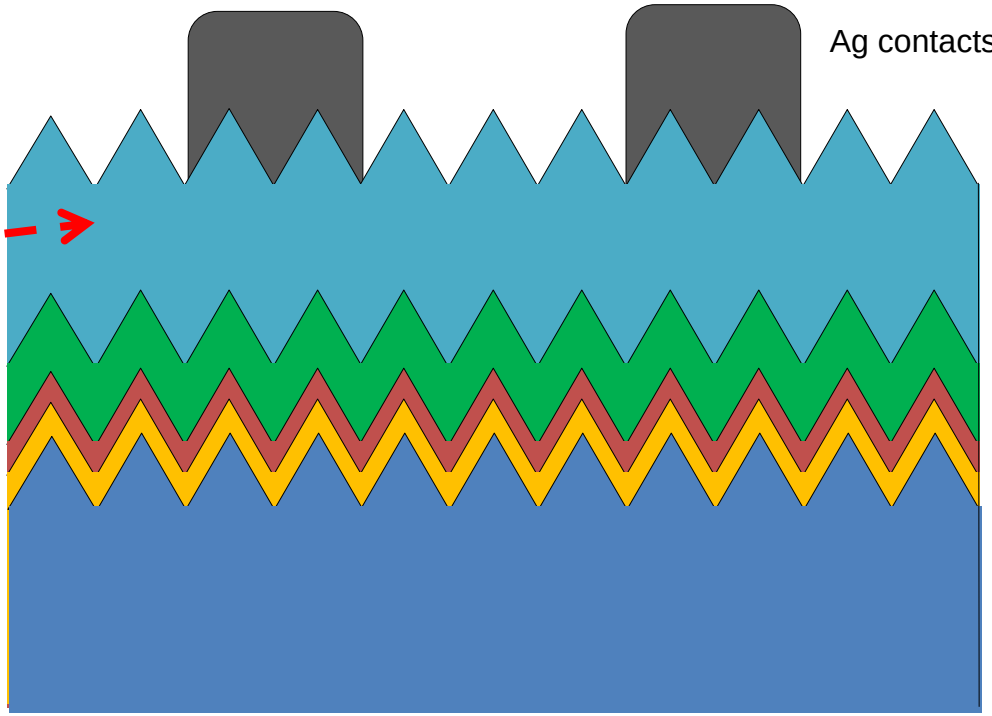
ALD 4 SHJ solar cells: Decoupling of the TCO functions

Potential application of ALD:

Graded doping and protection of the a-Si:H interface

Top TCO layer
Important aspects:

- High transparency
- Low sheet resistance
- Light incoupling into silicon (ARC)
- Industrial potential
- Effect on passivation of the cell



Decoupling of TCO functions

With ALD, the graded TCO can, in principle, still be processed in one single deposition

In the rest of this presentation

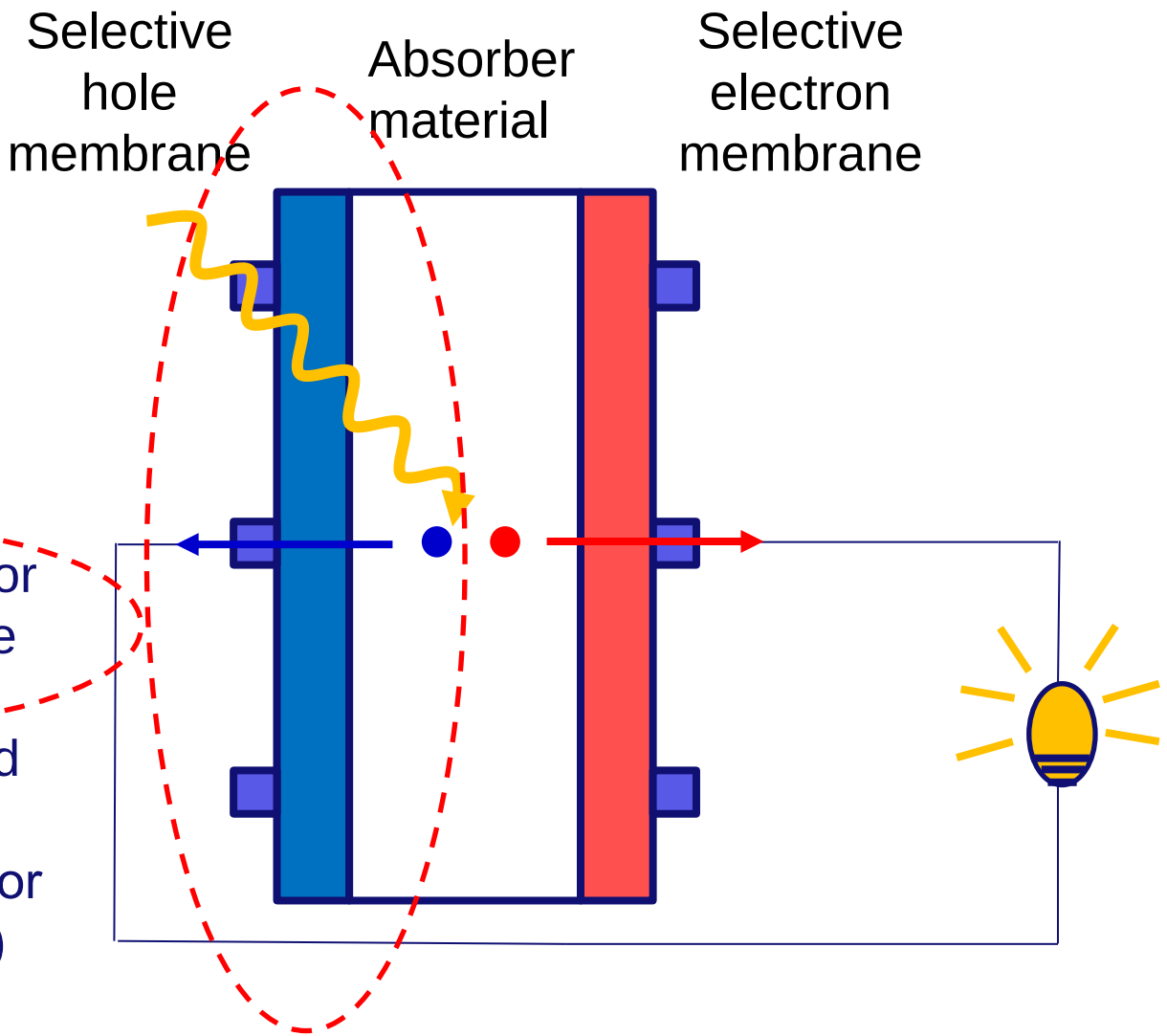
- Key advantages ALD
- ALD 4 silicon heterojunction solar (SHJ) cells
  - Reduction of deposition damage
  - Graded doping of TCOs
- **ALD 4 novel solar cell concepts**
  - **Al_2O_3 based junctions**
  - **TiO_2 based junctions**

ALD 4 new cell concepts

The selectivity is usually achieved by **doping**

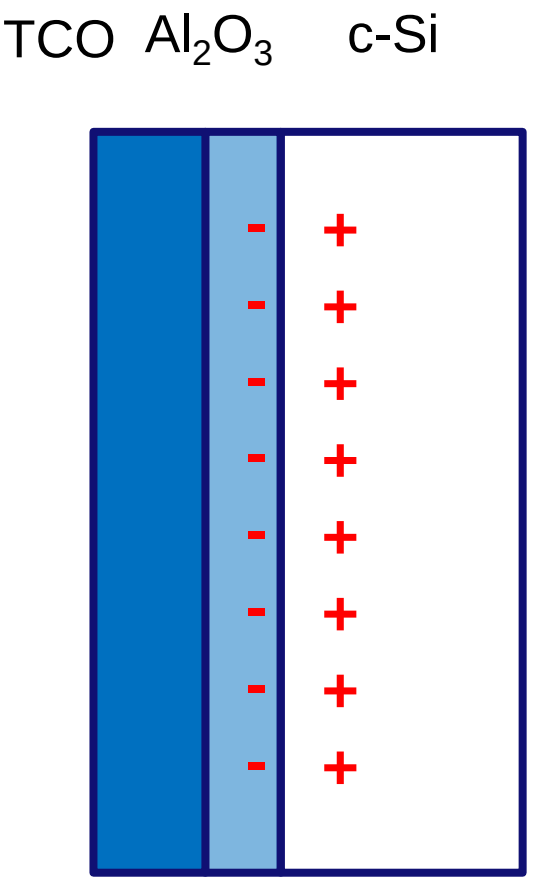
However, other methods exist:

1. Inducing mirror charges in the absorber
2. By using band offsets
3. … (exercise for the audience)



ALD 4 new cell concepts: Mirror charges by Al_2O_3

- The Al_2O_3/c-Si interface naturally contains a high density of negative charges (~$5*10^{12}$ e/cm^2)
- To maintain macroscopic charge neutrality, positive charge is induced in the c-Si, acting similarly to p-type doping



D. Garcia-Alonso (SST 2013): DOI 10.1088/0268-1242/28/8/082002
S. Smit (SOLMAT 2014): DOI 10.1016/j.solmat.2013.06.016

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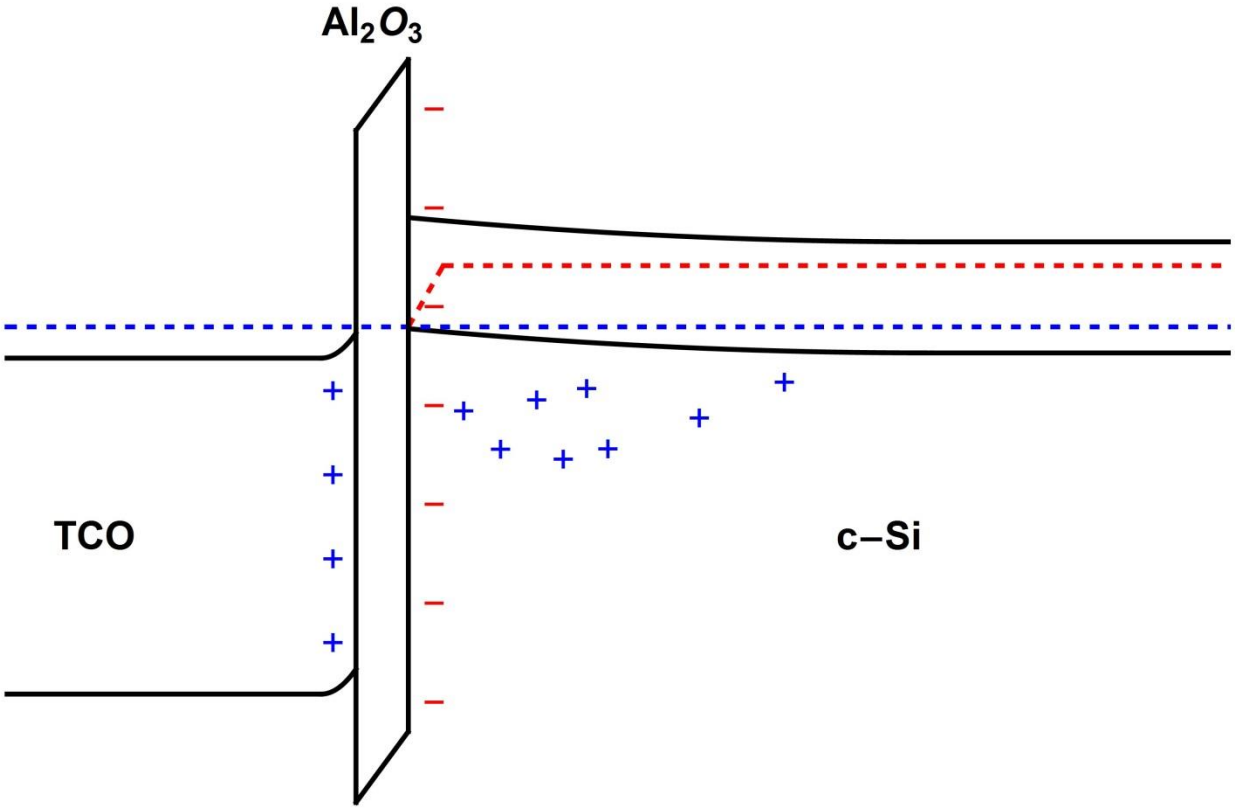

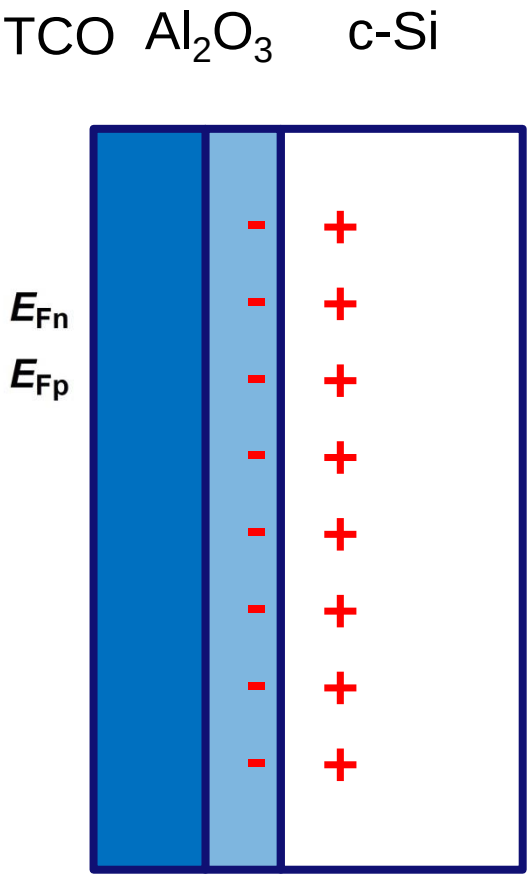

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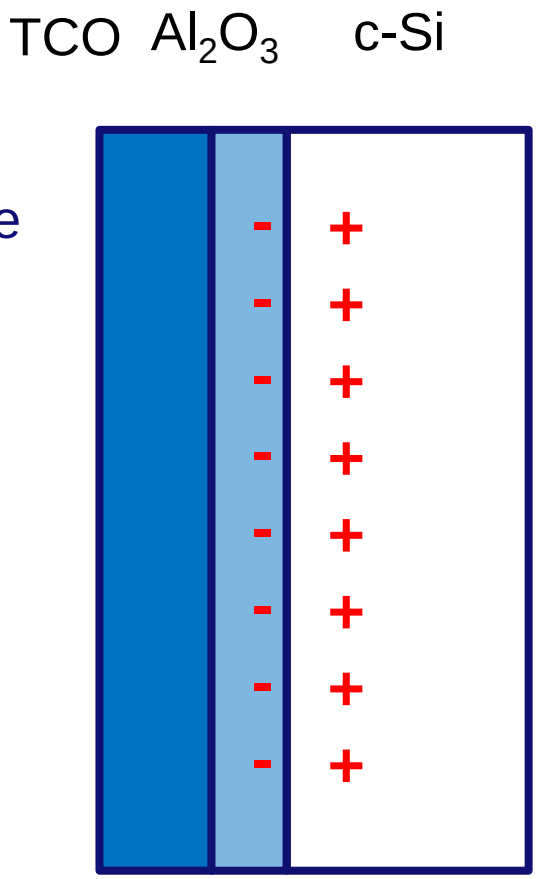

Y ALD 4 Al_2O_3 and TCO?

- Charge is collected by tunneling through the Al_2O_3, so thickness control is crucial
- High fixed charge density possible (plasma ALD)
- Prevent mirror charges in TCO (e.g. doping control)

D. Garcia-Alonso (SST 2013): DOI 10.1088/0268-1242/28/8/082002
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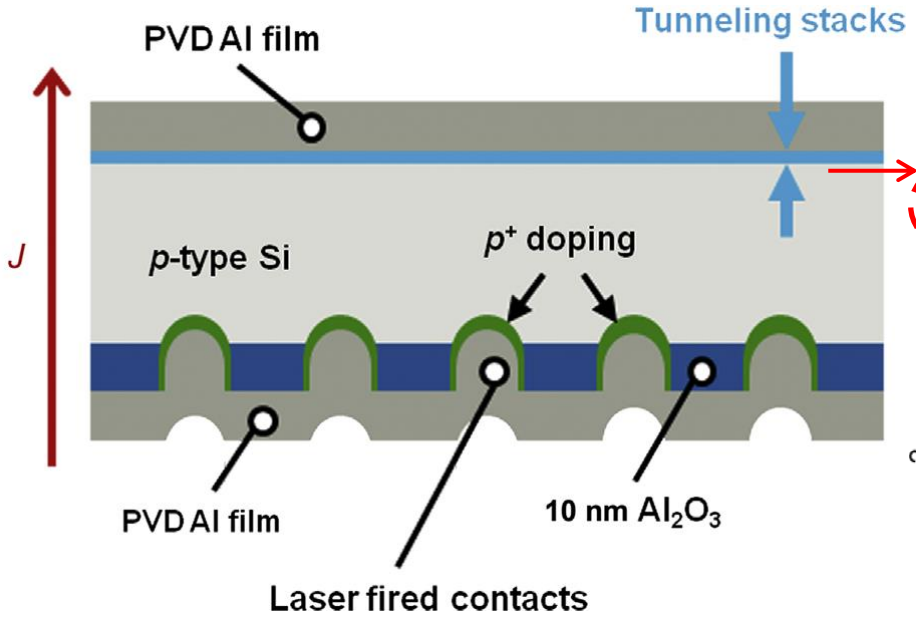
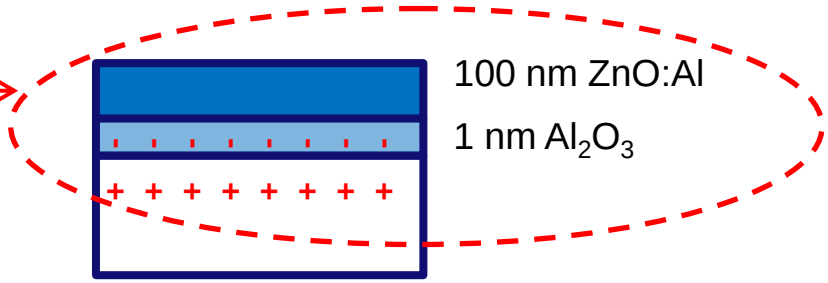
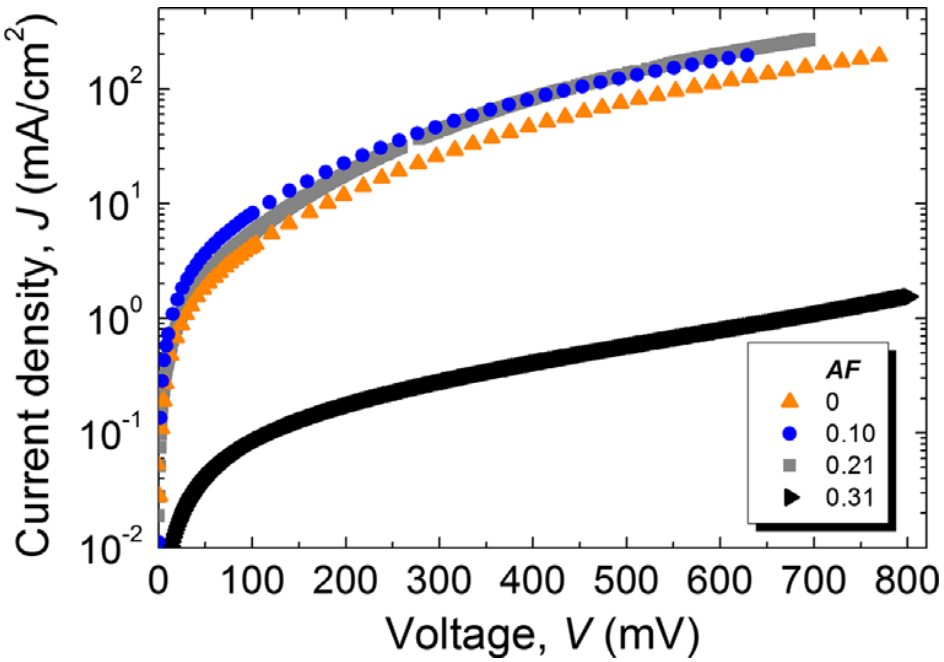
ALD 4 new cell concepts: Measuring current through Al_2O_3/ZnO stacks

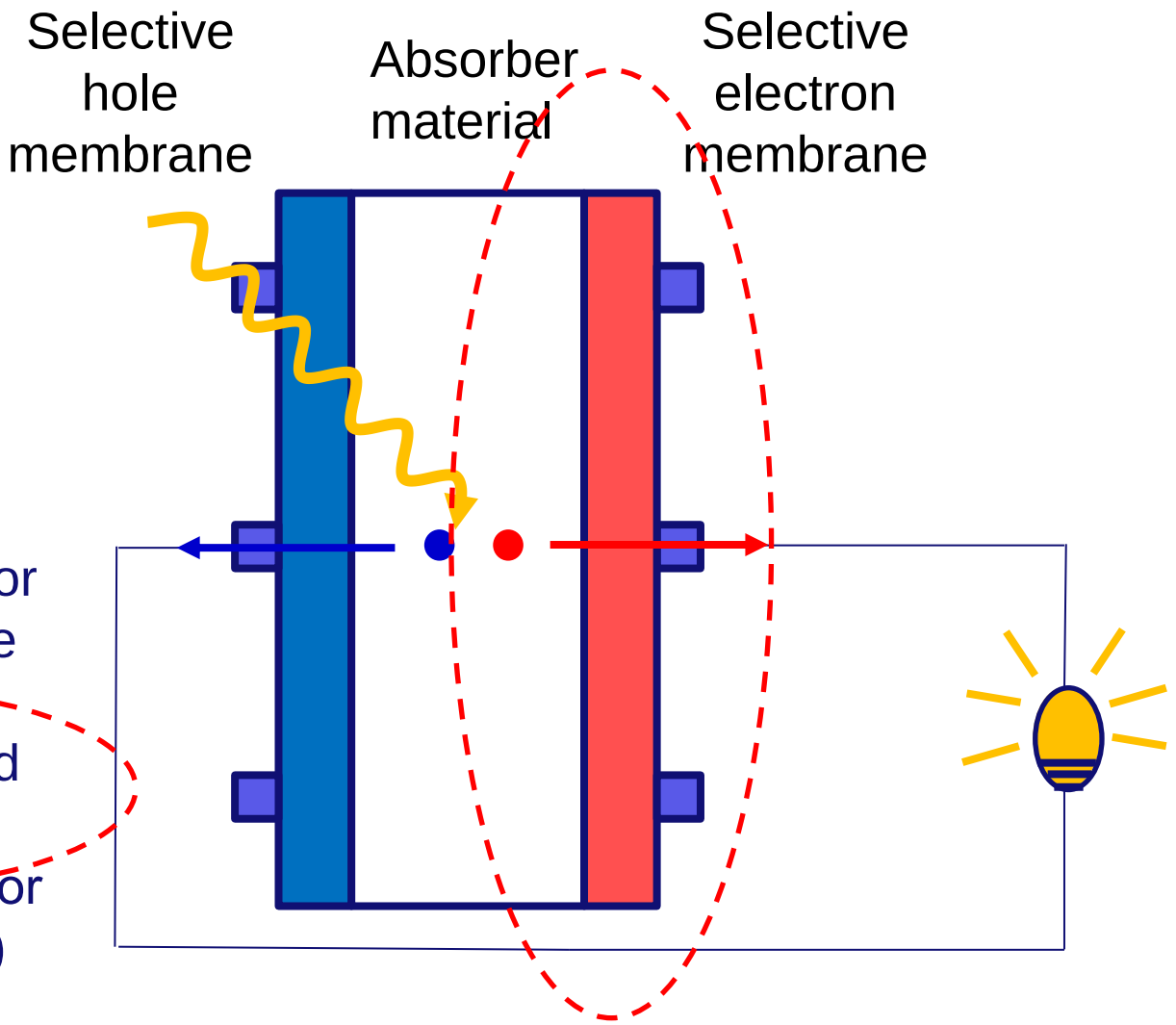






- Current high enough for c-Si solar cell applications
- ZnO doping control important for optimization

ALD 4 new cell concepts
Outlook



However, other methods exist:

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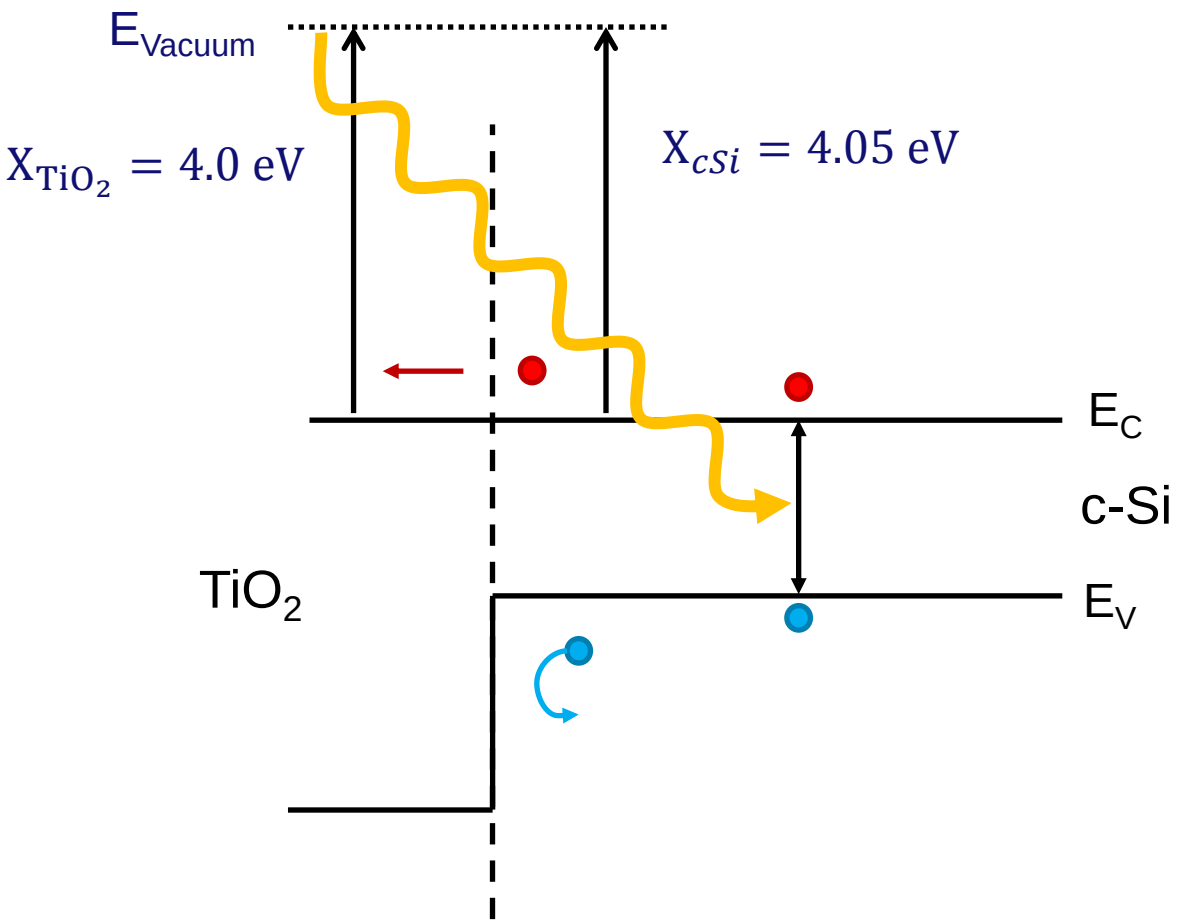
3. … (exercise for the audience)

ALD 4 new cell concepts: The TiO_2 heterojunction with c-Si

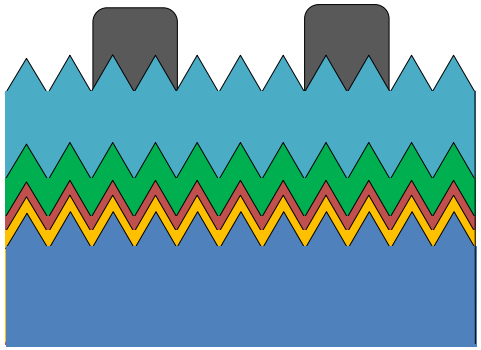
- TiO_2 and c-Si conductions bands align, thus TiO_2 is electron selective
- Unfortunately, TiO_2 does not passivate, so some sort of stack needs to be designed

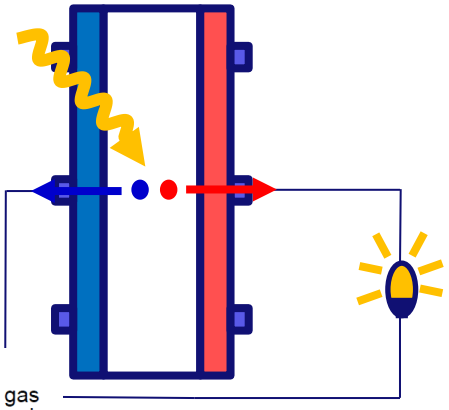


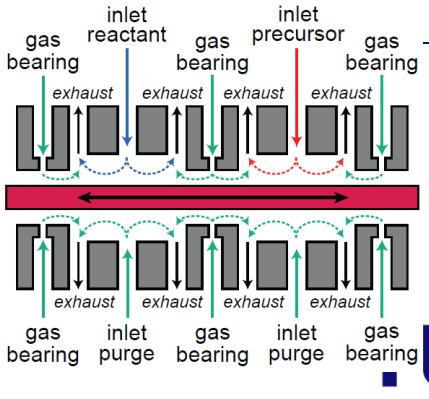
S. Avasthi (APL 2013) DOI: 10.1063/1.4803446 (Not ALD, btw)

Conclusions/Summary
The unique advantages of ALD 4 PV

- **SHJ solar cells can benefit from the ability of ALD to grade the TCO layer and the softness of the deposition**
- **ALD opens up new possibilities for fabricating carrier-selective layers in c-Si solar cells**
- **ALD has unique industrial advantages, such as capability for simultaneous double sided depositions**







Closing

Thank you for your attention!

Questions? Fire away!