Efficiency of double-sided TOPCon solar cells depending on Si surface: polished <100>, <111>, and textured

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1. Motivation for TOPCon structure

TOPCon (tunnel oxide passivated contact):
PCE > 25 % on c-Si wafers (n-type) [1]

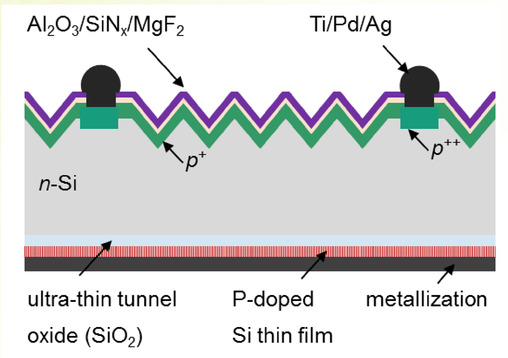
- Using conventional fabrication process (double-side ohmic contacts) => easy transfer to industrial processes

Main Advantages:

- Carrier-selective contacts (efficient quasi-fermi levels splitting between e⁻ and h⁺)
- Low contact resistivity for tunneling transport of carriers
- High transparency (wide bandgap)
- Superior thermal stability => can be use for TANDEM solar cell structure with PCE > 30%

Disadvantages:

- Weaker passivation on textured wafers
- Weaker passivation on (p-type, boron) poly-Si/SiO_x
- Front boron emitter diffusion can induce metallic impurities [2]

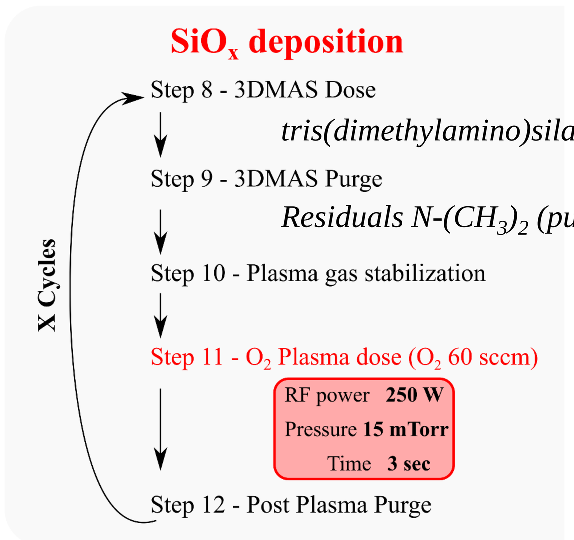


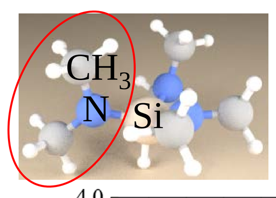
[1] A. Richter et al., *SOLMAT* **173** (2017) 96-105
[2] A. Richter et al., Progr. in PV **26** (2018) 342-350

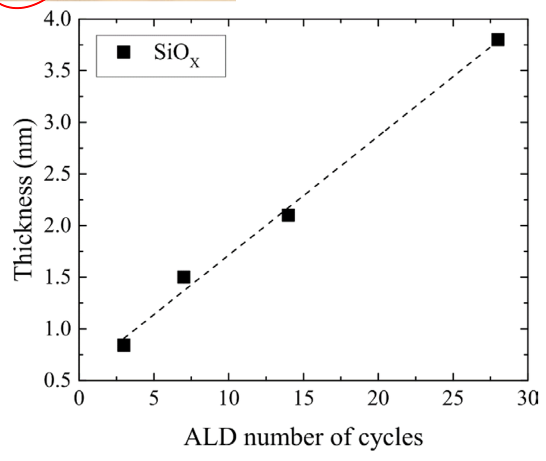
Requirements:
- Charges tunneling: SiO_x < **2 nm**

- Motivation to dvp an efficient front TOPCon-like structure
⇒**Selectivity** for **both front & rear** on **textured surfaces**
- **Control** of the thickness possible at **atomic scale**:
⇒Development of **Ultrathin** SiO_x by **ALD**

2. Plasma assisted ALD







FlexAL ALD System – Oxford Instruments

➢ Amorphous layer Si / O / Si …

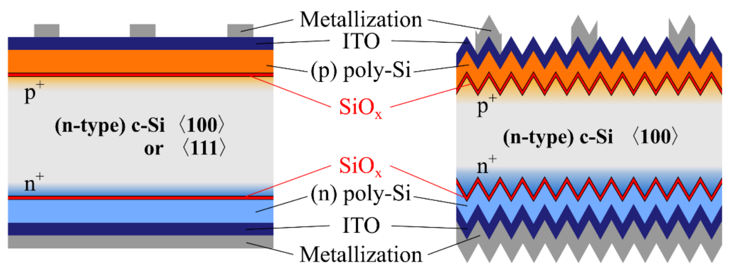
Reduced defect formation by:
➢ Low pressure (15 and 38 mTorr)
➢ Using ICP (Inductively Coupled Plasma)

➢ SiO_x linear thickness confirmed depending on the number of ALD cycle [3].

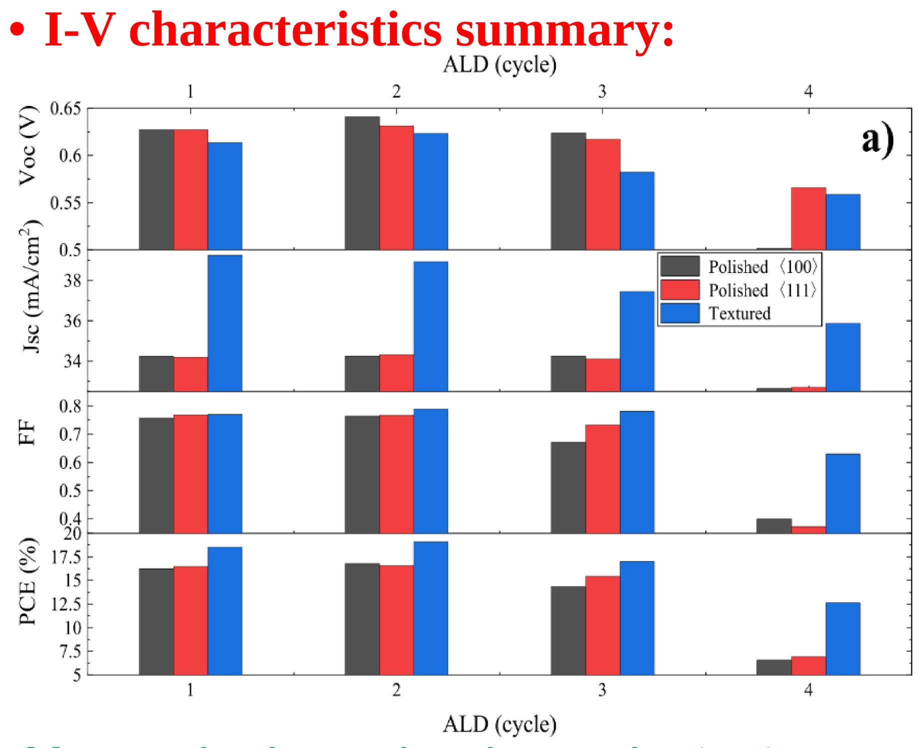
[3] M. Lozac'h et al., *SOLMAT* **185** (2018) 8-15

3. Double-sided TOPCon solar cells

- **Structures:**



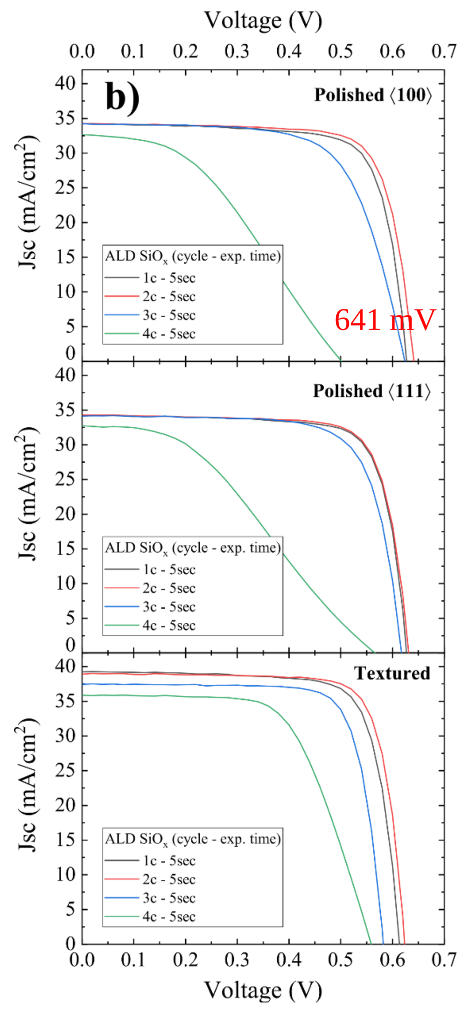
- **I-V characteristics summary:**



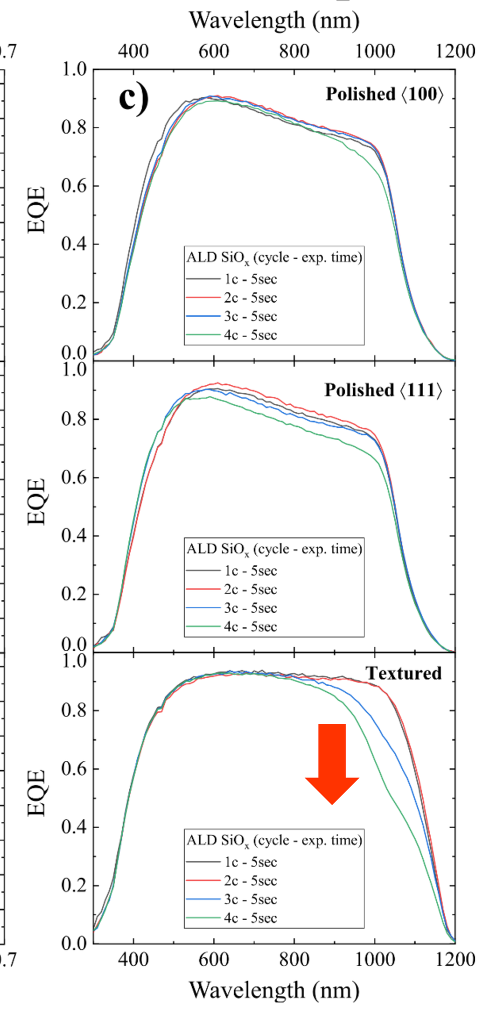
[4] M. Lozac'h et al., *Prog. Photovolt. Res. Appl.* **28** (2020) 1001-1011

- The V_{oc} and FF are optimized for SiO_x with ALD 2-cycles, showing a PCE of 19.1% [4].
- The highest V_{oc} is obtained on polished <100> surface with 641 mV.
- the J_{sc} is decreasing for thicker SiO_x (ALD 3-, 4-cycles).
- Regarding the EQE for textured Si, the lost in J_{sc} is mainly related to weaker absorption at wavelengths 800-1150.

- **I-V Graphs**



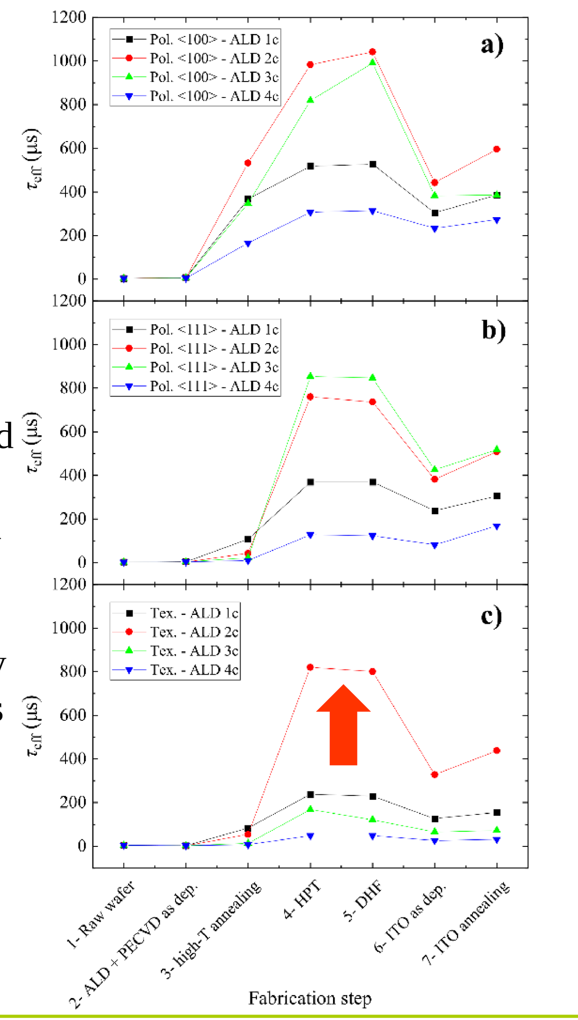
- **EQE Graphs**



- **τ_{eff} evolution with fabrication process**

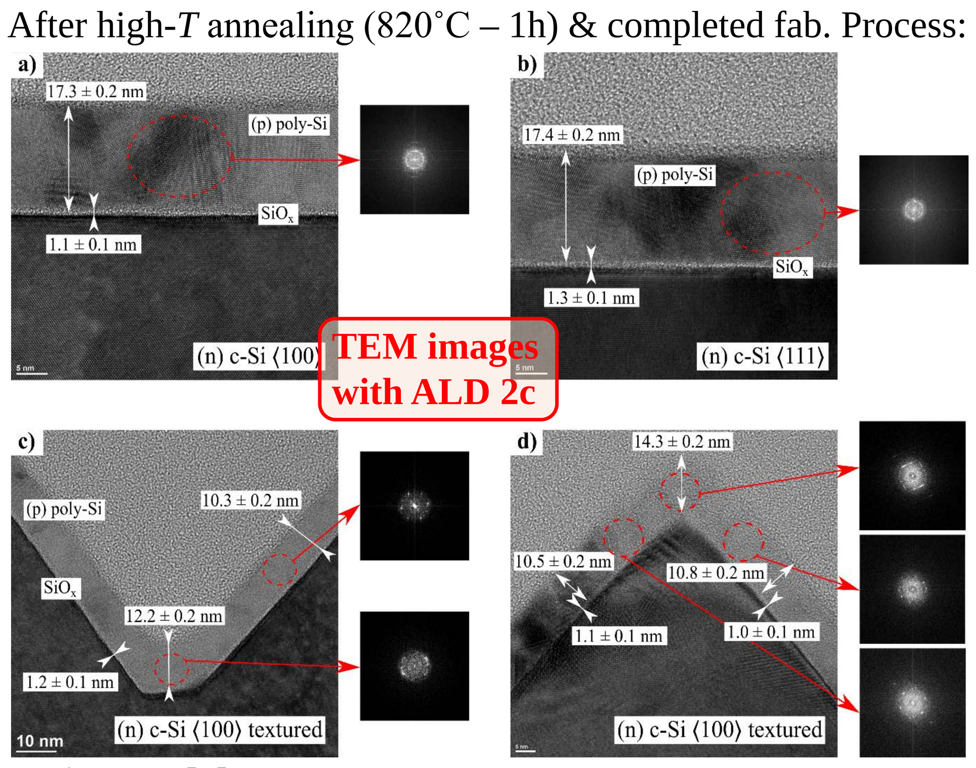
Concerning the lifetime (τ_{eff}) evolution with the fabrication process:

- τ_{eff} max. is about 1ms after hydrogen plasma treatment (HPT) on polished <100> Si, and about 0.8 ms on polished <111> Si and textured surface.
- We underline that only SiO_x with ALD-2c has τ_{eff} enhanced after HTP for textured surface.



4. Front poly-Si/SiO_x stack

- After high-*T* annealing (820°C – 1h) & completed fab. Process:

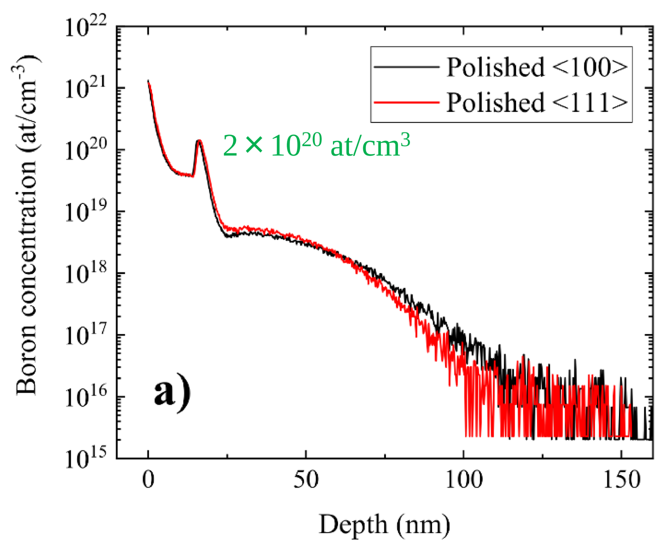


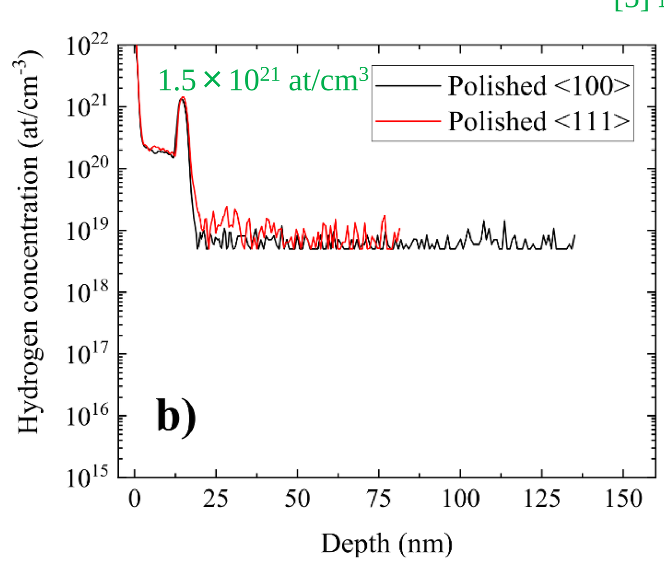
TEM images [4]:

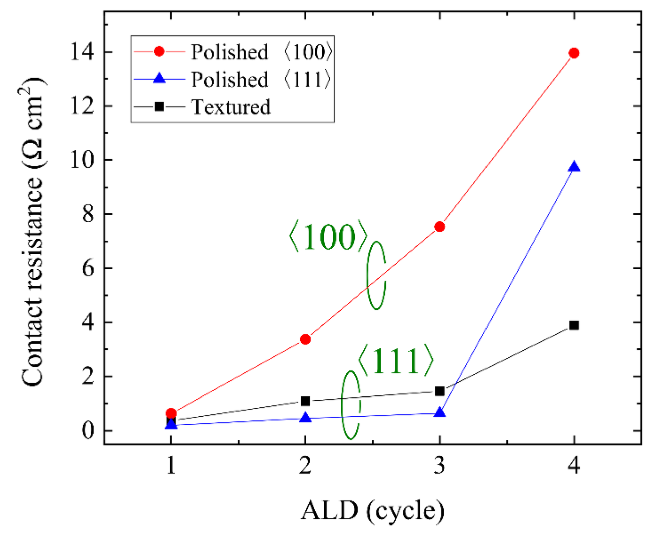
- **ALD 2c** corresponds to **SiO_x of 1.1 nm ± 0.1 nm** on **textured surface**.
- Nature of poly-Si is well **poly-Si** even at the valley or top of tip.

- **SIMS measurements on flat Si surface:**

[4] M. Lozac'h et al., *Prog. Photovolt. Res. Appl.* **28** (2020) 1001-1011
[5] M. Lozac'h et al., *SOLMAT* **185** (2018) 8-15







For polished Si surface samples:
- The difference in lifetime observed is not related to a different boron doping profile or H.
- At the interface SiO_x / c-Si, the boron concentration is about 2×10^{20} at/cm³, and the hydrogen concentration about 1.5×10^{20} at/cm³.

Regarding the FTIR analysis [5]:
- The **Stoichiometry** x of SiO_x confirmed about **1.7** for both polished <100> and <111>

- The contact resistance measured is lower on <111> oriented Si surface contrary to <100>, probably related to a higher density of Si for <111> atomic plan.

5. Summary

- The Si surface, polished <100>, <111>, or textured has been investigation on the efficiency of double-sided TOPCon solar cell structure.
- The best efficiency of 19.1 % is obtained on textured Si surface for SiO_x deposited by ALD 2-cycles that corresponds to a thickness of 1.1 ± 0.1 nm and 1.3 ± 0.1 nm on polished surface oriented <100> and <111>, respectively.
- We underlined that only SiO_x with ALD-2cycles improves the lifetime after the hydrogen plasma treatment step to about 0.8 ms on textured Si.
- A lower contact resistance for Si <111> atomic plan orientation is also underlined.

6. Acknowledgement

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