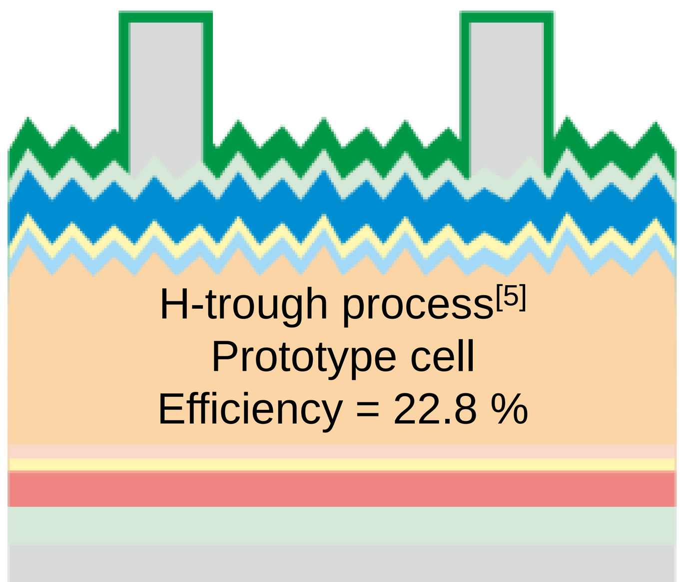
Optimization of front contacting methods for high-efficiency c-Si solar cells with co-annealed passivating contacts

Frank Meyer[1], Juan J. Diaz Leon[2], Gizem Nogay[2], Christophe Allebé[2], Matthieu Despeisse[2], Sylvain Nicolay[2], Franz-Josef. Haug[1], Andrea Ingenito[1,2] and Christophe Ballif[1,2]

[1] *École Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Photovoltaics and Thin-Film Electronics Laboratory (PVLAB), Rue de la Maladière 71b, 2000 Neuchâtel, Switzerland*
[2] *Swiss Center for Electronics and Microtechnology (CSEM), Rue Jaquet-Droz 1, 2000 Neuchâtel, Switzerland*

Front contacting methods: PVLAB strategies

Passivating contacts are keys to enable conversion efficiency >25%[1,2] and are temperature tolerant. These contacts need an hydrogenation step[3,4]. Combining this step with industrial mainstream and avoiding the use of a sacrificial SiN_x is a challenge.

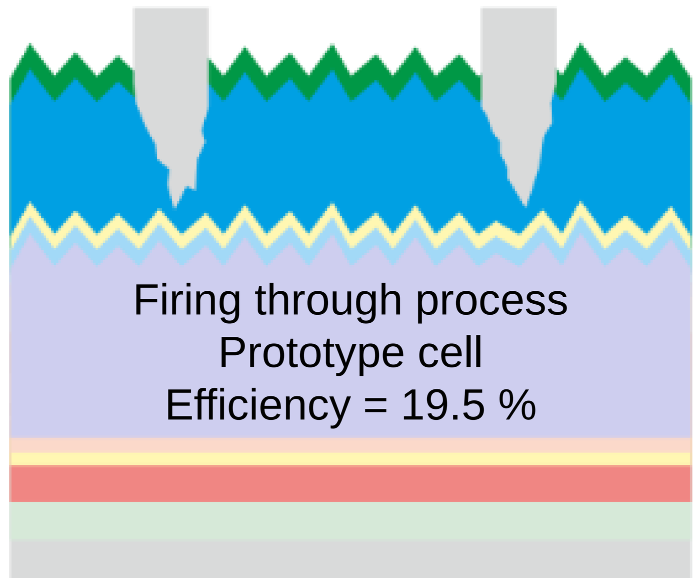


Advantages:
- H diffuses through ITO layer
- 4x thinner ITO at front side
- SiN_x is not a sacrificial layer
- SiN_x+ITO act as double ARC
- Fewer fabrication steps

Challenges:
- Good ITO electrical properties
- Diffuse H through ITO layer

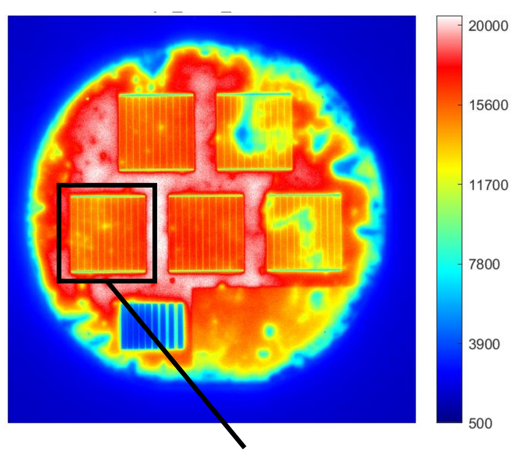
Advantages:
- H diffusion **and** contacting during a single firing step
- SiN_x is not a sacrificial layer
- Fewer fabrication steps
- No TCO is used at the front

Challenges:
- Develop a thick contact on txt surface to stop Ag paste



H-through process

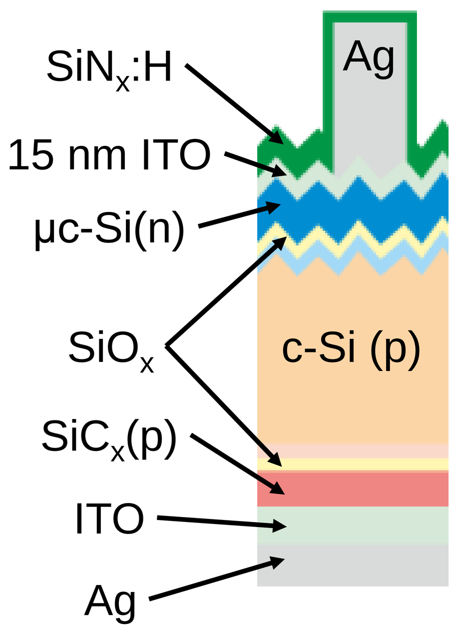
PLI after hydrogenation



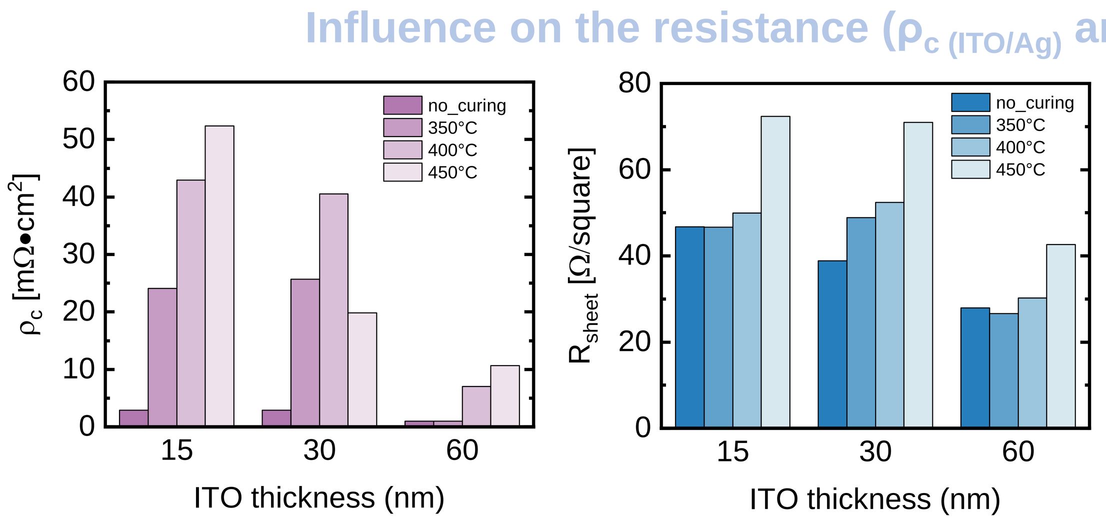
ITO area is approximately at the same passivation level than the outside region

Cell demonstrator:

- PECVD deposition of thin μc-Si(n) (front) and SiC(p) (rear)
- Co-annealing at 850°C
- ITO sputtering, Ag printing and SiN_x deposition (front)
- Annealing in N_2 atmosphere at 350°C for 30 min
- metallization with sputtered ITO/Ag stack at the rear



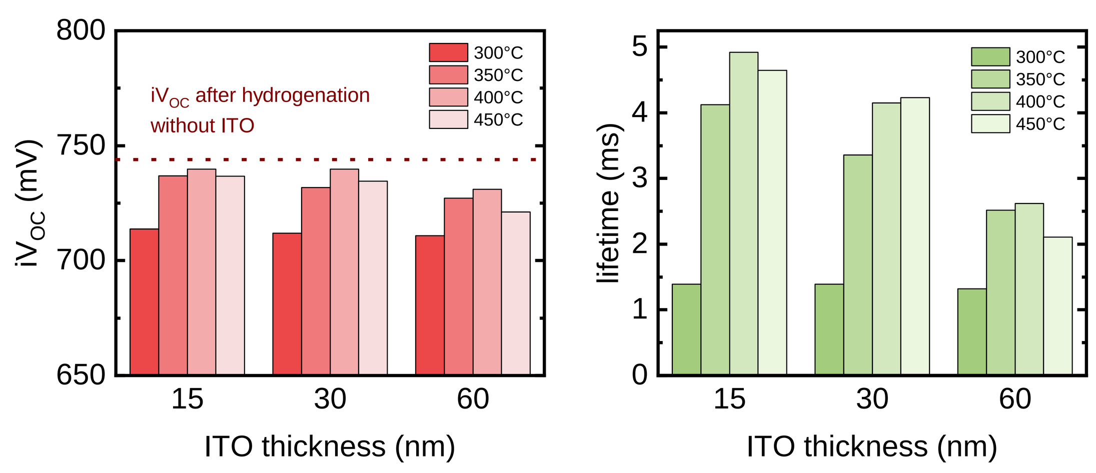
Influence on the resistance ($\rho_{c\ (ITO/Ag)}$ and $R_{sheet\ (ITO)}$)



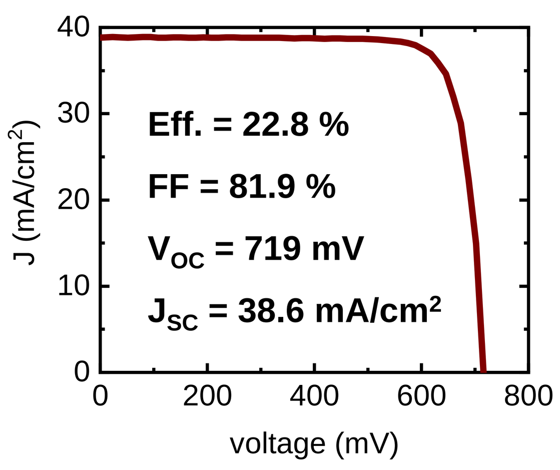
- ρ_c < 60 mΩ·cm² for H-through process even with 15 nm of ITO
- Sheet res. < 80 Ω/square even at 450°C with 15 nm of ITO

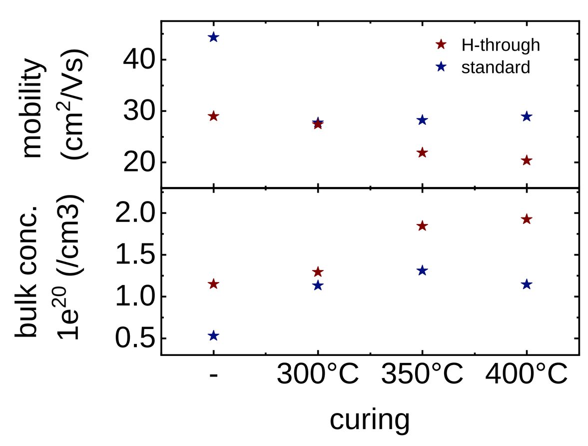
Feasibility of hydrogenation through the ITO layer

- High lifetime and iV_{OC}
- Higher values obtained for thinner ITO layers
- Negligible iV_{OC} loss compared to hydrogenation without ITO



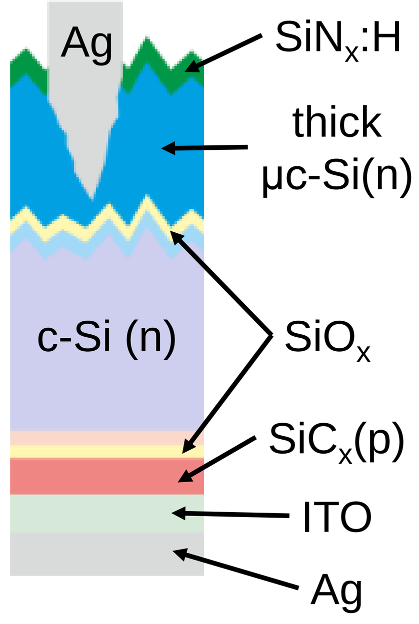
Best cell and limitation





- Eff. limited by the current
- Current loss due to free carrier absorption in the near IR-region

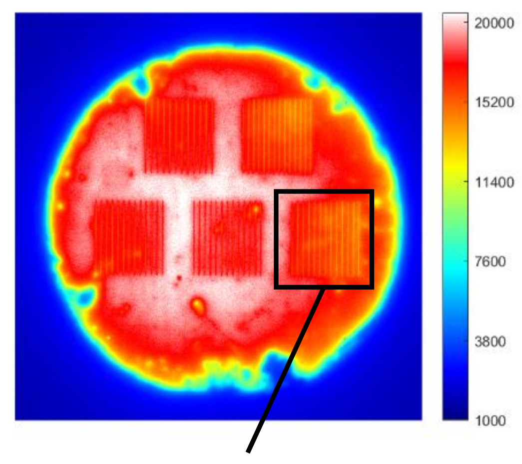
Firing through process



Cell demonstrator:

- PECVD deposition of thick μc-Si(n) (front) and SiC(p) (rear)
- Co-annealing at 850°C
- SiN_X deposition and Ag paste printing (front)
- Firing (hydrogenation and contacting of the Ag paste)
- metallization with sputtered ITO/Ag stack at the rear

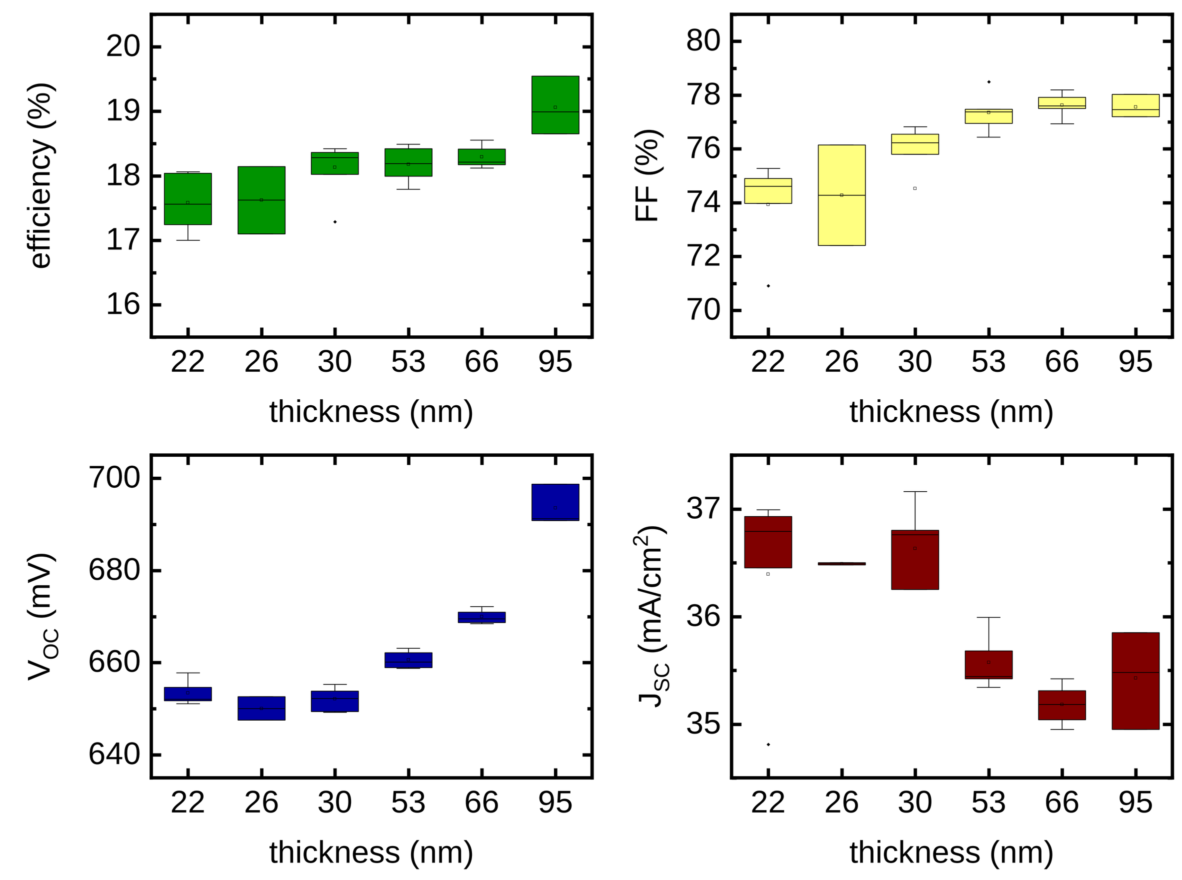
PLI after firing



Negligible degradation in the finger area, paste does not reach the oxide

Influence of the front contact thickness on the cell parameters

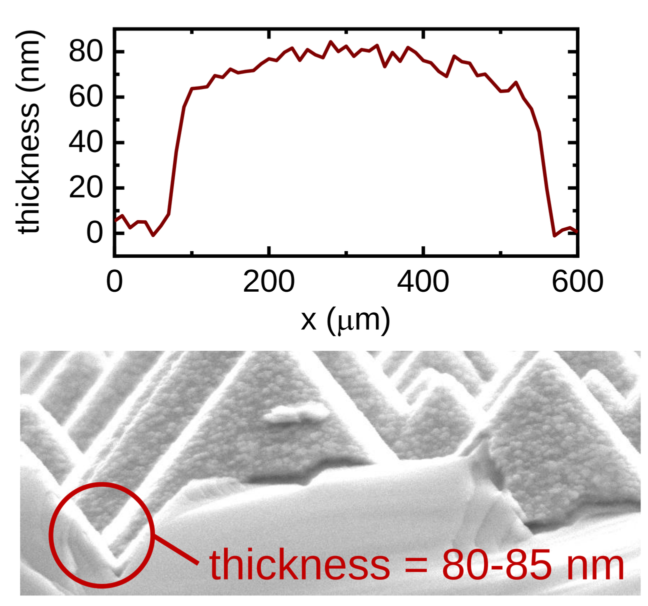
- Decrease of J_{SC} → thick contacts are not fully transparent
- Increase in V_{OC} → thick contacts can stop the Ag paste and protect the oxide
- FF quite constant → thick contacts ensure good current transport
- The efficiency is a trade-off between V_{OC} or the J_{SC}

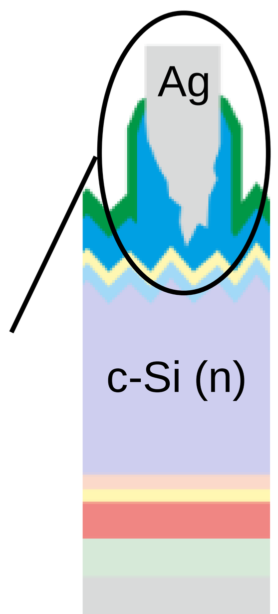


Localised contacts (cells in fabrication)

- Localization can be done by using a mask during the PECVD
- Loss in thickness due to the mask
- It can ensure high J_{SC} and high V_{OC} at the same time
- Predicted conversion efficiency:

Eff. = 22.2 % FF = 78 %
V_{OC} = 700 mV J_{SC} = 40.5 mA/cm²





Conclusion

H-through process:
- Demonstration of a SiN_x/ITO stack enabling 22.8% conversion efficiency with an impressive fill factor of 81 % in two-sides contacted c-Si solar cells with passivating contacts using only 15 nm thick ITO layer
- Further optimization is required to reduce parasitic absorption in the TCO. One possibility would be to replace the ITO with indium free TCO as they are more thermally stable.

Firing through process:
- Demonstration of a thick passivating contact deposited on front texturized surface in order to stop the silver paste
- Cell demonstrator enabling 19.4% conversion efficiency with a V_{OC} of almost 700 mV and a fill factor of 78 %
- Currently, cells are limited by the absorption in the thick passivating contact. Localization of this contact is under study to develop high efficiency solar cells

References

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