Self-Aligned Phase Separation for IBC Solar Cells using PVD Polysilicon

Erik Hoffmann[1], Geoffrey Gregory[1], Massimo Centazzo[1], Muhammad Khan[1], Nabeel Khan[1], Verena Mertens[2], Philip Jäger[2], Sarah Spätlich[2], Ulrike Baumann[2], Thorsten Dullweber[2]

[1]EnPV GmbH, Durlacher Allee 93, 76131 Karlsruhe, Germany

[2]Institute for Solar Energy Research Hamelin (ISFH), Am Ohrberg 1, 31860 Emmerthal, Germany

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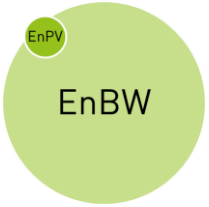
Who we are & what we do

- EnPV develops new products & manufacturing technologies for the PV industry:
  - 90% owned by EnBW Energie Baden-Württemberg AG, i.e.
  - the third largest utility company in Germany;
  - currently a team of 5 and looking to grow;
  - R&D activities at ISFH in Hameln;
  - patent pending proprietary technology (device & manufacturing method);
  - open to partnerships.



Comparing "traditional front-side" and "IBC-front-side" of a PV cell[1]

traditional cell

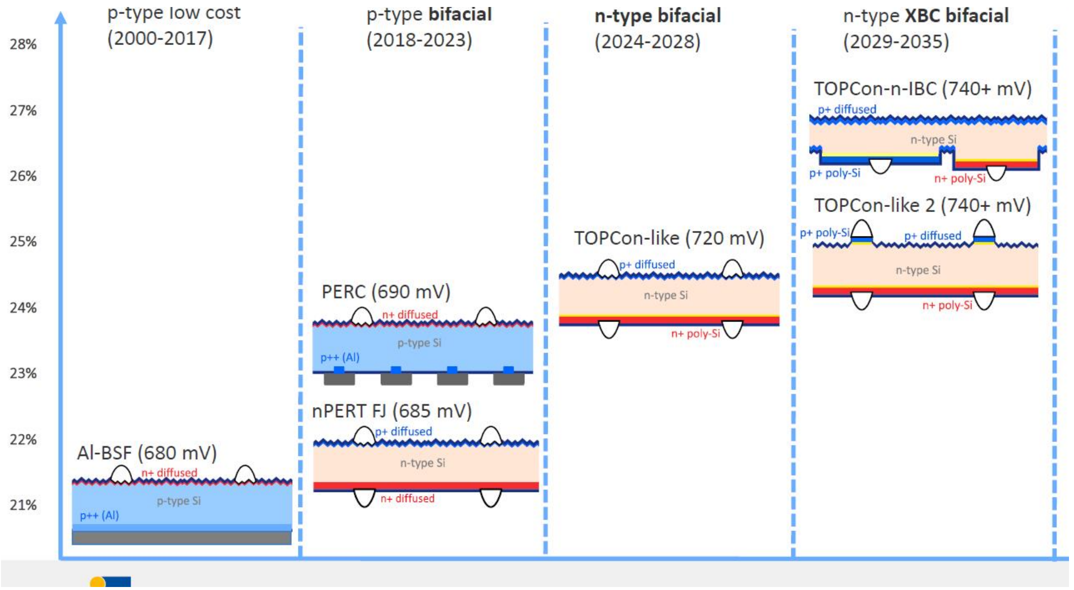
IBC cell

[1] Courtesy of WSL Solar, see https://www.wsl-solar.com/Product_News/2019/1217/IBC-Solar-Cell.html

Transition from TOPCon to TBC/XBC

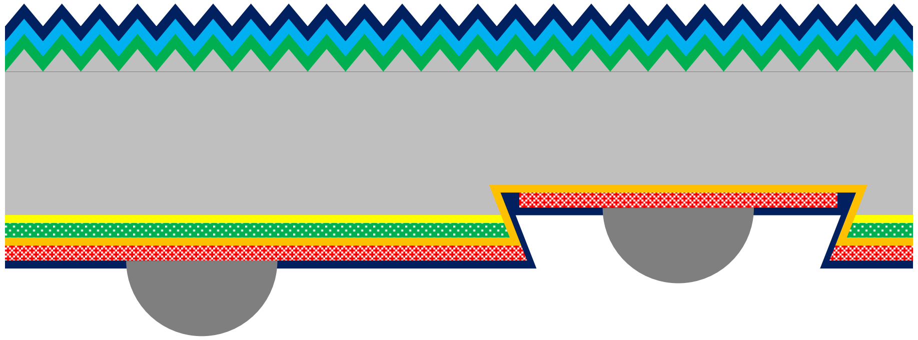
- TBC/XBC: passivating TOPcon contacts of both polarities on IBC structures
- Efficiency gain $\Delta\eta$ = 0.4-0.6 $\%_{abs}$ possible compared to TOPCon
- Complex structuring of the back side
- TBC/XBC often requires significantly different manufacturing line specification than TOPCon
- **TBC solar cell with self-aligned poly-Si insulation: SABC solar cell**
  - Requires only one patterning step of the 1st poly-Si
  - Under-etching of the 1st poly-Si
  - By Physical Vapor Deposition (PVD): directional deposition of the 2nd poly-Si

  → Ultrafine separation of n-type poly-Si across the under-cut
  - Natural upgrade of TOPCon, i.e. only two additional equipment required.



Kopecek et. TBC after TOPCon, PVCELLTECH2024

SABC solar

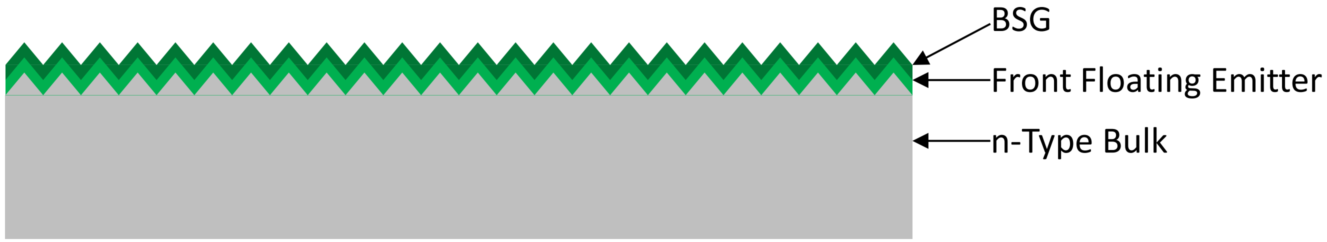


SABC process sequence

TXT

B (or P) Diffusion

Rear Polishing

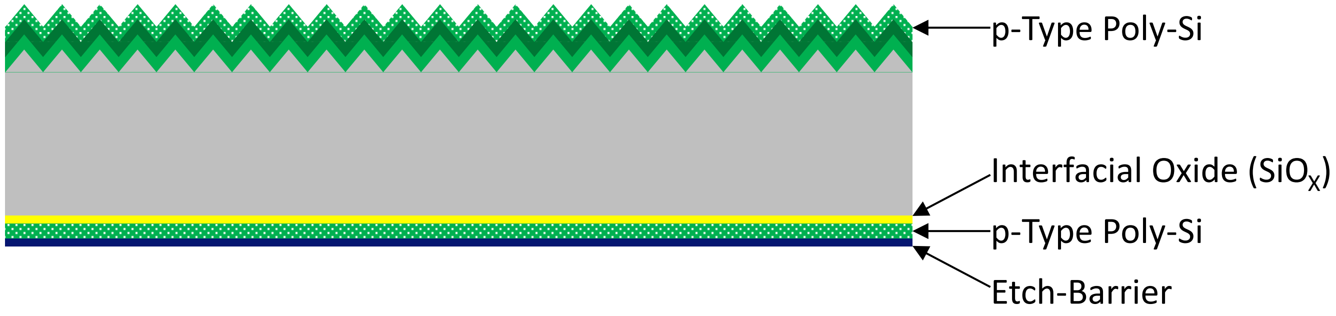


- Boron silicate glass (BSG) serves as etch-barrier in subsequent processing
- P-diffusion (front surface field) with PSG as etch-barrier may be beneficial due to better passivation properties: J_0 = 2 fA/cm² [1]

[1] Schmidt, J. et al., *Sol. Energy Mater. Sol. Cells* **2018**, 187, 39-54

SABC process sequence

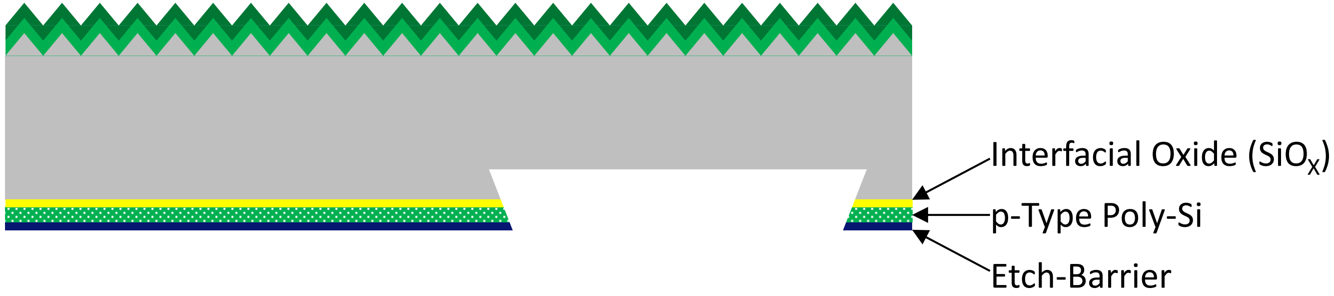
- TXT
- B (or P) Diffusion
- Rear Polishing
- LPCVD: 1st SiO_X+ p-poly-Si
- PECVD: Etch Barrier (EB)



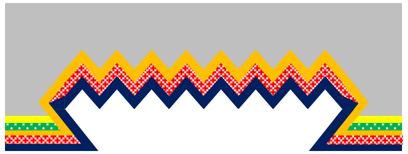
- Interfacial oxide and p-type poly-Si deposition on back and front side by LPCVD
- Etch-barrier deposition (e.g. SiN_X) by PECVD on back side

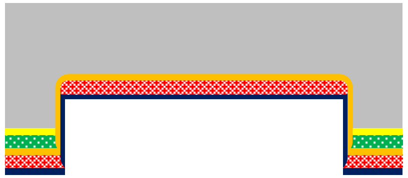
SABC process sequence


- TXT
- B (or P) Diffusion
- Rear Polishing
- LPCVD: 1st SiO_x+ p-poly-Si
- PECVD: Etch Barrier (EB)
- laser ablation
- Clean: p-poly-Si + EB + BSG



- Patterning of back side poly-Si by:
  - Laser ablation of etch-barrier
  - Wet chemical etching:
    1. front side p-type poly-Si etching up to BSG & back side p-type poly-Si etching of patterned regions
    2. Etching of wafer in patterned regions creates undercut
    3. Cleaning: removal of BSG and etch-barrier


Anisotropic Etch


Isotropic Etch

SABC process sequence

- TXT
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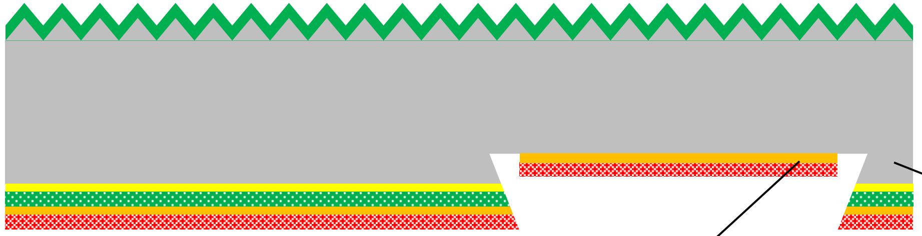
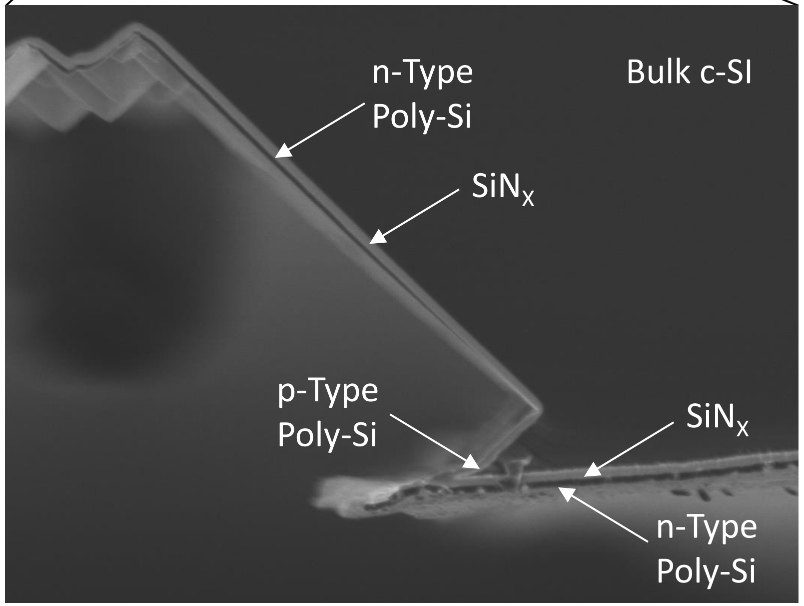
- Rear Polishing
- LPCVD: 1st $\mathrm{SiO_X}$+ p-poly-Si
- PECVD: Etch Barrier (EB)
- laser ablation
- Clean: p-poly-Si + EB + BSG
- PVD: 2nd $\mathrm{SiO_X}$+ n-poly-Si



SEM image of the trench wall

- Includes an additional $\mathrm{SiN_X}$ layer to enhance contrast between n-type poly-Si and c-Si bulk
- Poly-Si thickness reduces underneath undercut and eventually disappears



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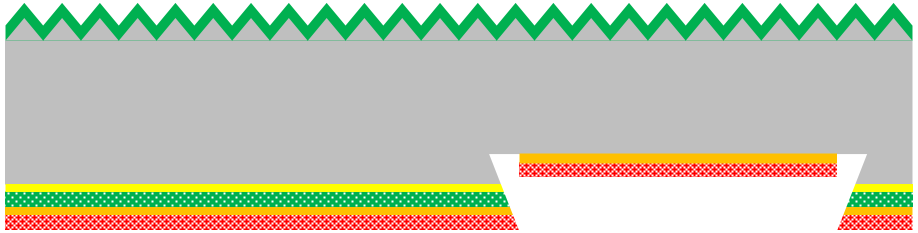
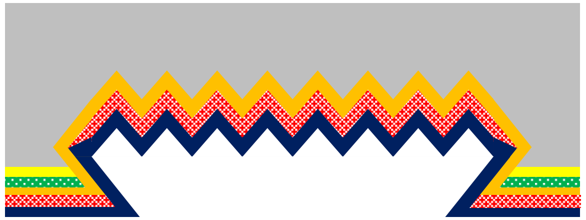
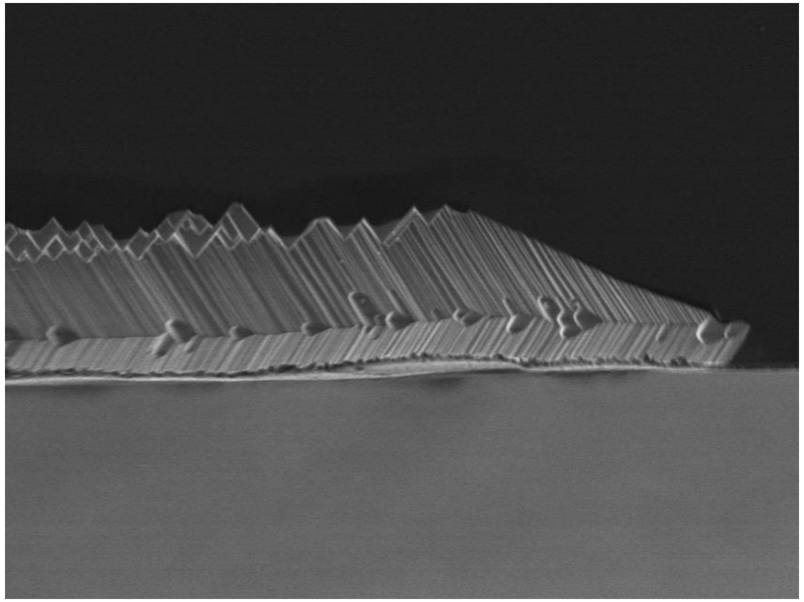


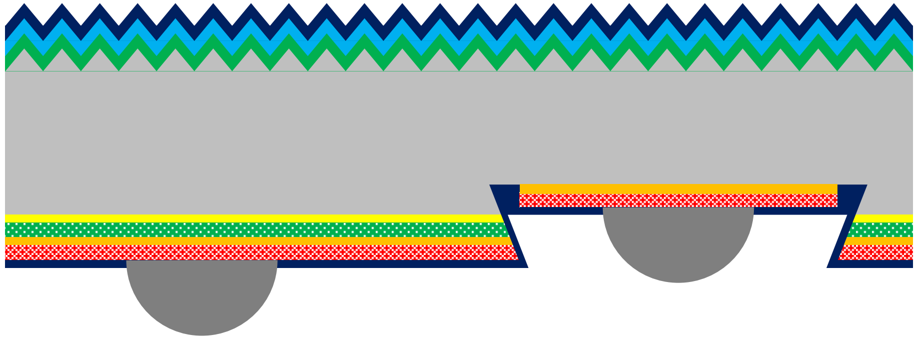


anisotropic etch



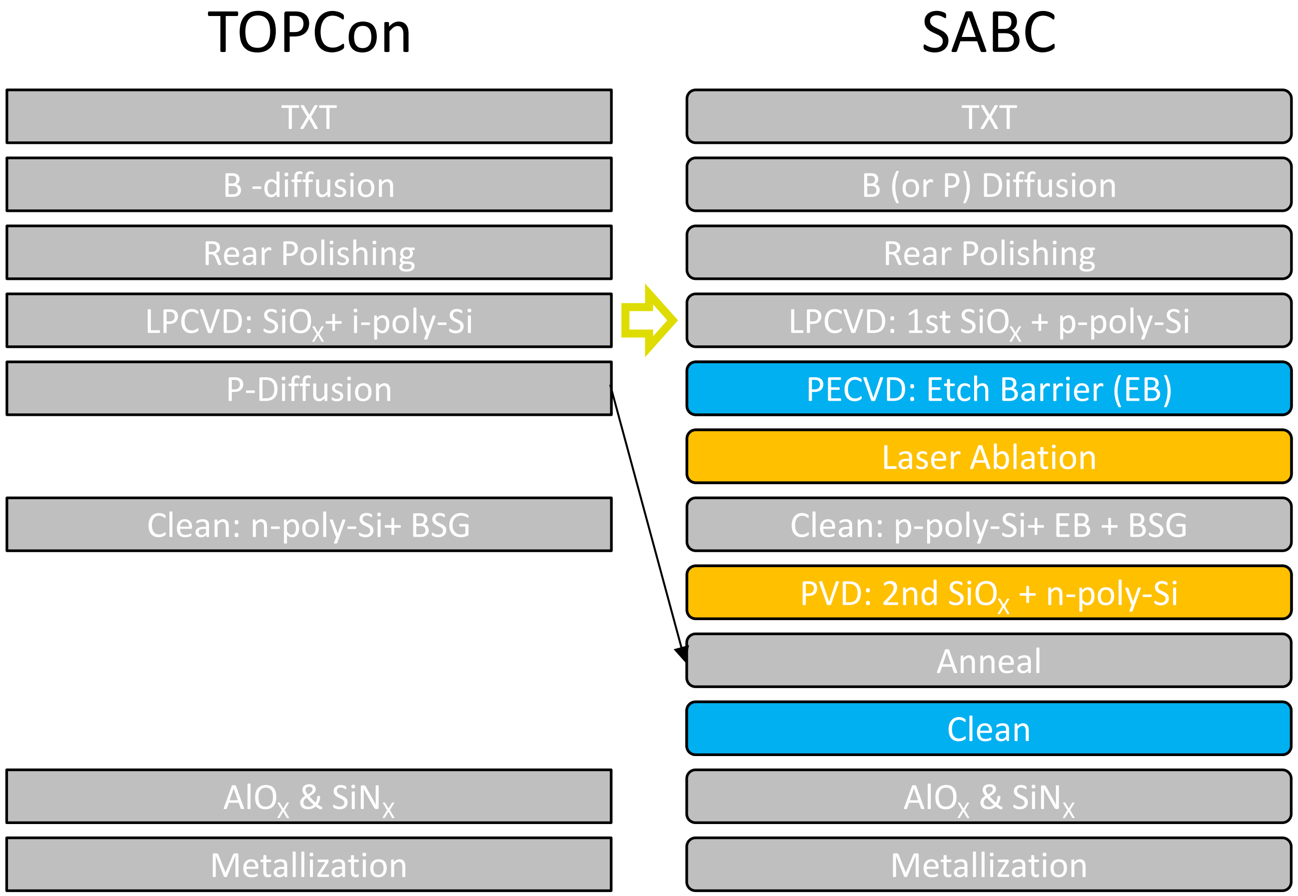
SABC process sequence

- TXT
- B (or P) Diffusion
- Rear Polishing
- LPCVD: 1st SiO_x+ p-poly-Si
- PECVD: Etch Barrier (EB)
- laser ablation
- Clean: p-poly -Si+ EB + BSG
- PVD: 2nd tunnel oxide + n-poly-Si
- Anneal
- Clean
- AlO_x & SiN_x
- Metallization



- Simultaneously annealing of both poly-Si layers to crystallize and activate dopants.
- Single print for metallization as both emitter and BSF are covered by the same n-type poly-Si layer.

TOPCon to SABC transition



TOPCon	SABC
TXT	TXT
B -diffusion	B (or P) Diffusion
Rear Polishing	Rear Polishing
LPCVD: SiO_x+ i-poly-Si	LPCVD: 1st SiO_x + p-poly-Si
P-Diffusion	PECVD: Etch Barrier (EB)
	Laser Ablation
Clean: n-poly-Si+ BSG	Clean: p-poly-Si+ EB + BSG
	PVD: 2nd SiO_x + n-poly-Si
	Anneal
	Clean
AlO_x & SiN_x	AlO_x & SiN_x
Metallization	Metallization

⇨ Retrofitting of LPCVD to deposit p-type poly-Si

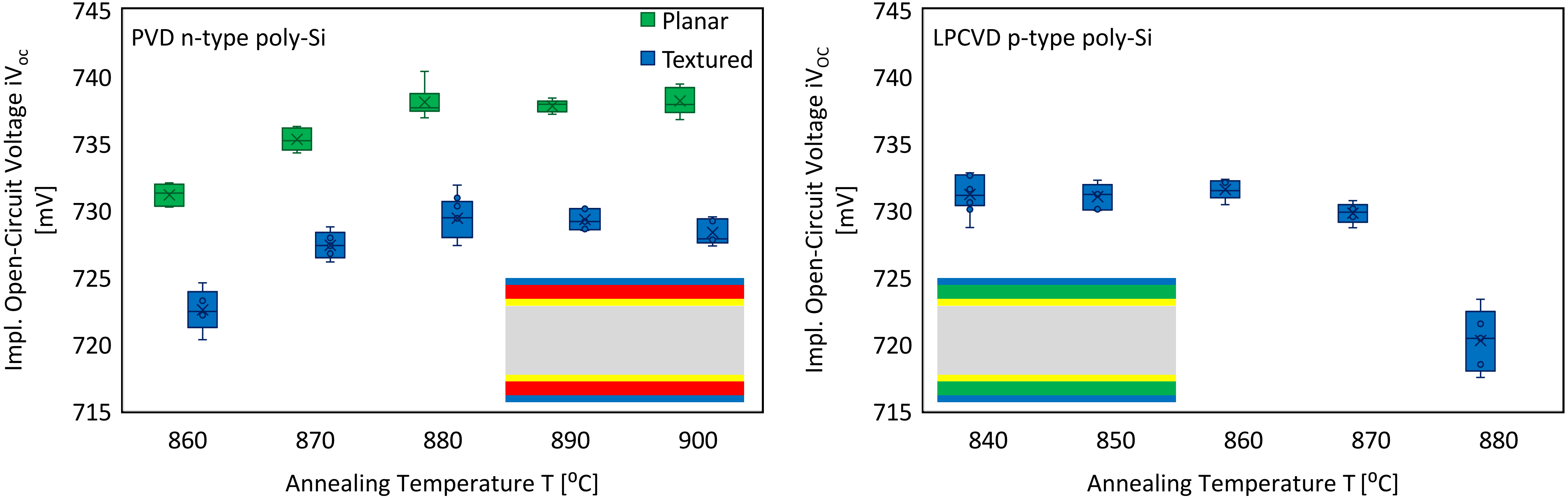
- Two additional processes in existing tools
  - Etch barrier by PECVD
  - Cleaning after n-poly anneal

- Two additional tools required:
  - Laser
  - PVD

→ P-diffusion furnace to be used for inert anneal

- Only single side screen print
- Same paste for emitter and base contact

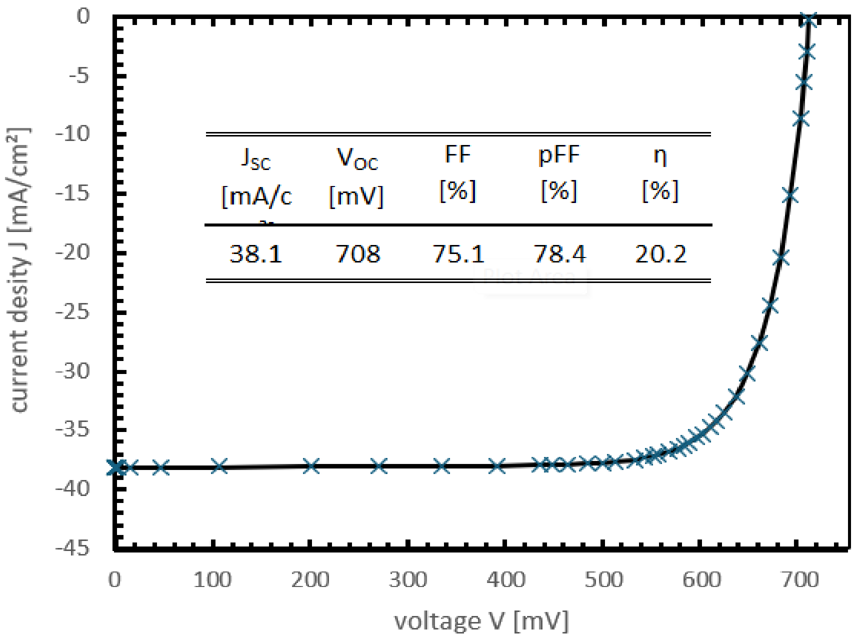
Passivating contacts



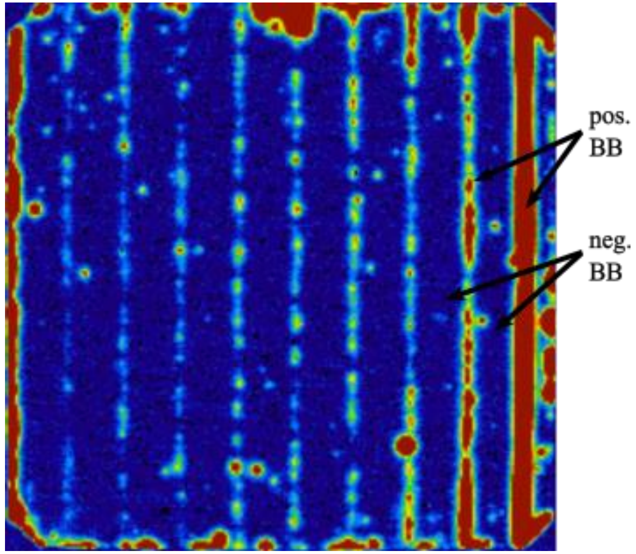
- Annealing of both poly-Si at the same temperature T = 870 °C yields:
  - BSF iV_{OC} = 735 mV
  - Emitter iV_{OC} = 730 mV
- For the cell process, we still implent two annealing steps, causing too much B in-diffusion, lowering iV_{OC} of the emitter
- Still under investigation: effect of n-type poly-Si on top p-type poly-Si

Proof-of-Concept

- First solar cell run yields max efficiency η = 20.2 %
- Slightly different processing sequence as described above:
  - No front side diffusion
  - Single side acidic etch back
  - Wet chemical interfacial oxides
  - Annealing of p-type poly-Si after LPCVD deposition
  - Metallization with non-fire through busbar paste
- Acceptable V_{OC} = 708 mV, considering annealing of p-poly twice.
- Fill factor and J_{SC} limit efficiency. A possible reason could be bulk related issues.
- Most importantly: acceptable shunt resistance R_{sh} = 3.3 kΩ.cm² indicating promising insulation of n-type poly silicon across the trench wall.
- Lock-In-Thermography shows local shunts at emitter busbars and edges, but little shunts between oppositely doped interdigitated electrodes.



J_{SC} [mA/c	V_{OC} [mV]	FF [%]	pFF [%]	η [%]
38.1	708	75.1	78.4	20.2



Summary

- SABC solar cell: novel TBC cell concept with self-aligned separation of the passivated contacts.
- Under-etching of first poly-Si and directional deposition of second poly-Si by PVD forms an insulation across the under-cut trench wall.
- Transition from TOPCon to SABC requires little modification.
- $iV_{oc} > 730$ mV for p-type (LPCVD) and n-type poly-Si (PVD) for the same annealing temperature and $iV_{OC} > 735$ mV for ideal annealing conditions.
- Proof of concept SABC solar cell yields $\eta = 20.2$ % and with a shunt resistance $R_{sh} = 3.3$ kΩ.cm².
- Lock-in-Thermography:
  - local shunts at emitter busbar, but
  - no widespread shunts between indigitated electrodes / across undercut.
- We would like to thank the EnPV team and ISFH for processing and for the valuable discussions.