



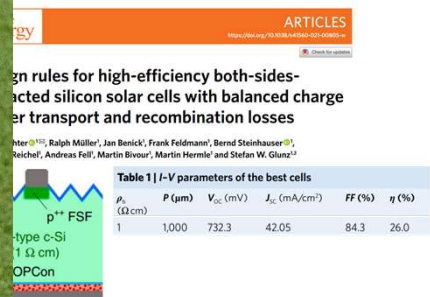
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Towards ultimate performances for mono Si technologies

March 2021:



July 2021:



How did we get there & what's next?

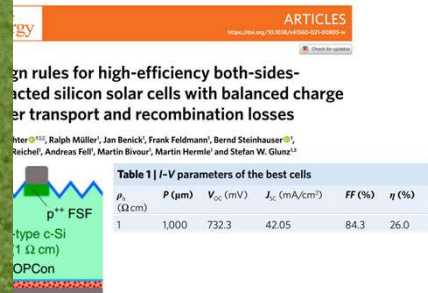
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Towards ultimate performances for mono Si technologies

March 2021:



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How did we get there & what's next?

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Agenda

1. Monocrystalline Si technologies: Status & Perspectives
 1. Modules
 2. Cells
2. Focus on PV-Lab/CSEM technologies
3. Conclusion

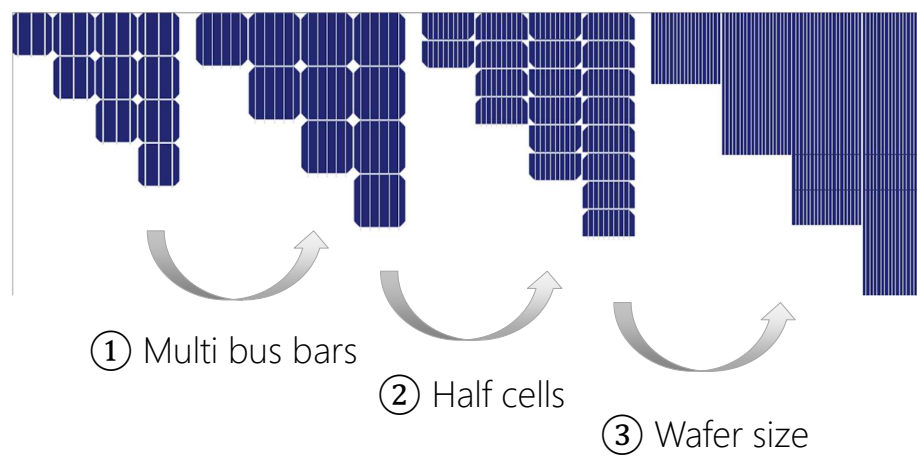
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Trends in mono Si modules

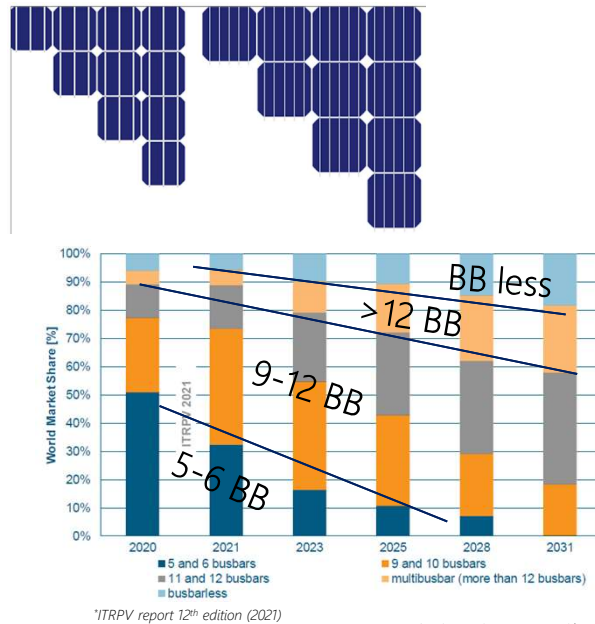


& also zero gap, bifaciality, shingling...

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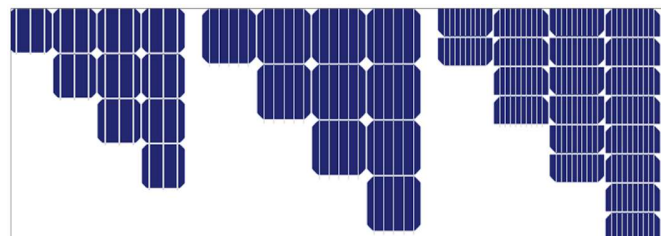
Trends in mono Si modules

- Multi bus bars:
 - Decrease of resistive losses along fingers allowing for Ag reduction



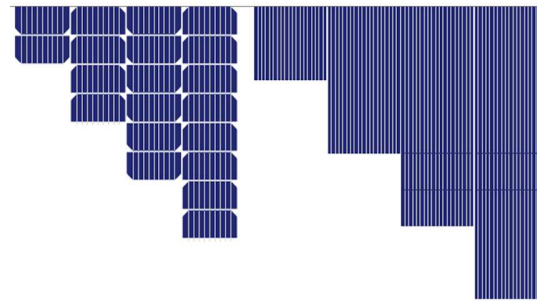
Trends in mono Si modules

- Multi bus bars:
 - Decrease of resistive losses along fingers allowing for Ag reduction
- Half cells:
 - Decrease of resistive losses along BB
 - Already mainstream for large wafers

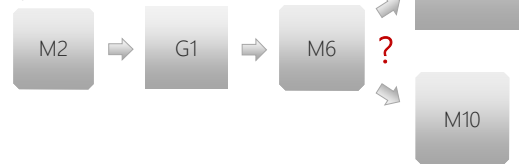


Trends in mono Si modules

- Increasing wafer size:
 - Increase of module power & efficiency
→ reduction of BOS costs
 - Increased productivity of cell fabrication
 - Increase of module size and weight

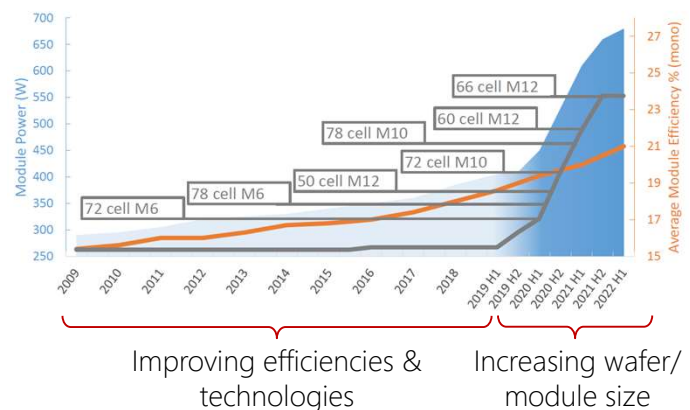


Up to 2016



Trends in mono Si modules

- Improvements at the module level has driven latest increase in module's performances:
 - Multi bus bars
 - Half cells
 - Increasing wafer/module size
- Further increase will rely again on improving cell efficiency



*A. Goscomb (Sunspire), pres. at the 11th SiliconPV/nPV workshop (2021)

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2. Cells

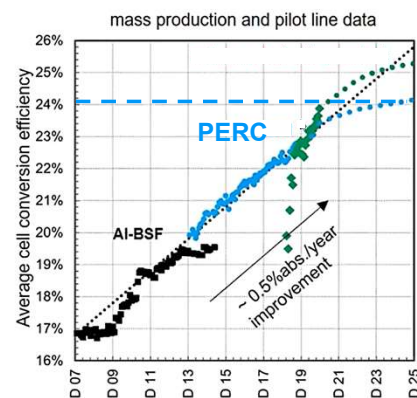
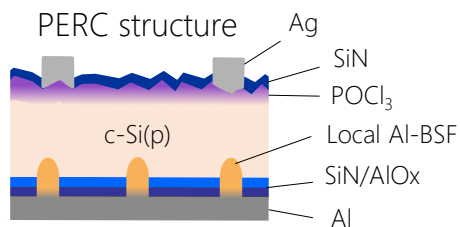
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Trends in mono Si cells

- Passivated and Emitter Rear Cell (PERC) will be limited to $\eta \sim 24\%$

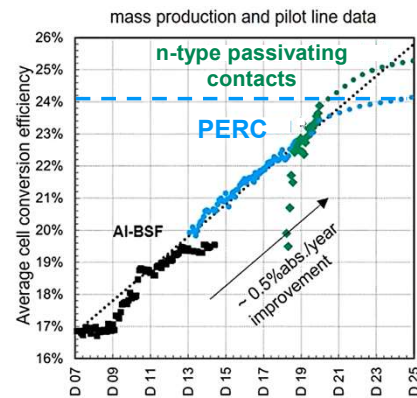
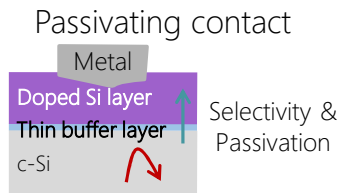


*J. Müller (Q-cells), pres. at the 11th SiliconPV/nPV workshop (2021)

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Trends in mono Si cells

- Passivated and Emitter Rear Cell (PERC) will be limited to $\eta \sim 24\%$
- Full-area passivating contacts:

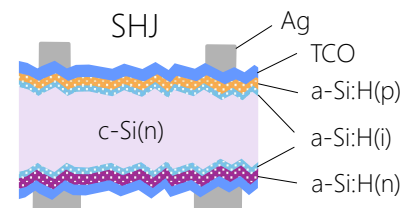


*J. Müller (Q-cells), pres. at the 11th SiliconPV/nPV workshop (2021)

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Full-area passivating contacts

a-Si:H heterojunction:



- Silicon Heterojunction (SHJ):
 - Independent manufacturing lines
- Meyer Burger:
 - 0.4 GW solar production just installed in Freiberg, Germany
 - Modules up to 21.8% including SmartWire interconnections investigated at PV-Lab/CSEM

MEYER BURGER

Meyer Burger Black
Heterojunction Module

- Maximum performance**
Up to 21.8% conversion efficiency in low light conditions, such as in the morning and evening hours or with cloudy skies
- Maximum quality**
Production of solar cells and modules according to the highest standards and exclusively in Germany
- Maximum durability**
Guaranteed power for 30 years
- Maximum reliability**
Patented SmartWire technology makes the modules extremely robust and safe
- Maximum elegance**
Innovative and elegant design, awarded in Switzerland

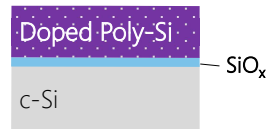
Meyer Burger Embedded GmbH
Carl-Neuberg-Str. 17
04500 Freiberg
Germany
www.meyerburger.com



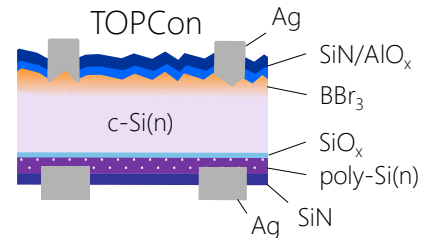
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Full-area passivating contacts

Poly-Si contact:



- Polycrystalline-Silicon based passivating contacts (TOPCon):
 - PERC upgrade
 - Already 25% in manufacturing pilot-lines



| Company | TOPCon technology | η (%) | Cell area (cm ²) |
|--------------------------|-------------------|------------|------------------------------|
| Jinko Solar ¹ | LPCVD | 25.25 | 267.4 |
| Longi ² | LPCVD | 25.21 | 244 |
| Trina Solar ³ | LPCVD | 24.58 | 244.6 |

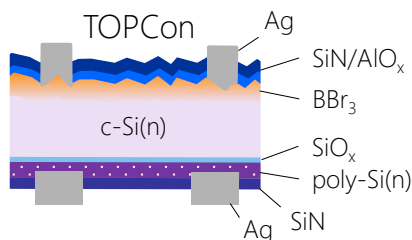
¹<https://ir.jinkosolar.com/news-releases/news-release-details/jinkosolar-large-area-n-type-monocrystalline-silicon-solar-0>

²http://www.longi-solar.com.au/home/events/press_detail/id/335.html

³D. Chen et al, Sol. Energy Mater. Sol. Cells. 206 (2020) 110258.

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Challenges for TOPCon industrialisation



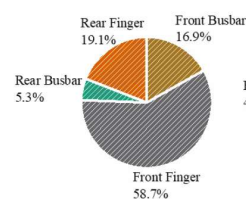
| | LPCVD | PECVD | PVD-Sputtering |
|----------------------|-------|-----------------------------|----------------|
| Avoiding wrap around | ✗ | ✓ | ✓✓✓ |
| Production volume | ✓✓✓ | Parallel plate: ✗ Tube: ✓✓✓ | ✓✓✓ |
| Maturity | ✓✓✓ | ✓✓ | ✓ |
| In-situ Doping | ✗ | ✓✓✓ | ✓ |
| Capex | ✓✓✓ | ✓ | ✓✓ |

Readiness: ✓✓✓ High ✓✓ Medium ✓ Low ✗ No

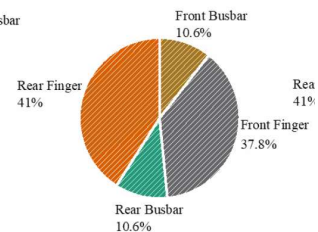
^{*}Adapted from: A. Ingenito et al, pres. at the 37th EUPVSEC (2020)

- Poly-Si deposition → preferred method not identified yet
- Higher metallization costs than PERC

Bifacial p-PERC

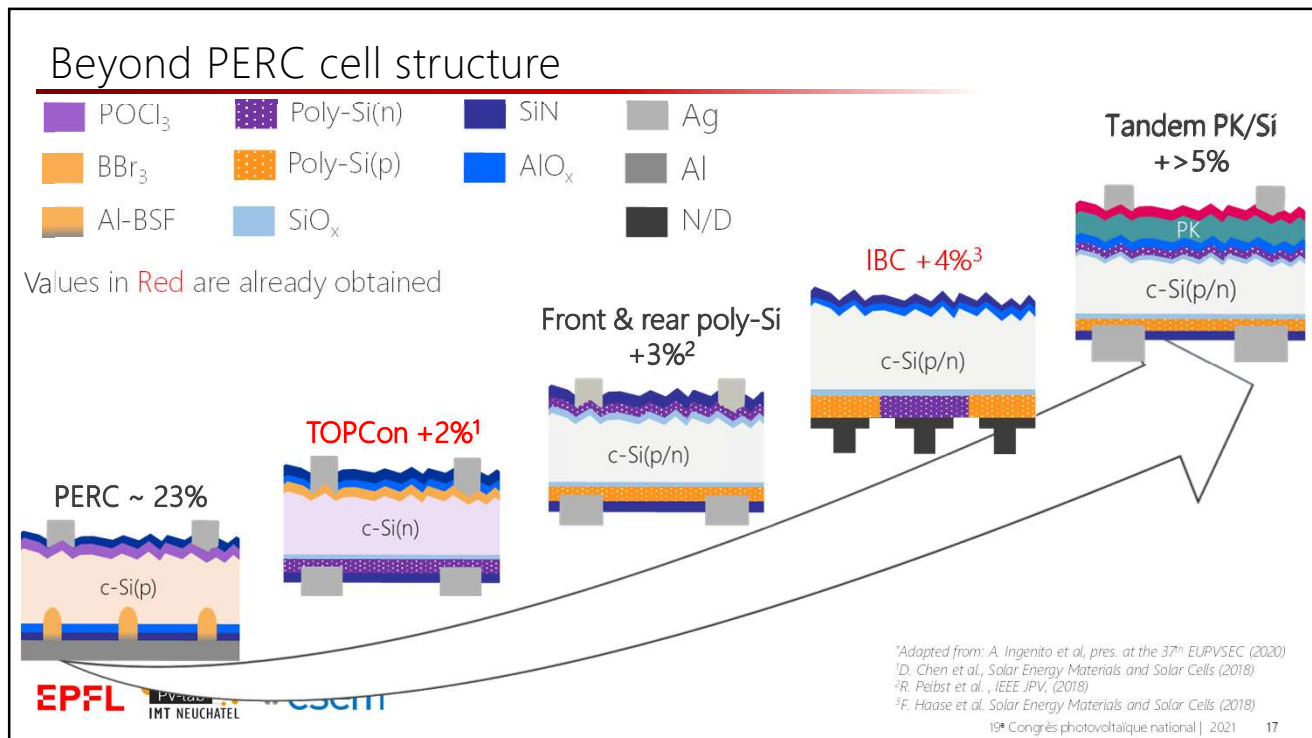


Bifacial n-TOPCon



^{*}J. Chen (Jolywood), pres. at the 11th SiliconPV/nPV workshop (2021)

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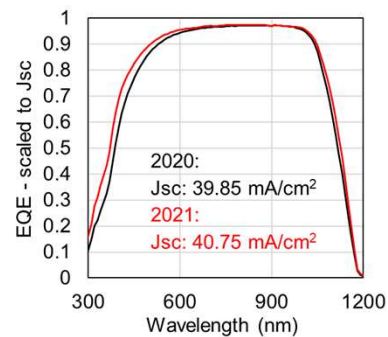
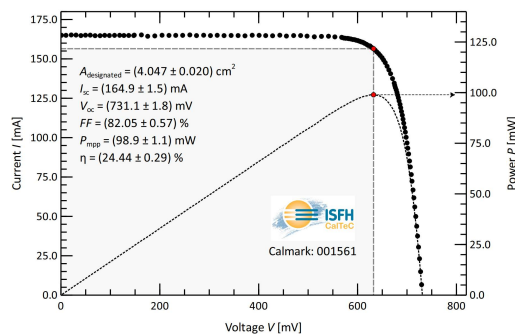
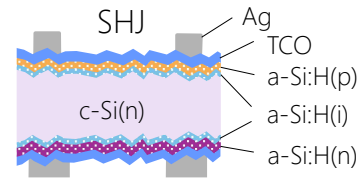
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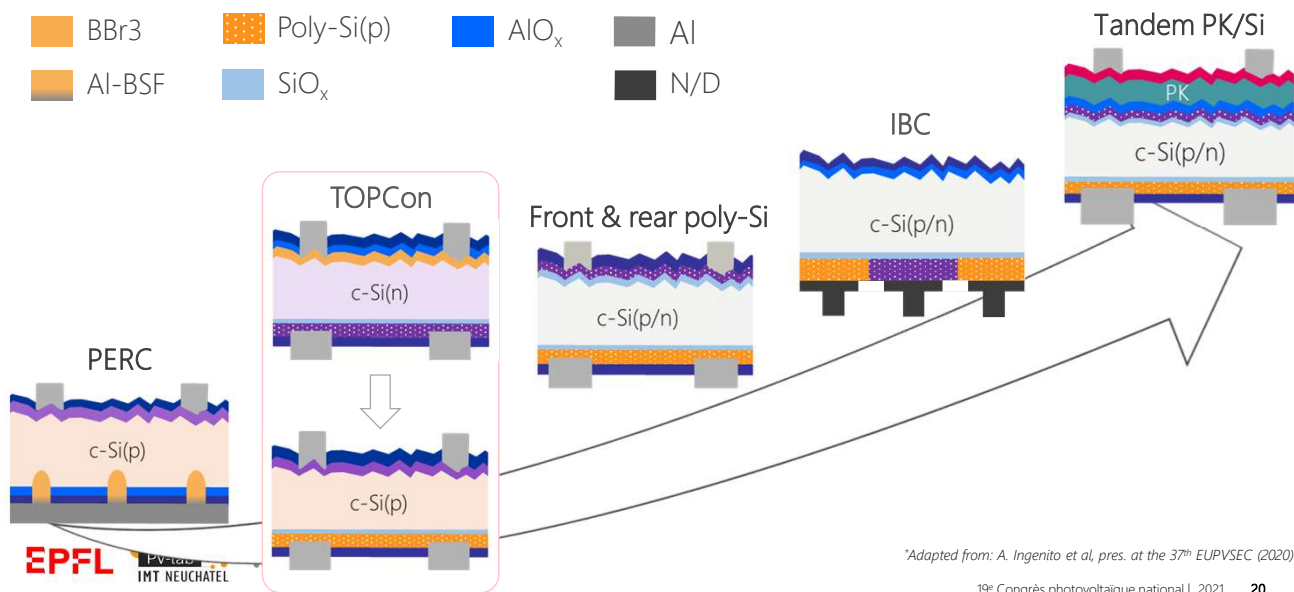
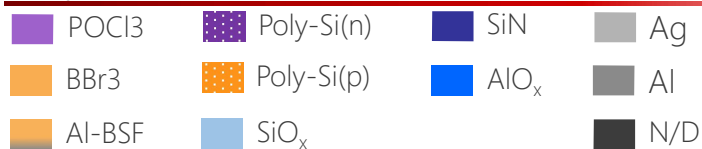
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Silicon Heterojunction structure

- PV-Lab pioneered SHJ cell structure in collaboration with CSEM and Meyer Burger
- Latest certified cell result → 24.44% with very high current of 40.75 mA/cm²



Beyond PERC structure



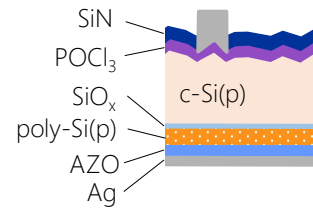
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Firing passivating contact concept

- Reduction of thermal budget for poly-Si contact fabrication

Poly-Si/SiO_x depositionLong ~~annealing~~

Firing



ARTICLES

<https://doi.org/10.1038/s41560-018-0239-4>
nature
energy

A passivating contact for silicon solar cells formed during a single firing thermal annealing

Andrea Ingenito^{1*}, Gizem Nogay¹, Quentin Jeangros¹, Esteban Rucavado¹, Christophe Allebé², Santhana Eswara³, Nathalie Valle¹, Tom Wirtz³, Jörg Horzel¹, Takashi Koida⁴, Monica Morales-Masis⁵, Matthieu Despeisse², Franz-Josef Haug¹, Philipp Löper⁶ and Christophe Ballif²

19^e Congrès photovoltaïque national | 2021

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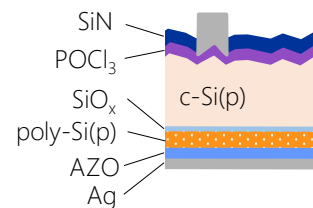
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Firing passivating contact concept

- Reduction of thermal budget for poly-Si contact fabrication
- Up to 22% large-area solar cells (& 22.5% on small-area)

Poly-Si/SiO_x depositionLong ~~annealing~~

Firing

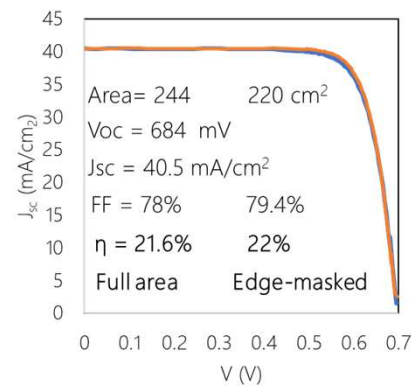


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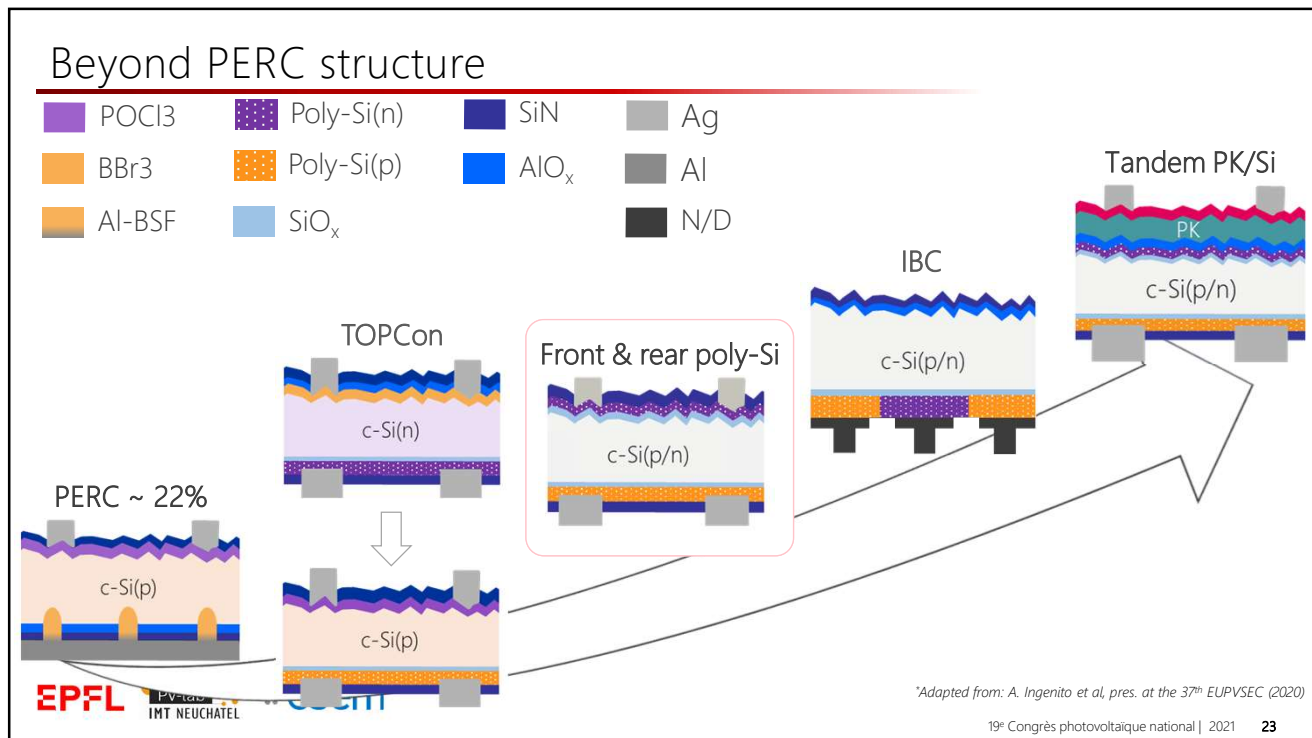
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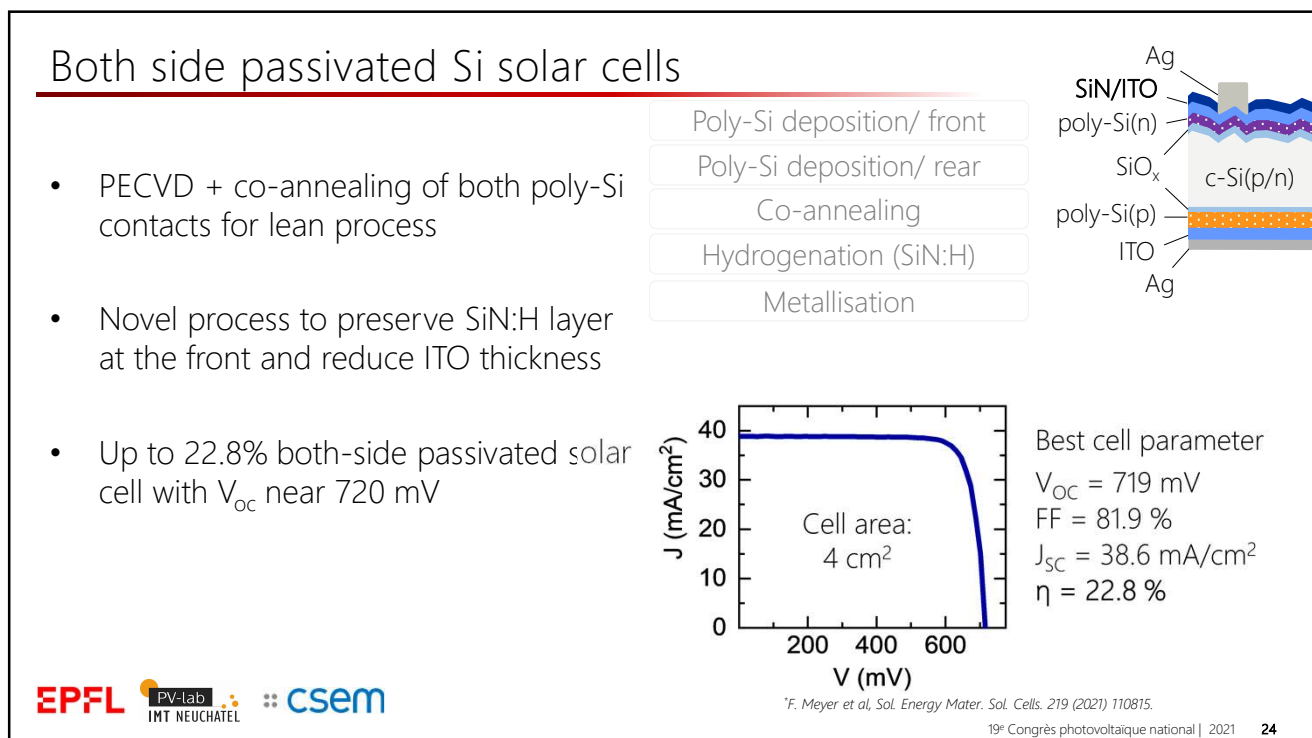
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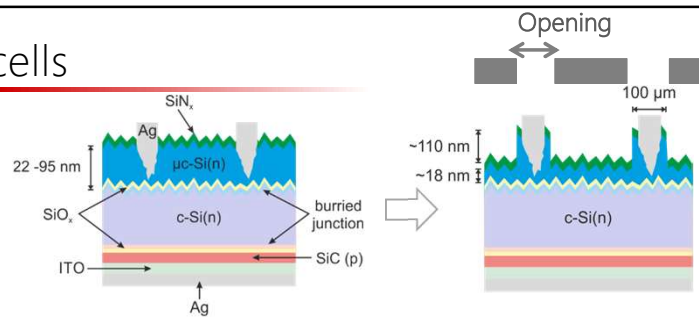
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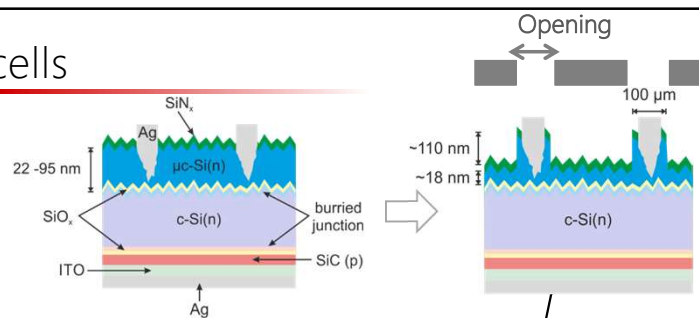
Both side passivated Si solar cells

- Direct metallization of front poly-Si → limited current due to absorption in poly-Si layer
- Localization of poly-Si under the metal using both PVD and PECVD



Both side passivated Si solar cells

- Direct metallization of front poly-Si → limited current due to absorption in poly-Si layer
- Localization of poly-Si under the metal using both PVD and PECVD
- 21.7% already demonstrated with room for further improvement



| Eff. (%) | FF (%) | V _{OC} (mV) | J _{SC} (mA/cm ²) |
|----------|--------|----------------------|---------------------------------------|
| 21.72 | 79.7 | 711.2 | 38.32 |

See poster from F. Haug et al. at this conference

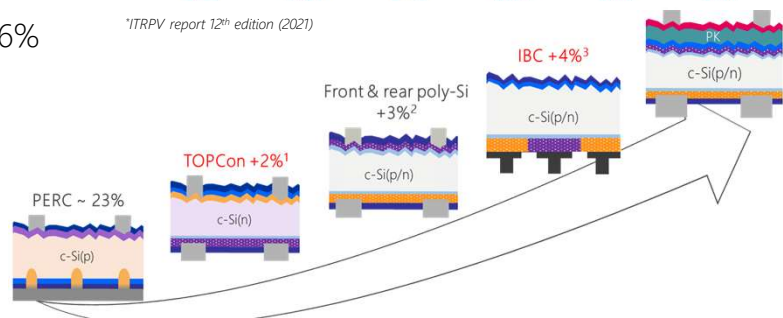
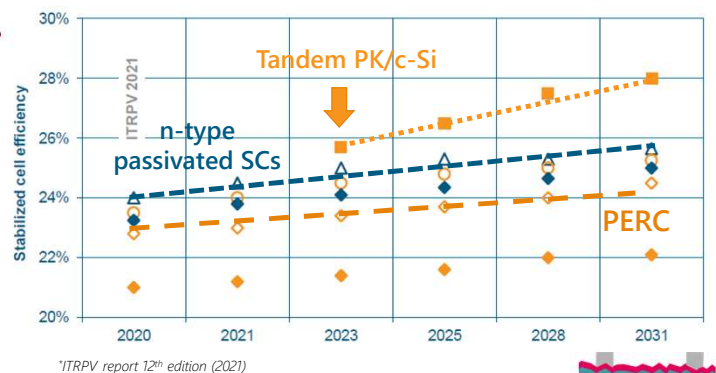
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Conclusion

- Mono Si technologies will soon reach ultimate performances (~26% cells and ~24% modules)
- The introduction of PK/Si tandem devices from 2023 will support future improvements beyond 26%



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