SILICON HETEROJUNCTION RESEARCH ON PILOT LINE LEVEL

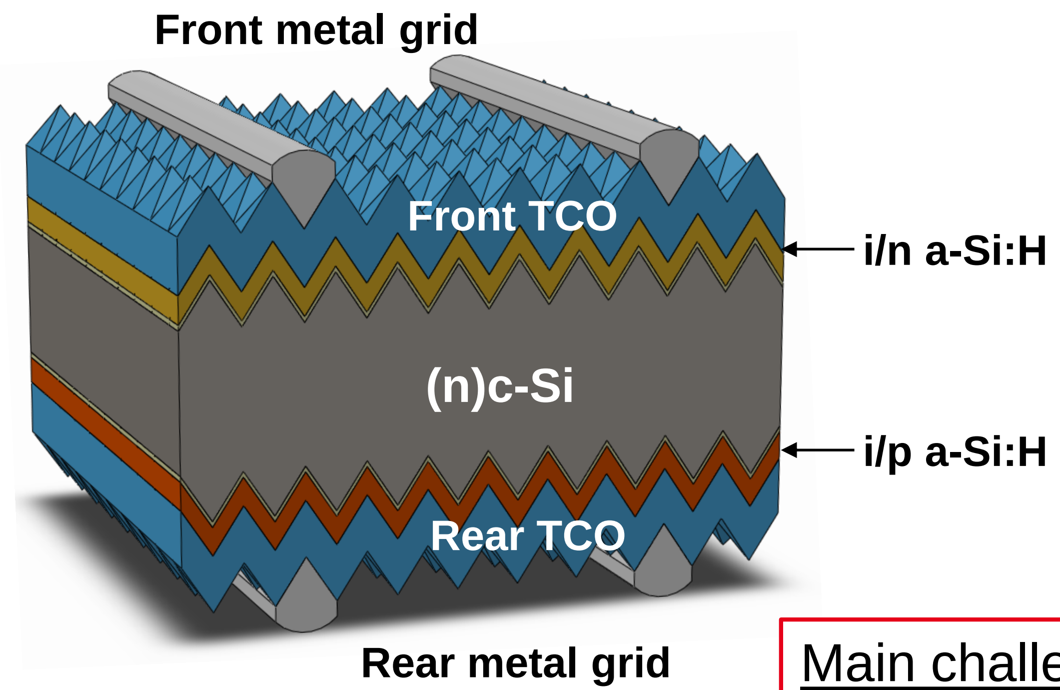
Samuel HARRISON, HERCULES Workshop 2016, Oct. 11th

Outline

- **Heterojunction solar cells (HJ)**
  - Cell architecture and η state of the art
  - Pilot Line at CEA-INES (LabFab)
  - Cell Activity Overview
- **HJ cells integration: some key points and recent LabFab learnings**
  - Substrates
  - Wet processing
  - PECVD
  - TCO
- **> 300Wp modules**
- **Summary & perspectives**

Heterojunction cells

Structure



Key features:

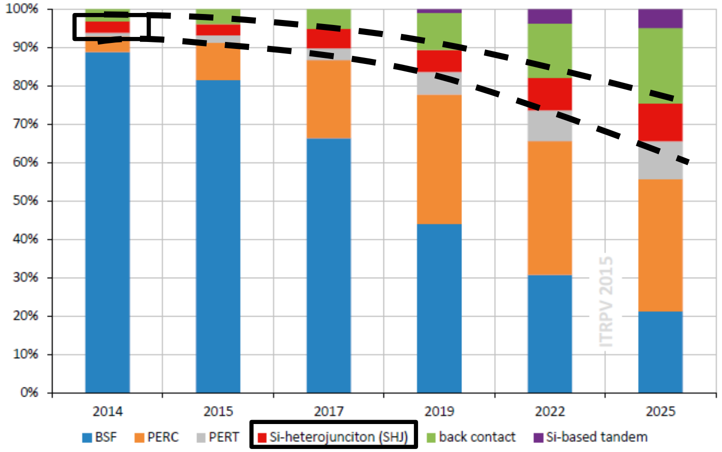
- Small number of process steps on (n)c-Si
- Passivation of c-Si surface by a-Si:H
- Electrostatic field from doped a-Si:H layers + a-Si:H/c-Si band offset
- TCO (most commonly ITO) to ensure lateral conduction and as anti-reflective coating
- Low temperature processes
- Mono or Bifacial cells
- Possible combination with homojunction & RCC processes
- High efficiency widely demonstrated

Main challenges:

- Optical losses: a-Si:H, TCO
- $Tau_{eff.}$: interface defects, bulk c-Si
- Lateral carrier transport: a-Si:H, TCO, metallization

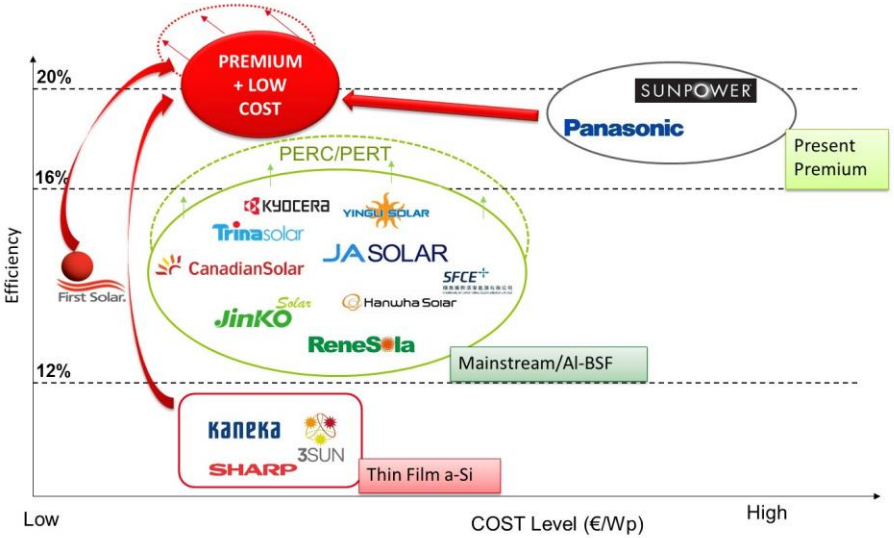
Heterojunction state of the art

Increased Market share



Company	Efficiency (%) Best cell	area (cm²)	Country	
Panasonic	24.7	100	Japan	
Kaneka	25.1	152	Japan	
Choshu	24.1 grid touch, busbarless	240	Japan	
R&R MB	23.4 grid touch, busbarless	240	Europe	
Kaneka	26,33	180	Japan	RCC-HJ
Panasonic	25.6	144	Japan	RCC-HJ
Sharp	25.1		Japan	RCC-HJ

Current Positionning



High Efficiencies already demonstrated
Improvement paths (efficiency, cost) still possible!

CEA-INES Pilot Line: « LabFab »

Line installed **S2 2011** – From startup to **20% baseline 2012** – **Production** mode **2013**

- ✓ 1500m^2 with 1200 m^2 ISO8 clean room, recycled DIW
- ✓ > 1000 Wph processes (156PSQ)
- ✓ Automated line: carriers on trolley ; cells on belts

CEA-INES HJ LabFab: bridge between R&D and Production

LABFAB Cell Results Overview

1200 Wafers/h capacity

⇩

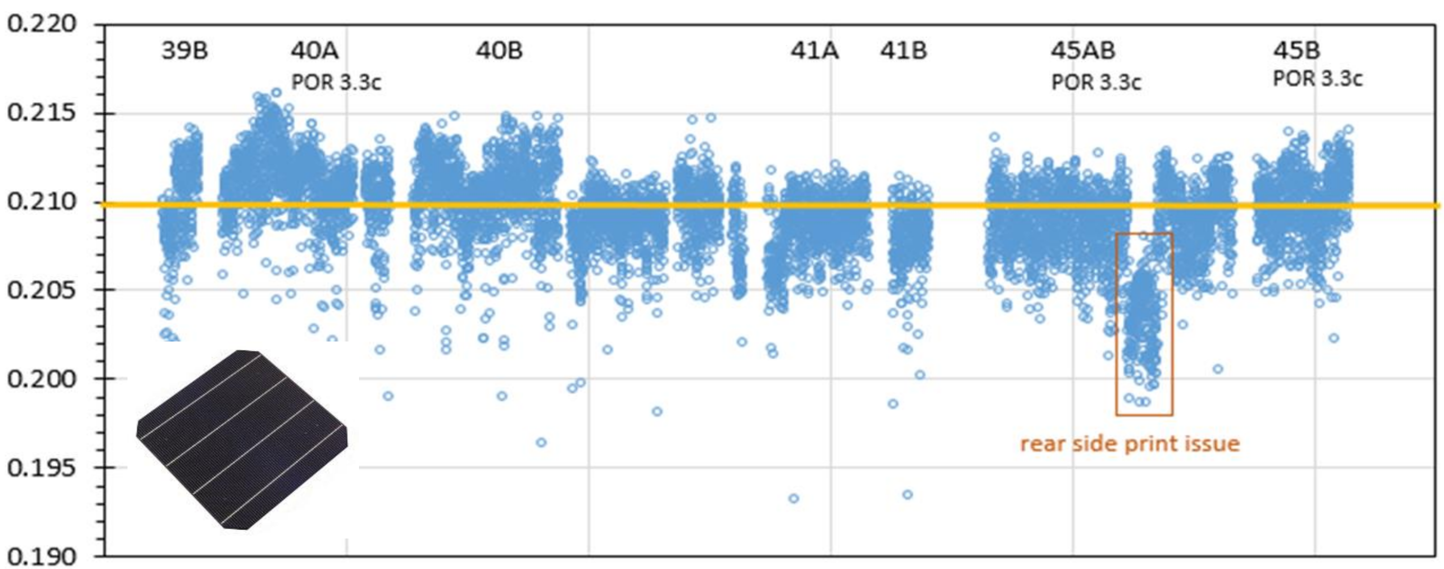
2400 wafers/h
TRL 5-7

2016 progress

- ✓ **Fast integration center**
- ✓ **High volume demo/pilote line: daily capability of a several thousands cells** for statistics, benchmark, cost model, mini production for modules & systems studies

Example of weekly activity on commercial 156PSQ c-Si substrates: 1200wph continuous production mode, 4BB Ag print bifacial cells, double-comb IV test

4BB INES: Efficiency **>10000 cells**



Baseline improved up to 21% BB

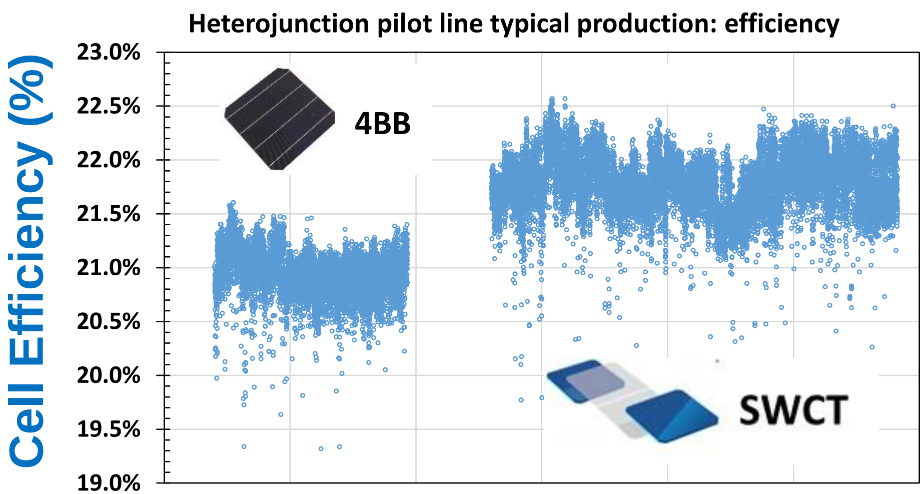
Record Batches (>200 Cells) 21.5% BB

Record Cells (production) 22.2% BB

Note: BB= bus bars

Two Technologies Developed

Two cell architectures

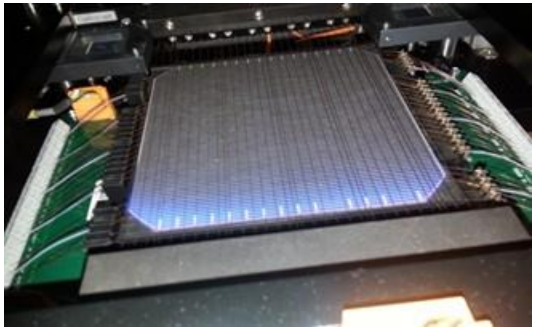


Example of weekly activity on commercial 156PSQ c-Si substrates (full ingot): 1100wph continuous production mode, 4BB Ag print bifacial cells (double-comb IV test) + Busbarless SWCT bifacial cells (IV GridTouch)

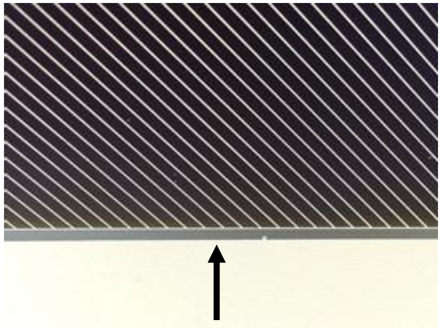
Baseline improved up to 22% busbarless

Record Batches (>200 Cells) 22.7% busbarless

Record Cells (production) 23.15% busbarless



InLine Grid Touch Measurement system



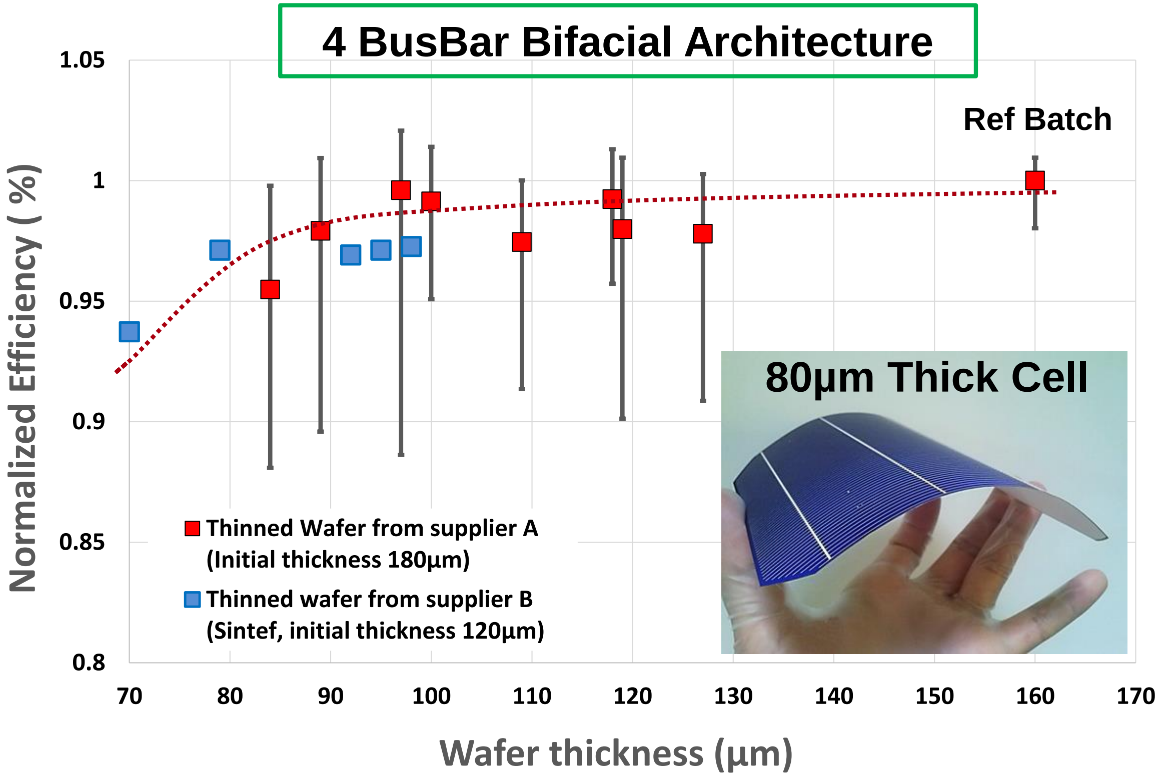
TCO edge exclusion solution

Thin wafers: First Evaluation

- **Two set of wafers:**
  - Standard production 190µm as-cut wafers thinned down by adapted SDR
  - Low volume of specific 120µm As-Cut set of wafers provided by SINTEF (CHEETAH) and thinned down by adapted SDR
- **Standard industrial process applied for all wafers, except manual transfer handling for the 70 and 80µm SINTEF wafer**

Wafer thickness impact

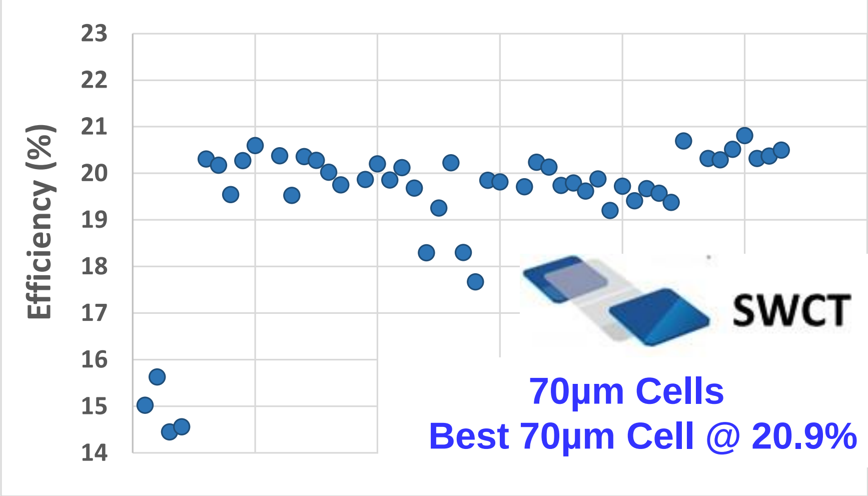
- ✓ Stable efficiency until 90µm
- ✓ Increased batch dispersion
- ✓ Record cells for 95-100µm
- ✓ Functionnal cells down to 70µm
- ✓ (best 70µm cell @ 18.9%)



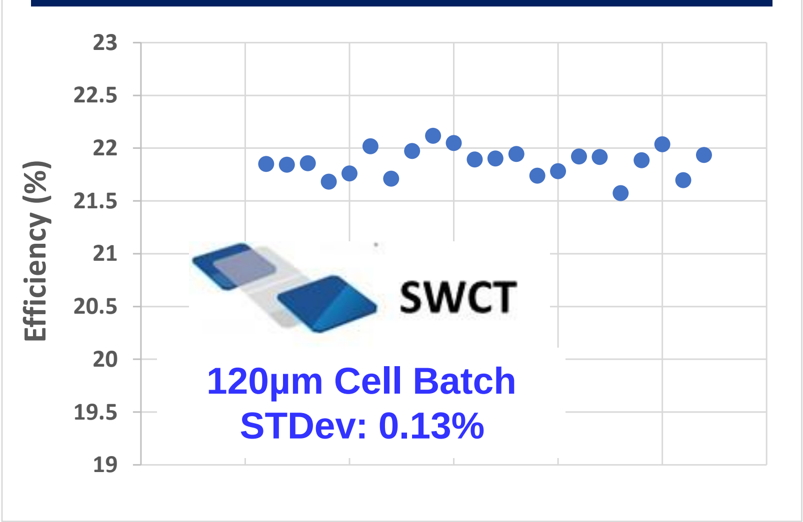
BusBarLess Thin cell Results

- New batches of thin wafer processed with line adjustments (picker speed, carriers, semi manual automation for thinner wafers). Switch to BBLess configuration

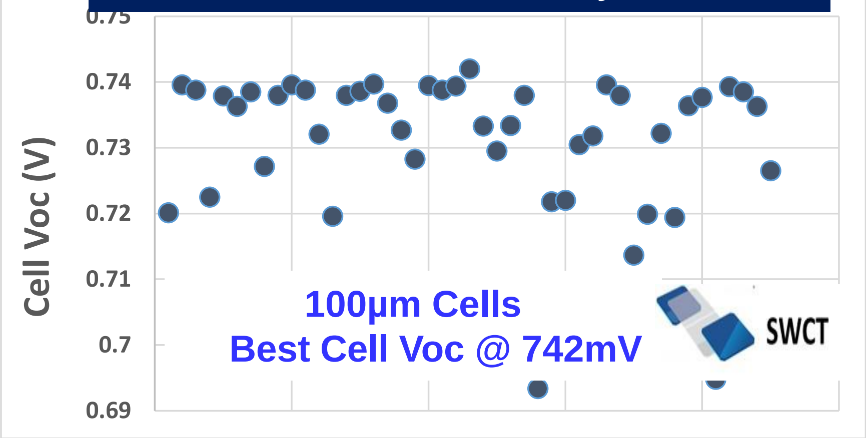
Improved Line reliability



Improved Intra-Batch uniformity



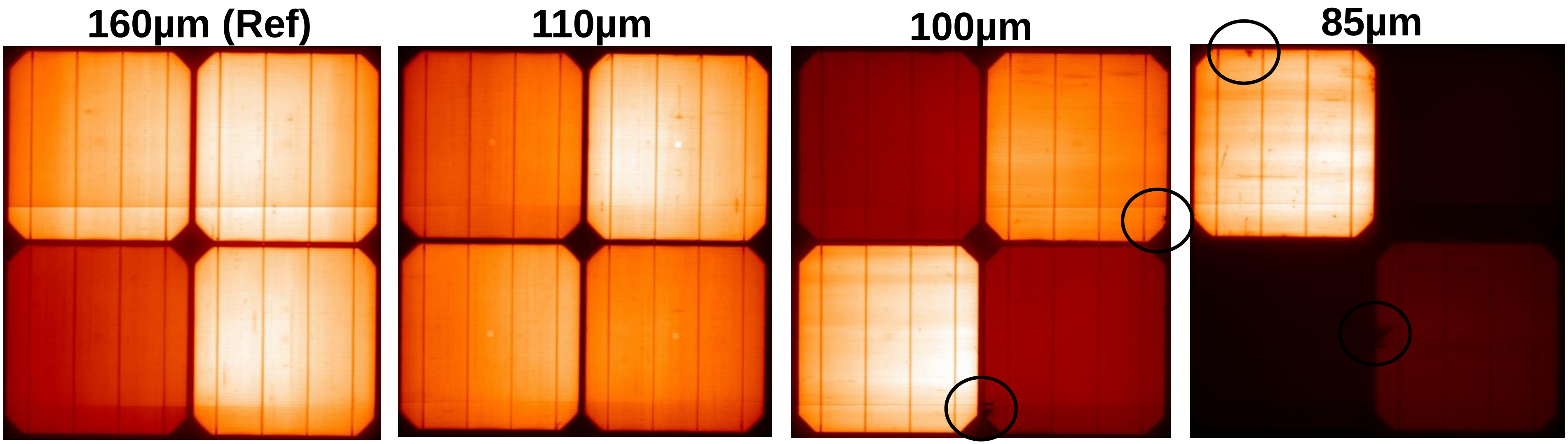
Lower defectivity



- ✓ Improved overall line performances
  - Reliability → high volume of very thin wafer (70µm) now possible to produce
  - Improved intra-batch uniformity
  - Better control of line overall induced defectivity (high cell Voc demonstrated)
- ✓ Promising preliminary results, higher efficiencies targeted in the following trials

Module Results: First Evaluation

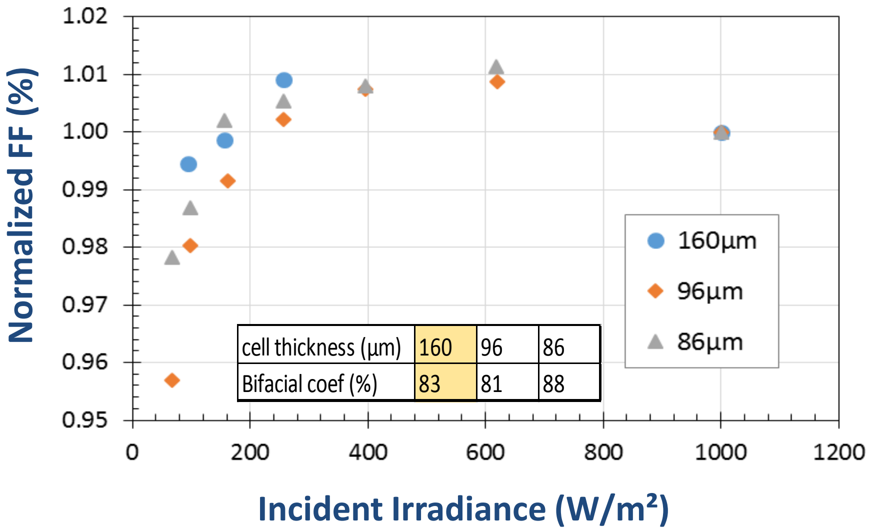
- 2x2 modules (white backsheet) realized with different wafer thicknesses: Ok until 100µm, small cracks start to appear < 100µm
- First trials on production stringer: OK without any adaptation for 110µm wafers. No tests yet on thinner wafers. 60 cell modules planned in the coming months

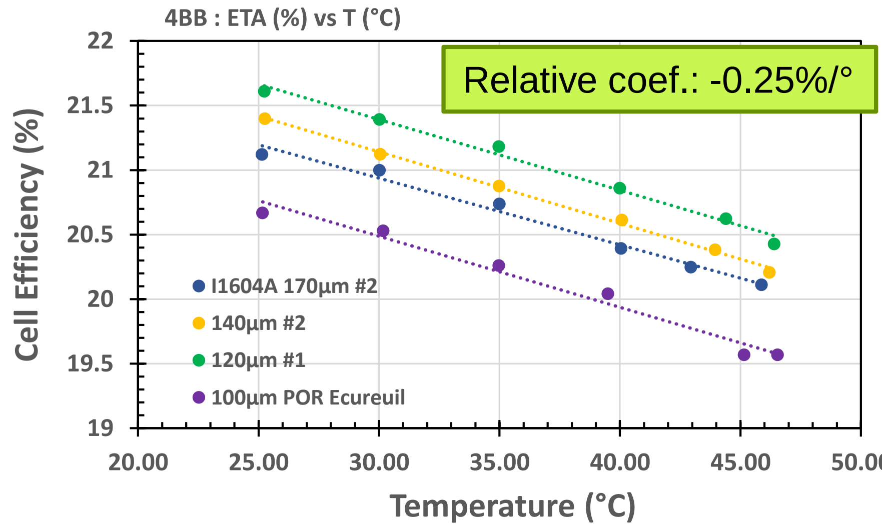


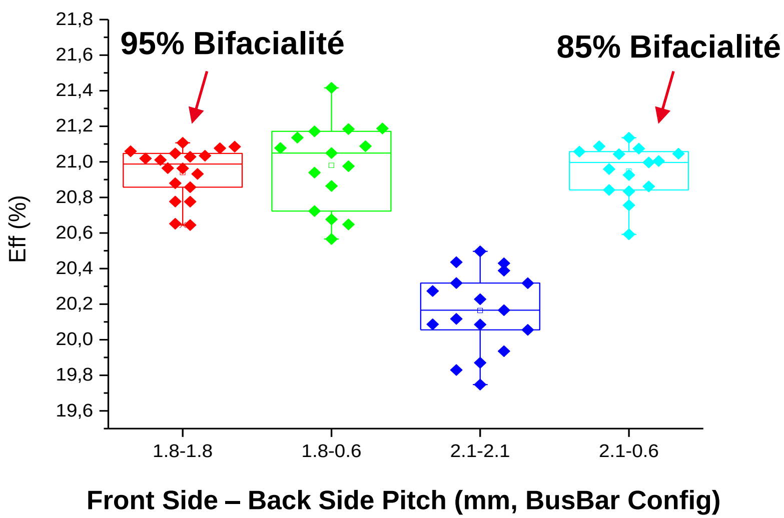
Thickness (µm)	Pmax (W)	Cell Efficiency (%)
160	18.19	19.03
110	18.42	19.27
100	18.38	19.23
85	16.8	17.58

- ✓ Stable module performances down to 100µm
- ✓ Functional modules demonstrated down to 85µm

Cell Results: Characterization







- **Excellent output complementary characteristics → increased productivity of HET systems**
- **No impact of wafer thickness reduction**

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  - Wet processing
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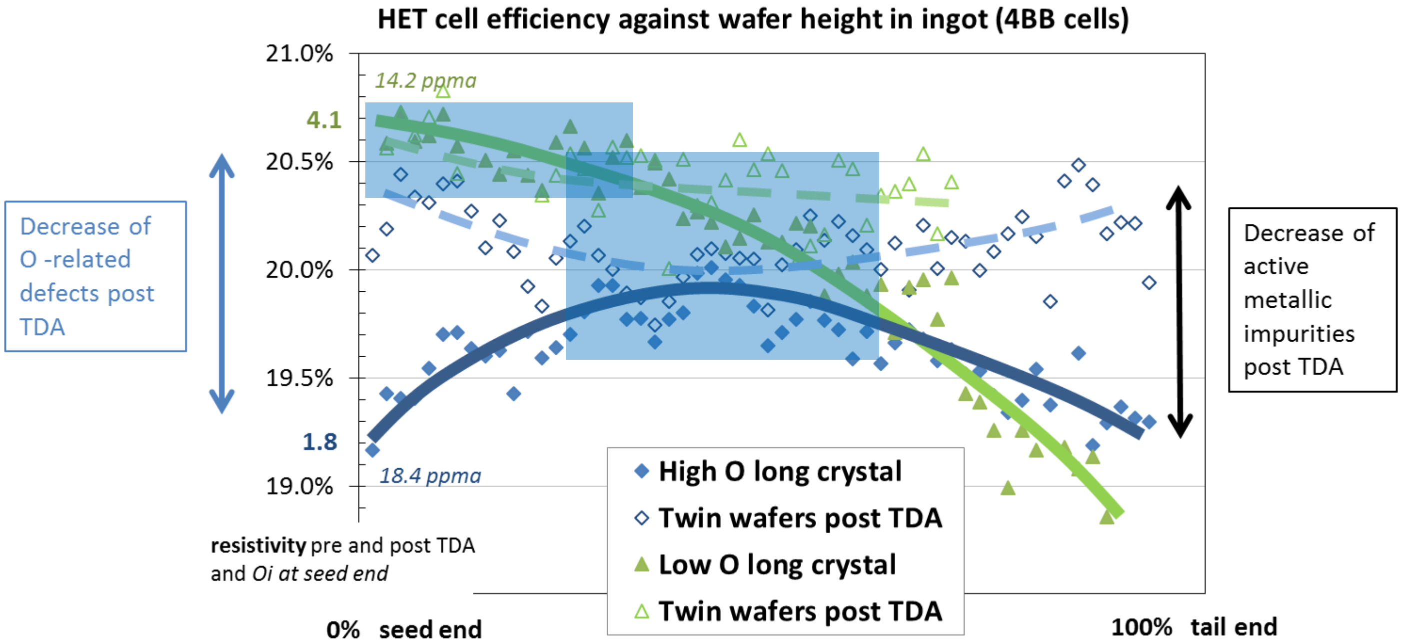
  - TCO

> 300Wp modules

Summary & perspectives

Substrates and TDA

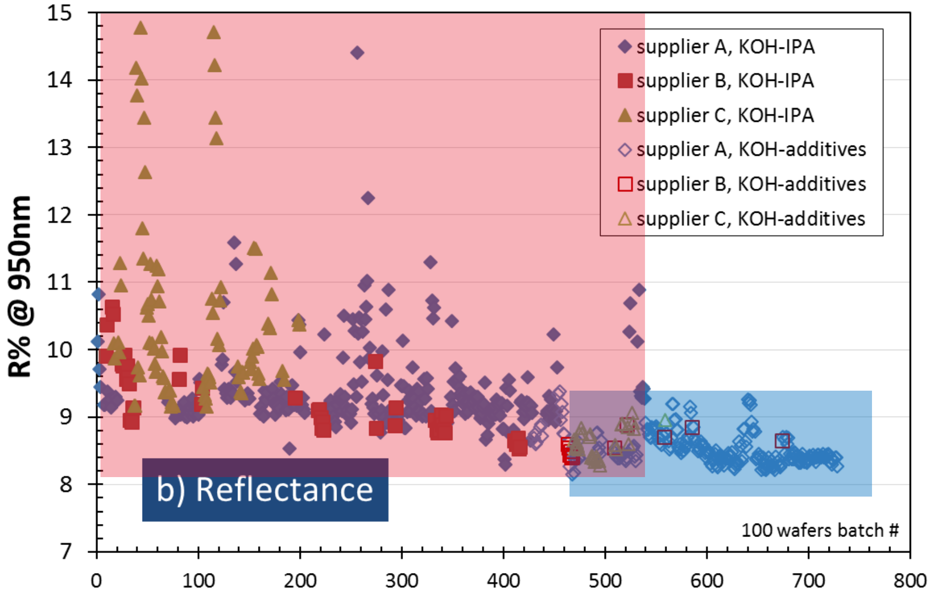
➢ High quality substrate mandatory for HJ: is usual LT spec >= 1msec enough ?



- **Strong benefit of TDA on seed part depending on Oxygen level: well predictable thanks to ρ data**
- **Benefit on tail part depends on crystal length and quality**

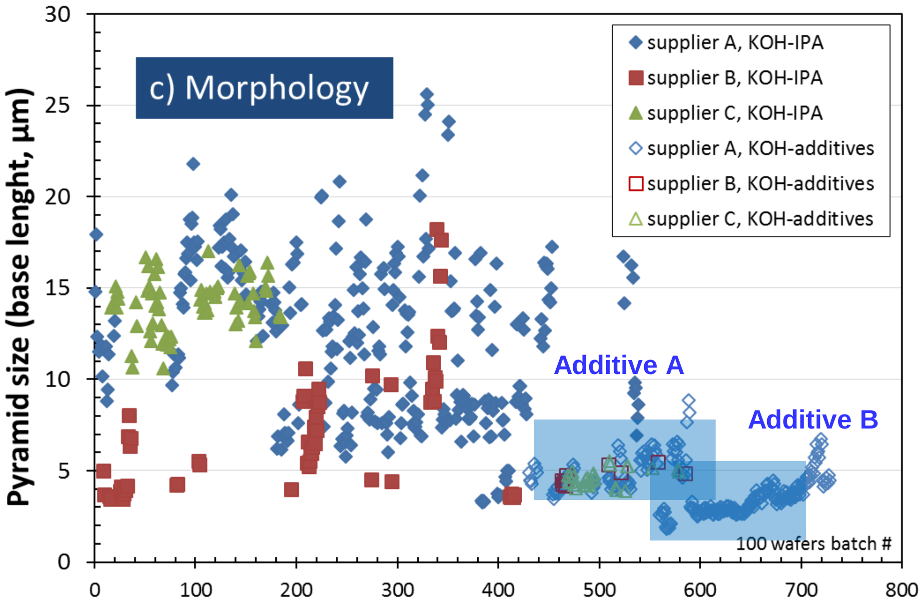
Wet Texturation

IPA -free textu: commercial additives in LabFab since mid-2014



Hard job on supplier A (diamond wire cut) and C (slurry cut) ; OK on B

Similar record reflectance on any wafer type



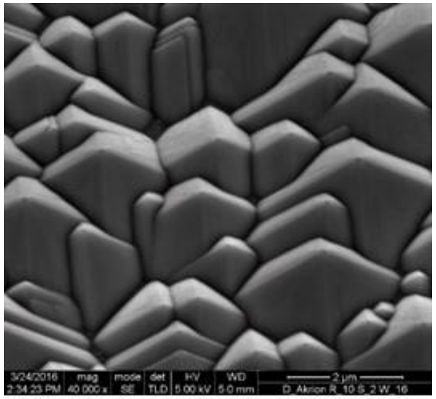
Intentional setup of pyramid size almost impossible with strong dependence on as-cut surface quality

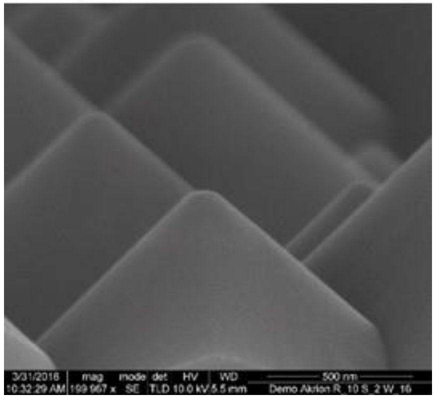
Morphology adjustable with additives type and concentration

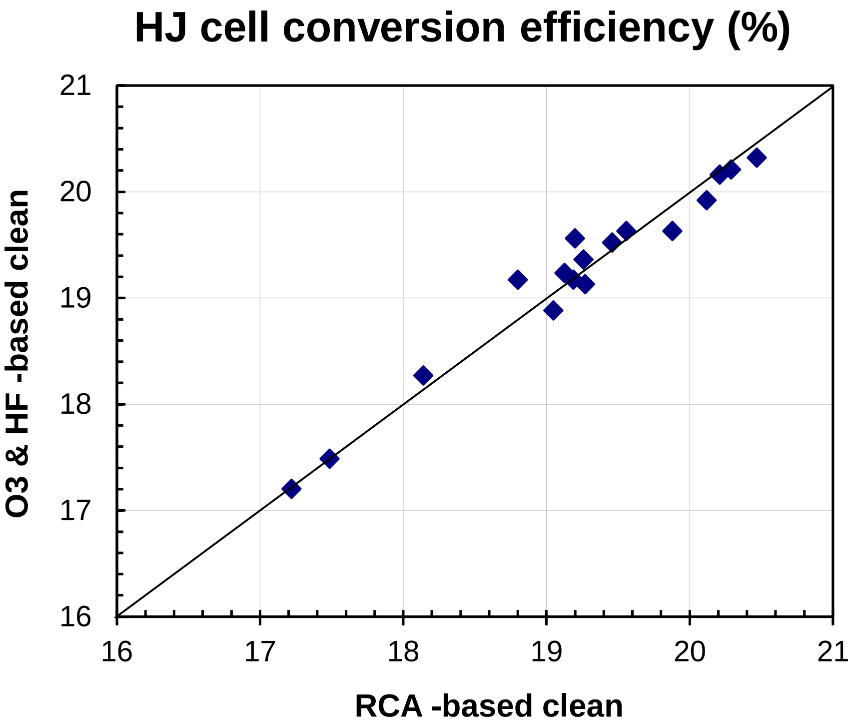
- Better process control and reproducibility. Lower dependence to as-cut surface (i.e. to wafer supplier): single recipe applied whatever the wafer type
- Si etch controlled by KOH dosing ; morphology controlled by additives
- No significant increase of cell efficiency, but **breakthrough** to facilitate R&D and production activities

Ozone Based Cleaning

- **Ozone based cleaning sequence instead of traditional RCA clean**
  - Same clean efficiency, no losses at cell level
  - Top rounding of pyramids at the wafer surface → slight impact on final Reff, but very limited impact on final cell currents
  - Huge gain in terms of chemicals and facilities



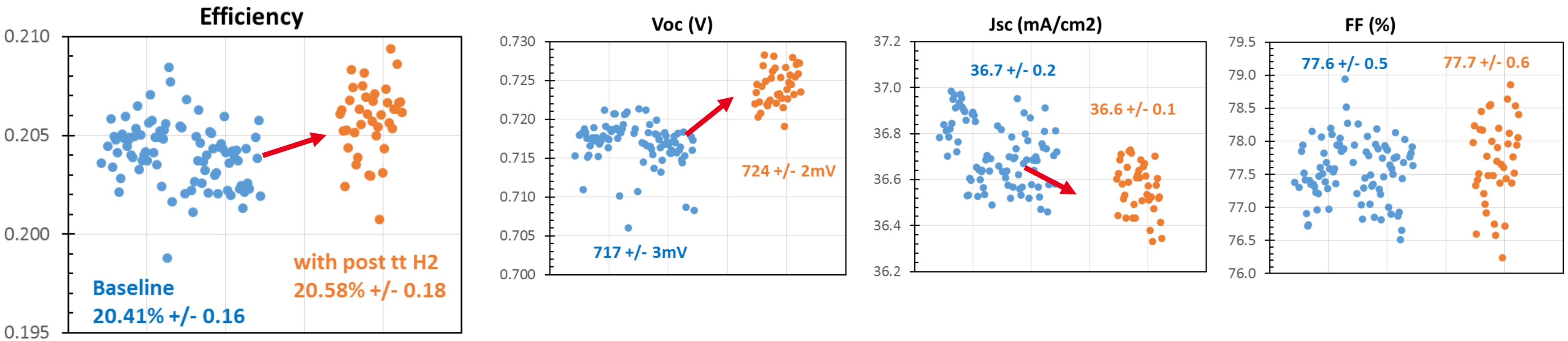




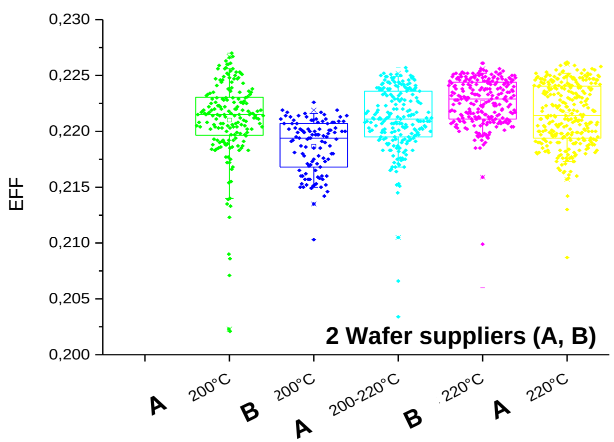
a-Si:H PECVD: H_2

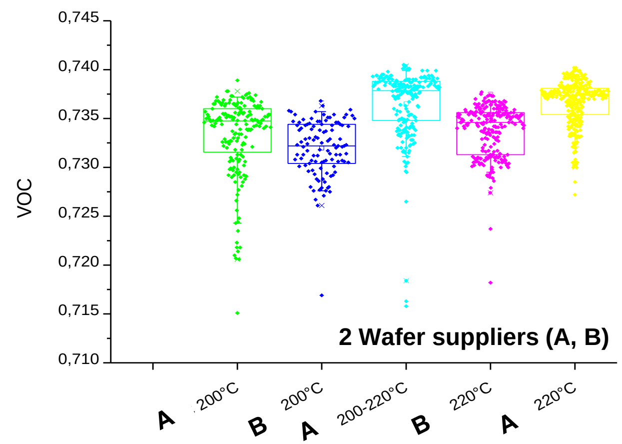
- LABFAB pilot Line particularly well adapted to PECVD splits with batch current organisation

LabFab: H_2 plasma treatment post deposition



Temperatures (deposition + chamber) critical for performances and uniformity





a-Si:H PECVD: heating

- **Cell uniformity intra run is strongly related to heating parameters (pre, during, post)**

Baseline: optimized heating steps

Voc	1	2	3	4	5	6	7	8
A	0.719	0.724	0.723	0.724	0.725	0.724	0.724	0.713
B	0.724	0.726	0.726	0.724	0.724	0.724	0.726	[illegible]
C	0.725	0.725	0.726	0.724	0.724	0.724	0.725	[illegible]
D	0.725	0.725	0.724	0.724	0.724	0.723	0.726	[illegible]
E	0.726	0.726	0.725	0.724	0.723	0.724	0.725	0.724
F	"	0.725	0.725	0.723	0.723	0.723	0.723	0.725
G	0.723	0.726	0.726	0.725	0.725	0.724	0.727	0.722

average 724.2 sigma 2.0

Tray cdt @ Lower T° → **on i-n stack**

Voc	1	2	3	4	5	6	7	8
A			0.723	0.721	0.720	0.721	0.718	0.713
B	0.721		0.720	0.719	0.717	0.721	0.720	0.721
C	0.723	0.721	0.720	0.718	0.717	0.721	0.719	0.722
D	0.723	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.720	0.723
E	0.722	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.717	0.722
F		0.721	0.718	0.713	0.713	0.717	0.718	
G	0.714	0.722	0.721	0.720	0.718	0.721	0.720	0.714

average 719.1 sigma 2.65

Tray cdt @ Higher T° → **on i-p stack**

Voc	1	2	3	4	5	6	7	8
A	0.698	0.710	0.713	0.706	0.707	0.712	0.711	0.701
B	0.706	0.714	0.715	0.704	0.706	0.717	0.717	0.710
C	0.706	0.713	[illegible]	[illegible]	[illegible]	[illegible]	0.715	0.712
D	0.706	0.710	[illegible]	[illegible]	[illegible]	[illegible]	0.715	0.712
E	0.705	0.708	0.708	0.700	0.706	0.717	0.717	0.713
F	0.705	0.707	0.710	0.704	0.709	0.718	0.718	0.713
G	0.700	0.709	0.712	0.706	0.709	0.718	0.716	0.708

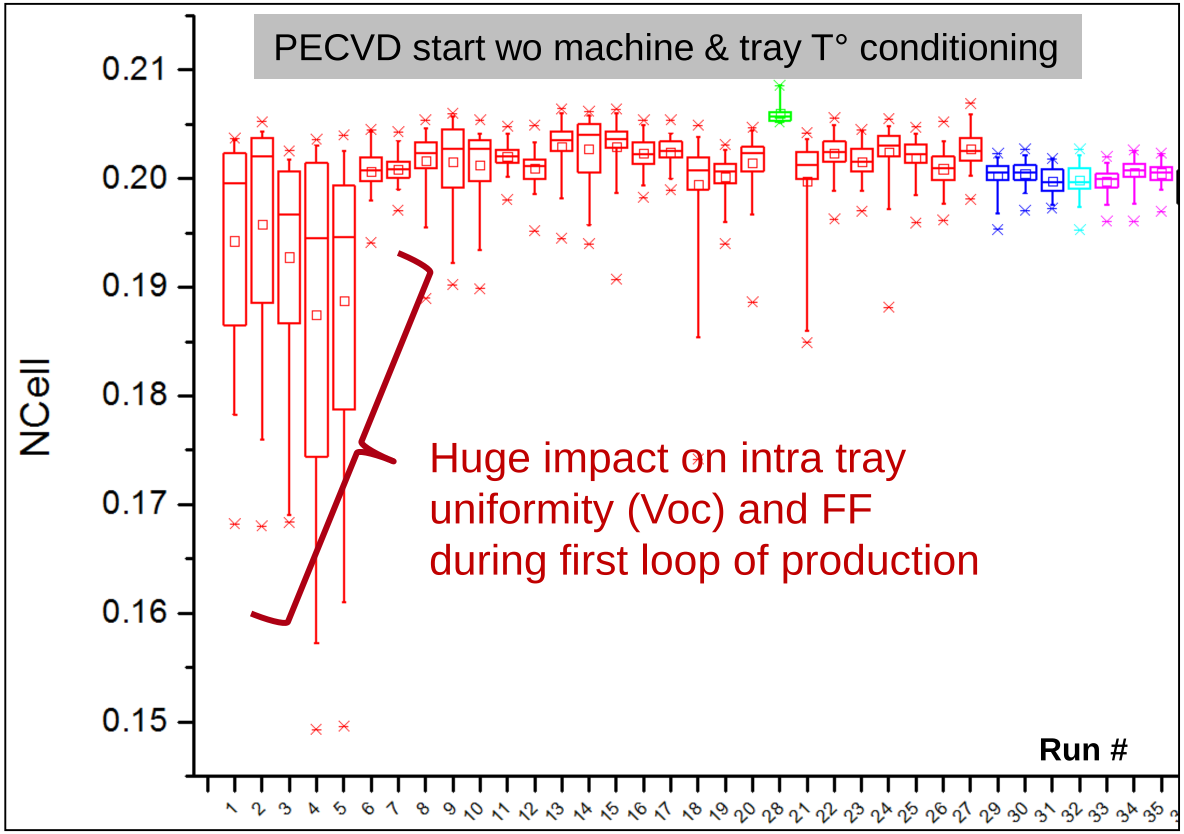
average 709.5 sigma 5.50

Voc	1	2	3	4	5	6	7	8
A	0.701	0.715	0.713	0.722	0.724	0.725	0.722	0.706
B	"	0.720	0.725	0.725	0.725	0.725	0.726	0.722
C	0.715	0.724	0.726	0.726	0.726	0.726	0.725	0.722
D	0.720	0.724	0.727	0.727	0.725	0.726	0.727	0.724
E	0.716	0.725	0.725	0.725	0.725	0.725	0.725	0.723
F	0.716	0.723	0.725	0.722	0.723	0.725	0.725	0.721
G	0.703	0.720	0.723	0.724	0.725	0.724	[illegible]	"

average 722.2 sigma 5.6

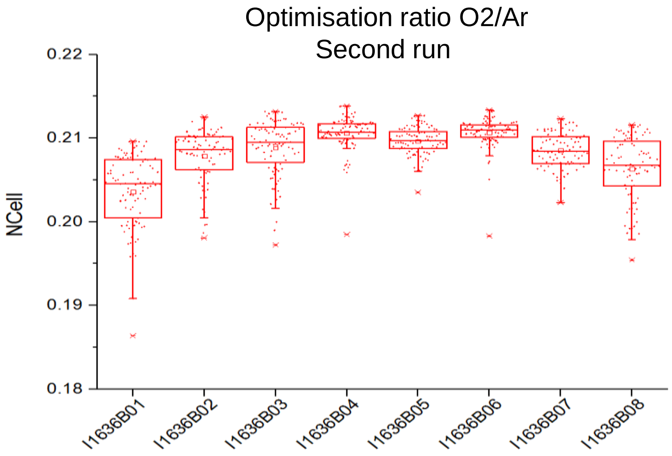
a-Si:H PECVD: heating

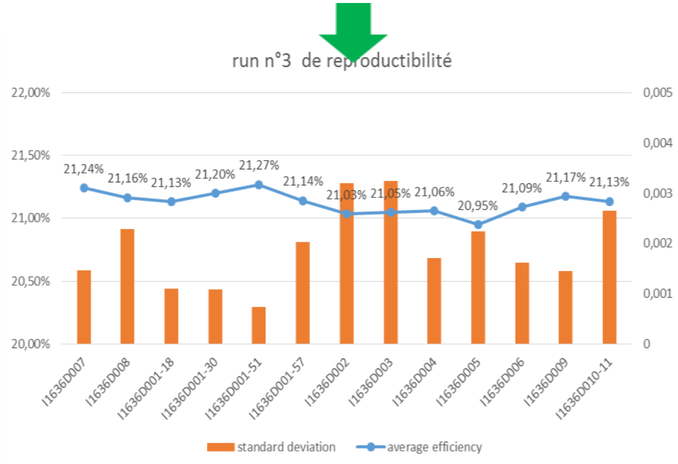
- Correct heating management (cells, trays, process modules) is key to achieve good cell performance distribution in production



TCO: Start-Up of HELIA PVD

- **Installation of new HELIA PVD (Meyer-Burger) deposition tool**
  - 3 process modules, rotative targets for ITO deposition, 3rd chamber with planar target for alternative TCO evaluation
  - Still in start-up phase: material optimization + reproducibility tests

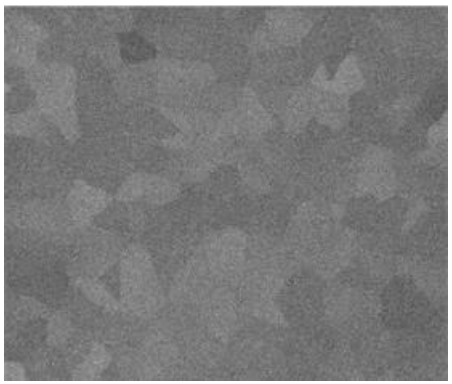


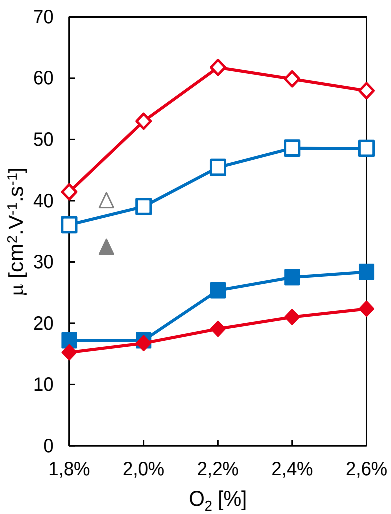


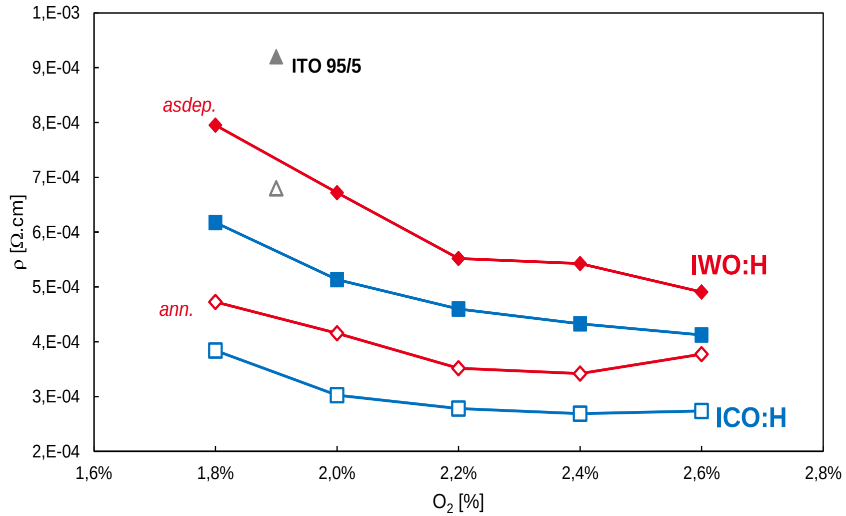
Alternative TCO: High Efficiency

Evaluation of alternative TCO: example of ICO and IWO.

- IWO:H appears as one of the most promising TCO for efficiency increase (better compromsie between electrical and optical properties)
- AZO development considered also (not shown) for low cost purpose





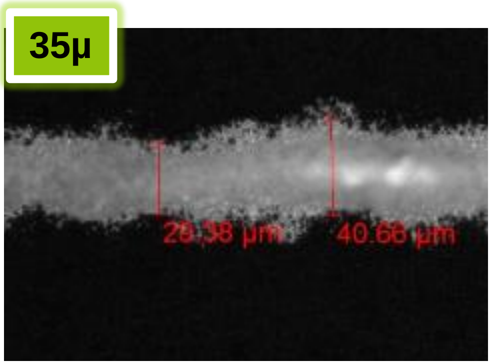


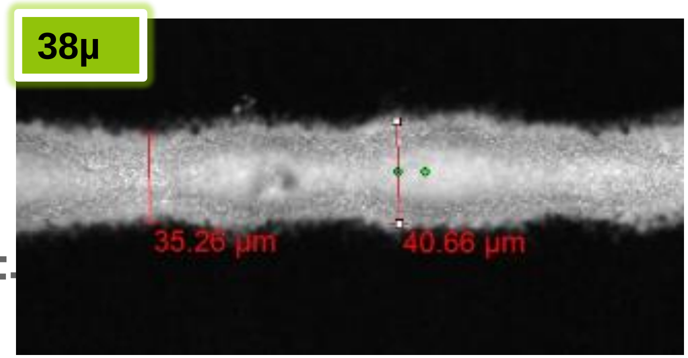
TCO	ρ [Ω.cm]	N [cm^{-3}]	μ [cm².V^{-1}.s^{-1}]	T [mA.cm^{-2}]
ITO 95/5	$6,8 .10^{-4}$	$2,3 .10^{20}$	40,1	41,71
ITO 99/1	$1,9 .10^{-3}$	$1,4 .10^{20}$	23,0	41,87
ITO:H 99/1	$4,3 .10^{-4}$	$2,6 .10^{20}$	55,9	42,49
ICO:H	$2,7 .10^{-4}$	$4,8 .10^{20}$	48,6	42,16
IWO:H	$3,5 .10^{-4}$	$2,9 .10^{20}$	61,8	42,41

Metallization Optimization

- New pastes and screen coninuous evaluation
- Line width / height optimization for both efficiency increase and costs reduction
- Very thin lines compatible with BBLess technology, wider lines needed for BBtechnology

SmartWire technology

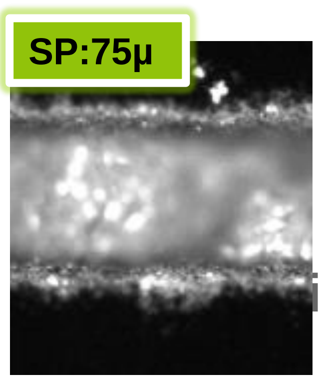


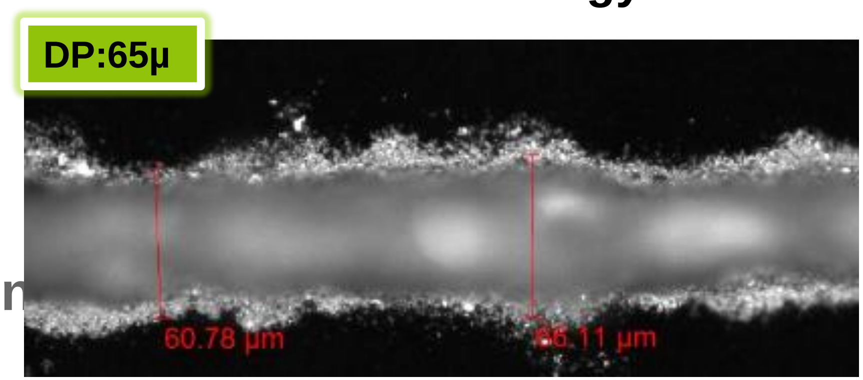


Finger width **<40µm**

Rcontact starts to be limiting

Busbar technology





Finger width **65µm**

R1cm <= 0,4Ω

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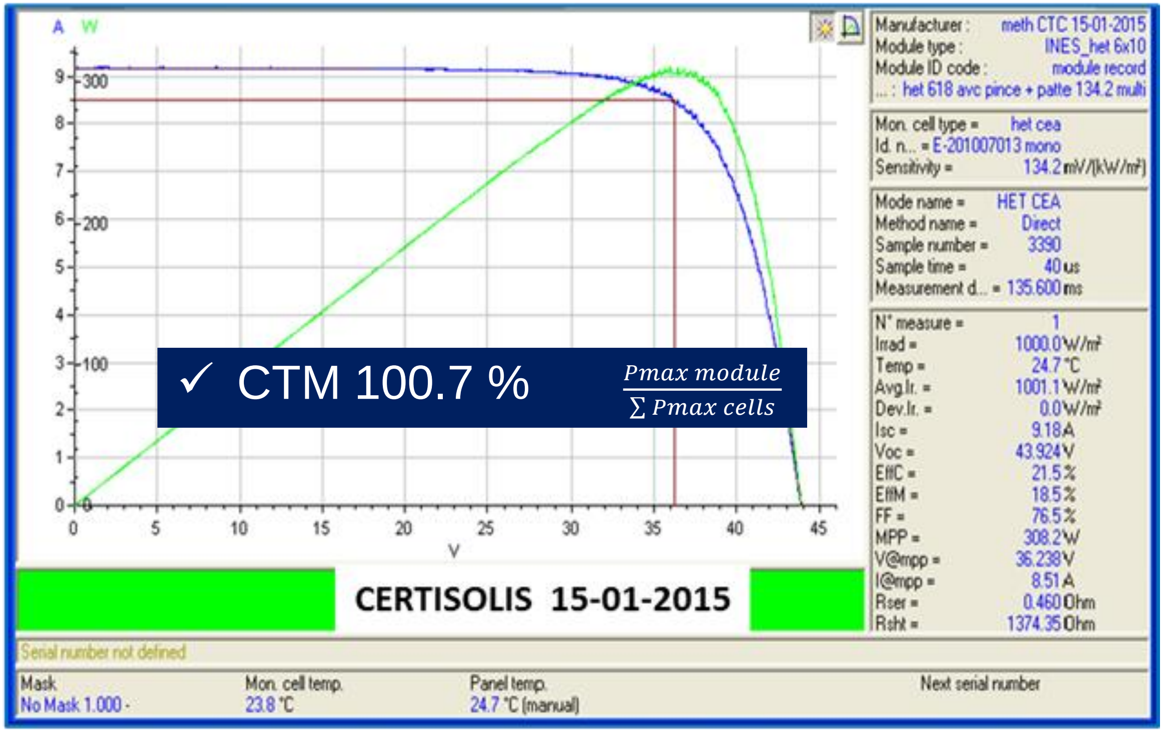
- **> 300Wp modules**
- **Summary & perspectives**

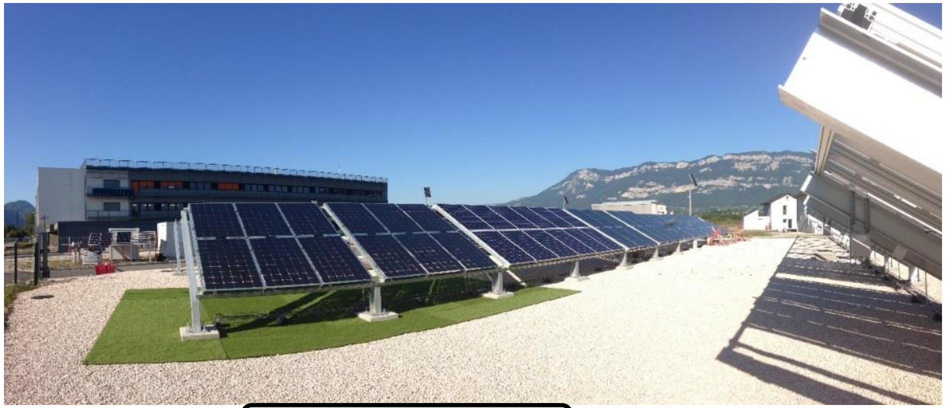
Modules: 308.2 Wp, INES record

- Glass – back sheet module on bifacial cells
- Interconnection performed on tabber-stringer at INES
- HENKEL conductive glue
- Textured interconnect ribbon
- 3.2mm antireflective glass
- ARKEMA Apolhya Exp-A (low cut-off) encapsulant



Monitoring and Field Data

Running



Bifaciality

- **Next generation of HTJ cells is developed, tested and benchmarked with best technologies**
- **Optimization of bifaciality (albedo impact; E/W application)**
- **Busbarless modules optimization on full and 1/2 cells: 360W and >400W for 60 and 72 cells**
- **HTJ-systems monitoring during long-term production, benchmarked to other cells technologies:**

  ➔ HTJ production yield and bankability

Summary

- **LabFab production baseline pushed to 21% for BusBar Cells, 22% for SmartWire Cells** (240cm^2, rear emitter, 4BB bifacial cells, > 1000 cells/h capability)
  - Record batches up to 21,5% for Busbar Cells, 22,7% for SmartWire Cells
  - Record cells up to 22,2% for Busbar Cells, 23,15 for SmartWire Cells

- **Current learnings and improvement patchs**
  - Better management and understanding of incoming wafer quality: TDA useful only on specific part of wafer supply
  - Improved and easier wet processes with IPA-free texturization
  - Optimization of a-Si:H stacks with H_2 and T° topics: +0.3 to +0.4%, tighter cell distribution
  - Evidence of TCO being key for high performance.

- **308Wp module already demonstrated, new modules planned with recent cell progresses : 320W targeted short term**

- **Phase 2** of CEA-INES HJ LabFab **on going** with industrial start-up of Meyer Burger productions tools : HELIA PVD, Automated IV GridTouch System, HELIA PECVD system about to be recieved

✓ Thanks to all colleagues of the **HJ Solar Cell and Module Lab. at CEA-INES**

✓ Special acknowledgements to the **DemoLine team at Meyer Burger Germany**

MEYER BURGER

Thank you for your attention

French Alternative Energies and Atomic Energy Commission

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