SILICON HETEROJUNCTION RESEARCH ON PILOT LINE LEVEL
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

**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
- $\tau_{\text{eff.}}$: interface defects, bulk c-Si
- Lateral carrier transport: a-Si:H, TCO, metallization
Heterojunction state of the art

Increased Market share

HJ 3%  
Source: ITRPV 2015

<table>
<thead>
<tr>
<th>Company</th>
<th>Efficiency (%)</th>
<th>Area (cm²)</th>
<th>Country</th>
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High Efficiencies already demonstrated!  
Improvement paths (efficiency, cost) still possible!

Company Efficiency (%)  
Best cell  
Area (cm²)  
Country

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

- 1500m² with 1200 m² 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

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

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

Heterojunction pilot line typical production: efficiency

- Baseline improved up to 22% busbarless
- Record Batches (>200 Cells) 22.7% busbarless
- Record Cells (production) 23.15% busbarless

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)

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%)

Diagram:
- 4 BusBar Bifacial Architecture
- Thinned Wafer from supplier A (Initial thickness 180µm)
- Thinned wafer from supplier B (Sintef, initial thickness 120µm)

Graph:
- Normalized Efficiency (%) vs. Wafer thickness (µm)
- Ref Batch
- 80µm Thick Cell
New batches of thin wafer processed with line adjustments (picker speed, carriers, semi manual automation for thinner wafers). Switch to BB Less 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
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

<table>
<thead>
<tr>
<th>Thickness (µm)</th>
<th>Pmax (W)</th>
<th>Cell Efficiency (%)</th>
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<td>160</td>
<td>18.19</td>
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<td>110</td>
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<td>100</td>
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<tr>
<td>85</td>
<td>16.8</td>
<td>17.58</td>
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</table>

- 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

- 95% Bifacialité
- 85% Bifacialité
Heterojunction solar cells (HJ)

Cell architecture and $\eta$ 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
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 $\rho$ 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 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
- LABFAB pilot Line particularly well adapted to PECVD splits with batch current organisation

- LabFab: H₂ plasma treatment post deposition

- Temperatures (deposition + chamber) critical for performances and uniformity
### Cell uniformity intra run is strongly related to heating parameters (pre, during, post)

<table>
<thead>
<tr>
<th>Voc</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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**Average:** 724.2, **Sigma:** 2.0

### Baseline: optimized heating steps

#### Tray cdt @ Lower T°

#### Tray cdt @ Higher T°

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**Average:** 722.2, **Sigma:** 5.6

### on i-n stack

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**Average:** 719.1, **Sigma:** 2.65

### on i-p stack

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**Average:** 709.5, **Sigma:** 5.50
Correct heating management (cells, trays, process modules) is key to achieve good cell performance distribution in production.

PECVD start wo machine & tray T° conditioning

Huge impact on intra tray uniformity (Voc) and FF during first loop of 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
Evaluation of alternative TCO: example of ICO and IWO.
- IWO:H appears as one of the most promising TCO for efficiency increase (better compromise between electrical and optical properties)
- AZO development considered also (not shown) for low cost purpose

### TCO

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<th>TCO</th>
<th>$\rho$ [(\Omega\cdot\text{cm})]</th>
<th>$N$ [(\text{cm}^{-3})]</th>
<th>$\mu$ [(\text{cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1})]</th>
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<td>42,41</td>
</tr>
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</table>
New pastes and screen continuous evaluation

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

**Metallization Optimization**

**SmartWire technology**

- Finger width < 40µm
- Rcontact starts to be limiting

**Busbar technology**

- Finger width 65µm
- R1cm ≤ 0.4Ω
Outline

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   Cell architecture and $\eta$ state of the art
   Pilot Line at CEA-INES (LabFab)

HJ cells integration: some key points and recent LabFab learnings
   Substrates
   Wet processing
   PECVD
   TCO

- > 300Wp modules

- Summary & perspectives
• 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

Modules: 308.2 Wp, INES record

Pmpp : 308.2 W
Isc : 9.18 A
Voc : 43.9V
FF : 76.2%
CTM : 100.7%

✓ CTM 100.7 %

CERTISOLIS 15-01-2015

Certified measurement
Monitoring and Field Data

- **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** (240cm², 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 patches**
  - 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 H₂ 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

Thank you for your attention