Reaching Higher Standards with Cell and Module Innovation

EU_PM Dept. 27 Mar ’18,
Andrea Viaro, Head of Technical Service Europe
Agenda

1. Jinko Solar Introduction

2. Technology Innovations from Jinko Solar
   a. Mono PERC
   b. Half-cell
   c. Next-gen. Poly
   d. Multi-Wire
   e. Bifacial

3. Summary
Key Facts of JinkoSolar

- 8 Global Factories
- 31 Subsidiaries
- 80+ Countries
- 15000 Employees

9.5 GW Capacity
26 GW Delivered (2017)
JinkoSolar R&D

State Key Laboratory

• Overall 328 full-time technical staff at Jinko Solar
• In-house R&D center for solar cell research: over 7,000 m² with 7 separate laboratory rooms and over 100 research equipment
• Close cooperation with global research institutes
• Filed 464 patents, authorized 232 (Till 2016)
Product Portfolio
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3. Summary
Mono PERC
Benefits of JinkoSolar Mono-PERC

- Higher $I_{sc}$ & $V_{oc}$
- Better IR response

Power

(Compared to Jinko Mono Standard)

- Power Range: 60 cell 295~315
  72cell 350W~370
- Module Eff. boost >1%
  Higher power density
  (no space constrains)
- Lower System Costs:
  -7% transp.
  -6% install.
  -4% BOS
**Mono-PERC** (Passivated Emitter Rear Contact)

**PERC cell Features**

- Enhanced internal backside reflectance to capture more long-wavelength light
- Decreased rear current carrier losses by reducing the rear side recombination
- Higher Quantum Efficiency than conventional cells

**Main Advantages:**

- The most cost-effective C-Si high-eff. leading technology
- Available at multi-gigawatt scale industrial production
- Mature technology and long track record
- Long-term established QA protocols during whole production
- High potential for further cell efficiency increase
Light Induced Degradation (LID) Solution

- Illumination of mono cz. P-type solar cells → Eff. reduction up to 5% abs
- Main cause: recombination of active Boron–Oxygen complexes (B-O), especially in highly Boron-doped & Oxygen-rich silicon

**Light-induced Hydrogen Passivation** (LiHP) can dramatically reduce LID, i.e. regeneration process
- Key parameters to deactivate Boron–Oxygen complex (Passivation): Temperature, carrier injection, Hydrogen diffusion
Regeneration Effect

Testing condition
Irr 900-1000 W/m²
Cell Temp. 50-60°C
Light Soaking 5 hours
Half-cell
Half Cell: Technology

Half-cell vs. Full-cell

Electrical current (i) flowing on busbar is halved

Resistive losses in a HC module is $\frac{1}{4}$ of a full-sized cell

$P_{\text{loss}} = I^2 \times R_s$
Half-Cell Module Higher Light Utilization

Water drop-like effect

- Larger overall “white” area
- Increased inter-cell reflecting area
- Increased internal reflections
- Higher light absorption
Advantages from HC Modules – Temperature Coefficient

Significant Temp. Coeff. improvement

Same nameplate power
280 Wp Mono-Si Module
Op. Temp.: 65 °C

Conventional → -0.4% → 235Wp
Half-cell → -0.37% → 240Wp

Difference > 2% rel

Superior Power Generation
at Higher Temperatures
Half-cell Standard solar module

Better Mismatch & Shading Mitigation

Jinko Solar

Half-cell

Standard solar module

~50% power output

0 power output

Lower shading losses of HC compared to normal module, in certain shading conditions
### Lower Hot-Spot Level, Despite Higher Wp

<table>
<thead>
<tr>
<th>Cell</th>
<th>Shading condition</th>
<th>Maxim temperature from test</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mc-Si</td>
<td>½ cell</td>
<td>115.4</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>½ half cell</td>
<td>96.0</td>
<td>19.4</td>
</tr>
<tr>
<td>Mono PERC</td>
<td>½ cell</td>
<td>122.4</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>½ half cell</td>
<td>98.0</td>
<td>24.4</td>
</tr>
</tbody>
</table>

- Current, thus Power of half-cell is halved
- Lower Power dissipated on shaded cell
- Around 20°C lower temp. In hot spot test
- Less risk for system operation

![Thermography images: Half-cell and Full-cell](image-url)
Next-gen. Poly
Green/Efficient Wafer Production Tech.

- Diamond cut leads to less waste material
- Dark-grey colour appearance → Improved light absorption
- Uniform cutting → More even and precise thickness of wafer
- Less damages on wafer surface (cracks, etc.) → Higher reliability
- Faster process, which consumes less energy and therefore is a ‘greener’ cell
Diamond-Wire Cutting + Metal-Catalyst Texturing (MCT)

Conventional Technology

SEM Photo

MCT Technology

Lower reflectance $\Rightarrow$ boosted light utilization

Applied to diamond-wire sawing wafers

Module power output increased by 2W~3W
MCT Theory:
Silicon is textured by Ag as catalyst, and optimized coating process

After MCT
Multi-wire
MBB: Module Busbar Evolution

Busbar Number trend

2010  →  2013  →  2016  →  2018  →  MBB
Lower current path distance

Path Distance: 19.25mm

Path Distance: 6.25mm

Power loss VS. Busbar Number

Compared to 4BB, power 12BB is around 3W higher
MBB: More internal reflection from round ribbon

3rd party data, power of MBB module is around 1% higher
Bifacial
With optimized PV system design, Bifacial module can generate up to 20~30% more energy compared to conventional monofacial module.

- **Bifacial module**: double-sided generation
- **Standard module**: front-sided generation
BiFacial: Tech. Concept

Conventional

- ARC
- Grid
- n^+
- P-type mono wafer
- Al contact
- Glass
- EVA
- cell
- BACKSHEET

Bifacial

- ARC
- Grid
- n^+/p^+
- P-type/N-type mono wafer
- ARC
- cell
- EVA
- cell

Front Side
Back Side
Front Side
Back Side
Benefits of JinkoSolar Bifacial

Save Module and BOS Cost

Assuming that two solar farms generate same amount of energy (1,414 MWh per yr), Jinko solar Bifacial farm can save BOS costs including land area, compared to single-face P-type

260W P type single-face module
2,743ha

300W Jinko Solar Bifacial
2,407ha
(Assuming max rear-sided generation 27.3%)
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3. Summary
### Summary

- Next PV module generation will be a combination of different technologies at both Cell and Module level

- Mono PERC is at present the most cost-effective C-Si high-eff. leading technology that is best used at multi-gigawatt scale industrial production

- HC modules currently present the most advantageous cost-benefits balance
  - At least 1 higher power bin compared to the standard technology and improved Temp. Coeff.
  - Even 2 classes higher if combined with other add-on features, such as White EVA+LRF

- Multi Bus Bar (MBB) is the next evolution of traditional busbar-based technology
  - Module power is boosted by about 3W and reliability is also improved

- Bifacial module offer the highest potential for reducing LCOE
  - With optimized PV system design, 20~30% more energy can be generated compared to conventional single-face module
More information can be found on our Website

www.jinkosolar.eu
Thank you!
Back Up Slides
Vision:
Optimize the energy portfolio, and take responsibility for enabling a sustainable future

Mission:
Provide a one-stop solution for clean energy and become an industry leader
## Major Milestones

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>JinkoSolar Co., Ltd. established</td>
</tr>
<tr>
<td>2010</td>
<td>Listed on New York Stock Exchange</td>
</tr>
<tr>
<td>2012</td>
<td>World First solar company passing 85-85 PID test</td>
</tr>
<tr>
<td></td>
<td>Ranked No.2 in Photon Lab Test</td>
</tr>
<tr>
<td></td>
<td>Rank No. 4 in the PV Sustainable Growth index by PwC</td>
</tr>
<tr>
<td>2013</td>
<td>Launched module manufacturing facility in South Africa</td>
</tr>
<tr>
<td></td>
<td>Reached &gt; 6 GW shipments</td>
</tr>
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<td>2015</td>
<td>Launched module manufacturing facility in Malaysia</td>
</tr>
<tr>
<td></td>
<td>Signed strategic collaboration agreement with DuPont Photovoltaic Materials</td>
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<tr>
<td>2016</td>
<td>Bankable with over 58 major international bank</td>
</tr>
<tr>
<td>2017</td>
<td>Largest producer of solar modules worldwide with 9.5 GW capacity per year</td>
</tr>
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</table>
Vertically-Integrated Production

- Quality Guarantee along the complete value chain
- Ideal supply chain management with top-class components
- Optimized cost structure with 10 years of experience
Diversified Module Portfolio

* Multiple combinations of different cell tech., module type, add-on solutions
Smaller cell area reduces the potential impact of micro-cracks

Reliability and Micro-Crack Impact Mitigation
Lower JB Operating Temperature

Innovation decentralized junction box for improved heat management and simple connection

Anode 290mm, Cathode 145mm or Customized Length
Higher Energy Output

From Jinko R&D PV system based on apple-to-apple comparison

~4% more energy

Note: Power output is affected by environmental conditions
Half-cell: Production Process

State-of-art Technologies

Laser scribing

Levering

Auto-stringing

I-V Test

EL Test

Visual Insp.
The laser cuts from the back side of cell.

Depth of cut is about 40-50% of the cell’s thickness.

Position of PN junction from the front side of cell is about 0.4-0.5μm.

Smooth area near the front side of cell, rough region affected by laser burning.

Distance between PN junction and laser cut area avoids damages to PN junction.
White EVA increases power thanks to internal light reflection (water-drop effect)

Up to 2~4W power increment (confirmed by internal tests)
### Traditional TPT Solution

<table>
<thead>
<tr>
<th>Glass</th>
<th>Cell</th>
<th>Traditional EVA</th>
<th>PVF</th>
<th>PVF</th>
</tr>
</thead>
</table>

### Improved TPE + White EVA Solution

<table>
<thead>
<tr>
<th>Glass</th>
<th>White EVA</th>
<th>PE</th>
<th>PET</th>
<th>PVF</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Yellowing Index (UV)</th>
<th>UV Block Ability (T%)</th>
<th>WVTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPT + Traditional EVA</td>
<td>6</td>
<td>0.012%</td>
<td>2.6</td>
</tr>
<tr>
<td>TPE + White EVA</td>
<td>0.88</td>
<td>0.010%</td>
<td>2.01</td>
</tr>
</tbody>
</table>

**Test purpose**

- 432 KW.h/m² UV irradiance = 30 times higher than natural conditions to simulate 25y aging in harsh environment
- Evaluate backsheet ability to protect the PET layer from UV light
- Protection ability against moisture ingress into the laminate

**Results**

- More than 10 times lower UV index → lower material aging
- PET core exposed to only 0.04kW.h/m² UV in 25y
- 20% better WVTR
Light-Redirecting Film (LRF)

**Traditional Ribbon**

- Glass
- Cell
- EVA
- Back-sheet

**Ribbon + LRF**

- Glass
- Cell
- EVA
- Back-sheet

**Ribbon cross-section**

- Light-Redirecting Film (LRF)

**LRF cross-section**

- Boosted light utilization at modul level thanks to higher internal reflections
- Module power output increased by more than 3W
- Thicker EVA alleviates internal stress
Multi-Wire: Reduced Shading Effect

Reduced shading through wire cell interconnection for more output
MBB: Less Sensitive to Micro-Crack

Short distance between Busbar leads less micro-crack
Mono PERC: Key Module Features & Benefits

The most cost-effective C-Si high-eff. leading technology

- Highest Efficiency, boosted yield

Available at multi-gigawatt scale industrial production

- Mature production process

Mature technology and long track record

- Bankable globally

Well understood LID stabilization solution

- High long-term reliability

Long-term established QA protocols and continuous R&D studies

- Potential for further efficiency and reliability increase
**Half-cell: Key Module Features & Benefits**

- **Lower resistive losses**
  - Higher Wp, higher yield, lower LCOE, higher IRR

- **Better Temp.Coeff.**
  - Higher performance in hot environment conditions

- **Split-cells in parallel**
  - Lower mismatch losses due to soiling, shading, cracks etc.

- **Lower Imp**
  - Hot-spot effect mitigation

- **Split Junction-Box**
  - Improved heat dissipation design
MBB: Key Module Features & Benefits

- Lower Losses
  - Higher Wp

- More Internal Reflection from Round Ribbon
  - Power gain

- Less Sensitive to Micro-crack
  - Higher reliability

- Lower cell shading effect
  - Better light utilization

- Thinner wire design
  - Better Aesthetic
Bifacial: Key Module Features & Benefits

- **Bifacial cell structure**
  - Double light collecting ability, higher power and energy yield

- **High Bifacial Factor**
  - Rear side efficiency higher than 15.5%, bifacial factor higher than 0.70 (P-type)

- **High Durability and Reliability**
  - Dual-glass durable encapsulation, high PID-resistance, 30y Warranty

- **1500V system voltage**
  - Longer strings, lower BOS costs

- **Frameless design**
  - Suitable for BIPV or other applications