Future cell technology

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Levelized Cost of Electricity (LCOE)

- **Initial cost ($)**
- **Ongoing cost ($)**
- **Energy harvest (kWh)**

**Low initial cost ($)**
- Modules
- Balance of system (BOS)
- Development / EPC
- Financing

**Low ongoing cost ($)**
- Operations & Maintenance (O&M)
- Insurance
- Taxes
- Others

**High energy harvest (kWh)**
- Irradiation
- Power plant performance
- Module degradation
- Low-light-behavior
- Temperature coefficient

Electricity is a commodity: the main parameter is LCOE.
LCOE Reduction: Key Technology Levers

New technologies: optimization of productivity, efficiency and reliability

- PERC / PERL Technology
- Next Gen. Emitter
- Superfine Line Print
- Alternative Metallization
- Power Optimized Module
- System Performance

Energy Conversion Efficiency

- Throughput
- Automation
- MES / Wafer Tracking
- Yield
- Ag Reduction
- Consumables
- Bill Of Materials Module

LCOE Reduction

- Testing /Characterization
- Failure Modes (e.g. LID)
- Material Characterization
- Climate Effects
- Aging Models

Reliability & Energy Yield

Productivity & Cost
Increase productivity in multi GW production

- **10 GW/a cell production**
  - \(~1\,800\,000\,000\) cells per year
  - \(~5\,000\,000\) cells per day
  - \(~60\) cells per second
  - \(~800\) process tools

- Needs fully automated production and manufacturing control
Single wafer tracking for efficient development and manufacturing control

- Each wafer marked with unique ID matrix
- ID can be linked with relevant process and measurement stations
- Worldwide standardization within SEMI
- TRA.Q manufacturing experience at Hanwha Q Cells since 2009

→ **Via TRA.Q:** Correlation of process parameters with Inline measured data and cell parameters possible
  - Very powerful for GW scale production → efficient data mining possible
  - Without any additional cell handling and cell withdrawals

Continuous improvement Analysis of wafer material influence

- Efficiency Data from 2300 cells ordered by time
  → Broad distribution of cell efficiency

- Efficiency Data ordered by TRA.Q ID
  → Distribution of cell efficiency shows pattern

- Wafer base resistivity ordered by TRA.Q ID
  → Distribution shows characteristic pattern
Increase efficiency cost effectively
Evolutionary Cell Device Optimization:

**Targets**
- Reduced light shading and silver consumption
- Increased blue response

**Approach**
- Fine line contacts → reduced metal coverage, contact to optimized emitter
- Emitter doping profile → reduced Auger recombination
- Surface passivation → optimized emitter passivation

**Targets**
- Improve surface passivation, increased red response

**Approach**
- Optimized rear passivation layer → reduced recombination
- Improved rear metallic mirror → increased light trapping
- Passivated local contacts → reduced recombination

**Boundary condition**
- Cost effective and module compatibility
Increase efficiency cost effectively
Evolutionary Cell Device Optimization:

- Increased photo generation
- Reduced rear-surface recombination
- Additional features to PERC

Increase efficiency cost effectively
Mass Production of Q.ANTUM mono

Conversion efficiency distribution

- Very tight distribution with efficiencies > 21.5 %
- Further improvement potential by optics and reduced recombination losses
- Efficiency headroom of Q.ANTUM exceeds 24 %
Increase efficiency cost effectively
Multi solar cell efficiency development

- Similar results using multi crystalline wafer
- > 5 years of high-quality Q.ANTUM mass production:
  - median cell efficiency: > 19.8 %
  - $N_{\text{cell}}$ increase: $+ 0.5 \%_{\text{abs}}/a$
  - Silver consumption: - 50 %
  - Upgrade of existing tool set
  - Throughput increase

- Currently ~ 3 GW Q.ANTUM multi capacity

B. Klöter et. al., 32nd EU-PVSEC 2016
Increase efficiency cost effectively
Q.ANTUM Multi: Champion cell result

- 5 years of high-quality Q.ANTUM production:
  - Median cell efficiencies of 19.8%
- Further improved optics and reduced recombination losses
- Champion cell efficiency 21.9%*
- Cost effective processes suitable for mass production
- Efficiency headroom of Q.ANTUM multi exceeds 22%

B. Klöter et al., 32nd EU-PVSEC 2016

* measurements independently confirmed by FhG ISE CalLab
LID degradation

- BO complex\textsuperscript{[1,2]}
- LeTID\textsuperscript{[3-5]}

- More severe w/ increasing eta
- If not suppressed, severe problem for Cz and mc-Si PERC cells
- Dedicated measures mandatory to suppress degradation

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Increase reliability
LID in PERC Solar Cells and Modules

LID due to BO complex

- First observed in the 70s\[1\]
- Most prominent LID mechanism in commercial Cz silicon
- More severe w/ increasing eta
- Possibility to permanently deactivate has been first presented in 2006\[2\]
- Intensively researched by many groups
- Solutions for MP commercially available

→ Q.ANTUM suppresses LID due to BO complex

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**LeTID: Light and elevated Temperature Induced Degradation**

**Characteristics and implications**

- First observed in mc-Si PERC
- If not suppressed, severe problem for mc-Si PERC cells
- Forms under charge carrier injection at elevated temperatures
- Formation kinetics depend on temperature and excess charge carrier density
- $T \uparrow$, $\Delta n \uparrow \rightarrow$ formation rate $\uparrow$
- Severity can be manipulated

**Q.ANTUM** suppresses LeTID in mc-Si

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Increase reliability LeTID in PERC Solar Cells and Module

- **LeTID** not only in *p*-type mc PERC but also in *p*-type Cz PERC
  - big challenge for MP of *p*-type Cz-Si PERC cells
  - much more difficult to control than BO complex formation

- **Q.ANTUM** technology suppresses LID and LeTID in Cz silicon
Future silicon cell technology | Jörg Müller | Future PV Forum, Munich, Germany, June 1st, 2017

- Electricity is commodity, **LCOE** is main development criteria, price reduction will continue → **cost per piece, efficiency** and **reliability** are crucial

- Increase **productivity** in multi GW production:
  - Several Mio cells per day needs powerful MES → **Single wafer tracking** for efficient HVM

- Increase **efficiency** cost effectively:
  - Still **significant headroom** for efficiency improvements via evolutionary development → keep **Q.ANTUM platform** for the coming years

- Increase **reliability**:
  - Degradation (e.g. LID/LeTID) can severely affect energy yield
  → Dedicated measures to suppress any degradation
Thank you.