

Looking Back at 10 Years of PV CellTech

Finlay Colville

Head of Research - PV Tech

Chair - PV CellTech & PV ModuleTech Conferences

Contents

1. The Malaysia years: 2016 to 2019
2. The UFLPA problem; the Patent problem

1. The Malaysia Years: 2016 to 2019

● ● 2016
Kuala Lumpur, Malaysia



EVENT PROGRAMME

16-17 MARCH 2016 | KUALA LUMPUR, MALAYSIA

celltech.solarenergyevents.com

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Lunch Partner



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Technology Innovation Partners



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MALAYSIA SOLAR ECOSYSTEM



Cell Production Still had Some of the First Technology Movers..

CONFIRMED SPEAKER BY CATEGORY:

PV Manufacturers

Akira Terakawa, R&D Project Leader, **Panasonic Corporation** ←

Bob Chen, Corporate VP & Head of Cell Business Unit, **Neo Solar Power** ←

Budi Tjahjono, CTO, **Sunrise Global Solar**

Denis de Ceuster, Director R&D Crystalline Silicon PV, **First Solar (TetraSun)**

Hannes Rostan, Director Cell Technology, **REC Solar** ←

Hao Jin, Chief Scientist, **JinkoSolar**

Holger Neuhaus, Managing Director, **SolarWorld Innovations GmbH** ←

Jack Song, Director of Product & Technology, **JA Solar**

Markus Fischer, Director R&D Processes, **Hanwha Q CELLS** ←

Paul Gupta, President, **IndoSolar**

Peter Cousins, Vice President Research, Development and Deployment, **SunPower Corporation** ←

Pierre Verlinden, Chief Scientist & Vice-Chair of the State Key Lab. of PV Science & Technology, **Trina Solar**

Shi Jinchao, Cell R&D Senior Director, **Yingli Green Energy**

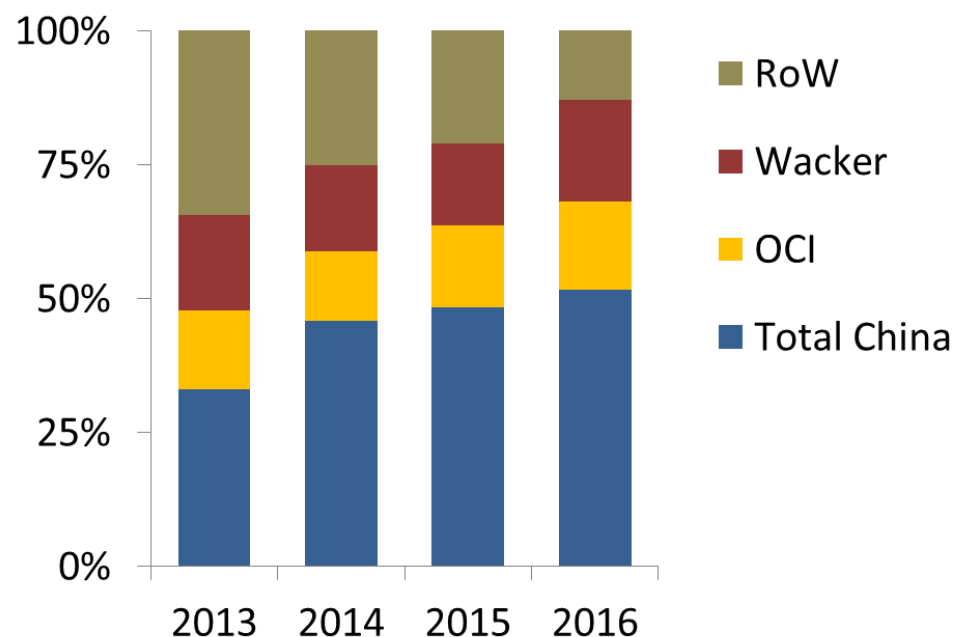
Walt Huang, CTO, **Gintech** ←

Xie Tian, Director of Wafer Quality Management, **Longi Silicon Materials**

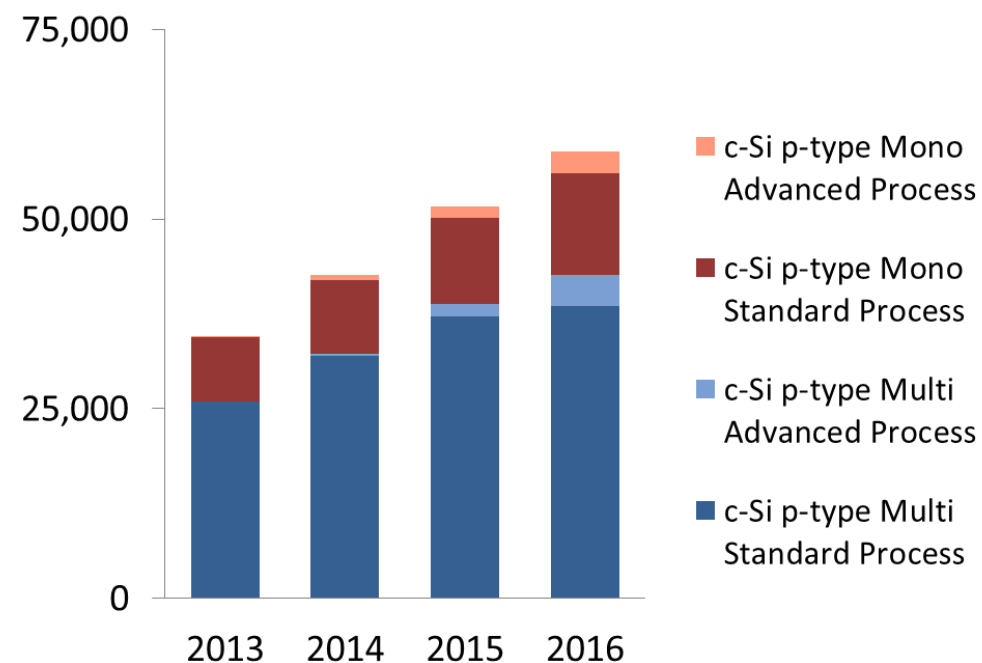
Zhang Chun, Senior Director of Cell Technology, **GCL System Integration Technology**

Only 50% of Poly was in China; Multi was Dominant


Polysilicon Production Share to PV



p-type Production (MW)



Major China Cell Makers Still Pushing Multi...



2006-2016 Year

20.13% P-type Multi-crystalline Silicon Solar Cells in Mass Production

March 2016, Kuala Lumpur

JinkoSolar Co., Ltd.

JinkoSolar
Building Your Trust in Solar

Trinasolar PVST 光伏科学与技术国家重点实验室
Smart Energy Together State Key Laboratory of PV Science & Technology

The prospect of mass-produced multi-crystalline cells above 20% efficiency: how high can p-type multi go?

Pierre J. Verlinden

Pietro P. Altermatt, Zhen Xiong, Weiwei Deng,

Yifeng Chen, Yang Yang, Zhiqiang Feng

PVCellTech Conference
Kuala Lumpur, Malaysia
March 16th – 17th, 2016



...but Main Topic was PERC Introduction to Mass Production

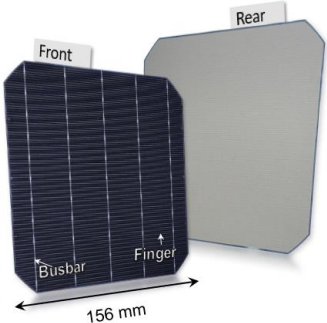
PERC in Fraunhofer's PVTEC pilot line Our standard route

- Cz-Si PERC (1,4 Ωcm, 156x156x0,18 mm³)
- Homogeneous Emitter

Saw damage removal and texture
Diffusion
Rear emitter removal / surface cleaning
PECVD Rear Al ₂ O ₃ /SiN _x , Front ARC
Laser Contact Opening Rear
Screen Print Contacting
Contact Firing

AR coating	V_{oc} (mV)	J_{sc} (mA/cm ²)	FF (%)	η (%)
Double SiOx/SiNx	668	40.0	80.2	21.4*
Single SiNx	665	39.4	80.3	21.1*

* calibrated measurement at Fraunhofer ISE CalLab PVCells

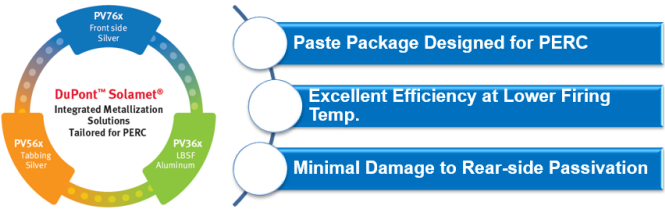


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Fraunhofer ISE

DuPont™ Solamet® Integrated Metallization Solutions for PERC with

- PV76x Front Side Silver Paste
- PV56x Back Side Tabbing Silver Paste
- PV36x aluminum Paste

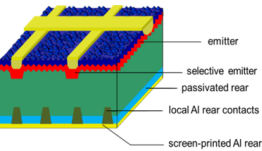


Efficiency gain exceeding 0.15% in production by the integrated solutions for PERC

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SolarWorld's PERC Approach



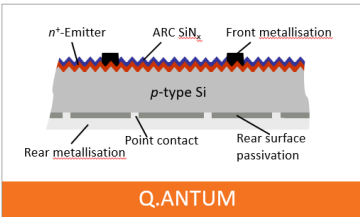
SolarWorld's PERC Cell Architecture

- PERC combines low manufacturing costs of conventional screen-printed solar cells with high cell efficiencies.
- Upgrade of screen-printed Al-BSF production lines:
 - Optimized selective emitter
 - Rear side polish
 - Dielectric rear passivation
 - Local laser contact opening
- Low equipment costs compared to new cell concepts, in particular when old Al-BSF lines are used, but for entire new lines as well.
- Simple and low-risk ramp-up compared to entire new cell concepts, because of know-how with Al-BSF.
- Benefit from cost reduction measures of mainstream Al-BSF and PERC.

Mass Producible PERC PV Cells With Over 20% Conversion Efficiency

Prepared by W. Shan
Presented by Jack Song
JASOLAR

Q.ANTUM: Q CELLS' High-Efficiency Si Cell

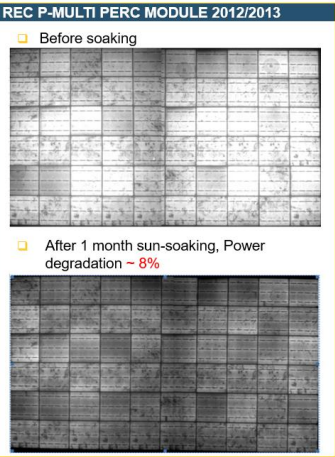


DIELECTRIC PASSIVATED REAR

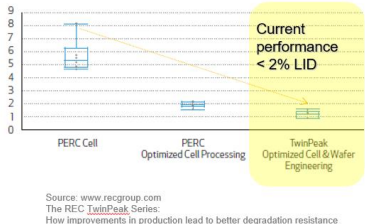
- Increased photo generation rate
 - Gain in J_{sc} of 2 – 3 %_{rel} (depends on IQE of base region)
 - Reduced S_{eff, rear}
 - Enlarged collection length
 - Reduced J_{0, rear}
 - V_{oc} ~ ln(J_{sc}/J_{0, total} + 1)
 - Lateral majority carrier transport
 - Additional spreading resistance R_{spread}
- S_{eff, rear}, J_{0, rear}, R_{spread} depend on wafer doping

...and Solving LID

Challenge: Multi-PERC LID performance



- LID was the key issue why REC has not implemented multi PERC in production initially
- REC spend RnD efforts over 2 years to solve the LID issue
- Similar issues on LID have been reported by Hanwha Q-Cells
- Today, REC has solved LID on multi-PERC

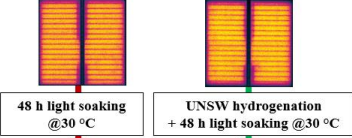


Mitigation of CID in Cz-Si PERC cells



Light (carrier)-induced degradation eliminated through UNSW technology [1,2]:

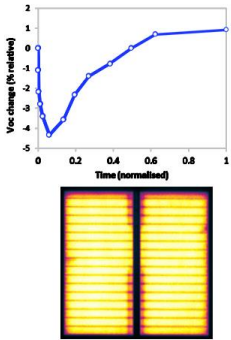
1. Accelerated BO defect formation
2. Passivation through hydrogen charge state control



$\Delta\eta = -1.0\%$ absolute $\Delta\eta = +0.5\%$ absolute
→ +1.5% absolute efficiency improvement

[1] P. Hamer, et al., "Accelerated formation of the boron-oxygen complex in p-type Czochralski silicon," PSS RRL, 2015
[2] B. Hallam, et al., "Rapid Processing of Boron Oxygen Defects" EUPVSEC, 2015

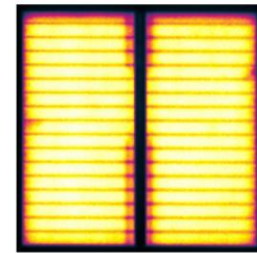
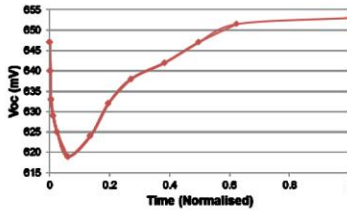
CONFIDENTIAL AND PROPRIETARY INFORMATION



Top: Relative change in V_{oc} of a Cz-Si PERC cell with continual laser treatment
Bottom: Associated photoluminescence images

Sino-American Silicon Products Inc. Yilan Branch

Accelerated Defect formation and Hydrogenation of p-type Cz, PERC cell – LID Solved!!



Sequential Photoluminescence Images

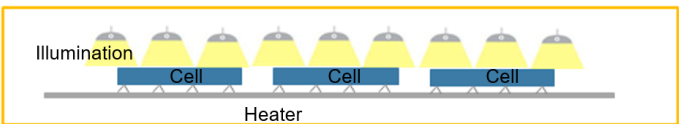
School of Photovoltaic and Renewable Energy Engineering UNSW

Alternative solutions to solve LID: LID recovery treatment at cell level on finished device



1. Degradation: Defects formation (e.g B-O complex) by heat and illumination
2. Regeneration: Passivation of defects by H₂

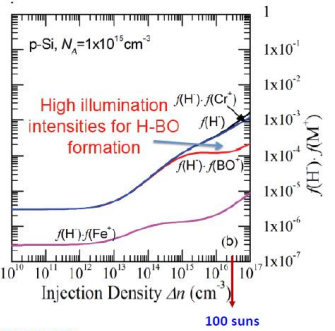
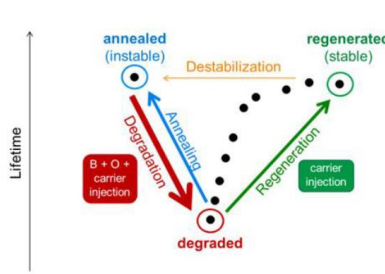
Source: University of Konstanz (Published 29th EUPVSEC)
HIGH SPEED REGENERATION OF BO-DEFECTS: IMPROVING LONG-TERM SOLAR CELL PERFORMANCE WITHIN SECONDS



Important process parameters for LID treatment process (3Ts)

Test matrix for REC PERC cells	Temperature	Illumination Intensity	Time
Test conditions	High	High intensity	Short process 10s
	Med	Low intensity rec	Long process 30s
REC observations	200C. Too high temperature results in H ₂ effusion.	High intensity accelerates the treatment recovery process	10s with high intensity is adequate for treatment.

LID issues greatly improved for P-PERC



LID decay could be reduced by regeneration process;
even some defects could be further passivated.

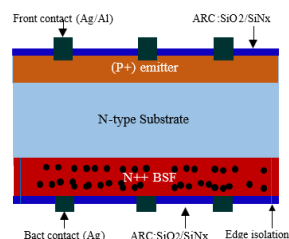
Source: HIGH SPEED REGENERATION OF BO-DEFECTS: IMPROVING LONG-TERM SOLAR CELL PERFORMANCE WITHIN SECONDS Svenja Wilking et al. 2014 EU PVSEC
A unified approach to modelling the charge state of monatomic hydrogen and other defects in crystalline silicon Chang Sun et al 2015 JAP

n-type Talk from TetraSun?

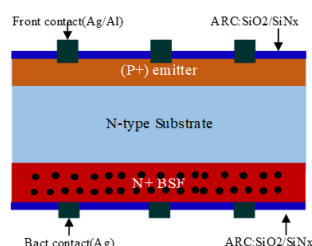
n-Si cell with Phosphorus ion implanted BSF



Conventional POCl_3 diffusion



Phosphorus ion implantation



- Lower rear surface recombination
- A improved cell efficiency
- Less process steps

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HOW IT STARTED

N-TYPE Si WAS THERE RIGHT FROM THE START ...

- In the beginning it was not clear which type of substrate to use
 - Bell labs produced the first results on p-type Si (4.5%)
 - But then switched to n-type Si (arsenic doped wafers) (6%)
- Efficiency of n-type Si based PV was higher till 1962/range of 10%
- The focus was on application in space at that time

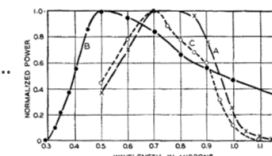


Fig. 1. Normalized spectral energy distribution. (A) Silicon photodiode response. (B) Solar energy at earth's surface. (C) Curve A times Curve B.

D. M. Chapin, C. S. Fuller, G. L. Pearson, A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power, *Journal of Applied Physics*, 25, 5, 676-677.

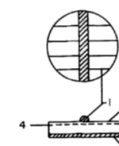


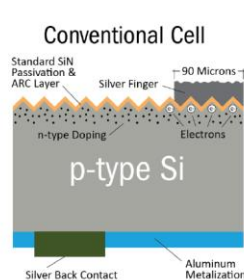
Fig. 2. Phosphorus solar cell structure, active surface Krypton coated: 1, nickel plate; solder dip contact; 2, diffused layer-phosphorus; 3, contact-rhodium plate; 4, junction, 0.6 mil deep.

J. Mandelkern, C. McAfee, J. Kesperis, L. Schwartz, W. Pharo, Fabrication and characterization of Phosphorus-diffused silicon solar cells, *Journal of Electrochemical society*, 109 (4), 313-318, (1962).

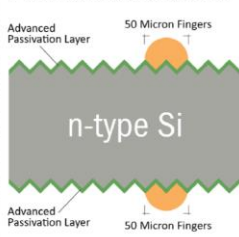
imec

4

Unique Cell Architecture



First Solar TetraSun Cell

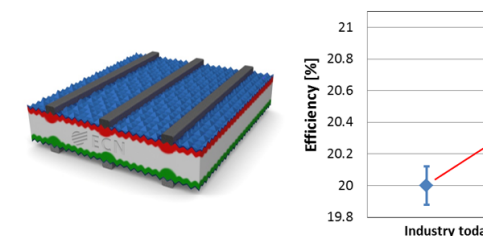


- Advanced passivation layers minimize recombination and improve efficiency
- Copper metallization improves conductivity vs. fired silver paste reducing resistivity losses
- Superior aspect ratio of narrow fingers reduces shading and reflects more light into active area, improving efficiency and reducing cell to module losses
- Exceptional temperature coefficient at -0.34%/K increases energy production
- Bifacial design allows for energy collection on back & front of cell
- No LID or PID degradation

© Copyright 2011 First Solar, Inc.

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Bifacial n-type cell: n-Pasha



- 6 inch, 4 busbars, fully printed cell
 - Emitter + BSF shaping, stencil print front
- Selective emitter + BSF
 - Using simultaneous etch-back using mask
 - Proven industrial method

+0.5%
+0.4%

→ 21% efficiency reached
→ 21.5% with process tuning

I. Romijn et al., *Photovoltaics International*, Vol.25, p.58-68, 2014
J. Liu et al., *proceedings 31st EUPVSEC, Hamburg, 2015*

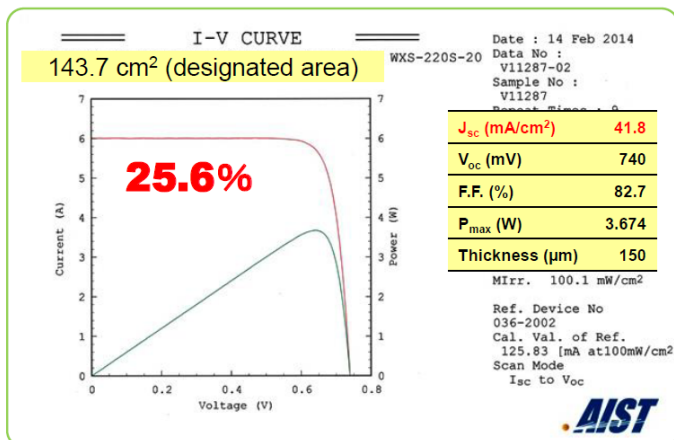
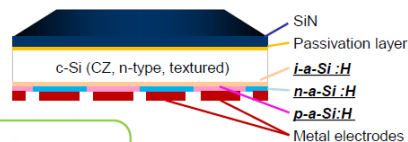
HJT & BC niche contributions

Brake through 25% efficiency

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■ Combination of SHJ and IBC technologies

➤ Reduction of the shadow & absorption loss of the light incidence side

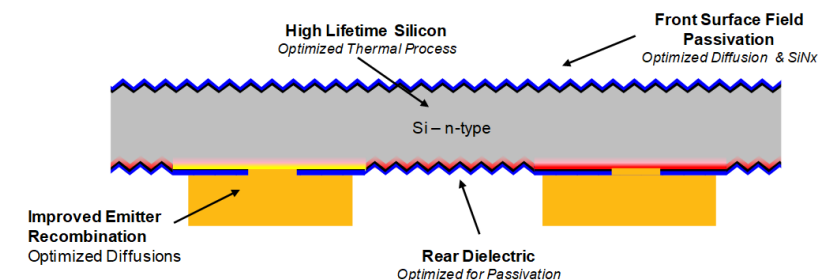
Temp. coeff. of η **-0.25% / °C**Mini-module using similar η cell

Summary

- GCL intends to develop large scale production high efficiency 156 mm HJ solar cells
- Edge effect is controllable in full size HJ cell and IWO is an attractive TCO alternative material with better IR response
- Advanced cell is the key for various high performance modules



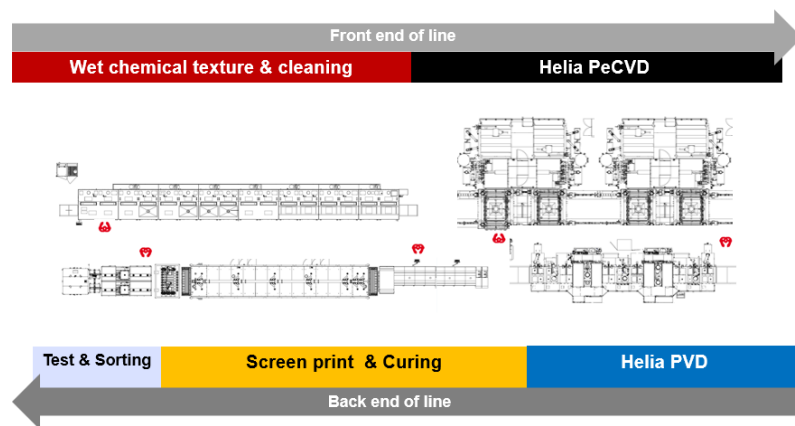
3. Manufacturable Design



- Complexity is a compound effect
- Robust architecture & manufacturing design
- Strict factory controls (e.g. Lifetime, patterning precision, environment)

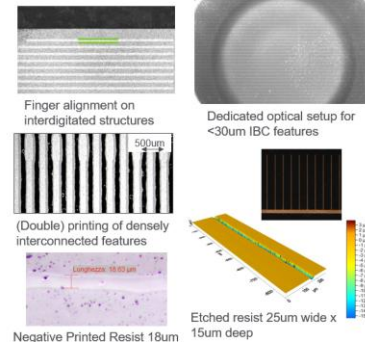
Tools & Materials Focused on n-type Options

HJT Line – Tool set



IBC cells: Metallization

- Pattern detection
 - Implanted or diffused features
 - Laser structured features
 - Advanced algorithms
- Printing
 - Direct printing of dopant inks
 - Printing of std and high aspect ratio resists
 - Printing and drying/curing of metal pastes, solders, ECAs
- Laser ablation
- IV testing



Multiple solutions available for IBC cells, working today in HVM

Applied Materials External Use

TUNNEL OXIDE / POLYSILICON LAYER

Tunnel oxide

- Typical tunnel oxide thickness of 1.5nm (15Å)
- Oxide thickness can be well controlled
- Contact resistance of tunnel oxide?
- Note
 - Difficult to measure exact thickness
 - Si-O bond distance in SiO₂ is 1.6Å

Polysilicon layer

- Thickness can be controlled well for 20 – 300nm
- For i-polysilicon and doped n+ or p+ polysilicon



Tempress Systems BV, PV-Tech conference Kuala Lumpur 2016

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INDEOTec
PLASMA PROCESS EQUIPMENT

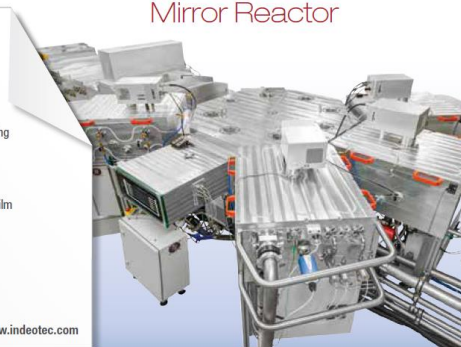
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Octopus
with
Mirror Reactor

A real innovation in PECVD
RF- and VHF-deposition technology

- Top & bottom thin film deposition in successive reactors without vacuum breakage or substrate flipping
- Special bifacial carrier plate hole design for minimized substrate edge bearing
- Secondary compensation electrode for excellent film thickness uniformity and passivation quality levels

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VISIT US Day two, 17. 3. 2016
Morning Session
Time: 11 am

Readiness of equipment
for mass production
of heterojunction cells
>22% average efficiency

Dr. Gunter Erfurt,
Managing Director



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Meyer Burger delivers the next generation PV technology

PERC industry leading solution:
Upgrades and new lines

Total installed base >12 GW



MAIA

Heterojunction (HJT):
>22% average efficiency

Ready for mass production



- Only 6 process steps
- Low energy production and low facility costs
- Ready for thin wafers and SWCT connection technology
- Installed base 3 productions

● ● 2017
Penang, Malaysia

New Home for PV CellTech in Penang, Malaysia



Sponsors & Partners



Conference 'Established' in Calendar

FEATURED PV MANUFACTURERS

- ▶ Adani Group
- ▶ Astronergy (Chint Solar)
- ▶ Boviet Solar Technology
- ▶ Canadian Solar
- ▶ First Solar
- ▶ GCL System Integration
- ▶ Hanwha Q-CELLS
- ▶ Indosolar
- ▶ JA Solar
- ▶ JinkoSolar
- ▶ LERRI Solar
- ▶ LONGi Green Energy
- ▶ Solar Frontier
- ▶ SolarWorld
- ▶ SunPower Corporation
- ▶ Sunpreme
- ▶ Wuxi Suntech
- ▶ Yingli Solar
- ▶ Zhongli Talesun Solar

MARKET RESEARCH

- ▶ PV-Tech & Solar Media Ltd

EQUIPMENT & MATERIALS SUPPLIERS

- ▶ ASM Alternative Energy
- ▶ Aurora Solar Technologies
- ▶ DuPont Photovoltaic Solutions
- ▶ h.a.l.m. Elektronik
- ▶ Horiba
- ▶ INDEOTec
- ▶ MacDermid Enthone
- ▶ Meco Equipment Engineers (Besi)
- ▶ Meyer Burger
- ▶ SCHMID Group
- ▶ Semco Technologies
- ▶ Semilab
- ▶ Von Ardenne

OTHER CONTRIBUTORS

- ▶ CLSA
- ▶ Fraunhofer ISE
- ▶ Gintech
- ▶ ITRPV
- ▶ Linde Electronics
- ▶ Malaysian Investment Development Authority (MIDA)
- ▶ National Institute of Solar Energy (INES R&D)
- ▶ REC Solar
- ▶ Roth Capital Partners
- ▶ Solar Energy Research Institute of Singapore (SERIS)
- ▶ Tempres Systems (Amtech Systems)
- ▶ Trina Solar
- ▶ University of New South Wales (UNSW)

11:00 - 11:30 Morning Break & Networking

MORNING SESSION: RETAINING THE MARKET COMPETITIVENESS OF P-TYPE MULTI CELLS

MODERATOR

Black silicon & diamond wire sawing of wafers: the future for multi c-Si technology

Guaqiang Xing, Corporate Vice President - Technology, Canadian Solar

Multi-crystalline product under pressure: securing its competitiveness using diamond wire & PERC technologies

Gunter Erfurt, Chief Operating Officer, Meyer Burger

Fabrication of high efficiency multi c-Si PERC solar cells & modules in mass production

Shiyong Liu, Technical Manager, Astronergy (Chint Solar)

Still Push to Keep Multi Going

AFTERNOON SESSION 1: HETEROJUNCTION CELL PRODUCTION: KEEPING AHEAD OF P-TYPE MONO PERC

MODERATOR

Finlay Colville, Head of Market Research, PV-Tech & Solar Media Ltd

Status of heterojunction cell production: from R&D to mass production, future development & equipment choice

Omid Shojei, CEO, INDEOTec

Hybrid cell manufacturing technology for high-efficiency bifacial modules

Ashok Sinha, Chairman & CEO, Sunpreme

Investigations on n-PERT bifacial solar cells

Feng Li, Deputy General Manager of Technology Center, Yingli Green

The path to 23% efficiency from heterojunction cells: perspectives from a decade of n-type heterojunction pilot line research at INES

Anis Jouini, CEO, National Institute of Solar Energy (INES R&D)

Again, PERC, PERC, PERC

Cell Activity in SEA, India...

MORNING SESSION: GW CELL MANUFACTURING EXPANSIONS IN INDIA, VIETNAM & THAILAND

MODERATOR

Finlay Colville, Head of Market Research, PV-Tech & Solar Media Ltd

India's first GW cell manufacturing fab

Srinvasamohan Narayanan, Technology Advisor, Adani Group

Vietnam: the new powerhouse for cell manufacturing in Southeast Asia

Chung-Han Wu, R&D Director, Boviet Solar Technology

PV equipment for emerging cell manufacturing regions & technology types

Christian Buchner, Vice President - Business Unit PV, SCHMID Group

From China to Thailand: Talesun's solar cell manufacturing & technology

Paul Ni, Vice President - Technology and R&D Center, Zhongli Talesun Solar

Increasing the efficiency and quality of Indian produced solar cells

Paul Gupta, President, Indosolar

Some of Major Players still Pushing Multi



Record Efficiency of Industrial Screen-printed Multi-crystalline Silicon Solar Cells

Hao Jin, Peiting Zheng, Haijie Sun, Jiaping Xu, Fan Zhang, Yao Guo and Qi Wang

JinKo R&D Center, JinkoSolar, March 15, 2017

www.jinkosolar.com

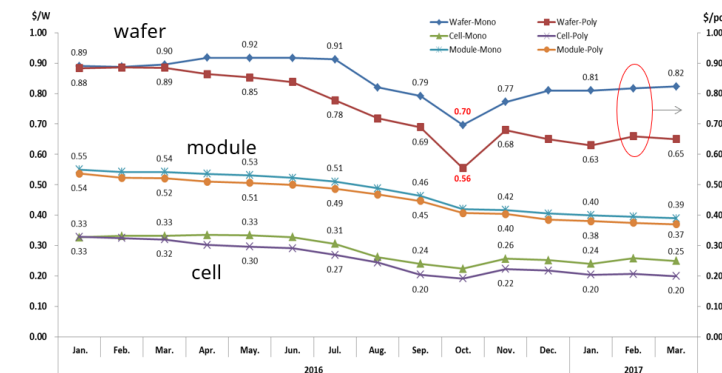


Dr. Liu Shiyong, Chint Solar(Zhejiang) Co., Ltd
March 14, 2017

A CHINT COMPANY | Copyright© 2013-2014



Price Comparison: Multi vs. Mono

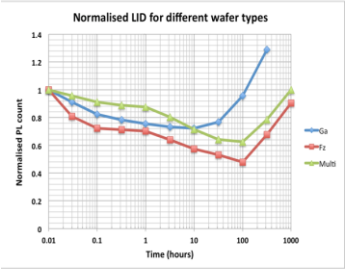


Are the PV crowd herded the right way?

Canadian Solar Inc.

PERC & LID

Defect causing LID in mc-Si PERC also occurs in mono-Si

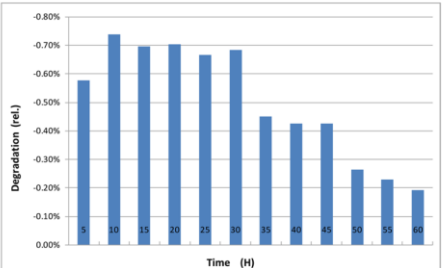


- AH can passivate type 1 & 2 defects
- AH can solve LID in multi
- Controlling the H charge state is important
- Great potential to passivate all defect types

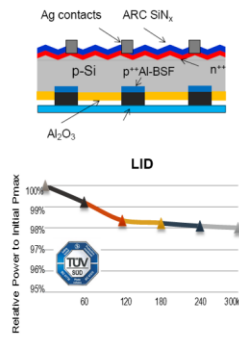


2. Solar Cells

- LID decrease by Hydrogenation

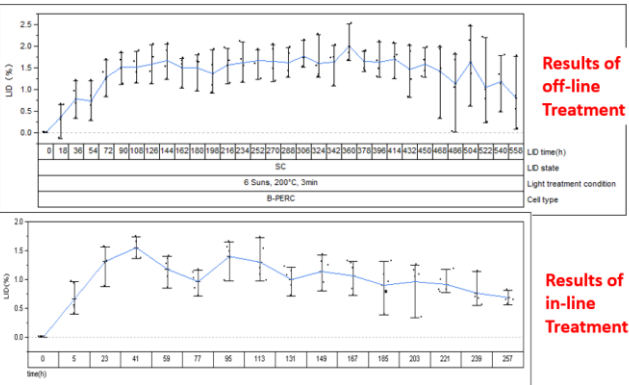


LONGi Solar's Low LID PERC: Hi-MO1

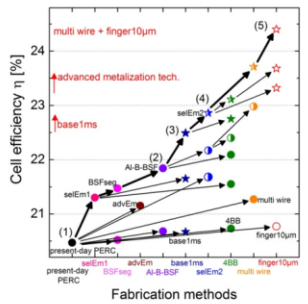


- ◆ 21%+ average cell efficiency, 295W/300W rated power for 60-cell module
- ◆ Outstanding low-light performance, which produces more energy than normal AlBSF mono module at system level
- ◆ Outstanding temperature coefficient
- ◆ Excellent LID performance validated by TUV
 - LID <2% after 300kWh exposure, enabling low 1st year degradation
- ◆ Suitable for utility, as well as commercial and residential rooftop applications

Long-term Stability of LID Mitigation JASOLAR



Efficiency path of PERC towards 24%

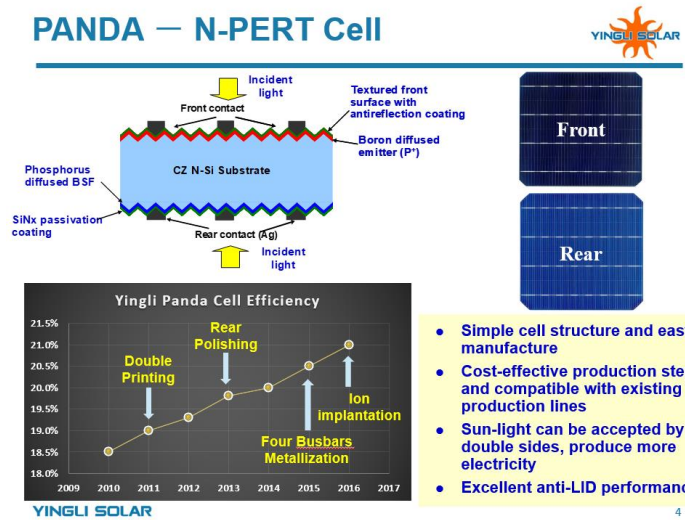


PERC efficiency improvements above 24.0% with different technological measures (published at 31st PVSEC 2015, ISFH & Solarworld)

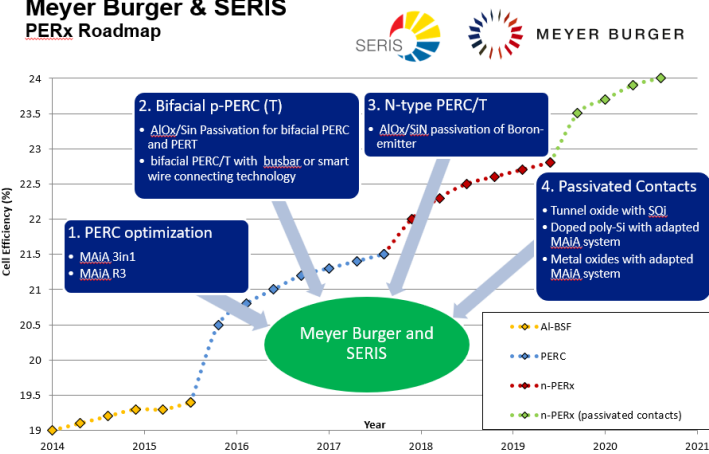
- ✎ In 1999, Green et al. already demonstrated PERC-like solar cells with efficiencies above 25% on p-type Si
- ✎ Manufacturing was complex, not suited for mass production and expensive, however, this has changed
- ✎ Industrial PERC with efficiencies between 21 and 22% is already possible today
- ✎ Sentaurus device simulations based on detailed characterization indicate that efficiencies above 24.0% will be possible with screen-printed PERC on p-type Cz-Si with further process improvements

More PERT & TOPCon

PANDA — N-PERT Cell

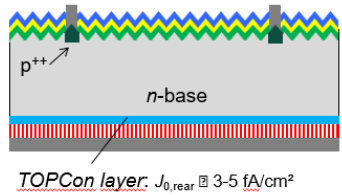


Meyer Burger & SERIS PERx Roadmap



Qualification of whole process and material flow for p-type PERC and n-type PERL/T technology at technology center HOT

Challenges & Solutions Thermal Oxide Passivated Contact (TOPCon)

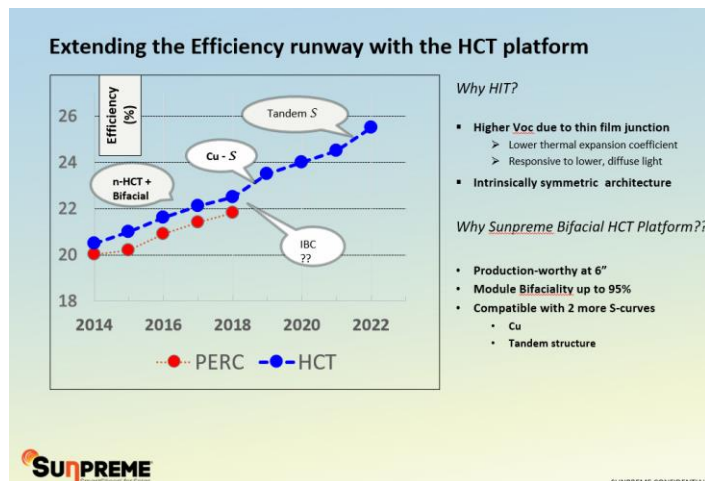


Material, type area (cm ²)	V _{oc} [mV]	J _{sc} [mA/cm ²]	FF [%]	η [%]
n-type HPM-Si, 10 x 10	712	41.2	82.8	24.3
n-type FZ-Si, 2 x 2	718	42.5	82.8	25.3

- Cell Concept
- Design Rules
- Manufacturing
- Module Integration

SPEERCon Cell

More HJT & BC from the Tool Makers



Heterojunction cells: from R&D to Mass-production

Dr. Omid Shojaei
PV-Cell Tech, Penang
March 2017



Inline measurements provide vital information and insights

- Faster, more precise line commissioning
- Data to support continuous improvement of the line
- Data to support device design improvement
- Best possible quality control
- Evaluation and cost control of raw material supply



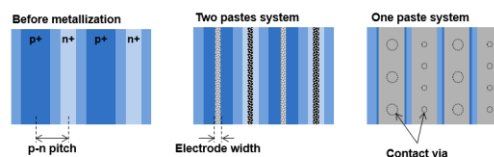
Example: inline bifacial cell measurement

Increasingly important with higher-efficiency cell designs

www.gyrasolartech.com

Metallization Options for IBC

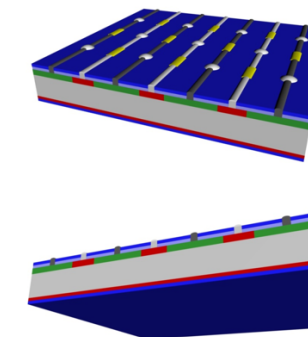
	Two Pastes System	One Paste System
Print/Dry	2 times	1 time
Contact via opening	No need (Fine-through)	Need (Laser Etching)
Firing temperature	700-800°C	550-600°C
Electrode width	As narrow as possible	< 600 μm less than p-n pitch
Electrode thickness	As thick as possible	< 10 μm
Passivation area loss by metallization	(electrode width) (p-n pitch)	No limitation with electrode width



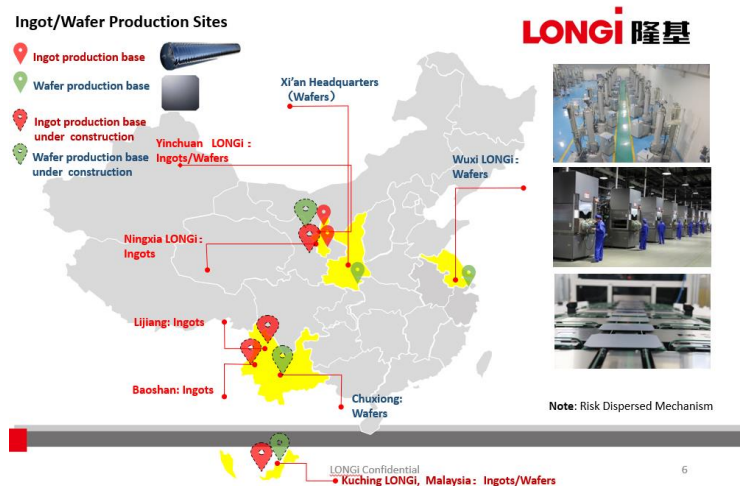
Further progress on IBC paste development will require close collaboration with cell / module customers

MBC: Gateway to IBC Cell Technology

Multi-busbar concept enables simplified metallization for 156mm bifacial IBC cell manufacturing!



Capacity Expansions Across Asia



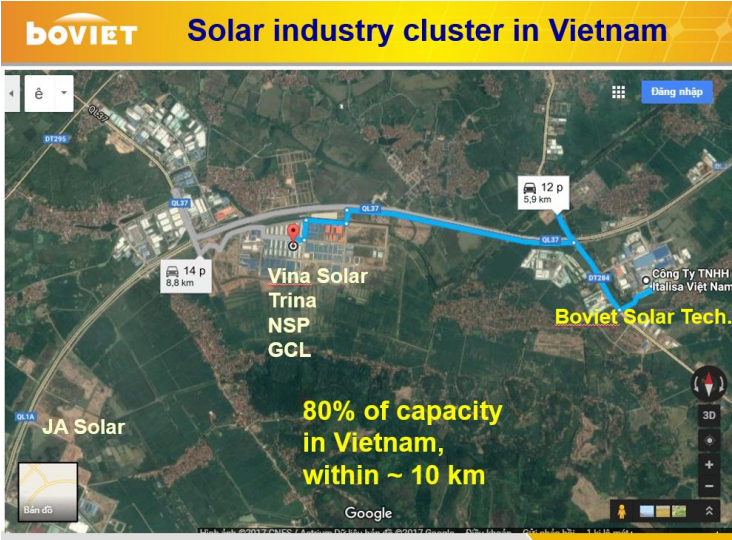
1.2 GW of Cell and Module manufacturing building...
State-of-the-art facility (3 floor architecture) built in a year



- Adani - well positioned for successful GW operations through an ecosystem of generation & manufacturing

adani

13



Thailand factory



- Founded in 2015, Located in Rayong, Thailand
- 100% owned by Talesun technologies
- Concentrate on European and American market
- Start production in Q4, 2015, 500MW cells and module



Thank You

INDOSOLAR
www.indosolar.co.in



22

● ● 2018
Penang, Malaysia

Back to Penang...



Cell technology trends impacting the 100GW-plus landscape

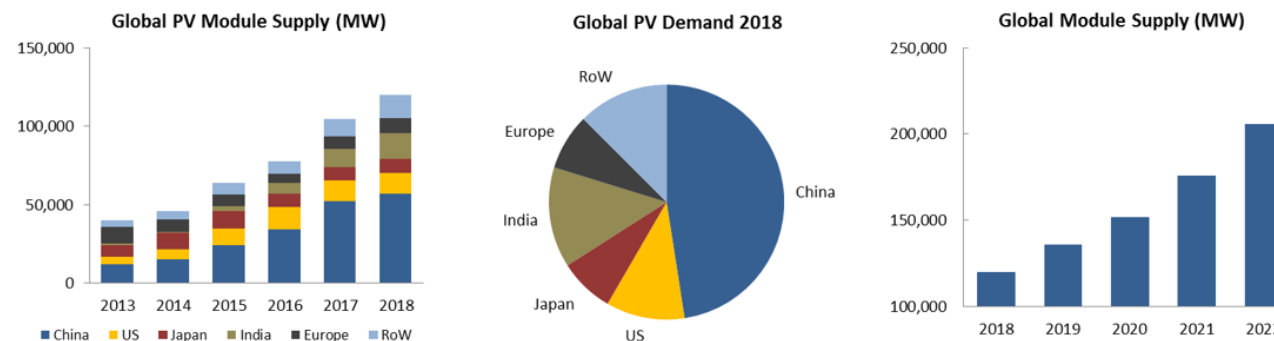
Finlay Colville, Head of Research

PV-Tech : Solar Media Ltd

PV CellTech 2018, Penang, Malaysia

© Solar Media Limited, 2018

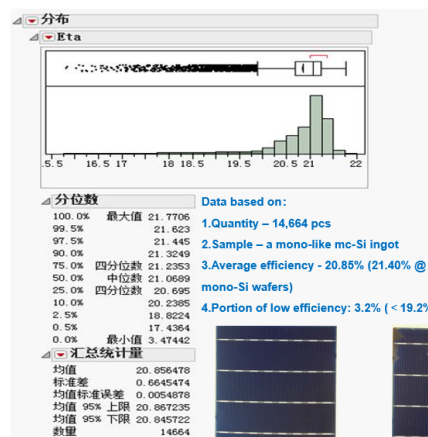
From 100GW to 200GW in 5 years



- From 2015, global growth has been dictated by China
- The end-market has doubled between 2013 and 2017
- Expect another 2X between 2017 and 2022
- This implies cell production >215GW in 2022

Multi & Cast-Mono Still Being Pushed

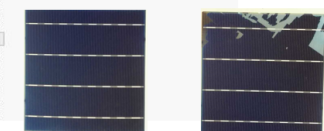
GCL mc-Si wafers with mono-casting technology



Quasi-mono mc-Si ingot achieved

- <0.5%
 - efficiency difference compared to mono-wafer
- Optimization
 - solving the tail of efficiency and lower yield
- Appearance
 - cooperative application with PV industry chain

1.Quantity - 14,664 pcs
2.Sample - a mono-like mc-Si ingot
3.Average efficiency - 20.85% (21.40% @ mono-Si wafers)
4.Portion of low efficiency: 3.2% (< 19.2%)



► Cells without 'crystal flowers' ► Cells with 'crystal flowers'



CanadianSolar

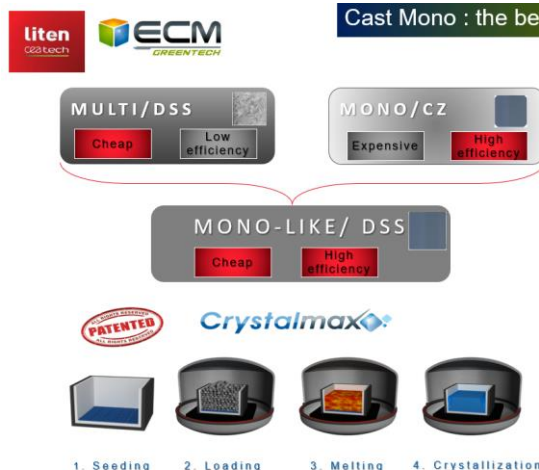
**MULTI-PERC:
THE NEXT TECHNOLOGY WAVE SWEEPING
THE PV INDUSTRY**

Guoqiang Xing, Ph.D
CTO, Canadian Solar

PV CellTech, Penang, Malaysia
March, 2018

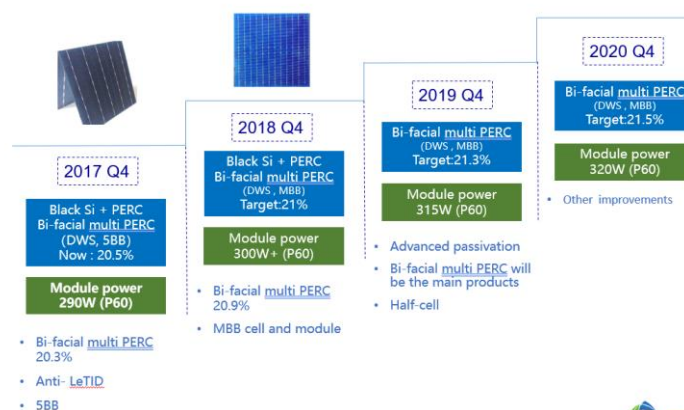
CSIQ NASDAQ Listed

Cast Mono : the best of both worlds



- 100 oriented wafers
- Fully mono ingots after cropping
- DW and KOH Texture compatible
- P/N Type compatible

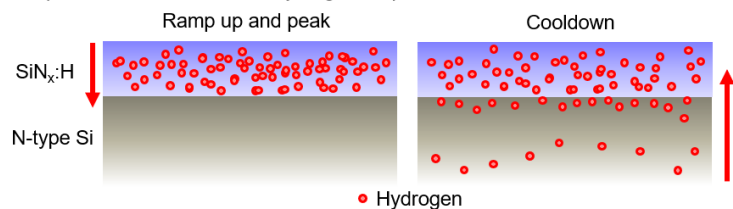
GCL multi cell efficiency roadmap 2018 to 2020



PERC 'Done' & What's Next?

Hydrogen – the problem and the solution!

- Complex, small and mobile atom
- Many charge states – good for passivation!
- LeTID caused by hydrogen diffusion and altering equilibrium conditions
- Excess hydrogen harms cells performance:
 - Bulk recombination
 - Surface passivation deterioration
 - Series resistance
- Optimal solution: Maximise hydrogen for passivation then remove excess



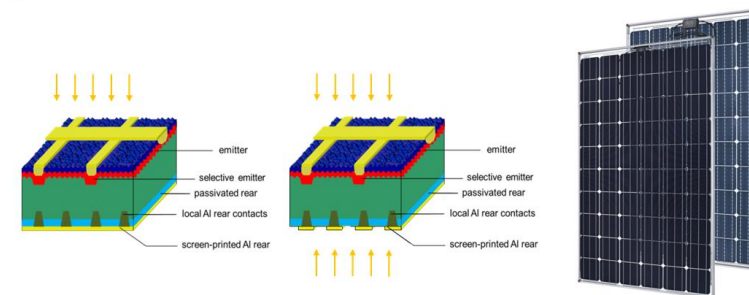
29



Bifacial PERC module



- PERC cell: Screen-printed Al rear contact with grind fingers (not fully covered)
- Module: Cells are embedded between two glass sheets
- Benefit: Additional power gain from diffuse light captured from the rear
- Product launch of bifacial PERC modules in 2015



20 Holger Neuhaus et al.

What comes next after PERC?

monofacial super high efficiency concepts ?

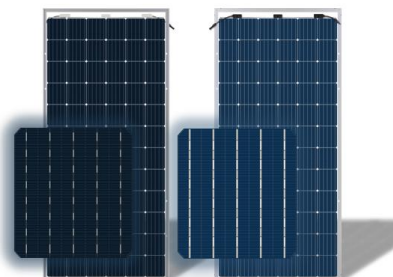
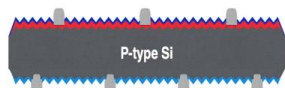
J. Libal, PV Cell Tech, March 13, 2018

17

Bifacial Technology

Mono-facial to Bifacial power generation

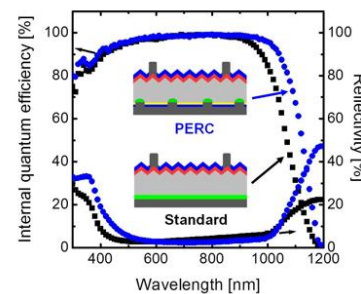
- LONGi Solar Bifacial PERC Hi-MO2 cell and module bifaciality >75%
- Significant increase on energy yield
- Double glass lamination, 30 year power degradation warranty



LONGiSolar

Advantages of PERC Cell

Jinko Solar

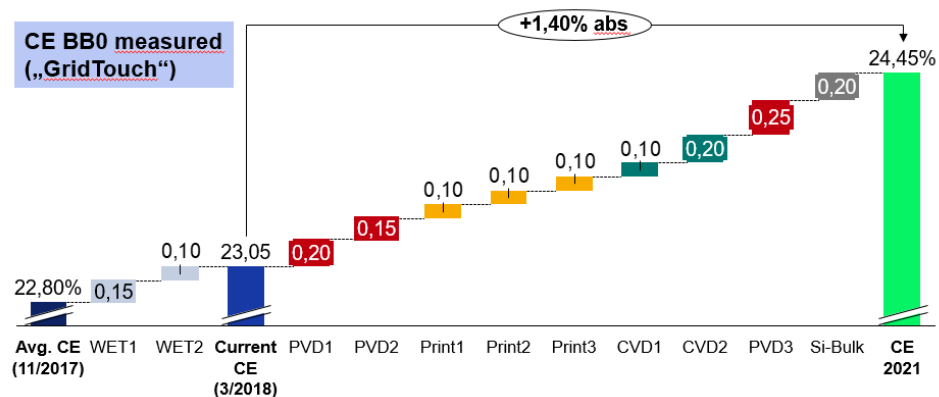


From ISFH

- Higher V_{OC}
- Better IR response

HJT Seeing Continued Interest

HJT just at the beginning of evolutionary continuous improvements



Meyer Burger (equipment maker – not solar cell manufacturer) managed to improve HJT efficiency by 1.2% abs in 12 months (Dec 2016 – Dec 2017)

HJT with huge continuous improvement potential and program launched at MB together with CSEM and CEA INES

16 Meyer Burger Technology Ltd, PV CELLTECH 2018, Penang MY, Feb 13 2018

JINERGY HJT Factory in Shanxi, China

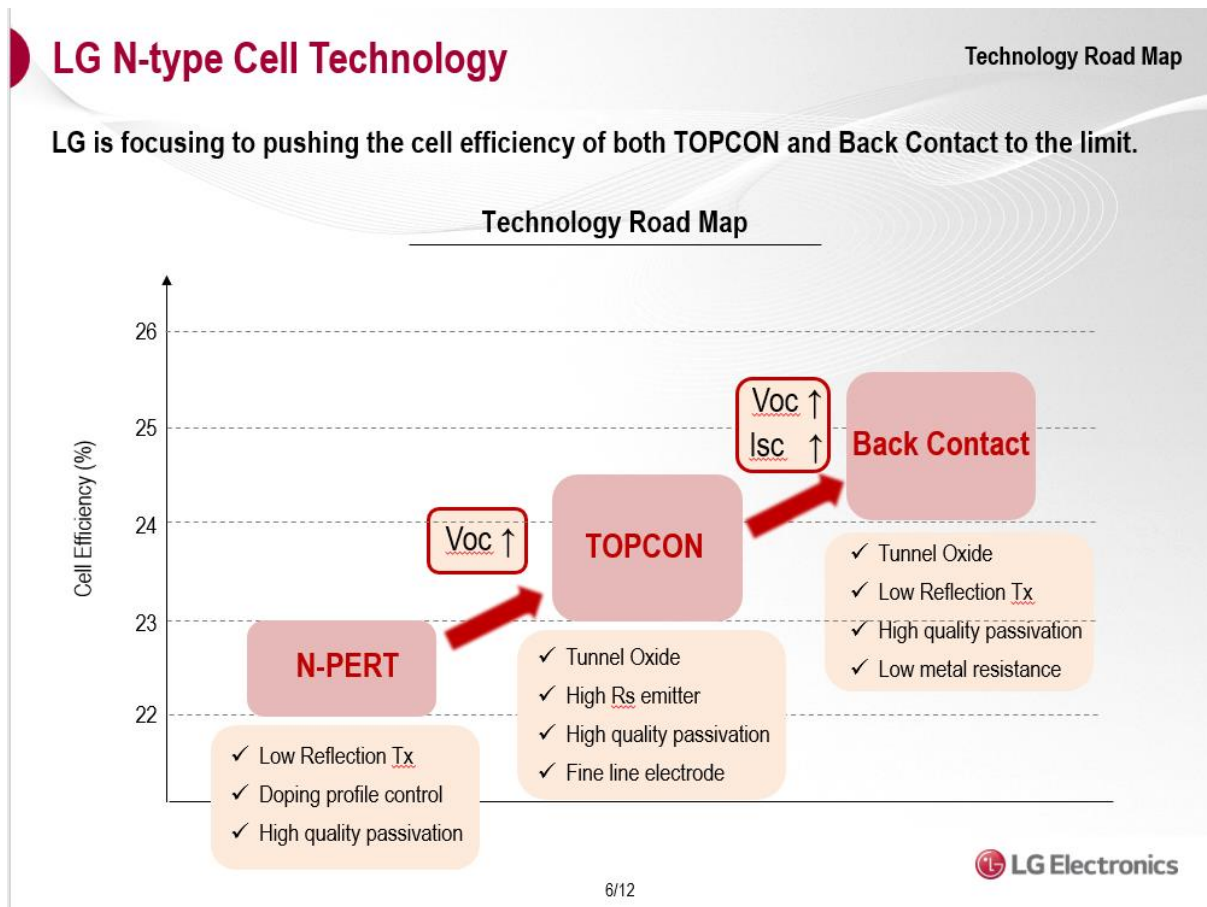


- 2 GW HJT in 5 years
- 100MW completed, second 100MW in 2018

10 Jinneng Clean Energy Technology Ltd.

2025/3/11

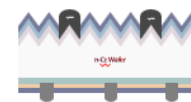
LG & Jolywood then the PERT/TOPCon Front Runners



Roadmap of Jolywood's N-type cell



>21.5%
Efficiency



N-type Bifacial
Mono Solar Cell
(N-PERT Cell)

Mass-produced
in Jolywood

>22%
Efficiency



Tunnel Oxide Passivated
Contact Cell
(N-TOPCon Cell)

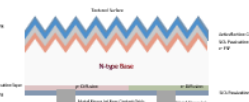
To be mass-produced
in Jolywood

>23.0%
Efficiency



Interdigitated
Back Contact Cell
(N-IBC Cell)

>24.0%
Efficiency



Heterojunction
Back Contact Cell
(N-HBC Cell)

Everyone Starting to go TOPCon

boVIET

Progress of n-TOPCon of Boviet Solar

N-TOPCon

Fabrication processes of the n-TOPCon structure

Remove Damaged layer

RCA Clean

Oxide

PECVD Si film

Post anneal

Passivating structure

N⁺ Si film

SiO₂

n-Si

SiO₂

N⁺ Si film

1. SiO₂ (1.2 nm–1.8 nm)

✓ HNO₃ bath

✓ Thermal oxidation

2. N⁺ Si film: PECVD.

3. Post anneal: 800-900°C

Wafer covered by SiO_x/poly-Si(n⁺)

Implied V_{oc}

Maximum I_{sc}: 732 mA by Sinton WT-120

New PV application

TOPCon cell architecture

The TopCon cell has been developed by Fraunhofer ISE. Our OCTOPUS is used for further research on the structure.

25.1 %

Fraunhofer ISE

SiO_x layer

n-doped c-Si layer

Back contact layer

AR layer

Passivation layer

P-doped layer

n-type Cz Si (239 cm²)

tunnel oxide

poly-Si

c-Si

5 nm

INDEOTEC intends to develop a process window for the PECVD deposition of both the SiO_x and n-doped c-Si layers by using the epitaxial layer deposition method for SiO_x (epi-deposition is also used for QUANT Austria).

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Confidential - Do NOT disclose

Page 55

Passivating and Selective Contacts High Temperature Approach

TOPCon Structure

1.1nm

a-/nc-Si

SiO_x

1.2nm

c-Si

5 nm

Tunnel oxide

E_c

E_f

E_v

n-Si Base

Polycrystalline Si(n)-Layer

Post, IEEE Transactions on Electron Devices (1992)

F. Feldmann et al., SOLMAT 120 (2014)

U. Rörmann, et al. IEEE Journal of Photovoltaics (2015)

D. Yan Solar Energy Materials and Solar Cells (2015)

16

© Fraunhofer ISE, FHG-ISC INTERNAL

Fraunhofer ISE

Semco | HORTUS LPCVD

HORTUS

Passivated Contacts

ONE STEP

Tunneling Oxide + In Situ Doped Polysilicon

7000 Wafers / Process Cycle

SEMCO

ECM Technology Group

Tunneling Contact (TOPCon)

TOPCon as Passivated Rear Contact
n-TOPCon BSF and High Efficiency Boron Front Side

	V _{oc} [mV]	J _{sc} [mA/cm ²]	FF [%]	PFF [%]	η [%]
TOPCon	715.5	41.5	82.1	85.0	24.4*

Tunneling Oxide Passivated contact (TOPCon)¹ combines

- High doping efficiency of partly crystallized silicon thin film
- Low minority carrier recombination
- Efficient majority carrier transport
- 1D junction
- SiO₂ buffer allows higher temperatures for back-end processing

¹Feldmann et al., SOLMAT (2014)
*FZ-Si, n-type, 212 cm² aperture area, confirmed by Fraunhofer ISE Callab

M. Bivour, F. Feldmann, K.-U. Ritzau, M. Hermle, S. Glunz, 24th Workshop on Cryst. Si Solar Cells & Modules, July 29, 2014

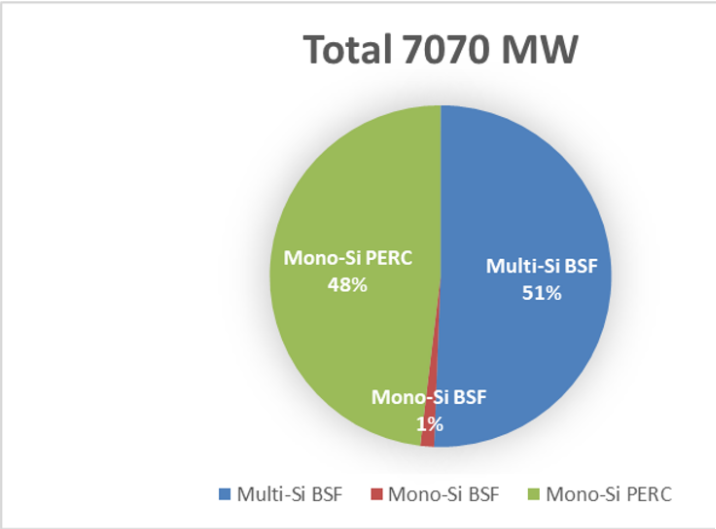
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● ● 2019
Penang, Malaysia

PERC Transition In Progress

Cells Produced by JA in 2018

JASOLAR

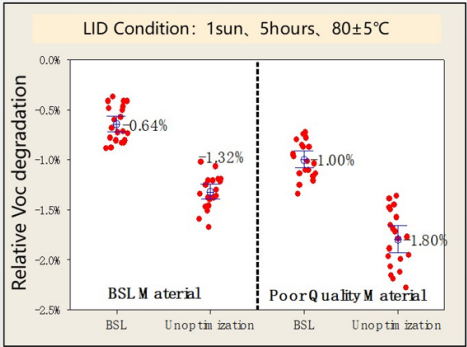


3/12/2019

PVCellTech 2019



LeTID on Mono PERC

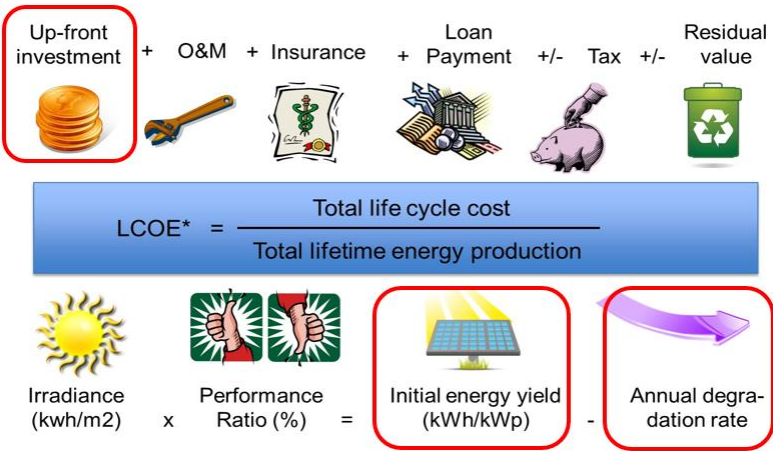


- LeTID is generally believed to be related to metal impurity and H defect in the wafer substrate
- LONGi Solar, as integrated ingot/wafer/cell/module manufacturer, has tackled this issue from multiple directions: improve wafer quality and optimize cell processes

2. Design and MFG the world best PERC



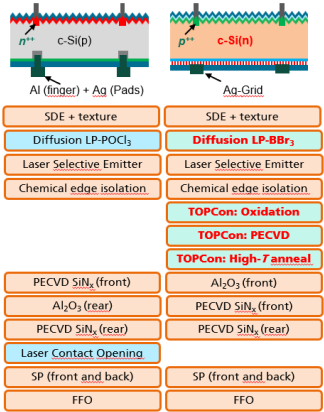
2.1 Criteria for selection: High Eff%, Good Passivation, Low Degradation



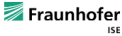
But Main Focus was on TOPCon ‘Industrialization’

Challenges for Industrial Implementation of TOPCon

- How to upgrade from existing PERC lines?
- Material
 - Change from p- to n-type silicon material
- Front side
 - Replace POCl₃ with BBr₃ diffusion, shift AlO_x/SiN_x passivation
- Rear side
 - Implement TOPCon layer formation (replacing LCO)
 - Adapt metallization grid

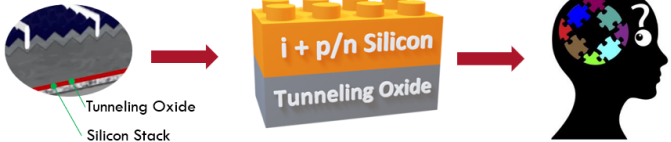


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© Fraunhofer ISE



Passivated Contacts

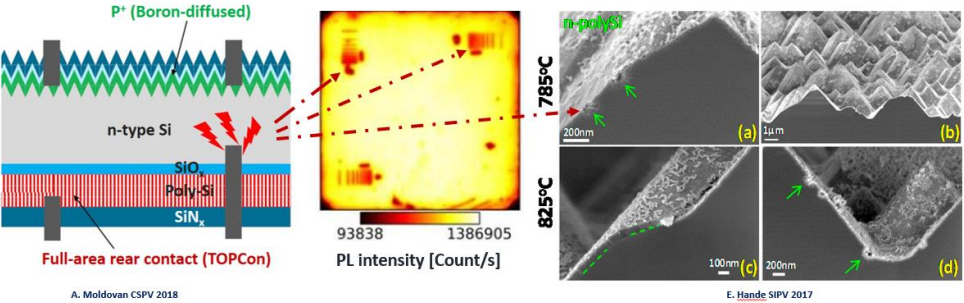
Manufacturing Basics



	Wet Process	ALD	APCVD	PECVD kHz	PECVD MHz	LPCVD Classic	Semco LPCVD	AP Diffusion	LP Diffusion	Ion Implant
n/p Doping	-	-	-	★★	★	★★	★★★	★	★★	★★★
Intrinsic Silicon	-	-	★	★★	★★	★★★	★★★	-	-	-
Tunneling Oxide	★★	★★★	★	★	★★	★★★	★★★	★	★★★	-
Best fit	⊖	⊖	⊖	⊖	⊖	⊕	⊕⊕	⊖	⊖	⊖



Challenges in its industrialization



Screen printing :

- Ag paste creating nanoclusters and penetration through poly
- Very thick poly-Si needed for current generation of pastes
- Further paste development essential to avoid spiking through the layer-stack

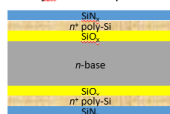
... and more on TOPCon into Mass Production

Results

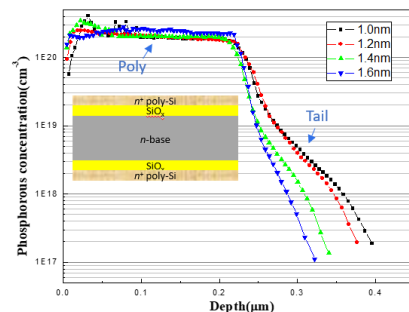
Rear tunnel oxide tuning

Oxide thickness (nm)	SHR (Ω/\square)	j_0 (fA/cm ²)
1.0	20.3	58.2
1.2	20.9	50.8
1.4	21.5	28.0
1.6	20.1	15.9

jo test sample



- 200nm doped (865°C POC13) poly atop thermal SiO_x by changing the oxidation temperatures
- Very deep diffusion profiles with decreasing SiO_x thickness results in poorer passivation
- A slight increase in the SiO_x thickness will significantly increases the contact resistivity (not showed here)



5

The questions for industrialization of TOPCon?

The process of industrial TOPCon cell is undefined, just like PERC in 2014!

Trinasolar

TOPCon

Substrate

- P-type?
- N-type?

Thin oxide

- Wet-chemical?
- UV?
- Thermal?

Poly silicon

- PECVD?
- LPCVD?
- in-situ doping?
- Ex-situ doping?
- Annealing?

Metallization

- Evaporation?
- Screen printing?
- TCO?

Others

- Cell structure?
- Process flow?
- Indus. maturity?
- Yield?
- Cost?

PERC in 2014

Substrate

- P-type?
- LID?

Passivation

- AlO_x:H?
- Thermal SiO₂?
- SiO_xN_y:H?
- SiN_x:H capping?

AlO_x

- ALD?
- PECVD?
- PVD?

Metallization

- LFC?
- Laser/chem. opening?
- Evaporation?
- Screen printing?

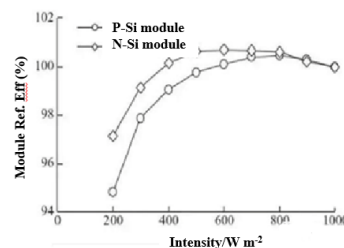
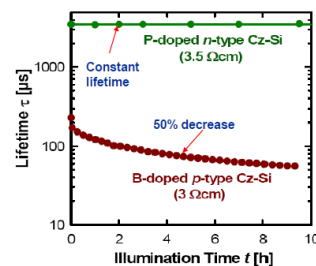
Others

- Cell structure?
- Process flow?
- Indus. maturity?
- Yield?
- Cost?

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16

Intrinsic Advantages of N-type Wafer: Higher Lifetime LONGI 隆基



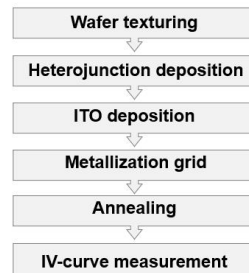
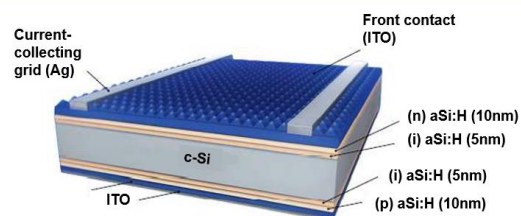
- ✓ N-type MCL is at least 1 order of magnitude higher than that of p-type
- ✓ N-type has better performance at low light intensities.

Ref: 1. P. P. Altermatt, *J. Comput. Electron.* (2011) 10:314-330.

2. Danyuan Song et al. Progress in n-type Si solar cell and module technology for high efficiency and low cost, 38th IEEE Photovoltaic Specialists Conference, Austin, USA 2012.

HJT Still Being Pushed

Why SHJ technology? - Simple technology with high efficiency!



World record for silicon-based solar cells - 26.3% (IBC-SHJ cell)
(Kaneka, 2017)

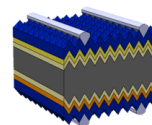
SHJ technology: c-Si substrate
high efficiency + low temp

Jinergy HJT Factory in Shanxi, China



- 2GW HJT production capacity planned in 5 years
- 100MW in commercial production now, 100MW new capacity will be added in 2019

liten



SHJ : A 10 GW EcoSystem is rising up
For the next three years

- HJT technology combines several key benefits to be among the next PV generations technologies

1. Power potential well above announced public roadmaps
2. Improved energy yield due to T coefficient and bifaciality
3. Adapted to thin wafer leading to cost reduction and LCA benefit

Looking for :

- Industrialization of HJT technology at GW scale associated to a development Roadmap towards Tandem for 30%.
- Collecting additional data regarding SHJ production yield benefits at the MW level including new features like

MEYER BURGER PROJECTS WITH EUROPEAN HETEROJUNCTION MANUFACTURERS 3SUN AND ECOSOLIFER



Ecosolifer Csorna, Hungary



3SUN/ENEL, Catania, Italy



Manufacturing 2019+ • PV CELLTECH 2019



Industrialization Development of Heterojunction Technology & Prospect

中智（泰兴）电力科技有限公司

China Intellectual Electric Power Technology(Taixing) Co., Ltd.

2. The UFLPA problem; the Patent problem

- Western relationships with China were good as China PV starting to become dominant
 - CTOs & R&D experts happy to talk technology
 - PV CellTech was chosen by many as a main route for this 2016-2019
- Then Xinjiang topic. Then patent/political protectionism.
- Climate flipped from happy-to-talk to frightened-to-talk. At least, nowhere near what we saw in the past.

- But...
- Technology in PV manufacturing is only starting and how the sector globally grows from 1 TW annual to 10 TW will not be driven by one company, one country, politics, protectionism, ... etc.
- In 10 years, likely a new set of companies will control the industry, with technologies nowhere near mass production today...

Thanks for the Past 10 Years!

Finlay Colville

Head of Research - PV Tech

Chair - PV CellTech & PV ModuleTech Conferences