Looking Back at 10 Years of PV CellTech

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Head of Research - PV Tech
Chair - PV CellTech & PV ModuleTech Conferences

PV CellTech Europe 2025 | Frankfurt, Germany | 12 March 2025

Contents

1. The Malaysia Years: 2016 to 2019

2016
Kuala Lumpur, Malaysia

2016

CONFERENCE

PVCELLTECH

EVENT PROGRAMME

16-17 MARCH 2016 | KUALA LUMPUR, MALAYSIA

celltech.solarenergyevents.com

Host Partner

MIDA
MALAYSIAN INVESTMENT DEVELOPMENT AUTHORITY

Lunch Partner

MEYER BURGER

Technology Innovation Partners

DUPONT

TEMPRESS AMTECH GROUP

Supporting Partners

COVEME THE VALUE OF INNOVATION

SWISS MADE INDEOtec PLASMA PROCESS EQUIPMENT

LUVATA

MacDermid Enthone ELECTRONICS SOLUTIONS

oerlikon leybold vacuum

2016

MALAYSIA SOLAR ECOSYSTEM

R&D → Metallurgical Silicon → Poly-Silicon → Ingot → Wafer → Cell → Modules → Balance of System

R&D: SERI Solar Energy Research Institute; AUO SunPower; Hanwha Q CELLS; HB; JinKO Solar

Metallurgical Silicon: ELPION

Poly-Silicon: TOKUYAMA

Ingot: COMTEC Solar Systems

Wafer:
- COMTEC Solar Systems (N-Type Mono-Crystalline)
- AUO (N-Type Mono-Crystalline)
- SunEdison (P-Type Mono-Crystalline)

Cell:
- JinKO Solar (Multi-crystalline)
- TS (Multi-crystalline)
- (Multi-crystalline)
- Hanwha Q CELLS (Multi-crystalline)
- AUO SunPower (N-Type Mono-Crystalline)

Modules:
- JinKO Solar (Multi-crystalline)
- First Solar (Cadmium Telluride (CdTe) Thin Film Module)
- Panasonic (High-efficiency HIT)
- flex (OEM Multi-crystalline)
- MSR (Mono & Multi-crystalline)
- SolarTIF (Multi-crystalline)
- PVHITECH (Multi-crystalline)
- EPV Inverters & Modules (Mono & Multi-crystalline)

Balance of System: ABB; HUBER+SUHNER; Schneider Electric; Innotech Synergy; BARYSOL; iti tech

System Integrator: Eco-Gallery; phoenix SOLAR; SOL Lite Malaysia; LAURENZ LEISTUNG; GADING KENCANA An Energy Service Company

MIDA "Invest In Malaysia > *Your Profit Centre In Asia*"

2016

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

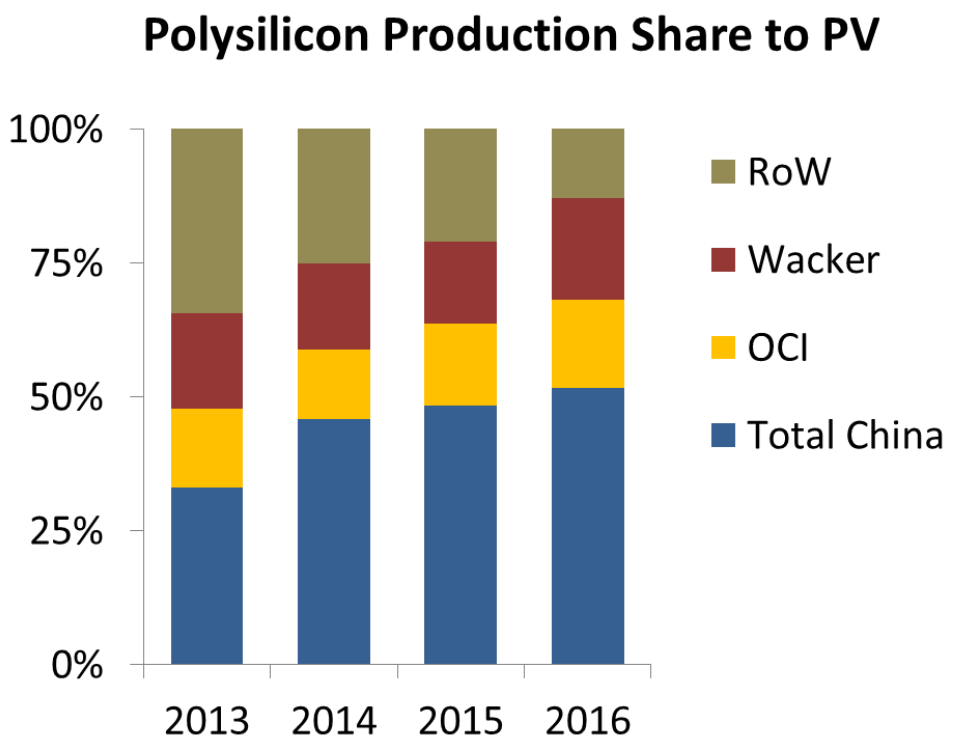
CONFIRMED SPEAKER BY CATEGORY:

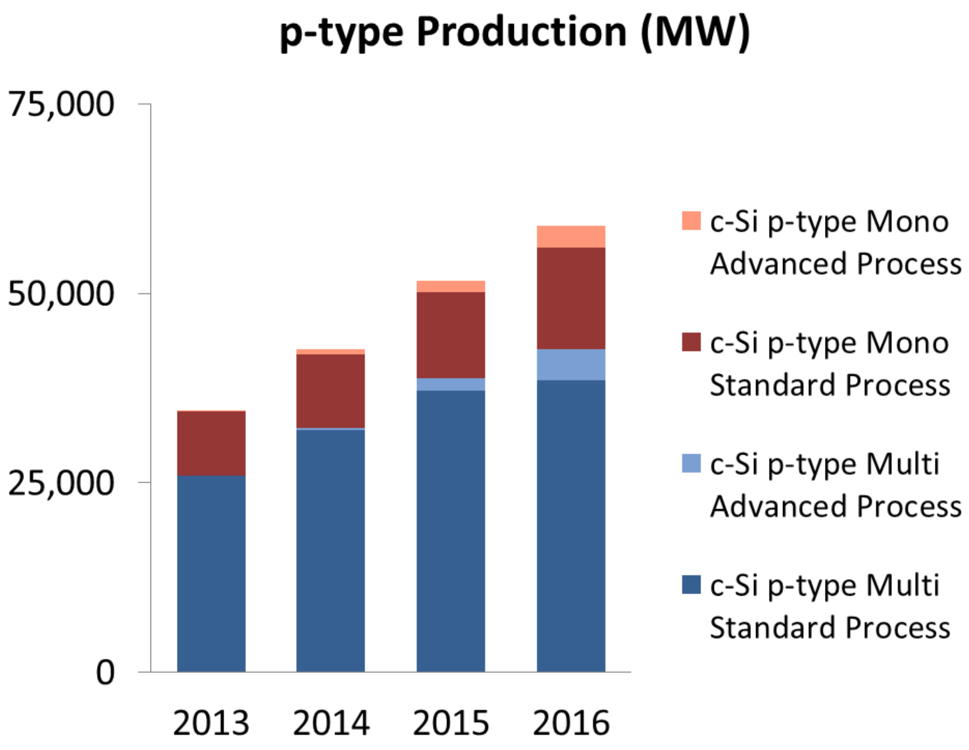
PV Manufacturers

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**

2016

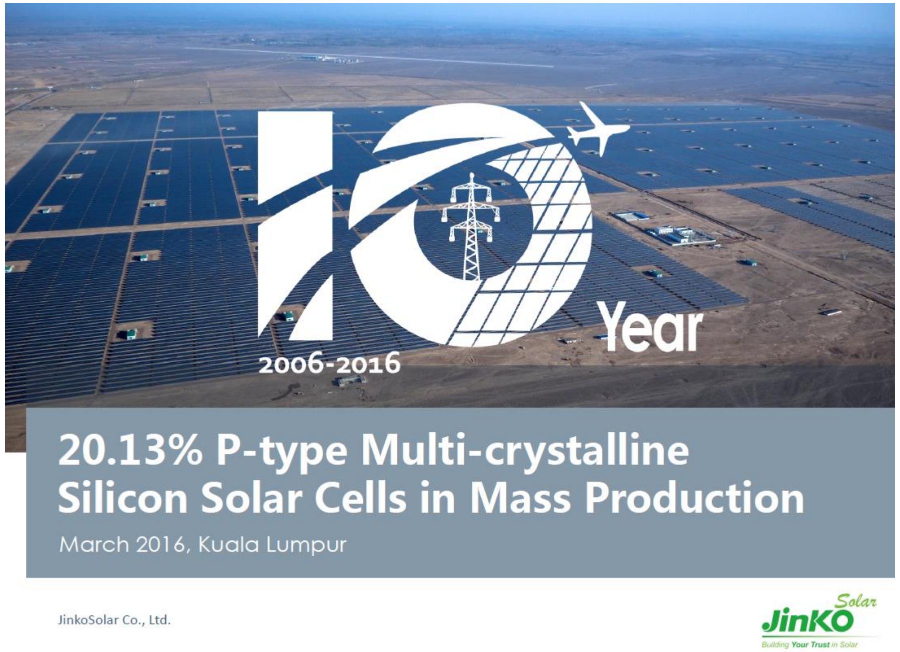
Only 50% of Poly was in China; Multi was Dominant





2016

Major China Cell Makers Still Pushing Multi…



2016

informa markets | PV TECH RESEARCH

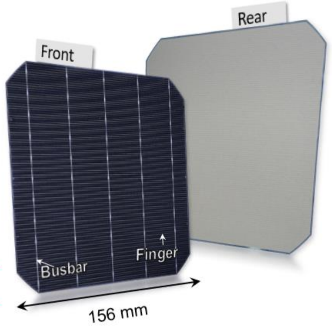
…but Main Topic was PERC Introduction to Mass Production

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_2O3/SiN_x Front ARC
Laser Contact Opening Rear
Screen Print Contacting
Contact Firing



AR coating	V_{oc} (mV)	J_{sc} (mA/cm²)	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

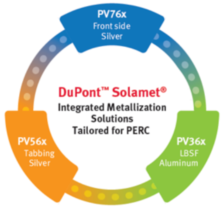
23

© Fraunhofer ISE

Fraunhofer ISE

DuPont™ Solamet® Integrated Metallization Solutions for PERC with

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

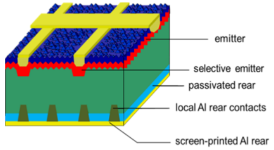


- Paste Package Designed for PERC
- Excellent Efficiency at Lower Firing Temp.
- Minimal Damage to Rear-side Passivation

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

17

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.

Progress & Perspectives in PERC / Holger Neuhaus / 16th March 2016 7

Mass Producible PERC PV Cells With Over 20% Conversion Efficiency

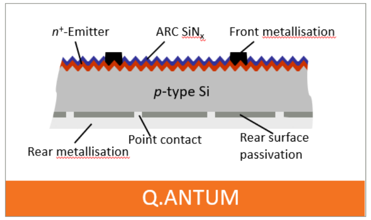
Prepared by W. Shan

Presented by Jack Song

JASOLAR

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

Hanwha Q CELLS



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 $J_{0,rear}$
- $V_{oc} \sim \ln(J_{sc}/J_{0,total}+1)$

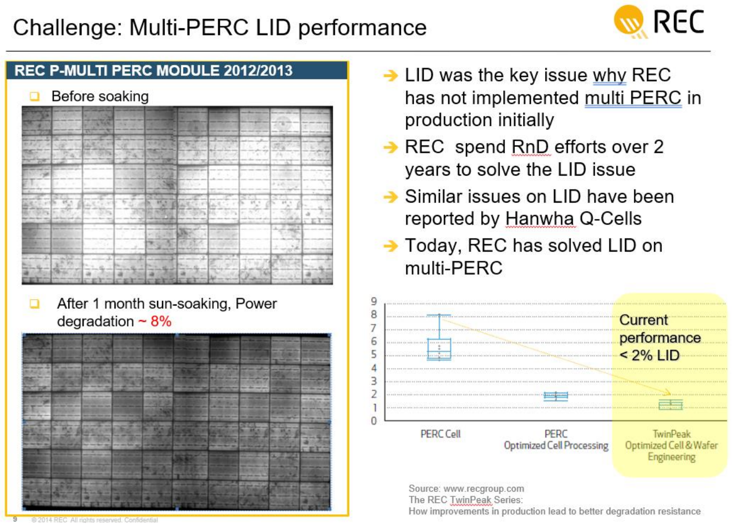
Lateral majority carrier transport
- Additional spreading resistance R_{spread}

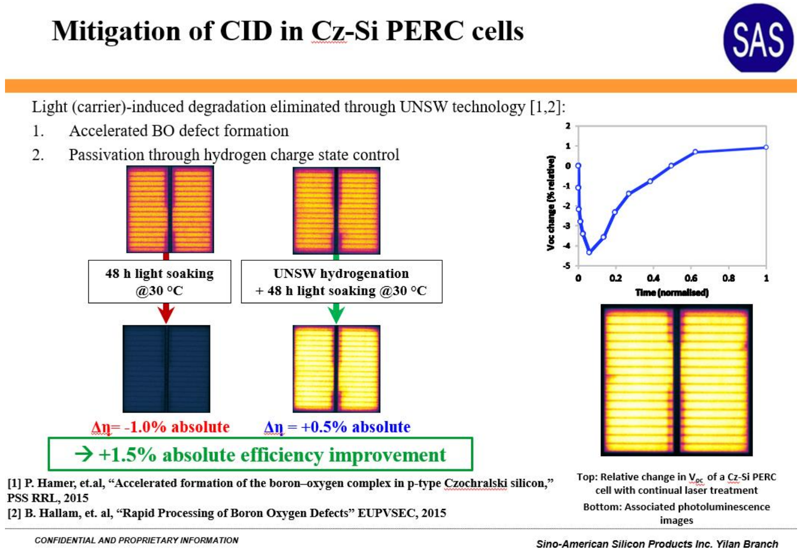
➢ $S_{eff,rear}$, $J_{0,rear}$, R_{spread} depend on wafer doping

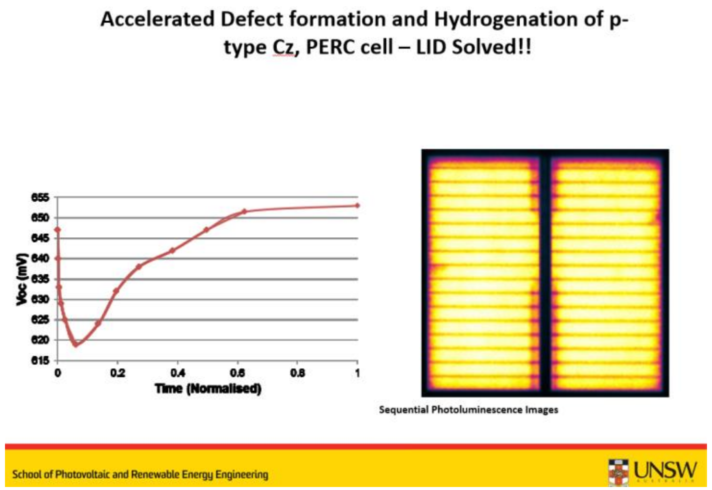
8 Leading edge Q.ANTUM Technology | Hanwha Q Cells | Jörg Müller | PV Cell Tech Conference | March 16th 2016

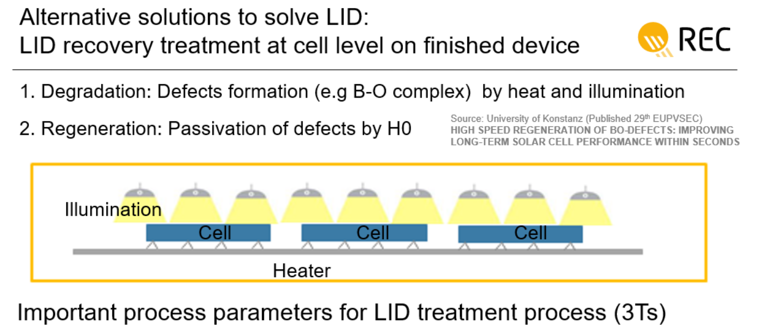
2016

…and Solving LID

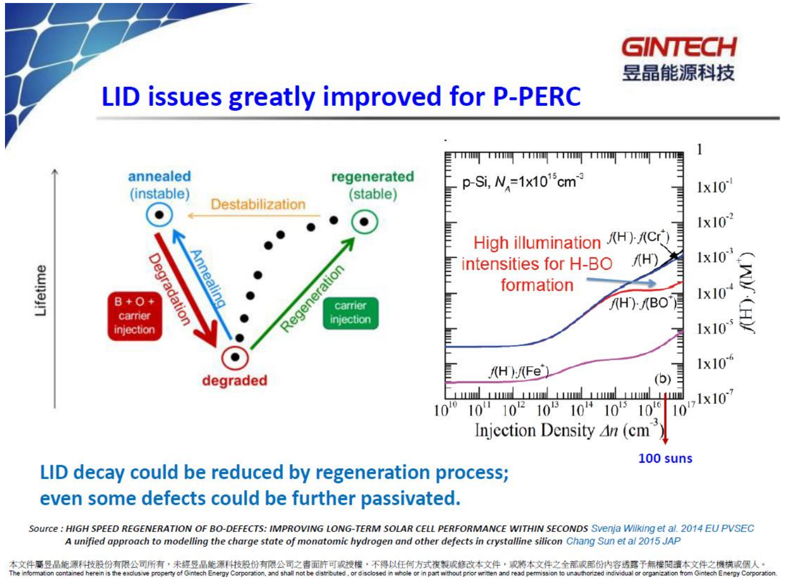






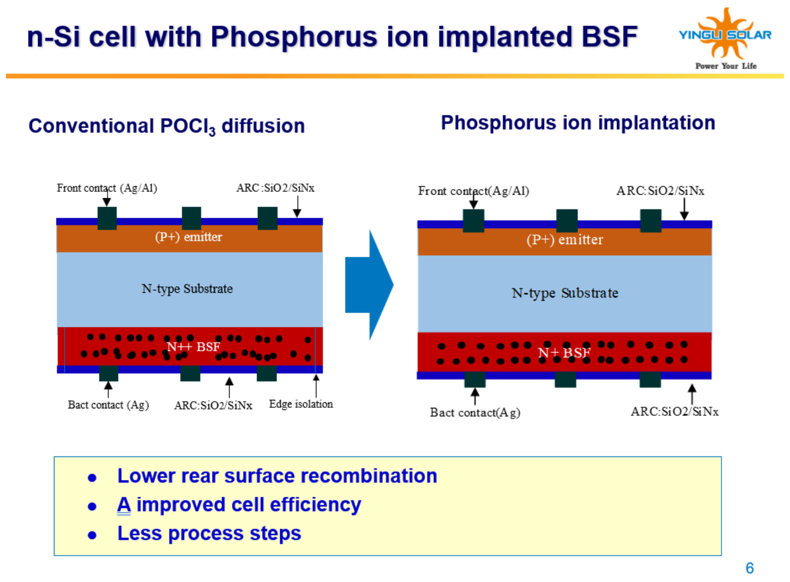


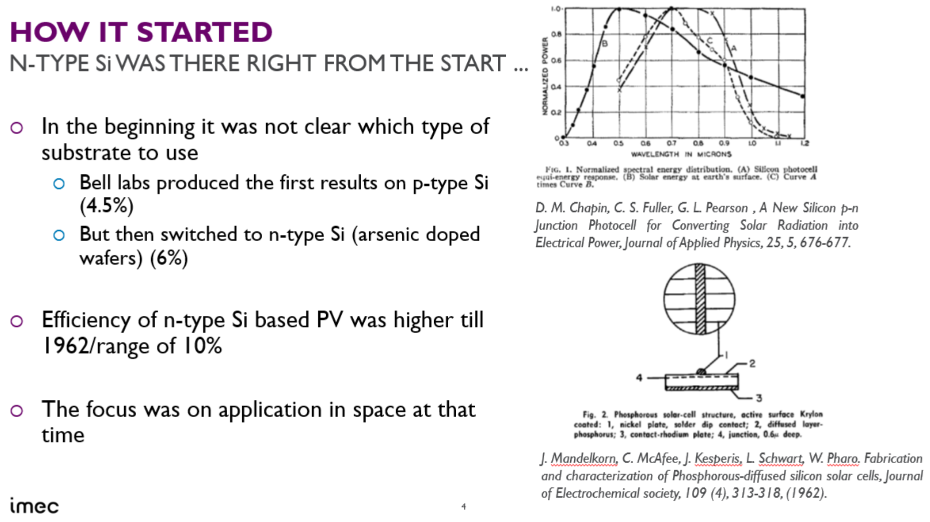
Test matrix for REC PERC cells	Temperature	Illumination InTensity	Time
Test conditions	High	High intensity	Short process 10s
	Med	Low intensity rec	Long process 30s
REC observations	200C. Too high temperature results in H0 effusion.	High intensity accelerates the treatment recovery process	10s with high intensity is adequate for treatment.

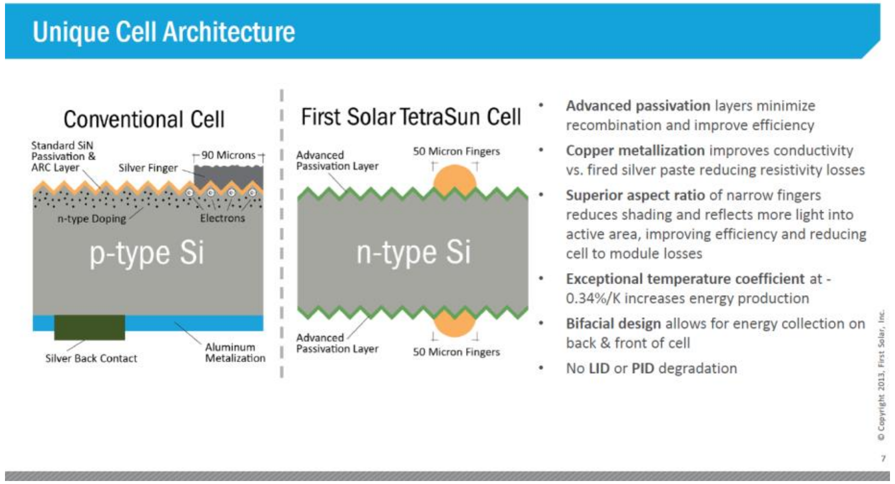


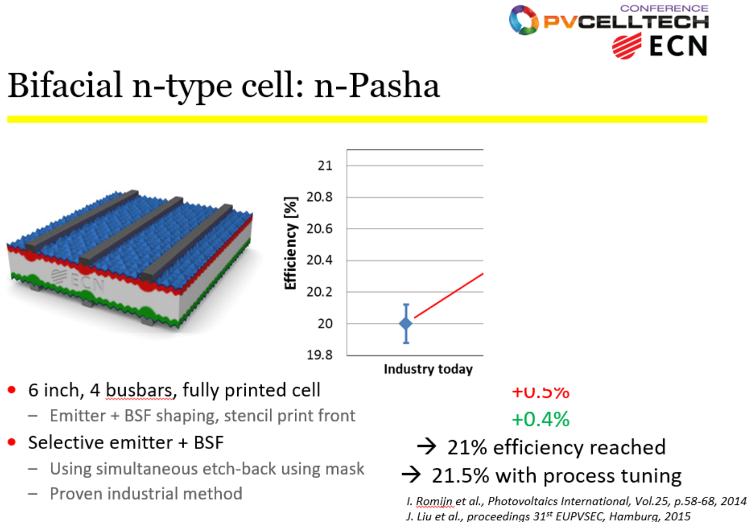
2016

n-type Talk from TetraSun?









2016

HJT & BC niche contributions

5.Summary

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

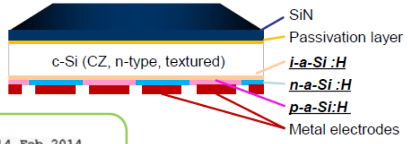
GCL

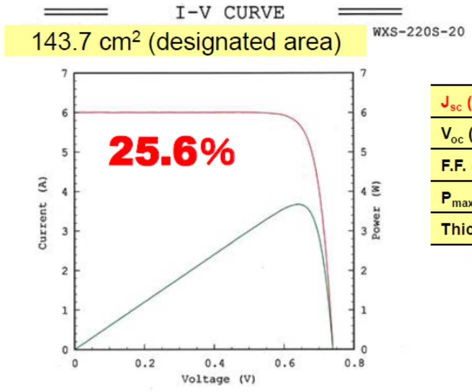
Brake through 25% efficiency

18

■ *Combination of SHJ and IBC technologies*

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





Date : 14 Feb 2014
Data No : V11287-02
Sample No : V11287

J_{sc} (mA/cm²)	41.8
V_{oc} (mV)	740
F.F. (%)	82.7
P_{max} (W)	3.674
Thickness (μm)	150

MIrr. 100.1 mW/cm2
Ref. Device No 036-2002
Cal. Val. of Ref. 125.83 [mA at100mW/cm2]
Scan Mode I_{sc} to V_{oc}

AIST

Temp. coeff. of η

-0.25% / °C

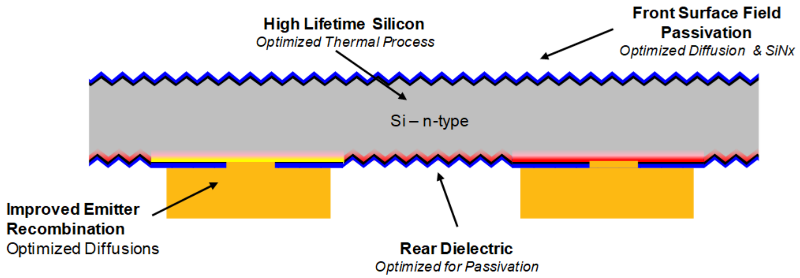
Mini-module using similar η cell

© Panasonic Corporation

PVCellTech Conference 2016, Kuala Lumpur

Panasonic

3. Manufacturable Design

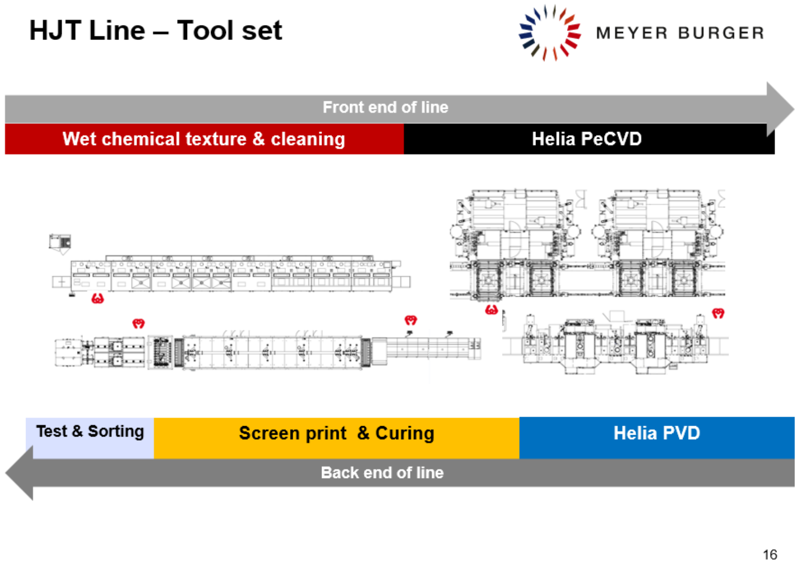


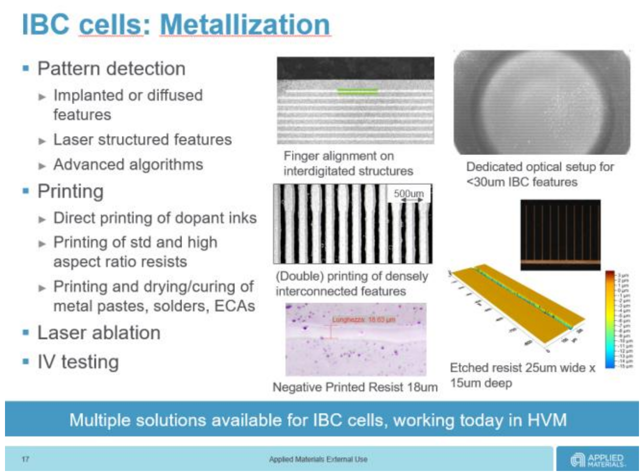
- Complexity is a compound effect
- Robust architecture & manufacturing design
- Strict factory controls (e.g. Lifetime, patterning precision, environment)

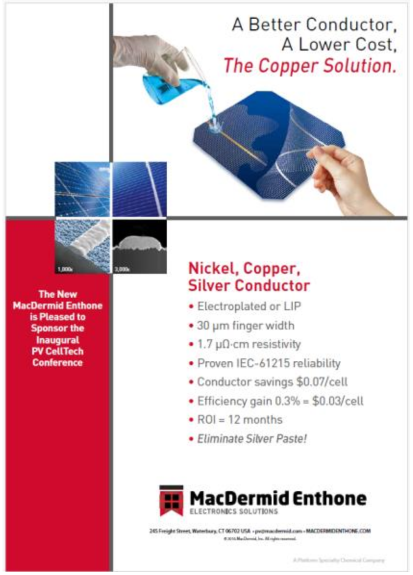
SUNPOWER

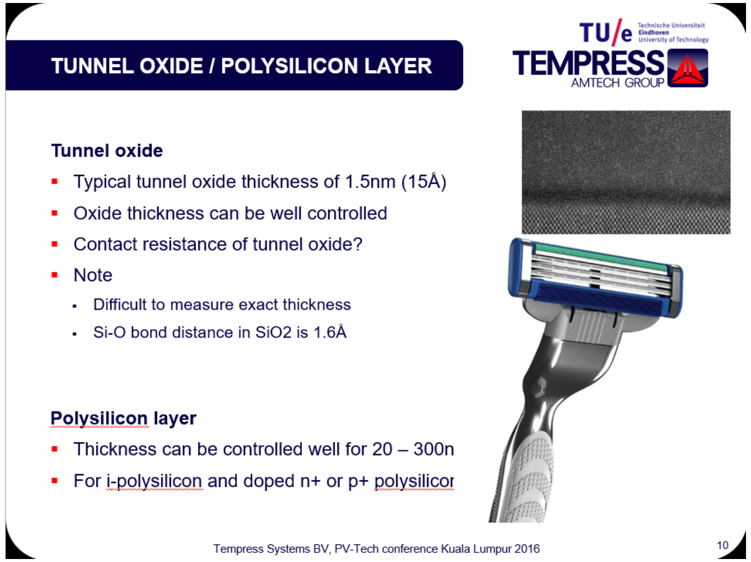
2016

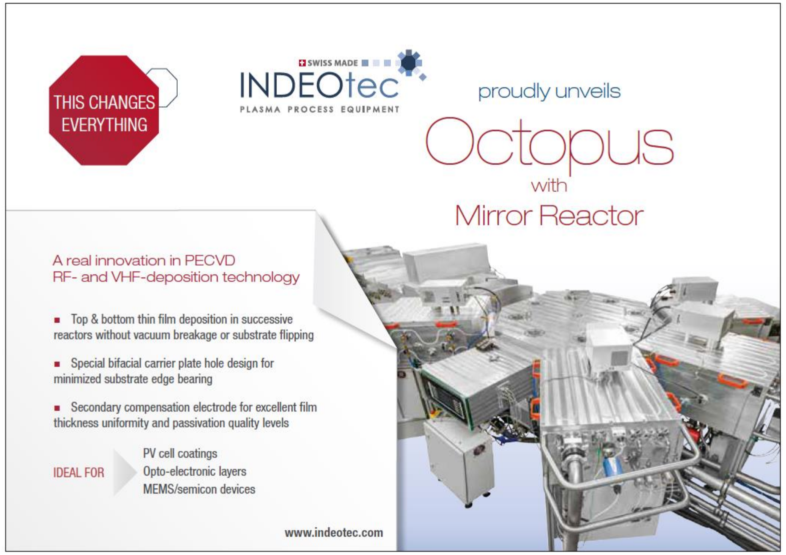
Tools & Materials Focused on n-type Options

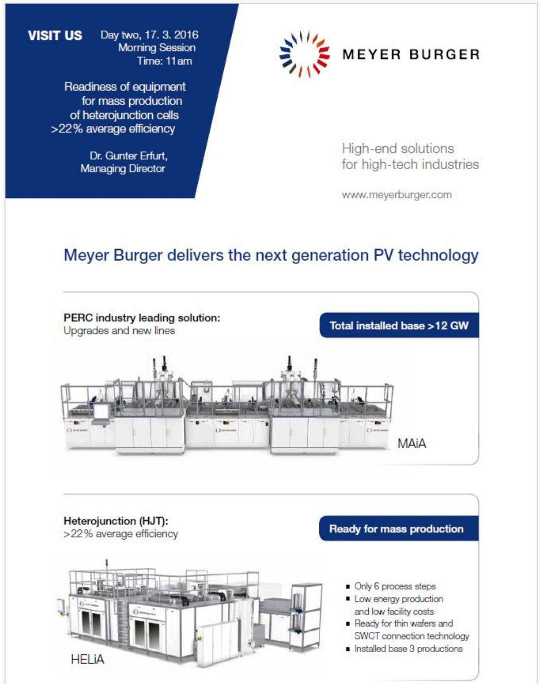












2017
Penang, Malaysia

2017

New Home for PV CellTech in Penang, Malaysia

Sponsors & Partners

2017

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. Elekronik
- 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)
- Tempress Systems (Amtech Systems)
- Trina Solar
- University of New South Wales (UNSW)

2017

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

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

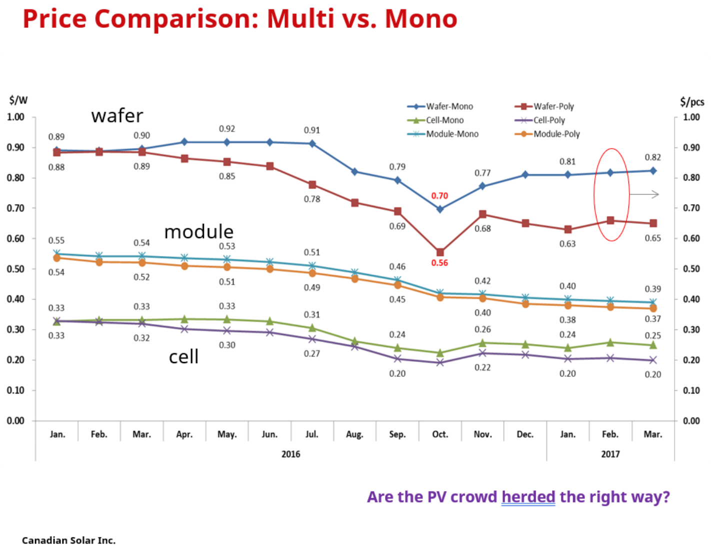
From China to Thailand: Talesun's solar cell manufacturing & technology
Paul Ni, Vice President - Technology and R&D Center, Zhongli Talesun Solar

Increasing the efficiency and quality of Indian produced solar cells
Paul Gupta, President, Indosolar

Cell Activity in SEA, India…

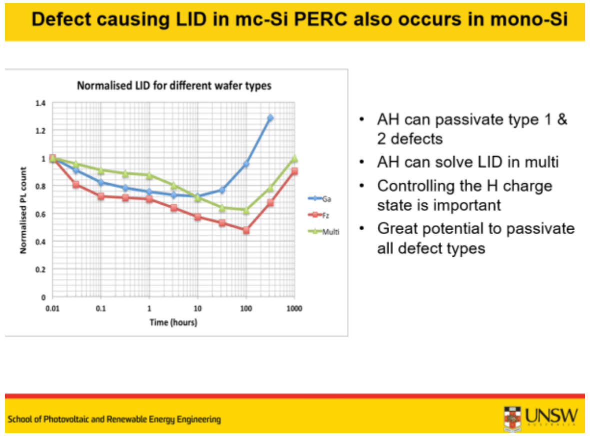
2017

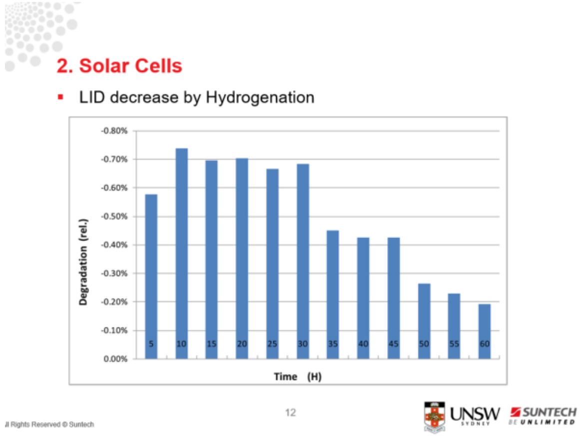
Some of Major Players still Pushing Multi

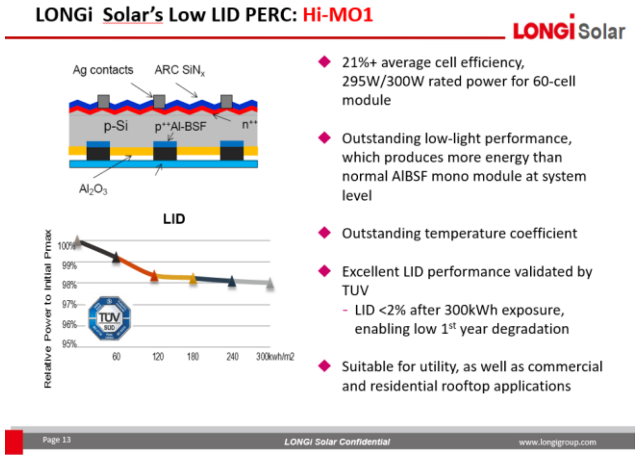


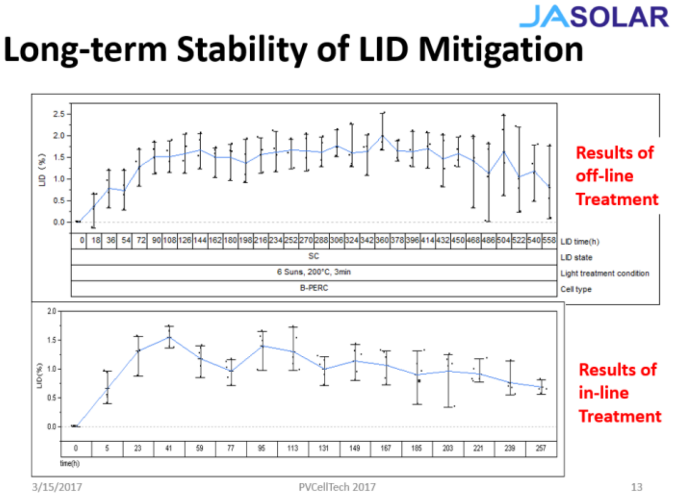
2017

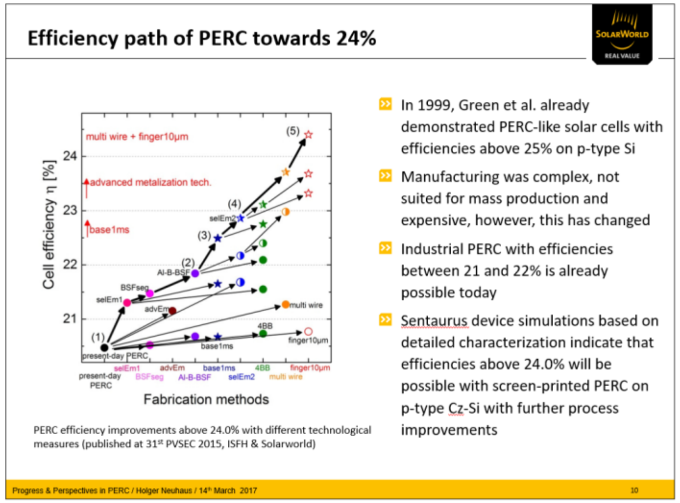
PERC & LID





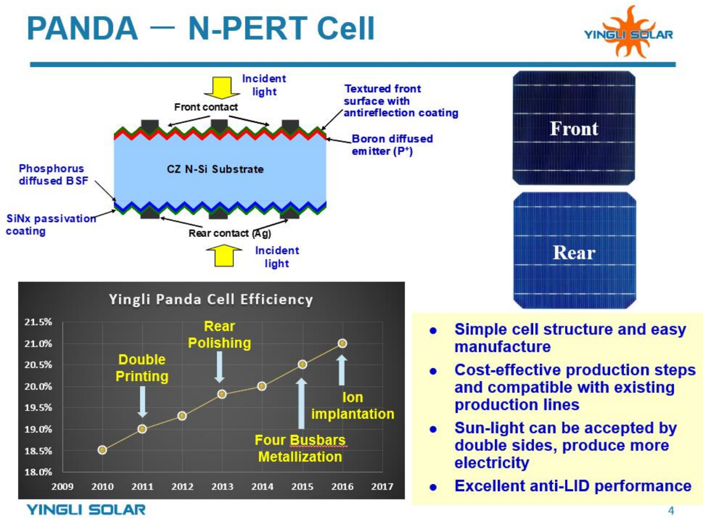


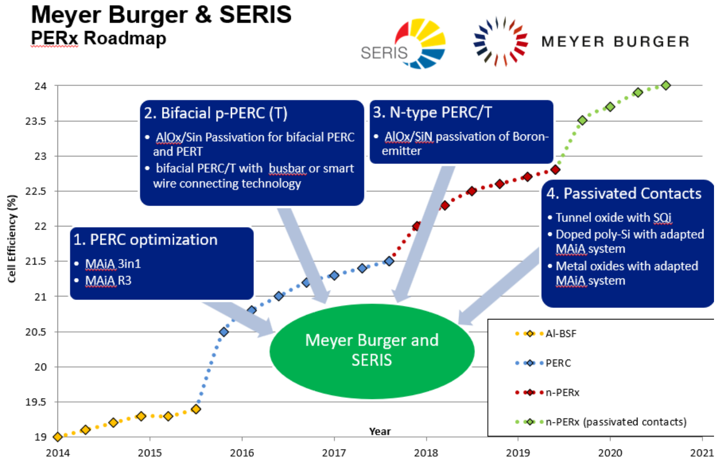


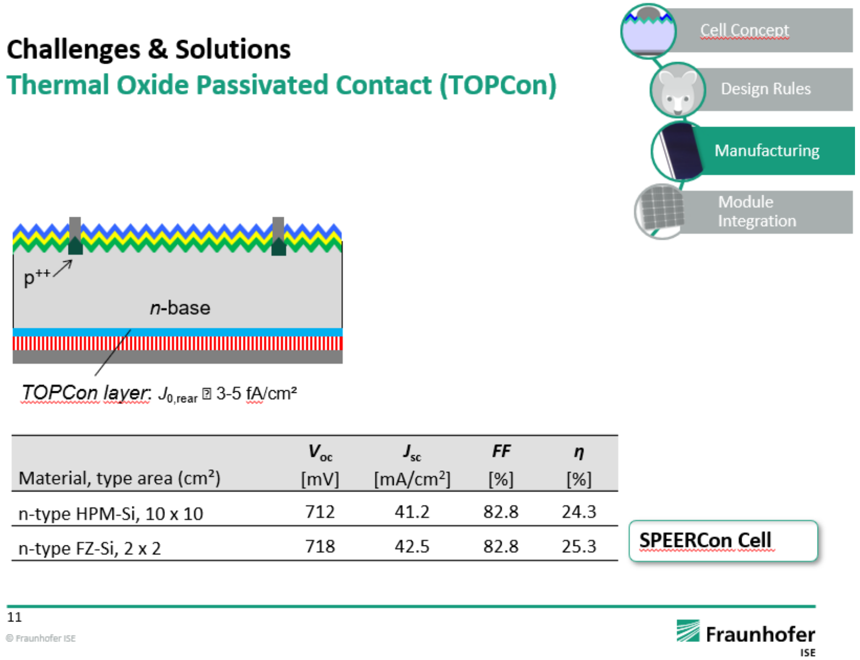


2017

More PERT & TOPCon



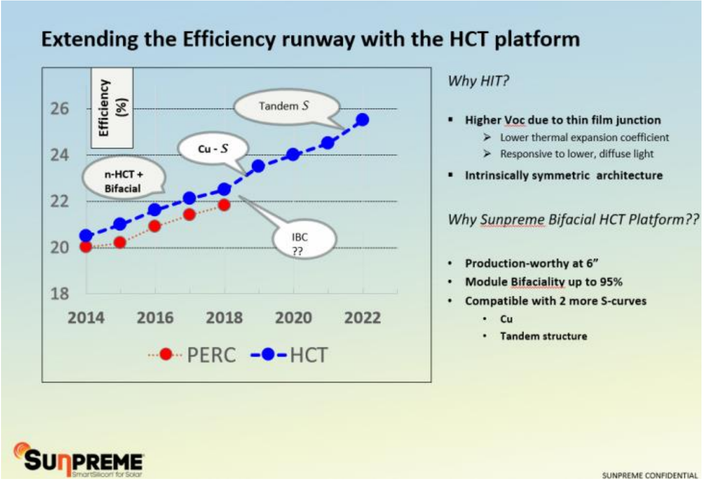


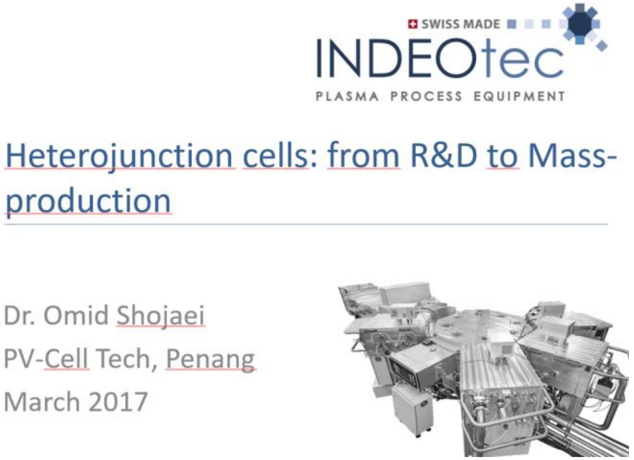


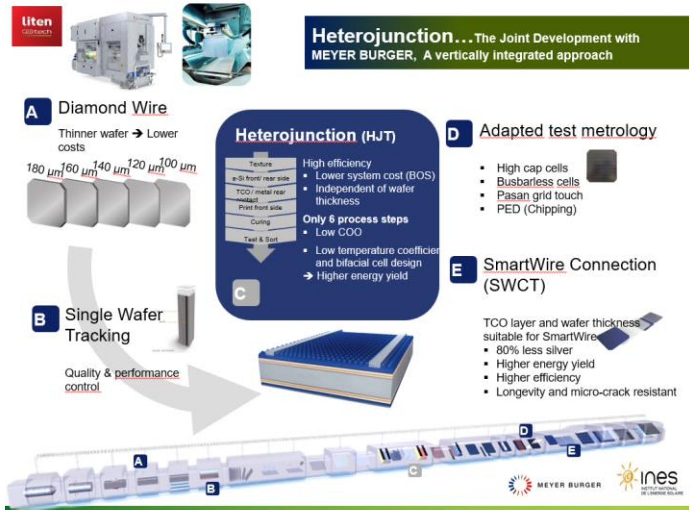
Material, type area (cm²)	V_{oc} [mV]	J_{sc} [mA/cm²]	FF [%]	η [%]
n-type HPM-Si, 10 x 10	712	41.2	82.8	24.3
n-type FZ-Si, 2 x 2	718	42.5	82.8	25.3

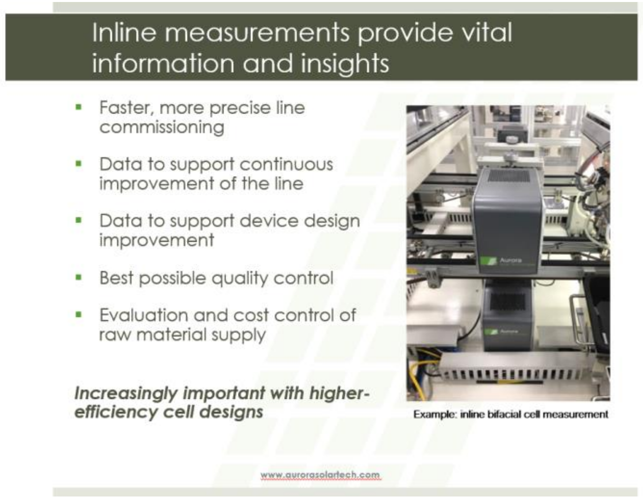
2017

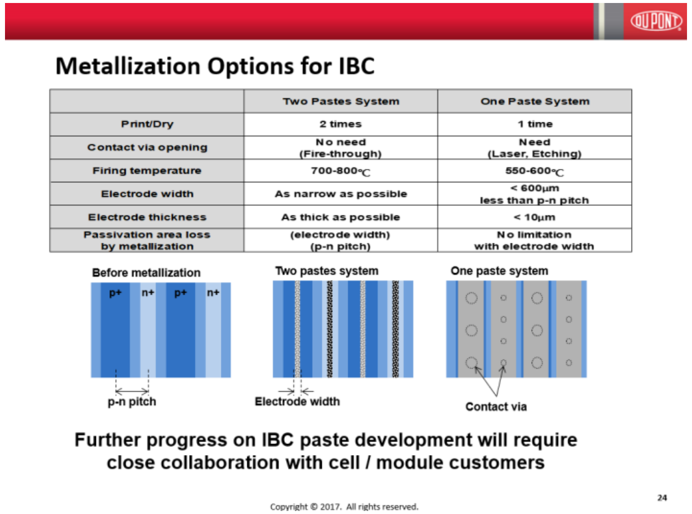
More HJT & BC from the Tool Makers



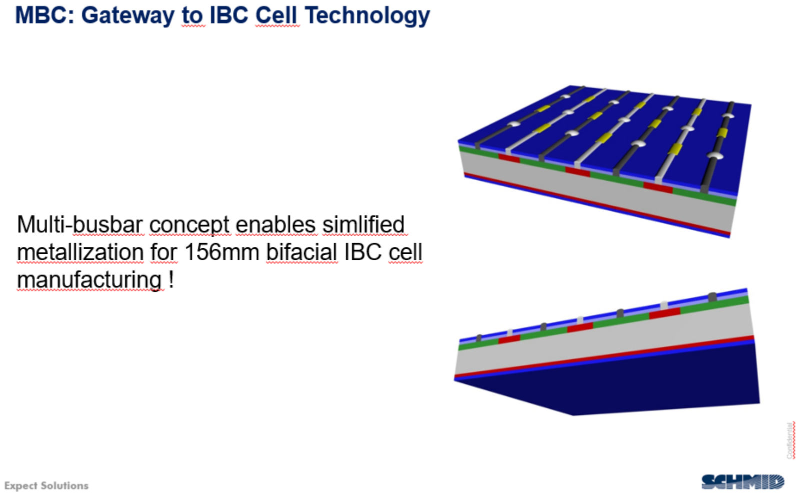






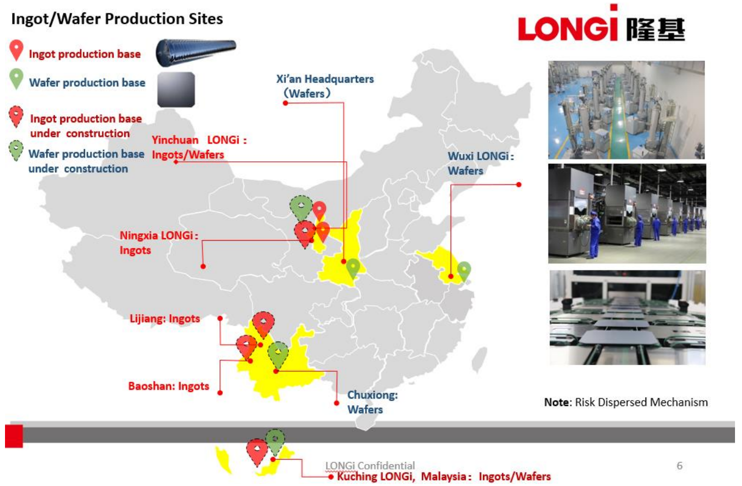


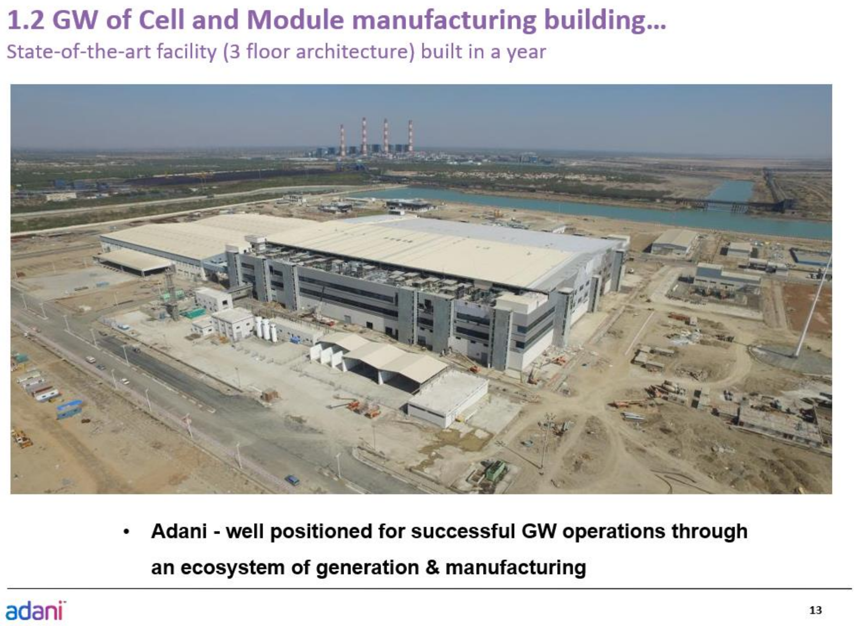
	Two Pastes System	One Paste System
Print/Dry	2 times	1 time
Contact via opening	No need (Fire-through)	Need (Laser, Etching)
Firing temperature	700-800℃	550-600℃
Electrode width	As narrow as possible	< 600µm less than p-n pitch
Electrode thickness	As thick as possible	< 10µm
Passivation area loss by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

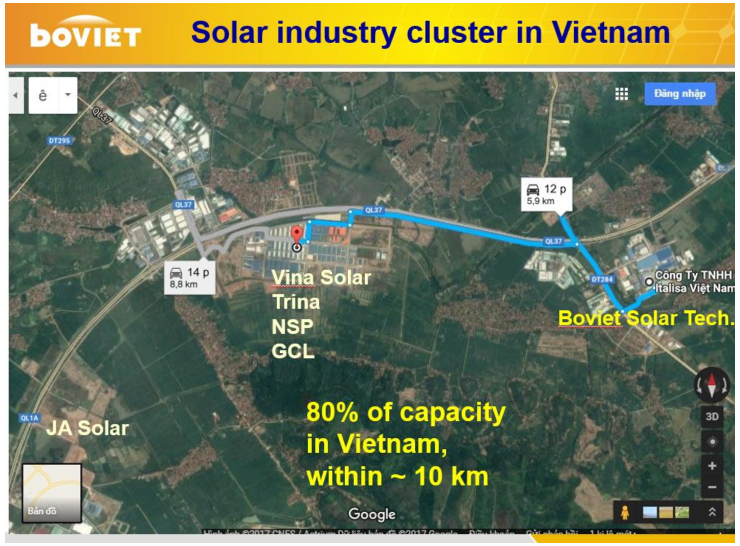


2017

Capacity Expansions Across Asia







2018
Penang, Malaysia

2018

Back to Penang...

PVTECH RESEARCH

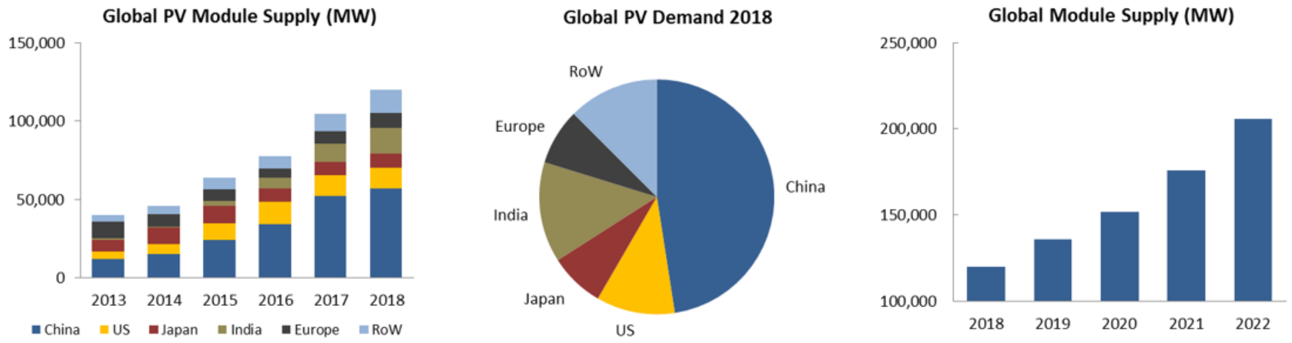
Cell technology trends impacting the 100GW-plus landscape

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

PV CellTech 2018, Penang, Malaysia

From 100GW to 200GW in 5 years

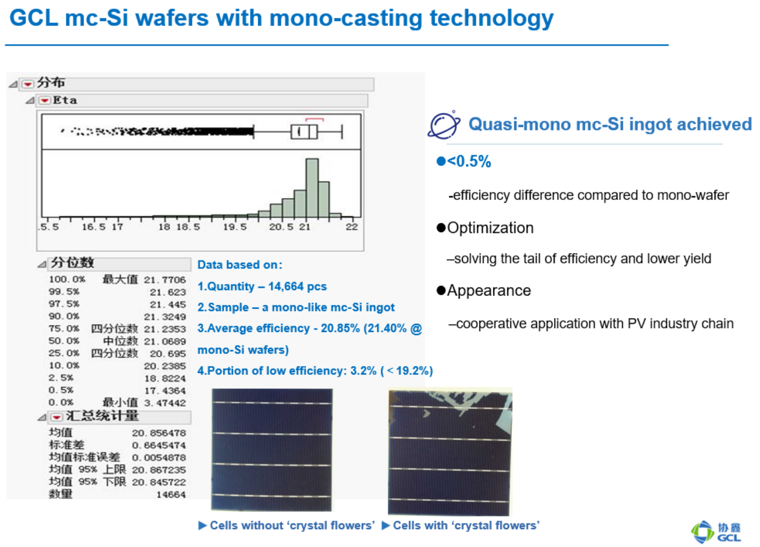
PVTECH RESEARCH

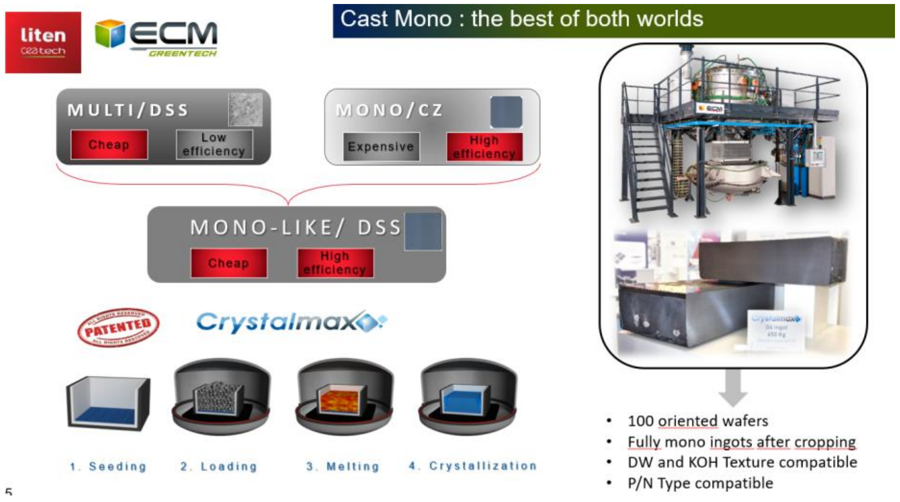


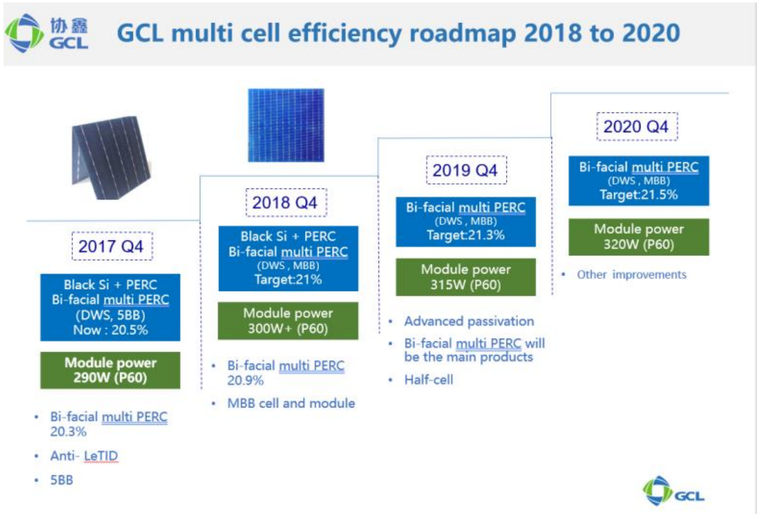
- From 2015, global growth has been dictated by China
- The end-market has doubled between 2013 and 2017
- Expect another 2X between 2017 and 2022
- This implies cell production >215GW in 2022

2018

Multi & Cast-Mono Still Being Pushed





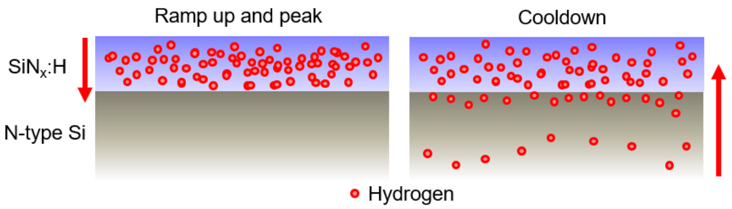


2018

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

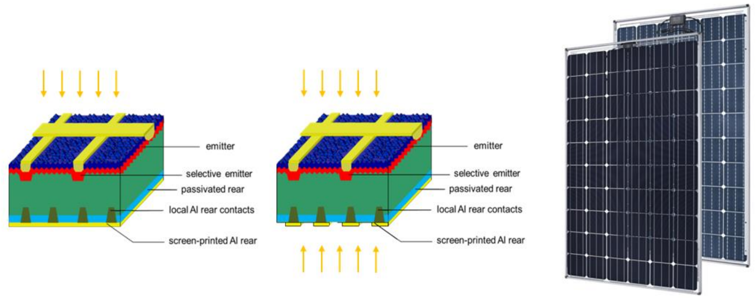


29 UNSW SYDNEY

Bifacial PERC module

SOLARWORLD QUALITY

- 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.*

ISC International Solar Energy Research Center Konstanz

What comes next after PERC?

monofacial super high efficiency concepts ?

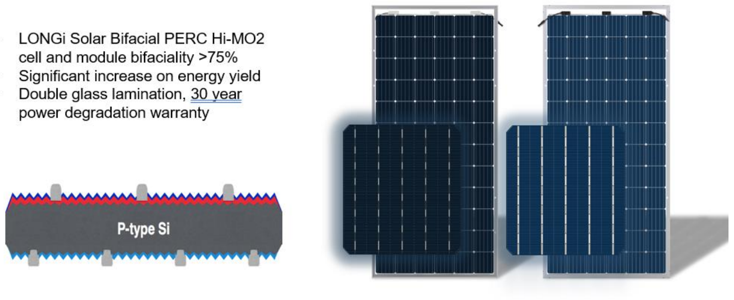
J. Libal, PV Cell Tech, March 13, 2018 17

LONGi Solar

Bifacial Technology

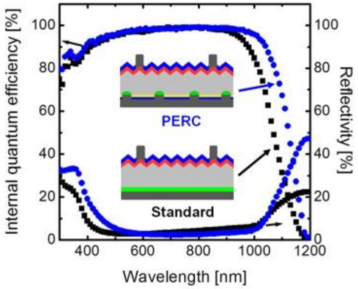
Mono-facial to Bifacial power generation

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



JinKO Solar

Advantages of PERC Cell

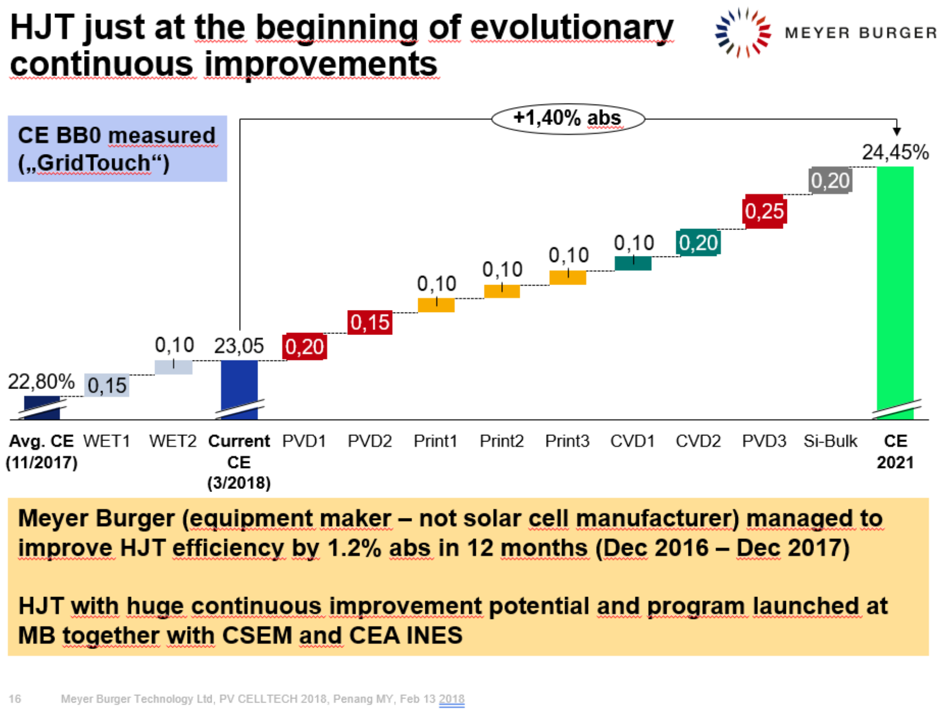


- Higher V_{oc}
- Better IR response

From ISFH

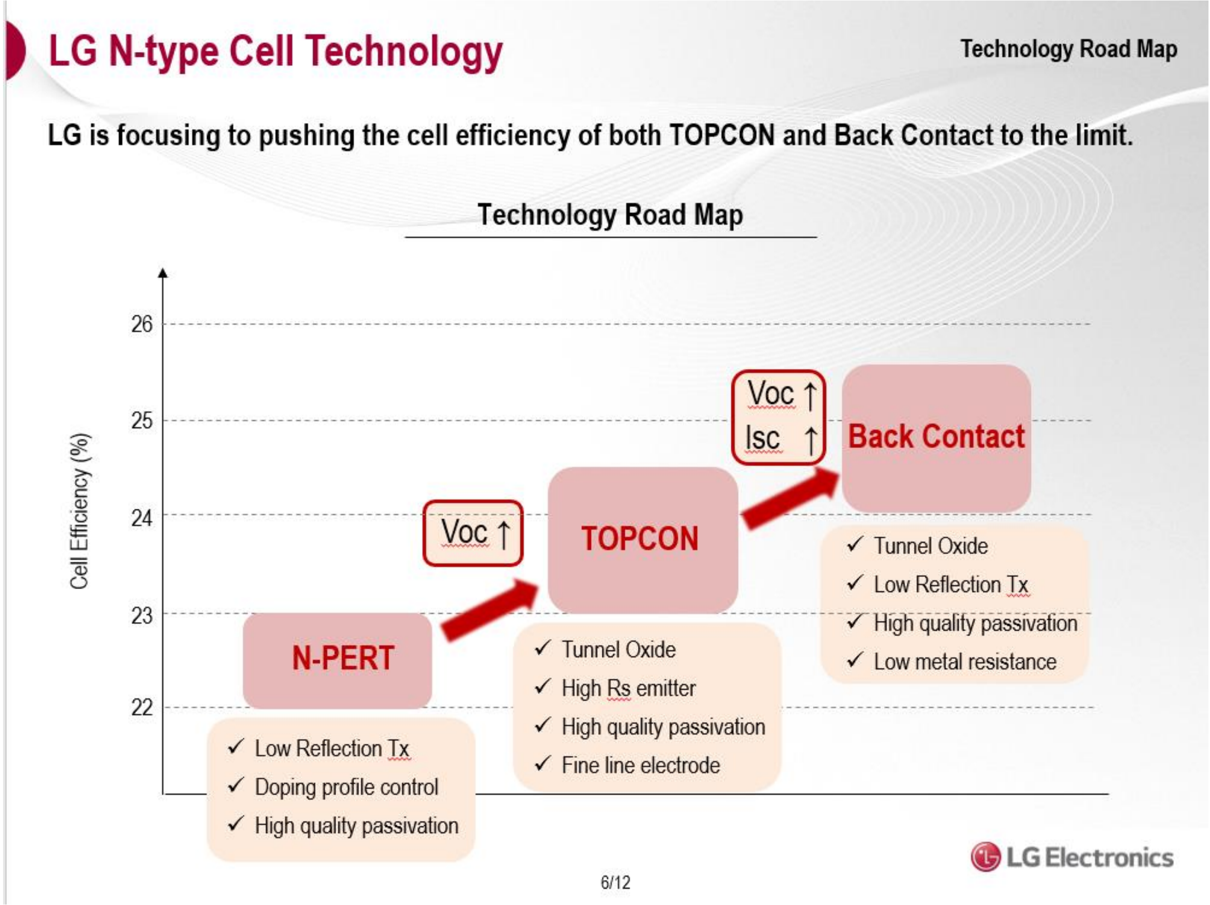
2018

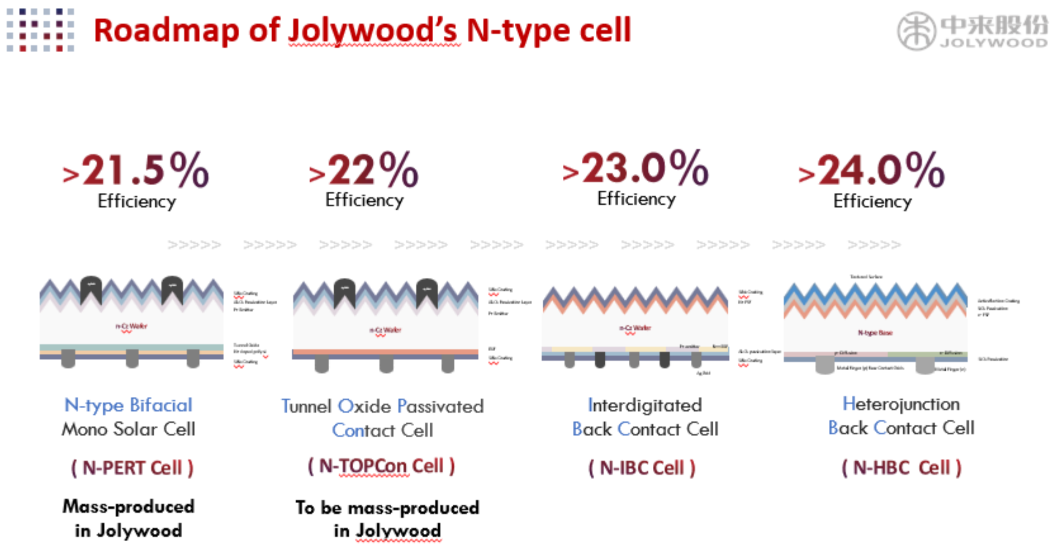
HJT Seeing Continued Interest



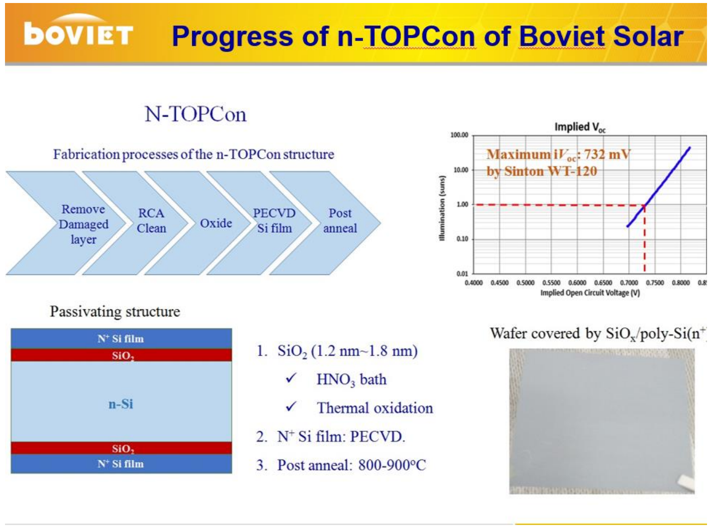
2018

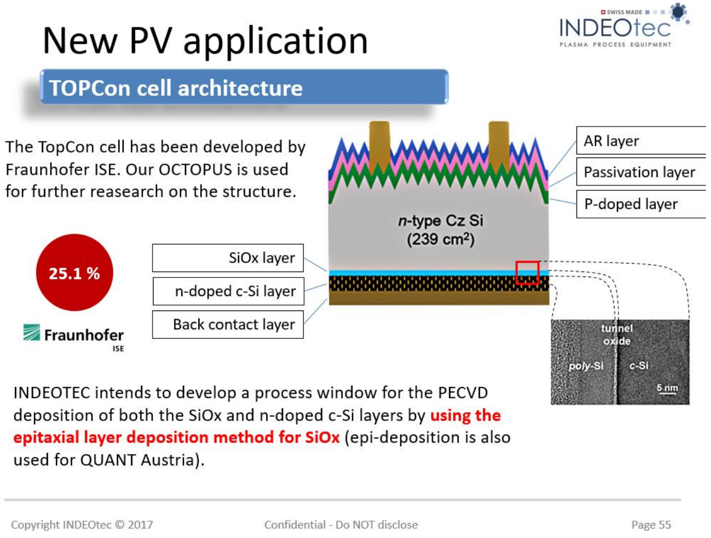
LG & Jolywood then the PERT/TOPCon Front Runners

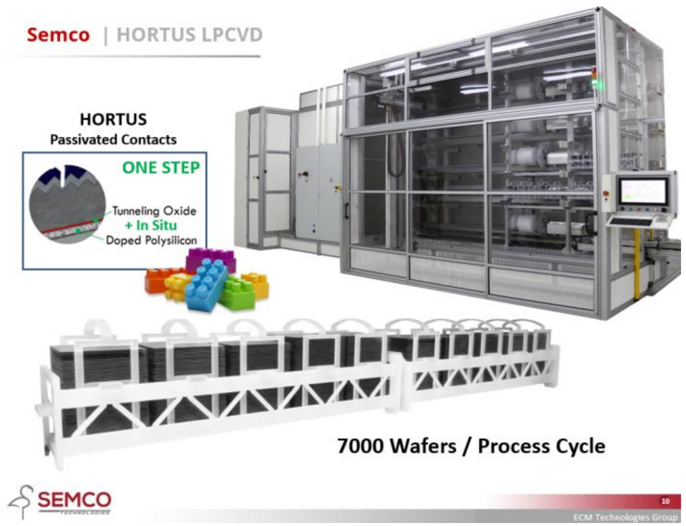


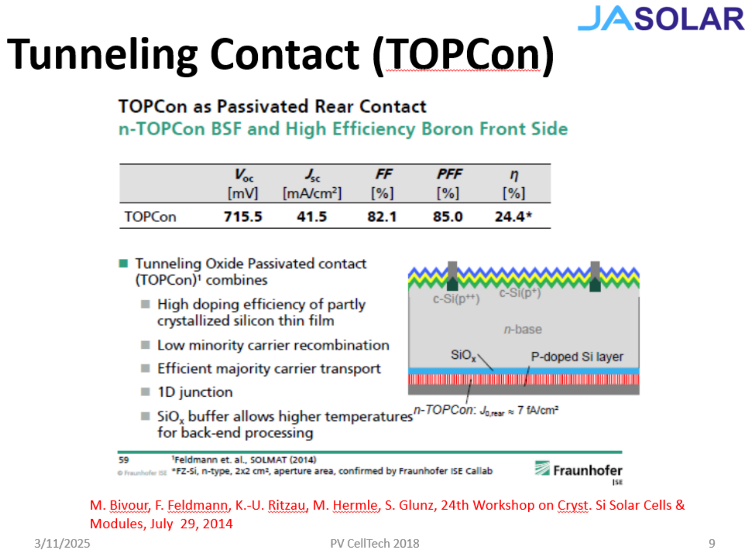


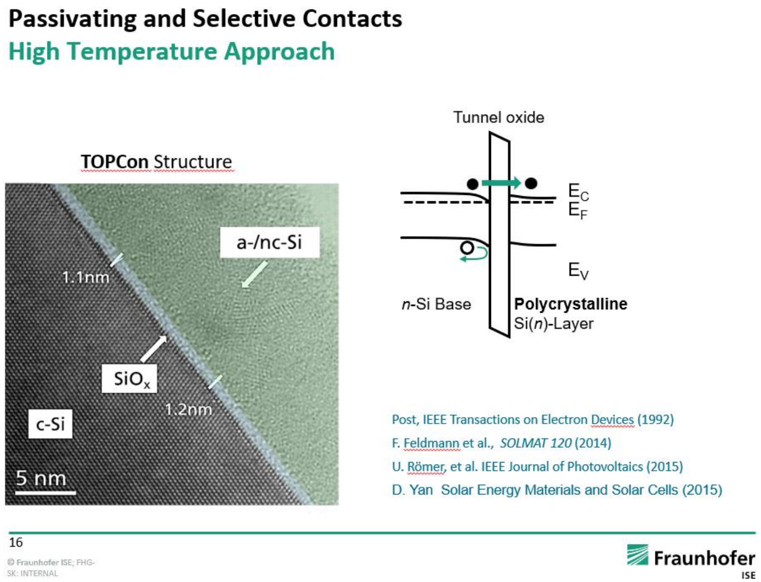
Everyone Starting to go TOPCon







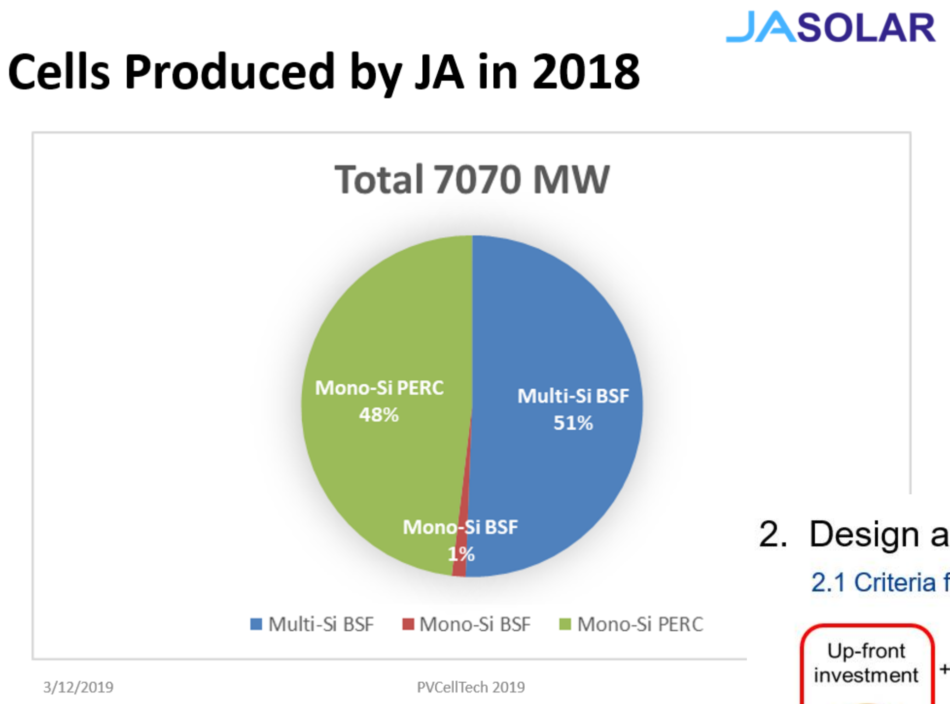


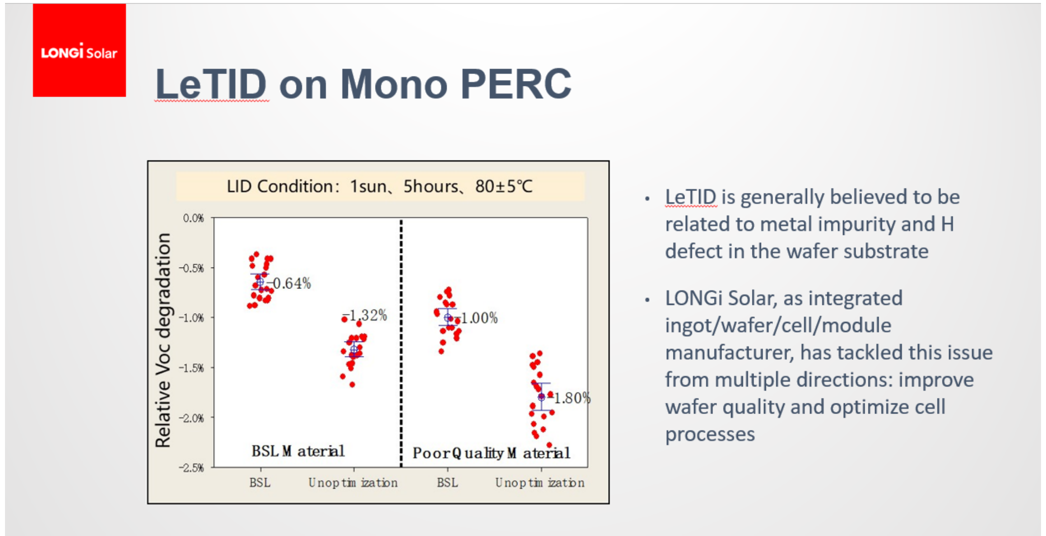


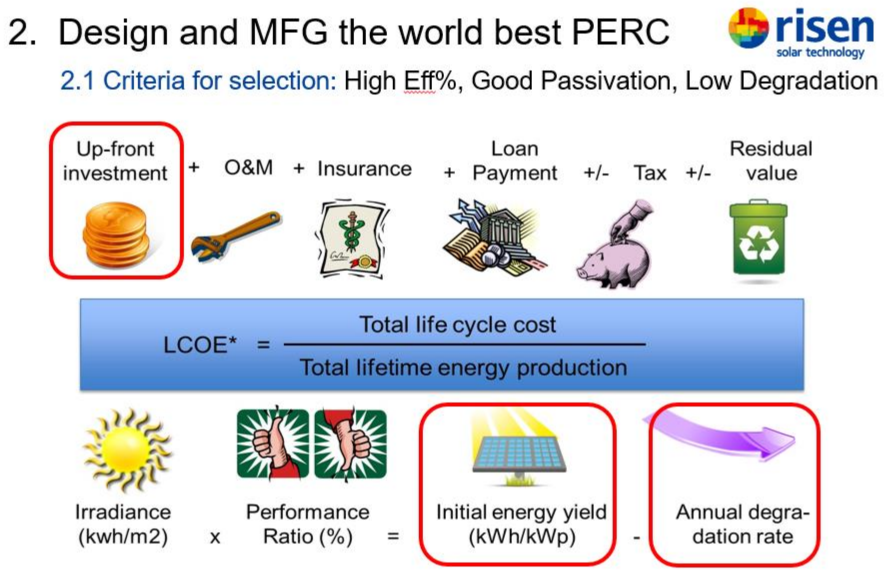
2019
Penang, Malaysia

2019

PERC Transition In Progress







But Main Focus was on TOPCon 'Industrialization'

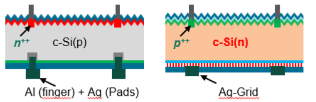
Challenges for Industrial Implementation of TOPCon

- How to upgrade from existing PERC lines?

Material
- Change from p- to n-type silicon material

Front side
- Replace $POCl_3$ with BBr_3 diffusion, shift AlO_x/SiN_x passivation

Rear side
- Implement TOPCon layer formation (replacing LCO)
- Adapt metallization grid



SDE + texture	SDE + texture
Diffusion LP-$POCl_3$	**Diffusion LP-BBr_3**
Laser Selective Emitter	Laser Selective Emitter
Chemical edge isolation	Chemical edge isolation
	TOPCon: Oxidation
	TOPCon: PECVD
	TOPCon: High-*T* anneal
PECVD SiN_x (front)	Al_2O_3 (front)
Al_2O_3 (rear)	PECVD SiN_x (front)
PECVD SiN_x (rear)	PECVD SiN_x (rear)
Laser Contact Opening	
SP (front and back)	SP (front and back)
FFO	FFO

15
© Fraunhofer ISE
Fraunhofer ISE

Passivated Contacts

Manufacturing Basics

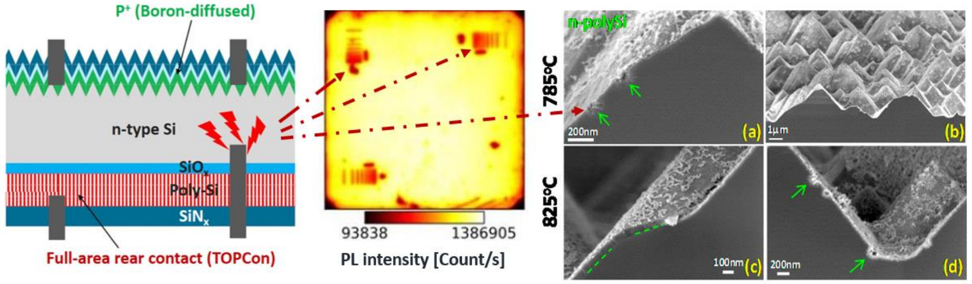
	Wet Process	ALD	APCVD	PECVD kHz	PECVD MHz	LPCVD Classic	Semco LPCVD	AP Diffusion	LP Diffusion	Ion Implant
n/p Doping	-	-	-	★★	★	★★	★★★	★	★★	★★★
Intrinsic Silicon	-	-	★	★★	★★	★★★	★★★	-	-	-
Tunneling Oxide	★★	★★★	★	★	★★	★★★	★★★	★	★★★	-
Best fit	☹	☹	☹	😐	😐	☺	☺☺	☹	😐	☹

SEMCO SMARTECH

9

中来股份 JOLYWOOD

Challenges in its industrialization



A. Moldovan CSPV 2018

E. Hande SIPV 2017

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

9

2019

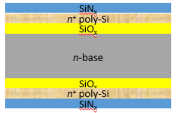
… and more on TOPCon into Mass Production

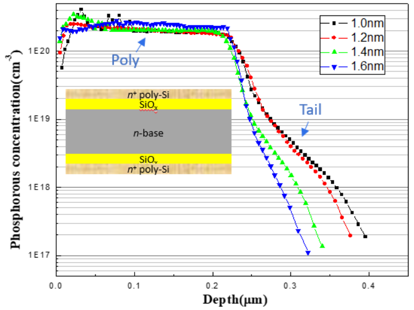
Results

Rear tunnel oxide tuning

Oxide thickness (nm)	SHR (Ω/□)	jo (fA/cm²)
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℃ POCl3) poly atop thermal SiOx by changing the oxidation temperatures
- Very deep diffusion profiles with decreasing SiOx thickness results in poorer passivation
- A slight increase in the SiOx thickness will significantly increases the contact resistivity (not showed here)

GCL

5

The questions for industrialization of TOPCon?

Trinasolar

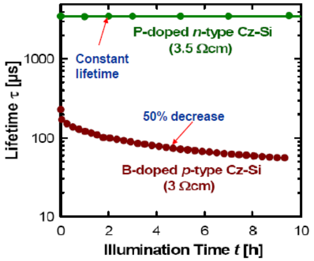
The process of industrial TOPCon cell is undefined, just like PERC in 2014!

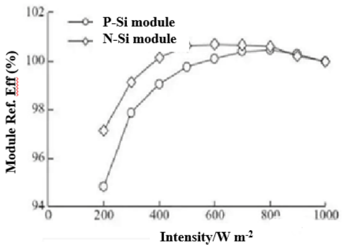
TOPCon	**Substrate** P-type? N-type?	**Thin oxide** Wet-chemical? UV? Thermal?	**Poly silicon** PECVD? LPCVD? in-situ doping? Ex-situ doping? Annealing?	**Metallization** Evaporation? Screen printing? TCO?	**Others** Cell structure? Process flow? Indus. maturity? Yield? **Cost?**
PERC in 2014	**Substrate** P-type? LID?	**Passivation** AlO_x:H? Thermal SiO_2? 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?**

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. Denyuan 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.

Page 9 www.longigroup.com

2019

HJT Still Being Pushed

liten ceatech

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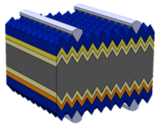


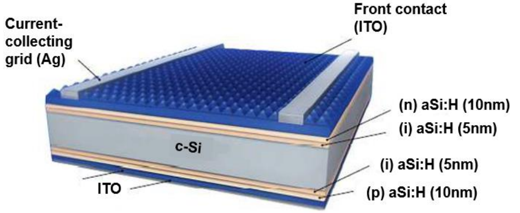
SHJ : A 10 GW EcoSystem is rising up For the next three years

- 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

Why SHJ technology? - Simple technology with high efficiency!

HEVEL SOLAR



Wafer texturing → Heterojunction deposition → ITO deposition → Metallization grid → Annealing → IV-curve measurement

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

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

The content of this presentation is for discussion purposes only, shall not be considered as an offer and doesn't lead to any obli responsibility for any and all mistakes, quality and completeness of the information.

MEYER BURGER PROJECTS WITH EUROPEAN HETEROJUNCTION MANUFACTURERS 3SUN AND ECOSOLIFER

MEYER BURGER

Ecosolifer Csorna, Hungary

3SUN/ENEL, Catania, Italy

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

JINERGY 10

ıfacturing 2019+ · PV CELLTECH 2019

CIE 中智电力 CIE POWER

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