Quo Vadis, Crystalline Silicon PV?

IMEC ENERGY

Ivan Gordon, Robert Mertens and Jef Poortmans

IMEC, BELGIUM

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SOME WORDS ABOUT IMEC

Independent research center in Leuven, Belgium

Key attributes:

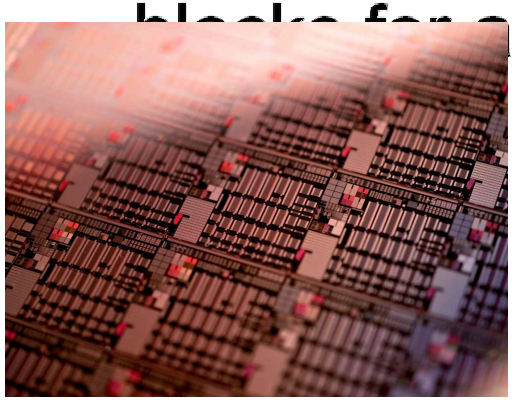
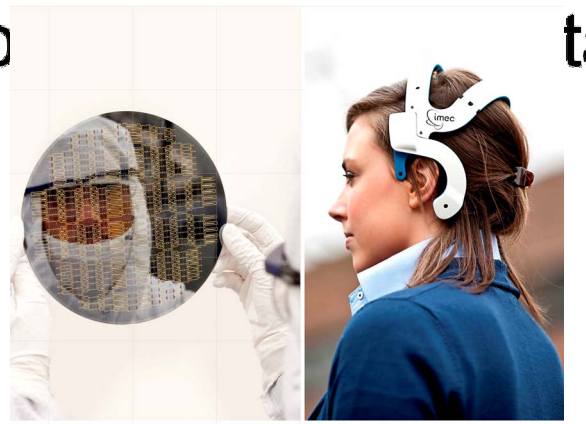
- Non-profit
- Independent
- Established by Flanders government in 1984
- Worldwide reach
- 2011 revenue: 300 M€
- 2011 staff: ~1950



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IMEC'S MISSION

- World-leading research in nano-electronics.
- Scientific knowledge with innovative power of global partnerships in ICT, healthcare and energy.
- Industry-relevant technology solutions.
- International top talent in a unique high-tech environment committed to provide building


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Si-PV partners



- Energy companies
- Solar cell producers
- Tool suppliers
- Material suppliers

TOTAL
SCHOTT solar
Photovoltech
Kaneka
SoLayTec
COHERENT
Meco
RENA
BTU
DOW CORNING
LEYBOLD OPTICS
MEMC
TECHNOLOGY IS BUILT ON US

OUTLINE

Introduction on PV market and industry

Standard c-Si cell concept

Future trends in c-Si PV

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THE PV WORLD IS CHANGING...

- PV-market has seen a tremendous growth in 2009-2011, mainly in Europe
- PV production has shifted to Asia
- PV-module prices and profit margins have decreased considerably
- Emphasis on efficiency (> 20%)
- Road-mapping exercises in Europe, US and Japan

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MARKET GROWTH AND PRICE REDUCTION

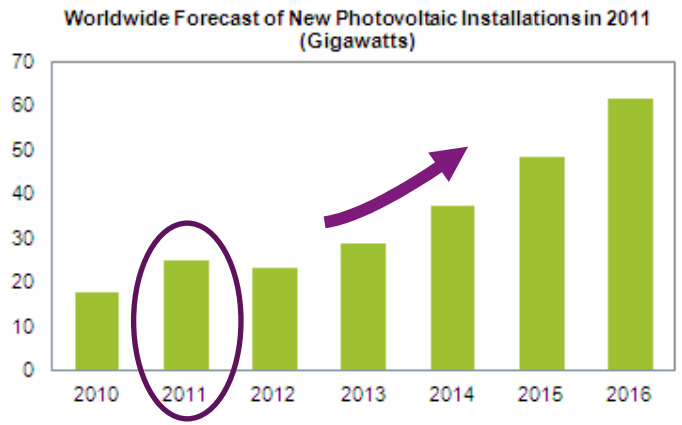
+35% world PV-market growth in 2011 (now at 25 GW_p)

Production capacity is more than double the market size (60-80 GW_p)

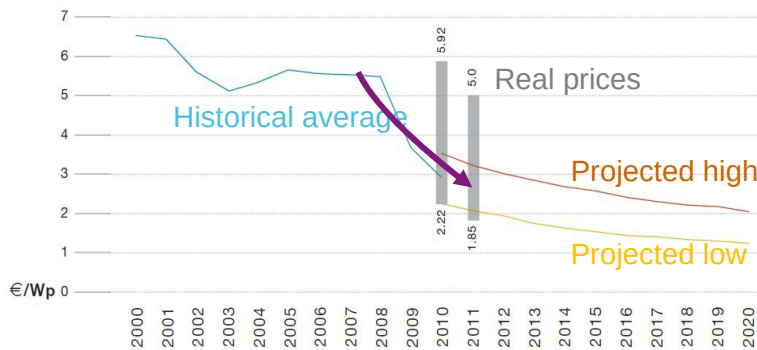
Module prices have declined by a factor 2-3 in 3 years

Predictions (source: PV Magazine)

- Predictions for 2012-2013 are uncertain
- Growth around the world (+43 %) with major deceleration expected within the European market (+6%)

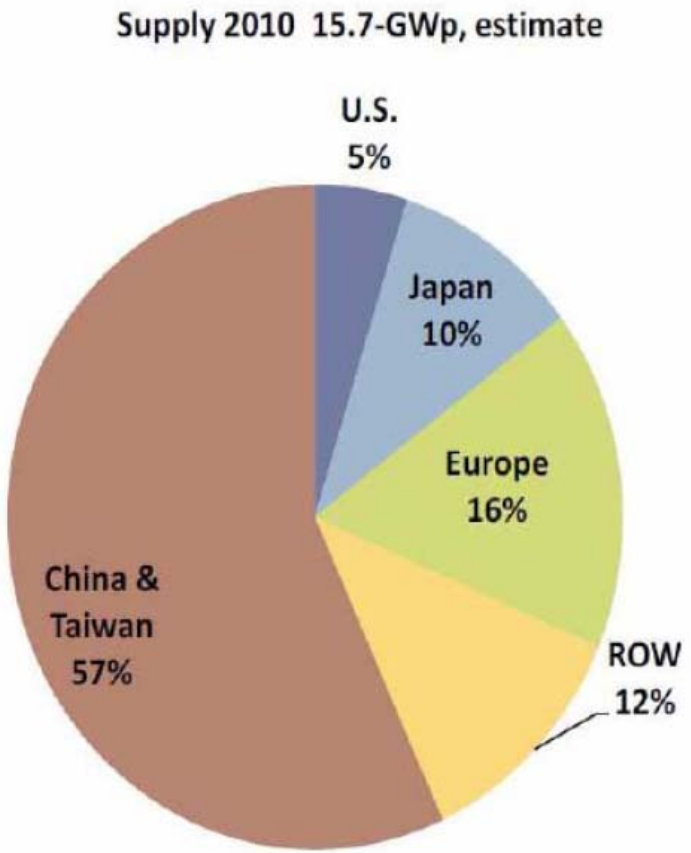


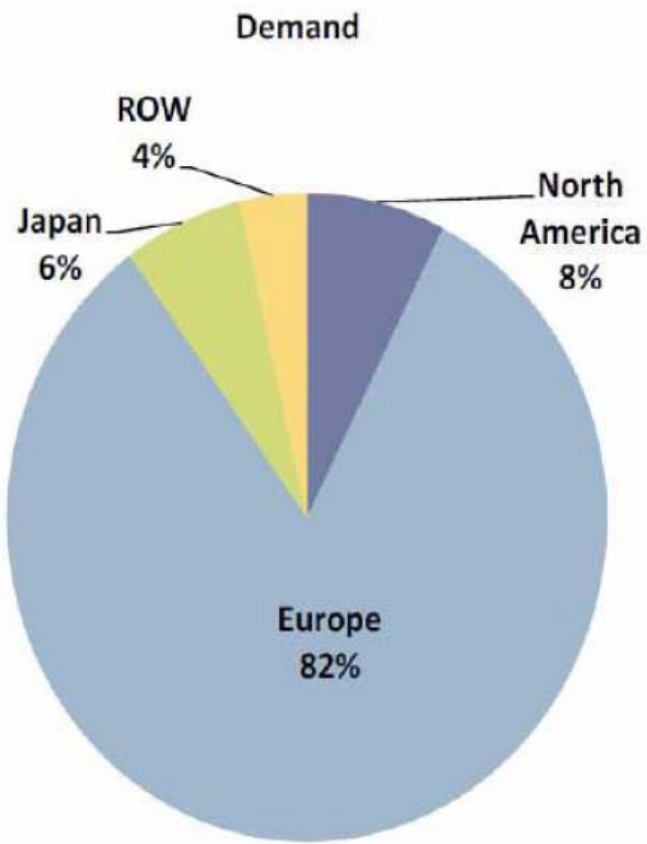
Source: IHS iSuppli Research, February 2011



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PARADOX SUPPLY-DEMAND





Source: Navigant Consulting

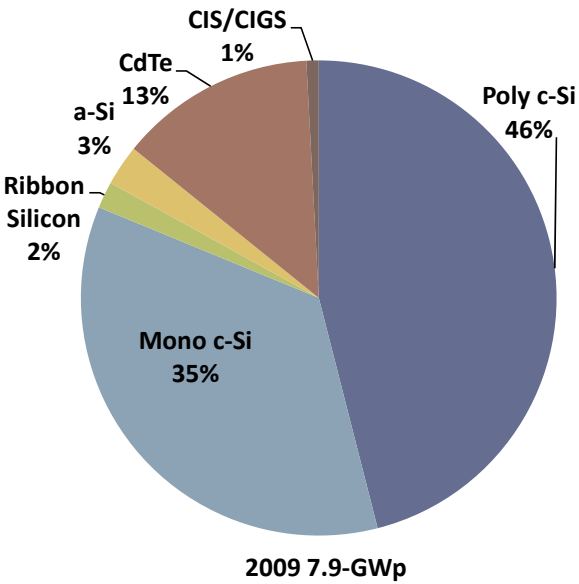
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PV-MARKET: TECHNOLOGY SHARE

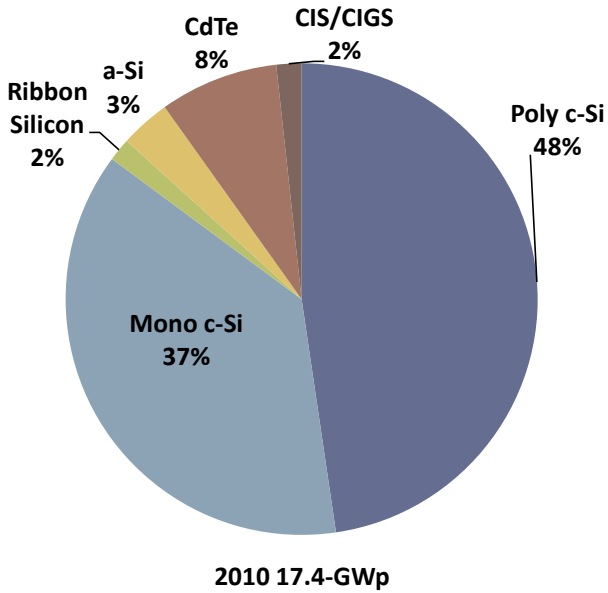
Crystalline Si PV-modules continue to dominate

Thin-Film PV-technologies

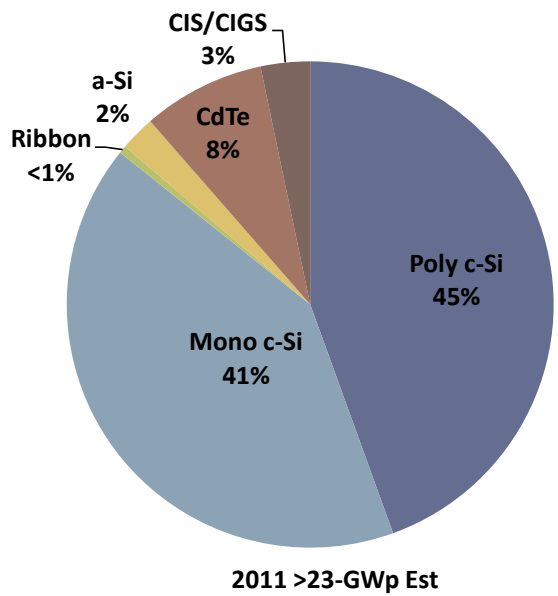
- Growth of CIGS at the expense of a-Si:H



2009 7.9-GWp



2010 17.4-GWp



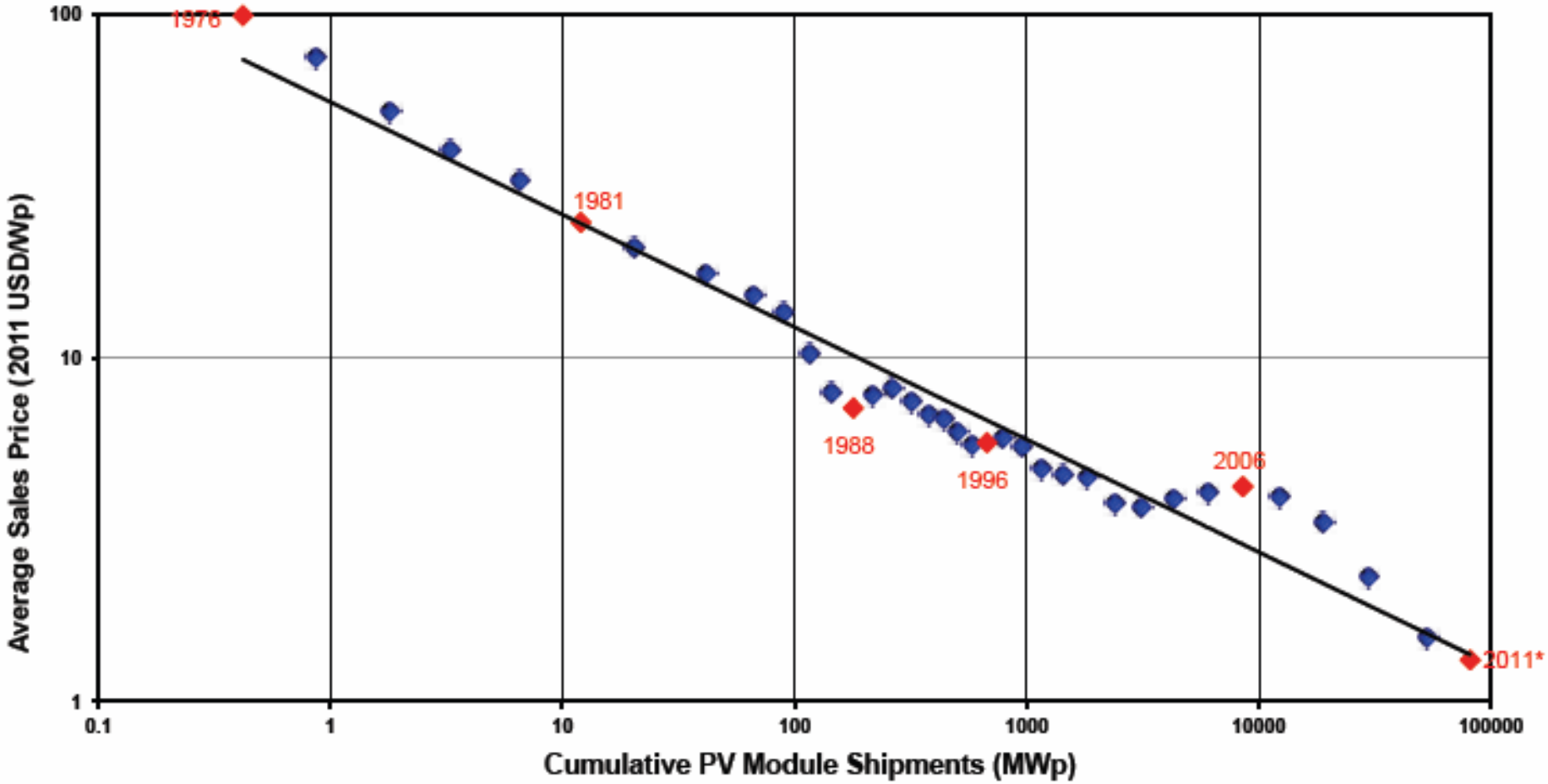
2011 >23-GWp Est

Source: Navigant Consulting

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LEARNING CURVE OF PV

Slope ~ 20%



Ristow, 2012

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SOME FIGURES

World energy consumption today ~ 16 TeraWatt (16×10^{12} W)

In 2050 ~ 30 TeraWatt needed (estimate)

If in 2050, 10% energy comes from PV: 3 TeraWatt of PV ne

This means ~12 TeraWatt installed PV in 2050 (load factor 4)

At present 20-30 GW is installed per year

To reach 12 TeraWatt in 2050, a serious acceleration in insta
PV is needed

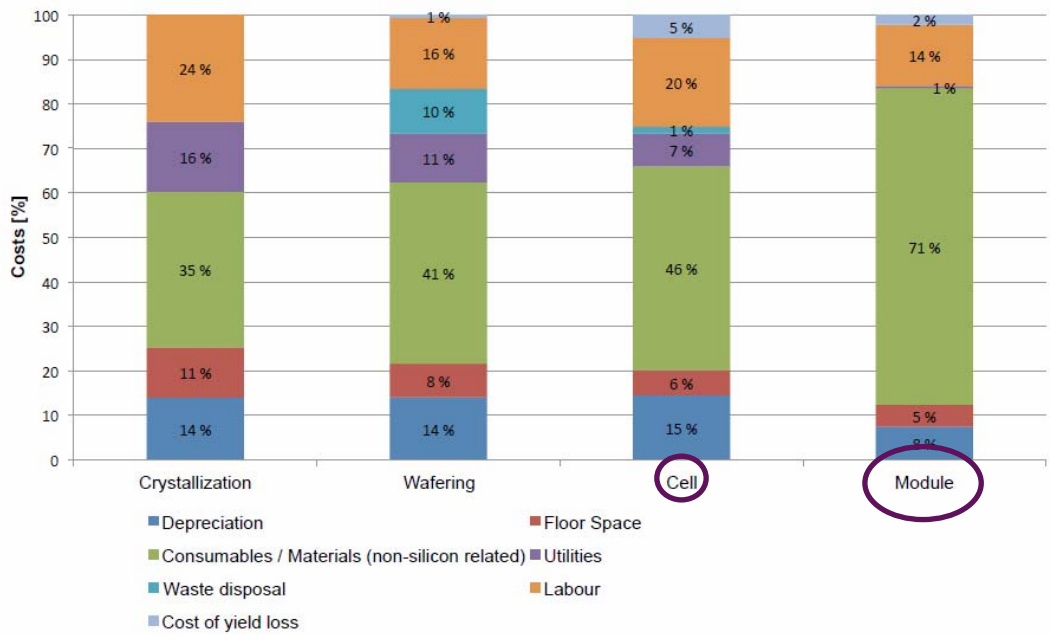
Courtesy Eicke Weber, IS

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CHALLENGE FOR PV

Only the combination of **increased module performance** and significantly **reduced manufacturing costs** will enable the PV industry to reach long term competitiveness in power generation.

Crystalline-silicon PV: Still a lot of innovation possible and needed



Source: ITRPV.net

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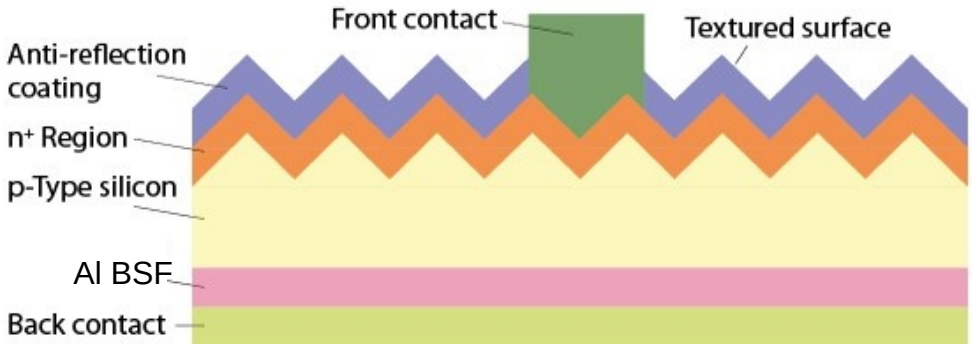
TYPICAL P-TYPE Si CELL PROCESS TODAY



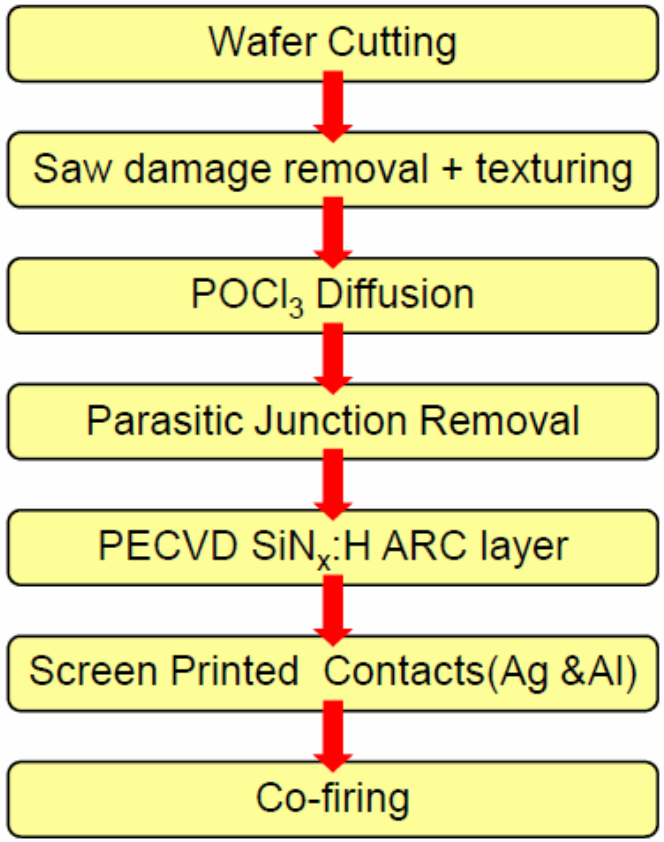
Monocrystalline silicon solar cell



Polycrystalline silicon solar cell



Courtesy Tatsuo Saga



Main limitations:

- full area BSF: Passivation quality is limited
- screen printing of Ag: substantial cost, limited resolution
- Relatively thick and expensive Si wafers

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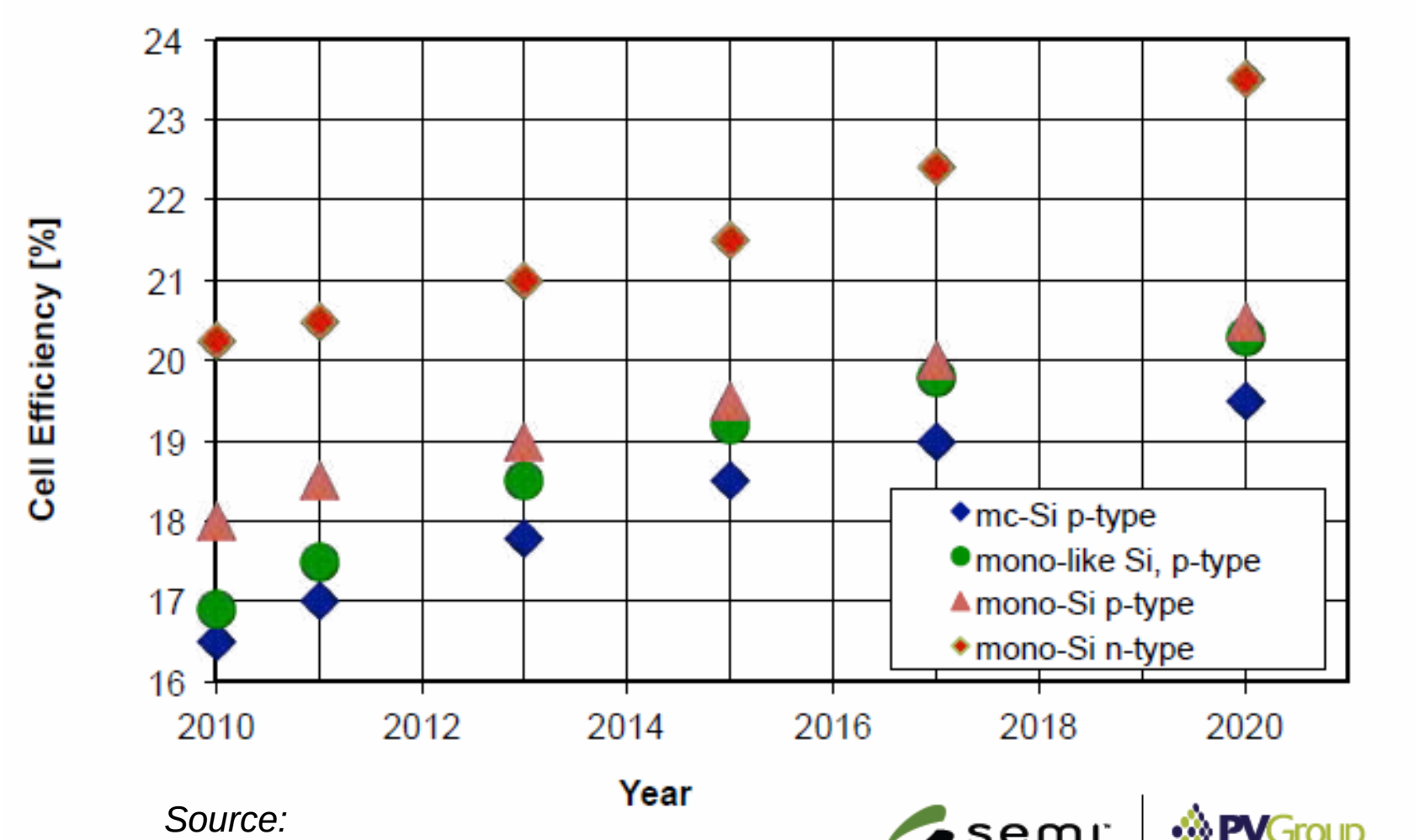
SOME FUTURE TRENDS FOR CRYSTALLINE Si PV

- New device structures for p-type industrial solar cells to obtain >20% efficiencies
- Transition from p-type to n-type Si substrates
- Reduced material costs / improved sustainability
- Thinner Si substrates
- PV meets nano-electronics and photonics

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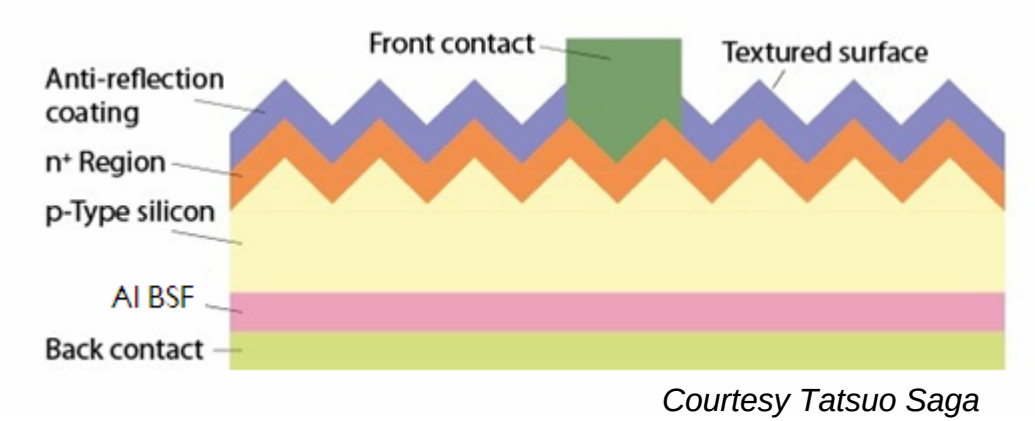
CELL EFFICIENCY ROADMAP

International technology roadmap for PV (ITRPV)



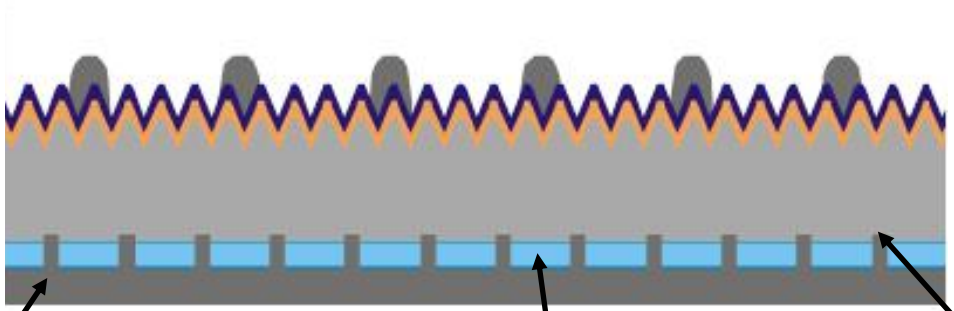
Source: ITRPV.net

MODIFICATIONS TO CELL ARCHITECTURE ARE NEEDED FOR HIGHER EFFICIENCIES



Courtesy Tatsuo Saga

"Standard cell"
Al-BSF



"PERC cell"
Passivated rear

Rear Al-Si contact and reflector:
- PVD Al
- Al paste

Rear dielectric layers: SiO_x; AlO_x; SiN_y:H

Local Si-Al BSF

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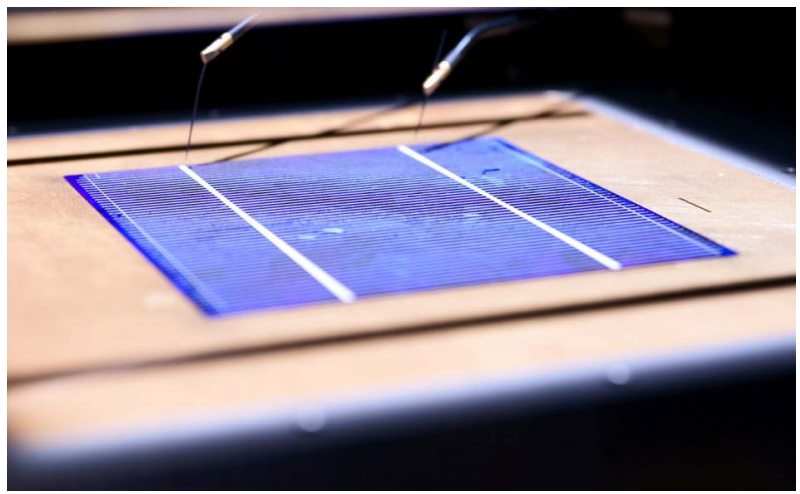
BEST PERC CELL RESULTS

Record p-type PERC cells (156x156 mm, Cz-Si):

Schott Solar: 20.1% with selective emitter and SP
Q-cells: 20.1% with seed and plating
ISFH: 20.1% with homogeneous emitter and double print SP

Recent results at imec (125x125 mm, CZ-Si, unconfirmed)

J_{sc}	V_{oc}	FF	eta
[mA/cm²]	[mV]	[% abs.]	[% abs.]
38.7	664	79.4	**20.4**
38.6	663	79.1	20.3
38.7	659	79.8	20.3
38.6	659	79.5	20.2



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SOME FUTURE TRENDS FOR CRYSTALLINE Si PV

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n-TYPE VERSUS p-TYPE Si

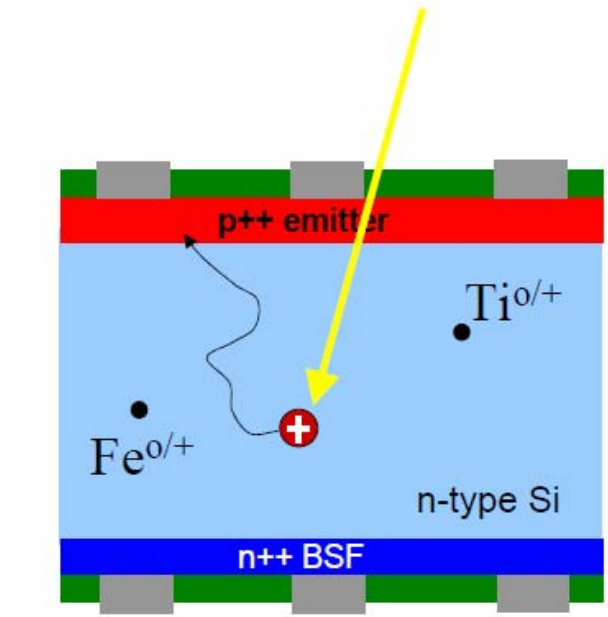
Pro n-type

- No light-induced degradation (no B-O complexes)
- More forgiving towards metallic impurities (Fe)
- Longer diffusion lengths

Contra n-type

- B-diffusion requires high temperature
- Emitter passivation

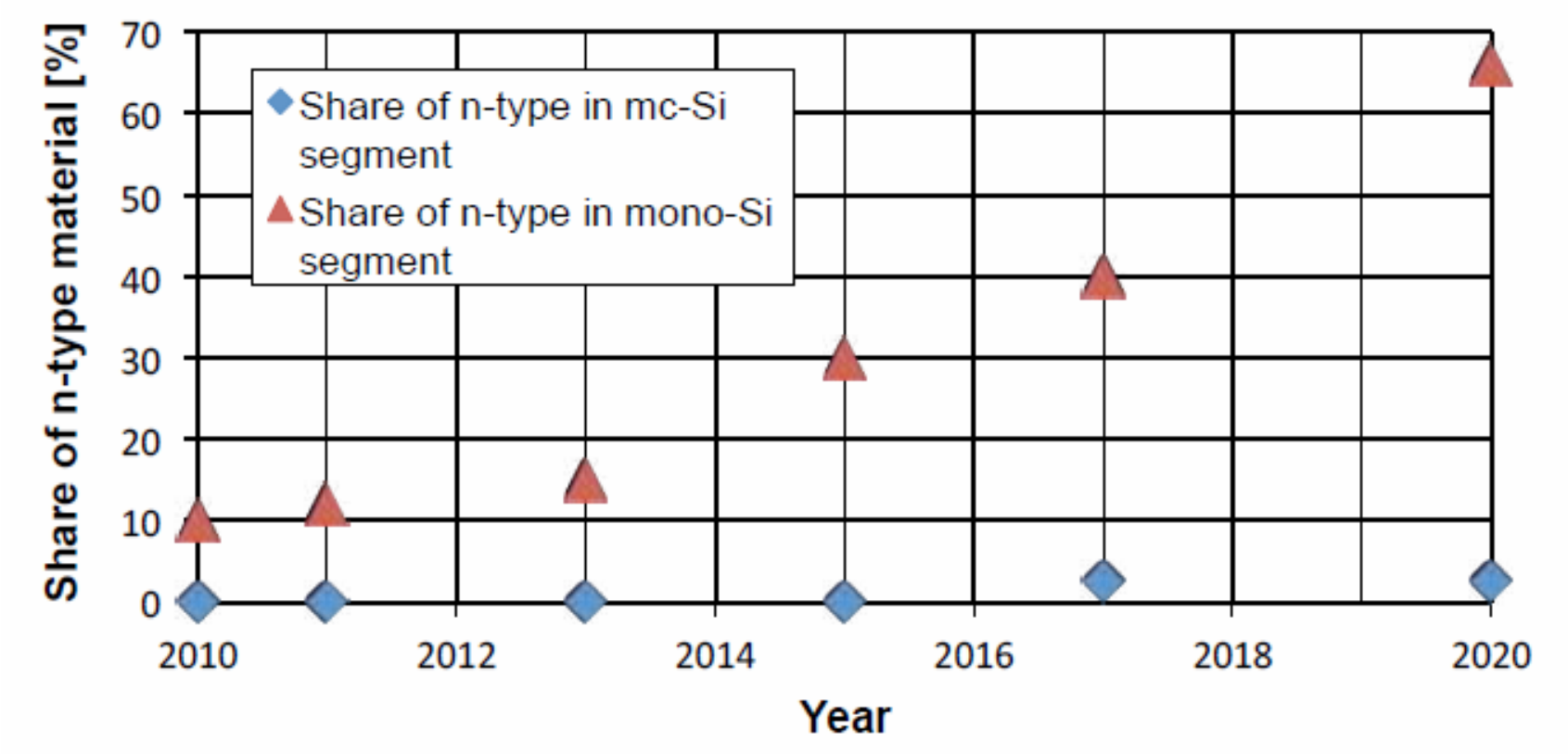
High-efficiency concepts are often based on n-type Si (Sunpower, Sanyo, Yingli Solar)



www.ecn.nl

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SHARE OF n-TYPE IN Si PV PRODUCTION WILL INCREASE

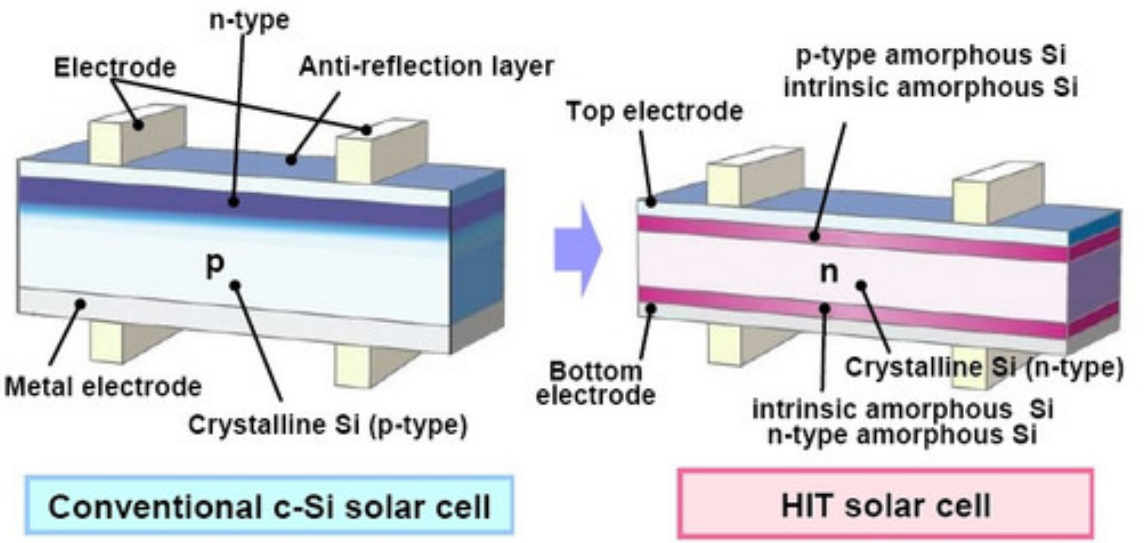


Source: ITRPV.net

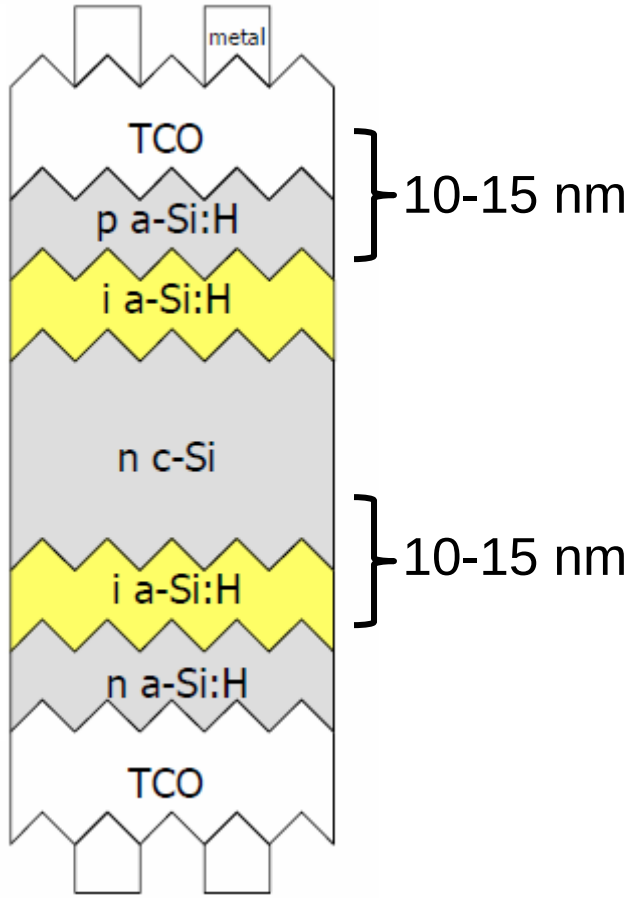
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n-TYPE CELLS REQUIRE NEW DEVICE ARCHITECTURES

HIT (Heterojunction with Intrinsic Thin Layer) Solar Cell is composed of thin single crystalline Si wafer sandwiched by ultra-thin a-Si layers



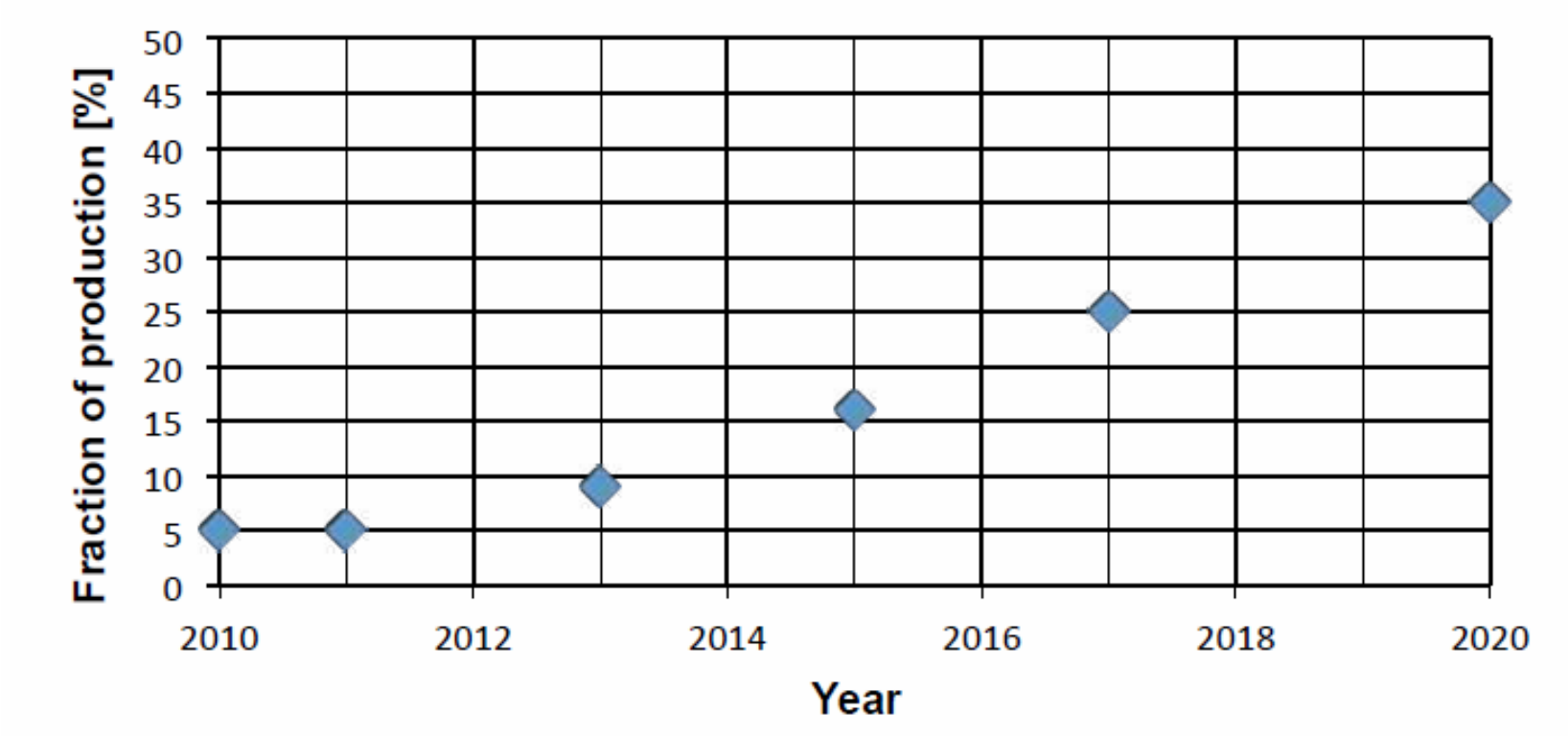
Courtesy Sanyo



Record n-type HIT cell by Sanyo: 23.7% on 10x10 mm

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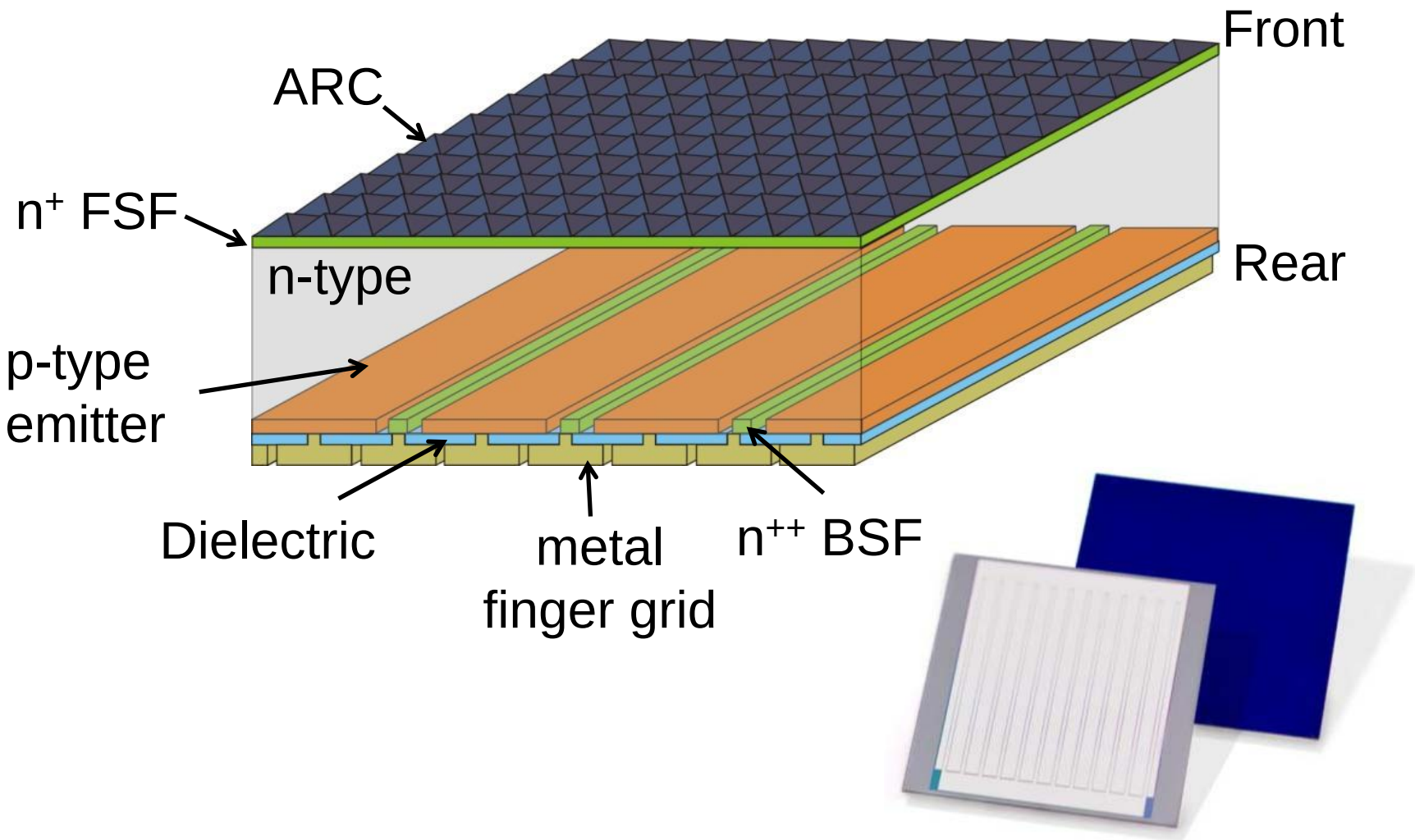
SHARE OF REAR SIDE CONTACTED CELLS IN Si PV PRODUCTION WILL INCREASE



Source: ITRPV.net

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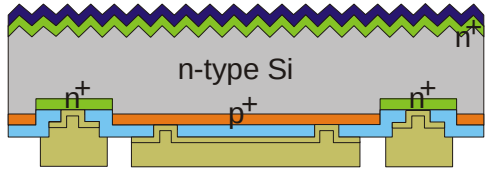
INTERDIGITATED BACK CONTACT (IBC) SILICON SOLAR CELLS



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STATE-OF-THE-ART IBC CELLS

- IBC cells with diffused junctions



Reference	Year	Substrate	Area (cm^2)	Eff. (%)
[1] P.J. Cousins, SunPower	2010	CZ, n-type	155	24.2
[2] imec december 2011	2011	FZ, n-type	4	23.3
[3] P. Verlinden, Sunpower	1997	FZ, n-type	21.2	23.2
[4] K. Yoshikawa, Kaneka & imec	2011	FZ, n-type	4	23.0
[5] C. Reichel, ISE	2011	FZ, n-type	4	23.0
[6] R. King, Stanford University	1990	FZ, n-type	35.7	22.7
[7] P. Engelhart, ISFH	2006	FZ, p-type	4	22.0
[8] Silfab / ISC Konstanz	2012	CZ, n-type	243	21.0

[1] P.J. Cousins, et. al. 35th IEEE-PVSC, Hawaii 2010

2 M. Aleman, et al. 2nd SiliconPV, Leuven 2012

[3] P. Verlinden, et. al., 14th EU-PVSEC Barcelona, 1997

[4] K. Yoshikawa, et. al. 21st Asian PVSEC, Fukuoka, 2011

[5] C. Reichel, et. al., 1st n-type Si PV workshop, Konstanz, 2011

[6] R. King, et. al., 21st IEEE PVSC, Florida, 1990, p. 227 – 232

[7] P. Engelhart, et. al., Progress in photovoltaics, vol. 15, p237-243

[8] Silfab/Konstanz, 2nd n-type Si PV workshop, Amsterdam 2012

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SOME FUTURE TRENDS FOR CRYSTALLINE Si PV

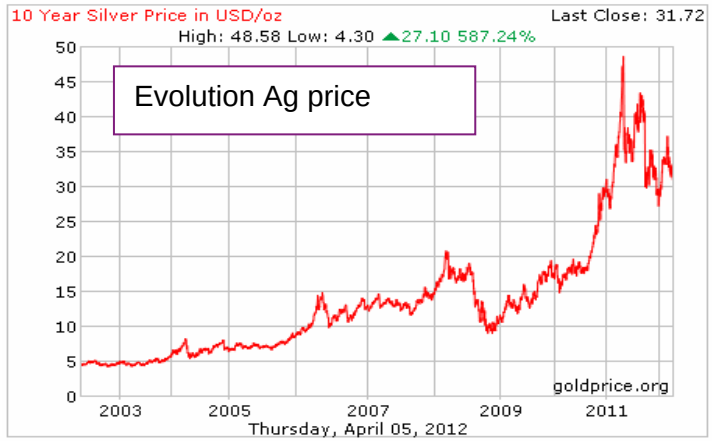
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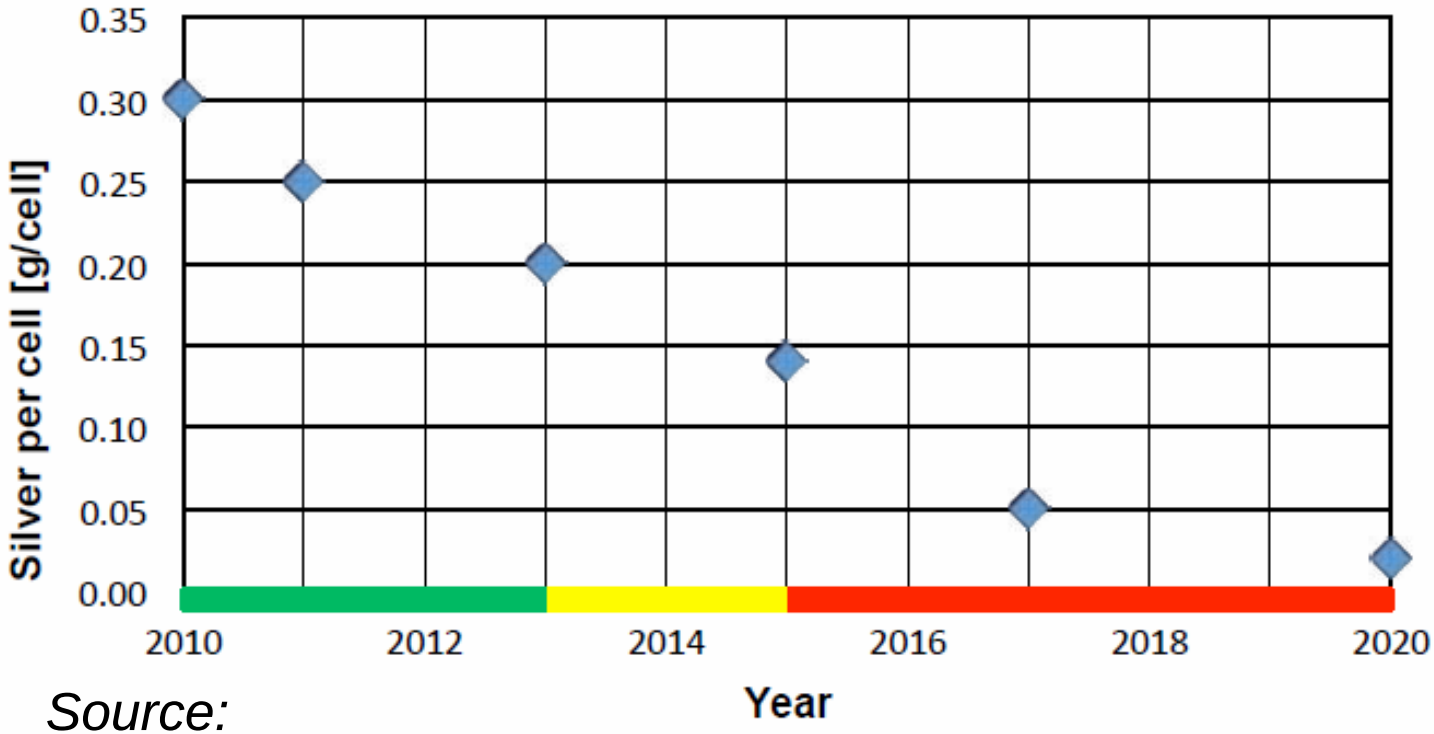
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SILVER METALLIZATION IS A SUBSTANTIAL COST

Improvements required in

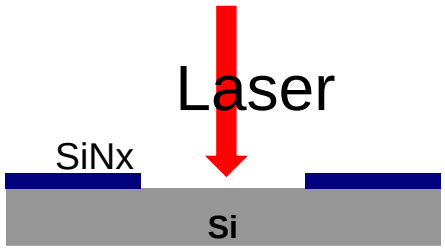
- Ag consumption / cell
- alignment accuracy
- Finger width





Source: ITRPV.net

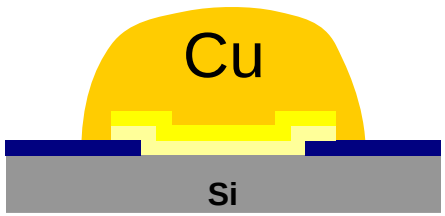
Cu METALLIZATION INSTEAD OF Ag



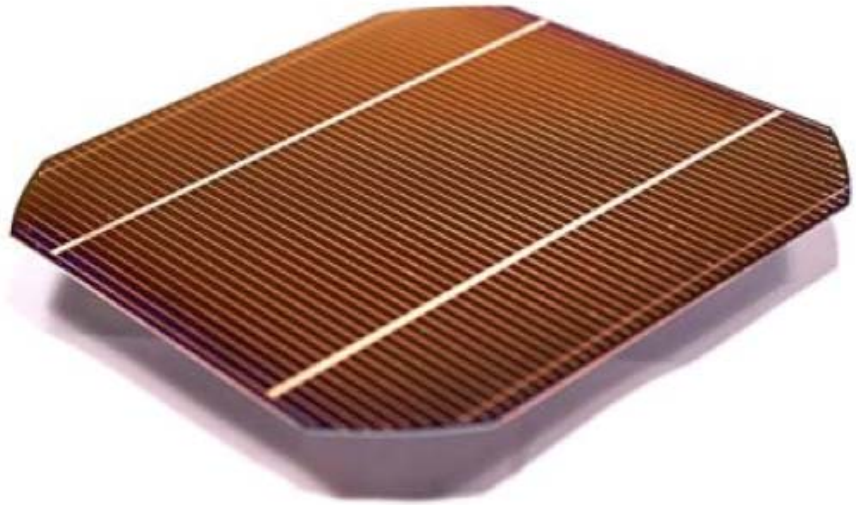
LASER ABLATION



Ni EL-PLATING



Cu E-PLATING



Cu metallisation can give you

- Cost reduction (Cu vs. Ag)
- Increased performance (lower resistance, less shadow loss)

Imec focuses on

- Cost effective and upscaleable processing
- Stability and reliability evaluation

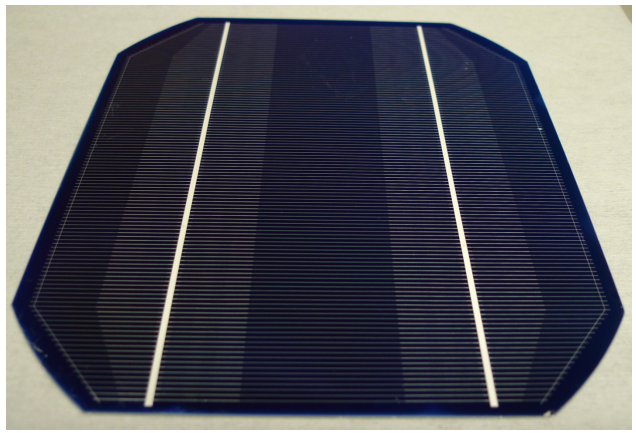
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RECENT RESULTS AT IMEC WITH Cu METALLIZATION

Two solar cell with **20.3%** efficiency **independently confirmed** by FhG-ISE**.**

125x125 mm, p-type Cz, PERC cells, homogeneous emitter, litho-free process

J_{sc}	V_{oc}	FF	eta
[mA/cm^2]	[mV]	[% abs.]	[% abs.]
38.7	663	79.3	20.3
38.8	661	79.2	20.3



Equals Suntech’s record cell on 5" Cz wafers

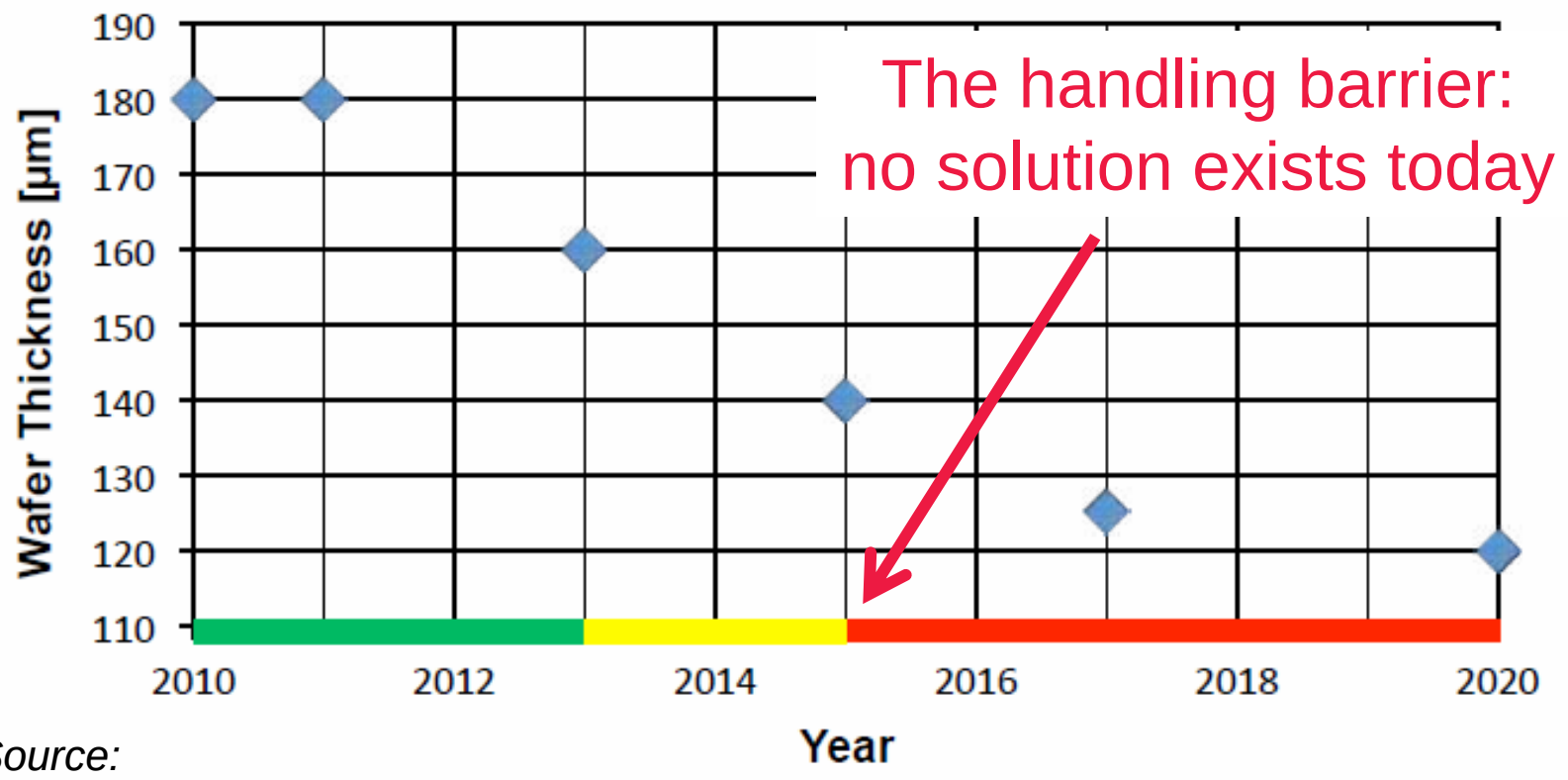
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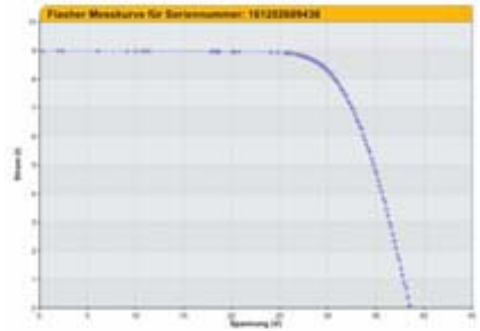
REDUCTION OF WAFER THICKNESS IS VERY IMPORTANT TO LOWER COSTS

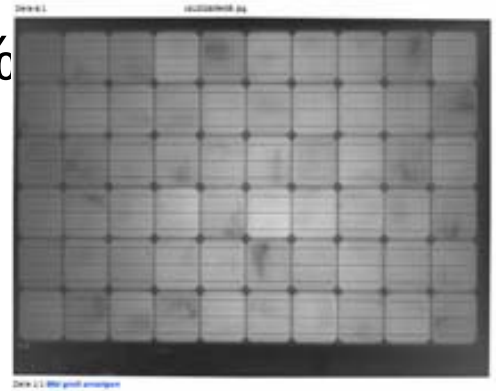


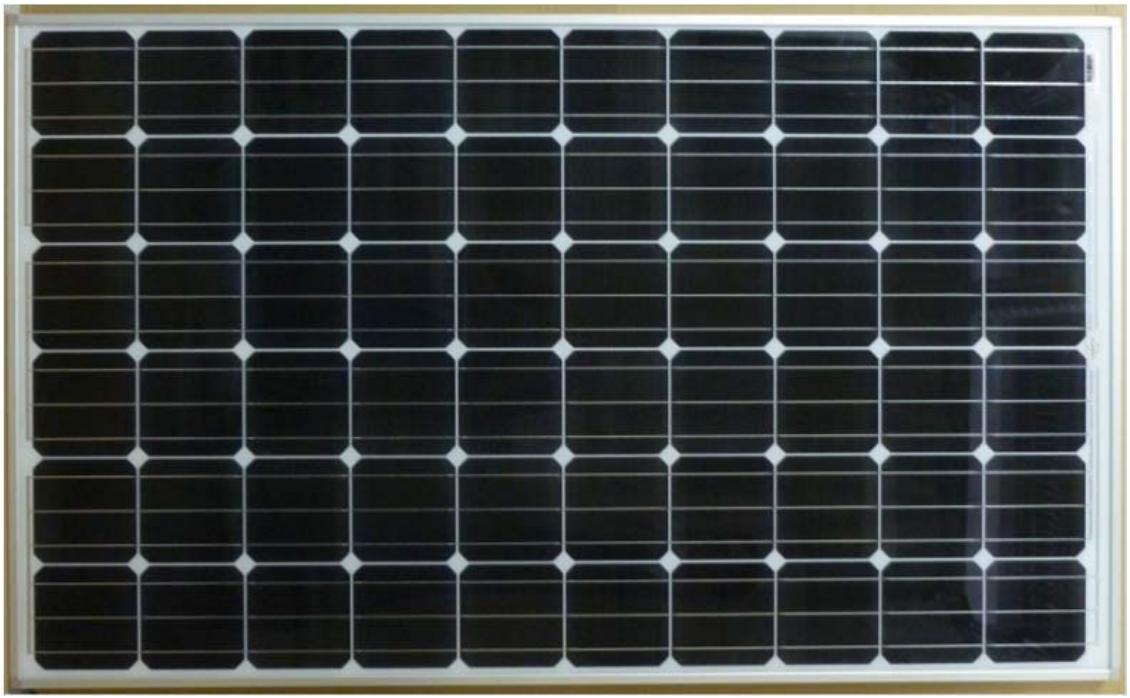
Source: ITRPV.net

PERC-BASED MODULE OF 110 μm CELLS

- > 300 cells
- Imec cells average efficiency 18.5 %
- Standard SolarWorld module line
- Result: class A module (>250 W)







imec inside

SOLARWORLD

We turn sunlight into power.

ULTIMATE

Ultra Thin Solar Cells for Module Assembly Tough & Efficient

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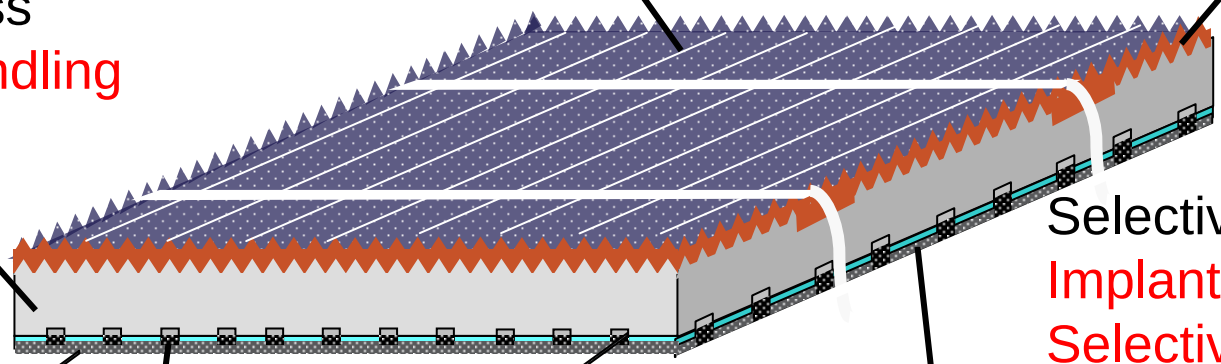
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WHERE PV MEETS NANO-ELECTRONICS

PERL-structure on p-type Cz



Front Side metallization
Cu-plating/barrier layers

Shallow n^+ emitter
Implantation

c-Si, p-type
Si thickness
Thin wafer handling

Selective emitter
Implantation
Selective epi

Dielectric
Back Side
passivation
Atomic Layer
Deposition

Laser-ablated
vias in
passivation

B-doped
local Back Surface Field
Implantation, Selective epi
Laser doping

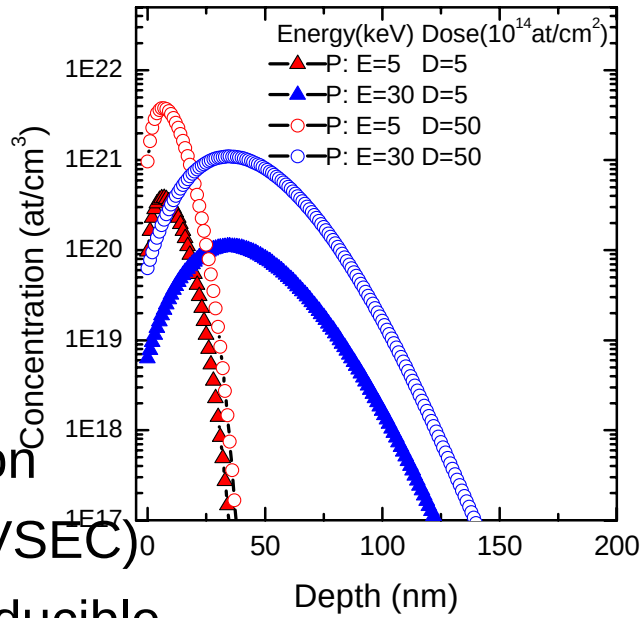
Sputtered Back Side
Metallization

Overall: cleaning

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IMPLANTATION AS AN ALTERNATIVE FOR DIFFUSION

Would allow an independent tuning of sheet resistance & profile shape

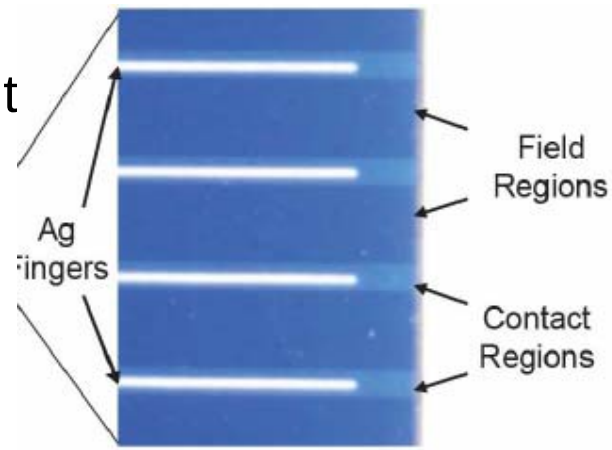


Advantages in integration

- Less processing steps than conventional diffusion
- Better uniformity (e.g. J. Benick,ISE, 25thEU PVSEC)
- Improved process control: very stable and reproducible process
- Patterned implantation possible (selective emit

Challenges

- Cost and throughput



Dube et al. (Varian), SiliconPV2

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IMPLANTATION DOES NOT HAVE TO BE TOO EXPENSIVE FOR PV

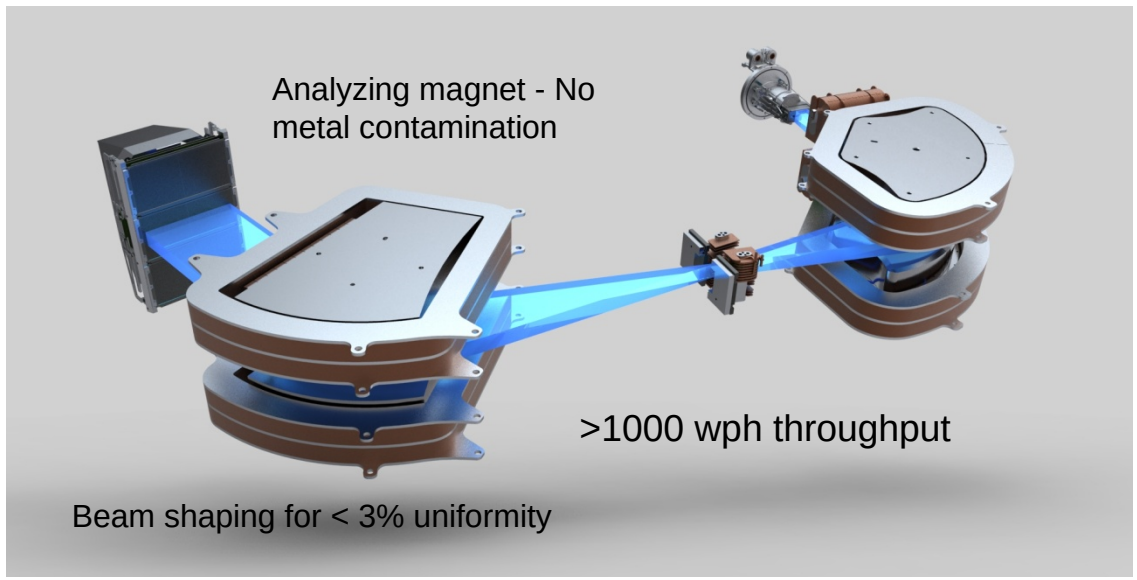
Throughput depends on tool parameters

- implantation current (ion source design, tool design**,** energy),
- handling time (robotics, pumping time),
- implantation dose (application related)

Implanter for PV by Varian Semiconductor Equipment Associates



solion simply efficient solar



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LARGE AREA CELLS WITH IMPLANTATION ARE ALREADY IN PRODUCTION

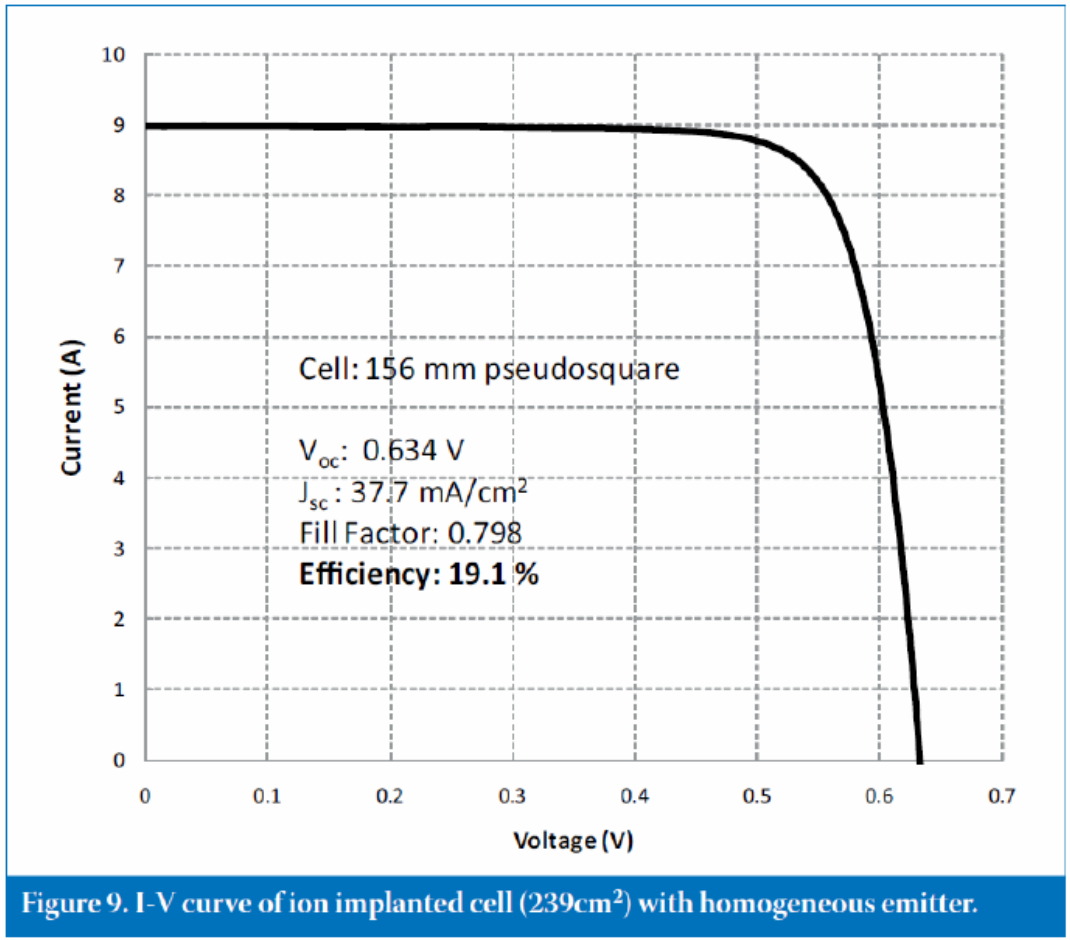


Figure 9. I-V curve of ion implanted cell (239cm^2) with homogeneous emitter.

A. Rohatgi & D. Meier , (SUNIVA) Photovoltaics International ,Nov. 2010

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SUMMARY

PV-sector is going through a consolidation period

Thanks to grid parity reached at many locations, healthy growth will resume.

A lot of innovation is still possible within c-Si PV. In fact, this is the perfect time for innovation to be ready for the next phase of growth in the PV-sector

Innovation is enabled and stimulated by cross-fertilization with other domains

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ACKNOWLEDGEMENTS

All people from the PV department at imec.

Financial support from the EC via the FP7 framework.

Financial support from the IIAP partners at imec.

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165.000 Tera Watt free solar power ...