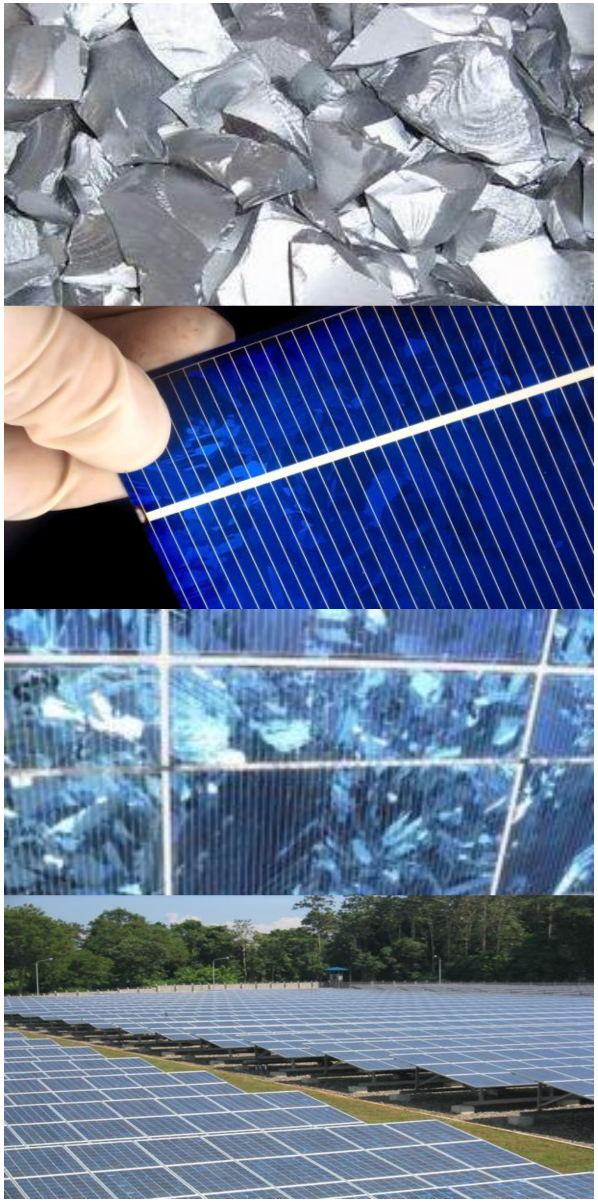


고효율 실리콘 태양전지의 개발현황과 시장전망

한화케미칼 중앙연구소

솔라연구센터

趙 在 億

jecho@hanwha.co.kr

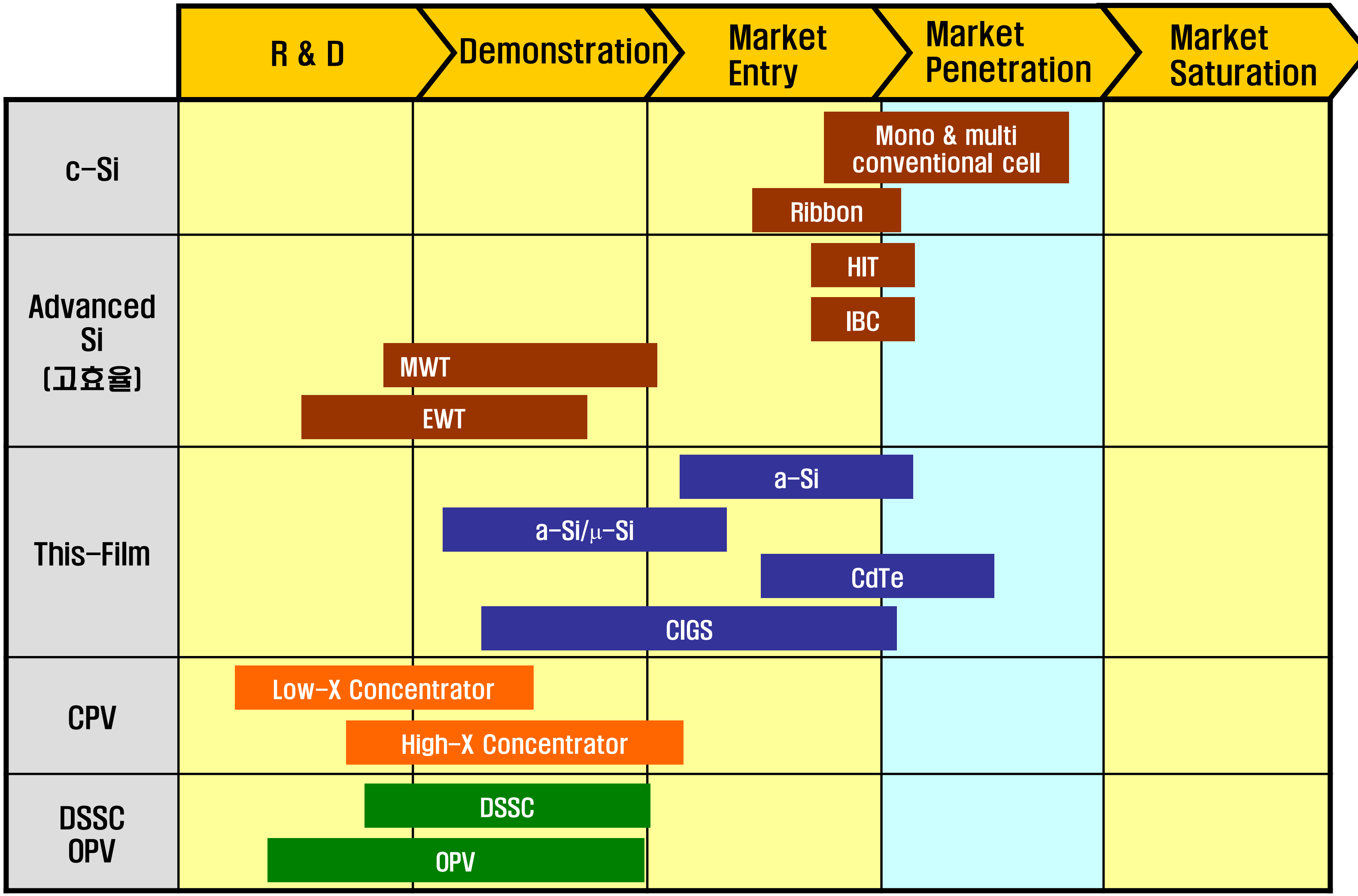
2010. 12. 10

Solar R&D Group
Solar Business Unit

Hanwha Chemical

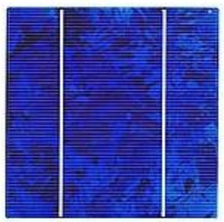
목 차

1. 태양전지 종류 및 Status



Source: Modified From "Renewable Energy Technologies", Lisa Frantzis, Navigant Consulting, Inc.(2005/2006)

2. c-Si 태양전지 : 기본개념

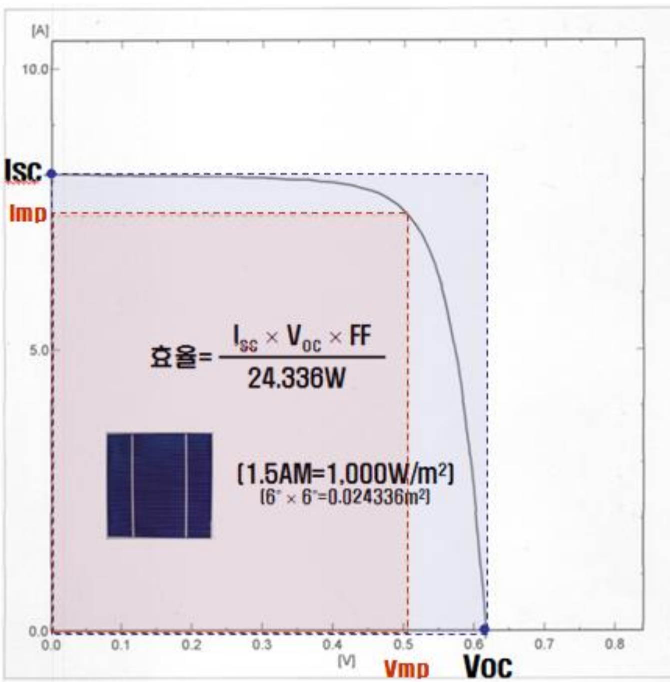


Multicrystalline photovoltaic solar cell
156 mm x 156 mm

Monocrystalline photovoltaic solar cell
156 mpsq

$$\text{태양전지 효율(\%)} = \frac{[\text{단락전류}(I_{sc}) \times \text{개방전압} (V_{oc}) \times \text{충실도}(FF)]\ (W)}{\text{입사광량}\ (W)}$$

Ex) 4W 출력 다결정 , 4W/24.336W ➔ 16.4% 효율

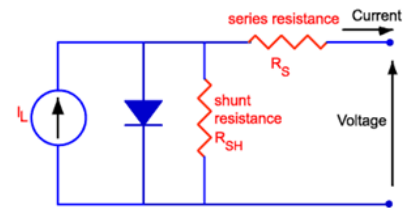


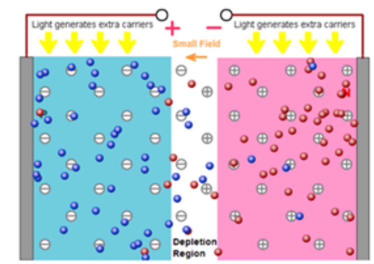
결함 (표면 >>> bulk)
온도

고효율 ➔ Isc↑, Voc ↑, FF ↑

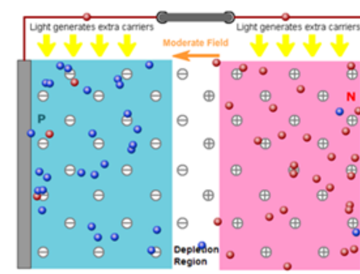
광량

저항





V_{OC} (open circuit voltage)

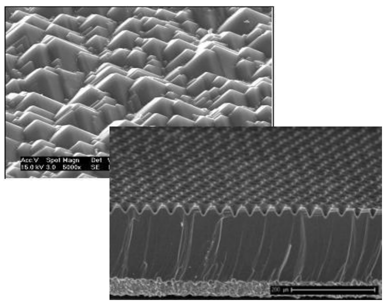


I_{SC} (short circuit current)

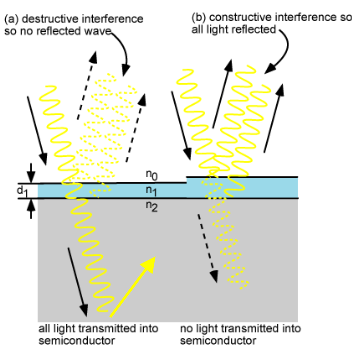
2. c-Si 태양전지: R&D 주제

Maximization of Light absorption(Isc)

- Surface texturing



- Antireflection coating

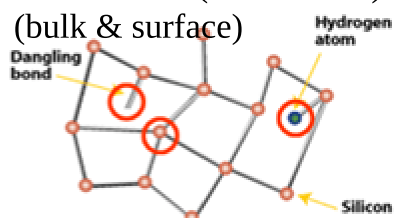


- Back Reflector

Charge separation (Voc, Isc)

☞ Carrier's lifetime depends on the wafer's crystal matrix defects and purity (Bulk & Surface)

- **Use of pure wafers**
  mono C-Si > multi C-Si > Ribbon Si > UMG-Si
  (High purity ➔ high cost)
- Impurity removing tech.
  -wafer gettring
- Passivation: removing broken bond (-Si-→-Si-H) (bulk & surface)



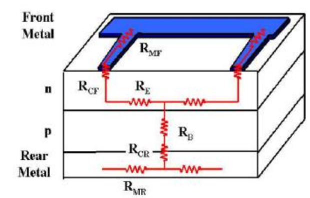
(박막코팅: method, 재료)

Minimization of Serial Resistance(FF)

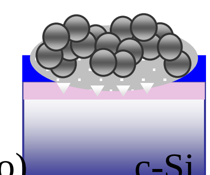
☞ PV Cell is a electric device.

- Design of low serial resistance

$$R_{Total} = R_{MF} + R_{CF} + R_E + R_B + R_{CR} + R_{MR}$$



- Good ohomic contact
  -low contact resistance
  -high conductivity

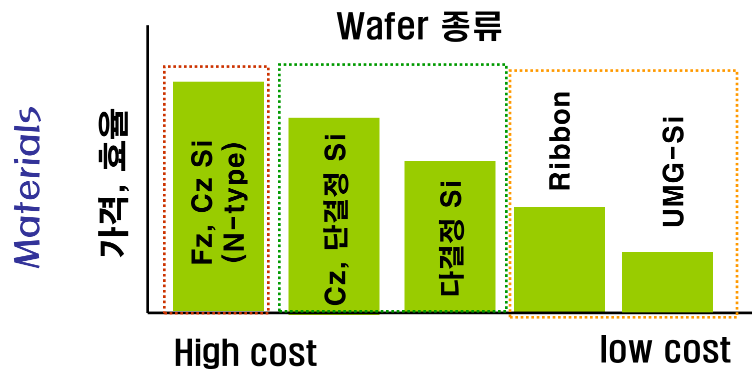


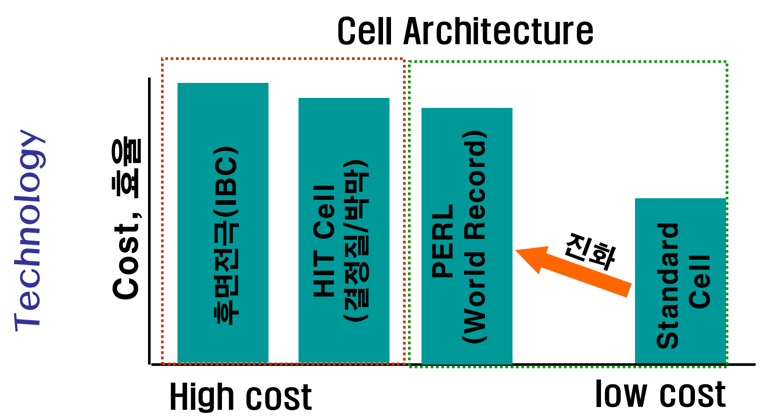
(Printing:SP, plating, depo)

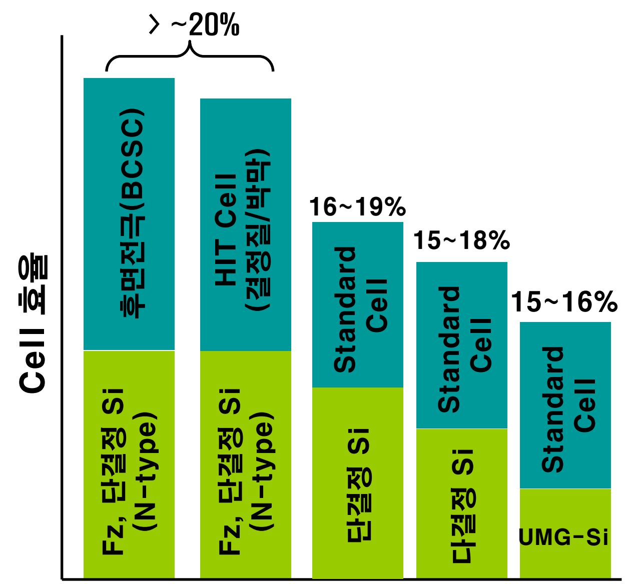
❖ 태양전지의 효율 증대 연구는 Isc, Voc, FF 증대에 초점

2. c-Si 태양전지: 효율특성 분석

Efficiency depends on wafers and fabrication method.





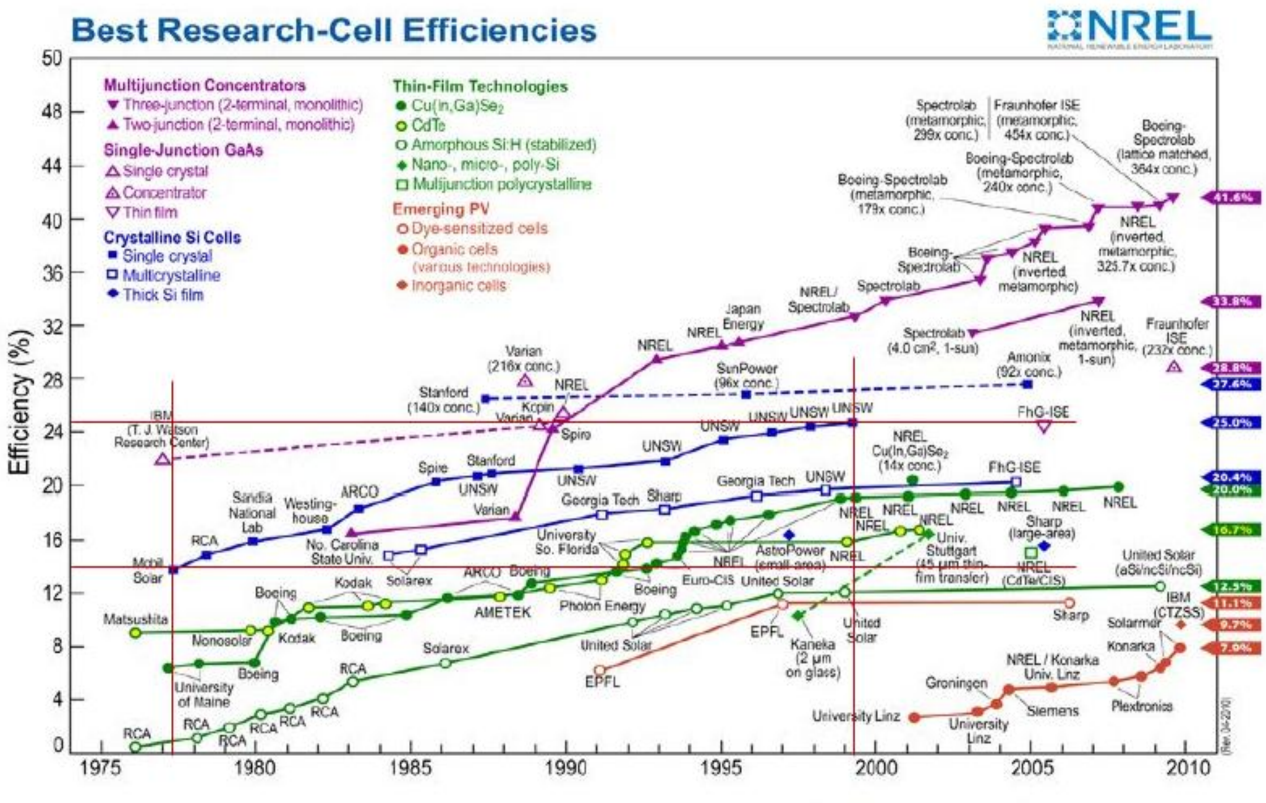


Premium Market: Sunpower, Sanyo
Average: Most
Economy Market: Canadian Solar

기술개발 priority: COST >> Efficiency

3. c-SI 태양전지 효율: R&D

Technology: Cell Efficiencies



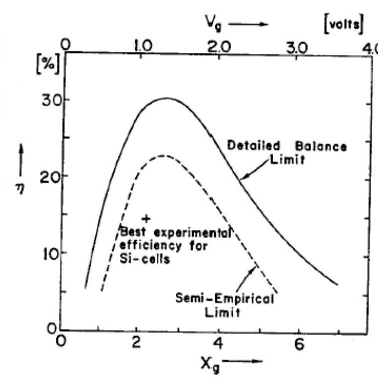
Technology S-Curve Source: NREL (National Renewable Energy Laboratory)

R&D:
cSi=11%/22Yr
(0.5%/Yr)

Industrial :
(0.25%/Yr >)

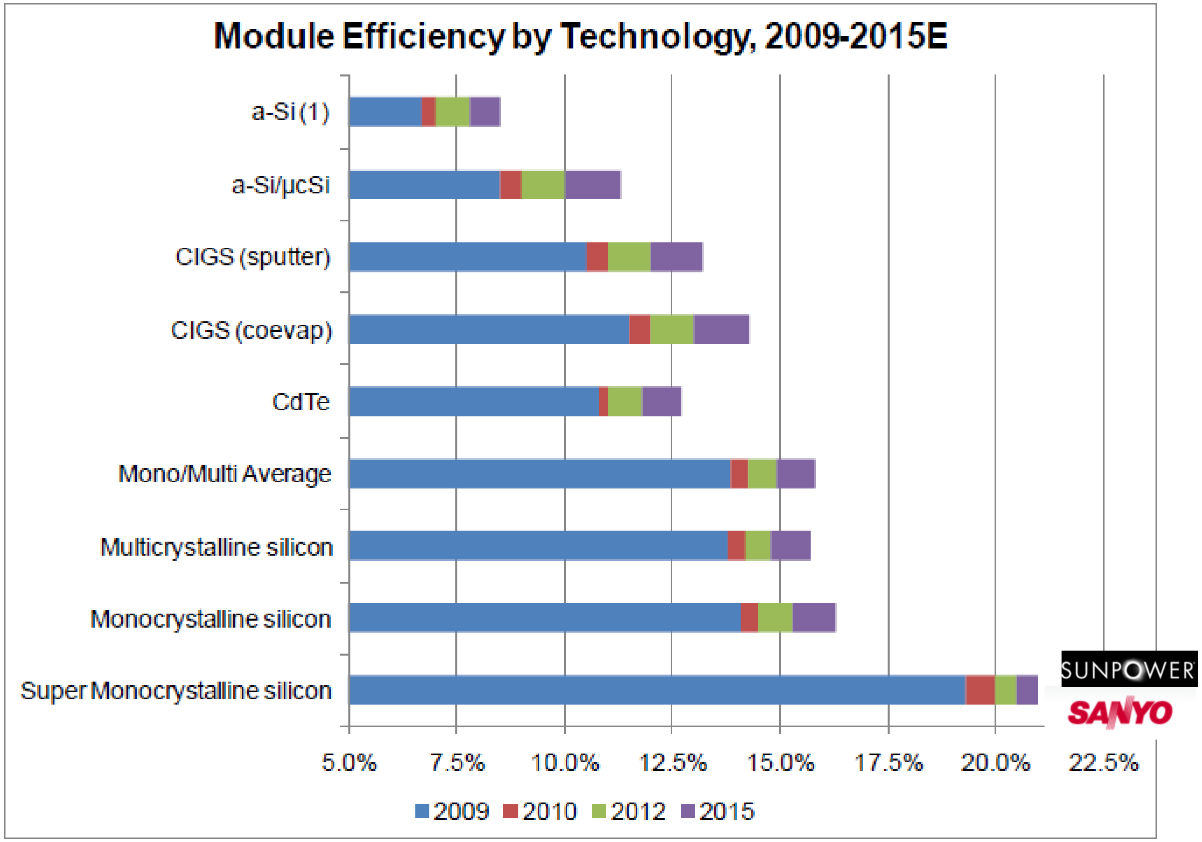
HCPV ≈ 1%/Yr

SQ-limit: ~30%



W Shockley and HJ Queisser, J Appl Phys 32, pp. 510-519, (1961)

3. c-SI 태양전지 효율: 상업용 모듈



Timing of efficiency improvements difficult to predict

By 2015:
- Standard c-Si: ~16.5%
- Super mono c-Si: ~21.5%
- CdTe: 12.5-13%
- CIGS: 13-14%
- 1-j a-Si: 8.5-9%
- Tandem Si: 11-11.5%

Source: Greentech Media Research, in SPI 2010, Oct 11 2010

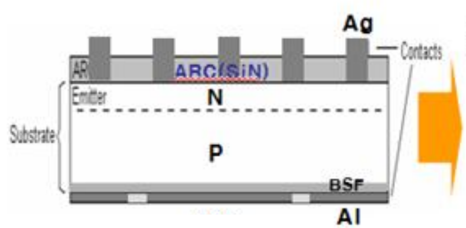
4. 실리콘 태양전지의 기술전망

Standard Cell 의 진화 : 전류증대 (광흡수), 전압증대 (passivation), 전극(FF) 개선

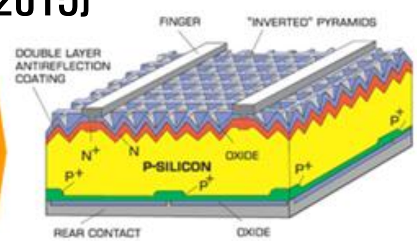
SunPower www.sunpowercorp.com	SPR-210-BLK	Mono	210	188.9	+/-5	15.7	16.9	40.0	5.25
	SPR-215-WHT		215	195.5		16.1	17.3	39.8	5.40
	SPR-225-BLK		225	202.9		16.8	18.1	41.0	5.49
	SPR-230-WHT		230	209.5		17.2	18.5	41.0	5.61
	SPR-305-WHT		305	280.6		17.4	18.7	54.7	5.58
	SPR-310-WHT		310	285.0		17.7	19.0	54.7	5.67
	SPR-315-WHT		315	290.0		17.9	19.3	54.7	5.76

Ref) home power 134/ december 2009 & january 2010

단기(~2015)



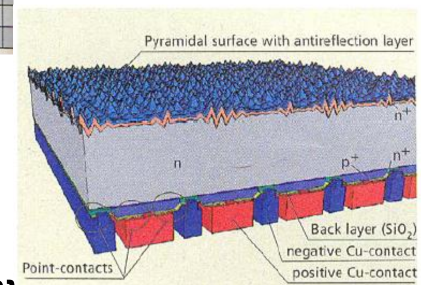
STD Cell

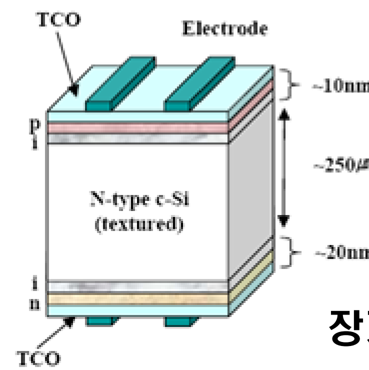


PERL Cell

중기(~2020)

Back-Contact SC





Bifacial

Tandem

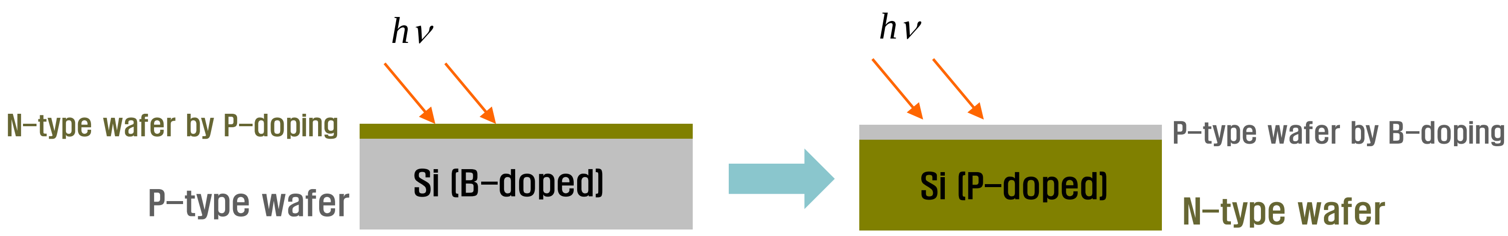
장기 (~2030)

Sanyo www.sanyo.com/solar	HIT-190BA19	Mono, a-Si	190	171.2	+10/-0	15.2	16.4	54.8	3.47
	HIT-186DA3[1]		186	172.6		14.2[2]/18.2[3]	15.3[2]/19.6[3]	54.8[2]/55.1[3]	3.40[2]/4.32[3]
	HIT-190DA3[1]		190	176.8		14.6[2]/18.6[3]	15.7[2]/20.0[3]	55.3[2]/55.6[3]	3.44[2]/4.37[3]
	HIT-195DA3[1]		195	181.1		14.9[2]/19.1[3]	16.1[2]/20.5[3]	55.8[2]/56.1[3]	3.50[2]/4.45[3]
	HIT-195BA19		195	179.8		15.6	16.8	55.3	3.53
	HIT-200BA19		200	184.5		16.0	17.2	55.8	3.59
	HIT-205BA19		205	185.1		16.4	17.7	56.7	3.62
	HIT-205NKHA1		205	190.2		15.1	16.3	40.7	5.05
	HIT-210NKHA1		210	194.9		15.5	16.7	41.3	5.09
	HIT-215NKHA1		215	199.6		15.9	17.1	42.0	5.13

3) At up to 30% backside irradiance contribution

4. 실리콘 태양전지의 기술전망

4.1 기판: N-type Cell, 고효율 원가절감 가능성 높음



N-type cell (Supermono)

Major issue:
B-doping, Surface passivation:
(SiN not work for N-type)

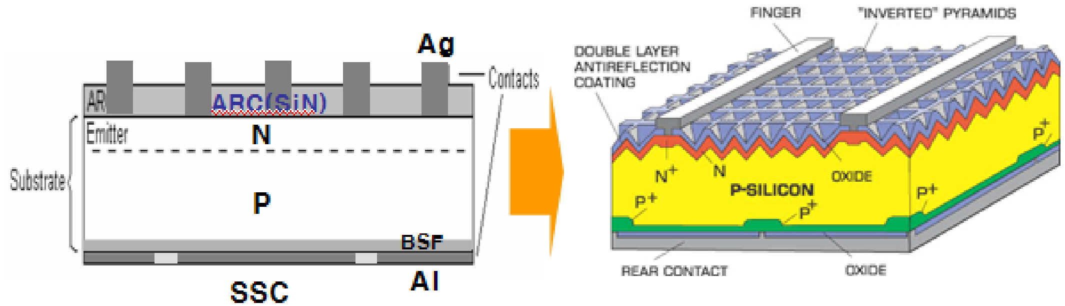
Sunpower (IBC), Sanyo(HIT)
➔ Std Cell 적용

YINGLI SOLAR

PANDA Project: ECN과 공동으로 N-type 고효율 셀 개발 :
ECN/Amtech자회사 (Tempress:diffusion furnace)
After 13 month: pilot line,19%< 생산라인, 18.5%<

-High Carrier lifetime (longer diff. length) ➔ crystal defect & metal 불순물에 덜 민감
☞ 동급 p-type에 비해 lifetime 5배
-광열화(B-O)를 피할 수 있다.
-Less recombination-active defects (theoretical & experimental)
-Unused potential supply of n-type Si (반도체 대부분 p-type)
-고온공정 유리
-저급 재료(ribbons, metallurigical)에 n-type doping 유리
-박형과 고효율에 n-type 유리
☞ P-type에 비해 최소 1% 효율증대

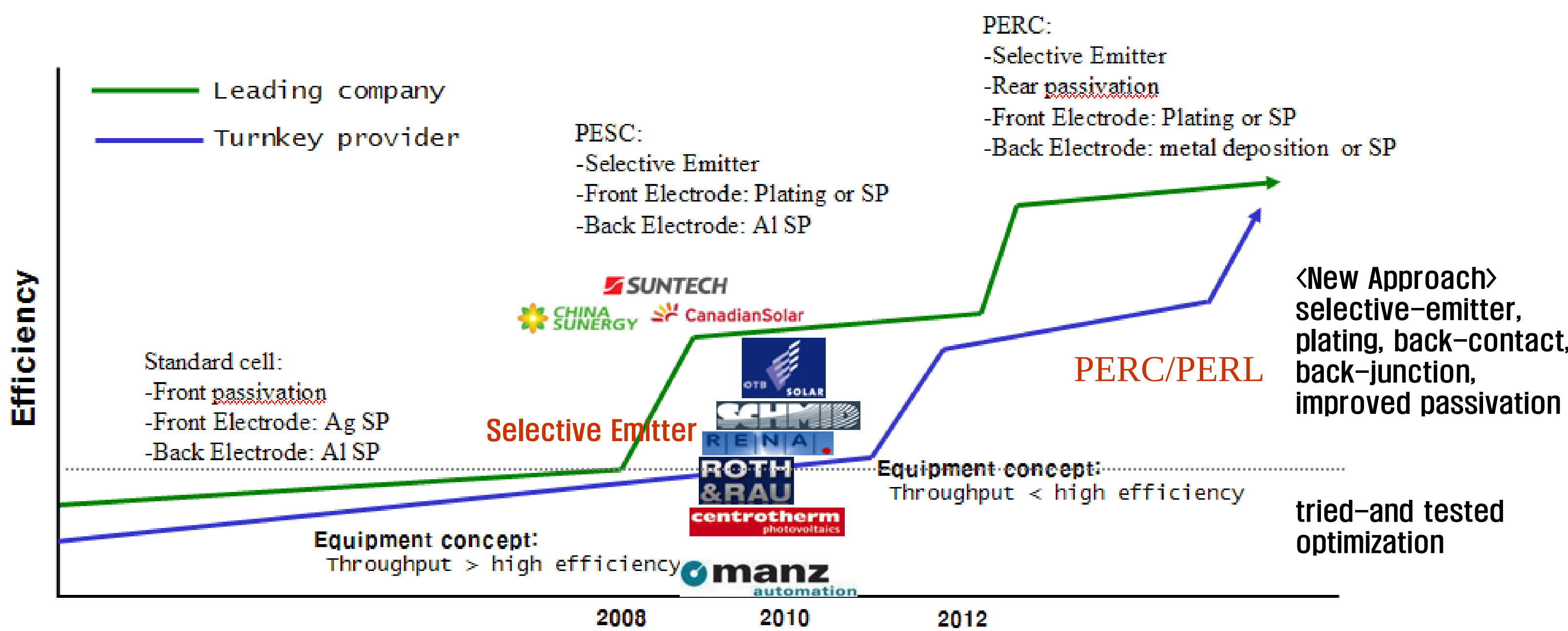
4.2 Standard solar cell vs. PERL cell (25.0%)



제 조 공 정		SSC (trun-key 기술)	PERL Cell	기술의 중요성 (효율기여도)
전면전극		Ag screen printing	Ti/Pd 증착→Ag 전해도금	7
Texturing		Wet etching(acid or alkali)	Lithography (역피라미드)	
AR Coating		SiN: AR Coating과 passivation을 겸함	Double layer	
Passivation	전면		SiO_2	
Doping	전면 전극하부	-	n^+	
	Emitter	n	n	
	Wafer	p	p	
	후면 전극상부	-	p^+	3
Passivation	후면	Al screen printing Al-BSF에 의한 passivation	SiO_2	
후면전극			Al/Ti/Pd 증착→Al 증착, anneal	
특징		효율은 낮더라고 저가공정	최고의 기술로 고효율	

4. 실리콘 태양전지의 기술전망

4.2 Trends in STD c-Si PV Manufacturing Technologies

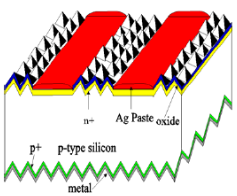


- c-Si 태양전지는 궁극적으로 PERL cell로 진화
- 상업적으로는 PERL cell 기술을 단계적으로 적용
  (→ SE → 후면 passivation → 후면 locally diff(point 전극)
- 전극 (전면: SP→도금, 후면 LFC 등등…)

☞ 2013년 i-PERL 상업화 turnkey provider 등장 가능성 매우 높음

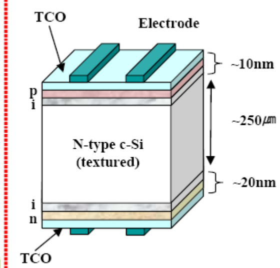
4. 상업화 고효율 셀

4.3 Sanyo사의 HIT (Heterojunction with Intrinsic Thin layer)Cell



- Texture etching
- $POCl_3$ Diffusion emitter, ~ 900°C)
- Oxide etching
- PECVD SiN_x AR
- Al Screen-printing
- Ag Screen-printing
- Belt Co-firing ~ 900°C
- Edge Isolation
- FGA

- Texture etching
- Cleaning (front)
- a-Si:H deposition Front emitter (PECVD, ~200°C)
- ITO sputtering Front TCO & AR
- Cleaning (back)
- a-Si:H deposition Back passivation (PECVD, ~200°C)
- ITO sputtering back
- Ag Screen-printing
- Al Screen-printing
- Low temp. anneal.



전후면 a-Si passivation: Voc↑

후면 투명전극: 광흡수 증대 (bifacial)

HIT cell의 특징은

- n-type의 결정질 실리콘
- 전후면에 a-Si:H 박막을 이용한 저온접합형성 (전후면 passivation)➔ High Voc (0.7V<)
- 300°C 이하의 저온공정: cell 제조과정에서 cell이 받는 열 stress가 적어 cell 파손 가능성이 낮기 때문에 wafer 박형화에 매우 유리한 공정 임.
- TCO 사용으로 current resistance, 저온소성용 paste 사용으로 finger line 형성

Bifacial: up to 30% backside irradiance contribution

2010年12月03日

高効率な太陽電池モジュールを欧州より商品展開

世界No．1[※1]、セル変換効率21．6％のHIT[®※2]太陽電池を量産化

	New N series
Product name	HIT-N240SE10
Pmax	240W
Vmp, Imp	43.7V, 5.51A
Dimensions	1,580 × 798 × 35mm
Weight	15.0kg
Cell efficiency	21.6%
Module efficiency	19.0%

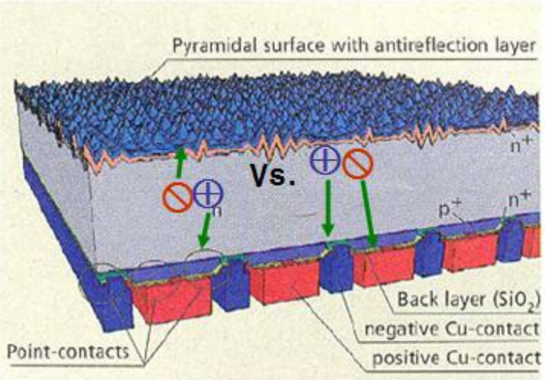
HIT®
Photovoltaic Module

※1　2010年12月3日発表時時点、三洋電機調べ。モジュール出力と総セル面積から算出。

4. 상업화 고효율 셀

4.4 후면전극 (Back-Junction Back-contact: IBC)

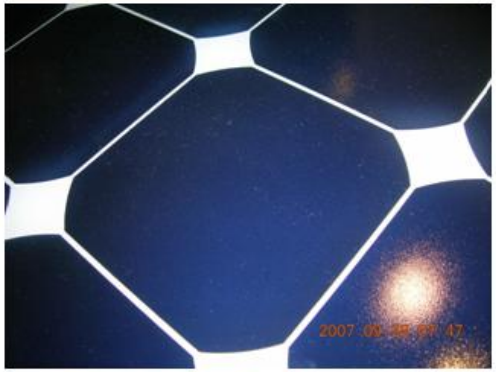
SUNPOWER



- 후면 전극은 carrier의 이동거리가 길어 life time 이 크지 않으면 효율이 증가하지 않는다.
- Life time이 큰 n-type 사용

❖전극을 후면에 배치하여 shading loss가 없음➔ Isc ↑

❖최고 24.2% 효율, 고품위 기판 및 semi-process로 원가경쟁력 취약($0.8/W)



후면전극을 따라 형성하는 n형과 p형의 확산층 간격이 종래의 2mm에서 1mm로 변경으로 효율 증대

SUNPOWER ANNOUNCES NEW WORLD RECORD SOLAR CELL EFFICIENCY

Full-Scale Prototype Produced at 24.2 Percent

SAN JOSE, Calif., June 23, 2010 /PRNewswire via COMTEX News Network/ -- SunPower Corp. (Nasdaq: SPWRA, SPWRB), a Silicon Valley-based manufacturer of high-efficiency solar cells, solar panels and solar systems, announced today that it has produced a full-scale solar cell with a sunlight to electricity conversion efficiency of 24.2 percent at its manufacturing plant in the Philippines. This is a new world record, confirmed by the U.S. Department of Energy's National Renewable Energy Lab (NREL), for large area silicon wafers.

Where Will Destiny Take SunPower?

Seeking Alpha α

June 01, 2010 | about: SPWRA

Customize Font Size: T T | Print | Email   αRecommend 0   Share 0   1 retweet

Greentech Media

834 Followers | 1 Following

by Michael Kanellos

Will SunPower (SPWRA) make it?

For the past six or seven months, that's been one of the primary questions in the solar market. Will the pioneering manufacturer of high-end, high-efficiency solar panels succumb to competitors, or somehow pull through.

First, the dismal take. SunPower appears stuck in an unenviable spot. It competes against First Solar (FSLR), which can offer lower prices for utility-scale contracts. In the residential market, it must contend with Suntech Power Holdings (STP) and a raft of other Chinese manufacturers that [a] can produce products for less and [b] are increasing the efficiency of their products.

-Brand power 탁월 (기술혁신 기업, 외관미려)
-Solar park 개발능력, racking & installation 기술보유
-PowerLight, SunRay 인수, AU Optoelectronics와 JV

-2010년 말 Cell 효율: 23% 도달 (한계직면)➔ concentrator, different material 연구 (상업적 미검증)
-Utility용은 First Solar에 Roof top은 Suntech 등에 밀림➔ 저가모듈 출시

http://sharp-world.com/corporate/news/101201.html

SHARP

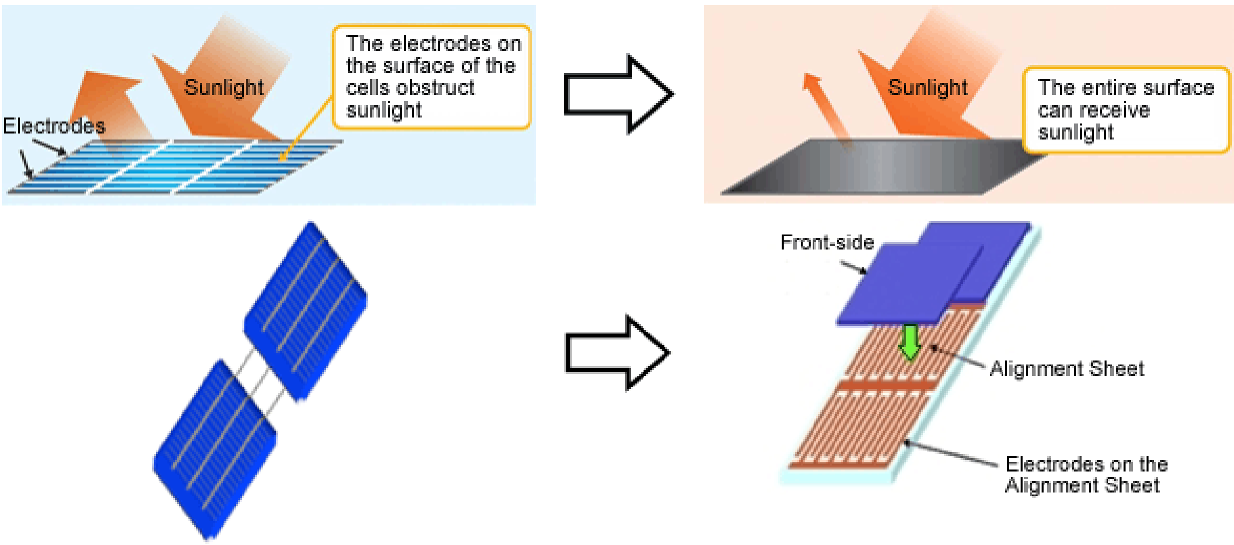
Press Release

December 1, 2010

Solar Cell Plant in GREEN FRONT SAKAI

Single Crystalline Silicon Solar Cell Module with High Conversion Efficiency

Sharp to Begin Mass Production of New Single Crystalline Solar Cells with High Conversion Efficiency at GREEN FRONT SAKAI



Overview of the Production of Single Crystalline Silicon Solar Cell Modules with High Conversion Efficiency

Location	:	Solar cell plant, GREEN FRONT SAKAI 1 Takumi-cho, Sakai-ku, Sakai City, Osaka Prefecture, Japan
Production Capacity	:	200 MW/year (initial phase)
Investment Amount	:	Approximately 15 billion yen
Start of Operations	:	Within fiscal year 2010 (plan)

Hanwha Chemical

Prog. Photovolt: Res. Appl. 2010; 18:346–352 Solar Cell Efficiency Tables (version 36)

Table I. Confirmed terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at 25°C (IEC 60904-3: 2008, ASTM G-173-03 global).

Classification[a]	Effic.[b] (%)	Area[c] (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF[d] (%)	Test centre[e] (and date)	Description
Silicon							
Si (crystalline)	25.0 ± 0.5	4.00 (da)	0.706	42.7	82.8	Sandia (3/99)[f]	UNSW PERL [10]
Si (multicrystalline)	20.4 ± 0.5	1.002 (ap)	0.664	38.0	80.9	NREL (5/04)[f]	FhG-ISE [11]
Si (thin film transfer)	16.7 ± 0.4	4.017 (ap)	0.645	33.0	78.2	FhG-ISE (7/01)[f]	U. Stuttgart (45 μm thick) [12]
Si (thin film submodule)	10.5 ± 0.3	94.0 (ap)	0.492[g]	29.7[g]	72.1	FhG-ISE (8/07)[f]	CSG Solar (1–2 μm on glass; 20 cells) [13]

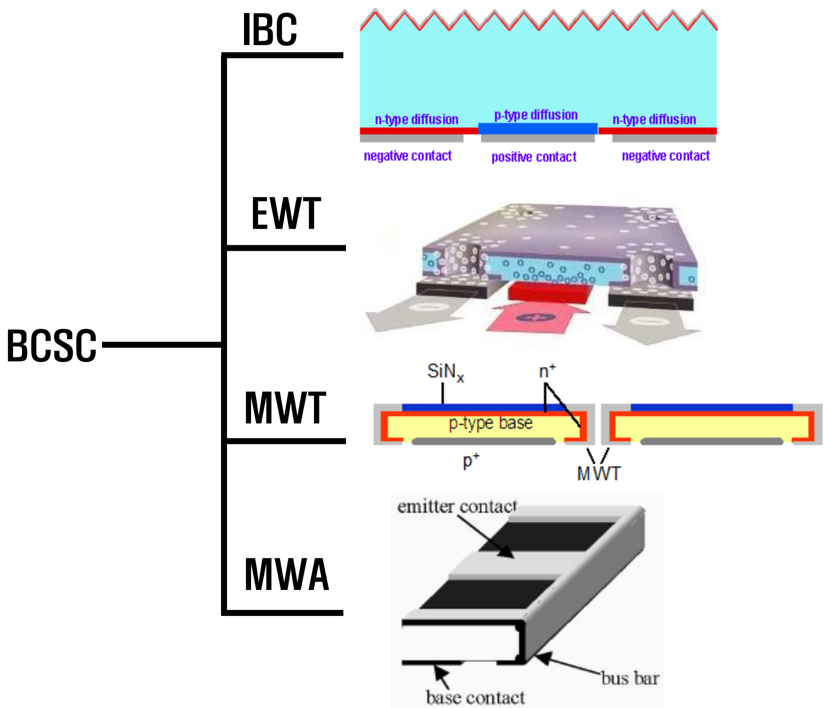
Table II. Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25°C (IEC 60904-3: 2008, ASTM G-173-03 global).

	Classification[a]	Effic.[b] (%)	Area[c] (cm^2)	V_{oc} (V)	I_{sc} (A)	FF[d] (%)	Test centre (and date)	Description
	Si (crystalline)	22.9 ± 0.6	778 (da)	5.60	3.97	80.3	Sandia (9/96)[e]	UNSW/Gochermann [30]
IBC	Si (large crystalline)	21.4 ± 0.6	15780 (ap)	68.6	6.293	78.4	NREL (10/09)	SunPower [31]
MWT	**Si (multicrystalline)**	**17.3 ± 0.5**	**12753 (ap)**	**33.6**	**8.63**	**76.1**	**AIST (x/10)**	**Kyocera**
	Si (thin-film polycrystalline)	8.2 ± 0.2	661 (ap)	25.0	0.320	68.0	Sandia (7/02)[e]	Pacific Solar (1–2 μm on glass) [32]
	CIGS	**13.8 ± 0.5**	**9762 (ap)**	**26.34**	**7.167**	**71.2**	**NREL (4/10)**	**Miasole** [6]
	CIGSS (Cd free)	13.5 ± 0.7	3459 (ap)	31.2	2.18	68.9	NREL (8/02)[e]	Showa Shell [33]
	CdTe	10.9 ± 0.5	4874 (ap)	26.21	3.24	62.3	NREL (4/00)[e]	BP Solarex [34]
	a-Si/a-SiGe/a-SiGe (tandem)[f]	10.4 ± 0.5[g]	905 (ap)	4.353	3.285	66.0	NREL (10/98)[e]	USSC [35]

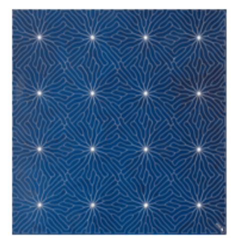
☞ **최고효율의 c-Si 단결정 및 다결정 모듈이 모두 후면전극**

5. 후면전극 개발현황

Back Contact Solar Cell (BCSC)

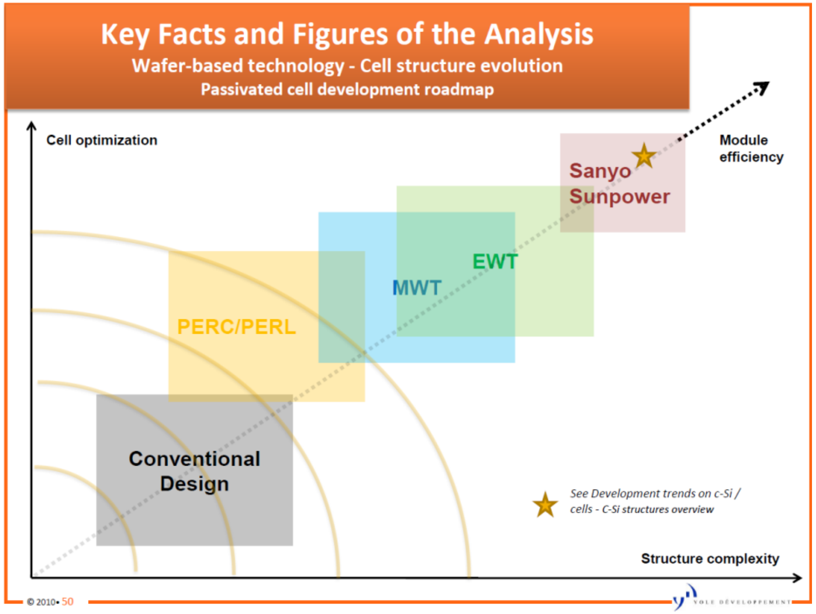


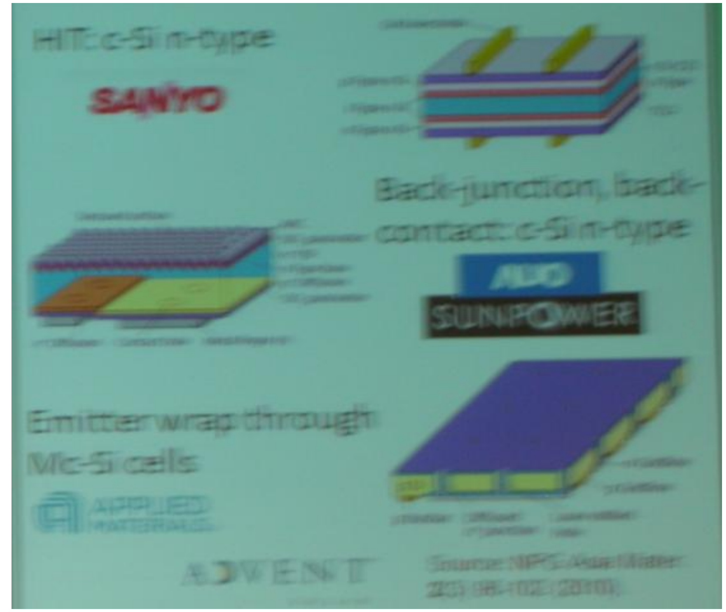
☞ BCSC 장점
- 전류증대 (lack of shading loss-up to 10%)
- 전면 passivation 최적화 유리
- 외관 미려
- 모듈효율 증대
- 모듈공정 단순화 (coplanar interconnection) (inter connection from front to back ➔ 자동화 어려움)



IBC: interdigitated back-contact (back/rear junction)
MWT: metal wrap-through
MWA: metal wrap-around
EWT: emitter wrap-through

☞ 후면전극의 가장 큰 문제점
- 공정 단축
- (+)/(-) grid 및 junction을 전기적으로 절연시키는 sequence 개발: 절연 passivation



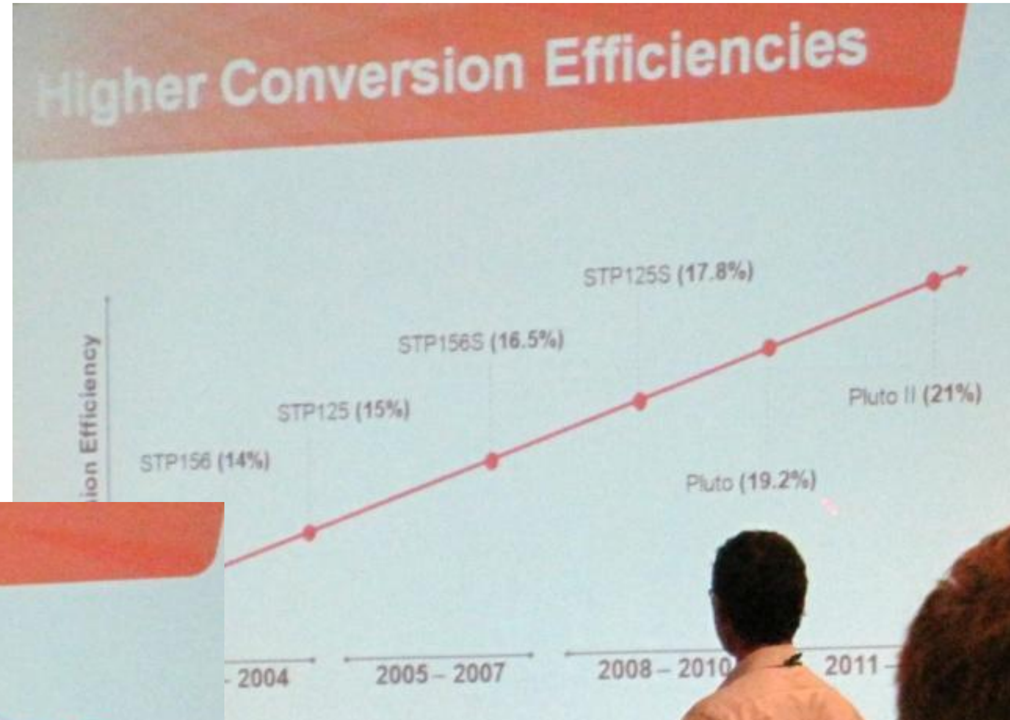


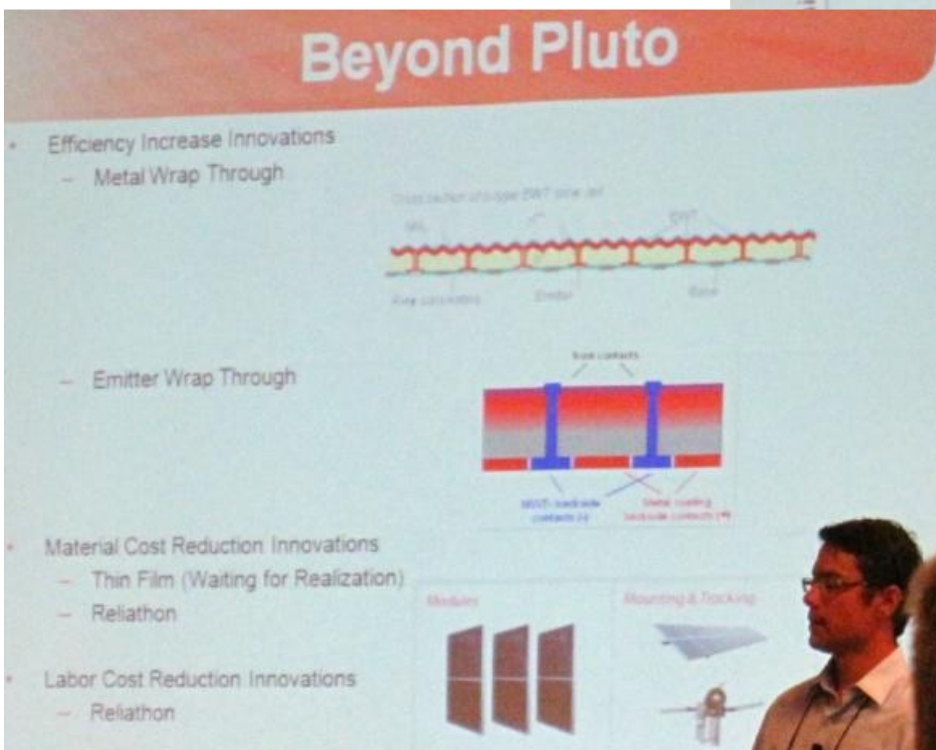
Source: PV Technology Roadmap (Yole development), 2010. 8
SPI 2010, LUX Research, 2010.10

	Junction	Shading Loss	Wafer	공정 cost
IBC	Back	None	고품위 n-type	High (litho, sput, 도금..)
EWT	Front+Back	None	Solar grade(단, 다, UMG)	low ~ medium
MWT	Front	Busbarless	Solar grade(단, 다, UMG)	

☞ 저가 고효율에 가장 적합한 cell type: EWT

SUNTECH





20th Workshop on crystalline Silicon Solar Cells & Modules: Materials and Processes
July 2010, Breckenridge, CO.

Invented for life BOSCH

c-Si 태양전지개발

SE ➔ MWT ➔ Back Junction Cell

2010 SiSoC Summer Meeting Breckenridge, CO.

The microtech market research company describes all the existing technologies: From those developed by the University of New South Wales (UNS W), to the metal wrap through (MWT) concept developed by the ECN and industrialized with Solland, to the new emitter wrap through (EWT) technology being developed by Bosh Solar.

Aug. 2010: PV Technology Road Map by YOLE Report.

1st Generation Research

Screen Printing	· Mono / Multi, P-Type · Buried contact
Semi conductor Finger	· Mono / Multi, P-Type
Laser Doping	· Mono / Multi, P-Type
Laser Doping Semi Conductor Finger	· Mono / Multi, P-Type
Ink Jet Printing	· Indirect · Direct
The Future	· Bifacial · N-type

NSi

Source: UNSW/NSi (July 5, 2010 入手)

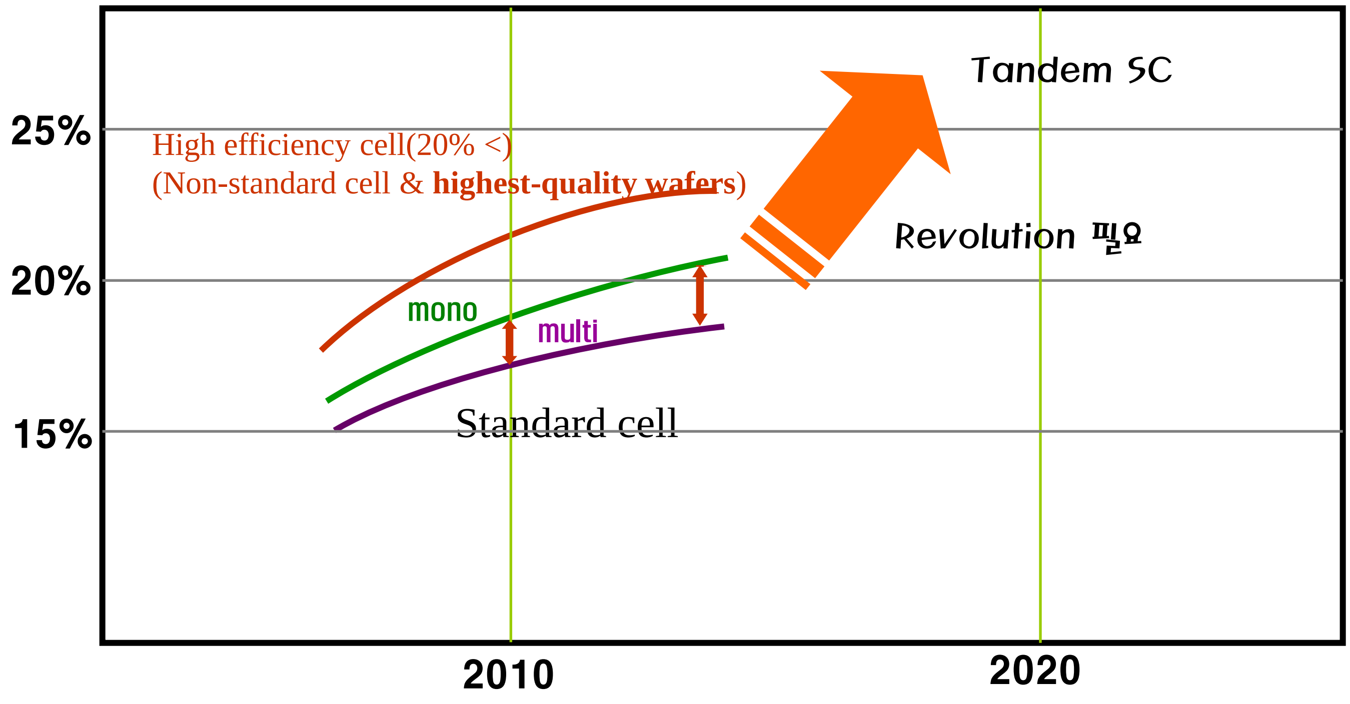
6. 차세대 실리콘 태양전지

선도업체들의 고효율 cell 전략

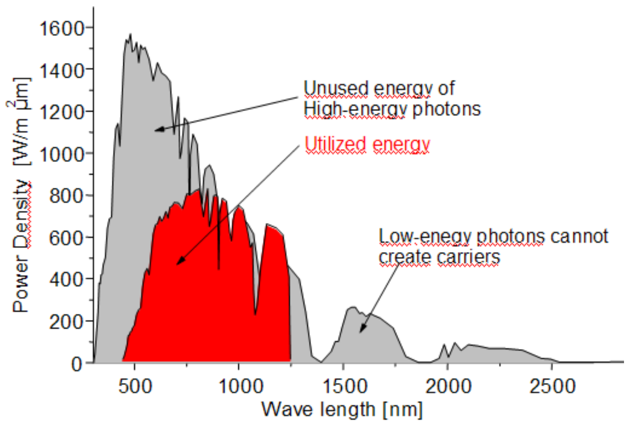
	Cell device		Cowork
Suntech	Pluto cell→MWT→EWT	Pluto Cell:17.2%, 18.9%	UNSW
Sanyo	HIT→QD		
Sharp	Back Contact Solar Cell		
Q-Cells	Back Contact Solar Cell		
Yingli	N-type Cell (PANDA Project)	18.5%< (cell)	ECN
JA solar	SECIUM (Si ink-SE) MWT	18.9% (cell)	 ECN
Trina	Back Contact Solar Cell		NUS
Kyocera	MWT	17.3 (module)	
Mitsubishi	STD cell 최적화	19.3%	
Bosch	SE→MWT→EWT		

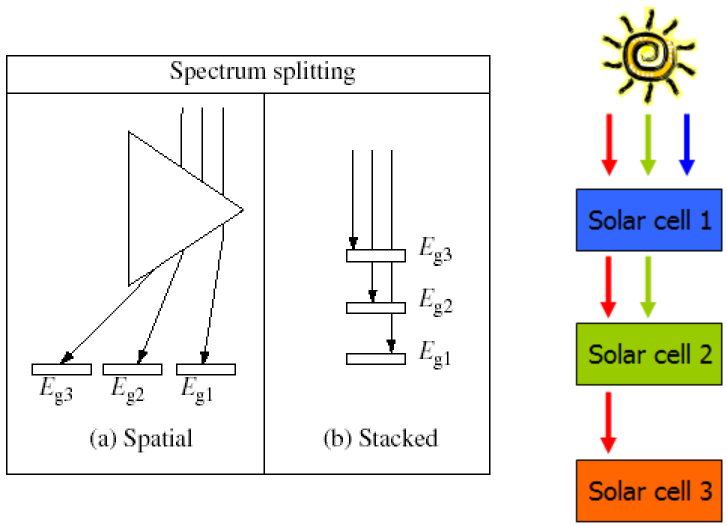
7. 차차세대 실리콘 태양전지 전망

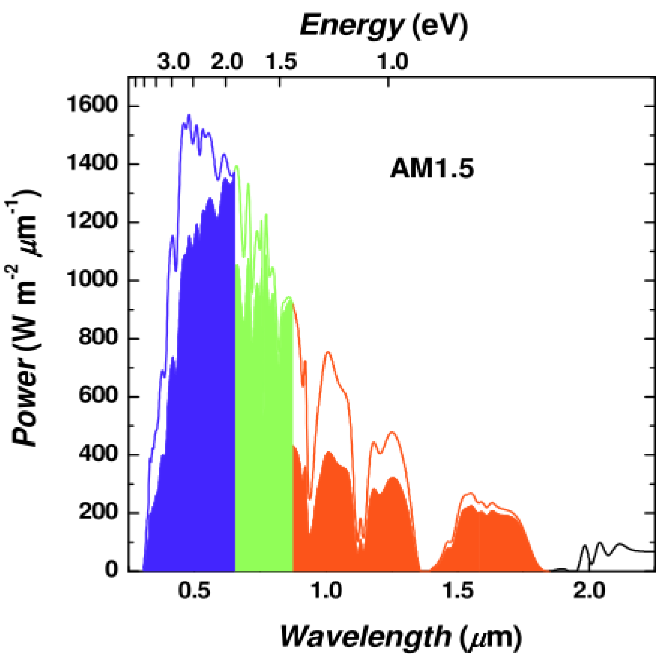
PV Cell 효율전망: Evolution vs Revolution



초고효율의 관건: 태양광 스페트럼의 효율적 사용 (Tandem Structure)







❖ 화합물반도체 이론적 셀 효율

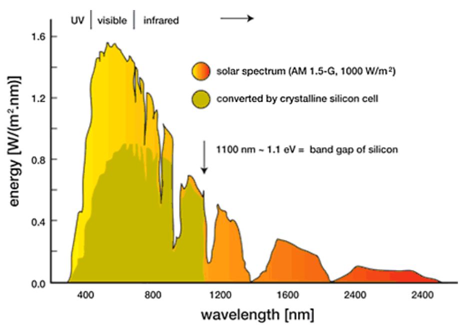
에너지밴드 수	셀효율 (1 sun)
1	37
2	50
3	56
36	72

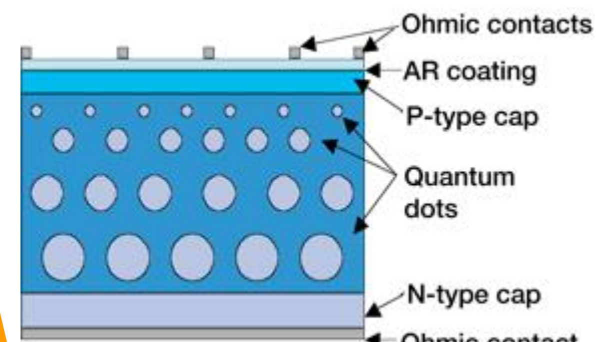
☞ 문제는 적당한 band gap material과 공정 cost

☞ Band gap 조절이 가능한 태양전지는 화합물 반도체 태양전지

7. 차차세대 실리콘 태양전지 전망

Your beginning will seem humble, so prosperous will your future be. <Job 8:7>





Pure QD Solar Cell

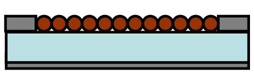
innovaLIGHT

Solexant

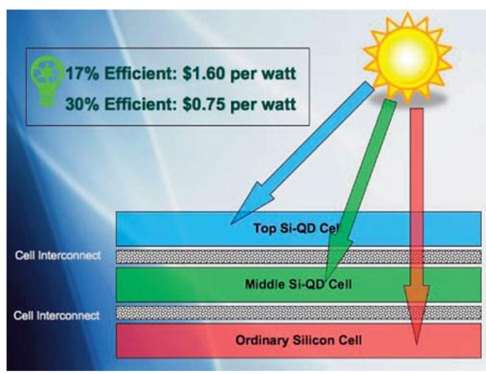
SOLTERRA RENEWABLE TECHNOLOGIES INC See The Light

natcoretechnology advancing solar science

Down→Shift



흡수효율이 높은 파장으로 광변조



탠덤 Si 태양전지

QD Application to c-Si Solar Cell

결론

C-Si 태양전지 고효율 기술개발 전망

재료
-Si : P-type ➔ N-type(고효율 및 원가절감)
-박형화: 고효율, breakage감소, 자동화 (셀 & 모듈라인)

Cell device
-단기(~2015): Std Cell ➔ PERL
-중기(~2020): 효율 20% 이상의 후면전극이 50% 이상 점유
-장기: Tandem (QD 접목), >25%

☞ 문제는 고효율과 저가화를 동시에 달성해야 한다는 점이다.

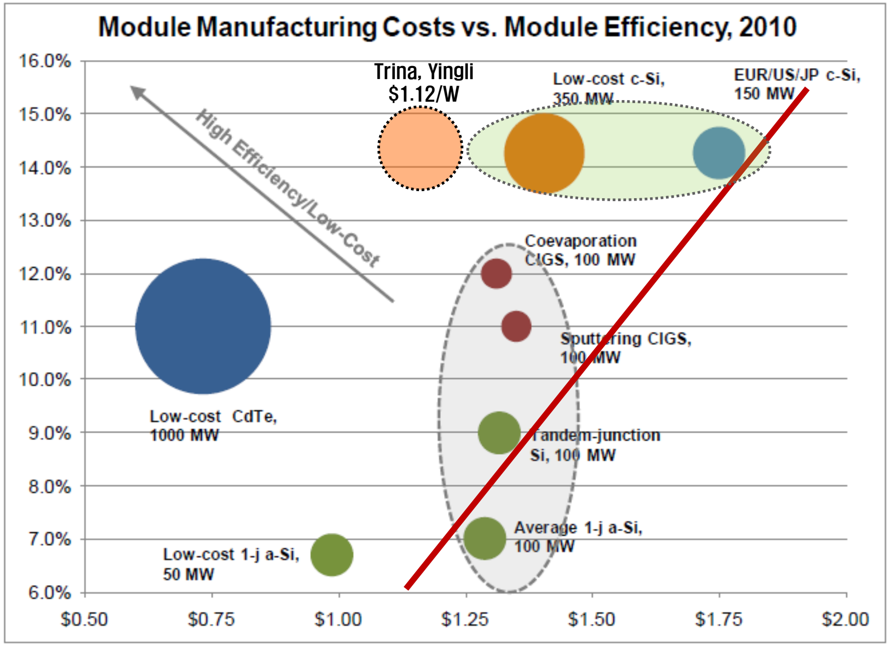
PV Technology Development

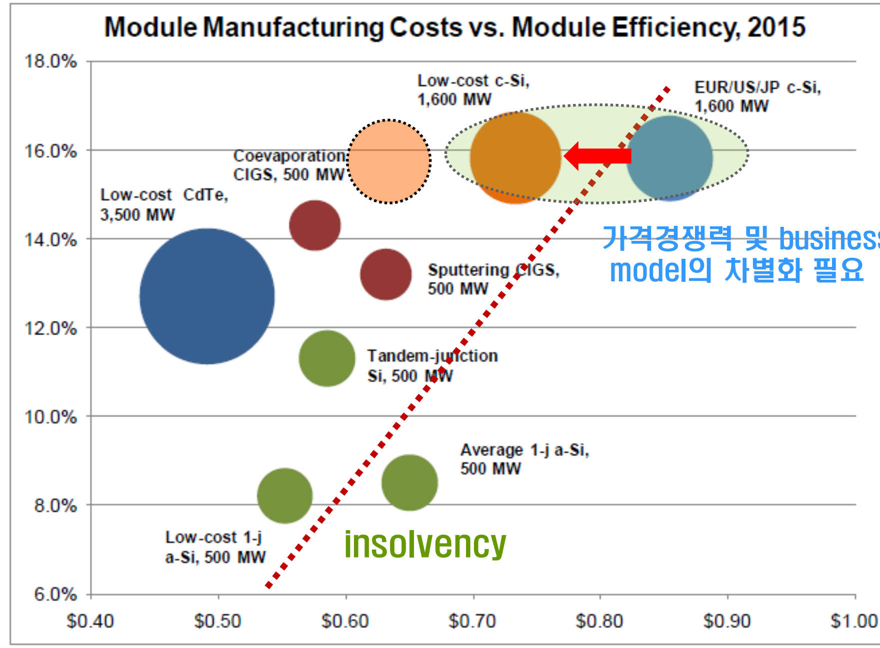
It was not until 2002, almost 20 years after its inception, that First Solar shipped commercial product. Founder Harold McMaster had confidently predicted that "in five years SCI [First Solar's previous incarnation] will be able to produce a watt of solar energy for 60￠"; this was in 1998.

Hofstadter's Law: "It always takes longer than you expect, even when you take Hofstadter's Law into account."

<참고자료>

Cost vs. Efficiency





Production and Cost Outlook: 2010–2015, the panel prices on the retail market will drop to less than USD 1 (EUR 0.727) a watt by 2012, driven by solid competition.

Source: Greentech Media Research, in SPI 2010, Oct 11 2010

<참고자료>

Trinasolar

Source: TSL earnings presentation

YINGLI SOLAR

than expected results. Yingli is one of the globe's largest vertically integrated solar firms.

- Q3 Revenue: $491 million (vs. Street at $477 million)
- Q3 Gross Margins: 33.3 percent (vs. Street at 31.7 percent)
- EPS: $0.44 (vs. Street at $0.36).

SUNTECH

In the reported quarter, Suntech's gross profit was $122 million and gross margin was 16.4% compared to gross profit of $113.9 million and gross margin of 18.2% in the second quarter of 2010. The sequential

Q3/2010 중국 top tier gross margin rate
-Trina: 37%
-Yingli: 33.3%
-Suntech: 16.4%

Hanwha Chemical

THANK YOU!