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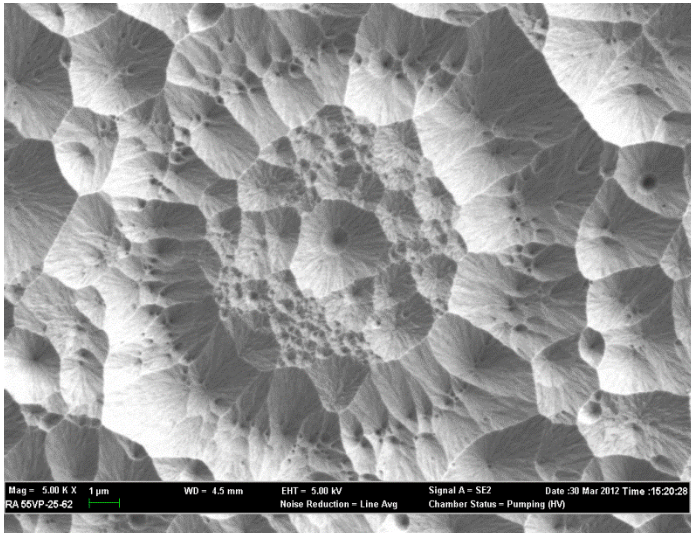
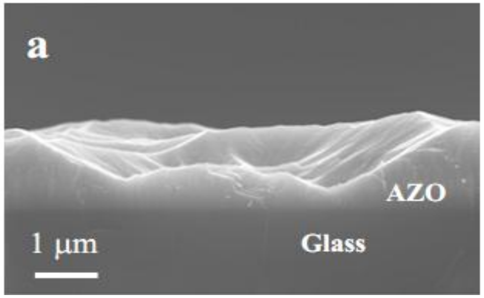
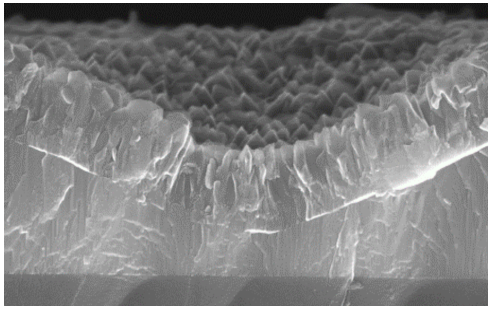
Nankai University

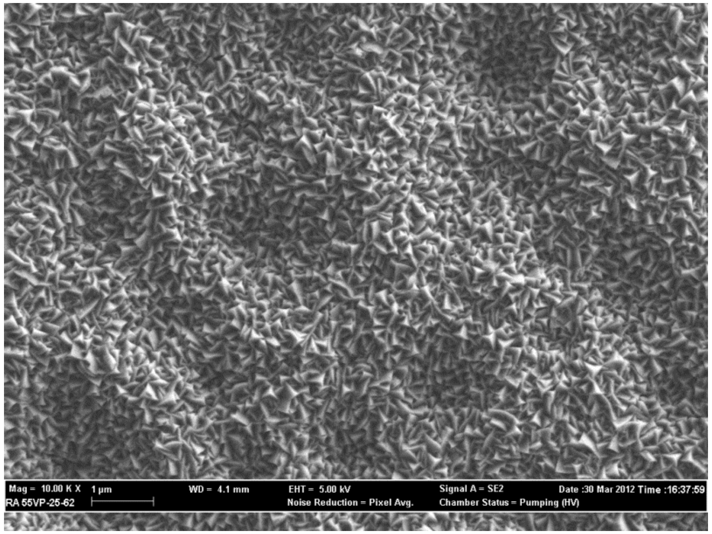
Institute of photo-electronics thin film devices and technique

Research on high efficiency and low cost thin film silicon solar cells





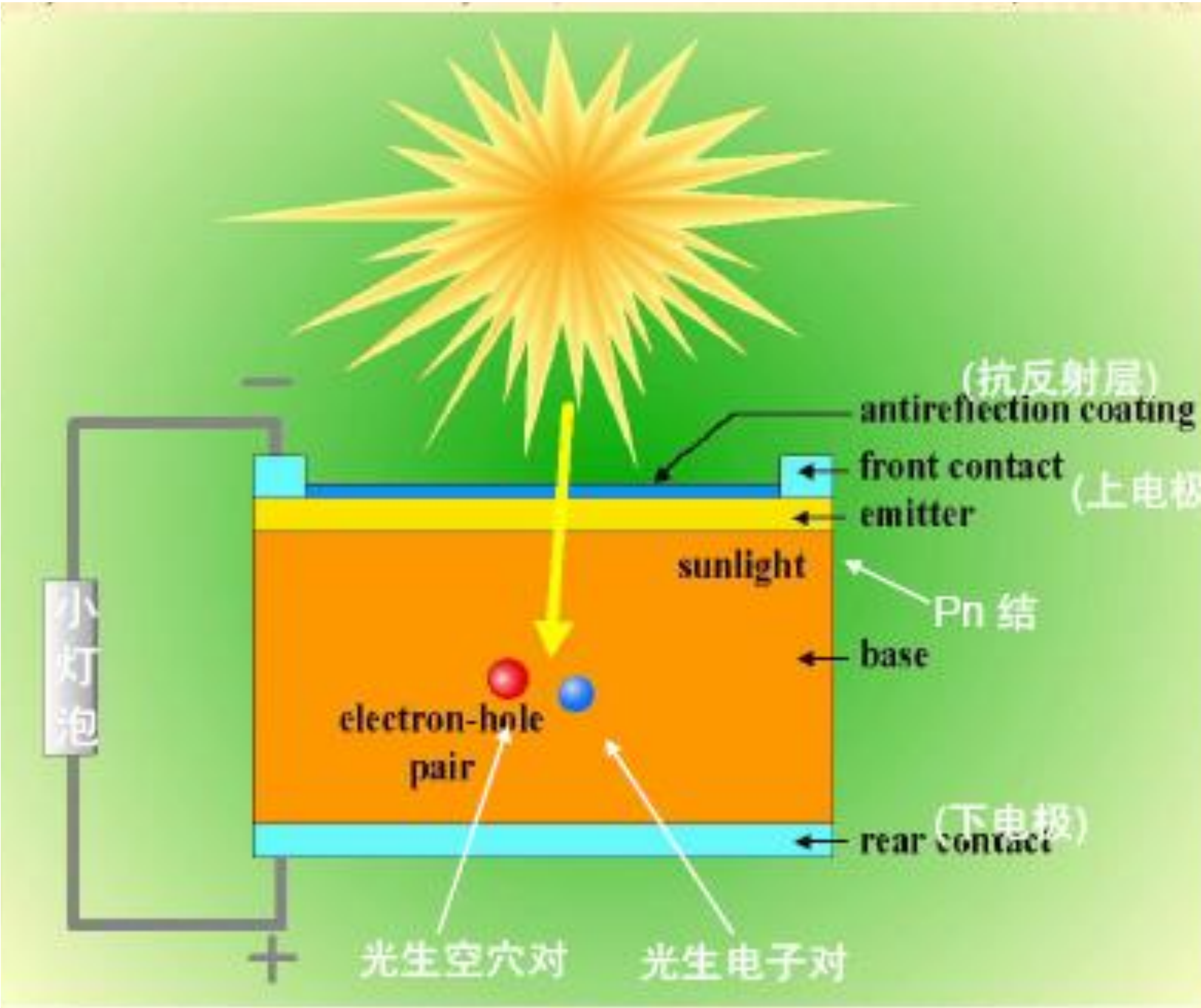




Xiaodan Zhang

Nankai University

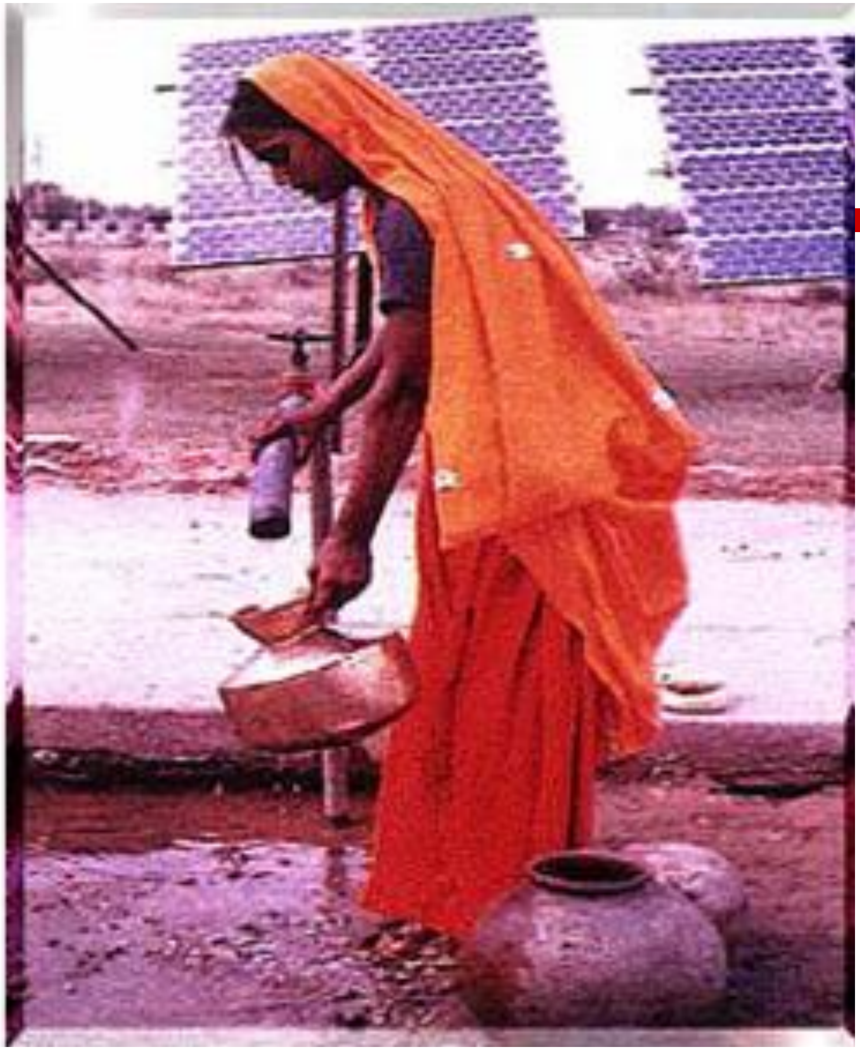
2013 China-America Frontiers of Engineering, May 15-17, Beijing, China

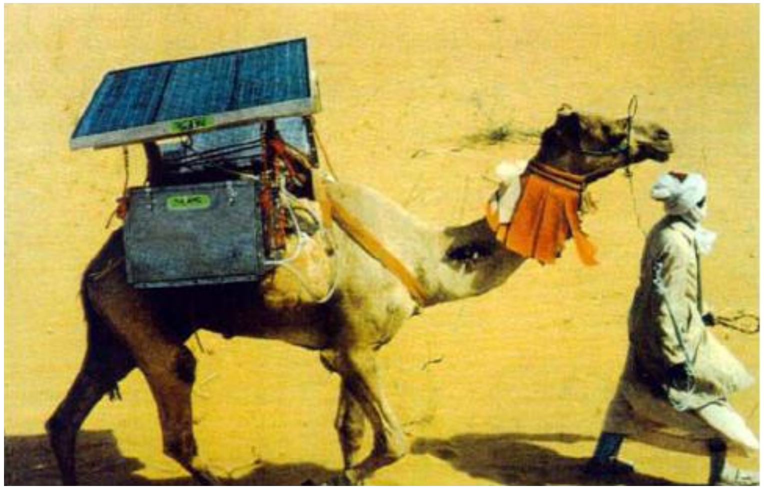


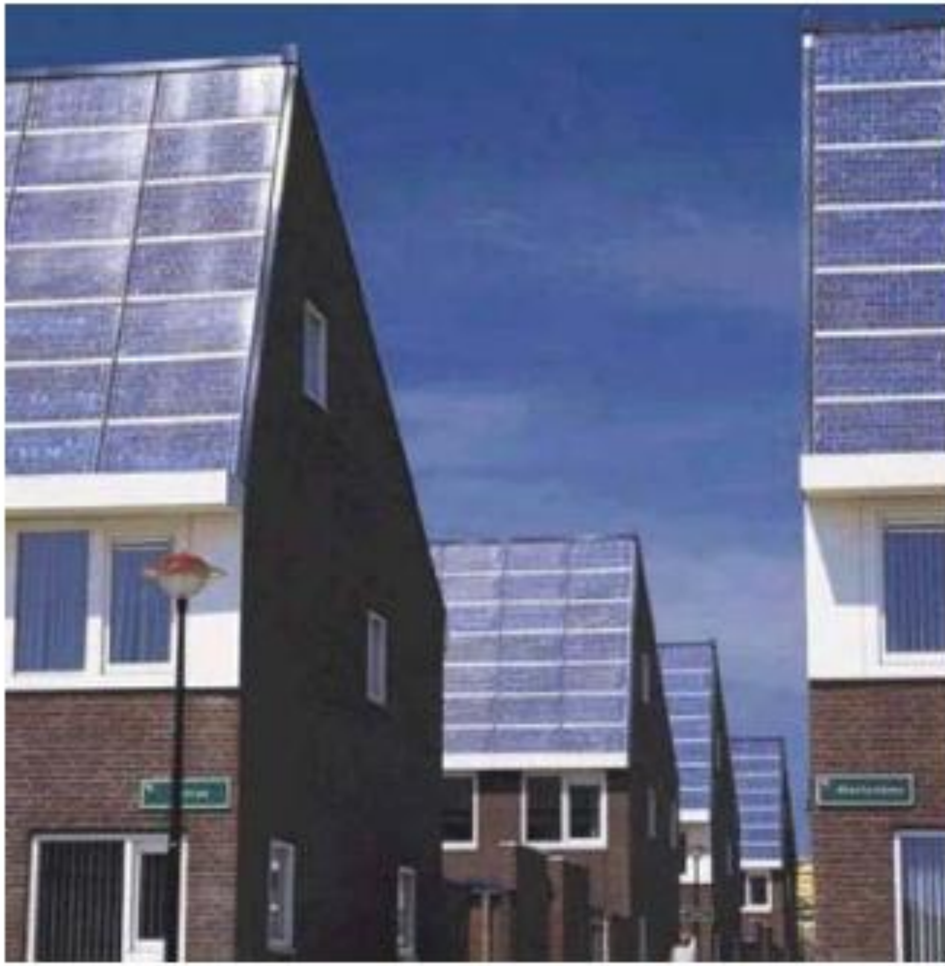
−
(抗反射层)
antireflection coating
front contact
(上电极)
emitter
sunlight
Pn 结
base
小灯泡
electron-hole
pair
(下电极)
rear contact
+
光生空穴对
光生电子对


(Sonnen, Bayern, Germany)


maier





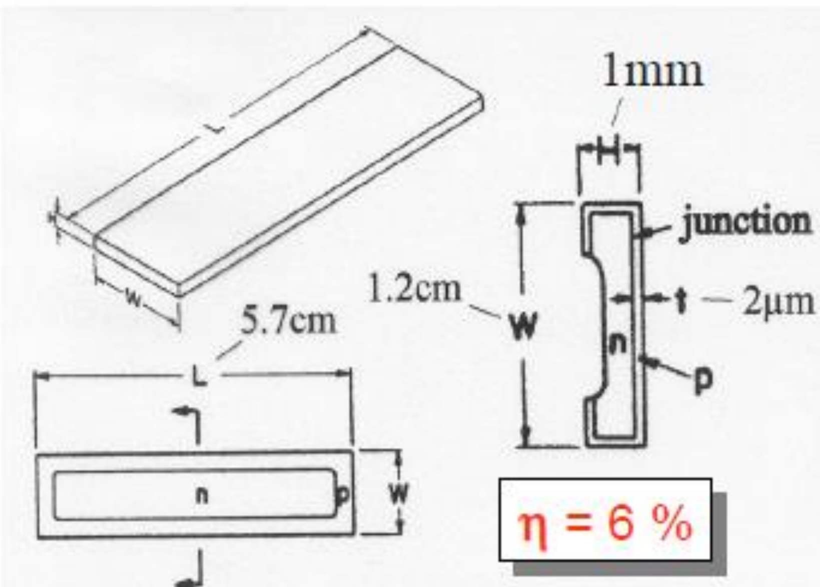


1954: The Birth of Solar Photovoltaics

A New Silicon *p-n* Junction Photocell for Converting Solar Radiation into Electrical Power

D. M. Chapin, C. S. Fuller, and G. L. Pearson
Bell Telephone Laboratories, Inc., Murray Hill, New Jersey

(Received January 11, 1954)



1. **Crystalline silicon solar cells**

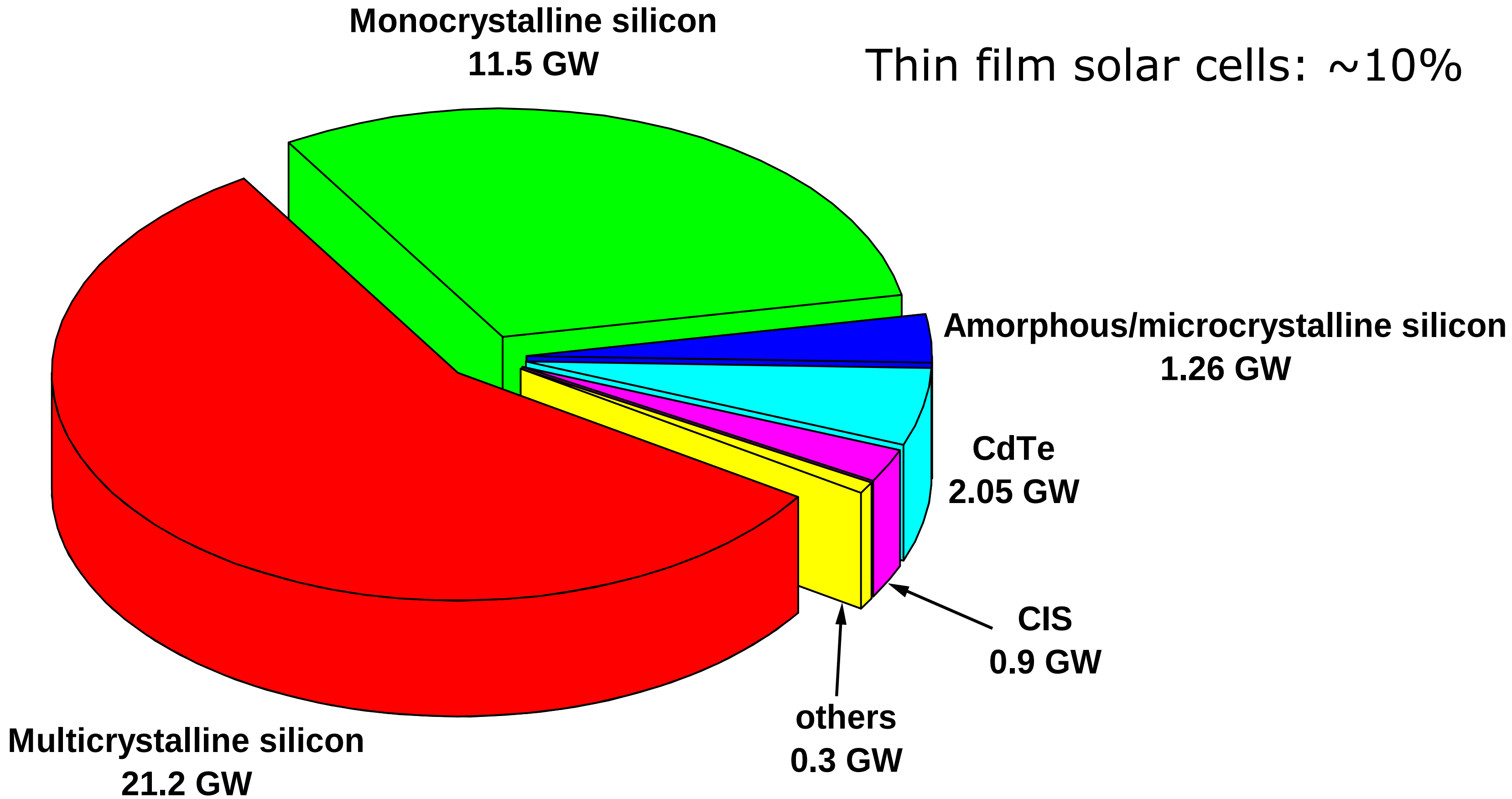
- Mono-crystalline and poly-crystalline solar cells

2. **Thin film solar cells**

- Silicon-based thin film solar cells
- Copper Indium Gallium Selenium solar cells (CIGS)
- CdTe solar cells
- Dye sensitized solar cell (DSC)

3. **Concentrated solar cells**

Thin film solar cells: ~10%



2011 Total Production : 37 GW

Source:Photon Int.

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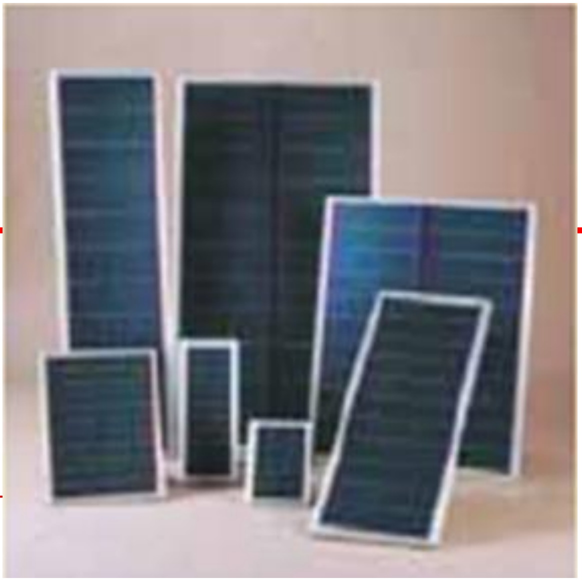
Thin film silicon solar cells



Advantages:

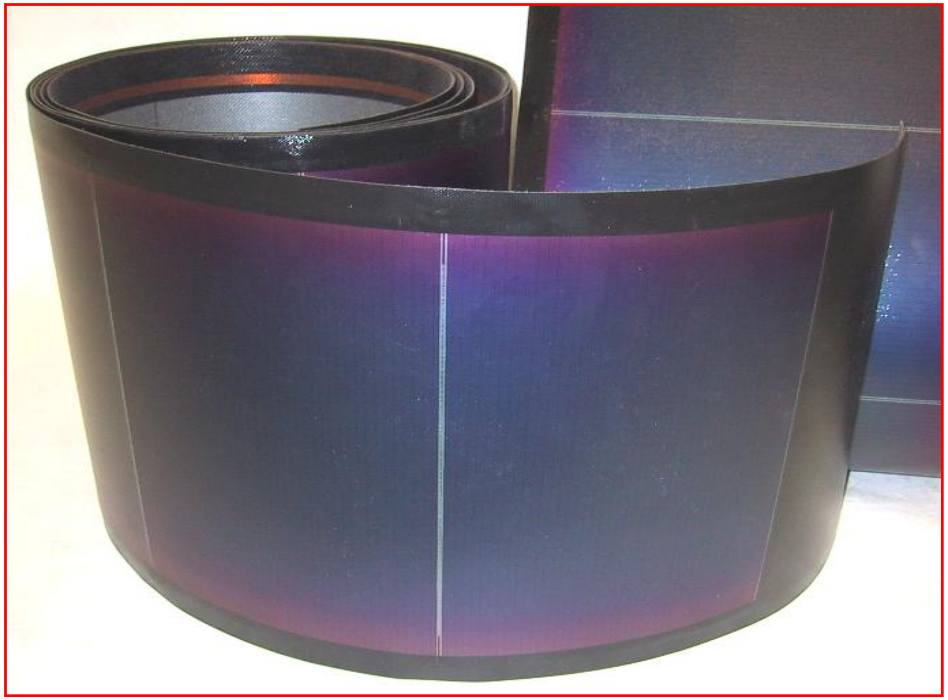
- No materials limited
- Low deposited temperature (<200℃)
- Deposited on different substrates

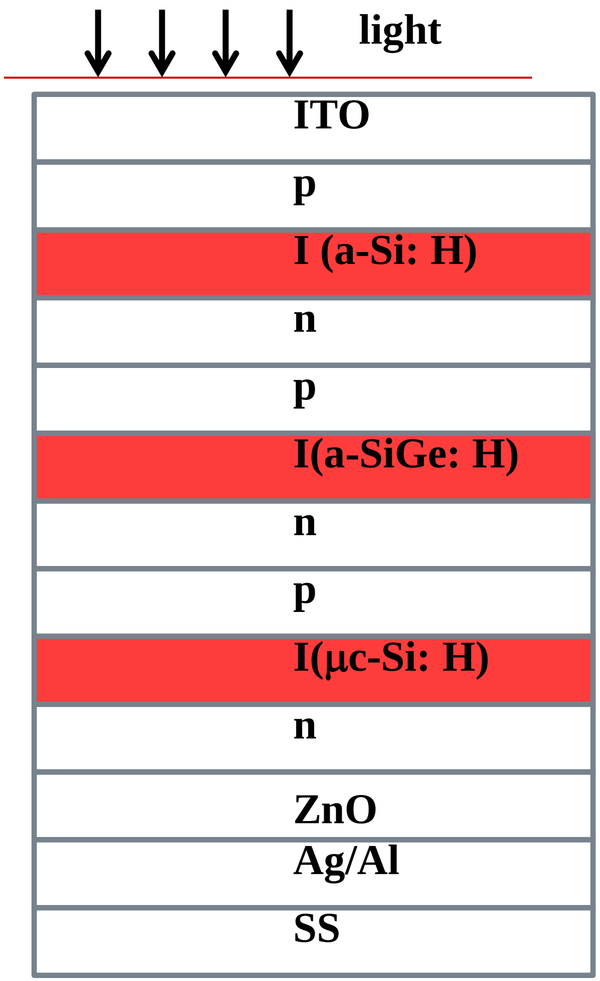
Disadvantages:

- Low conversion efficiency
- Light induced degradation efficiency

Thin film Silicon solar cell structures: substrate configuration

1. Initial 16.3% efficiency has been achieved using **a-Si:H**/a-SiGe:H/ μ**c-Si:H** structure . -----nip

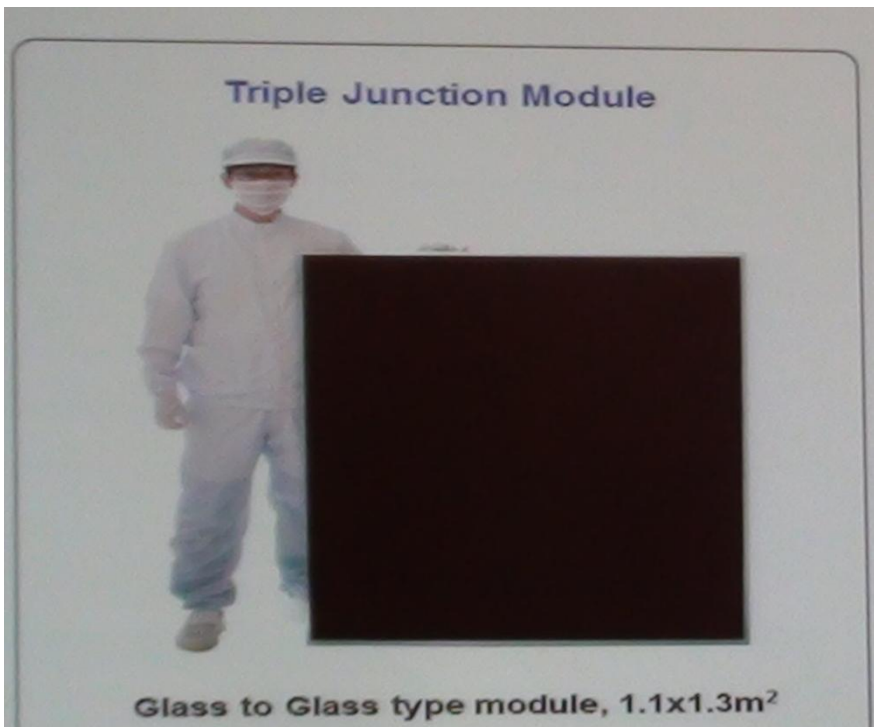


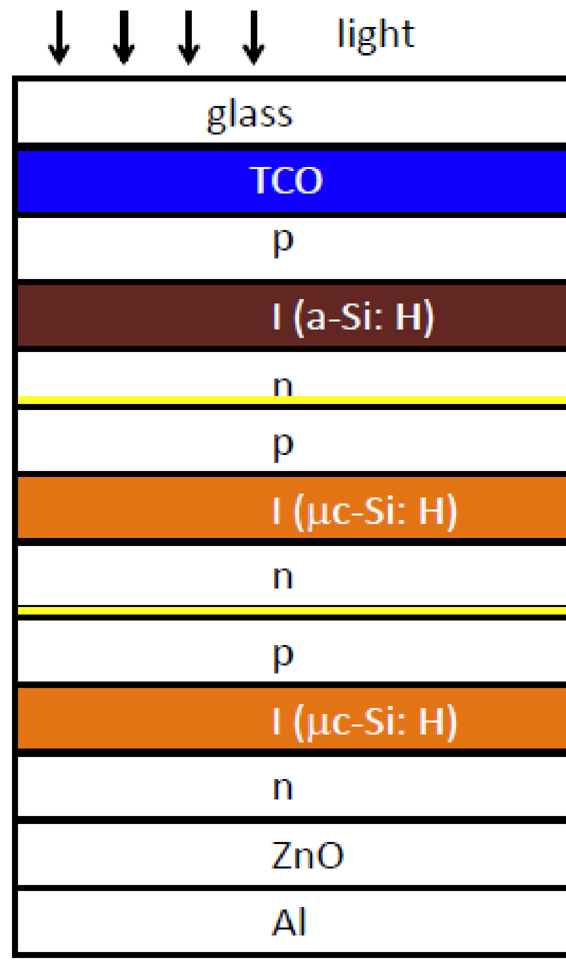


Baojie Yan et al. *Appl. Phys. Lett.* **2011**.

Thin film Silicon solar cell structures: superstrate configuration

2. Stable 13.44% efficiency has been achieved using **a-Si:H**/ **μc-Si:H** / **μc-Si:H** structure .-------pin

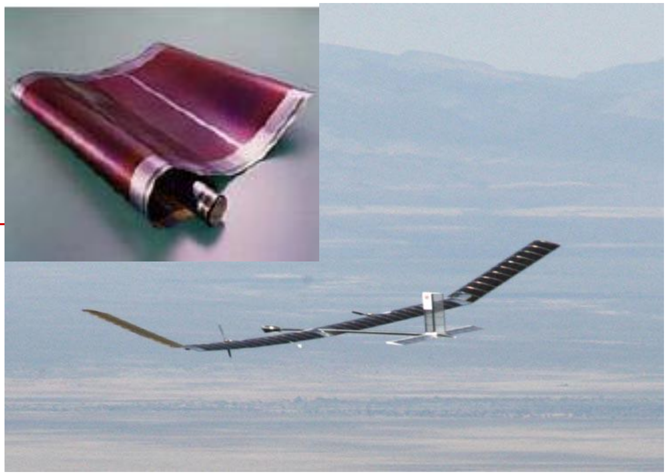




Soohyun Kim et al. 27th EU-PVSEC **2012**.

Thin film silicon PV technology

Target: Low cost and high conversion efficiency



1. Key issue: increase efficiency

- Multi-junction for full use of solar spectrum
- New materials
- Advanced light trapping
- New structures
- New concepts
- ……

2. Key issue: reduce cost

- High deposition rate
- High stable efficiency
- Single chamber deposition
- Suitable large area
- ……

3. Summary and outlook

1. Key issue: increase efficiency

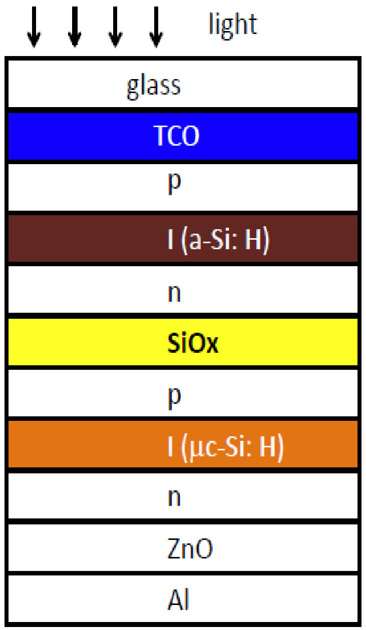
New materials: Amorphous and microcrystalline silicon alloys

Deposition technique:

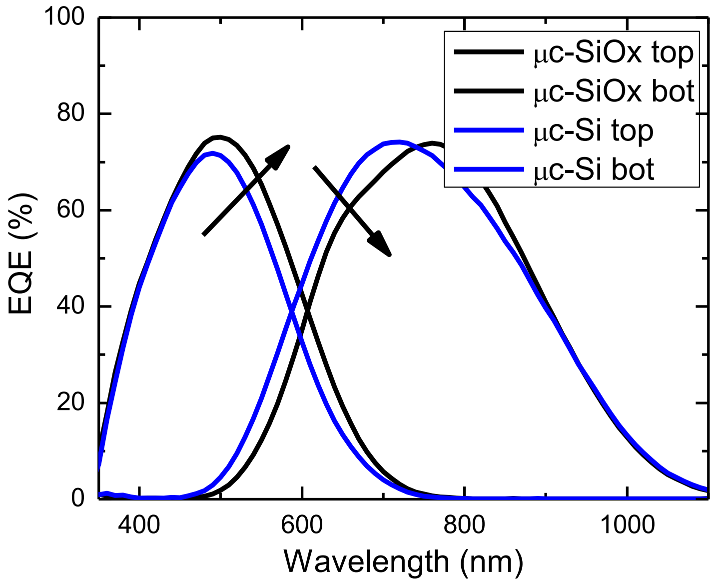
- PECVD, VHF-PECVD

Applications:

- Doped layers
- Intermediate reflectors
- Index matching layers
- ……



For example: μc-SiOx



Light trapping: Trap light inside the absorber layer

Approaches:

- Effective light in-coupling at the front side

✓ **Nano-structured ARC**

- Scattering at rough interfaces

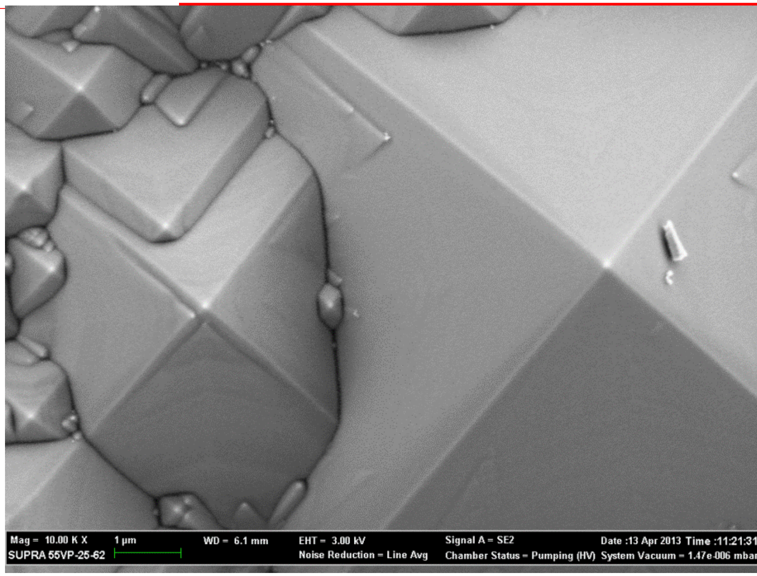
✓ **Broad band light scattering**

- Reflection at the back side

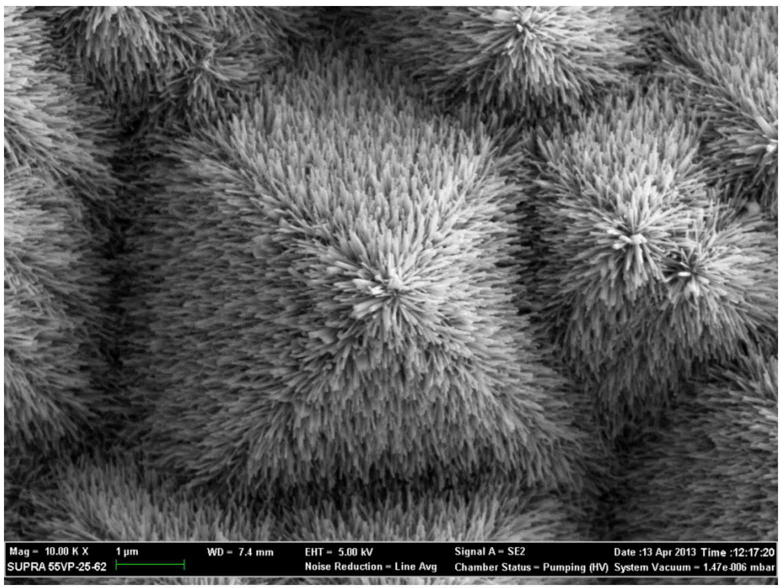
✓ **Random structure**

✓ **Periodic structure**

ZnO NW :



Mag = 10.00 K X
1 μm
WD = 6.1 mm
EHT = 3.00 kV
Signal A = SE2
Date :13 Apr 2013 Time :11:21:31
SUPRA 55VP-25-62
Noise Reduction = Line Avg
Chamber Status = Pumping (HV)
System Vacuum = 1.47e-006 mbar



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1 μm
WD = 7.4 mm
EHT = 5.00 kV
Signal A = SE2
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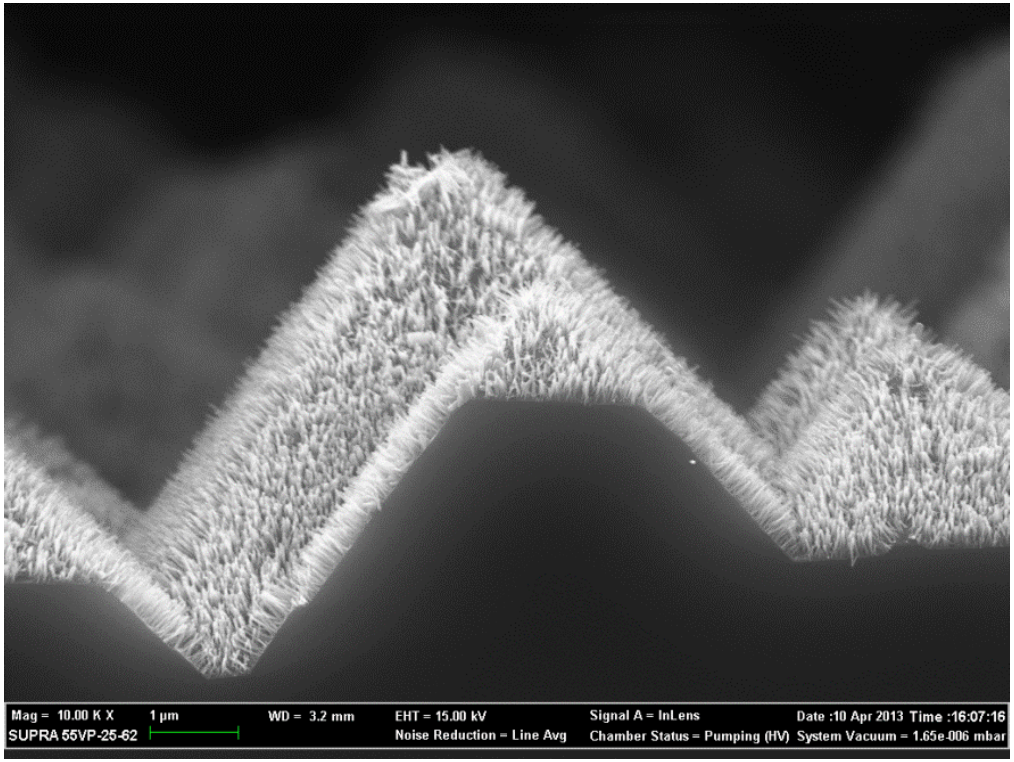
SUPRA 55VP-25-62
Noise Reduction = Line Avg
Chamber Status = Pumping (HV)
System Vacuum = 1.47e-006 mbar



Mag = 10.00 K X
1 μm
WD = 3.2 mm
EHT = 15.00 kV
Signal A = InLens
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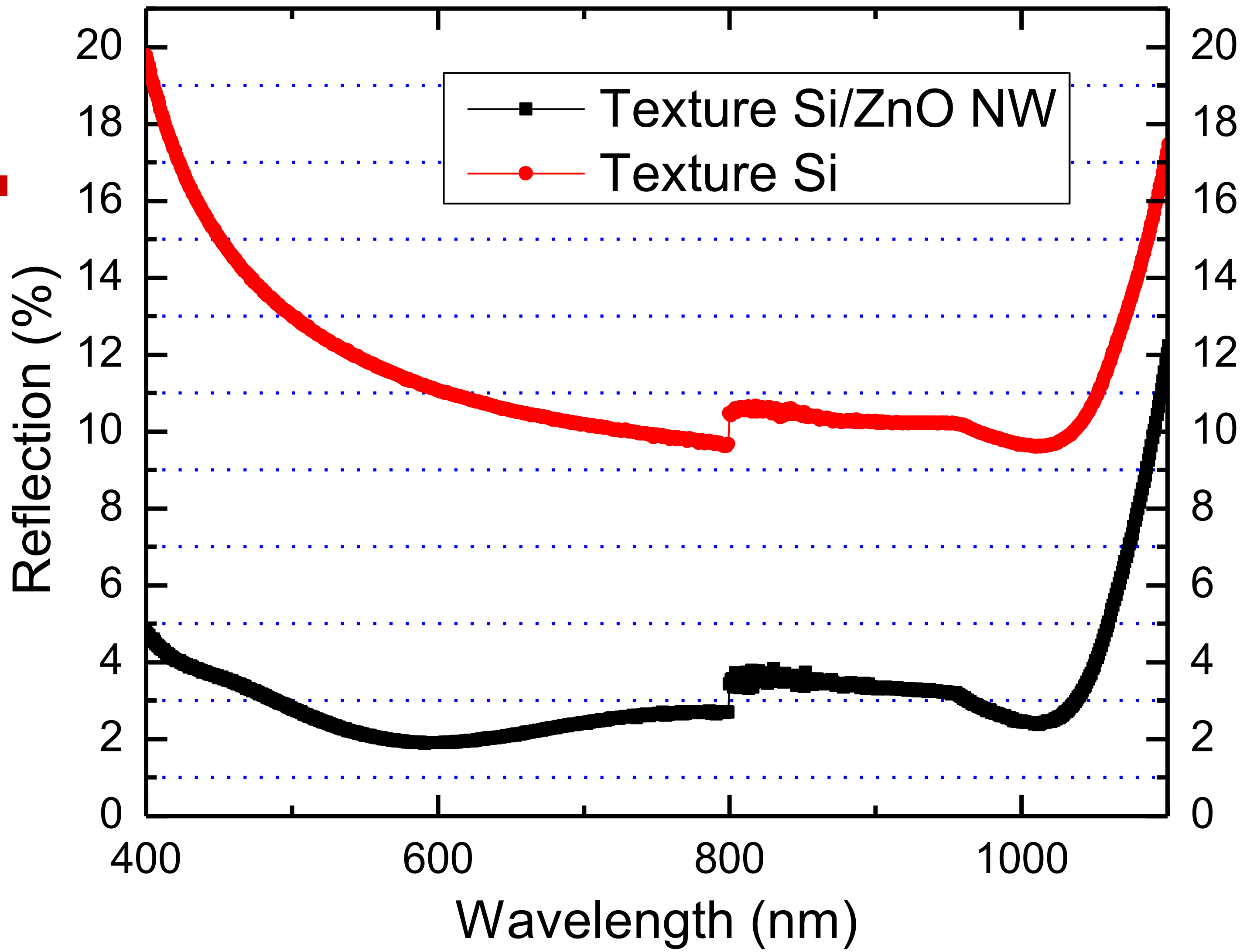
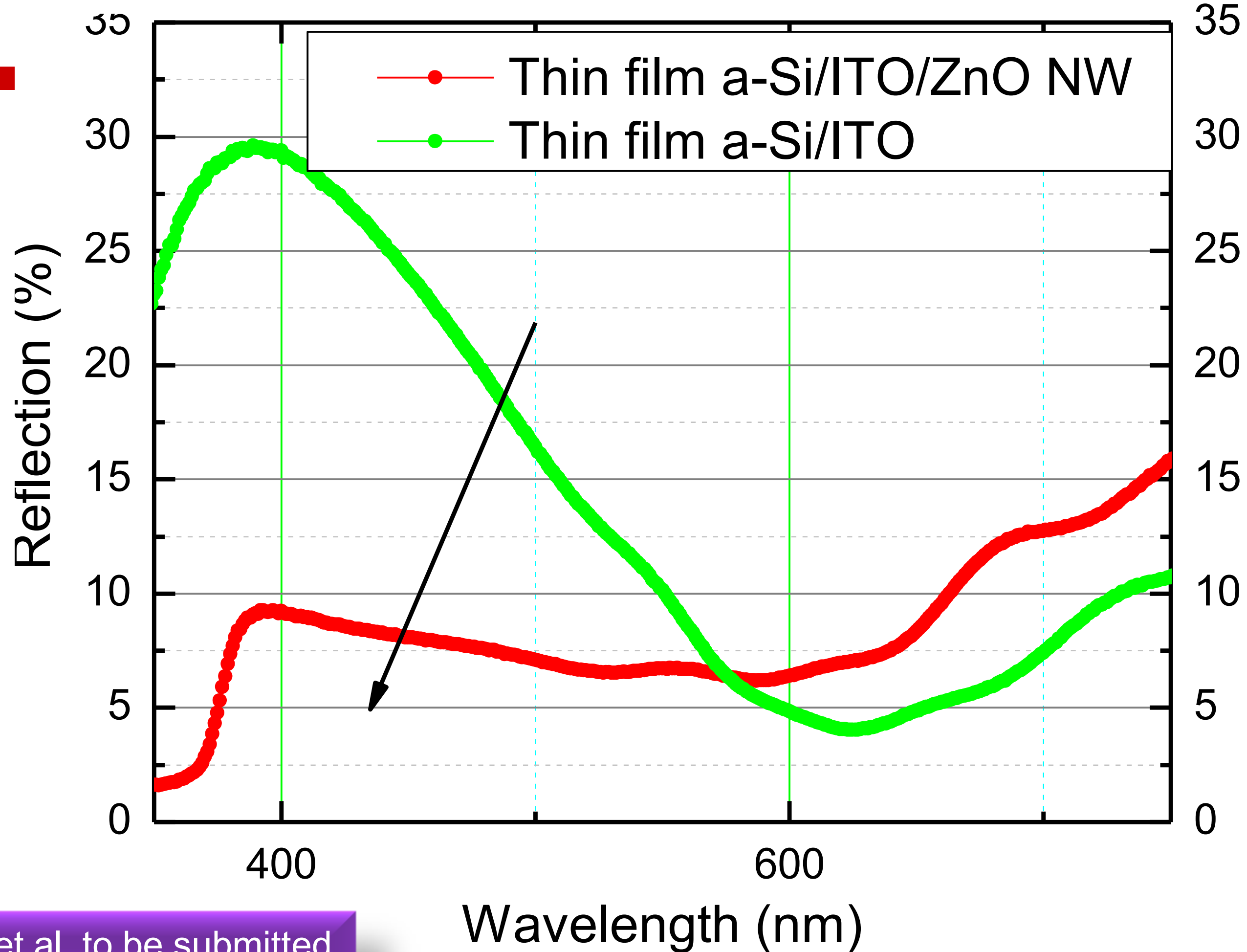
SUPRA 55VP-25-62
Noise Reduction = Line Avg
Chamber Status = Pumping (HV)
System Vacuum = 1.65e-006 mbar


Texture Si/ZnO NW
Texture Si
Reflection (%)
Wavelength (nm)
0
2
4
6
8
10
12
14
16
18
20
400
600
800
1000

ZnO NW : amorphous silicon

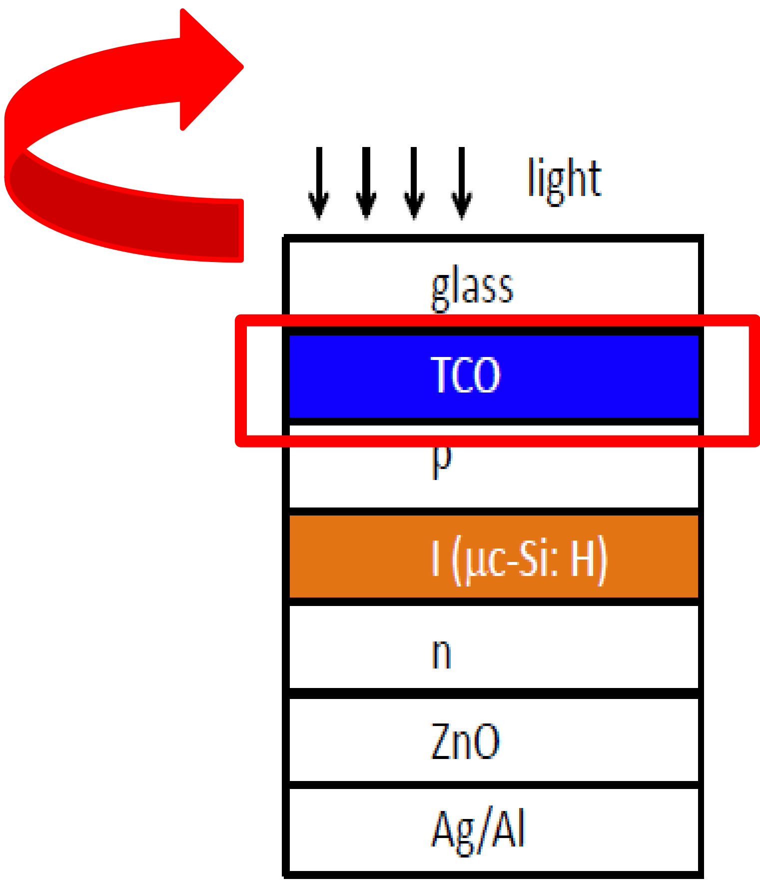


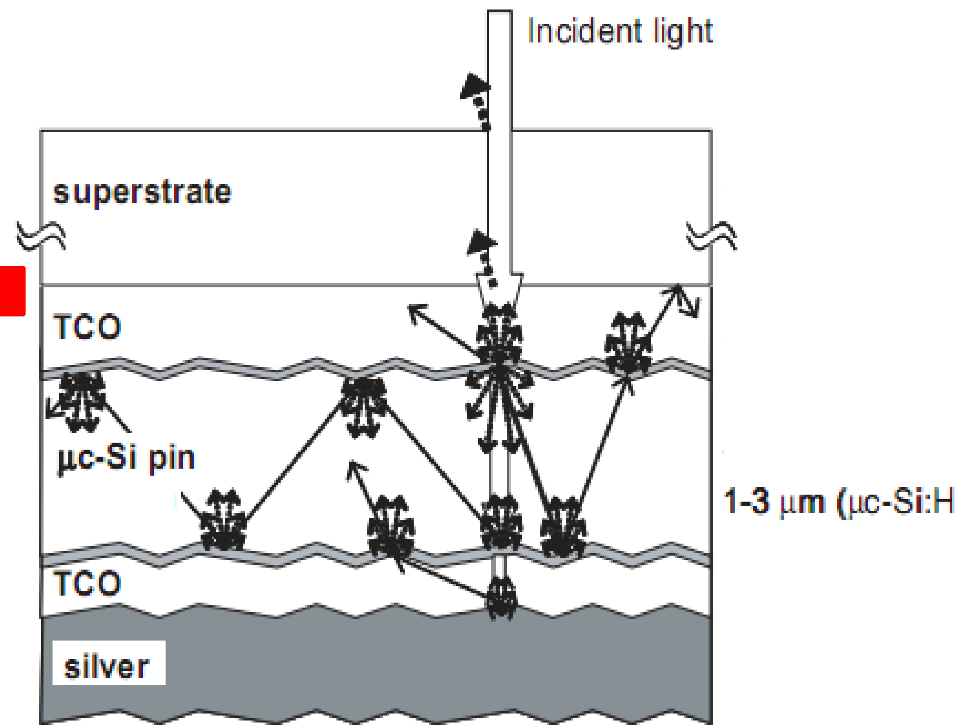
Xiaoping Yang et al. to be submitted

● Scattering at rough interfaces

✓To scatter the incident light for effective light trapping

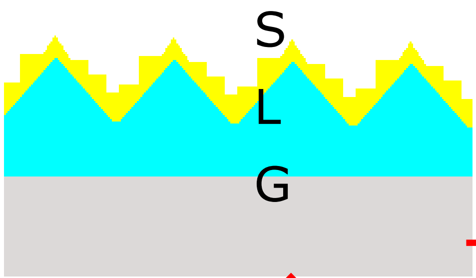
✓ To increase the short circuit current density (Jsc) in the solar cells.





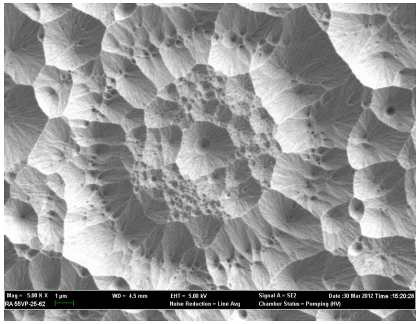
- Scattering at rough interfaces

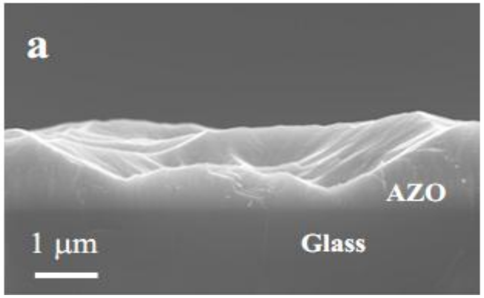
✓ **Broad band light scattering: double 'period' structure--Sputtering+ MOCVD**



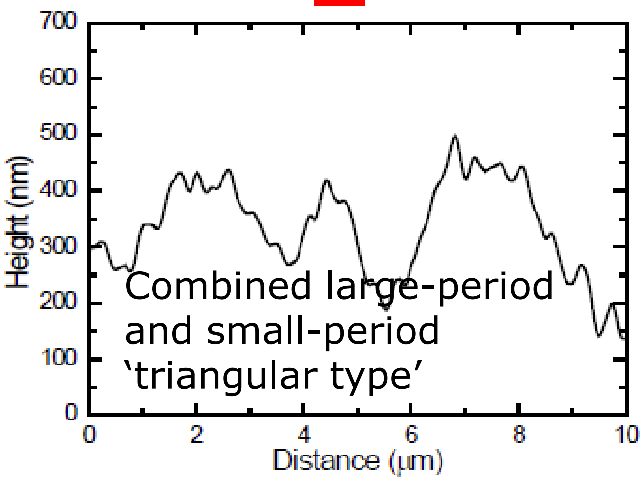
Sputtering

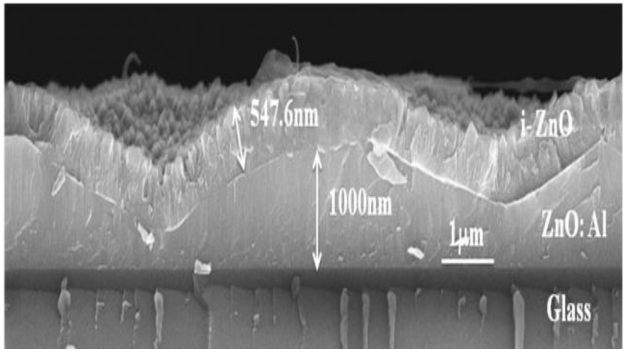
+ Wet etching

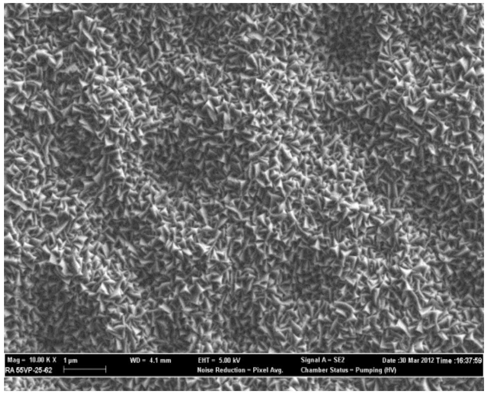




MOCVD

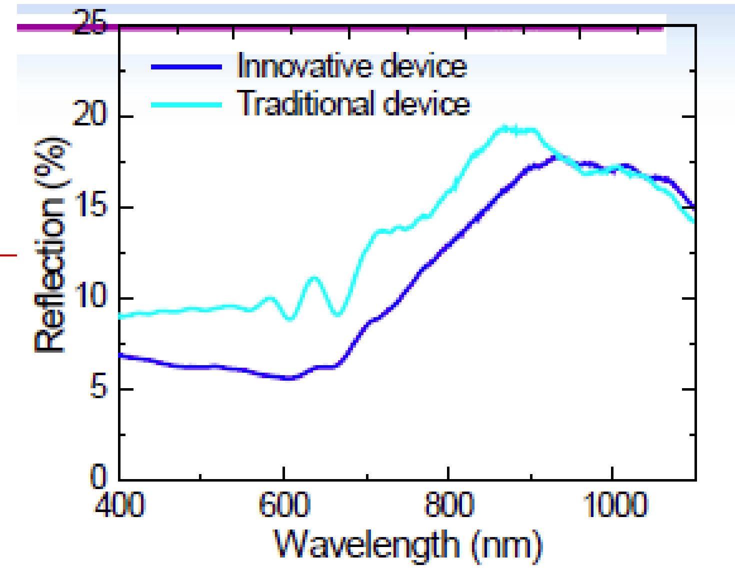


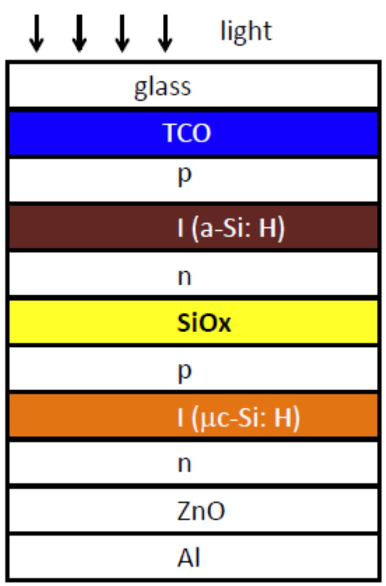




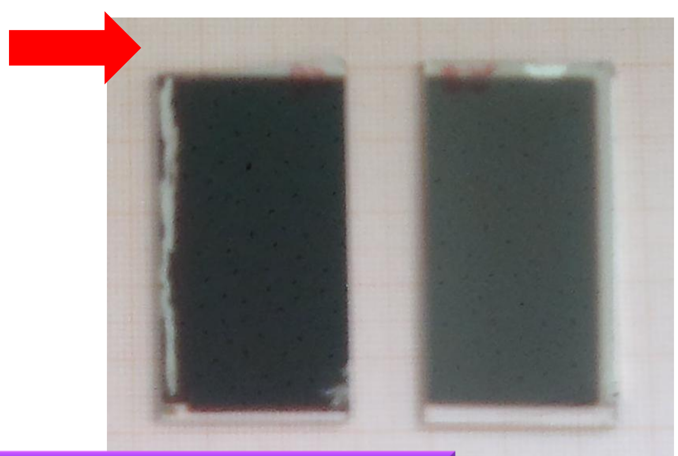
Miocromorph tandem solar cells with the innovative front electrode:

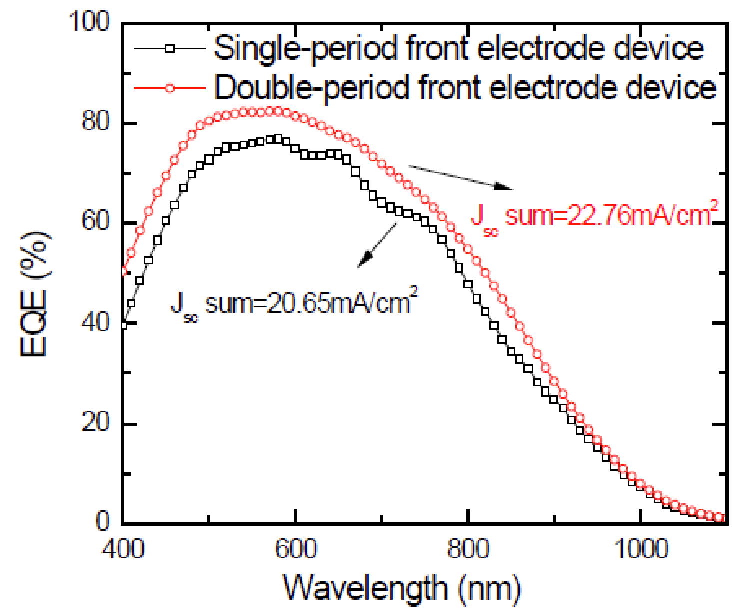
- Looks black
- Low reflection
- High current density





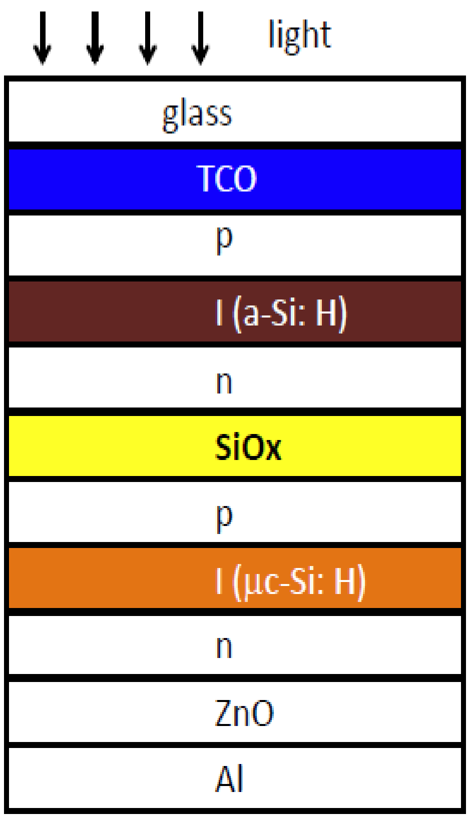
Innovative Traditional

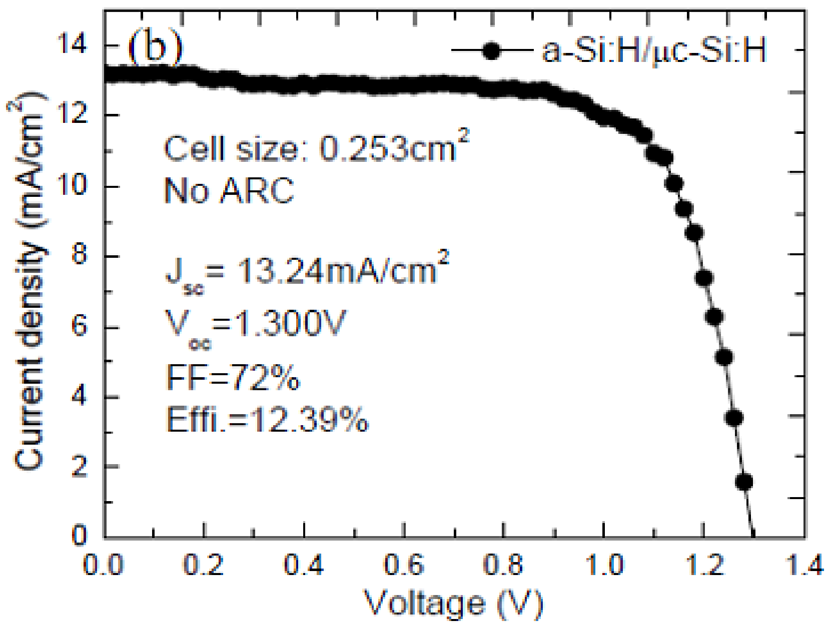




Susu Yang et al. *RSC Advances*. 2013, 3, 208-214

a-Si/μc-Si tandem solar cells





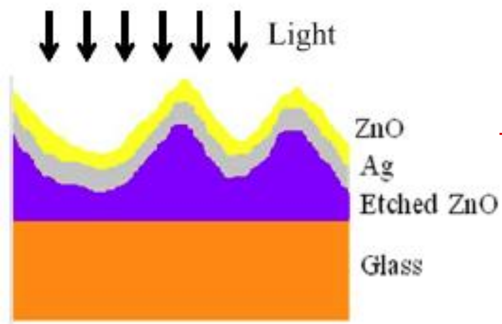
- **Optimization of microcrystalline silicon solar cells**
- **Incorporation of n type SiO_x—Two-phase structure**
- **Front transparent conductive oxide**

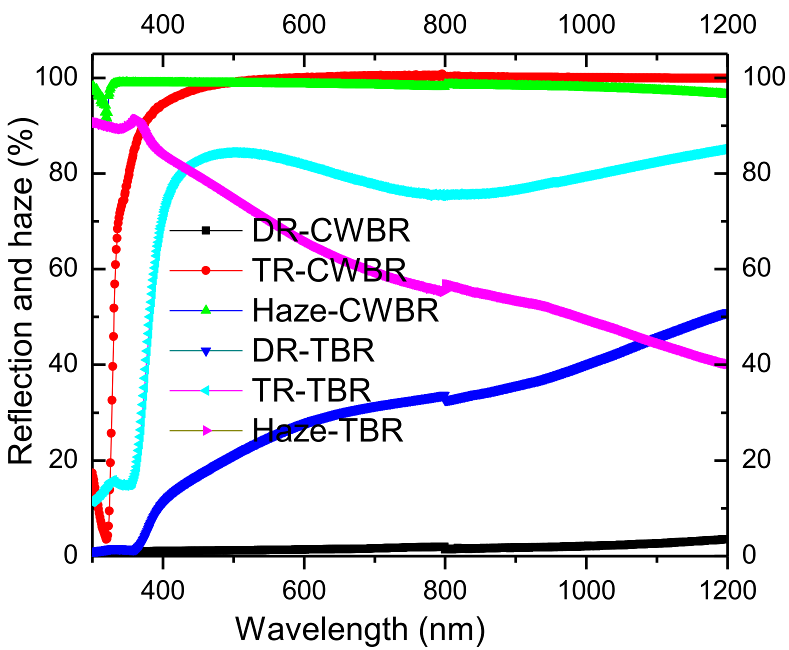
• Reflection at the back side

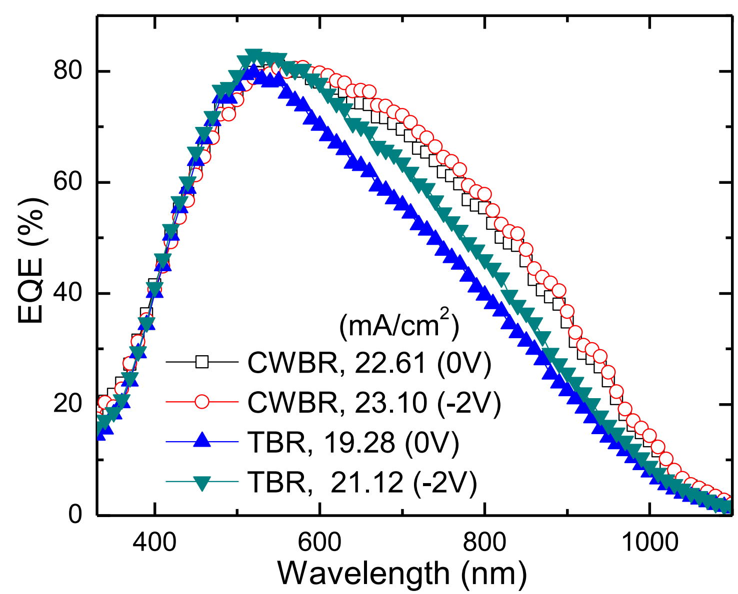
CWBR: conductive white back reflector

✓ **Random structure**

✓ **Periodic structure**





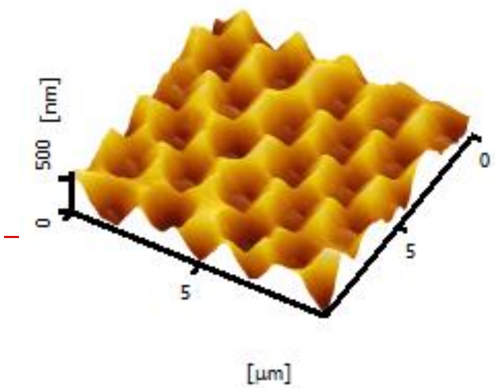


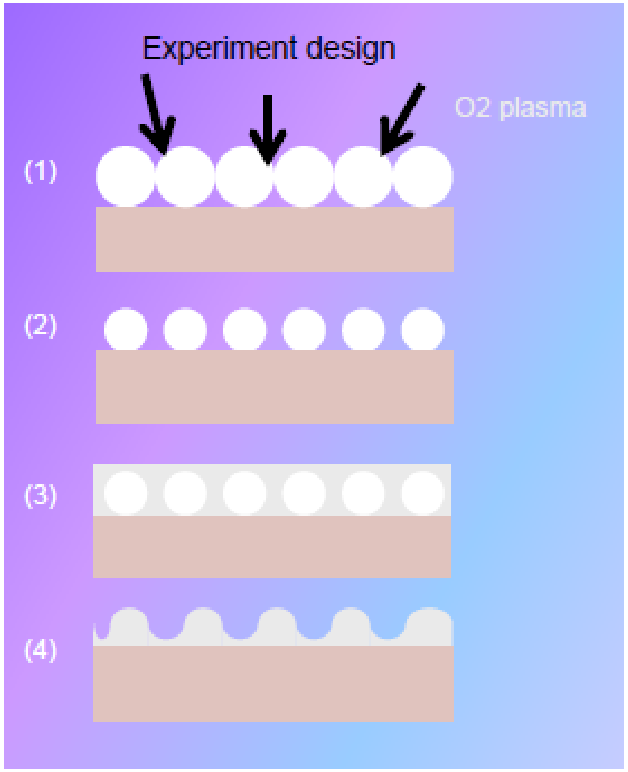
Lisha Bai et al. to be submitted

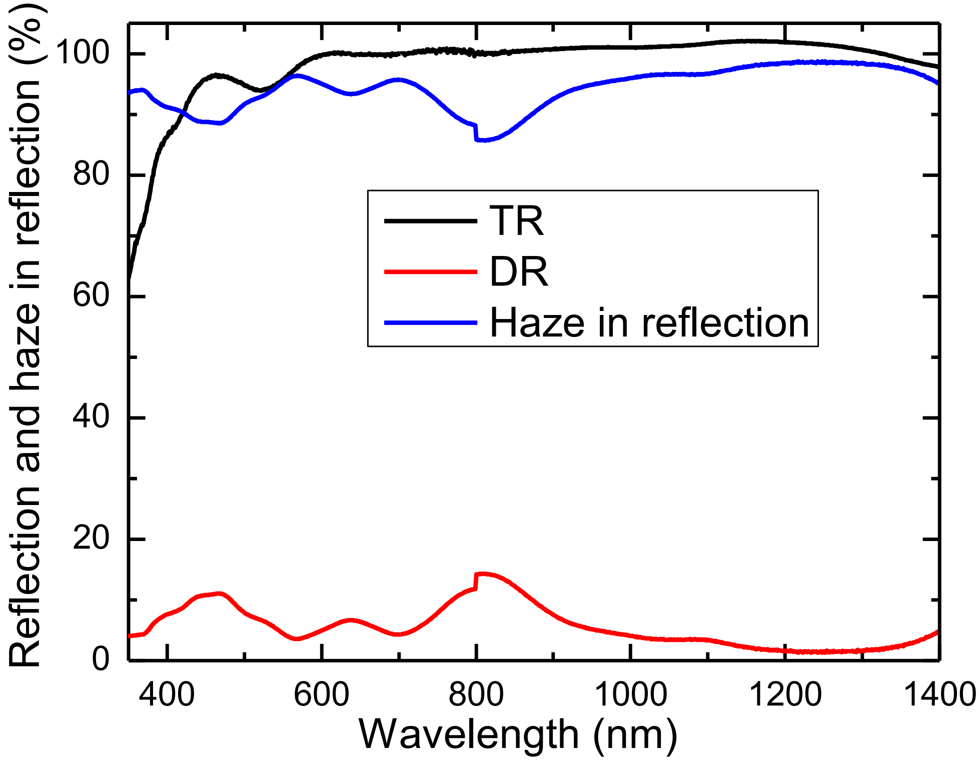
• Reflection at the back side

✓ **Random structure**

✓ **Periodic structure：** Polystyrene spheres (PS)







Xuejiao Liang et al. to be submitted

2. Key issue: reduce cost

- High deposition rate
- High stable efficiency
- Single chamber deposition
- Suitable large area
- ……

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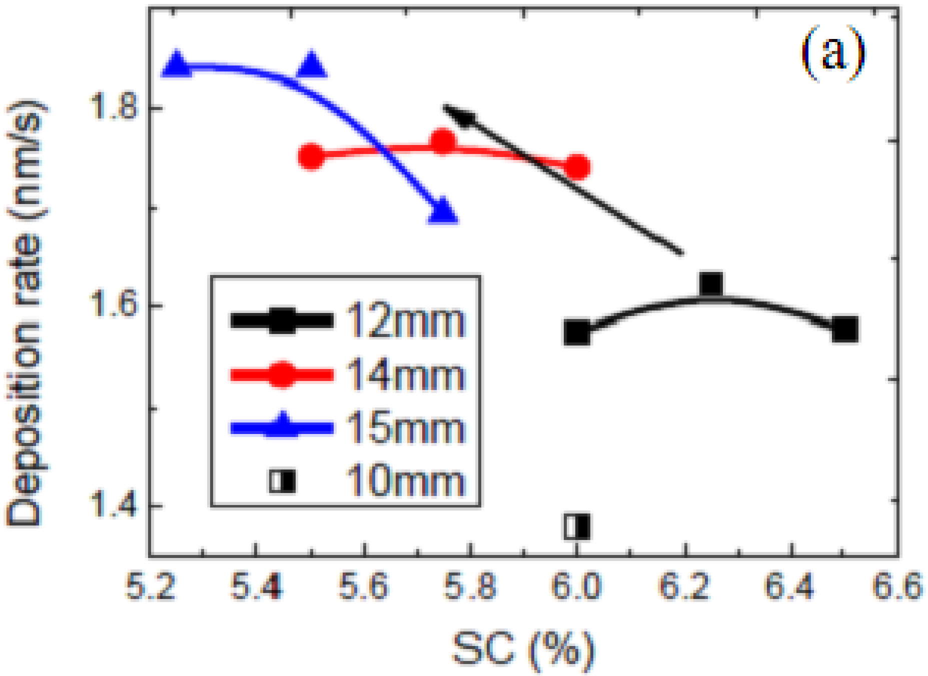
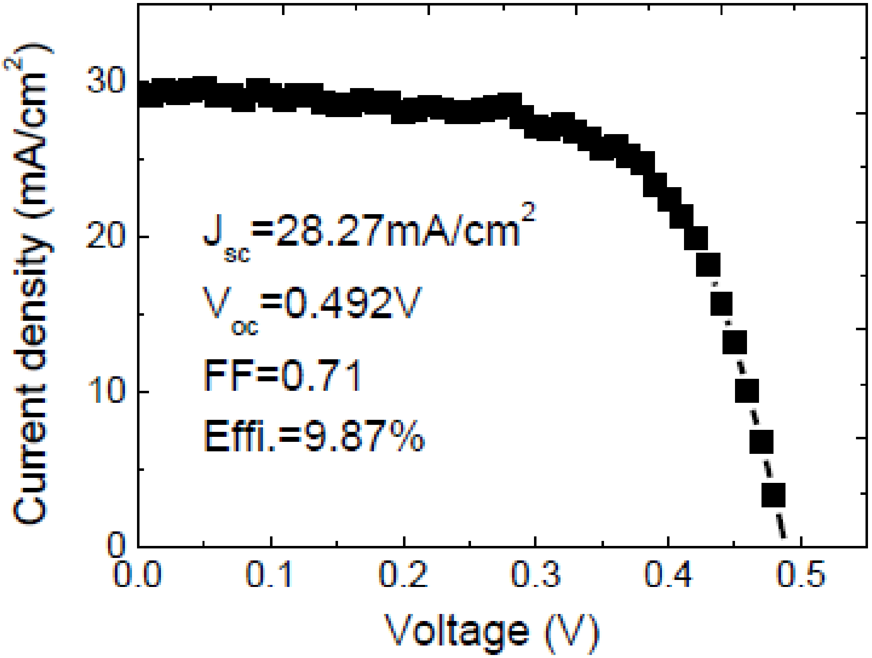
A: High deposition rate

◆ **High pressure and high power (3Torr and 70W(powered electrode area: >100cm²)**

Home made

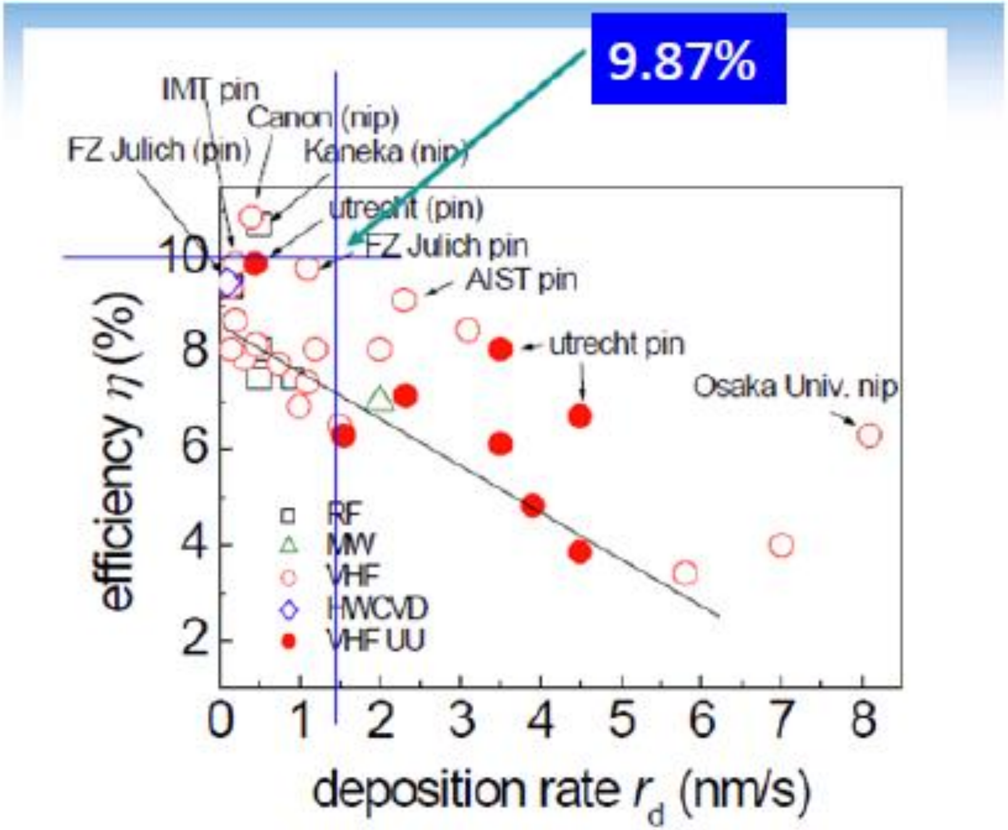




VHF-PECVD system

Lisha Bai et al. *PVSEC-22* . **2012**

Microcrystalline silicon solar cell



Deposition rate: 1.5nm/s; Conversion efficiency: 9.87%

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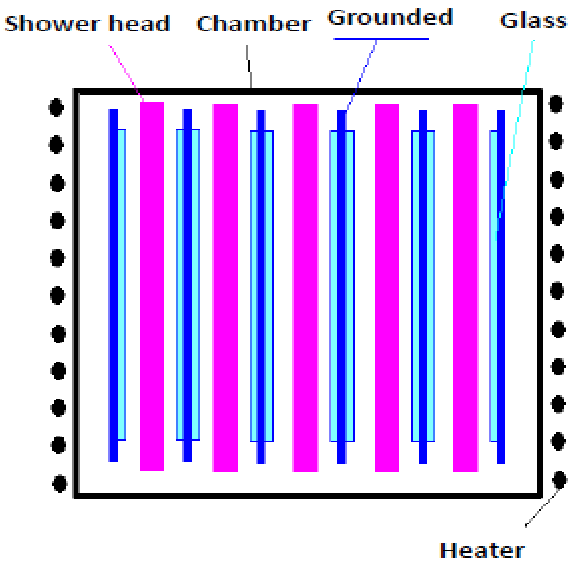
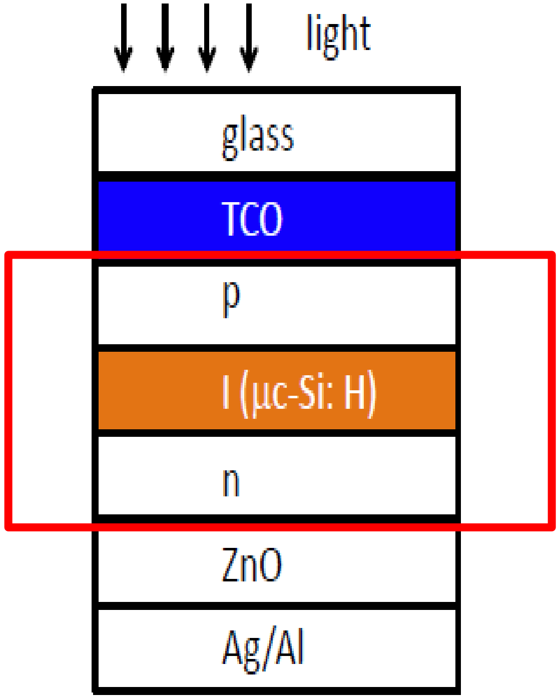
Nankai University **Home made**

B: Single chamber

◆ **P, I, N deposited in a chamber**



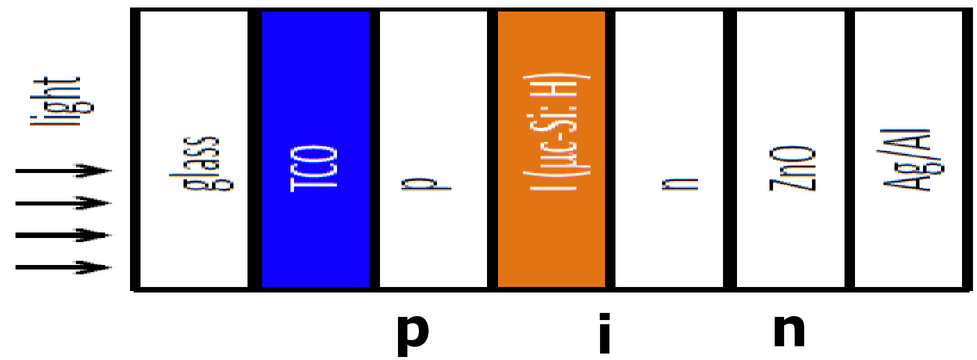


- **Advantages**
- High electrode utilizatior
- High gas utilization
- Easy operation and less servicing.
- **Disadvantages**
- Contamination-doping gas
- Serious for microcrystalline silicon

B: Single chamber

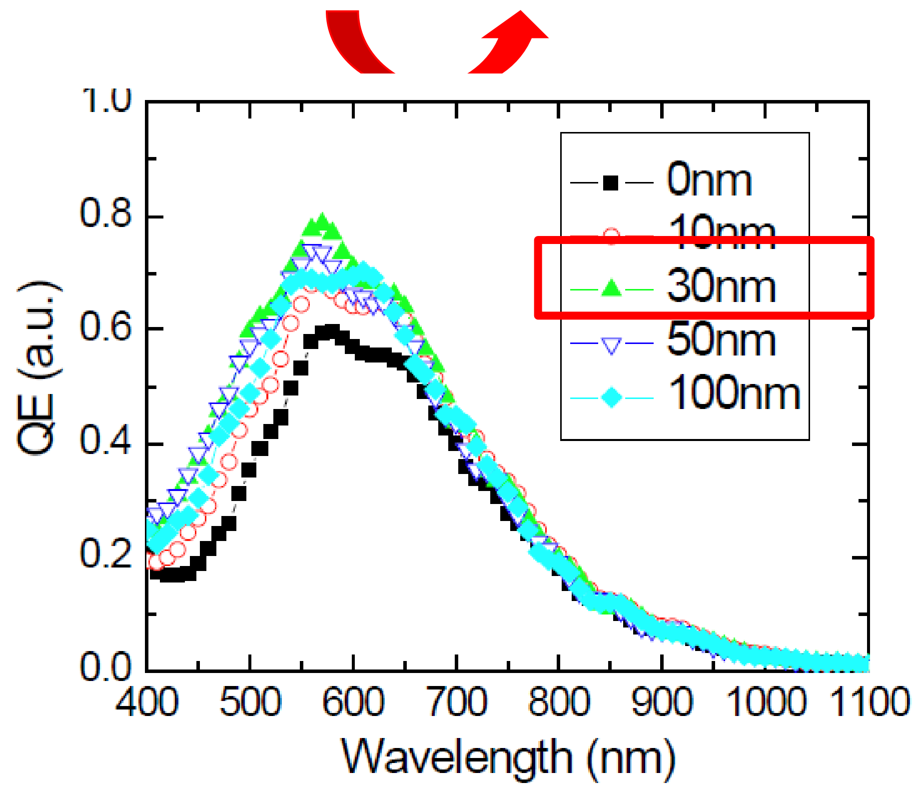
Boron contamination:

p/I interface



High *Xc* interface layer

- **Improved short wavelength response**
- **Suitable thickness**



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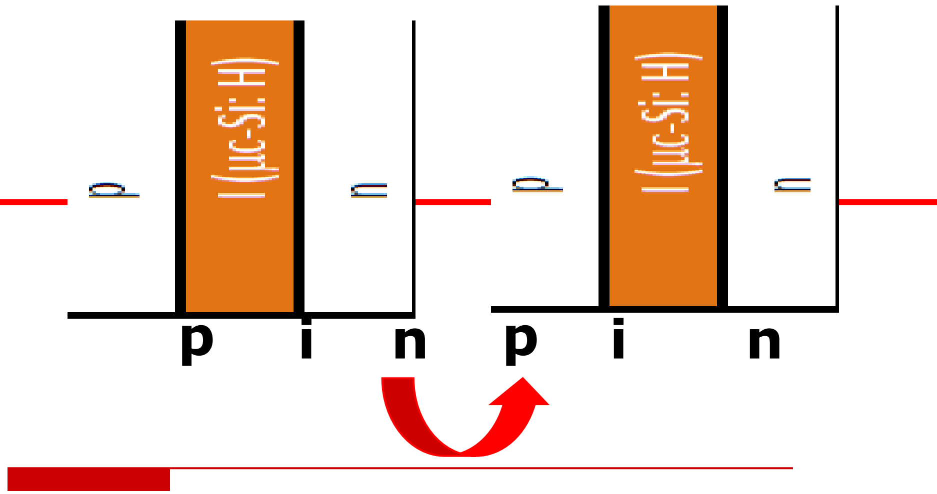
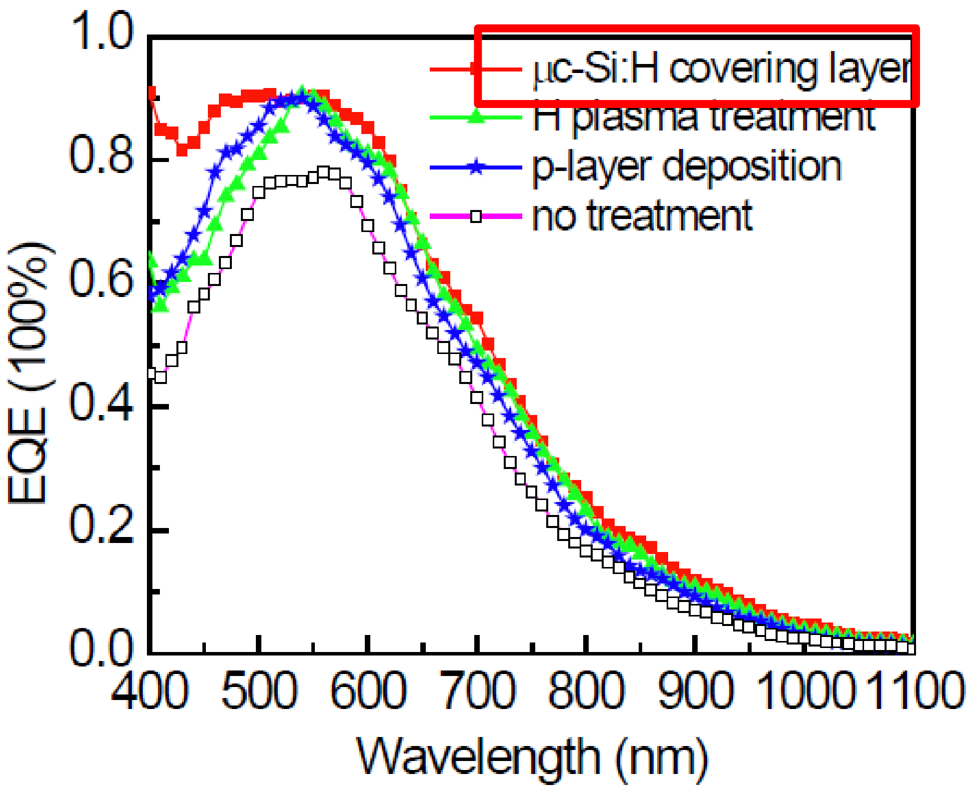
B: Single chamber

Phosphorus contamination:

n/p interface



- **Improved short and long wavelength response**
- **The μc-Si: H covering layer is the best method to reduce phosphorus contamination.**



a-Si/μc-Si tandem solar cells

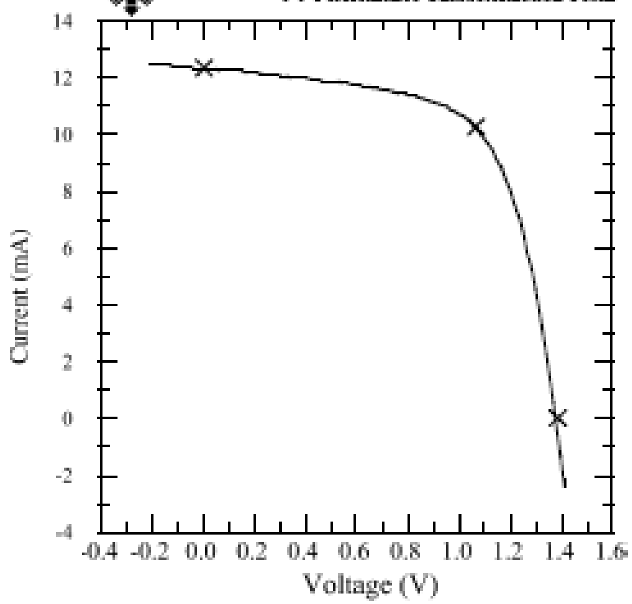
Single chamber

Nankai University (China)
a-Si/multi-Si Cell

Device ID: Cell A L1
Jan 26, 2010 12:49
Spectrum: ASTM G173 global

Device Temperature: 30.0 ± 10.0 °C
Device Area: 1.027 cm^2
Irradiance: 1000.0 W/m^2

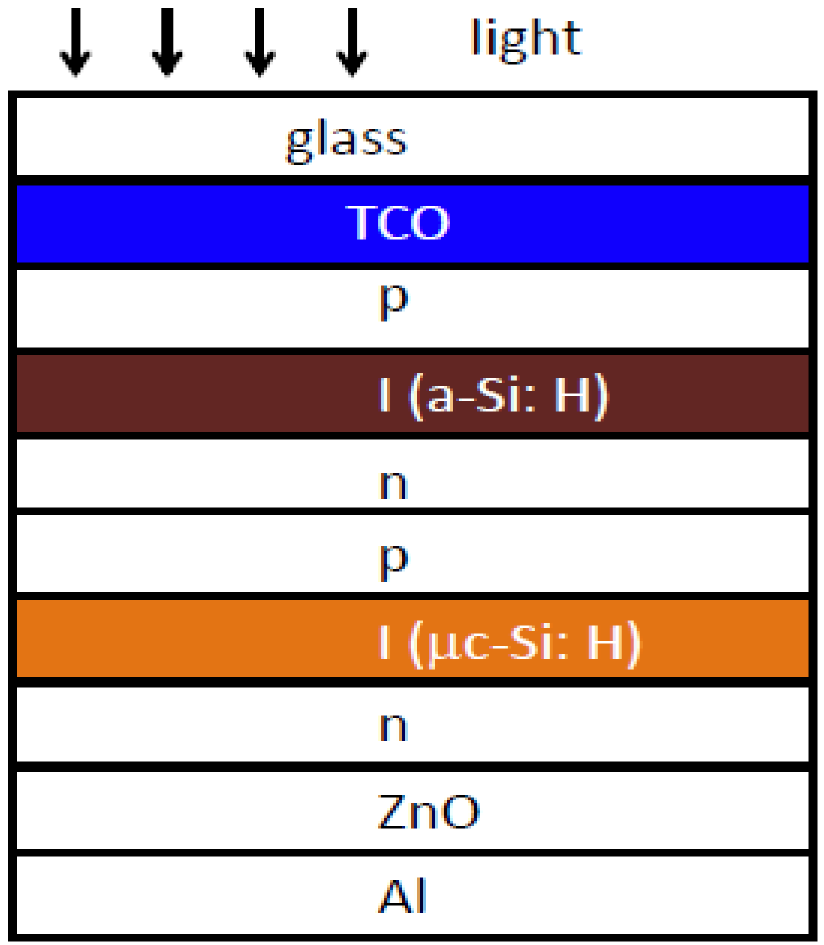
NREL X25 IV System
PV Performance Characterization Team



V_{oc} = 1.3864 V
I_{sc} = 12.289 mA
J_{sc} = 11.963 mA/cm^2
Fill Factor = 63.83 %

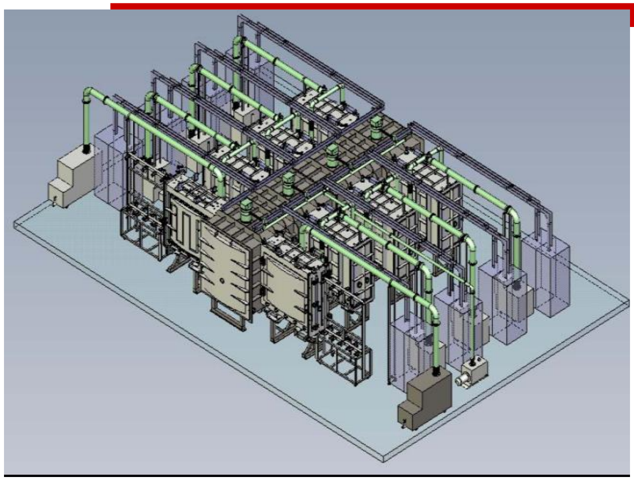
I_{max} = 10.233 mA
V_{max} = 1.0627 V
P_{max} = 10.875 mW
Efficiency = 10.59 %

Fan used for cooling

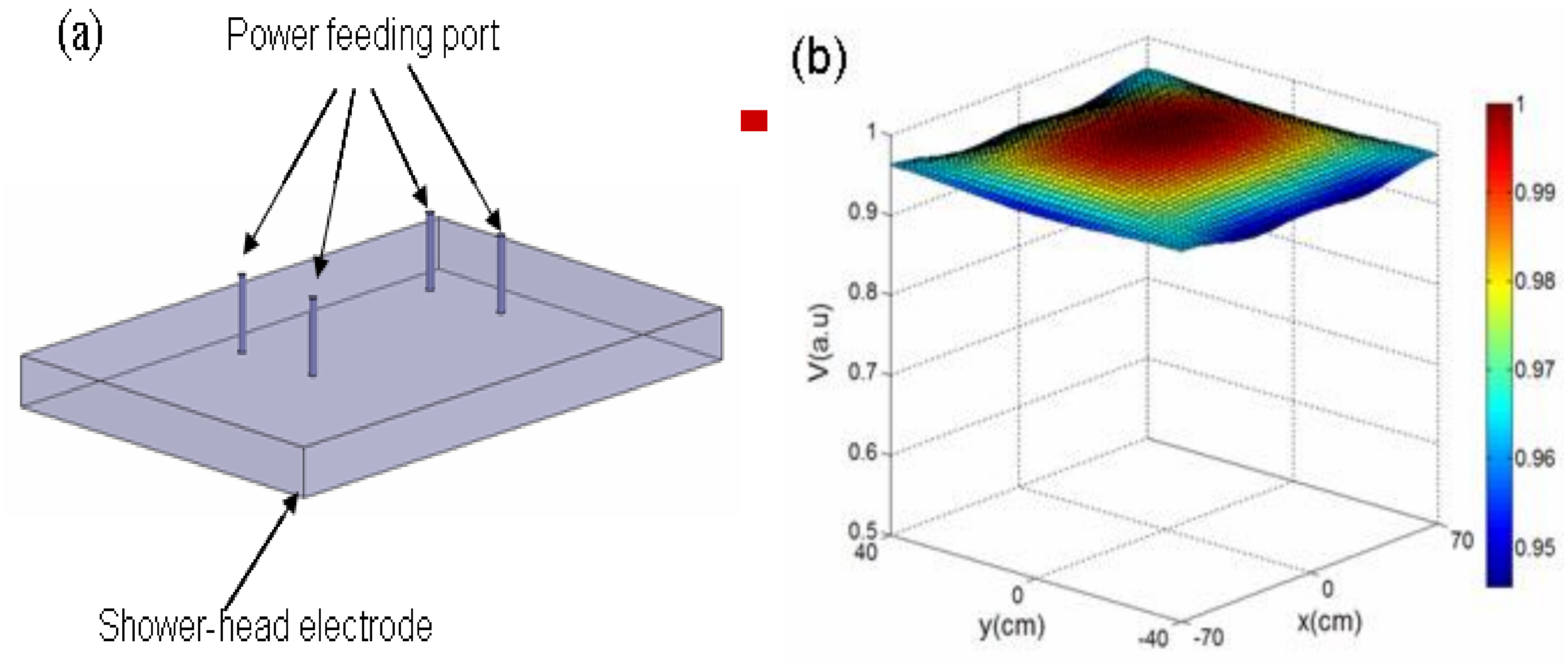


Large area:

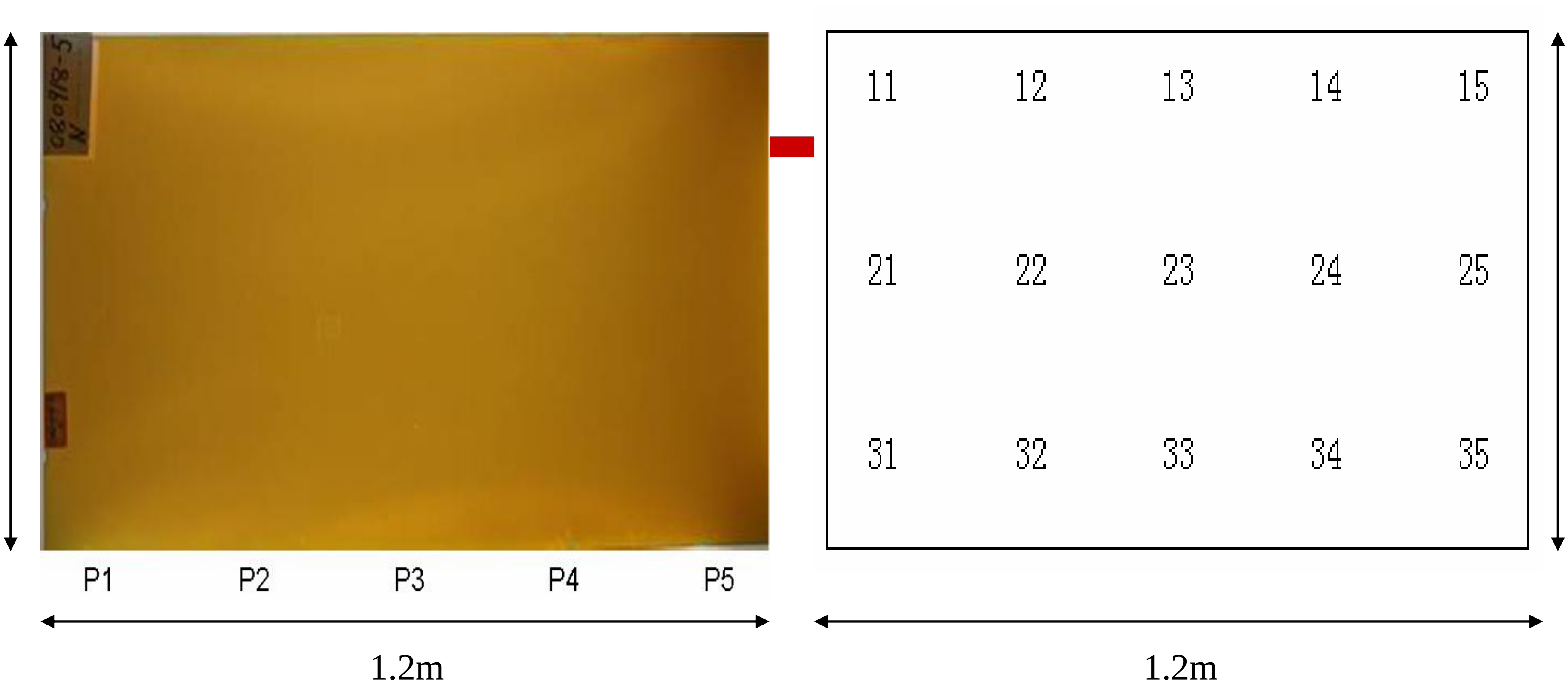
In 2011, developed a VHF-PECVD system with the capacity of 2MW/year .



- 8 chambers in this system;
- 40.68 MHz;
- substrate area is 2 feet by 4 feet;
- Each chamber simultaneously deposited two pieces.



Uniformity distribution of electric field


P1
P2
P3
P4
P5
1.2m
11
12
13
14
15
21
22
23
24
25
31
32
33
34
35
1.2m

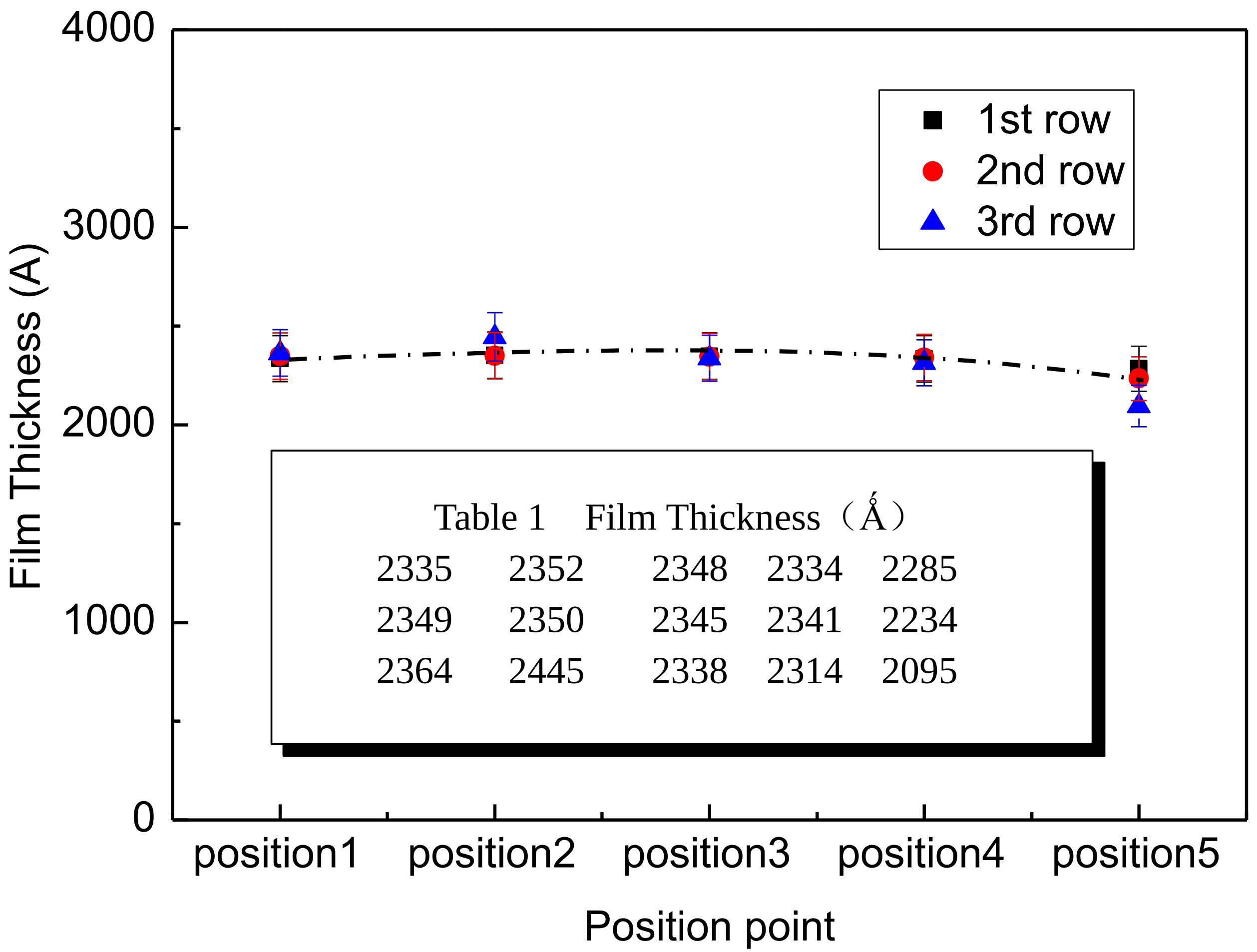


Table 1 Film Thickness（Å）

2335	2352	2348	2334	2285
2349	2350	2345	2341	2234
2364	2445	2338	2314	2095

Un-uniformity for thickness:

Less than 3.85% was achieved at edge exclusion 2cm

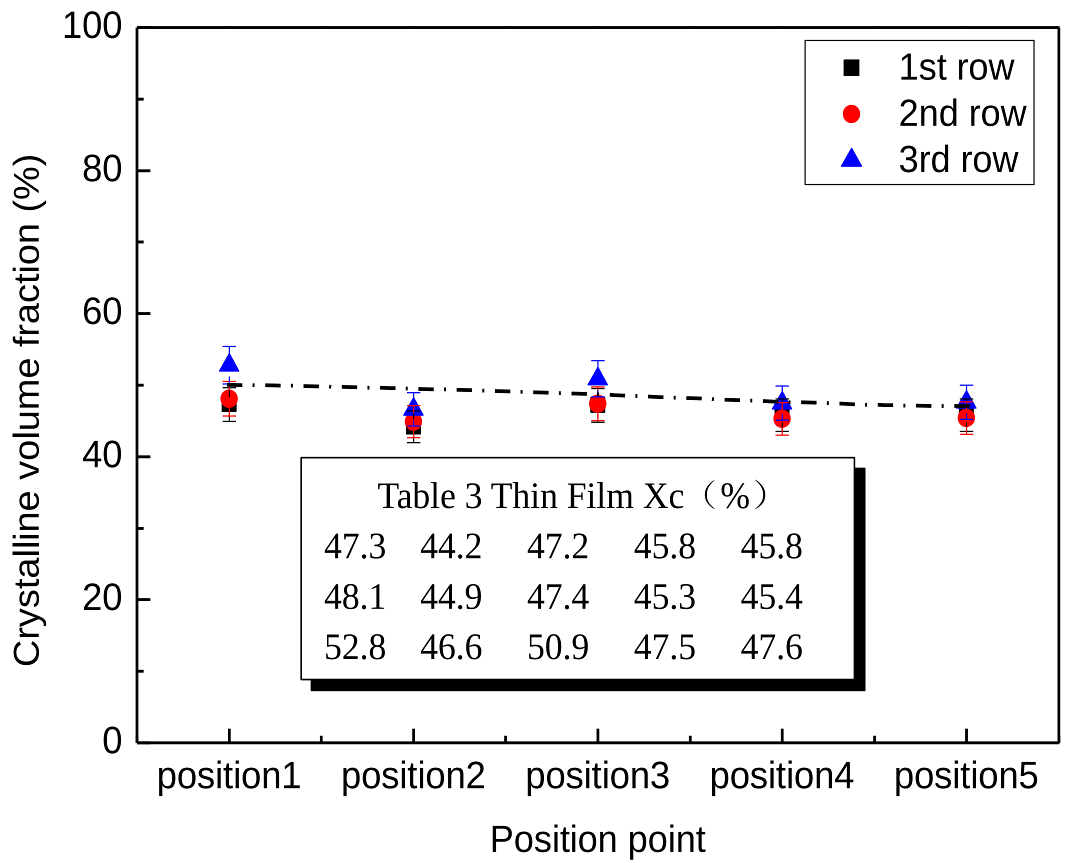
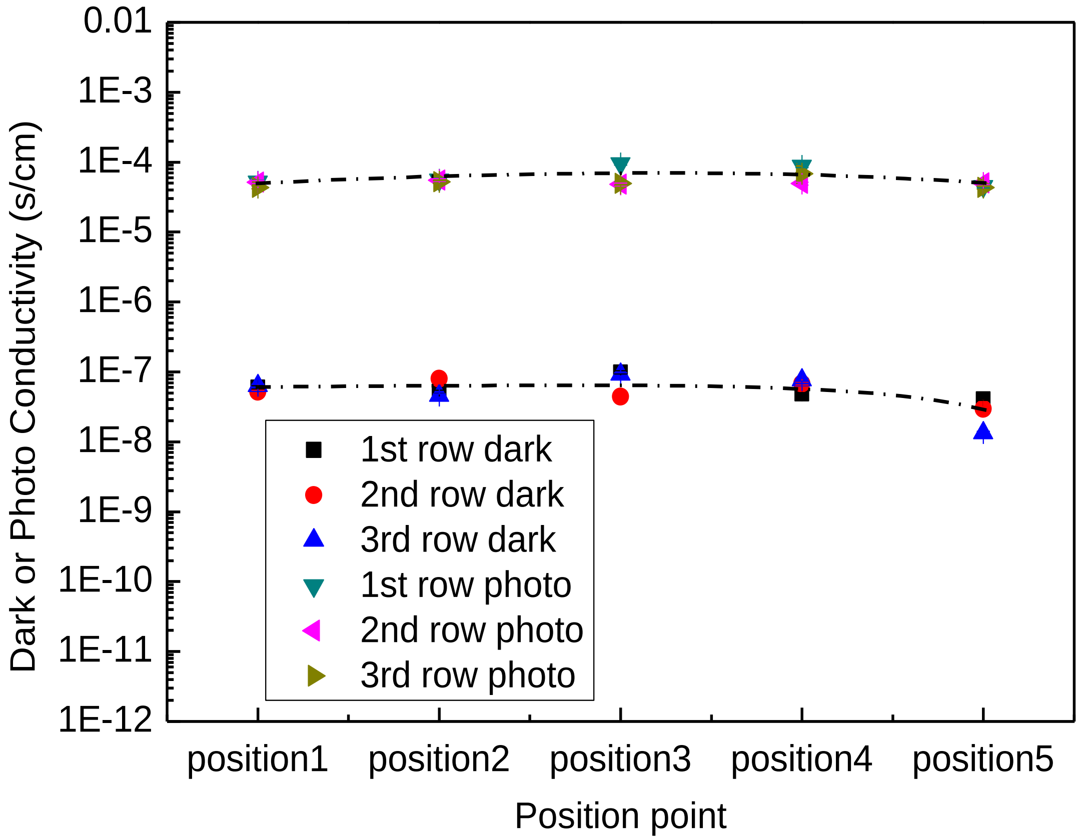


Table 3 Thin Film Xc（%）

47.3	44.2	47.2	45.8	45.8
48.1	44.9	47.4	45.3	45.4
52.8	46.6	50.9	47.5	47.6

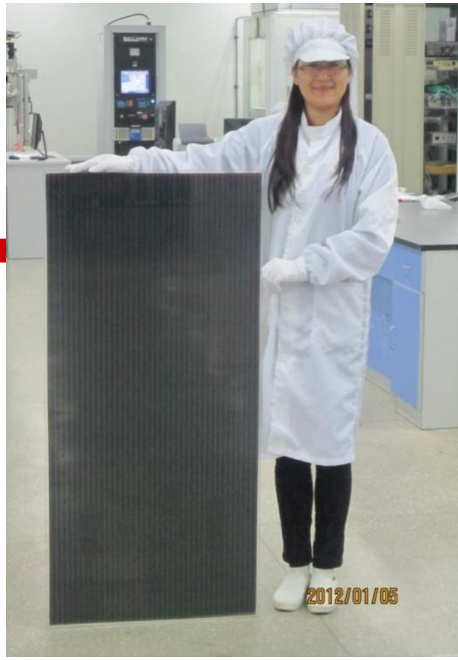
Un-uniformity for Xc:

Less than 4.8% was achieved at edge exclusion 2cm

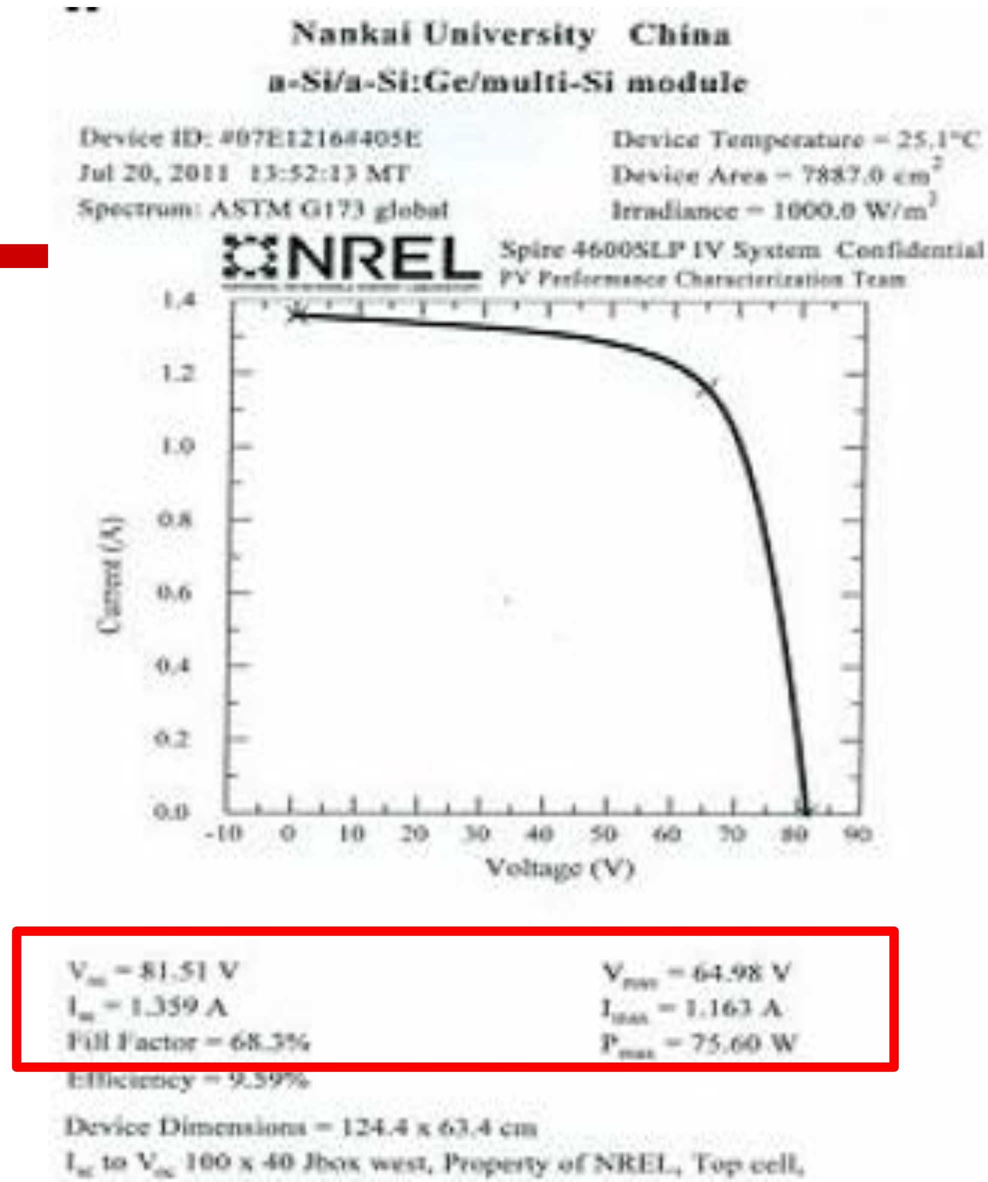


Un-uniformity for electrical properties:

Dark conductivity: 10^{-8}S/cm; Photosensitivity: ~1000



13KW a-Si/a-SiGe/µc-Si solar module PV station



Summary

◆ Improving efficiency

- **New Materials**
- **Light management**

✓ ZnO NW ARC

✓ Innovative front electrode

✓ Back reflector

◆ Low Cost technique

- High initial conversion efficiency 12.39% for a micromorph tandem cell;
- Single chamber-deposited tandem solar cells with an efficiency of 10.59%;
- Triple-junction module has achieved at 9.59% (NREL, 0.79m2) and increased by 20% compared to commercial module.

Future research directions----thin film silicon

Light management: (Suitable for other solar cells)

- External ARC and low absorption TCOs
- 2-D or 3-D photonic crystals (PC) based flat substrates

New materials :

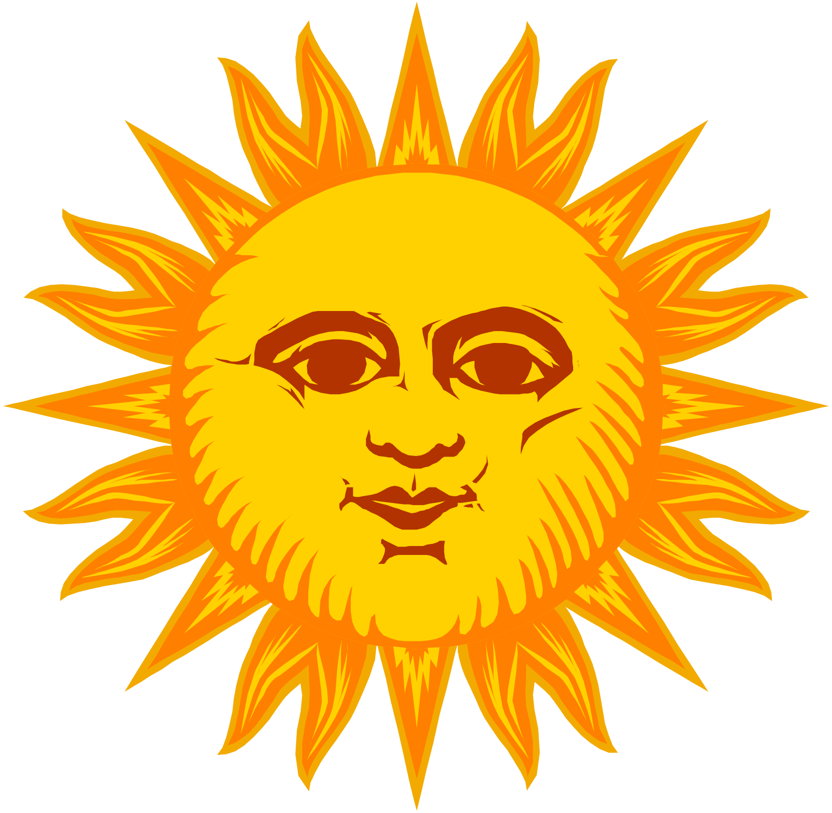
- Silicon based alloys with O, C, and Ge

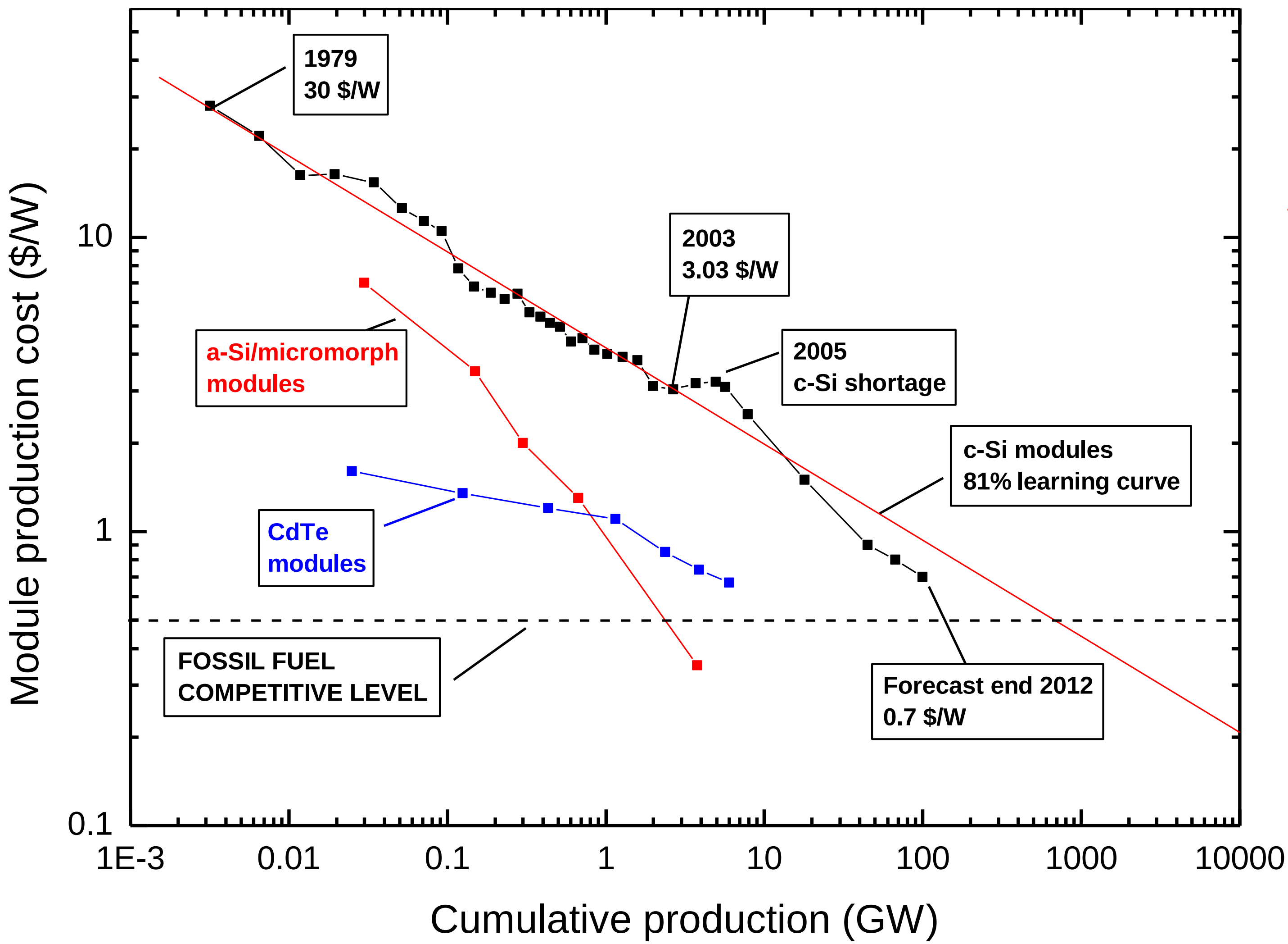
Performance (η>20%):

- Increase Voc (growth on flat substrates)

Acknowledgements !

Thank you for your attention !





Production costs:

C-Si (lower limit):
0.8 $/W ≈0.6 €/W
~~Eff≈15 %~~

CdTe (First Solar):
0.67 $/W ≈0.51 €/W
Eff=12.2 %

a-Si:H/mcSi (Oerlikon,ThinFab140):
0.35 $/W ≈0.27 €/W
Eff=10.8 %

CIGS (Manz AG)
0.55 $/W ≈0.42 €/W
Eff=12.6% (Solar Frontier)