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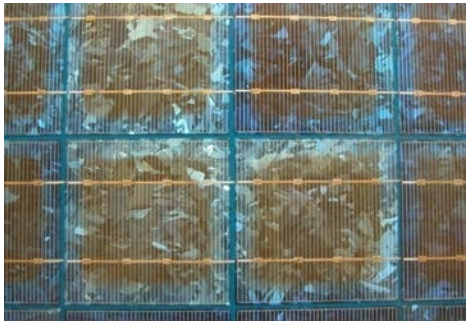
DEGRADATION STUDY OF FIELDED PV MODULES FROM DIFFERENT CLIMATES IN CHINA

Dec 8th, 2015

Xian Dong

Shunde SYSU Institute for Solar Energy

Outline

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1. Introduction

2. Work about reliability of PV modules

3. Degradation mechanism

4. Summary&Outlook

1. Introduction

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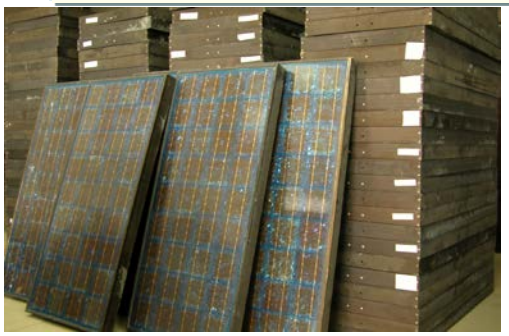

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Collaboration platforms

- **State Key Laboratory of Optoelectronic Materials and Technologies**
- **South China Branch of NERCRE (National Engineering Research Center of Renewable Energy)**
- **Guangdong Provincial Key Laboratory of Photovoltaic Technologies**
- **Cooperation Base of CPVT (National Center of Supervision and Inspection on Solar Photovoltaic Products Quality) and Sun Yat-Sen University**
- **Key Laboratory of Solar Energy of Education Department, Guangdong Province**
- **Cooperating with multiple enterprises**

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2. Work about reliability of PV modules

- Why and how we do these work
- Distribution of experimental systems
- Collections of fielded PV modules
- Re-installation of fielded modules

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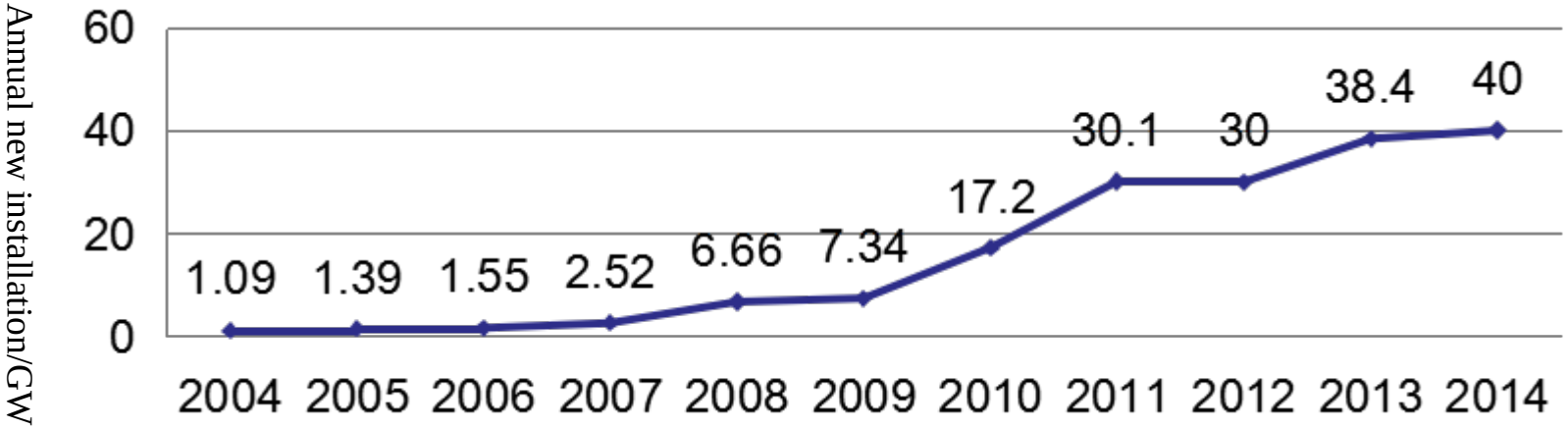
2. Work about reliability of PV modules

The Global PV market progressed in 2014: after three years of 30's GW of installation annually, reached 40 GW in 2014. (EPIA)



China is the world's biggest PV market now!

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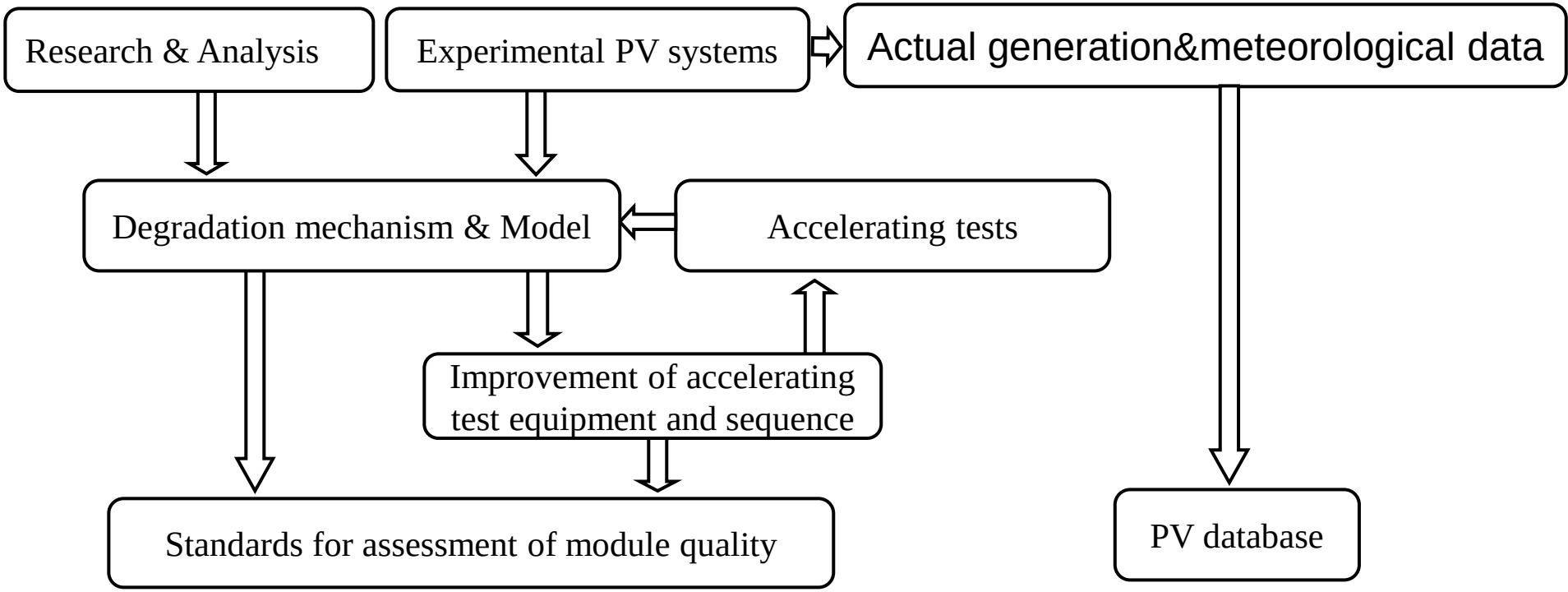
Why and how we do these work

- **Reliability and Life-cycle of modules are key points for PV systems**
- **Scheme of quality assessment for PV modules**
- **Set up a performance appraisal system for PV products**



Distribution of experimental PV modules

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No.	Module	Location
1	Poly-Si	Guanghzou
2	Amorphous	Guanghzou
3	Mono-Si	Guanghzou
4	CIGS	Guanghzou
5	CdTe	Guanghzou
6	HIT	Guanghzou
7	Poly-Si	Guanghzou
8	mono,double glass	Guanghzou
9	a-Si (5%）	Guanghzou
10	a-Si (25%）	Guanghzou
11	a-Si (25%）	Guanghzou
12	Poly-Si	Qiqihaer
13	Mono/Poly	Xining
14	Mono-Si	Guilin
15	Poly-Si	Xichang
16	Poly-Si	Shunde
17	Poly-Si	Shunde
18	Poly-Si	Shunde

Comparison of different technologies

Appearance of Kyocera module systems

BIPV installation at SYSU(east campus)

Re-installation of fielded Solarex moduels

Xining,Qinghai（2011-）

Qiqihaer,Heilongjiang（2011- ）

Xichang,Sichuan （2013 - ）

Guilin,Guangxi （2012- ）

Distribution of 6 climates types in China

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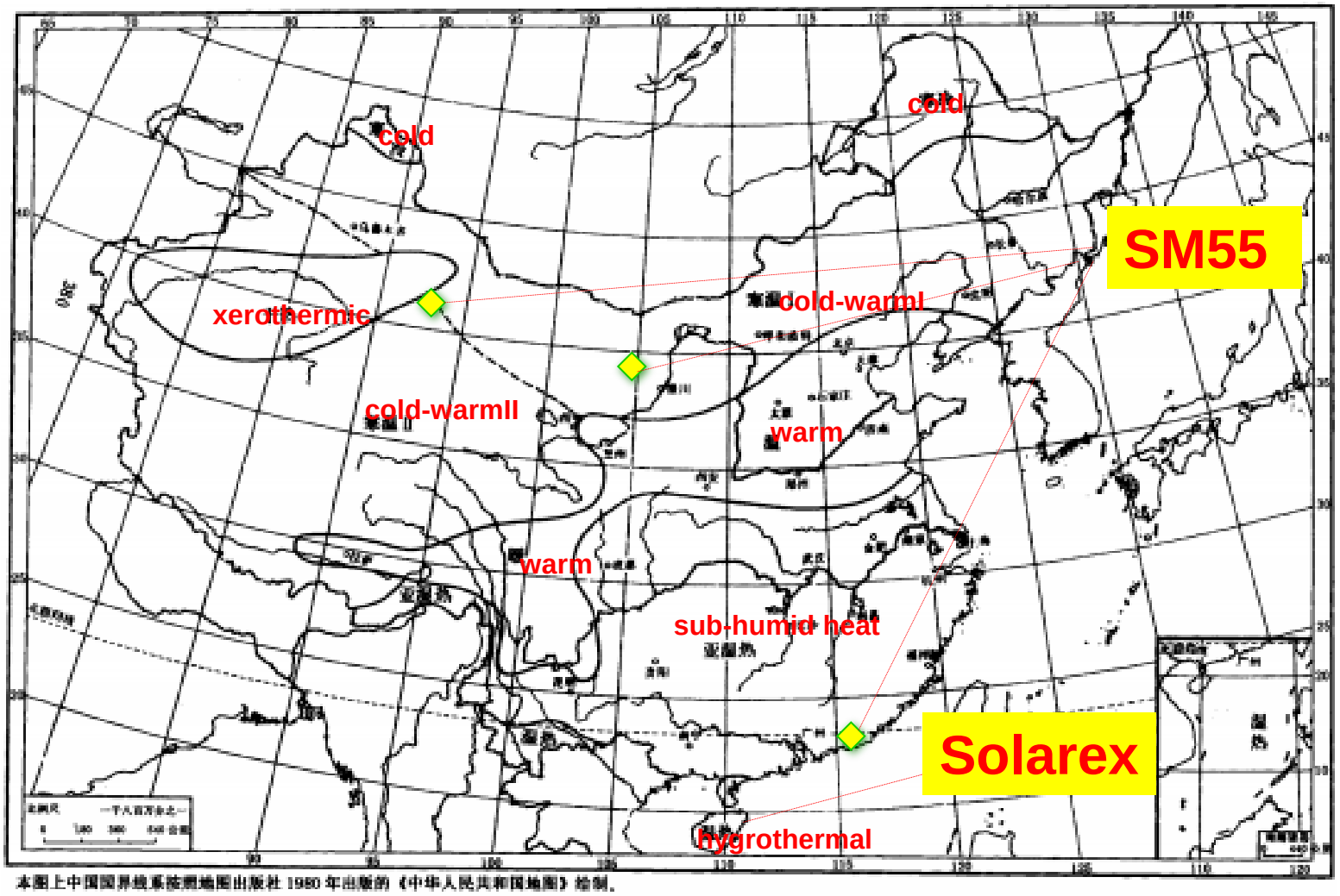
(cold- xerothermic - cold-warm - warm- sub-humid heat - hygrothermal)



(From: GB/T 4797.1-2005 Environmental conditions appearing in nature of electric and electronic products-Temperature and humidity)

Collection of fielded PV modules

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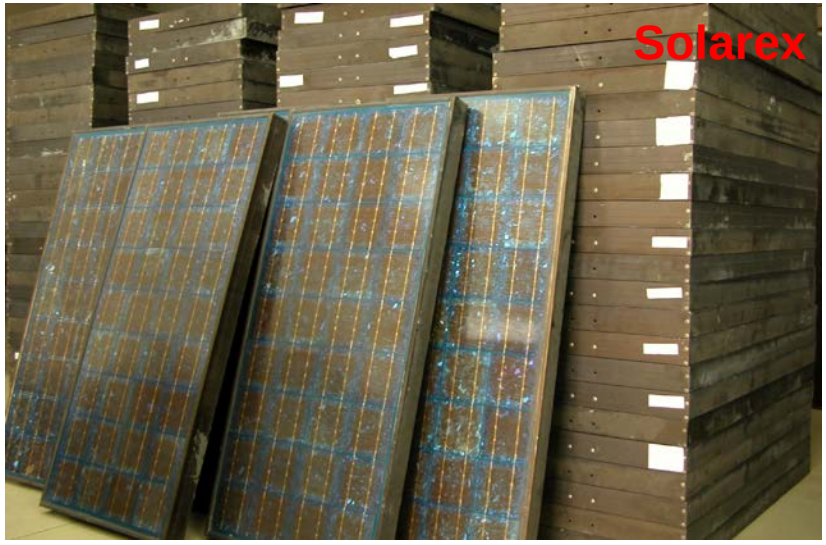
Module information					testing method					
Type	Model	Location	Qty	Age	IV[1*]	IV[2*]	EL	IR	Material test	Notes
Poly	Solarex	Haikou	177	30	√		√	√	√	re-used
Mono	BP270	Shenzhen	50	28	√		√	√	√	re-used
	SM55	Shenzhen	2051	20	√		√	√	√	re-used
	M75	Dunhuang	100+	23	√	√	√	√		
	SP75	Dunhuang	10	15		√	√			
	M75	Haixi	112	23	√	√	√			
	SP75	Zhangye	96	15		√		√		
	S(M)55	Baiyin	80	18		√		√		
	SM55	Longnan[1]	64	17		√		√		
	SM55	Longnan[2]	60	17		√		√		
	Shell 85-P	Longnan[2]	20	15		√		√		

(IV[1]:STC test；IV[2*]:outdoor test)*


Solarex


BP-270
深圳市日恒利实业有限公司1987年建设


SM55


Shell-85W


SP75


M75

Re-installation of Siemens modules

- Modules of the same batch worked in different climates were studied.
- 13 PV systems would be re-installed with these 17-year-old modules in typical climate locations.

3. Degradation mechanism

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- Failure from terminal connection
- Failure from Al-frame, silicone sealant
- Degradation from pollutant
- Degradation from encapsulant material-2 cases

  case 1: Tracking degradation of Solarex modules

  case 2: Compare of Siemens modules from different climates

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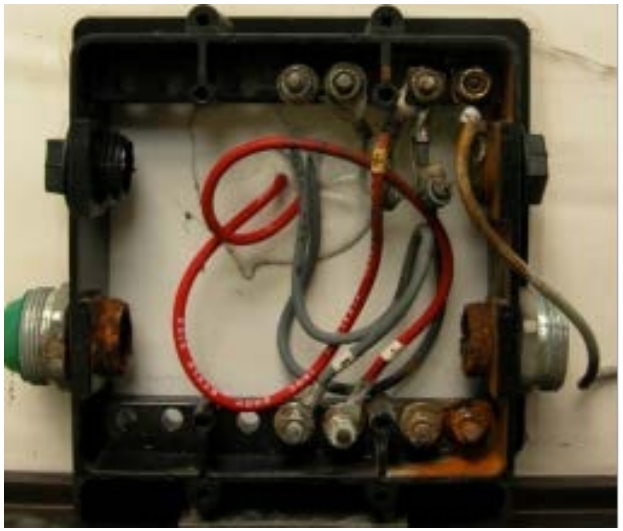
Failure from terminal connection

Statistical analysis of appearance defects for 177 Solarex modules in 2009

Appearance defects	Ratio (%)	Remarks
Appearance crack, bending or broken	79.7	including backsheet crack
Broken cells	1.7	-
Cell cracks	63.3	possible crack or snail trails
Junction box rusty	12.4	3.4% without output
Delaminated of EVA	57.6	bubbles inside EVA
Cable failures	2.8	no cable or without outer plastic protect
Diode failures	2.8	
Yellow/brown appearance	100	encapsulation material aging
Dirt or dust on the surface glass	100	part of them could be cleaned

Degradation of encapsulant material

Sealability of J-box



6/177 modules failed for bad terminal connection-Solarex module produced in 1982

Improvement of quality and process for J-box after 1990s.

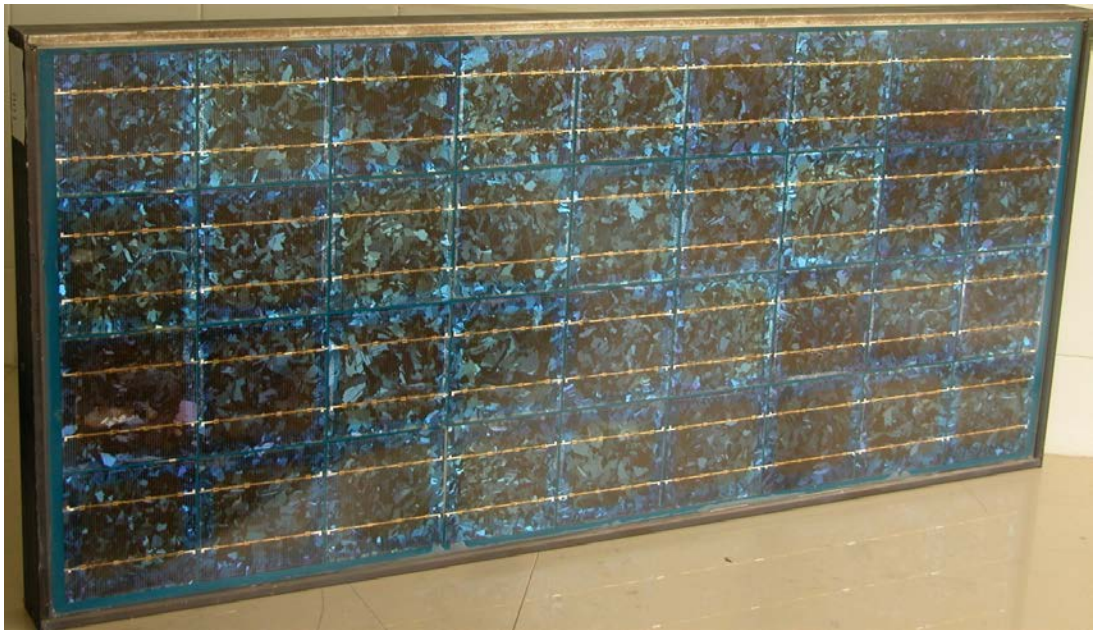
Diodes and J-box failure-PVQAT

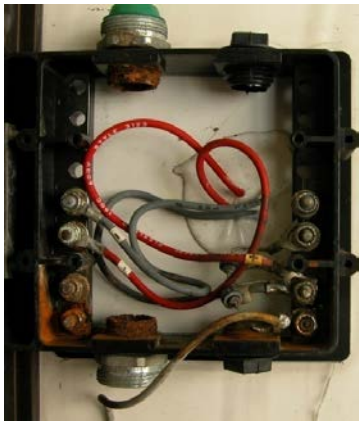
DC1500V module

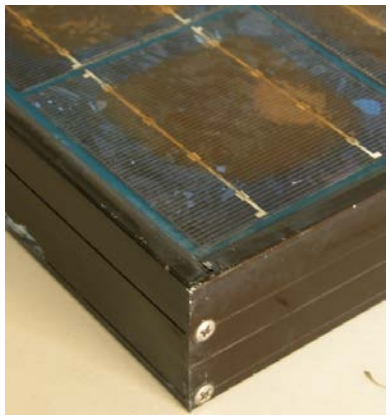
Failure from Al-frame and silicone sealant

Degradation from pollutant

Case1:Tracking degradation of Solarex modules







Poly module

- Glass: 3.2mm
- EVA
- laminated
- Backsheet: Tedlar only
- Solar cell: thckness 425μm, size 101×101mm
- Rated value：

P=42.6Wp

Voc=20.8V

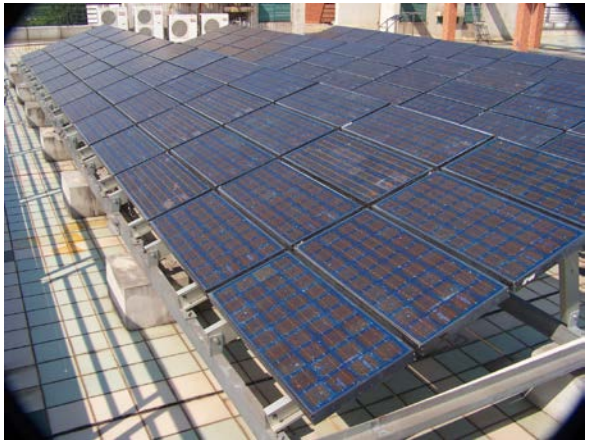
Isc=3.04A

Vm=15.1V

Im=2.82A

Hainan(1985-2008, off-grid)

144 modules
re-installed in Guangzhou



Guangzhou(2010-, on-grid)

HISTORY

Procuce: 1982

Installation:1985

Location:Hainan(1985-2008)

18°23′~18°50′N,

108°36′~109°05′E

- Sub-tropic climate
- sub-humid heat climate

Location:Guangzhou(2010-)

23°3′N,

113°22′E

- Sub-tropic climate
- Sub-humid heat climate

Historical meteorological data of the two places

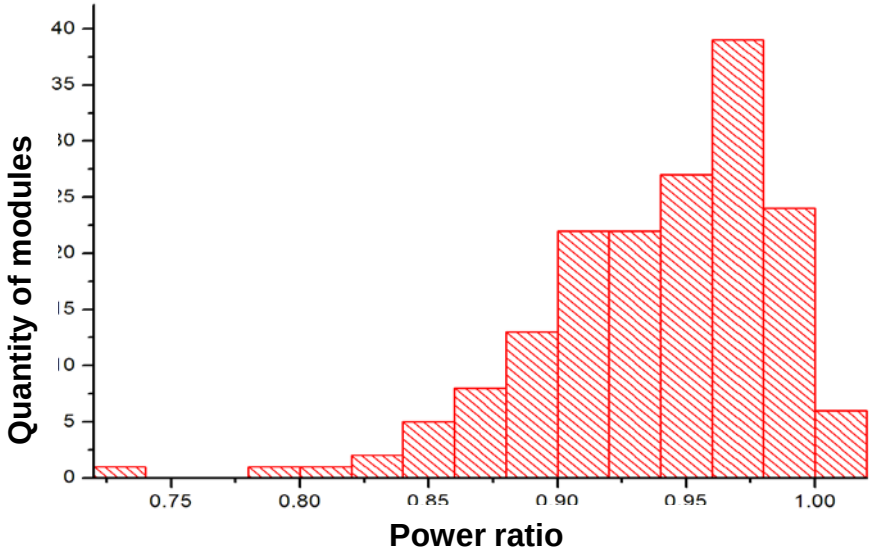
Place	$\bar{T}$ (℃)	$\bar{T}_{\max}$(℃)	$\bar{T}_{\min}$ (℃)	$\bar{R}$(%)	$\bar{S}$(hour)	year
HK	24.2	28.0	21.3	84	2070	1971-2000
GZ	22.1	26.7	19.3	78	1617	2001-2010

Degradation of 22-year-old multi-crystalline Si modules(1986-2008)

	Pm/W	Im/A	Vm/V	Isc/A	Voc/V	FF
Rated values	42.6	2.82	15.1	3.02	20.8	0.68
Actual values	39.7	2.50	15.9	2.8	20.3	0.7
Relative ratio	93.9	88.7	105.2	92.1	97.5	103.9

(171 modules, for 6 modules with rusty-broken junction-box leading to no electrical output)

Decrease by current



144 selected modules were tested in 2009, 2014, 2015 at standard test condition

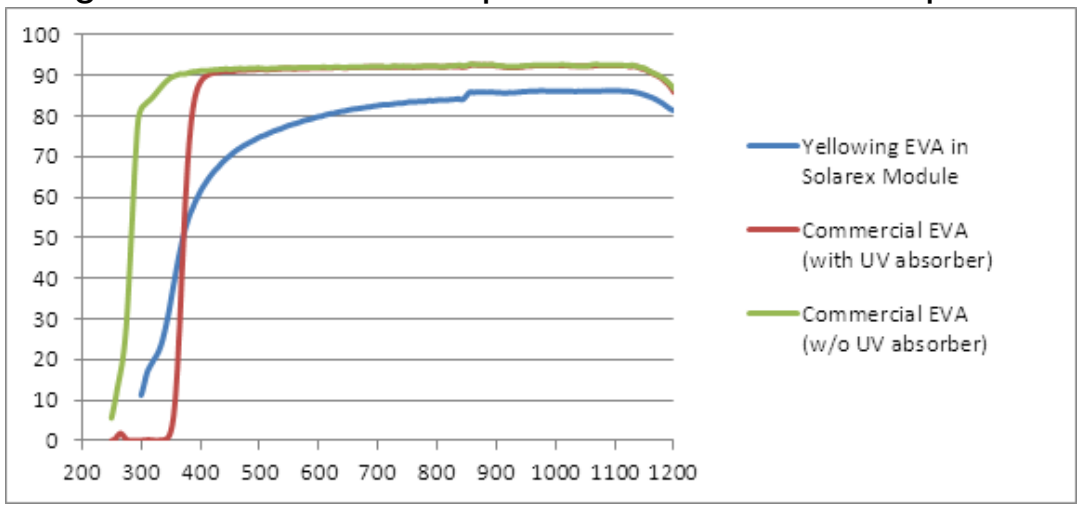
Degradation Ratio to the rated value

Test time	Pm	Im	Vm	Isc	Voc
2009	0.96	0.88	1.1	0.91	0.98
2014	0.95	0.86	1.1	0.89	0.99
2015	0.94	0.86	1.1	0.89	0.99

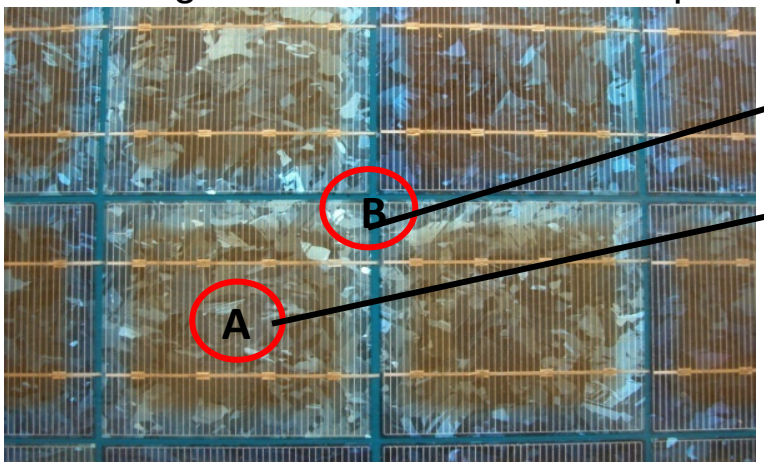
EVA Analysis

	method	reference	aged module
crosslinking-degree	exylene extraction	80-90	73 (marginal part)
light transmittance	ultraviolet spectrophotometer	91-93	<80
melting point	DSC	62-72	71
heat of solidification	DSC	5	0.54
VA content	TGA	28-33	33
PH	PH meter	5.69	5.09
yellowness index	colorimeter	0.9	11.5
tensile strength	Electronic Pull and Push Strength Caculator	18	3
breakage elongation		800	697
IR	IR spectrophotometer	-	acetic acid

Light ransmittance comparison of surface encapsulant



Crosslink degree of EVA from different parts in the module



THEORY

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REALITY

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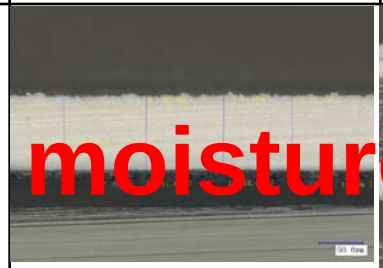
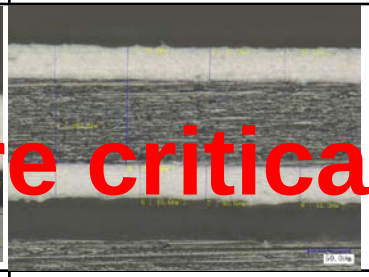
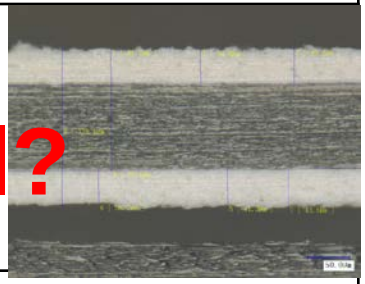
Back-sheet analysis Solarex/BP270/SM55

		Solarex	BP270	SM55
WVT（gm/[m²-day]）		8.21	3.98	3.64
Thickness（um）		108	177	174
Thickness of fluride film（um）		96.8	40.3	40.5
Structure				
Tensile strenth (Mpa)	MD	46.52	93.52	95.06
	TD	73.18	110.65	127.59
breakage elongation (%)	MD	184.45	165.45	178.4
	TD	122.92	116.34	80.56
breakdown-voltage (kV)		6.66	15.66	15.83
volume resistivity		$1.964*10^{16}$	$1.266*10^{16}$	$1.364*10^{16}$

Is moisture critical?

WVT is at least 3 times as much as the reference value.

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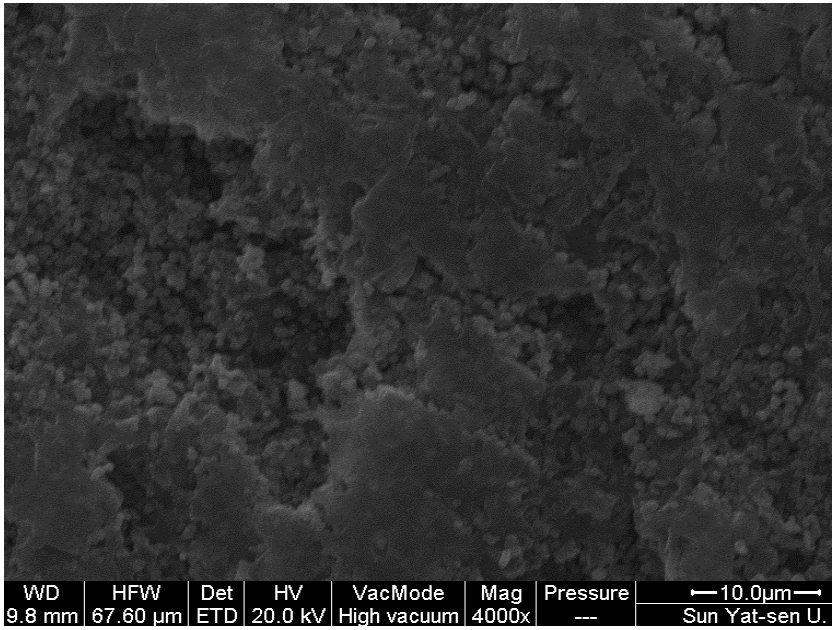
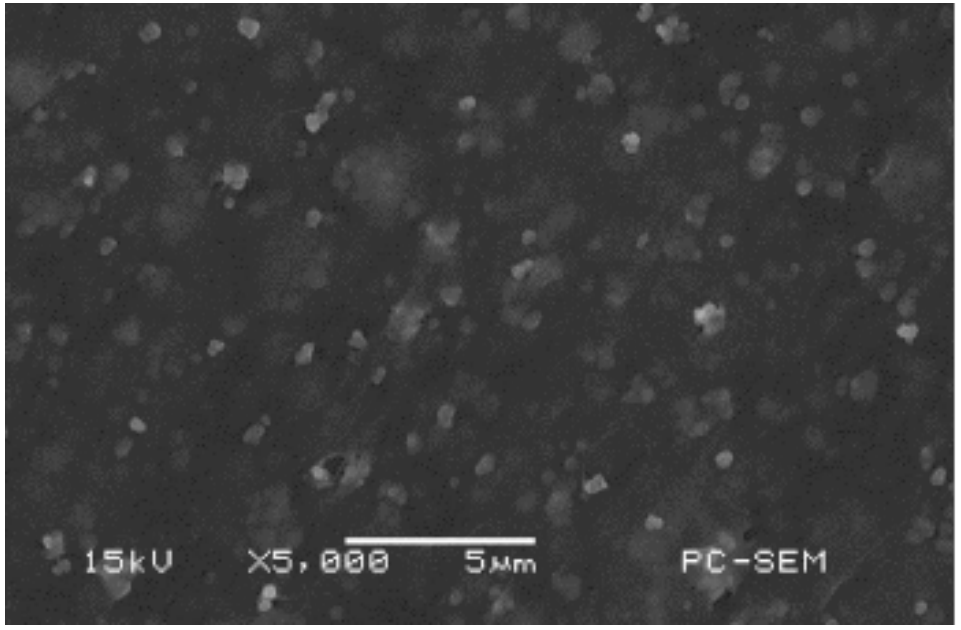
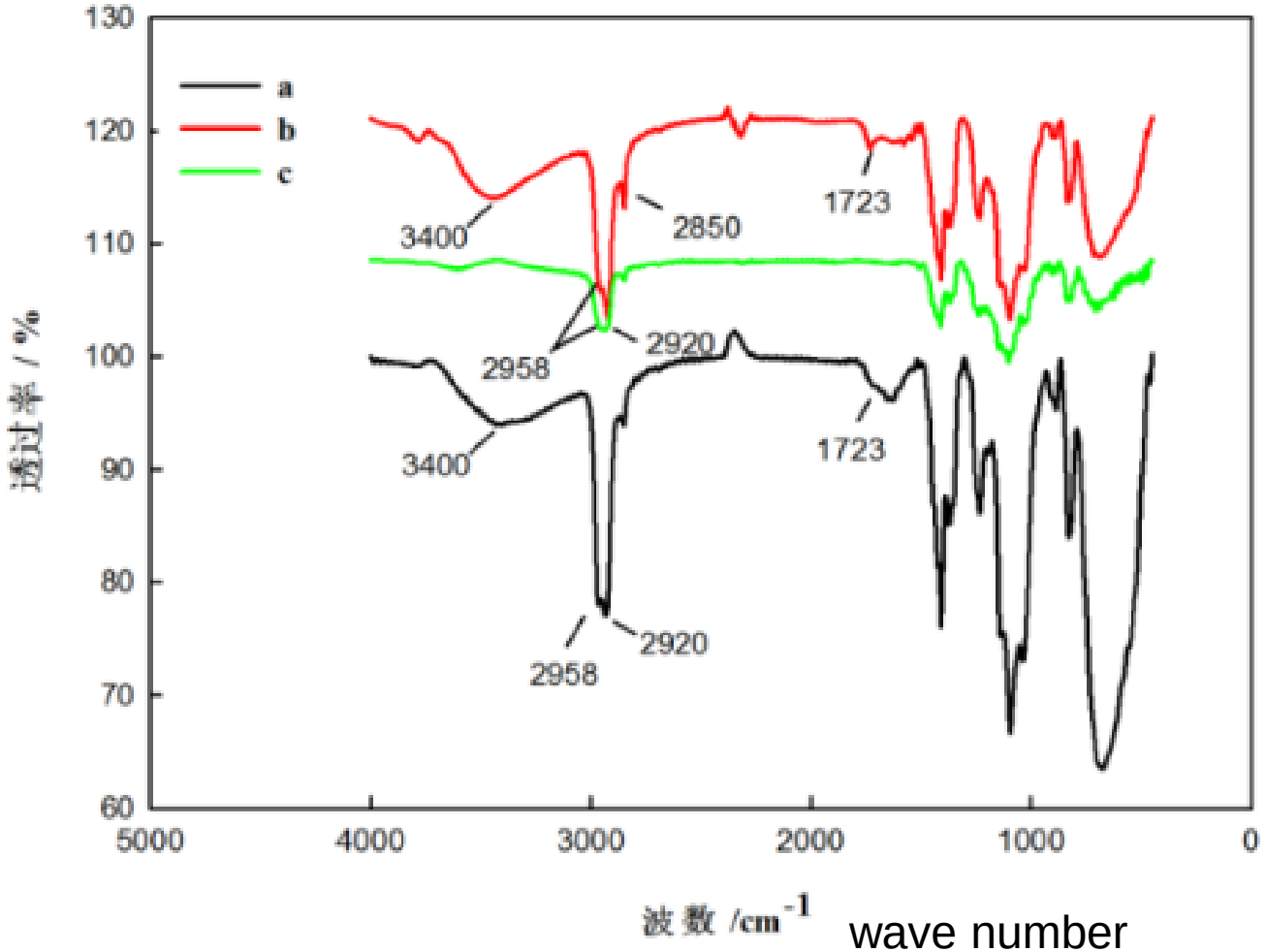
Backsheet pulverization



Sample from Solarex module

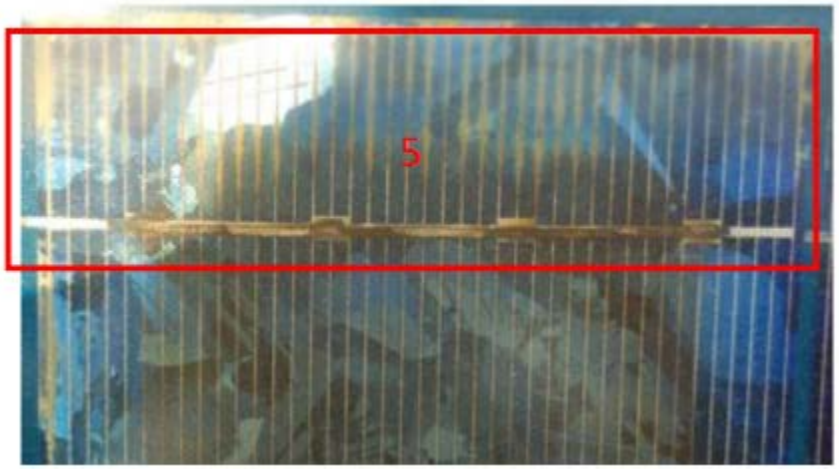


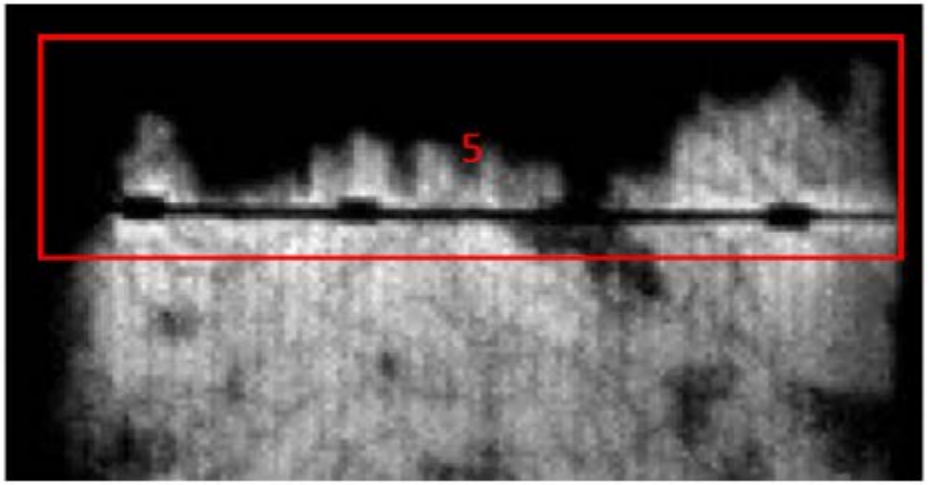
New backsheet-Tedalar PV2001



2920-2960: -CH_2-
1400-1000: C-F
1723: C=O
3400: hydroperoxide
580: Ti-O

（a）Sample from Solarex module
（b）Sample from Solarex module-covered by the label
（c）Tedlar PV2001





Degradation mechanism:

Optical loss

↑

Yellowness of EVA

Electrical loss

↑

Moistrue intrusion & micro crack

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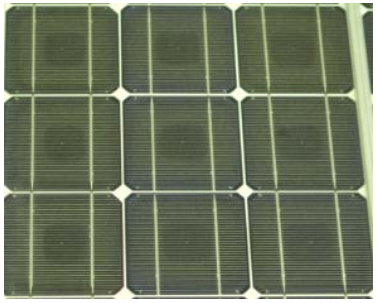
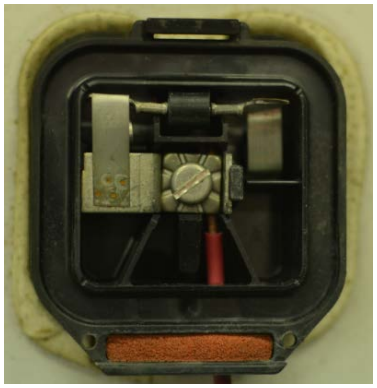
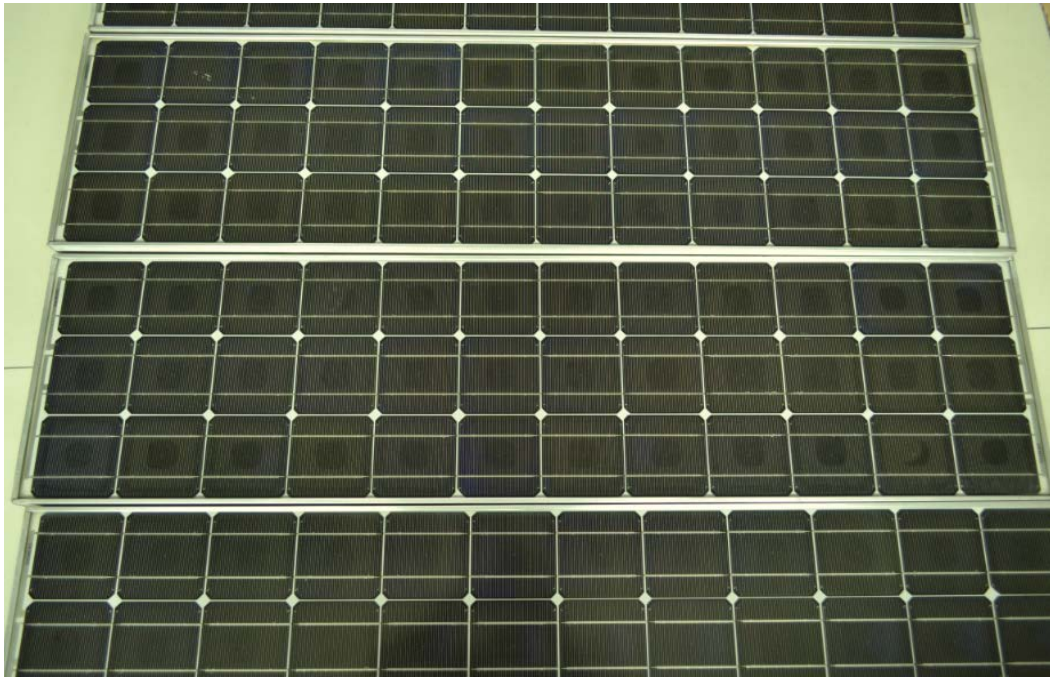
Case2:Compare of Siemens modules from different climates

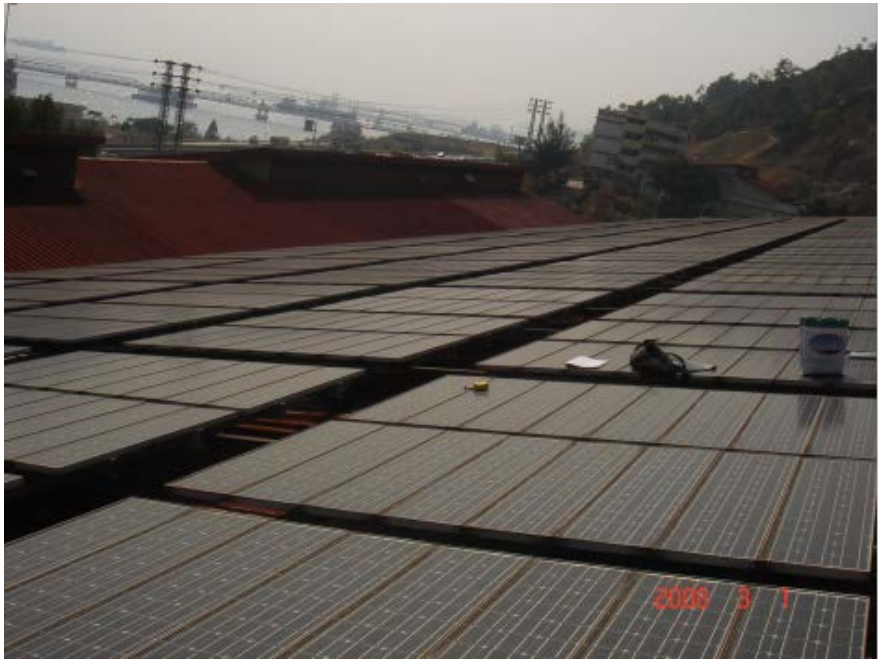






Mono module

- Glass 3.2mm, EVA laminated
- Pruduce/installation time:1992-1998
- Back-sheet: Tedlar/PET/Tedlar
- Cell thickness 320μm, size 101×101mm
- Rated value： P = 55 Wp， Voc = 21.7 V，
  Isc = 3.45 A, Vm =17.4 V， Im = 3.15 A



HISTORY SM55

- Procuce and installation: 1995
- Location:Shenzhen(1995-2014)
  18°23′N, 108°36′E
- Sub-humid heat climate
- Nearby the sea(<1000m)

M75

- Procuce and installation: 1992
- Location:Shenzhen(1992-2015)
  38°79′N, 93°35′E
- Cold-warm climate
- Desert

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Siemens modules produced during 1992-1998

Climates covers cold-warmI, cold-warmII and warm area

Dunhuang

Haixi

Zhangye

Longnan[1]

Baiyin

Longnan[2]

Degradation compare of modules from different climates(STC)

SM55	Age	Qty	Pm/W	Im/A	Vm/V	Isc/A	Voc/V	FF
Rated value			55	3.15	17.4	3.45	21.7	0.73
Storage		1	51.6	3.03	17.0	3.35	21.6	0.71
Shenzhen	20	500	41.3	2.77	14.8	3.19	21.2	0.61

6% **25%** **7%** **13%**

M75	Age	Qty	Pm/W	Im/A	Vm/V	Isc/A	Voc/V	FF
Rated Value			48	3.02	15.9	3.35	19.8	0.72
Dunhang	23	61	44.6	2.92	15.3	3.25	19.7	0.70
Haixi	23	41	41.8	2.77	15.1	3.14	19.6	0.68

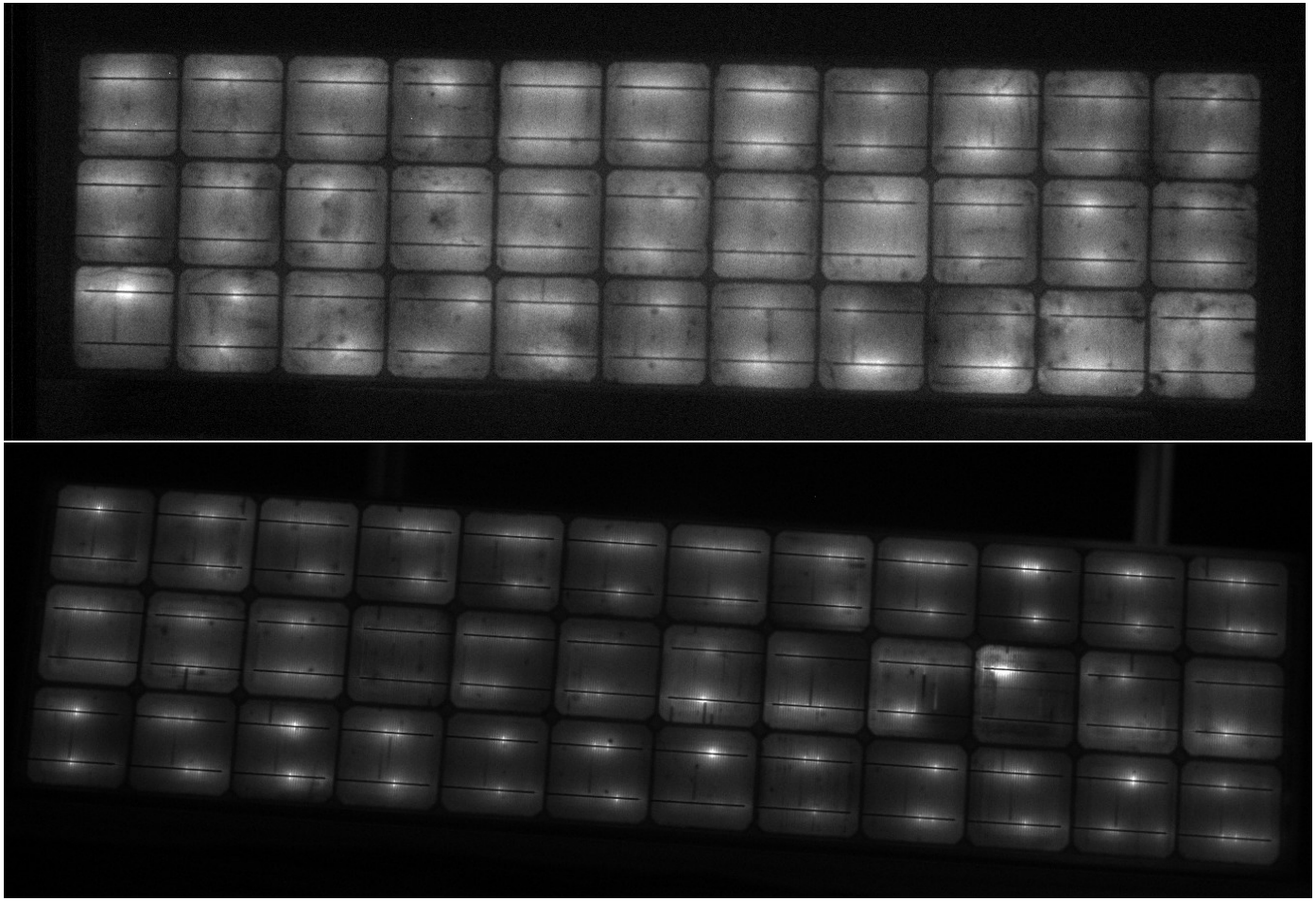
Relationship between degradation and climates?

Big deviation beween STC and outdoor testing result

Dunhuang	Pmax	Voc	Vmpp	Impp	Isc	FF
Rated	48	19.80	15.90	3.02	3.35	0.72
STC	44.6	19.68	15.29	2.92	3.25	0.70
Outdoor	31.1	17.61	13.29	2.34	2.62	0.67

Haixi	Pmax	Voc	Vmpp	Impp	Isc	FF
Rated	48	19.80	15.90	3.02	3.35	0.72
STC	41.8	19.63	3.14	15.09	2.77	0.68
Outdoor	30.4	18.31	13.45	2.26	2.63	0.63

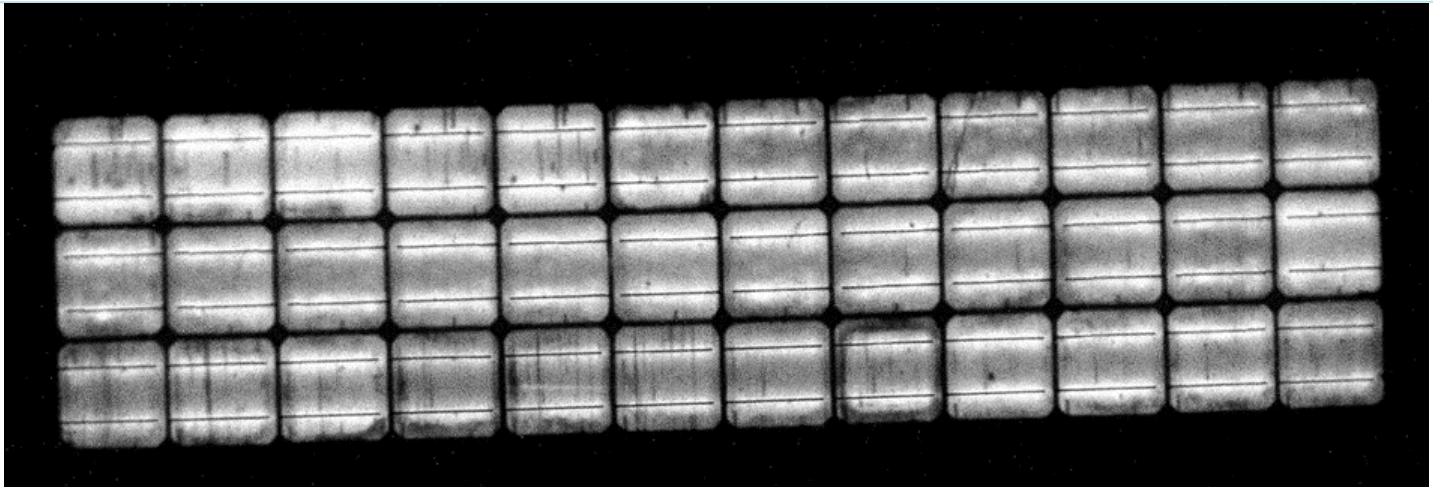
Deviation: 30%



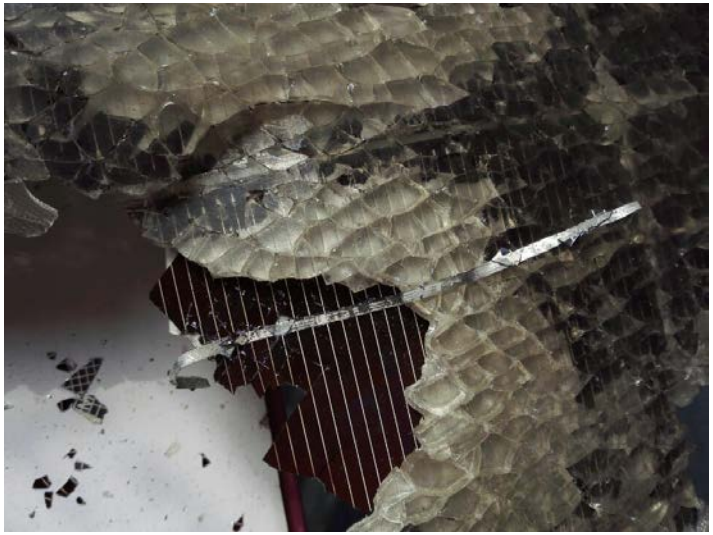
M75

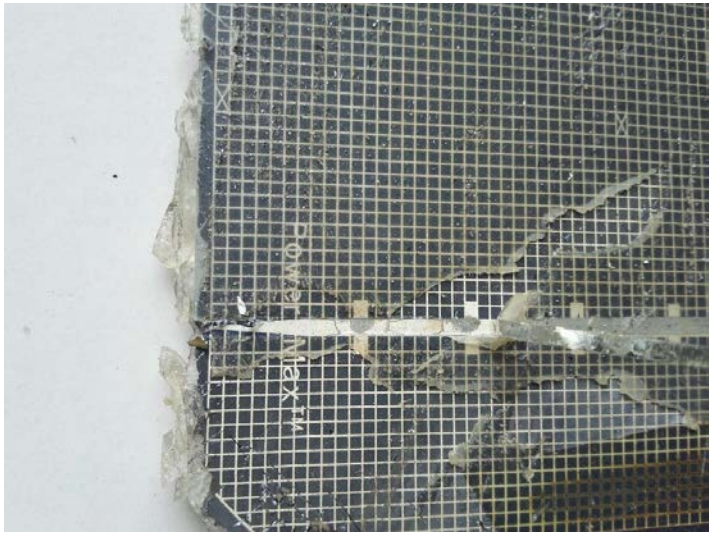
SM55

Why high series resistance?

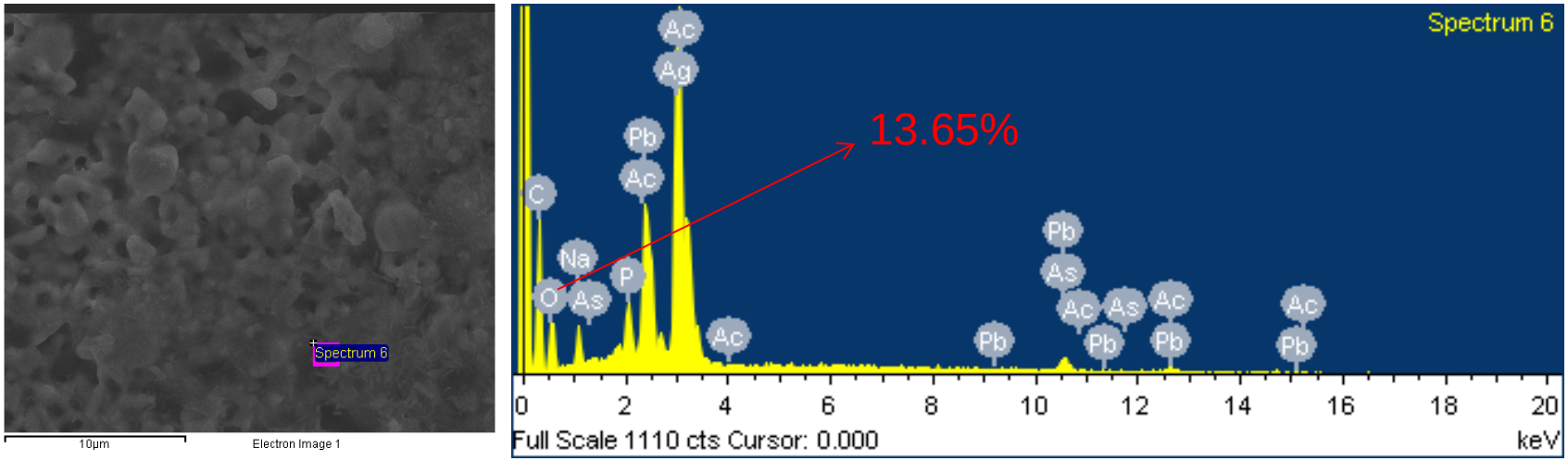


SM55 Storage indoor

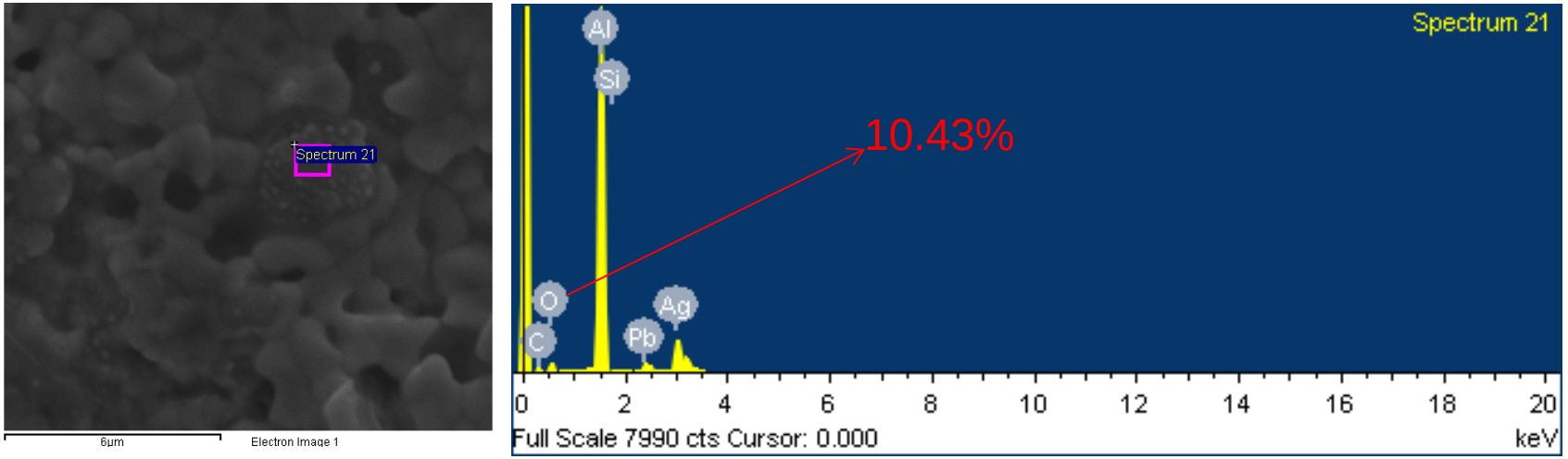




Structrue of electron connection in front surface and back surface



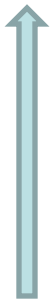
Ag fingers on the front surface of solar cell



Fingers on the back surface of solar cell

Degradation mechanism:

Bad contact between solar cell and ribbon



Al-Ag paste/Soldering process/severe climate

4. Summary

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- Degradation are caused by complex reasons, so it's hard to reach a conclusion. More data should be collected from different typical climates to study the effect of humidity, temperature and UV dose, salt mist, etc. to modules.
- The Solarex modules were firstly degraded by degradation of EVA(for loss of light transmittance), then by the crosion of fingers and ribbons. Power degradation of fielded modules is less than 10% for 28-year outdoor operation. Poly-Si modules show lower degradation rate than mono-Si modules.
- Accelerating test procedures should be optimized according to practice.New analysis method should be developed to test modules without damage.
- During work of reliability, it's important to announce the testing condition for it would cause big deviation.
- Lack of original information of PV modules and test conditions are great obstacles we met during study of degradation. So our test result could only supply a reference.

Outlook

1. How to define module's life rationally? It's quite different from business warranty.

2. Select modules according to local circumstances. Meanwhile, standards of accelerating tests should be localization and detailed.

3. Mono-Si and poly-Si modules?

4. We are building a living fossil of fielded modules in order to track the degradate trend, it would be a reference to the testing dose and sequence.

5. No snail trails were found in these Siemens modules. Semiconductor is very stable theoritically, but is there any relationship between the module performance and cell thickness?

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Thanks for your attention!




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