MODULE MANUFACTURING AND TESTING

BY

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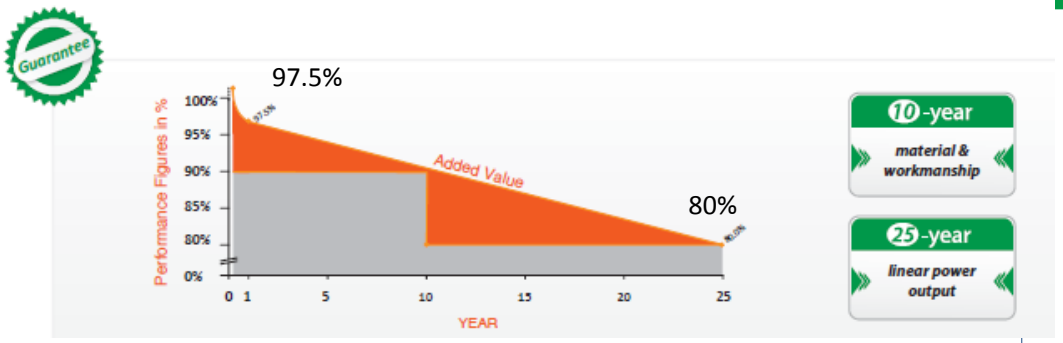
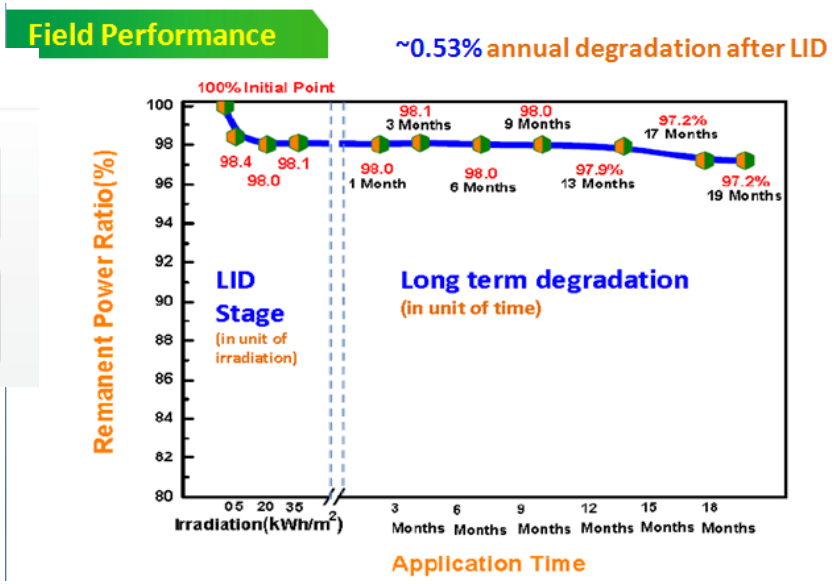
TOPICS

1. Lifetime of PV Module
2. Module Structure
3. Importance of each Component used in Module Manufacturing
   A. Solar Cell
   B. EVA
   C. Back-sheet
   D. Glass
   E. Junction box with Bypass diodes and Connecting cables
   F. Connecting ribbon
   G. Sealant
   H. Short and Long Frames
4. Crystalline Si- Module Assembly Process Flow Chart
5. Description of purpose of each Process Step and QC
6. Module Reliability tests

1. Lifetime for PV Module (Made to work for 25 Years and Beyond)

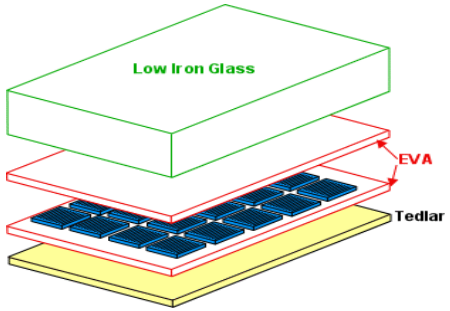
WEBEL SOLAR





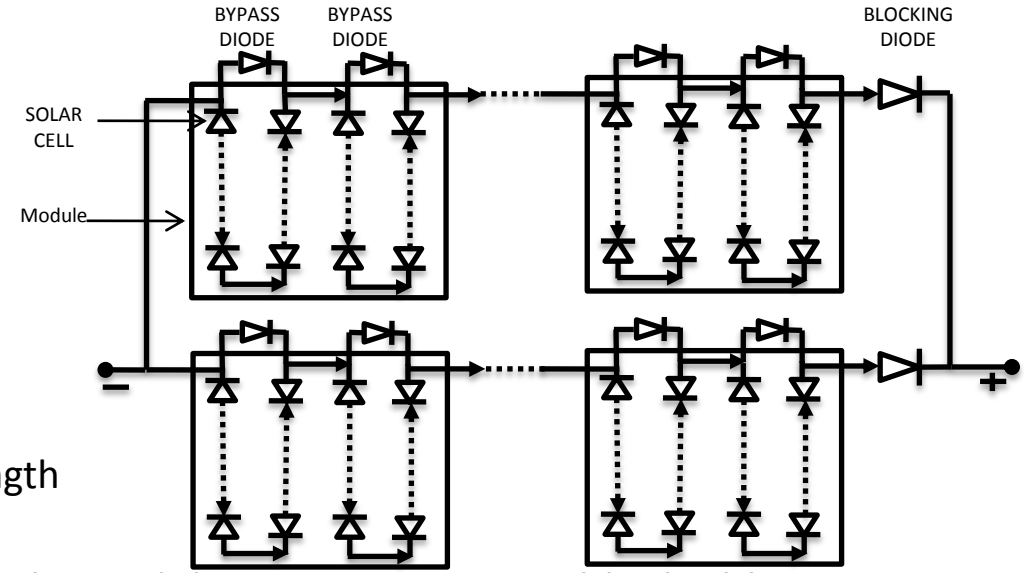
2. Module Structure

- Module consists of number of interconnected encapsulated cells (sealed hermetically)
- Provides mechanical support to crystalline silicon solar cell, relatively very thin material
- Protection to electrical interconnection from harsh environment
- Prevent water or water vapor from corroding the electrical contacts
- Number of cells: Typically 60 or 72 cells for 240 to 260 watts or 290 to 310 watts



Modules consists of:

- a transparent top cover, **Glass**
- an encapsulant, **EVA (ethyl vinyl acetate)**
- a rear support layer, **Tedlar**
- a **Frame**
- a **Junction box** with connecting cables



Top cover requirements:

- Should have **high transmittance**
- **low reflection** preferably with Anti-reflection coating (ARC) on Glass
- **Impervious to water**
- **Stable under prolonged UV exposure**
- **high thermal conductivity**
- **mechanically rigid** to provide mechanical strength

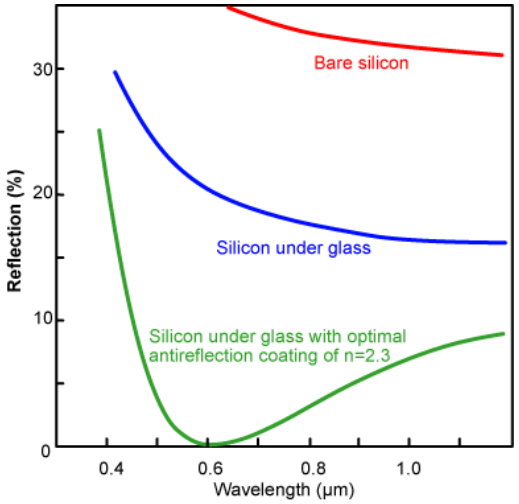
Low iron-content ARC **Glass** is most commonly used :low cost, strong, stable, highly transparent, impervious to water, good self-cleaning properties

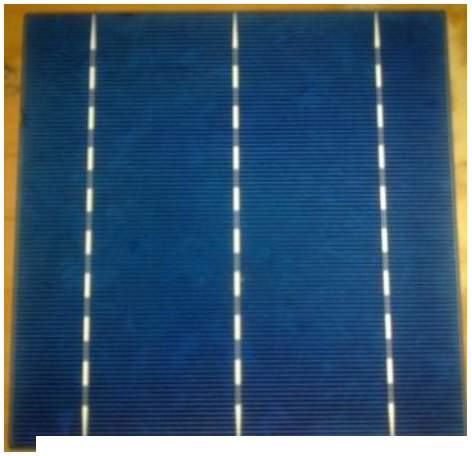
3. Importance of each Component used in Module Manufacturing

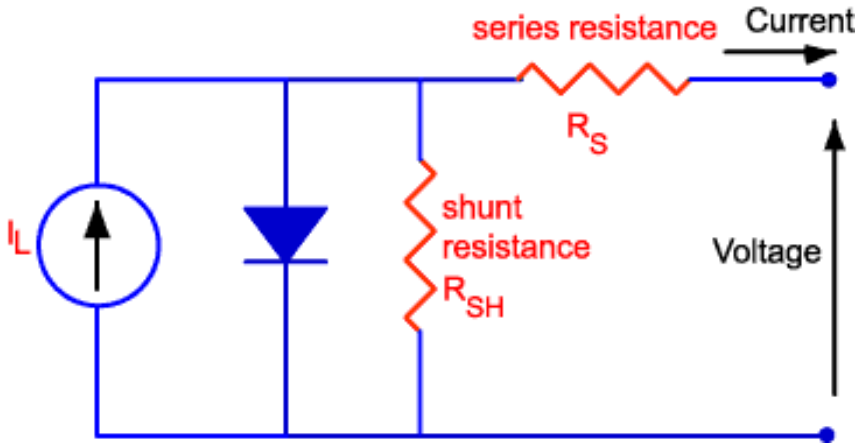
A. Solar Cell
B. EVA
C. Back-sheet
D. Glass
E. Junction box with Bypass diodes and Connecting cables
F. Connecting ribbon
G. Sealant
H. Short and Long Frames

A. Solar Cell

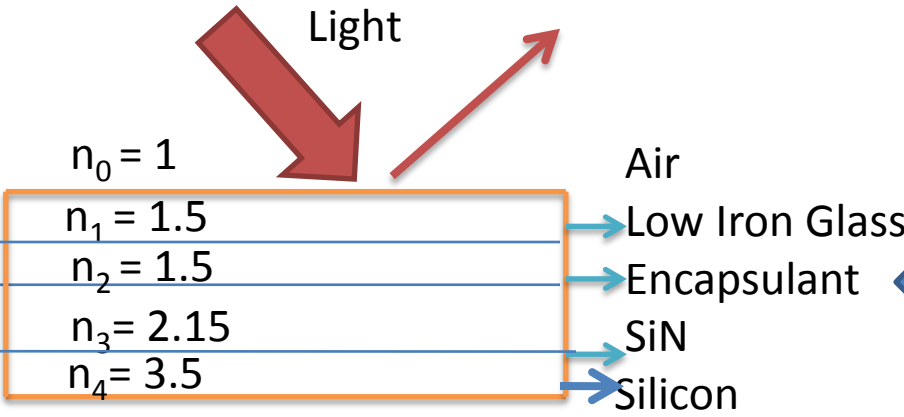
- Good Solderable pads
- PID Resistant
- No printing defect
- No Micro cracks







Equivalent Circuit of solar cell



DIFFERENT LAYERS WITH DIFFERENT REFRACTIVE INDEX LEADS TO OPTICAL LOSSES

B. EVA(Ethylene Vinyl Acetate)

WEBEL SOLAR

•Encapsulant's (EVA) requirements:

➢ Adhesive between solar cells

➢ Stable at elevated temperatures and high UV exposure.

➢ It should also be optically transparent and should have a low thermal resistance.

➢EVA (ethylene vinyl acetate) is the most commonly used encapsulant material. Cell are sandwiched between thin **EVA sheets**

➢**High Level Transmission Front EVA** is also used i.e. Transmission @ 362nm – Minimum of 70% to improve Blue response

➢**GEL CONTENT > 75%**

➢**Shelf life – 9 Months**

➢**Storage conditions – 5 to 30^0 C,**

RH - < 60%

➢**EVA rolls comes in vacuum sealed bag, when it is opened then it should be consumed i.e. Module lamination completed within 8 hours**

COA of FRONT EVA

Characteristic	Requirement	Result
Thickness:	0.430 mm – 0.530 mm	0.469 mm
Width:	977 mm – 983 mm	981 mm
Adhesion:	30 lb / in minimum	104.42 lb/in
Optical Transmission at 360nm:	70% minimum	85.7%
Texture:	uniform	uniform
Aesthetics:	pass/fail	pass

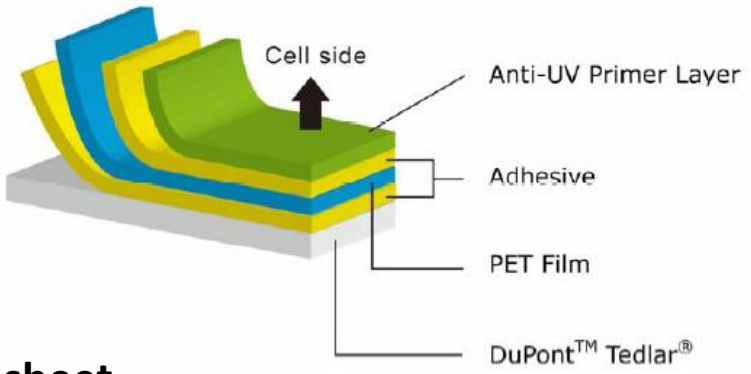
COA of BACK EVA

Characteristic	Requirement	Result
Thickness:	0.430 mm – 0.530 mm	0.469 mm
Width:	988 mm – 994 mm	991 mm
Adhesion:	30 lb / in minimum	96.04 lb/in
UV stabilizer:	present	present
Texture:	uniform	uniform
Aesthetics:	pass/fail	pass

C. BACKSHEET

Requirements of rear surface:

- Low thermal resistance
- It must prevent the ingress of water or water vapour
- A thin polymer sheet, called **Tedlar**, is used as the rear surface
- **Shelf life – 24 Months**



Specifications of Back sheet

厚度 Thickness	台虹規格 Taiflex Spec.	368um±10%
層間剝離強度 Interlayer Peel Strength	IPC TM-650 No. 2.4.9	≧ 6N/cm
與 EVA 剝離強度 Peel Strength with EVA	台虹規格 Taiflex Spec.	≧ 40N/cm
尺寸安定性 Dimensional Stability	IPC TM-650 No. 2.2.4 (160°C / 30min)	< 2%
破壞電壓 Breakdown Voltage	ASTM D-149	≧ 17KV
局部放電測試 Partial Discharge	IEC60664-1 IEC61730	≦1000VDC (from TŰV)
水分穿透率 Water Vapor Permeability Rate	ASTM F1249 40°C / 90%RH	≦3.0g/M^2.day
寬度 Width	台虹規格 Taiflex Spec.	1000±5 mm

D. Glass

Requirements :-

1. Flat Glass with Anti Reflection coating
2. No Bubbles / scratch / chipping at edges / stain

Glass Capability Tests @ Vendors end

Capability Test							
No.	Test Item	Test Methods	Standard	Unit	Equipment	Testing Data	Test
1	Bending	Place the glass vertically, attach the horizontal ruler to the glass surface and measure theratio of the glass bending chord high and chord length . The Ratio less than 0.3%.	<0.3	%	Horizontal Ruler Steel Ruler	0.12%	ok
2	Waveform Bending	Knife-foot (300 mm) of any range, close to the glass surface with a feeler knife feet between the glass and the maximum gap L, L / knife length	<0.167	%	Knife-foot/ Feeler	0.14%	ok
3	Temper Test	Count fragment quantity in selected 50*50mm place with minimal fragments, Fragment quantity equal of more than 40	>40	pcs	Shock Pen Hammer	78	ok
4	Impact Test	Support the glass with Table. (pad rubber hardness A50 width 15mm), drop the 227g iron ball from 1 meter high to the center of the glass. The glass not broken.	Not broken	/	Table 227g Iron Ball	Pass	ok
5	Thermal Shock Test	Heat the tempered glass to 200℃, Leaving for 30min, then pour the water over the glass. The glass not broken.	Not broken	/	Furnace	Pass	ok
6	Static Test	Support the glass with Table. (pad rubber hardness A50 width 15mm), add 20kg sand bags to the pressure 300kg/㎡. Leaving for 1 hr. The glass not broken.	>2400	pa	Table Sand bags	2500 pa	ok
7	Ironoxide Content	<200ppm	<200	ppm	Lab	87ppm	ok
8	Transmission	93.6% above	≥93.6	%	Spectrometer	93.85%	ok
9	Coating Thickness	Use equipment for testing	120±10	nm	Ellipsometer	112nm	ok
10	Pencil Hardness	Pencil hardness: according to ASTM D3363, the pencil hardness of the test the membrane surface with a pencil hardness tester, ≥ 4H	4	H	Pencil hardness tester	4H	ok

Glass pellet with paper separators

E. Junction Box with Bypass diodes and connecting cables

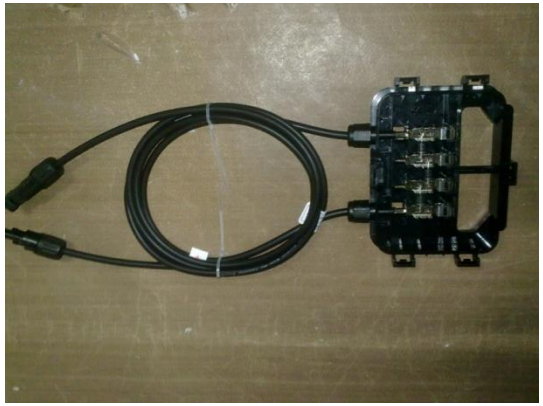
Junction box consists of the following:-

1. JB can be **IP 65** / IP 67 (INGRESS PROTECTION LEVELS)

   IP **XY**
   X(6) – Totally protected against dust ingress
   Y(5)- Protected against low pressure water jets from any direction, limited ingress permitted
   Y(7)- Protected against short periods of water

2. Bypass diodes (Schottky Diodes)

3. Connecting cables 1 meters / 1.2 meters



F. Connecting Ribbon

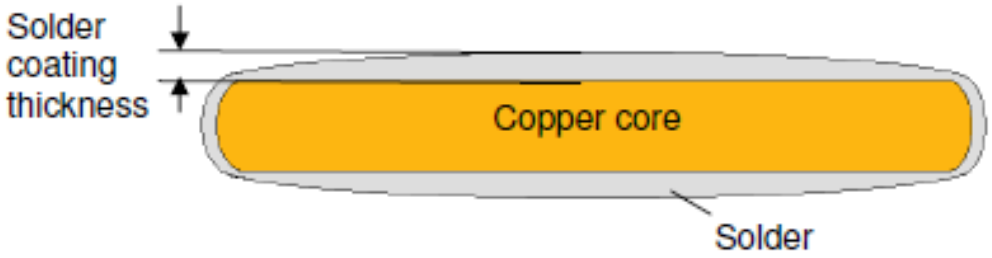
Two Types of connecting ribbon are used

1. 5mm X 0.22 mm called **string connectors** (Fig 1)

2. 1.6 mm X 0.23 mm ribbon for **cell interconnectors**

Solder

Alloy:	Sn60Pb40	acc. ISO 9453
Melting temperature:	183/190 °C	
Sn:	Rem	
Pb:	39,5 – 40,5 %	
Impurities:	≤ 1 %	



Solder coating thickness:	25 +/- 10	µm
	- Measured by XRF - The average of 5 readings across the ribbon width (average thickness)	

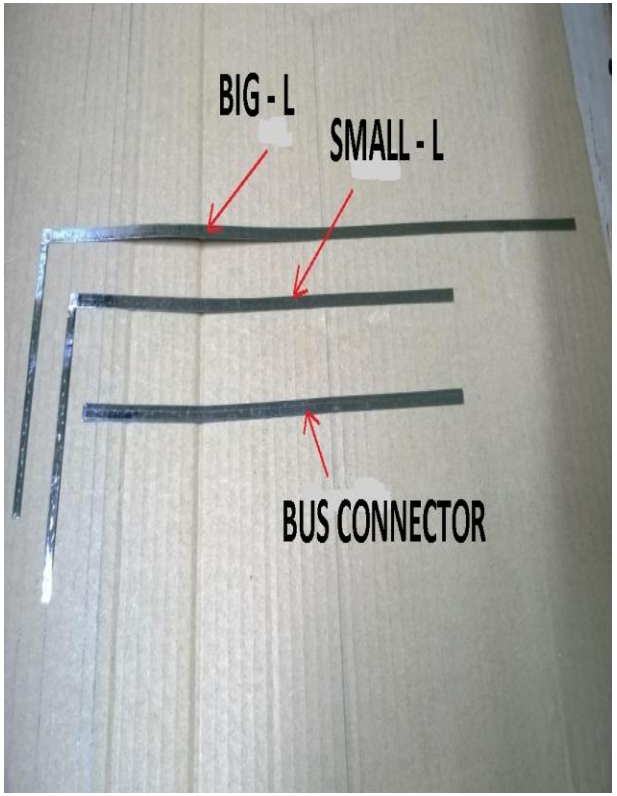


Fig 1

G. Silicone Sealant

Typical properties of Silicone sealant after curing

1. Super resistance to UV, Rain, Contamination and Hail
2. It is used to seal the frames with the edge trimmed laminates
3. It is also used as adhesives for Junction Box

CURED PROPERTIES

Measured on cured sheets ~2mm. Cured @ (23±2)℃, (50±5)% RH for 14 days, tested at 25℃.

Operating Temperature Range(℃) .....-54 to 210
Hardness (Shore A) (ISO7619, GB/T531) 48
Elongation at break (%) (ISO37, GB/528).....300
Tensile Strength (MPa) (ISO37, GB/528).....2.3
Adhesion Strength(MPa) (ISO4587, GB7124)..... .....1.8

Damp-Heat aging properties(Damp-Heat aging at 85℃, 85%RH for 1000h)

Elongation at break (%)(ISO37, GB/528).....320
Tensile Strength (MPa) (ISO37, GB/528).....1.6

Electrical Properties

Volume resistivity(Ω.cm) (IEC60093, GB/T1692) .....
.....1.0×10^{15}

Breakdown tension（kv/mm）(IEC 60243-1, GB/T16--95) 20

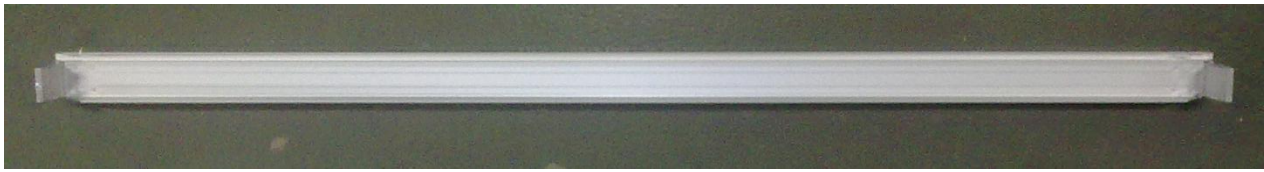
H. Short and long Frames(Backbone of the module structure)

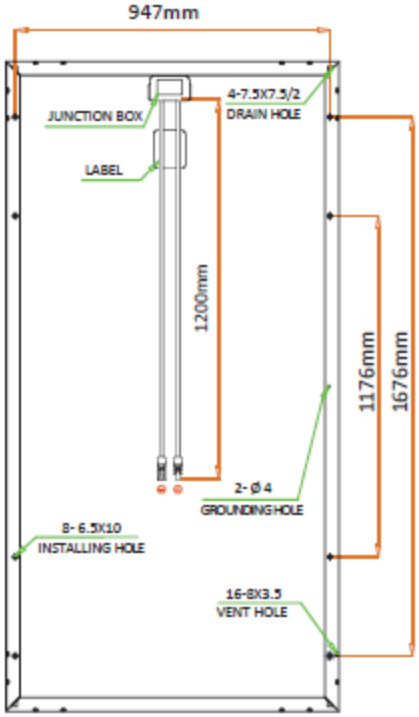
Short and long Anodized Aluminum Frames

Long Frame consists of the following:-

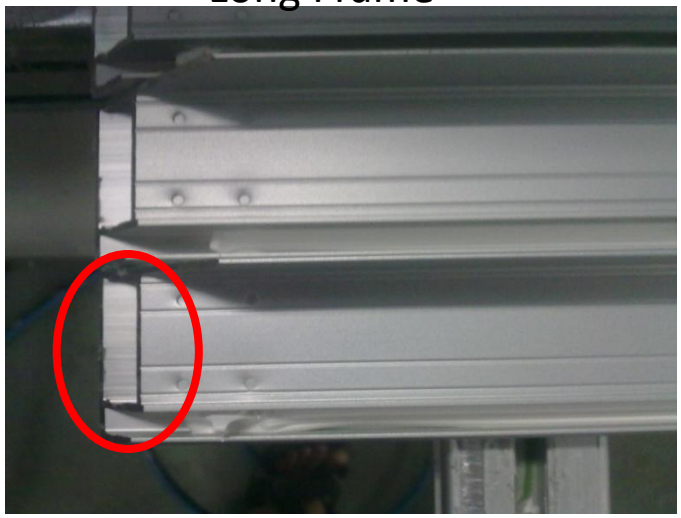
1. Installation holes (Used for installation of the module)
2. Drain Holes (For draining of water from the melting snow)
3. Ground Symbol with holes (Part of the frame from where the grounding is done)
4. Vent Holes

Short Frame

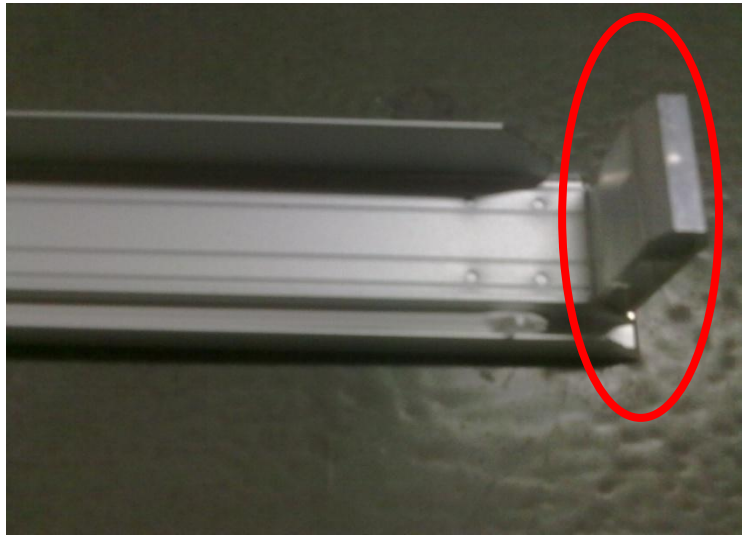




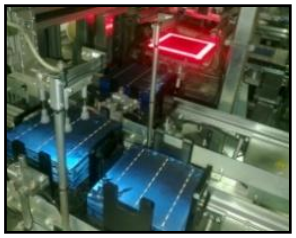
Edge of the Long Frame



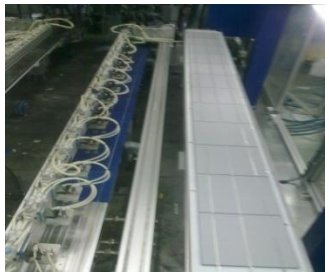
Edge of the Short Frame



4. Crystalline Si- Module Assembly Process Flow Chart



Cell Stack



Tabbing Machine

Connection

+

Back Sheet Cutting

+

EVA Cutting

Layup

Lamination

Trimming

Silicon Glue filling machine

Framing

JB Fixing

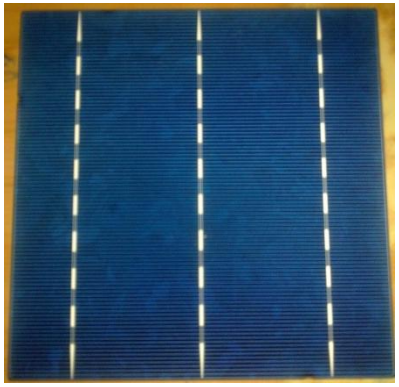
Module Testing

EL Testing

Module Packing & Dispatch

5. Description of purpose of each Process Step and QC

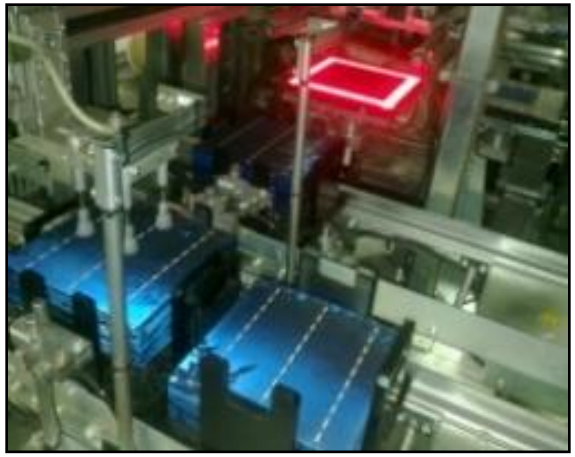
5A. Cell Stack – QC1



Purpose -Coin stacked cells after QC are loaded at Tabber and Stringer Zig

QC 1 :-

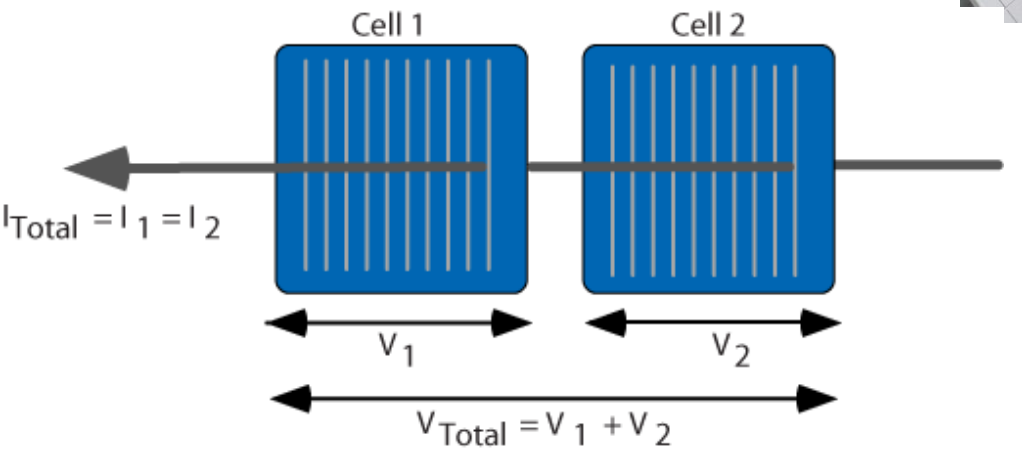
- Sorted Cells of defined Efficiency band (To minimize mismatch loss)
- Same Color class
- Quality Checked for all visual front and back defects



5B. Stringing and Tabbing – QC2

Purpose –Cells are inter-connected to form string as per requirement
e.g. **For 250 watts module**
Each String – 10 cells, 6 Strings
For 300 watts module
Each String – 12 cells, 6 Strings

QC2 points:-
- No Cell Breakage / Chipping
- Cell to Cell Gap in string
- Pull strength of Ribbon on Front and Back bus bar(> 2Newtons)



Cell connected by ribbon in series

5C. Back sheet cutting-QC3

Purpose – Cut the back sheet by automatic machine as per the requirement

QC3 points :-

- Correct dimension of back sheet
- No mark or damage / contamination on any side of the sheet

5D. Front and Back EVA cutting- QC4

Purpose – Cut the Front and Back EVA as per the requirement

QC4 Points :-

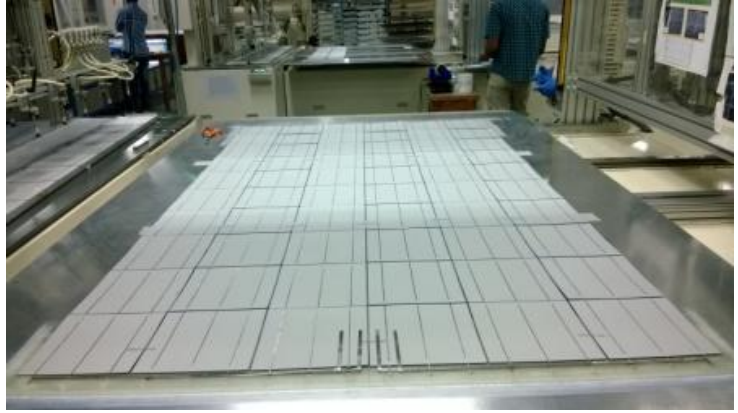
- Correct dimension of back sheet
- Place both types of EVA separately
- No mark or damage / contamination on any side of the sheet
- Follow FIFO and use it before 8 hrs after opening the EVA from sealed packet as received from the vendor
- Do touch EVA with bare hands

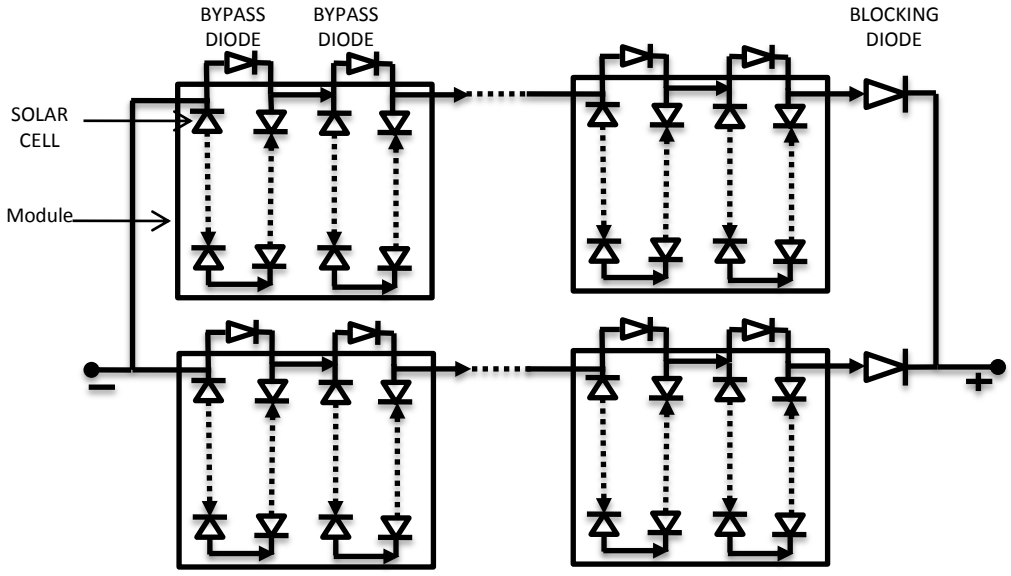
5E. Connection- QC5

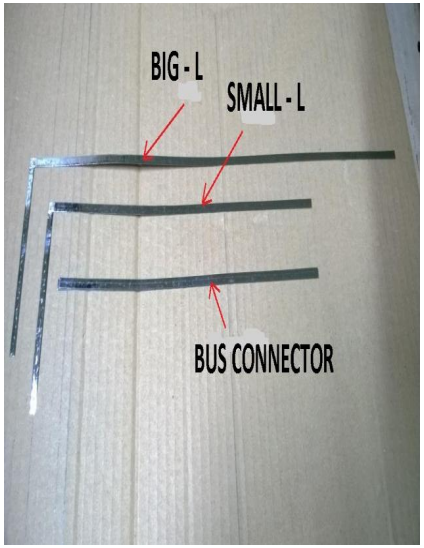
Purpose – To connect the strings using string connectors and fix EVA tapes

QC5 points:-

- No Cell Breakage
- Correct position of EVA fixing tape
- Correct placement of direction of strings
- String to string / cell to connection ribbon gap
- Check the visual defects after pickup







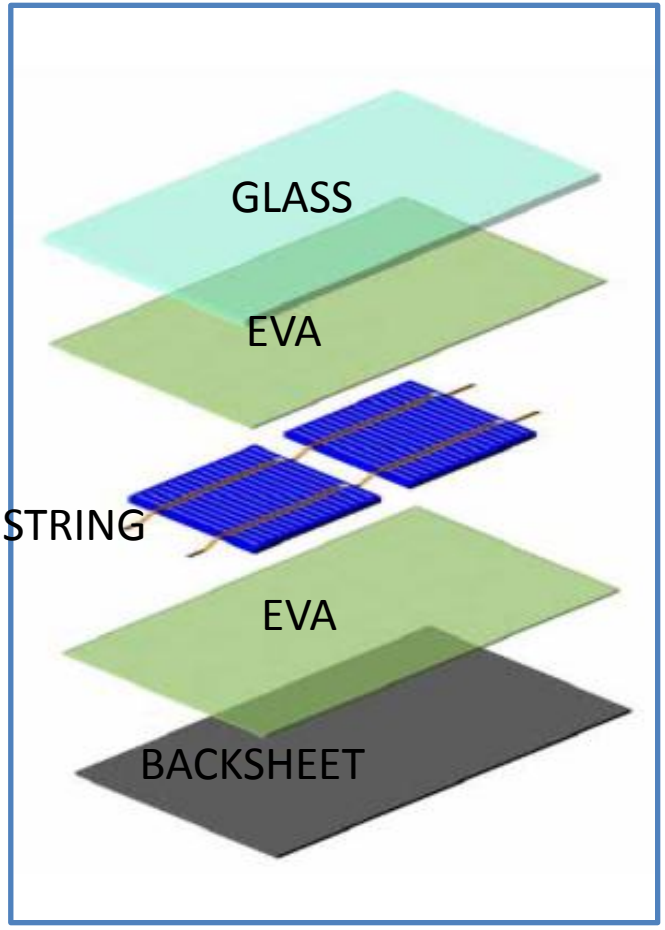
5F. Layup – QC6

Purpose – Place the Layup sequence i.e. Glass-Front EVA-Connected Strings-Back EVA-Back sheet. Check DIV and correct faults at Connection / layup before the Lamination

Layup station

QC6 points :-

- No scratch / defect on Glass
- Ensure template is placed on Glass
- No visual defect in the cells before layup
- Correct dimensions of Front, Back EVA and Back sheet
- Correct placement of RFID and Serial No
- Check **DIV** for identification of any defects and verify in EL, If defects are found then it sent for repair and check EL again to confirm the correction



5F. Layup – QC6

DIV Testing procedure

Steps to identify the defect:-

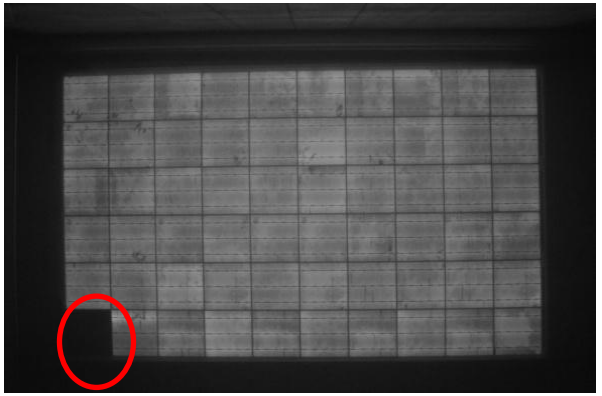
1. Check the voltage across each strings after passing the minimum amount of current
2. If the difference in voltage across the strings is>= 0.3 volts then it is sent for EL for identifying the root cause
3. After root cause identification the string is repaired and checked for EL again to confirm for the same

Types of defects which can be identified:-

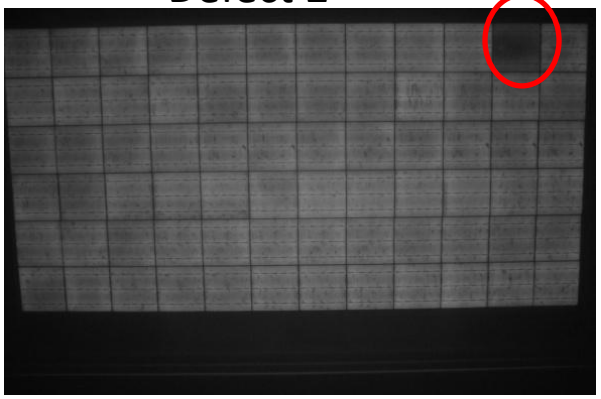
1. Black cell
2. Dry solder
3. Broken cell
4. Shorted string
5. Wrong connection

DIV TESTER

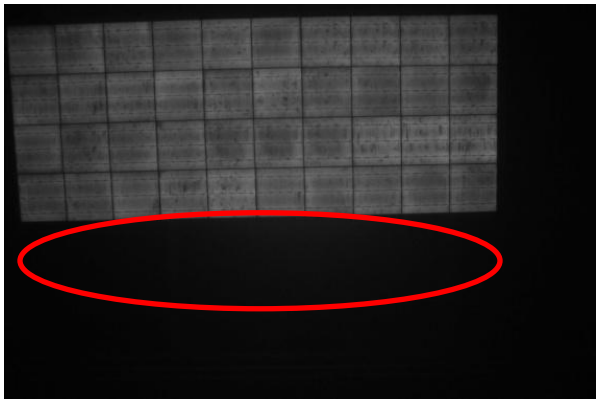
Defect 1



Defect 2



Defect 3



5G. Lamination-QC7

Purpose – Lamination of the module protects it from harsh environmental conditions for > 25 years. Good lamination is the key for its long life.

QC 7

- Gel Test > 75% (Details in Next slide)
- Peel strength > 40N between Glass to EVA / EVA to Back sheet (Details in Next Slide)


LAMINATOR

LAMINATION DEFECTS

A. POOR LAMINATION PROCESS CAN LEAD TO DELAMINATION OF EVA FROM EDGES OR INSIDE. THIS CAN CORRODE CELLS WHEN EXPOSED TO ENVIRONMENT
B. POOR LAMINATION CAN CAUSE BUBBLES TRAPPED INSIDE LAMINATE THAT CAN ALSO CAUSE CORROSION
C. POOR GEL CONTENT CAN ALLOW SEEPAGE OF MOISTURE OVER TIME THAT CAN CAUSE CORROSION OF CONTACTS.

PUMPING AIR OUT OF LAYERS IN VACUUM CHAMBER AND HEATING THE LAYERS

PRESSING THE LAYERS WITH FLEXIBLE DIAPHRAGM FOR PROPER EMBEDDING OF CELLS

CURING OF ENCAPSULANT FOR REQUIRED TIME WITH PRESSURE TO ENSURE PERFECT SEALING OF LAMINATE

5G. What is Gel Content -

Gel Content determines the Insoluble Fraction of cured EVA, produced by Cross linking reaction of plastic (EVA)

CALCULATION OF GEL CONTENT:

Chemicals used–Xylene and Antioxidant 2246 : 2,2`-methylenebis(6-tert-butyl-4-methylphenol)

$$\% \text{ Cross linked Material} = \frac{W3 - W2}{W1} \times 100$$

W1 – Weight of original specimen in grams

W2 – Weight of the SS mesh in which sample is placed

W3 - Weight of the cured sample along with the SS mesh

Gel Test Setup

Sample preparation for PEEL Test:-

1. Prepare the samples in the following sequence as shown below at 5 different positions of the laminate
2. Cut the samples at defined positions and check PEEL TEST

Glass to EVA

GLASS
FIBER CLOTH
FRONT EVA
BACK EVA
BACKSHEET

EVA to Back sheet

GLASS
FRONT EVA
BACK EVA
FIBER CLOTH
BACKSHEET

Peel Test in progress

5H. Trimming-QC8

Purpose – After Lamination excess EVA and back sheet coming out of the glass is trimmed by tool before the framing process

QC8 Points :-

- No bubbles / contamination or dust / flies / back sheet impression
- Dimensions as per layup criteria i.e. Cell to cell / cell to ribbon / row to row / Layup to Glass edges
- Smooth edge trimmed laminate

Module ready for Trimming

Trimmed Laminate

5I. Silicon Glue Filling machine-QC9

Purpose – Fill the short and long frames grooves uniformly with the silicone sealant

QC9 Points :-

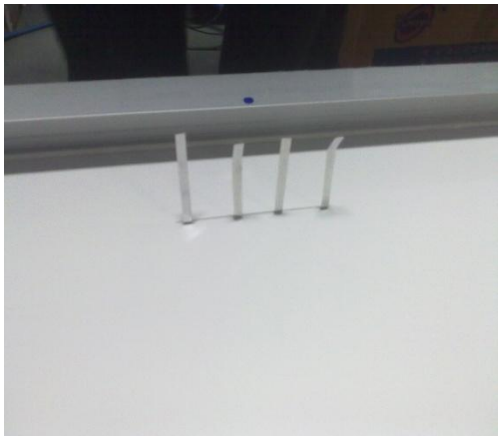
- Ensure silicon glue falls across the length of the frame uniformly
- Any deformation / scratch on frame is rejected

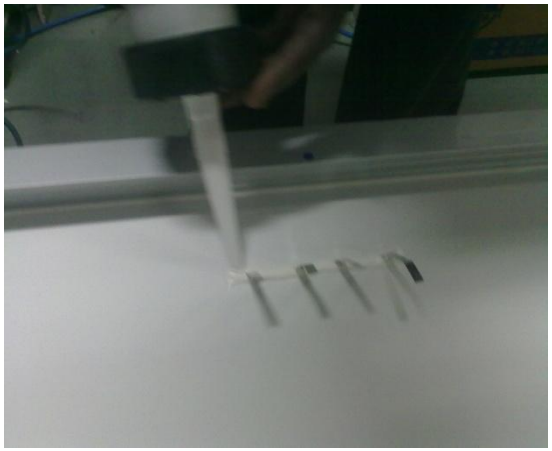
5J. Framing-QC10

Purpose – Filled short and long frames with silicone sealant are pressed with all the sides laminate edges by machine so that Laminate is covered with it uniformly

QC10 Points:-

- Silicon Glue uniformly comes across all the area from the front and back side
- No corner gaps, burr in frame edges are allowed
- Dimensions cross check including diagonals
- No loose connection between connectors and JB
- Modules sent for Curing for > = 8 hours





5K. Electrical safety testing-QC11

Purpose – Ensure that the module is electrically safe

Method - Connect the shorted output terminals of the module to the positive terminal and the frame is connected to negative terminal of the DC Insulation tester and conduct the following measurements

QC11

1. High Pot Test (Purpose – For High Voltage insulation)

TEST CONDITIONS –

Applied Voltage – 3.6 KV, Time – 1 secs

Pass Criteria - < 50uA

2. Ground Continuity Test

TEST CONDITIONS –

Current – 20 Amperes, Time – 5 Secs

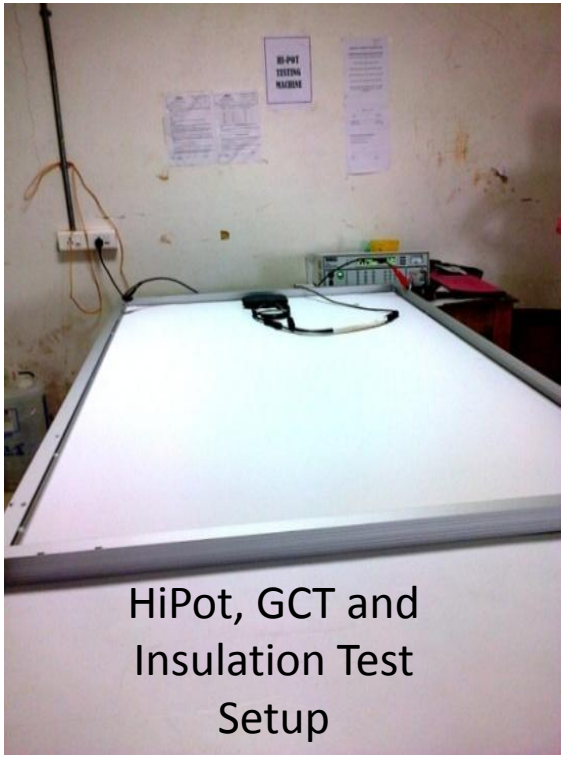
Pass Criteria – Resistance should be less than 0.1 Ohms

3. Insulation Test (Purpose - To ensure the insulation between current carrying parts of the module and the frame)

Test Conditions –

Voltage – 1000 Volts, Time -2 minutes

Pass Criteria – Minimum Insulation Resistance should be 24.54 Mega-Ohms



HiPot, GCT and Insulation Test Setup

5K. Electrical safety testing-QC11

Purpose – Ensure that the module is electrically safe

Method - Connect the shorted output terminals of the module to the positive terminal and the frame is connected to negative terminal of the DC Insulation tester and conduct the following measurements

QC11

4. Wet Leakage Test (Purpose - This test verifies that rain, fog, dew or melted snow does not enter the active circuit of the module, as it will lead to corrosion and power degradation of module)

Test Conditions –

Voltage – 1000 Volts, Time -2 minutes

Pass Criteria – Minimum Insulation Resistance should be 24.54 Mega-Ohms

Wet Leakage Test Setup

5L. Module Flash testing

Purpose - Modules as per the Flash Test data are segregated as per defined Wattage bins

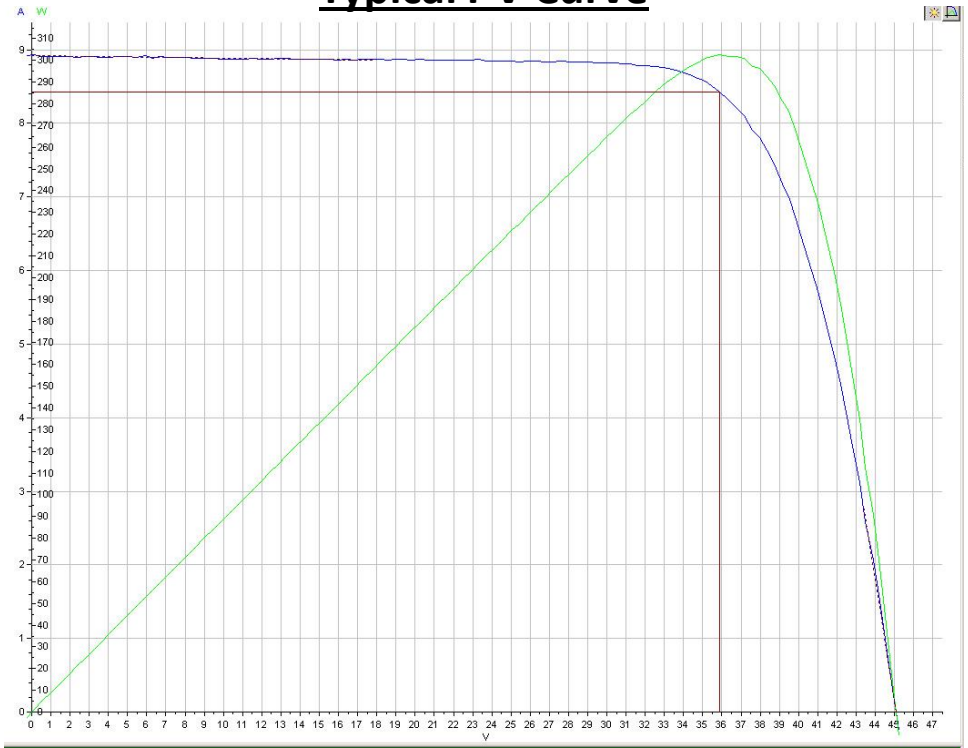
MODULE TESTER PARTS:-

➢**Flash Generator** gives power to Xenon lamp and **AM 1.5 Filter.** IV Curve is generated using Electronic load. It is recommended to use (a) 200 to 400 points / Flash (b) Flash time =3 to 10 msecs

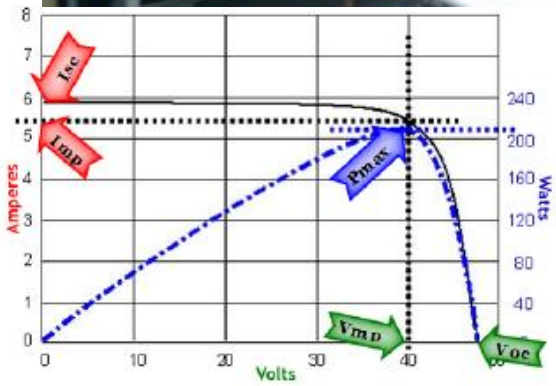
➢**IR sensor** to give the actual temperature of the module

➢**Monitor cell** (a) Adjust Irradiance to 1000 W/m2 by giving feedback to the Flash generator (b) Ambient temperature

Typical I-V Curve



Flash Tester



Irrad =	1.000 kW/m²
Temp =	24.2 °C
Avg.Ir. =	1.009 kW/m²
Dev.Ir. =	0.006 kW/m²
Isc =	8.92 A
Voc =	45.108 V
EffC =	17.3 %
EffM =	15.6 %
FF =	75.2 %
MPP =	302.614 W
V@mpp =	35.904 V
I@mpp =	8.43 A
Rser =	0.610 Ohm
Rsht =	324.55 Ohm

5M. FQA & EL Testing – QC12

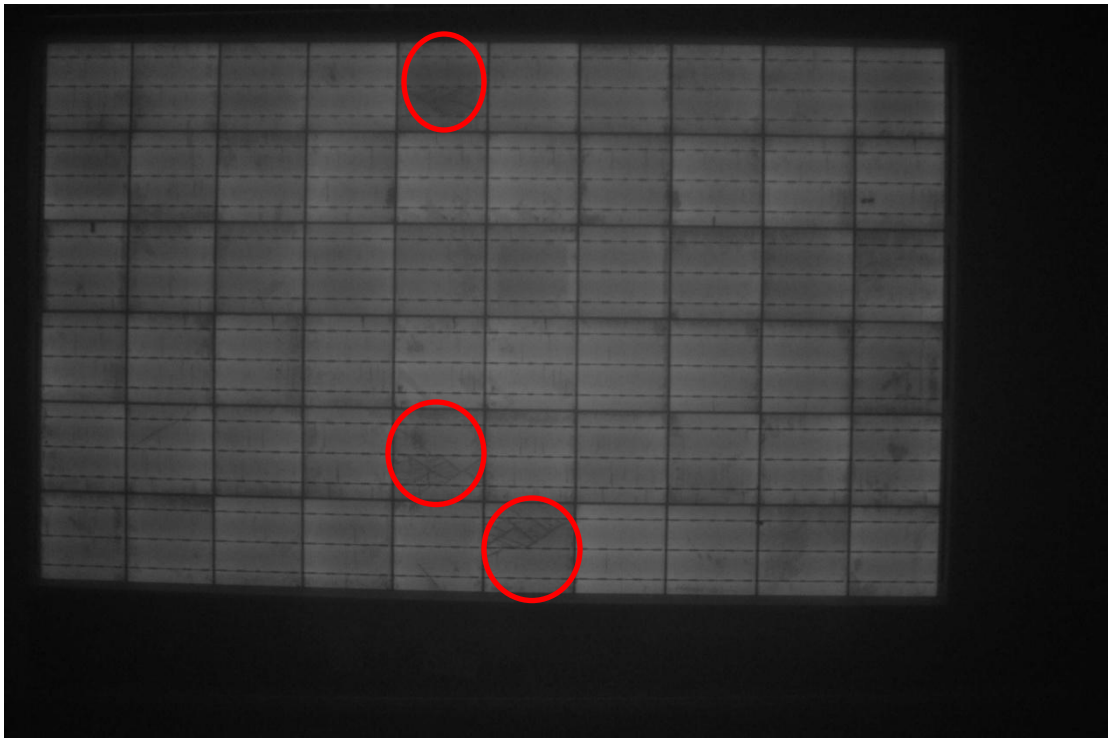
Purpose – Check the visual defects and Cracks / Black cells in modules

QC12 Points:-

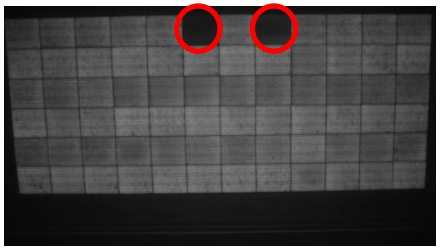
- After Flash the modules are taken for Final Quality Assurance / EL Test for identification of any defects / cracks in the cells

EL Defects in the Module

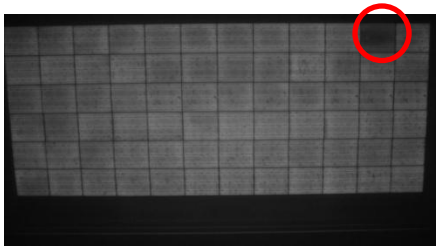
Defect1



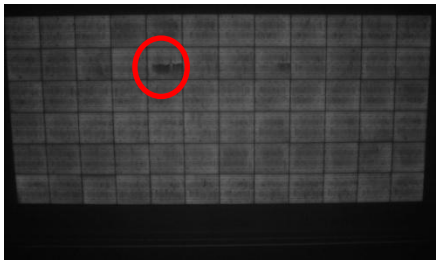
Defect2



Defect3



Defect4



6. MODULE RELIABILITY TESTS

6A.Thermal Cycling Test

Purpose of the Test – It checks the ability of the module to withstand the thermal mismatch, fatigue and other stresses caused by repeated changes in temperatures of the ambient

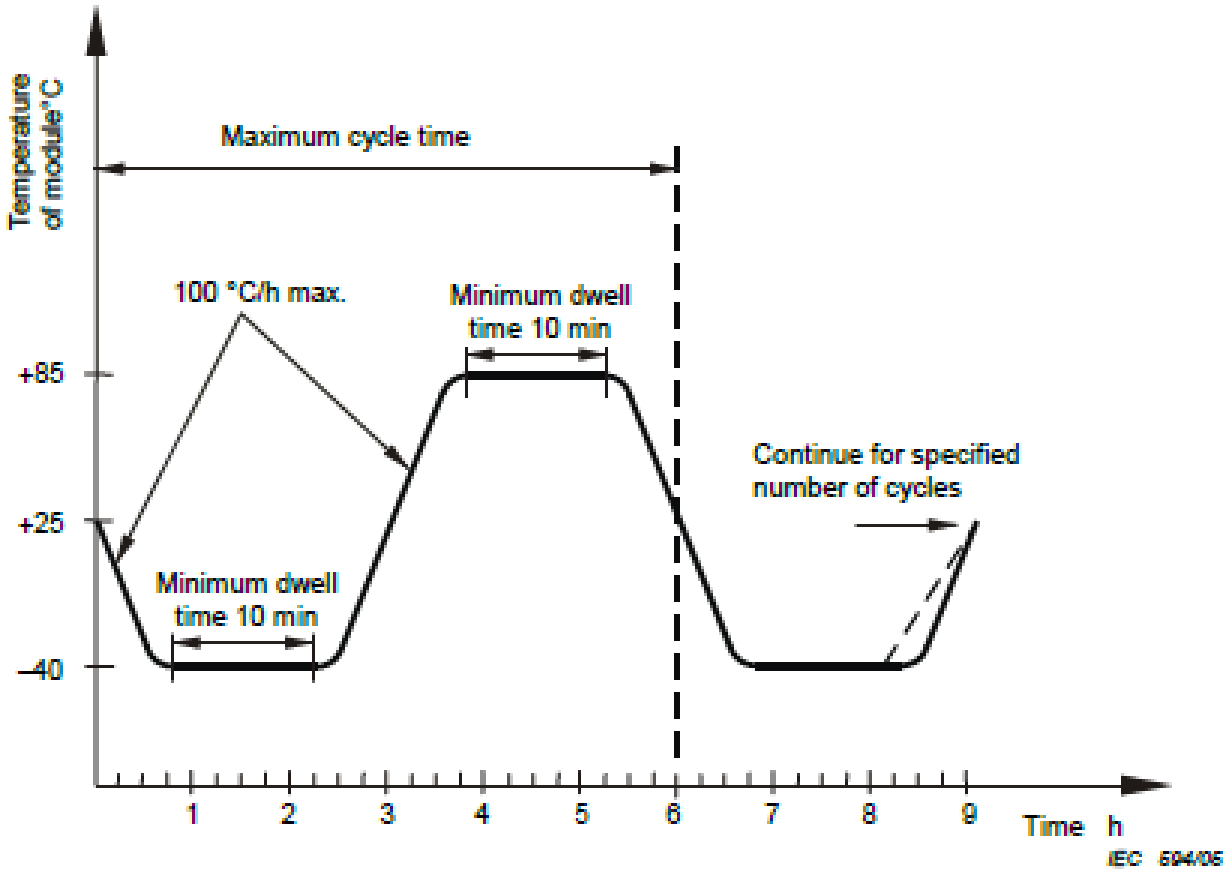
Test Conditions:-

1. TC50, No current is flowed
2. TC200, Current flowed = Peak power current

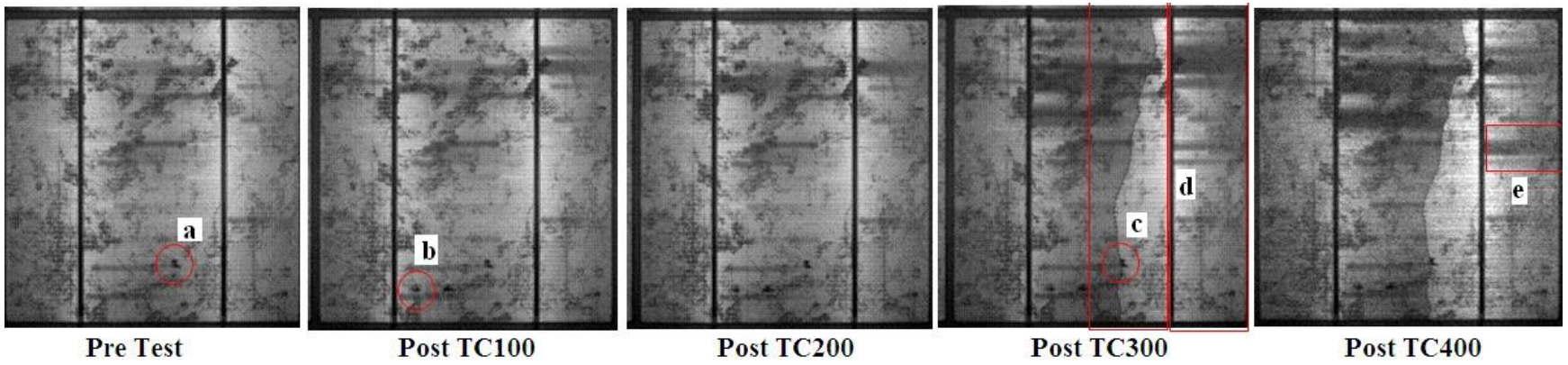
Note – One cycle details given below

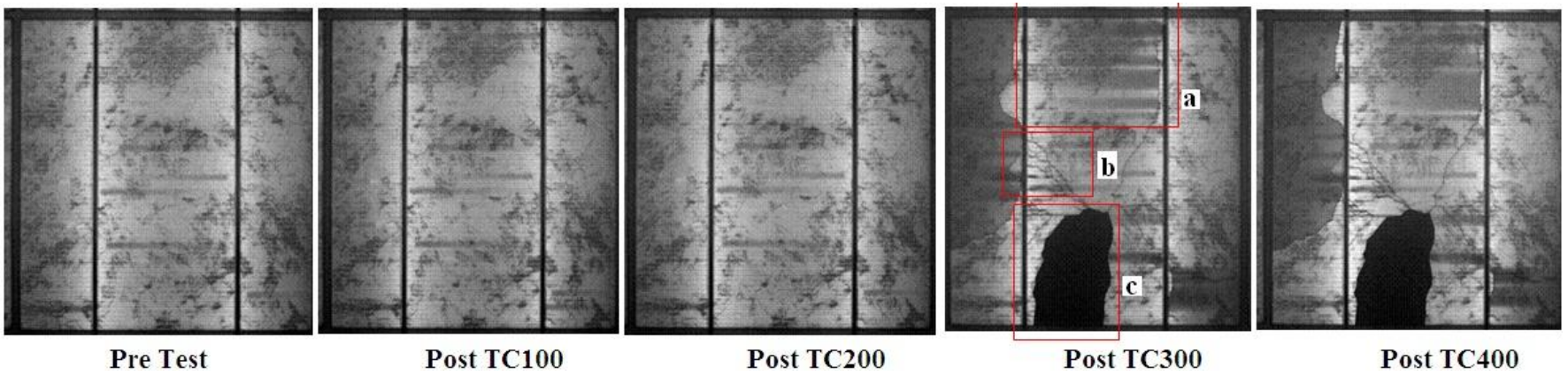
Requirement –

1. No interruption of current during the test
2. No major visual defects after the completion of the test
3. Degradation of output power should be less than 5% of the value measured before the test
4. Insulation resistance should meet the same requirement as before the test



6A. Thermal Cycling Test e.g. One Cell laminate





Cracks and finger defects developed during thermal cycling test contributed to power reduction

6B. Damp Heat Test

Purpose of the Test – It determines the ability of the module to with stand the long term effects of penetration of humidity

Requirement –

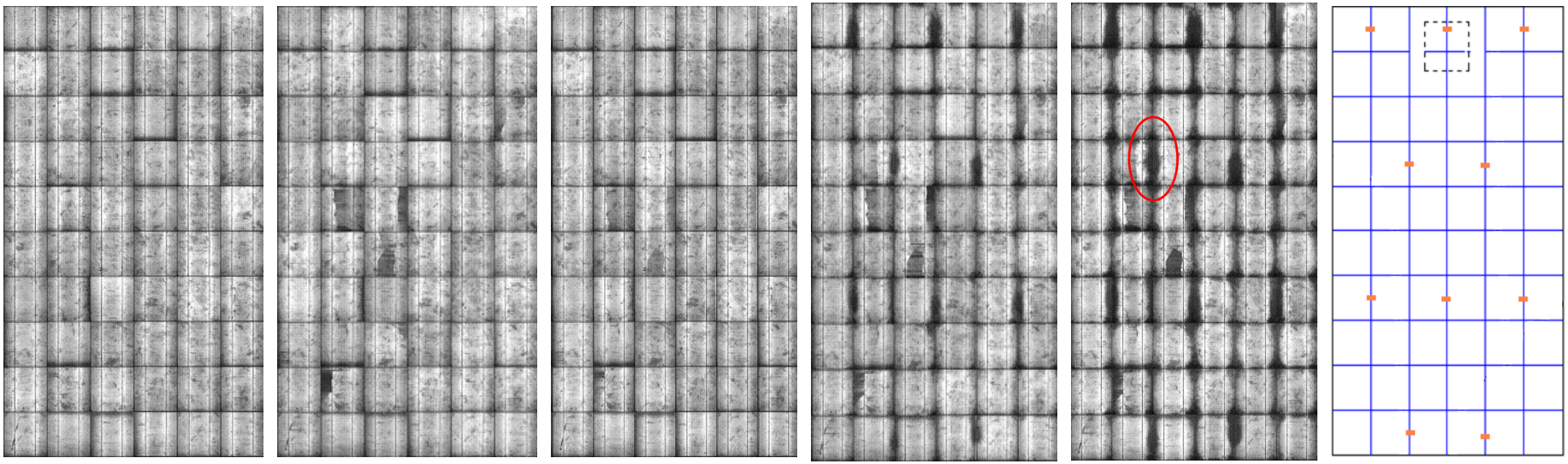
1. No major visual defects after the completion of the test
2. Degradation of output power should be less than 5% of the value measured before the test
3. Insulation resistance and wet leakage current test should meet the same requirement as before the test

TEST CONDITIONS

Test temperature:	85 °C ± 2 °C
Relative humidity:	85 % ± 5 %
Test duration:	1 000 h.

6B. Damp Heat Test (Long Term studies done for Damp Heat 3100 Hours

EL Inspection



Pre Test | Damp Heat 1000 | Damp Heat 2000 | Damp Heat 3000 | Damp Heat 3100

Moisture ingress through cracked back-sheet degraded silver contacts or back aluminum.

6C. Potential Induced Degradation

Purpose of the Test – With growing PV systems and corresponding higher system voltages, Potential Induced Degradation (PID) effect is the next challenge we might be facing in future. This test confirms that the Module is PID resistant

Requirement –

1. No major visual defects after the completion of the test
2. Degradation of output power should be less than 5% of the value measured before the test
3. El image should not start showing

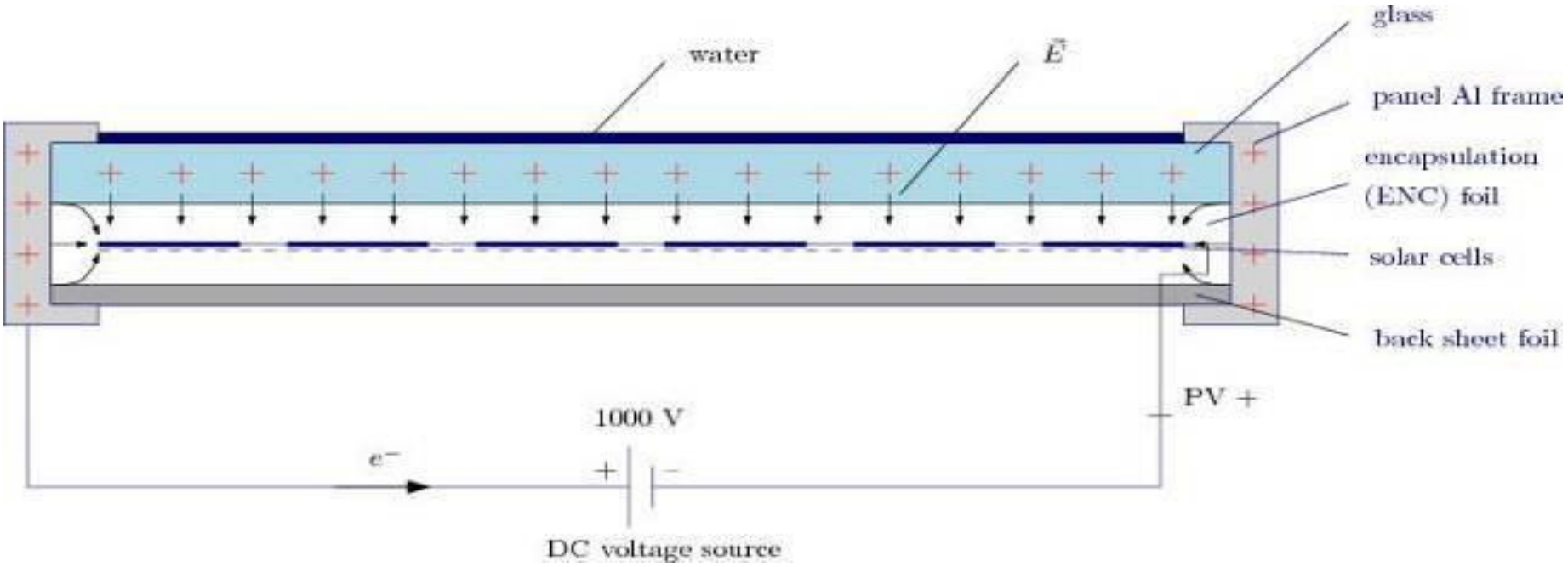
Test Conditions :-

Temperature – 65^0C

Relative Humidity – 85%

Voltage = 1000Volts

Time = 150 Hours



6C. Potential Induced Degradation

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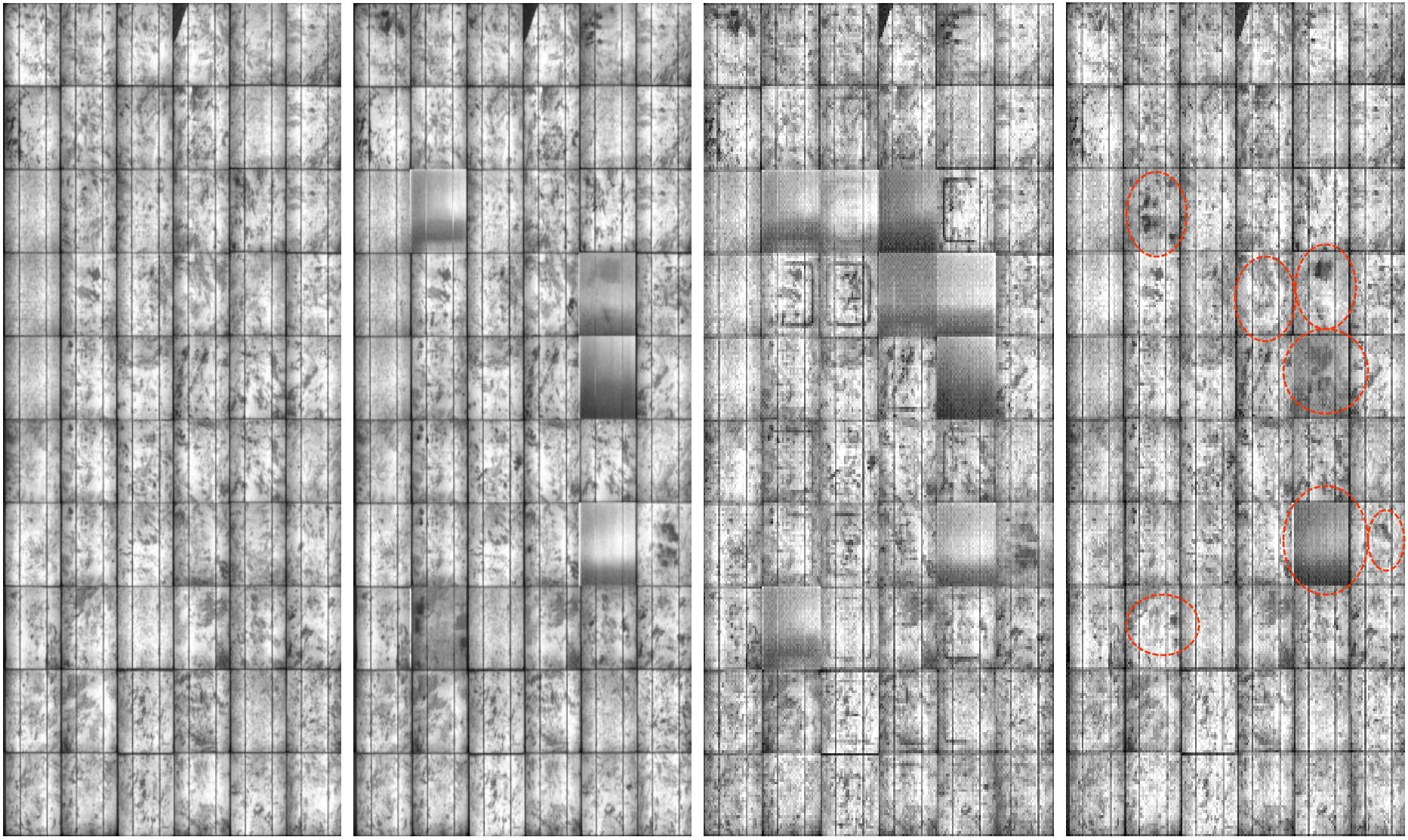
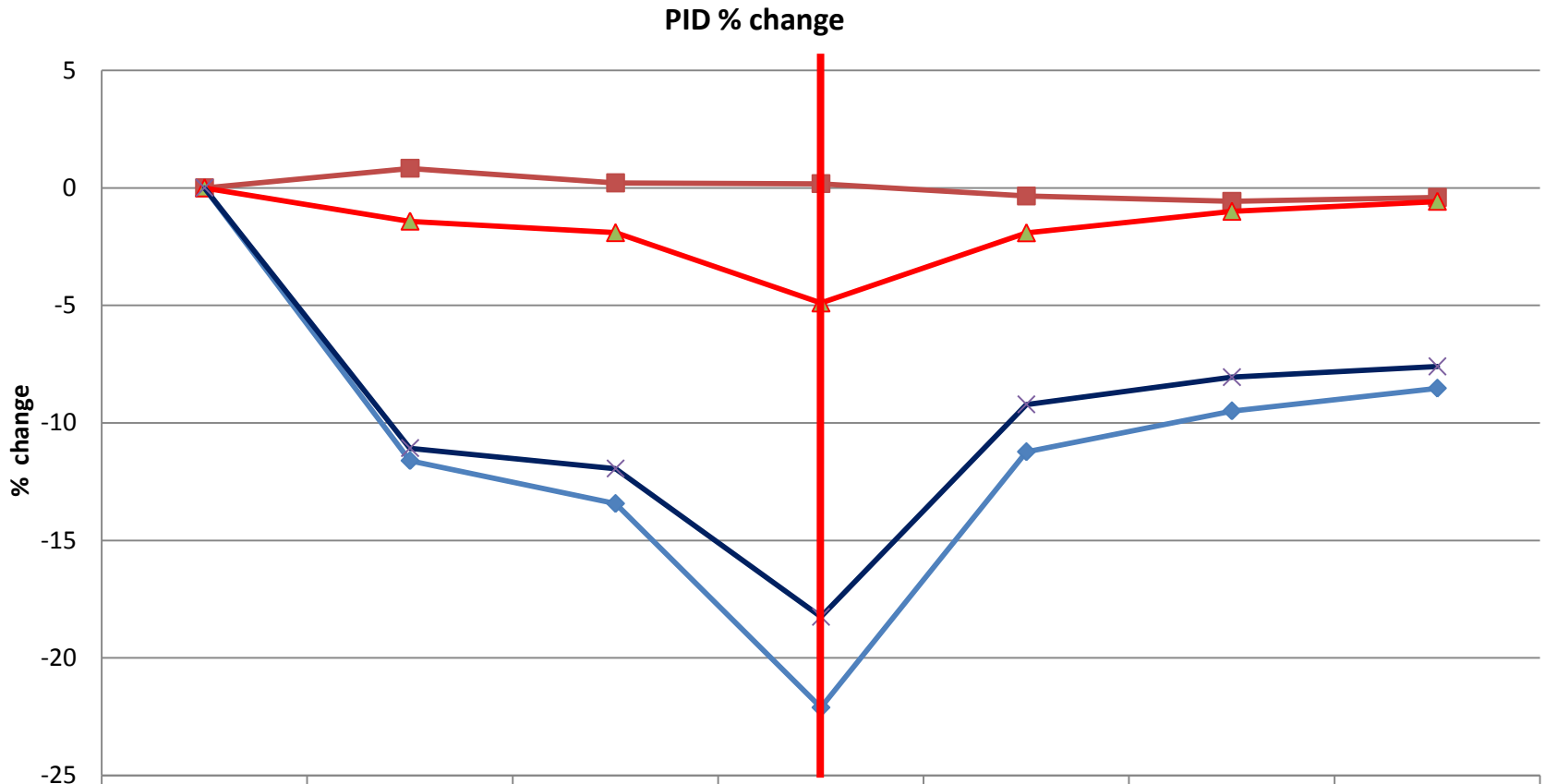
Initial | After 96 hours | After 150 hours | After 150 hrs recovery



PID Conditions | Recovery

6C. Potential Induced Degradation



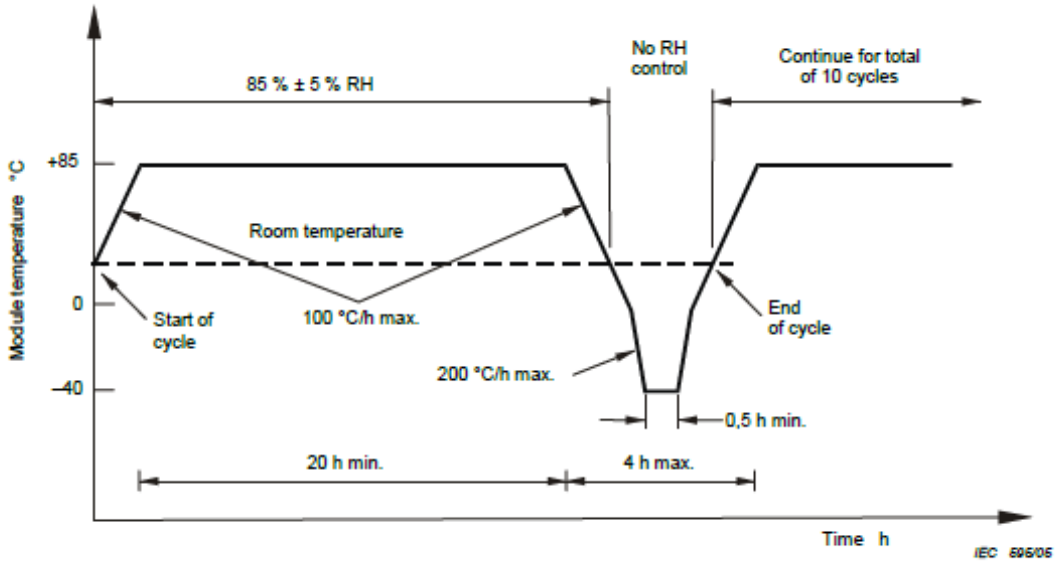
	0 hrs	72 hrs	96 hrs	150 hrs	50 hrs	100 hrs	150 hrs
Mpp	0	-11.61	-13.44	-22.11	-11.23	-9.49	-8.53
Isc	0	0.83	0.21	0.18	-0.34	-0.57	-0.40
Voc	0	-1.42	-1.91	-4.90	-1.91	-1.00	-0.57
FF	0	-11.08	-11.94	-18.25	-9.21	-8.05	-7.60

6D. Humidity Freeze

Purpose :- This test determines the ability of the module to withstand the effects of the high temperatures and humidity followed by subzero temperatures.
Note :- This is not a thermal shock test

Test Conditions:-
10 Cycles, +85^{0}C to 85% RH to -40^{0}C

Requirements:-
1. No evidence of visual defects
2. Degradation of power should not be > 5%
3. Insulation Resistance should meet the same requirements as before starting the measurements



6E. Mechanical load test

Purpose :- The test determines the ability of the module to withstand wind, snow, static or ice loads

Requirements:-

1. No evidence of visual defects
2. Degradation of power should not be > 5%
3. Insulation Resistance should meet the same requirements as before starting the measurements
4. No intermittent open circuit fault detected during the test

Test Conditions:-

1. Front Surface :- Apply load corresponding to 2400 Pa spread uniformly the entire surface of the module. Hold it for 1 hrs.
2. Back surface :- Apply load corresponding to 2400 Pa spread uniformly the entire surface of the module. Hold it for 1 hrs.
3. Repeat the point no 1, 2 for 3 cycles

Note:- 2400 Pa = Wind pressure of 130 km/hr (± 800 Pa) with safety factor of 3 for gusty winds For heavy snow and ice areas, the last cycle of the test is increased from 2400 to 5400 Pa

Electrical continuity of the module is monitored continuously during the test.

6F. Bypass Diode Test

Purpose :- To access the thermal design and long term reliability of Bypass diode

Requirements:-
1. No evidence of visual defects
2. Measure the forward and Reverse characteristics of Bypass diode before and after the testing. Deviation should be < 5%

Test Conditions:-
1. One Hour @ Isc and Temperature = 75^0C
2. One Hour @ 1.25 times Isc and Temperature = 75^0C

6G. Hail test

Purpose :- To ensure that the module is capable of withstanding the impact of Hailstorms.

Requirements:-
1. No visual defects of visual defects
2. Power degrdation should be < 5%
3. Insulation Resistance should meet the same requirements as before starting the measurements

Test Conditions:-
23 mm diameter ice ball @ 23 m/s directed at 11 impact locations of the module

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THANK YOU

FOR YOUR KIND ATTENTION