2013 NREL PV Module Reliability Workshop
@ Marriott Denver West

2013.02.26

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Delamination failures in long-term field-aged PV modules from point of view of encapsulant

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Outline

1. Background

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✓There have been some failure modes of PV modules concerning encapsulant. ex) discoloration, delamination, corrosion, etc…

✓We have not known clearly correlation between these failure modes and encapsulant yet. But many people hears a “rumor ” that degradation of EVA encapsulant is the root of all evil, especially, for over-stressed accelerated tests. We believe that most of rumors have not been based on scientific evidence.

✓To understand properly and quantitatively these failures is necessary for prediction of lifetime of a PV module or a PV component and improvements of their performances.

2. Mitsui's approach

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✓We have attempted to figure out correlation between power reduction of a PV module and degradation of an EVA encapsulant using long-term field aged PV modules and then disclose these information as much as possible.

✓We, Mitsui Chemicals groups, have 30-year-old history for commercialization of EVA encapsulant sheet. Furthermore, we have been manufacturing old grade EVA sheets since 1992, thus we can compare performances of field aged EVA with initial one.

✓First of all, we have focused on understanding properly and quantitatively what happened in a long term field aged PV modules for each failure mode from point of view of encapsulant.

2. Mitsui's approach

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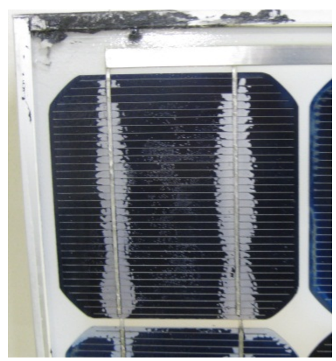
Failure modes related to encapsulant

- Discoloration
- Corrosion
- Delamination

Photos of typical examples for each failure mode

We have already proposed degradation prediction by appropriate UV irradiation.

Ongoing.
We already reported very low amount of free acetic acid in 17y field aged modules, as compared to over-stressed DH test results.



Report today.

3. Analyses results –delamination failure–

Our analyses flow

Aged PV module

Module level

- Appearance (eye, EL, thermo-view)
- Performance check (IV curve, insulation)

Destructive analyses

- Appearance
- Adhesion strength (under development)
- Analysis for encapsulant
  - Mechanical (DMA)
  - Electrical (resistivity)
  - Optical (transmission)
  - Chemical (acetic acid, etc)
- Analysis for cell / interconnectors
- Analysis for back-sheet

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3.1 Appearance

We have 17y field aged PV modules with “typical” delamination failure.

(photo)

(EL image)

(photo)

(EL image)

Manufacturer A
Module “A”

Manufacturer B
Module “B”

3.1 Appearance

Features of these PV modules :

1. Delamination is mainly observed in the vicinity of interconnectors on cells.
2. Delamination is observed at the outer portions in a plane of the PV module.
3. We can not see a clear correlation between delamination failure and dark portions in EL images.

3.2 Electrical performance

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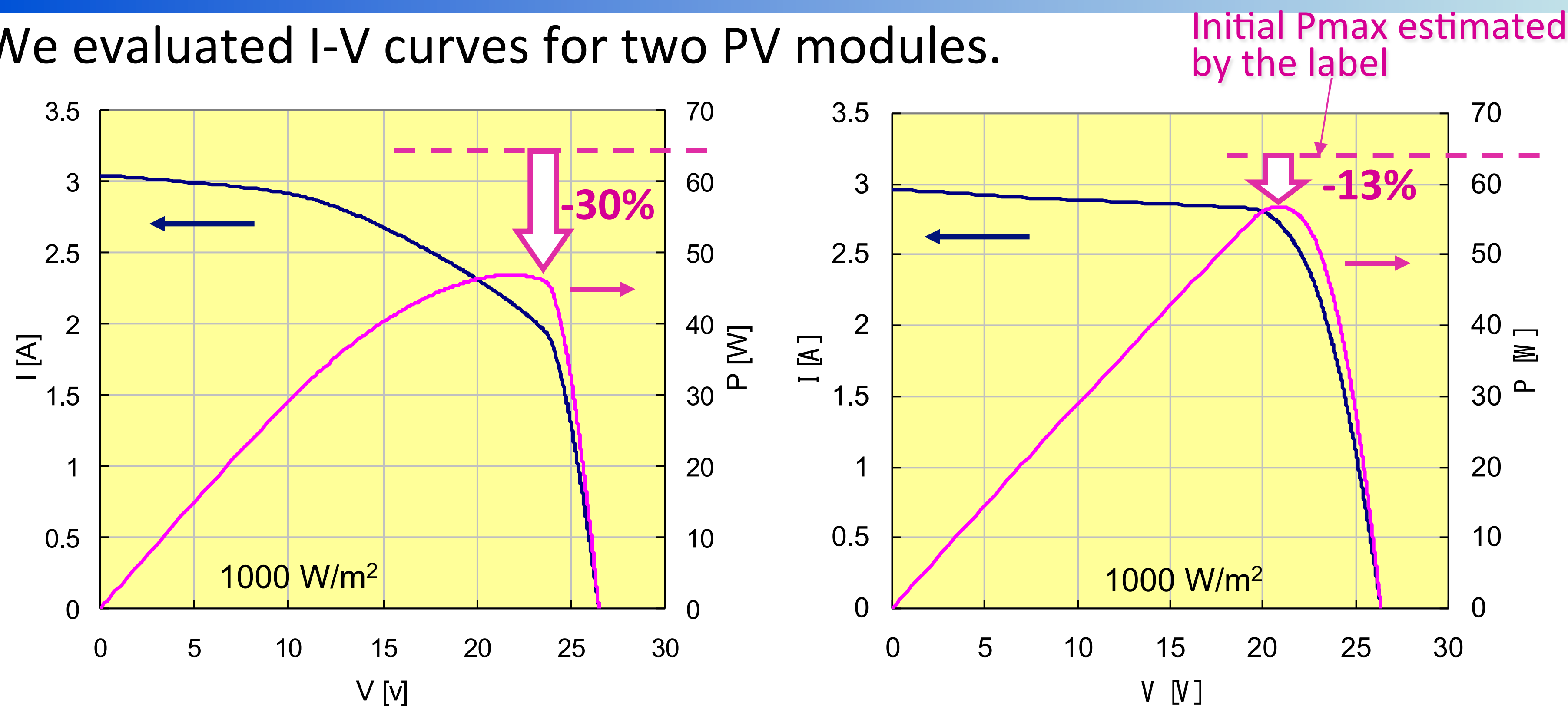
We evaluated I-V curves for two PV modules.



Module "A"

Decreases in Isc by 13% and FF by 17%

Module "B"

Decrease in Isc by 14%

✓Decrease in Isc mainly depends on discoloration of EVA and delamination.

3.2 Electrical performance –cell level–

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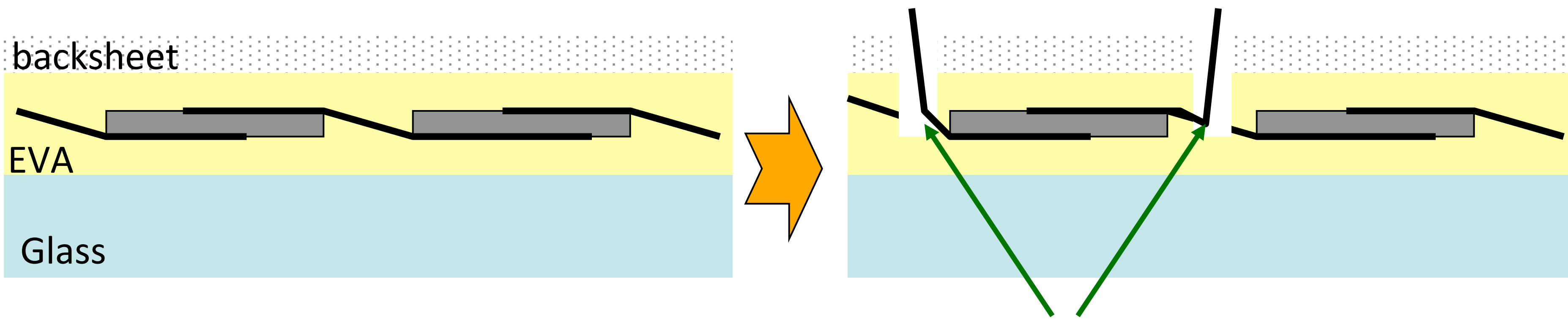
We attempted to evaluate an I-V curve for each cell in Module "A" in order to find out a correlation between delamination and power reduction.



1. Cut these ribbons (isolation)
2. Connect probes to cut ribbons
3. Put a whole module on a solar simulator in order to obtain I-V curve for each cell.

3.2 Electrical performance –cell level–

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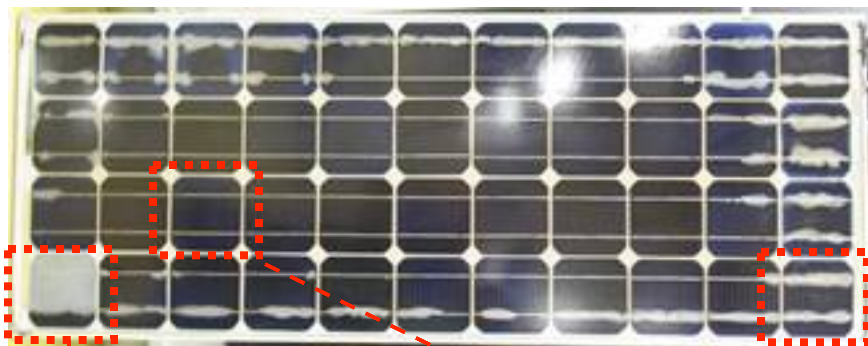
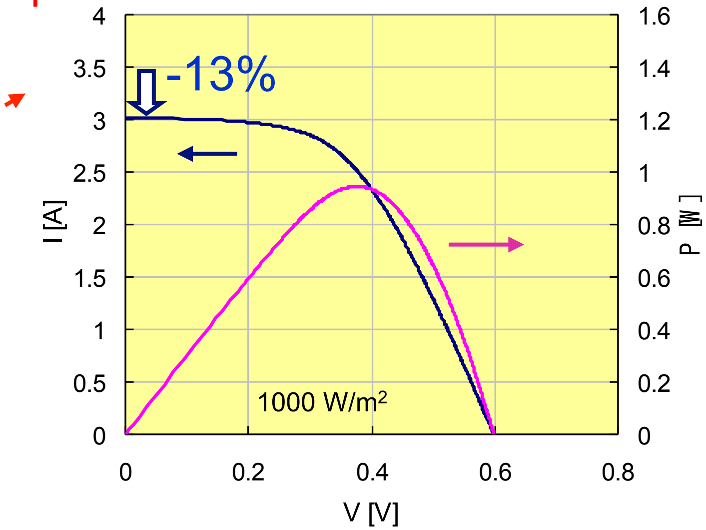
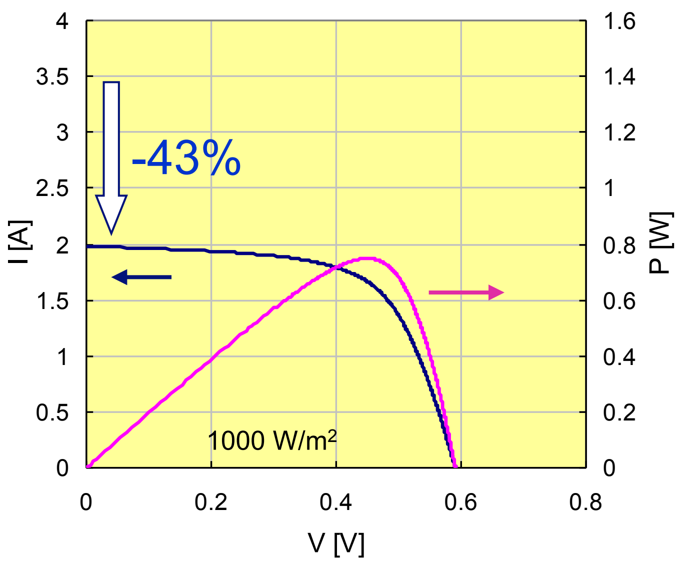


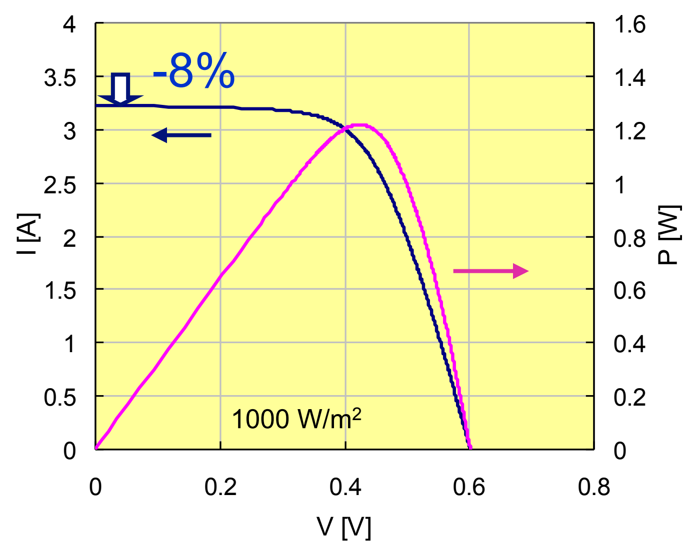
partial delamination



Large delamination



No delamination



3.2 Electrical performance

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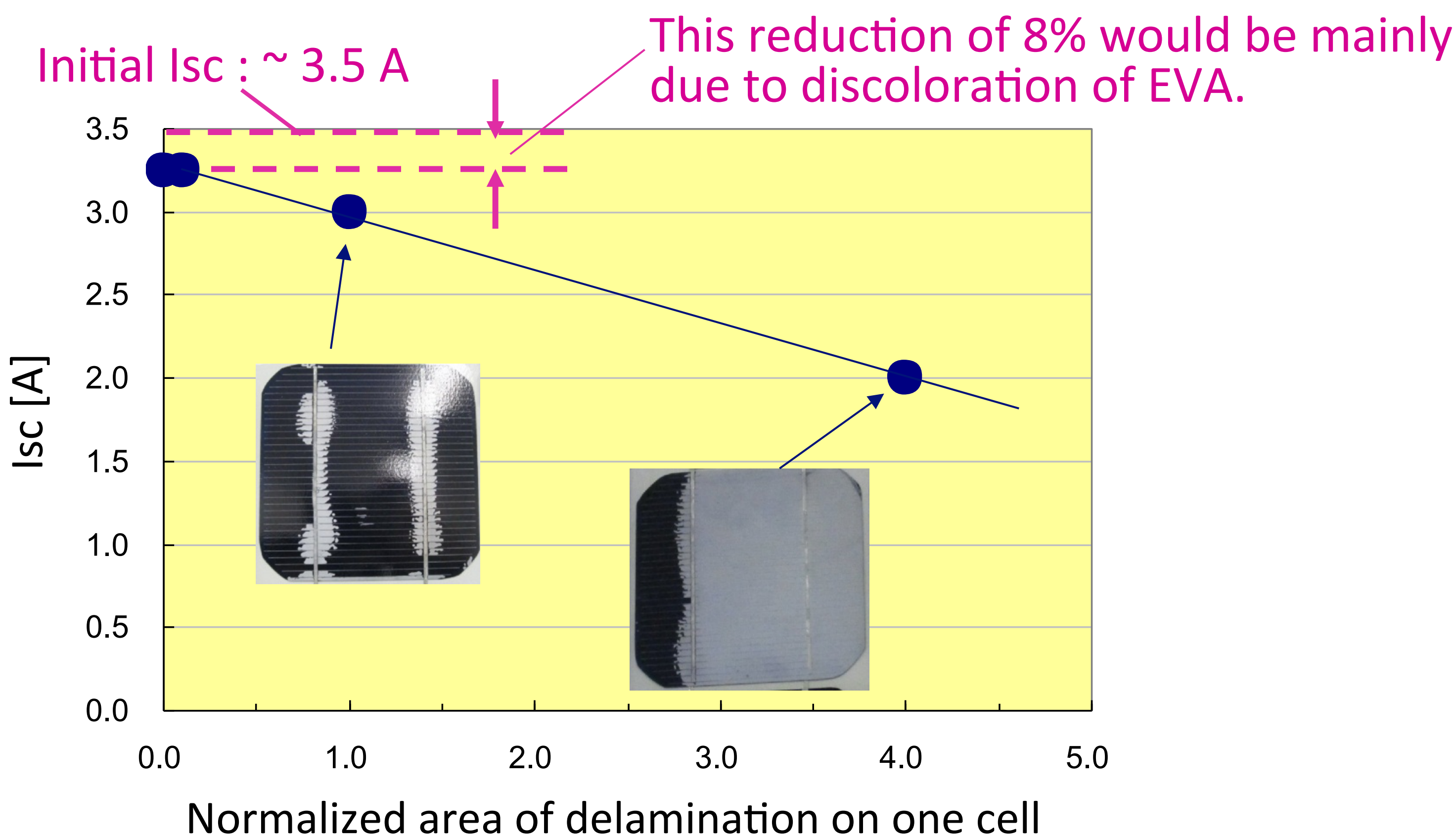
✓Delamination area was estimated roughly by image processing for each cell. We estimated Isc change as a function of delamination area.



Delamination leads to decrease in Isc.

Outline

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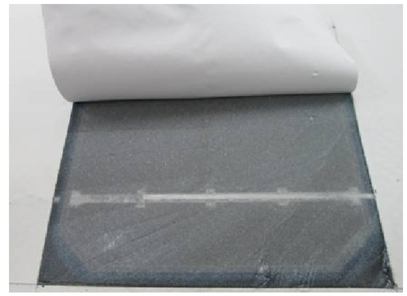
1. Background
2. Mitsui's approach
3. Analyses results -delamination failure-
   - 3.1 Appearance
   - 3.2 Electrical performance
   - 3.3 Destructive analyses
     - 3.3.1 Interface for delamination
     - 3.3.2 Encapsulant
   - 3.4 Other failures
4. Summary

3.3 Destructive analyses

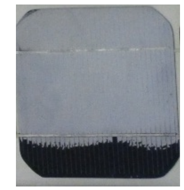
Sampling procedures

1. Separate backsheet from a module

   Sampling EVA, backsheet

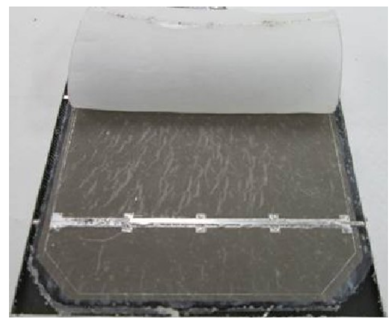


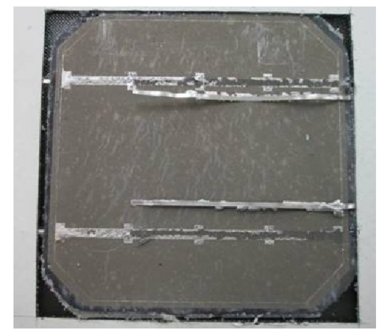
Large delamination portion



2. Separate an EVA sheet backside of a cell
   Detach ribbons from a cell
   (if necessary)

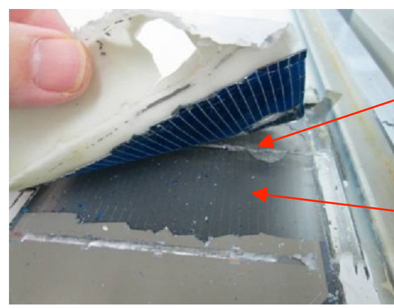
   Sampling an electrode, a ribbon





3. Separate a cell from EVA/Glass

   Sampling EVA,
   electrodes / solder / AR coat of a cell

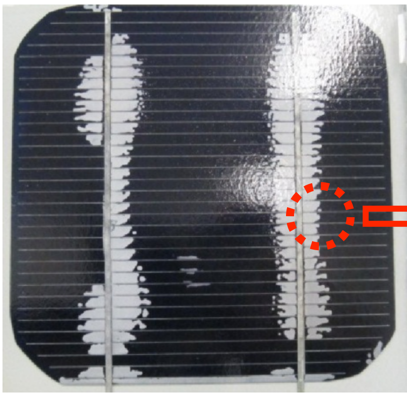


ribbon

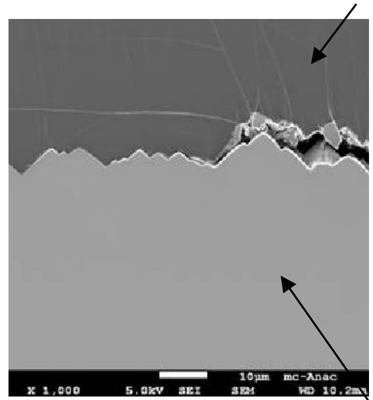
Delaminated portion

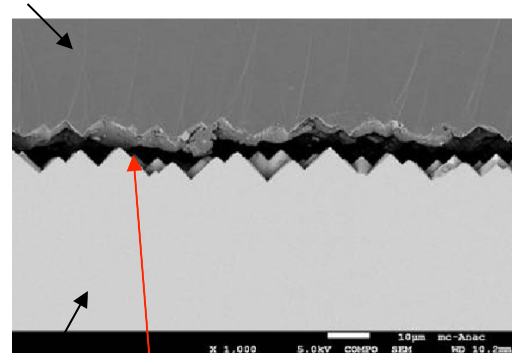
4. Separate an EVA sheet from a Glass

3.3.1 Interface for delamination



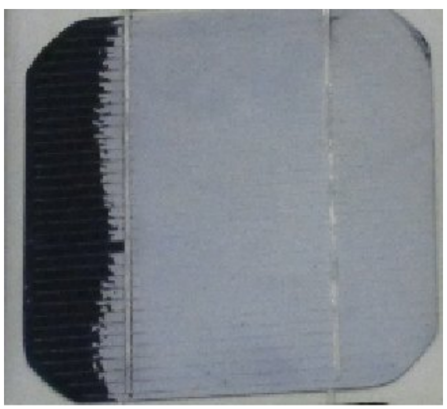
EVA



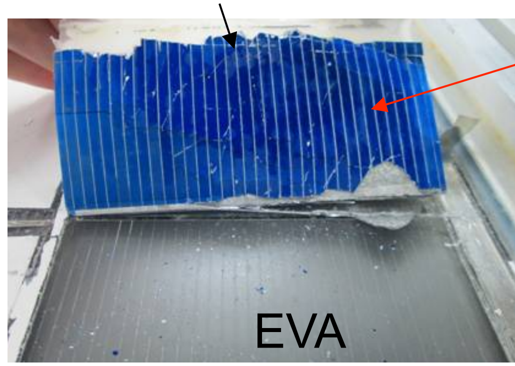


cell

Cross-sectional view by SEM



cell



We confirmed that the surface layer of the cell was **TiOx** deposited as an AR-coating of the cell using XPS measurement.

Delamination was observed at the interface between EVA and TiOx.

3.3.1 Interface for delamination

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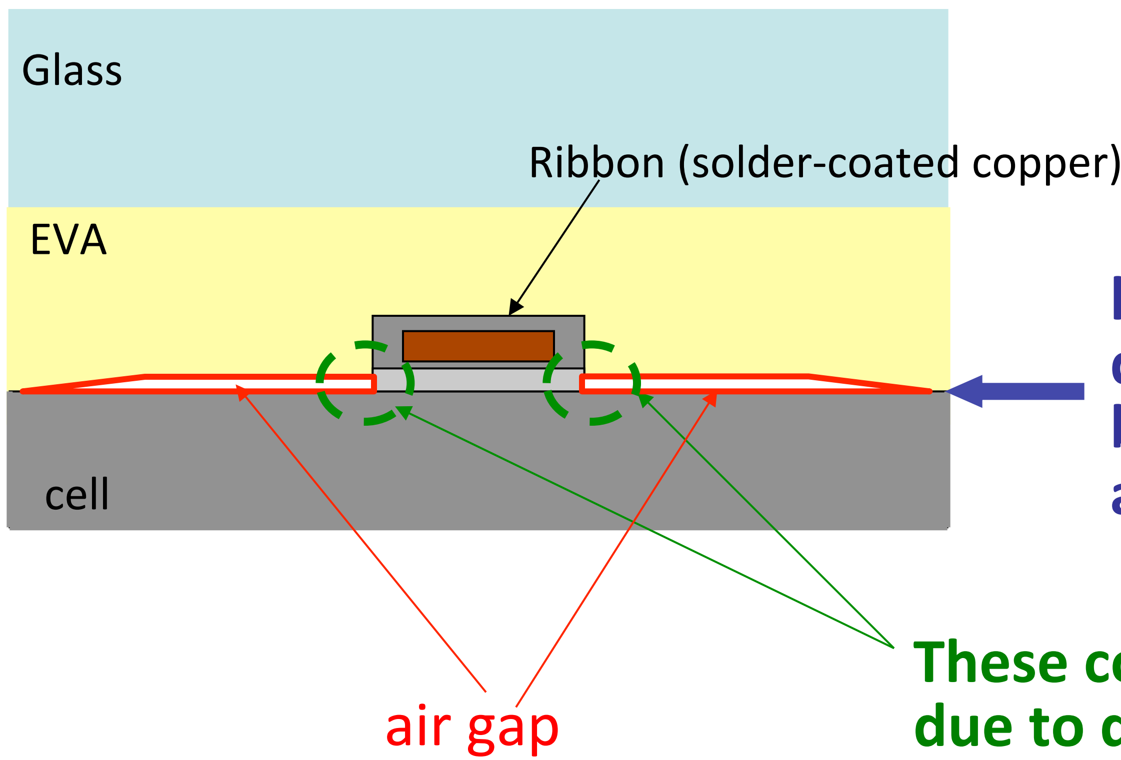
Schematic of cross-section view : upper side of a module



lower chemical bonding during field ageing, because of use of TiOx as an AR coating

These corners have high strain due to difference in CTE among ribbon, cell (Si) and EVA.

3.3.1 Interface for delamination

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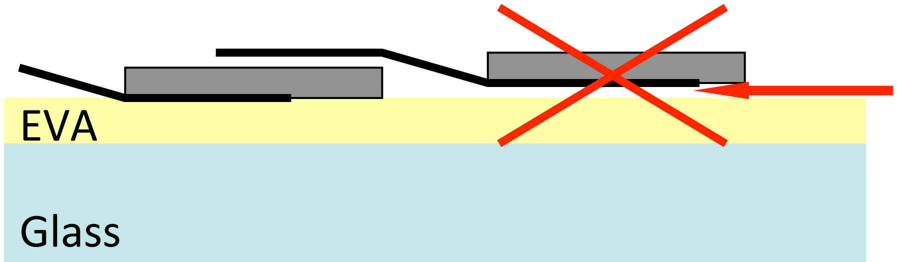
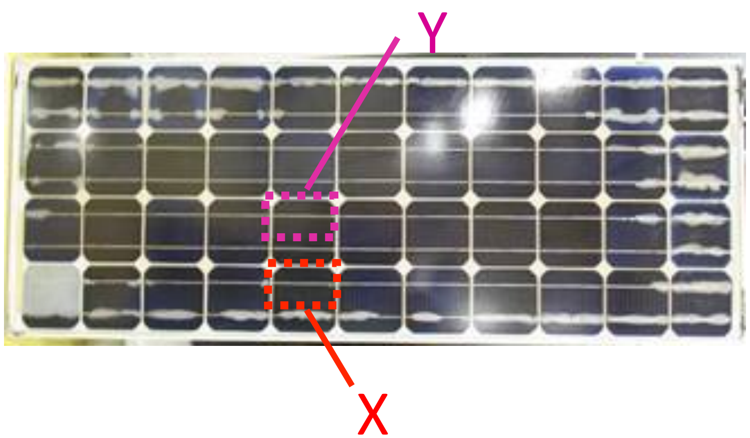


When we attempted to separate a cell from EVA/Glass, a cell broke into bits due to brittleness of a cell.



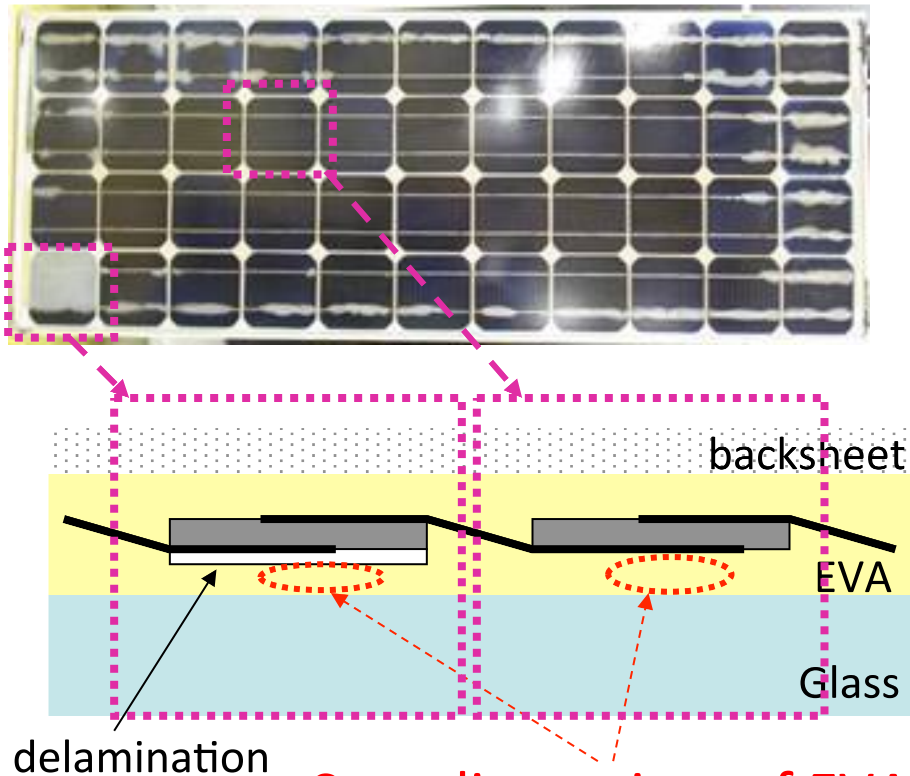
✓To separate a cell from glass side EVA at the **X** is **easier** than that at the **Y**.

✓The stress at the **X** is **higher** than that at the **Y**, because the **X** is **outer** position as compared to the **Y** in a plane of the PV module.

✓We speculate that delamination is induced by weakening chemical adhesion (led by use of TiOx) and high strain at the interface.

✓We should confirm change of performances of EVA encapsulant.

3.3.2 Encapsulant -EVA-



Analysis items

Performance	Delamination Portion (Glass side)	No delamination portion (Glass side)
Mechanical DMA (Dynamic Mechanical Analysis)		
Electrical Volume resistivity		
Optical Transmission		
Chemical Amount of free acetic acid		

Mechanical : DMA

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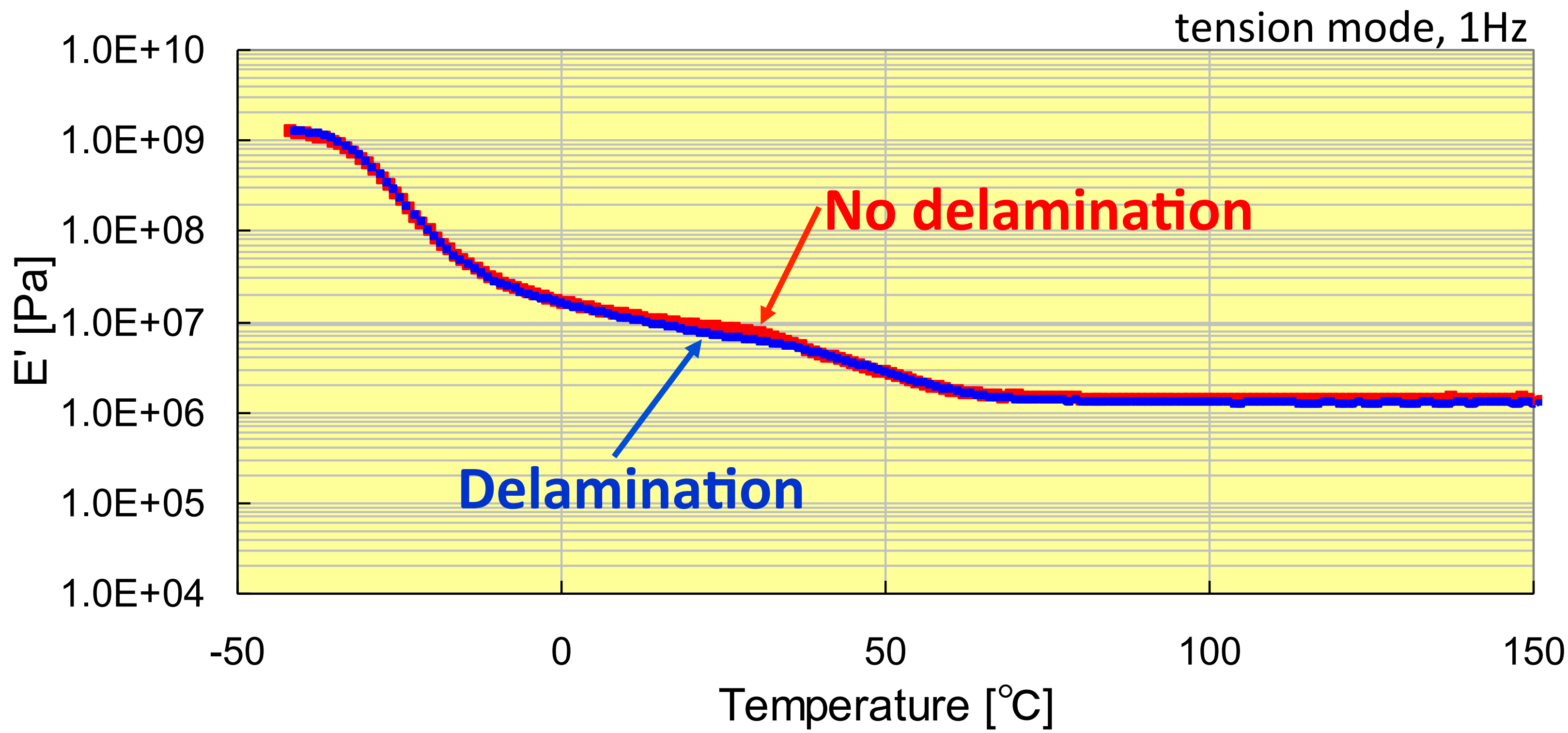
We have obtained viscoelastic curves with a rheometer.



✓There was no difference between E' for delamination and non delamination.

✓We can not see mechanical degradation of both these EVA samples.

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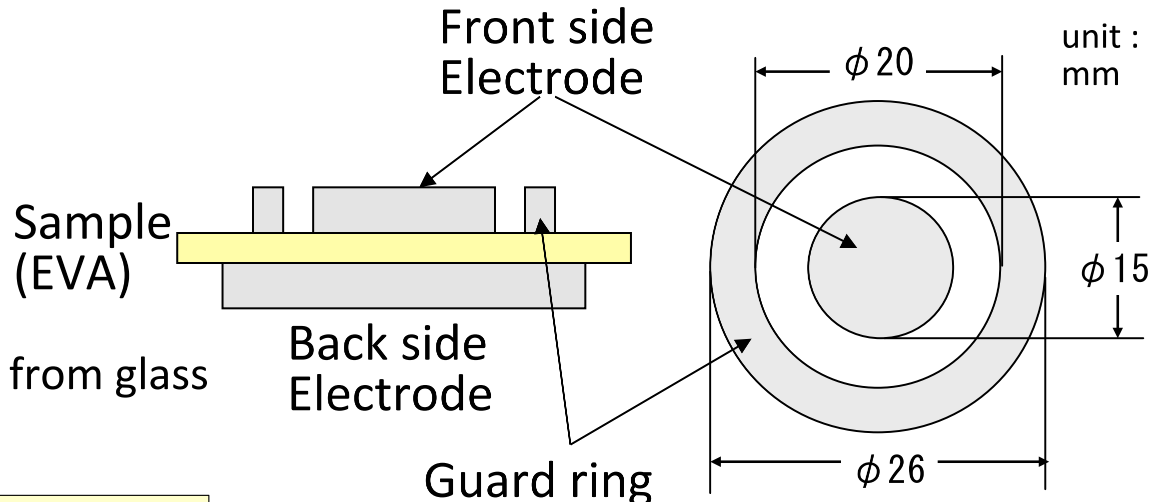
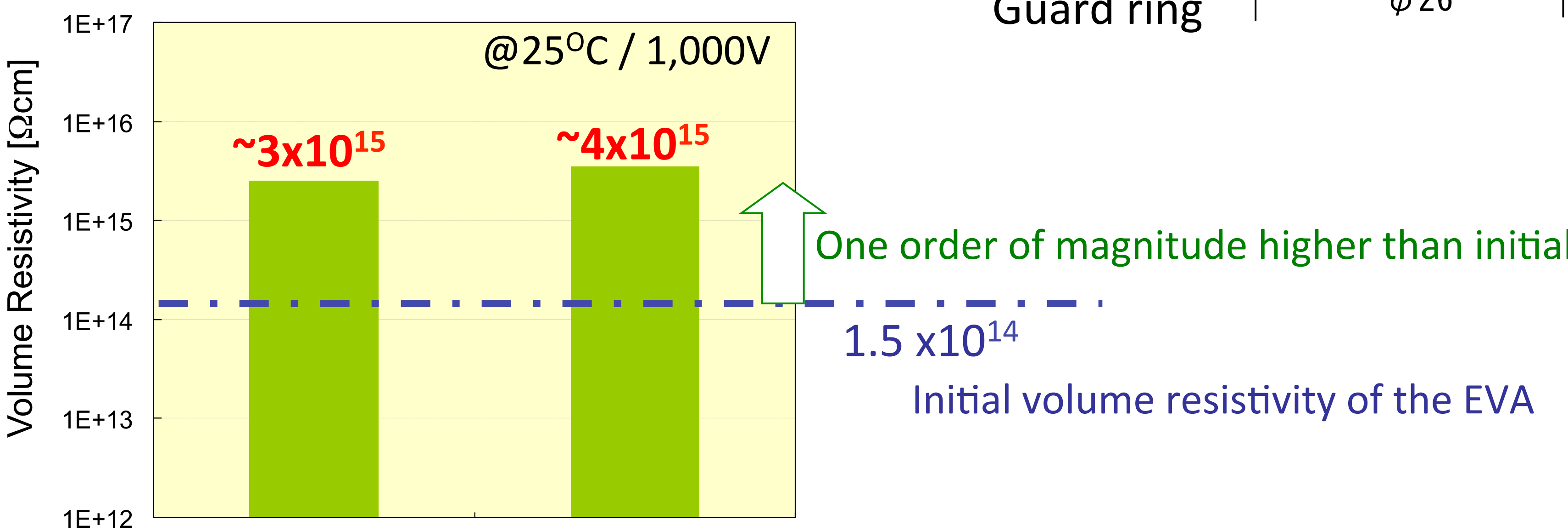
Electrical : Volume resistivity

Photo of EVA sample separated from glass for <u>no delamination portion</u>.

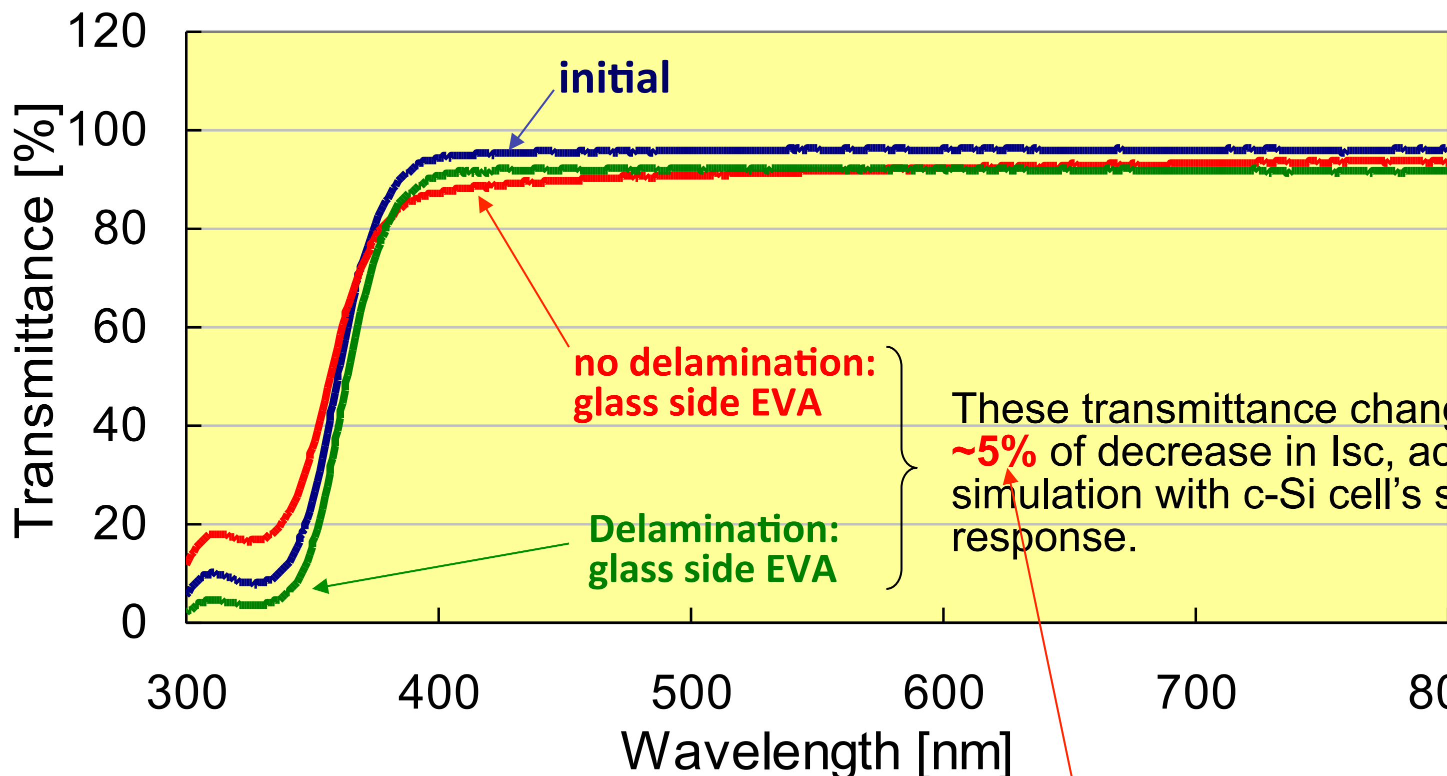




✓**There was no difference between volume resistivities of EVA for delamination and non delamination portions.**

Optical : Transmittance spectrum

We have observed transmittance spectra of glass side EVA for delamination and no delamination portions and confirmed high transmission over 90%.



These transmittance changes lead to **~5%** of decrease in Isc, according to our simulation with c-Si cell's spectrum response.

Sample thickness was **~100μm** and we smoothed surfaces preventing from light scattering.

~5% would be underestimated value because of thinner sample than actual encapsulant layer.
More evaluation is necessary.

Chemical : free acetic acid

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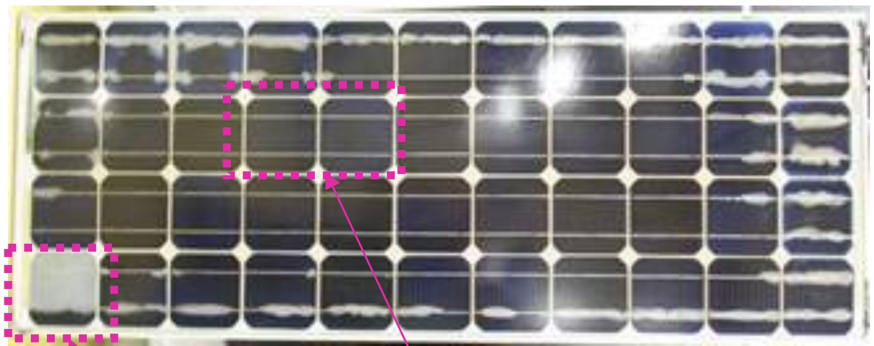

70~400μg/g

70~400μg/g

We have estimated amount of free acetic acid in glass side EVA at delamination and no delamination portions.

✓We observed similar amount of free acetic acid to that for other aged PV modules we already reported.

✓There was no difference between the amounts for delamination and no delamination portions

3.3.2 Encapsulant -Summary-

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Performance	Delamination Portion (Glass side)	No delamination portion (Glass side)
Mechanical DMA (Dynamic Mechanical Analysis) E'	3×10^6 Pa @25°C 1×10^6 Pa @100°C	3×10^6 Pa @25°C 1×10^6 Pa @100°C
Electrical Volume resistivity	3×10^{15} Ωcm	4×10^{15} Ωcm
Optical Total light transmittance	>90 %	>90 %
Chemical Amount of free acetic acid	70~400 μg/g	70~400 μg/g

There were no differences between any data for glass side EVA for delamination and no delamination portions

Outline

3.4 Other failures -Corrosion-

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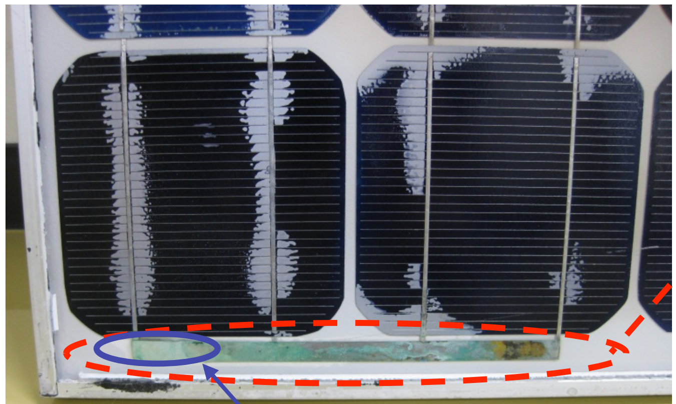
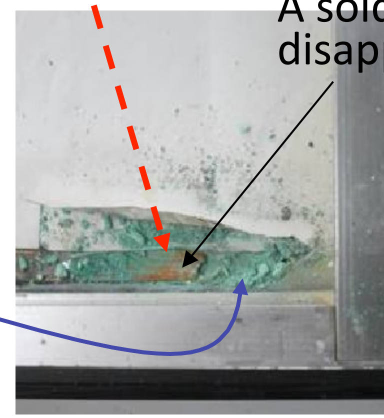
closeup picture



Patina

Severe degradation of copper

A solder layer disappeared.



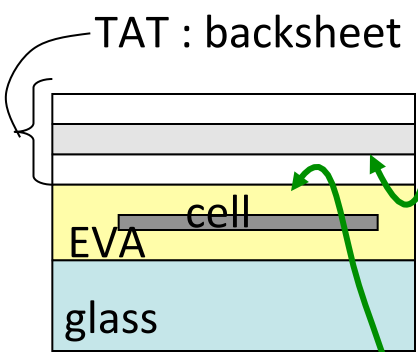
A part of Copper ribbon disappeared.
= No electrical conduction

Backsheet/EVA were cut at the bus-bar portion.
We observed the corroded bus-bar.

EL image

✓Adhesion strength among inner layers of the backsheet "TAT" was extremely low.

3.4 Other failures -Corrosion-



Inner Al layer of backsheet
(EVA side)

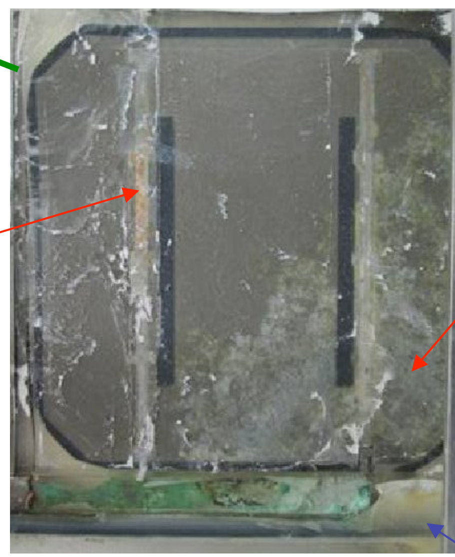
Backside of the module at corrosion portion

water stain
like an arc

Al(OH)x, AlxOy

evidence of water "liquid" ingress

Corner of Al frame side



Backside of the cell

Severe corrosion of Al layer

We can see clearly "copper".
(= coated solder disappeared.)

We think that this corrosion corresponds to to dark portion of the EL image

Corner of Al frame side

4. Summary

✓We analyzed long term field aged PV modules with typical delamination failures.

✓Delamination on cells led to decrease in Isc.

✓There were no differences between performances of EVA encapsulant of delamination and no delamination portions.

✓We consider that delamination is induced due to weakening chemical adhesion (led by use of TiOx) and high strain at the interface.

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Future works

✓We also found corrosion failure in the PV module “A”.

✓Appearance indicated that “water” ingress into an inner layer of backsheet from a corner of Al frame would lead to severe corrosion of copper ribbon.

✓Detail analyses are ongoing.

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Acknowledgment

✓These analyses were carried out collaborating with Mitsui Chemicals Analysis & Consulting Services, Inc (mcAnac).

✓We thank Mr. Yamada and Mr. Kuwahara of mcAnac, for their continuous efforts.

✓If you are interested in detail analyses for aged PV modules, please let me know.

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