Research Center for Photovoltaics

c-Si 太陽電池セル裏面の腐食劣化態様

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Background & Experimental Procedures

Background (1) (HAc = Acetic Acid)

Corrosion in Alumina Paste Layer (APL)

25 °C / 45% rh, 2 months　25 °C / 85% rh, 240 h　25 °C / 85% rh, 240 h with HAc Atmosphere

H. Xiong *et al.*, "Corrosion behavior of crystalline silicon solar cells," *Microelectron. Reliab.*, vol. 70, pp. 49–58, Mar. 2017.

Background (2) (HAc = Acetic Acid)

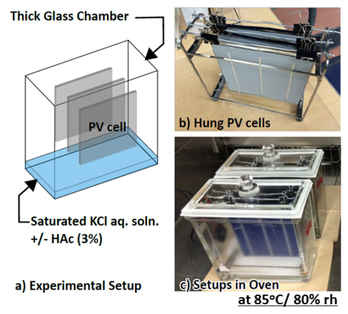
Proposed Corrosion Models

Front Side　Rear Side

H. Xiong *et al.*, "Corrosion behavior of crystalline silicon solar cells," *Microelectron. Reliab.*, vol. 70, pp. 49–58, Mar. 2017.

Experimental (1) (HAc = Acetic Acid)

HAc-Vapor Exposure of Bare PV Cells



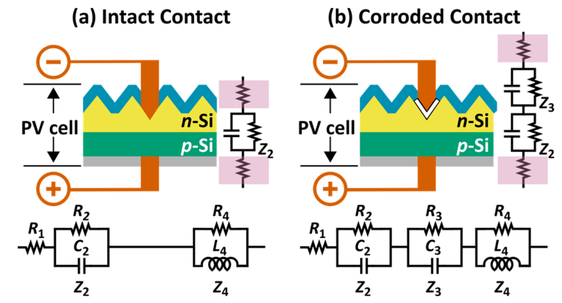
Whole planes of both surfaces in a testing PV cell are uniformly surrounded by the applied stressors (temperature, humidity, and HAc vapor).

→ Spatiotemporally harmonized power-loss and *R*s-elevation are supposed to be observed in the testing PV cell.

T. Tanahashi, N. Sakamoto, H. Shibata, and A. Masuda, "Localization and characterization of a degraded site in crystalline silicon photovoltaic cells exposed to acetic acid vapor," *IEEE J. Photovolt.*, vol. 8, no. 4, pp. 997–1004, Jul. 2018.

Experimental (2)

Localization of Series Resistance (R_1)



,with the respective AC equivalent circuits (under dark conditions) Rectangles colored in pink indicate the assumed locations of R_1.

Summary

To address the origin of the elevated series-resistance (R_S) that is a primary cause of corrosive degradation observed in field-aged photovoltaic (PV) modules*, we evaluated the electrical characteristics of PV cells corroded with acetic acid (HAc) vapor.

The origin in R_S-elevation during corrosion of PV cells is fixed underneath front electrodes, from the following observations.

(a) Evolution of EL-, R_S-, and visual-images during corrosion (**Panel 1 to 3**)
(b) Effects of resistances in the Al bulk and the interconnector-busbar interface on power-loss (**Panel 4 to 5**)
(c) Localization of R_1 ($\simeq R_S$) in a corroded PV cell with single comb grid-fingers (**Panel 6 to 9**)

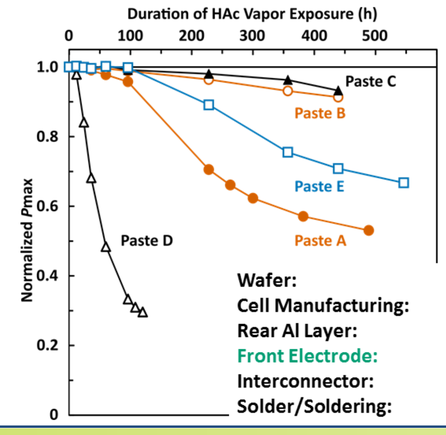
Because we have reported that Z_3 (a novel AC-impedance component that emerges during corrosive degradation) is also localized underneath the front electrodes**, it can be concluded that performance degradation with corrosion is preferentially caused by the evolution of electrical characteristics at this interface, but not at anyplace within a PV cell.

*Tanahashi *et al.*, *IEEE J. Photovolt.*, **9**: 741-751 (2019)

Tanahashi *et al.*, *IEEE J. Photovolt.*, **8: 997-1004 (2018)

A Convincing Demonstration

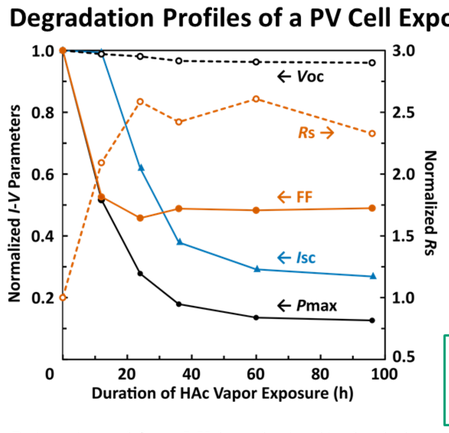
Degradation Profiles of PV Cells (with Different Compositions of Paste) Exposed to HAc Vapor at 85 °C / 80% rh



Results

Panel 1: Degradation Behavior

Degradation Profiles of a PV Cell Exposed to HAc Vapor



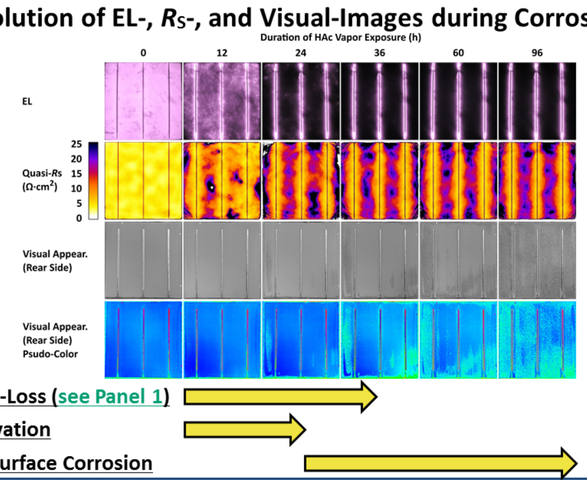
- Rapid power-loss correlated with FF-reduction.
- Decrease in FF synchronized to the increase in R_S.

Concurrently observed EL-, R_S-, and visual-images are indicated in Panel 2.

R_S is estimated from *I-V* data obtained in the dark.
Both vertical axes indicate *I-V* parameters normalized by their initial values.

Panel 2: Degradation Behavior

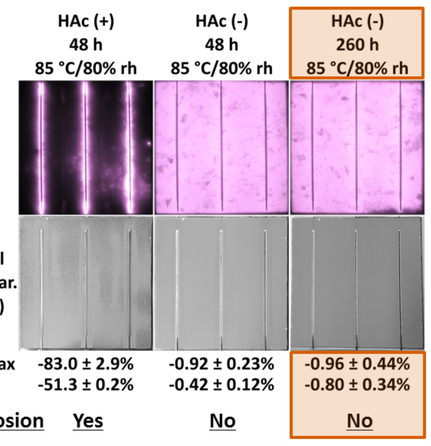
Evolution of EL-, R_S-, and Visual-Images during Corrosion



Power-Loss (see Panel 1)
R_S Elevation
Rear Surface Corrosion

Panel 3: Degradation Behavior

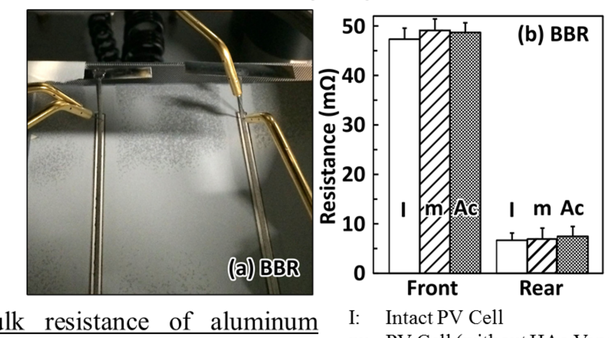
Corrosion in Rear Surface



	HAc (+) 48 h 85 °C/80% rh	HAc (-) 48 h 85 °C/80% rh	HAc (-) 260 h 85 °C/80% rh
Δ *P*max	-83.0 ± 2.9%	-0.92 ± 0.23%	-0.96 ± 0.44%
Δ FF	-51.3 ± 0.2%	-0.42 ± 0.12%	-0.80 ± 0.34%
Rear Surface Corrosion	Yes	No	No

Panel 4: Bulk Resistance

Busbar - Busbar Resistance (BBR)



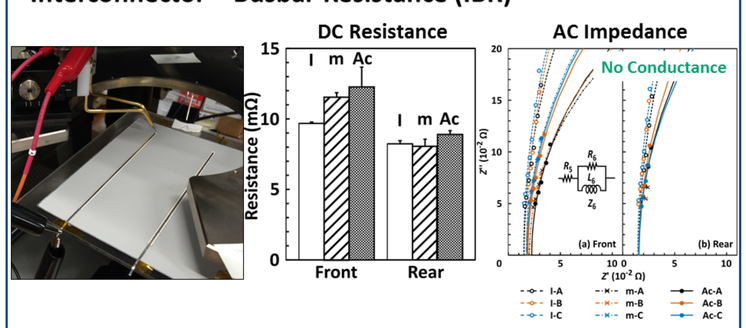
Bulk resistance of aluminum layer (with rear busbars) does not contribute to the power-loss in the corroded PV cells.

I: Intact PV Cell
m: PV Cell (without HAc Vapor)
Ac: PV Cell (with HAc Vapor)

m- and AC-PV cells were incubated at 85 °C/80% rh for 48 h.

Panel 5: Interface Resistance

Interconnector – Busbar Resistance (IBR)

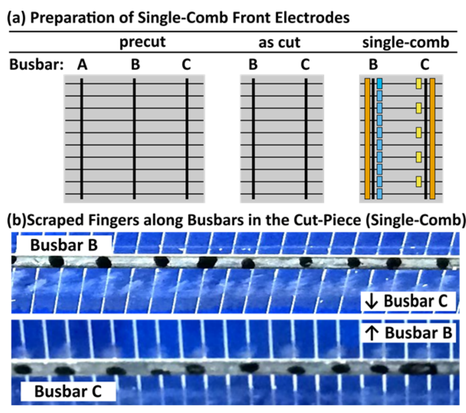


Obvious enhancement of the resistance at solder joint is not confirmed, even when PV cells were nearly completely degraded with HAc vapor.

I, m, and Ac: see Panel 4
A, B, and C in the right graph indicate the respective interconnector-busbar pairs.

Panel 6: Identification of R_1-Origin

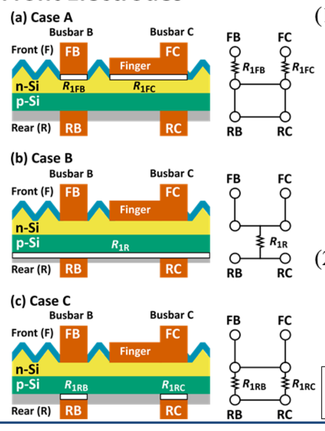
Preparation of a Cut Piece with Single-Comb Front Electrodes



Squares colored in orange, blue, and yellow indicate the scraped positions of the front electrodes.

Panel 7: Identification of R_1-Origin

Determination of R_1–Origin in a Cut Piece with Single-Comb Front Electrodes



(1) If R_1 associates with front electrodes (a), the respective extents of R_{1FB} and R_{1FC} are independently assessed by various contacts of the probes (Panel 8). When the summation of R_{1FB} and R_{1FC} agrees with R_1 determined by the FB-FC contact, we conclude that R_1 is associated with the front electrodes.

(2) In other cases (b and c), the extents of R_1 measured by various contacts are equivalent (Panel 8), and R_1 assessed by the FB-FC contact is nearly zero.

Figure Caption: Corroded site(s) is indicated as colorless box(es)

Panel 8: Identification of R_1-Origin

Assumed and Measured R_1 at Various Contacts

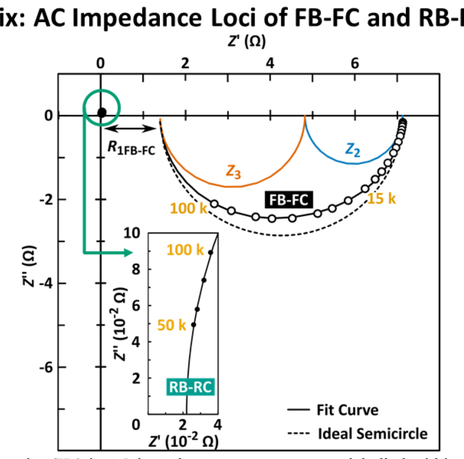
Contacted Terminals	Assumed R_1 Case A	Case B	Case C	R_1 (Ω) Meas.	Case A
FB-RB	R_{1FB}	R_{1R}	$R_{1RB\|RC}$ [a]	0.945	0.907 [b]
FB-RC	R_{1FB}	R_{1R}	$R_{1RB\|RC}$ [a]	0.868	
FC-RB	R_{1FC}	R_{1R}	$R_{1RB\|RC}$ [a]	0.724	0.734 [b]
FC-RC	R_{1FC}	R_{1R}	$R_{1RB\|RC}$ [a]	0.744	
FB-FC	$R_{1FB} + R_{1FC}$	≈ 0	≈ 0	1.404	1.641
RB-RC	≈ 0	≈ 0	≈ 0	0.022	0.022

[a] $R_{1RB\|RC}$ denotes the resistance in a parallel circuit with R_{1RB} and R_{1RC} [i.e., $R_{1RB\|RC} = (R_{1RB} \times R_{1RC}) / (R_{1RB} + R_{1RC})$].
[b] These values indicate the respective mean resistances in FB-RB/RC and FC-RB/RC contacts.

Actual data completely agree with those assumed in Case A.

Panel 9: Identification of R_1-Origin

Appendix: AC Impedance Loci of FB-FC and RB-RC Contacts



Frequencies (Hz) in AC impedance spectroscopy are labelled within this chart.

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