Sequential and Combined Acceleration Tests for Physical and Mechanical Stresses in Crystalline Si Photovoltaic Modules

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Outline

- Background and introduction
- DH/TC(/HF) sequential test
- DML/TC sequential test
Recently, reliability of PV modules will be more important since value of kWh increases by FIT.

Certification test based on IEC61215 etc. is not appropriate to guarantee long-term reliability.

Degradation phenomena in PV modules observed by outside exposure should be reproduced by indoor acceleration test.

Required test time should be reduced. Simple extension test may not be acceptable.

In this study, damp-heat, thermal-cycle, humidity-freeze and dynamic mechanical-load tests are sequentially combined.
Increase in contact resistance at electrode/cell due to corrosion by acid

Break and detachment by thermal cycle, wind pressure and snow

PID by diffusion of Na from cover glass due to high system voltage

Browning by UV

Encapsulant

Tempered glass

Crystalline Si PV module

Solar cell

Al frame, edge sealing

Junction box, pottant

Interconnector

Browning by reflective UV

Back sheet

Acid generation from encapsulant due to water vapor ingress through back sheet.
Outline

• Background and introduction
• DH/TC(/HF) sequential test
• DML/TC sequential test
DH extension test
85°C, 85%RH (IEC61215; 1000 h)

- Increase in Rs due to corrosion by acetic acid
- Yellowing of EVA encapsulant
Acetate ion concentration at glass side for modules with PVF/PET/PVF back sheet

Masuda et al., Proc. 29th EUPVSEC, 2015, p. 2566.
TC extension test

85°C ⇔ -40°C (IEC61215; 200 cyc)

- Increase in Rs due to mechanical damage on electrodes and/or interconnector ribbons.

Damage at intersection between busbar and finger electrodes.

Damage at interconnector ribbons.
DH → TC test

- Increase in Rs.
- DH2000 before TC has no influence on degradation.
- DH3000 before TC accelerates degradation.
- Degradation by acetic acid generated during DH progresses by heat during TC.
## DH→TC test

<table>
<thead>
<tr>
<th>DH2000→TC</th>
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</thead>
<tbody>
<tr>
<td>DH2000+TC200</td>
<td>DH2000+TC400</td>
<td>DH2000+TC600</td>
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<tr>
<td>DH3000→TC</td>
<td>DH3000→TC</td>
<td>DH3000→TC</td>
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<tr>
<td>DH3000</td>
<td>DH3000+TC200</td>
<td>DH3000+TC400</td>
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<tr>
<td>DH4000→TC</td>
<td>DH4000→TC</td>
<td>DH4000→TC</td>
</tr>
<tr>
<td>DH3000</td>
<td>DH4000</td>
<td>DH4000+TC200</td>
</tr>
</tbody>
</table>

- **DH2000→TC**
- **DH3000→TC**
- **DH4000→TC**
DH/TC sequential test

DH1000 ⇒ TC200 ⇒ DH1000 ⇒ TC200 ⇒ •••
Delamination between glass and EVA was observed after TC test of 250 cycles including HF test of 10 cycles just after the first TC test of 50 cycles.

No delamination was observed even after TC test of 800 cycles if including no HF test.
with delamination  |  glass side

with delamination  |  EVA side

w/o delamination  |  glass side

w/o delamination  |  EVA side

Na accumulation by EPMA

TC50 $\rightarrow$ HF10 $\rightarrow$ TC800
Outline

• Background and introduction
• DH/TC(HF) sequential test
• DML/TC sequential test
DML + TC sequential test

DML test conditions
- Load: +1000 Pa ↔ -1000 Pa
- Cycle time: 20 s/cycle
- Cycle number: 50 cycle/set

TC test conditions
- Temperature: -40°C ↔ 85°C
- Cycle time: <6 h/cycle
- Cycle number: 50 cycle/set
EL images during DML test
with microcracks

-1000 Pa

0 Pa

initial

+1000 Pa

100 cycles

500 cycles

1000 cycles
Positive load of +1000 Pa

neutral axis

compressive
tensile
negative load of -1000 Pa
neutral axis
compressive
tensile
negative load of -1000 Pa
DML test followed by TC test
with microcracks

<table>
<thead>
<tr>
<th></th>
<th>DML1000</th>
<th>DML1000/TC200</th>
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<tbody>
<tr>
<td>initial</td>
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<tr>
<td>DML1000/TC400</td>
<td></td>
<td></td>
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<tr>
<td>DML1000/TC600</td>
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<tr>
<td>DML1000/TC800</td>
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</tbody>
</table>

- Growth of microcracks after DML1000
- Break of fingers after the first TC.
DML+TC sequential test

DML test conditions
- Load: +1000 Pa ↔ -1000 Pa
- Cycle time: 20 s/cycle
- Cycle number: 50 cycle/set

TC test conditions
- Temperature: -40°C ↔ 85°C
- Cycle time: <6 h/cycle
- Cycle number: 50 cycle/set

<table>
<thead>
<tr>
<th>module type</th>
<th>sequence number</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>No. 1 w/o microcracks</td>
<td>DML50</td>
</tr>
<tr>
<td>No. 2 with microcracks</td>
<td>DML50</td>
</tr>
<tr>
<td>No. 3 with microcracks</td>
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DML+TC sequential test

<table>
<thead>
<tr>
<th></th>
<th>initial</th>
<th>DML/TC=50/0</th>
<th>DML/TC=50/50</th>
<th>DML/TC=100/50</th>
<th>DML/TC=100/100</th>
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</thead>
<tbody>
<tr>
<td>w/o microcracks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DML/TC=150/100</td>
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<td>DML/TC=150/150</td>
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<tr>
<td>DML/TC=200/150</td>
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</tr>
<tr>
<td>DML/TC=200/20</td>
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</tbody>
</table>

- Generation of microcracks after DML100/TC50.
# DML+TC sequential test

<table>
<thead>
<tr>
<th></th>
<th>initial</th>
<th>DML/TC=50/0</th>
<th>DML/TC=50/50</th>
<th>DML/TC=100/50</th>
<th>DML/TC=100/100</th>
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</thead>
<tbody>
<tr>
<td>with microcracks</td>
<td></td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
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<tr>
<td>DML/TC=150/100</td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
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<tr>
<td>DML/TC=150/150</td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
</tr>
<tr>
<td>DML/TC=200/150</td>
<td><img src="image15.png" alt="Image" /></td>
<td><img src="image16.png" alt="Image" /></td>
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<tr>
<td>DML/TC=200/200</td>
<td><img src="image20.png" alt="Image" /></td>
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<td><img src="image22.png" alt="Image" /></td>
<td><img src="image23.png" alt="Image" /></td>
<td><img src="image24.png" alt="Image" /></td>
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</tbody>
</table>

- Yellow circles show progress in dark regions. Red circles show fading of dark regions.
- Growth of microcracks after the first DML. Break of fingers after TC.
- Fading of dark regions after DML.
Only TC test

<table>
<thead>
<tr>
<th></th>
<th>initial</th>
<th>DML/TC=0/50</th>
<th>DML/TC=0/100</th>
<th>DML/TC=0/150</th>
<th>DML/TC=0/200</th>
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<td><img src="DML/TC=0/50.png" alt="Image" /></td>
<td><img src="DML/TC=0/100.png" alt="Image" /></td>
<td><img src="DML/TC=0/150.png" alt="Image" /></td>
<td><img src="DML/TC=0/200.png" alt="Image" /></td>
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</tbody>
</table>

- Growth of microcracks after the first TC.
- No growth after successive TC.
Main degradation factors are FF with increase in Rs.
Gradual decrease by TC/DML for cells w/o microcracks and by TC for cells with microcracks.
Large decrease by the first TC and oscillation of small recovery by DML and small degradation by TC for cells with microcracks.
DML50/TC50 and DML200/TC200 sequential tests accelerate degradation by about 7-11 times in comparison with the results by only TC test.

<table>
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<tr>
<td>No. 1 w/o microcracks</td>
<td>DML50 TC50 DML50 TC50 DML50 TC50 DML50 TC50</td>
</tr>
<tr>
<td>No. 2 with microcracks</td>
<td>DML50 TC50 DML50 TC50 DML50 TC50 DML50 TC50</td>
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<tr>
<td>No. 3 with microcracks</td>
<td>- TC50 - TC50 - TC50 - TC50</td>
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DML-TC sequential test

Retention of maximum power (%)
Conclusions

• Combination test accelerates degradation and also reproduces degradation observed outside such as cracks on backsheet.
• DH3000/TC600 sequential test induces much large degradation in comparison with the sum of degradation by only DH3000 and by only TC600.
• HF test is effective for generating delamination between glass and EVA.
• DML/TC sequential tests accelerate degradation by about 10 times in comparison with the results by only TC test.
• There are many degradation factors, high temperature, high humidity, thermal cycle, UV irradiation, current flow, high voltage, salt mist, mechanical stress, etc. It is also important which degradation factors should be combined.