Relation of Wet Leakage Resistance with Module Front Glass Resistivity

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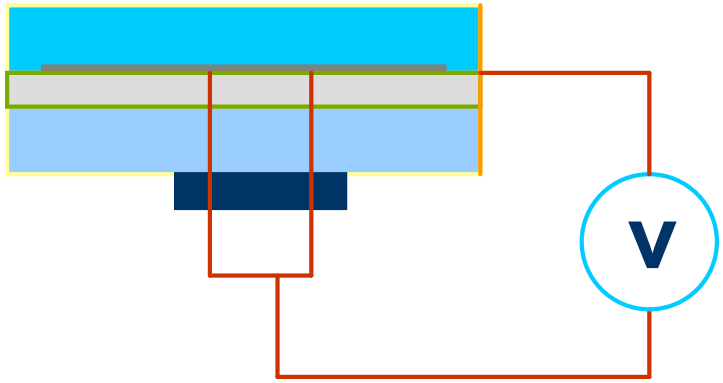
Introduction

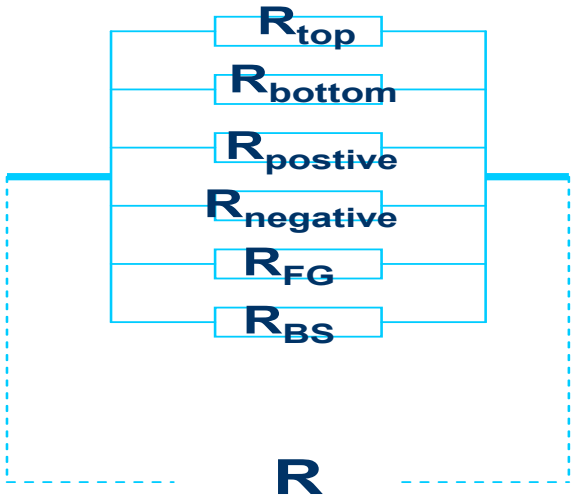
- **Wet Leakage Resistance (WLR)**
  - **An important module safety measure**
- **Criteria of Certification Standard**
  - **IEC 61646 ed. 2.0 10.15**
    > 40 MOhm.m^2 under 1000 v bias if module area > 0.1 m^2
  - **UL 1703**
    > 40 MOhm. m^2 under 500 v bias if module area > 0.1 m^2
- **Determination Factors**
  - TCO front glass (FG)
  - Back side (BS)
  - Edge deletion area
- **This Work**
  - **Explored the front glass resistance on thin film modules by using a resistance segmentation technique;**
  - **Characterized the WLR variation of the modules with different front glass bulk resistivity and the temperature dependence of glass resistivity;**
  - **Observed the correlation of WLR pre and post stress test;**
  - **Provided a criteria for front glass bulk resistivity to get an appropriate margin for WLR passing standards after stress tests.**

Equivalent Circuit and Resistance

- Measurement Set-up



- Equivalent Circuit



$$R_{parallel} = 1 / (1 / R_{top} + 1 / R_{bottom} + 1 / R_{positve} + 1 / R_{negative})$$

$$R_{FG} = 1 / (1 / R_{dry\ back} - 1 / R_{parallel})$$

$$R_{BS} = 1 / (1 / R_{module} - 1 / R_{dry\ back})$$

Measurement Methodology

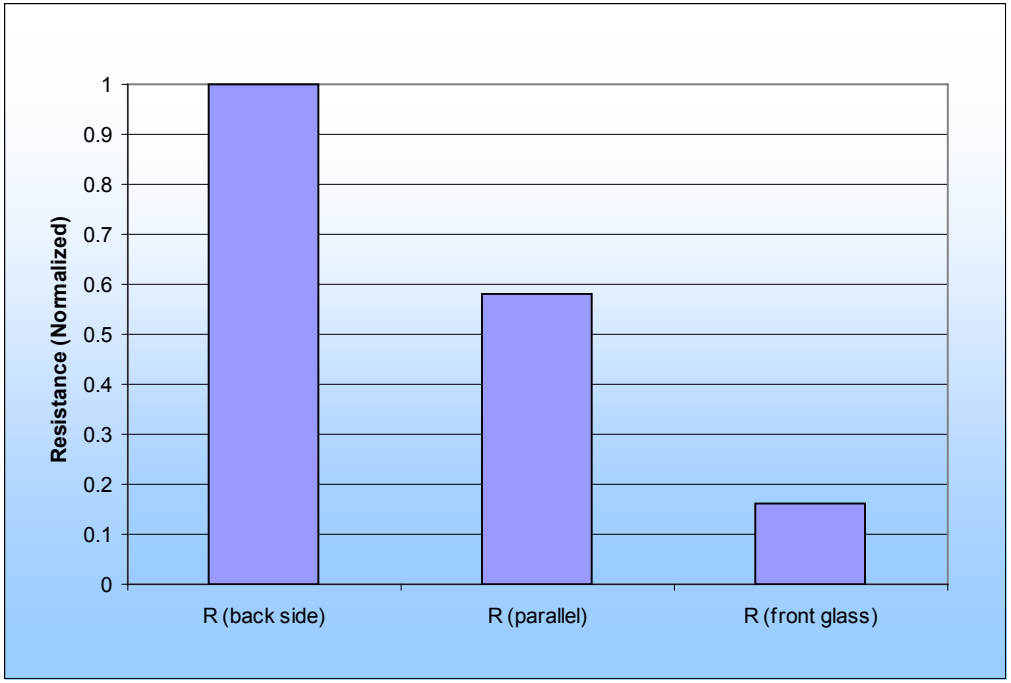
- **Measure WLR of individual panel edges**
  - Damp probe or 4mm wet solution can be used
  - Use parallel resistance addition to calculate total edge WLR term
- **Measure WLR of FG with 4 edges combined**
  - Use parallel resistance subtraction to extract FG WLR term
- **Measure WLR of full panel**
  - Use parallel resistance subtraction to extract BS WLR term

Segmentation of Initial Resistance

- For Initial Leakage Resistance:

$$R_{BS} > R_{parallel} >> R_{FG}$$

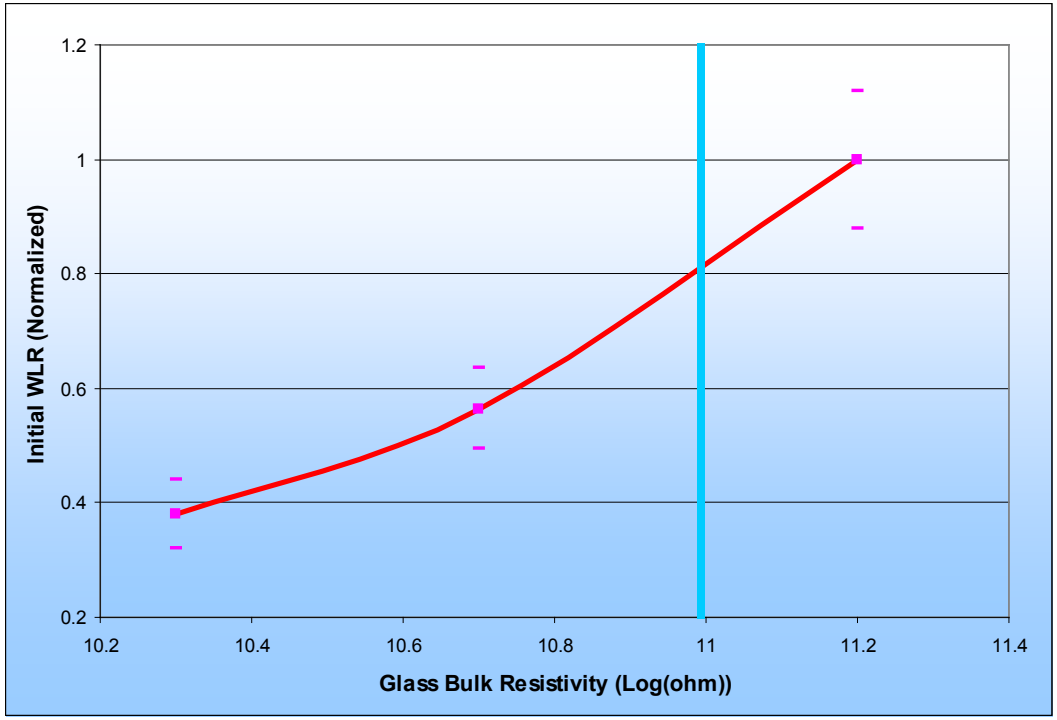
- Front Glass → dominant *leakage path* of initial WLRs



Initial leakage resistance of each part of a module

Dependence on FG Resistivity

- A set of glass materials were evaluated over a range of resistivity typical in the solar industry
- Module WLR performance evaluated as a function of resistivity



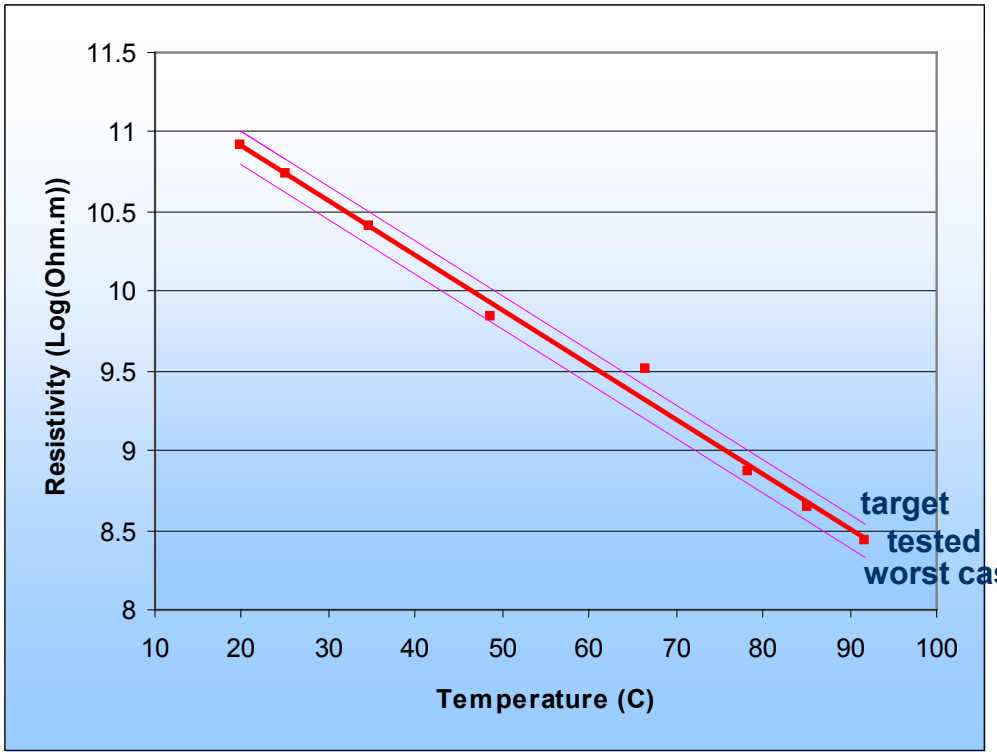
Initial WLR of the modules vs FG bulk resistivity

Dependence on FG Resistivity (cont'd)

- Front glass bulk resistivity can be the dominant term controlling WLR
- Requirement to front glass (FG)
  - High resistivity: >1e11Ohm·m recommended
  - Validated tight run-to-run quality control
    - Requires composition control and resistivity monitoring

T Dependence of FG Resistivity

- FG resistivity is known to have an exponential temperature dependence[1]
  - Roughly, every 25 degree temperature variation results in a 10x glass resistivity change



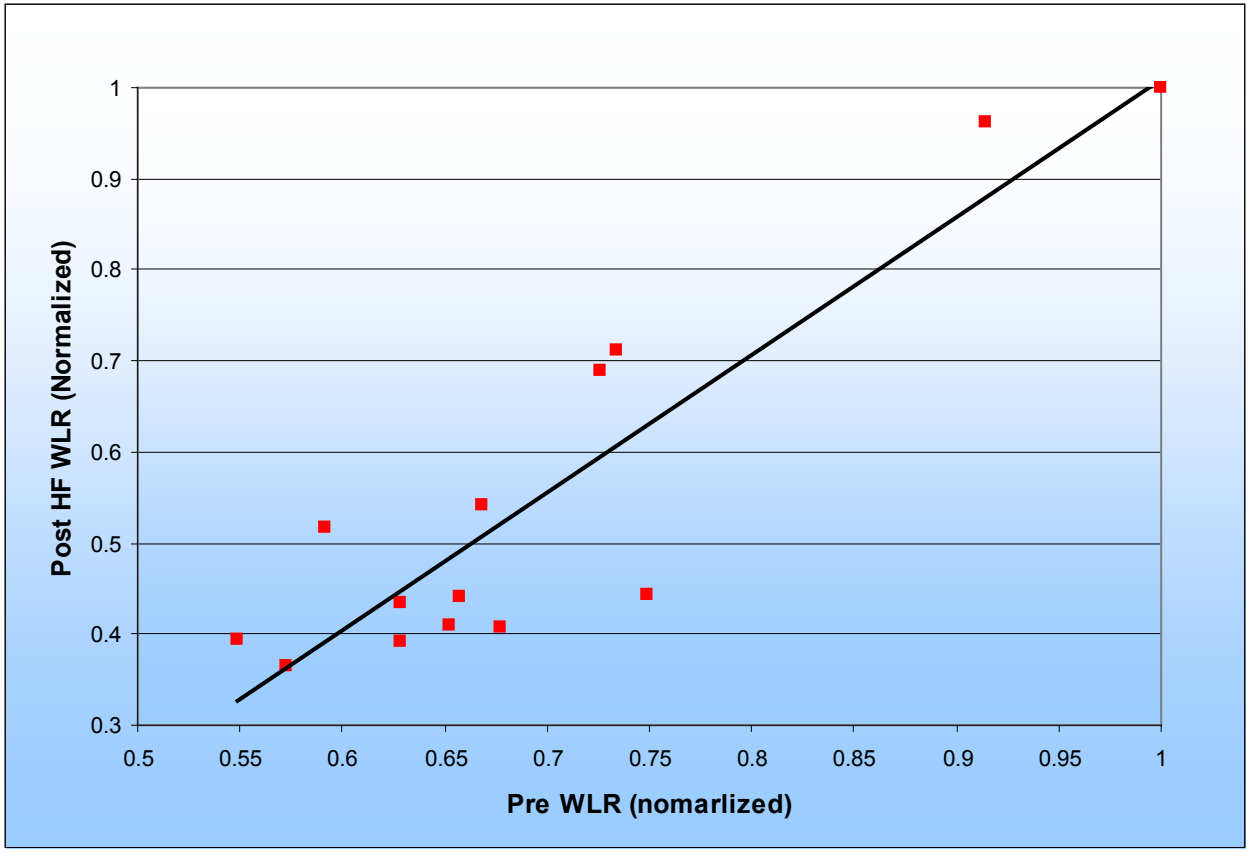
Glass resistivity vs. temperature

[1]E. Guyer, Electrical Glass, Proceedings of the IRE, December 1944, p. 743-750

FG Resistivity Spec Considerations

- **IEC spec mandates all components meet 40 MOhm.m^2 at 25°C**
  - If FG were the only component w.c. value of $10^{10.1}$ will apply
- **FG resistivity spec needs to allow for several components:**
  - Partitioning of the leakage budget across all leakage paths
    - Reserve 1/3 of conductivity budget each for FG, edges and BS ($10^{0.5}$).
  - Margin for drift in resistivity over environmental exposure ($10^{0.2}$)
  - Margin for process variation
    - 2X variation margin is recommended ($10^{0.2}$).
  - **Net spec is $10^{(10.1 + 0.5 + 0.2 + 0.2)} = 10^{11 \pm 0.2}$**

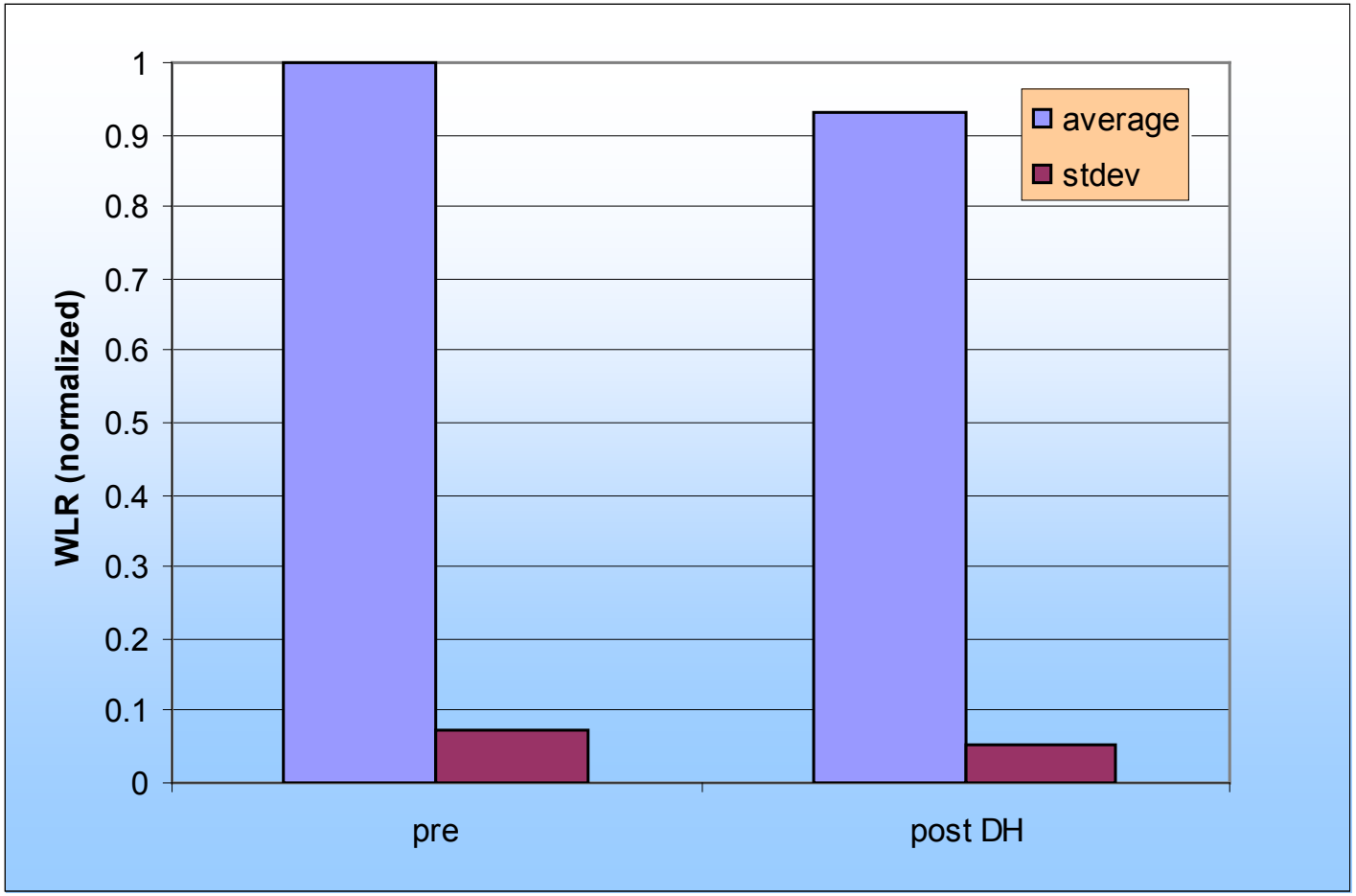
Degradation post HF Stress Test



Correlation of WLR pre and post HF

Higher initial WLR correlated to higher post stress WLR

Degradation post DH Stress Test



WLRs of the modules (front glass bulk resistivity = 10.7 log(MOhm.m)) post DH

Degradation post Stress Tests

- **WLR degradation post stress tests from moisture uptake**
  - **~ 10% WLR reduction post DH**
- **Higher initial WLRs → more margin for environmental exposure**
- **Higher FG resistivity → higher initial WLRs**
- **Recommendation: FG bulk resistivity: > 11.0 Log(Ohm.m)**
  - ***Delivers WLR with an appropriate margin passing industrial standards after stress tests.***

Conclusions

- ***WLR is an important safety indicator, which is affected by all encapsulating components of the module***
- ***The segmentation test can be used to identify the component leakage paths for initial WLR***
- ***Initial WLR has a strong correlation with front glass resistivity, which is highly temperature accelerated***
- ***WLR degraded after stress tests due to moisture penetration and the modules with higher initial WLRs resulted in higher post stress WLR***
- ***Front glass with bulk resistivity higher than 10.8 Log(Ohm.m) is expected to have module WLR with an appropriate margin passing the industrial standards***