Hot-spot measurements on crystalline silicon solar cells with different reverse-current characteristics

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Introduction

- Hot spots in general are a major failure mode of modules (reliability and safety)
- 8% of all IEC 61215 failures are related to the hot spot test according to TÜV (2012)
- This work links hot spot test results of cells in bare and in laminated state with focus on:

  Correlation of maximum hot spot temperatures bare vs. laminated cell

  Temperature increase over time for module hot spots with test times up to 10 minutes

  Use worst case shading conditions to measure the maximum hotspot temperature

Test procedure

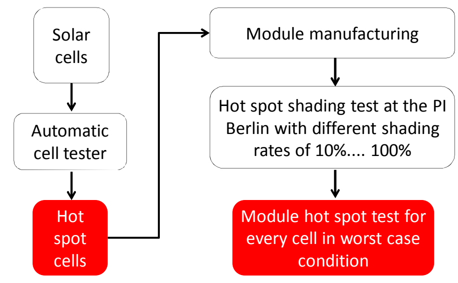


Fig. 1: Test procedure: *Automatic tester* performs IV curves incl. hot spot test for bare cells (@-12V). After lamination the PI Berlin hot spot test is performed. In addition to 100% also lower shading rates (ShR) can be used to find worst case condition (max. T) for every cell.

Module hot spot test at the PI Berlin

Fig. 2: The module hot spot test uses HQI lamps which generate 700 W/m² and a temperature of approx. 65 °C on module backside surface. For first test each cell is completely shaded for 15s (module is short-circuited). Backsheet temperature is monitored with an IR camera.

Hot spot IR images: bare vs. laminated

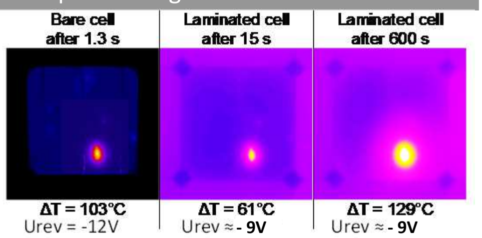


Fig. 3: The IR image on the left shows the hot spot of a bare cell after applying a reverse voltage of -12V for 1.3s. The middle and right IR images show the same cell during the module hot spot test after 15s and 600s. All temperatures are corrected by the environmental temperature T_{env} which was 25 °C for bare cell and approx. 65 °C for module test ($\Delta T = T_{hotspot} - T_{env}$). Cell reverse voltage when shaded is **-9V** instead of -12V.

T max: Bare cell (1.3s) vs. laminated (15s)

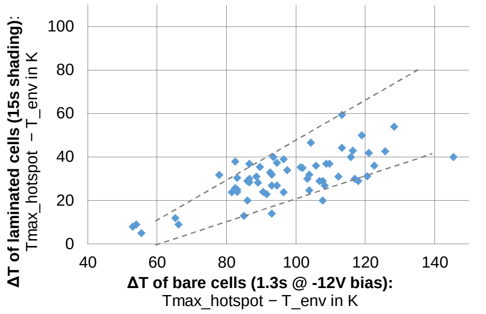


Fig. 4: Comparison of hot spot temperatures of bare cells (after 1.3s @-12V bias) vs. laminated cells (after 15s shading). The weak correlation is caused by hot spot size: small hot spots are overrated when testing bare cells with very little thermal mass (m_cell = 10g)

Module hot spots: Tmax after 15s vs. 10min

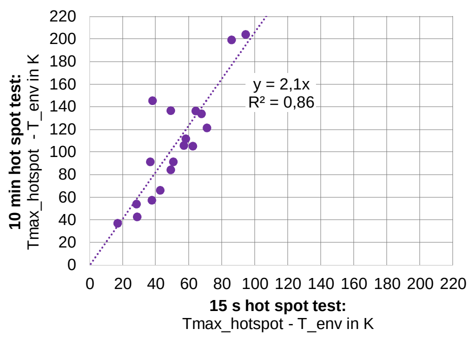


Fig. 5: Correlation of hot-spot temperatures on module surface after 15 s and 10 min (time factor 40). The linear regression within this time shows a factor 2 for the difference in hot-spot temperatures for both times.

Next step: From reverse current to partial shading and worst case temperatures

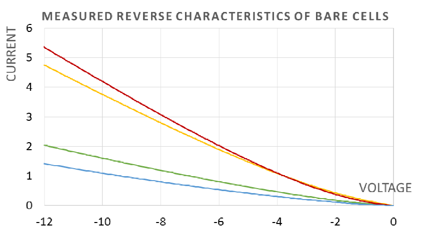
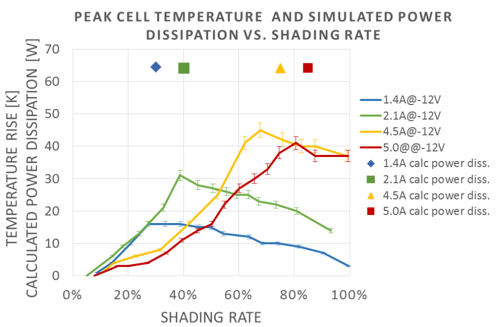
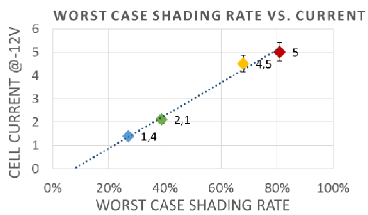


Fig. 6: Exemplarly measured reverse characteristics of 4 cells indicate the current *and* shading rate needed to operate the cell in worst case condition.

Fig. 7: Temperature rise and simulated maximum power dissipation matches the shading rate. But despite of same values of approx. 60W power dissipation the ***maximum temperature rise is very different for each cell.*** Maximum hotspot temperature should not be determined with reverse measurements only but with IR camera to detect "current density" of hotspot.

Fig. 8: Partial shading of those cells show a good correlation of *shading rate* and *current@-12V*.





Conclusion

In this study hot spot behavior of bare and laminated cells have been compared. After sorting bare cells by high hotspot temperature those cells were laminated into modules. After performing a module shading test the following can be stated:

For bare cells a reverse bias of 12V applied for 1.3s is sufficient to reach close to max temperatures (Fig 3)

Correlation bare vs. laminated hotspot: After lamination those cells show a wide spread of hot spot temperatures when performing a 15s shading test → not very strong correlation (Fig 4). It is assumed that small hot spots are overrated when testing bare cells with little thermal mass

Temperature progression of module hot spots shows a correlation of factor 2 in temperature when extending shading time from 15 s to 10 min (Fig 5)

Partial shading and worst case: Adding several shading grids to the hotspot tester will enable PI Berlin to find the real worst case shading conditions. It is not sufficient to just select the cell with highest reverse current (IEC test) but to really test every cell in its worst case shading conditions and monitor the max. temperature with an IR camera