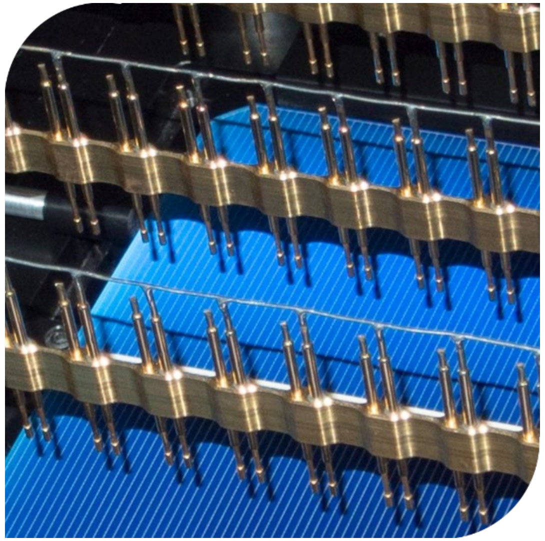   

A simulation study of temperature of partially shaded modules

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12th Back Contact (BC) Workshop, 4-5 December 2024, Delft, the Netherlands

ISC research for a sunny future

Motivation

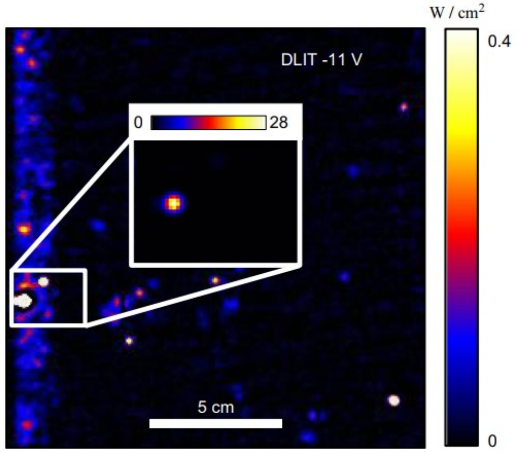
- Hot spots: most important degradation mode*
- Larger module, higher power
- Residential application

*D. Jordan et. al., Prog. Photovolt: Res. Appl. 2017, 25

Industry progress of solar cells

- In the past:

p-type multicrystalline Si solar cell



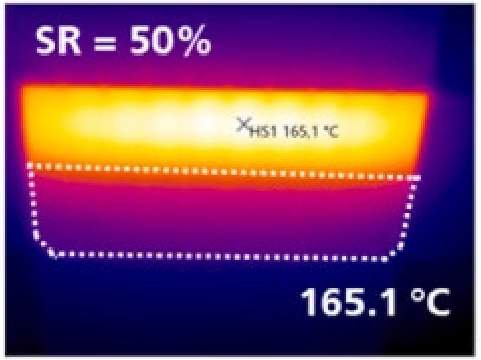
dark lock-in thermography image reverse biased at -11V

I. Geysemeyer et al., Solar enery materials & solar cells (120), 2014

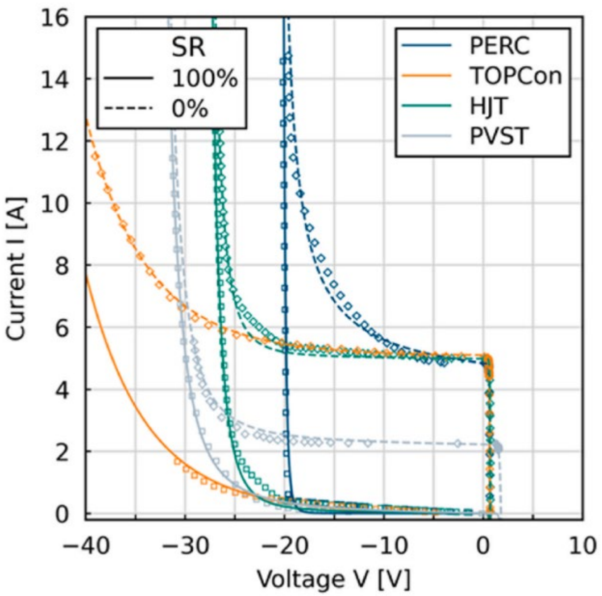
→ Global reverse *IV* curve is not sufficient to predict temperature

- Recent years:

uniform breakdown

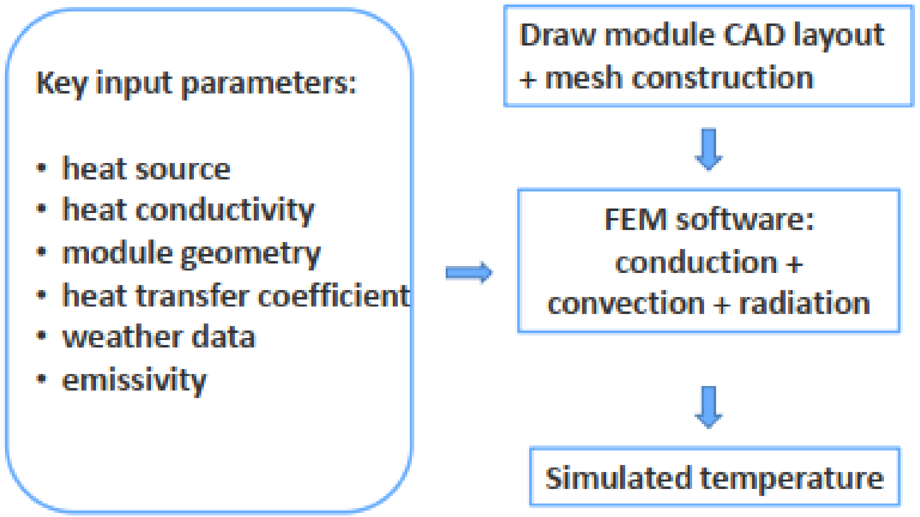


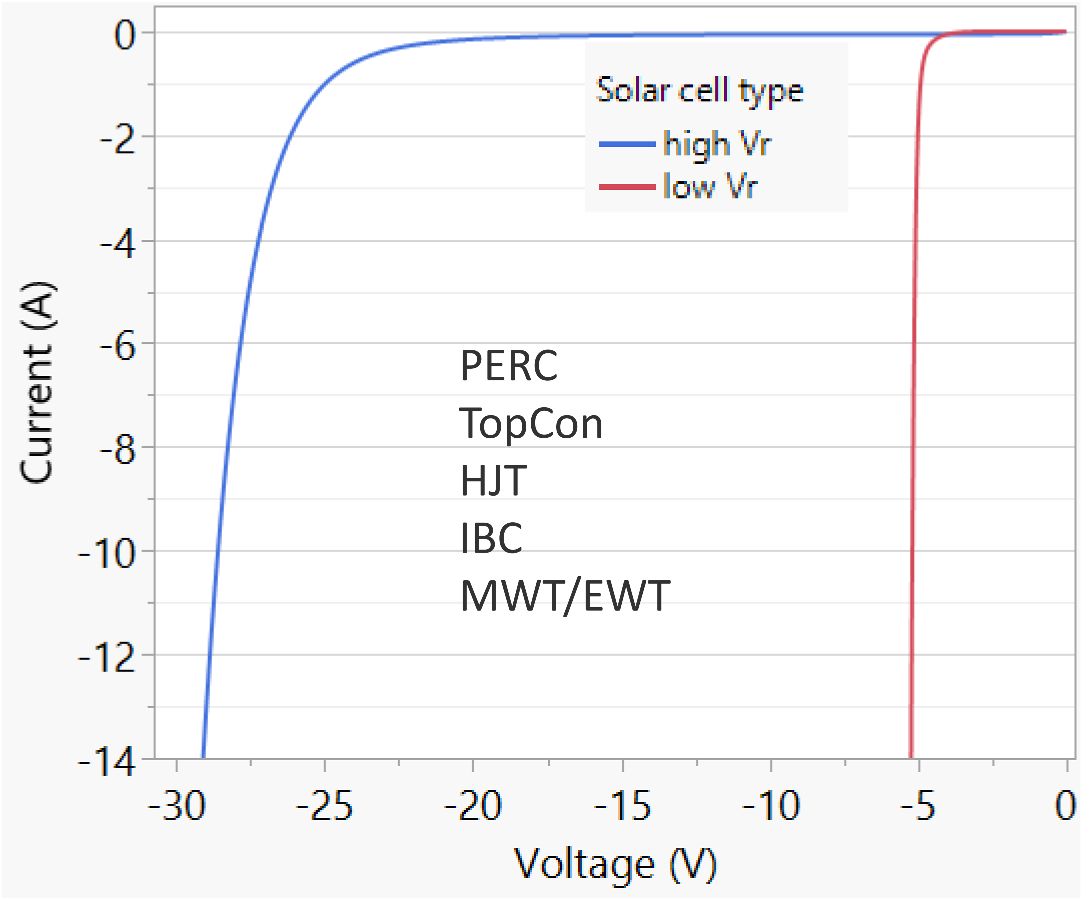
IR image of a shaded PERC cell



C. Reichel et al., Solar energy materials & solar cells (276), 2024

Simulation



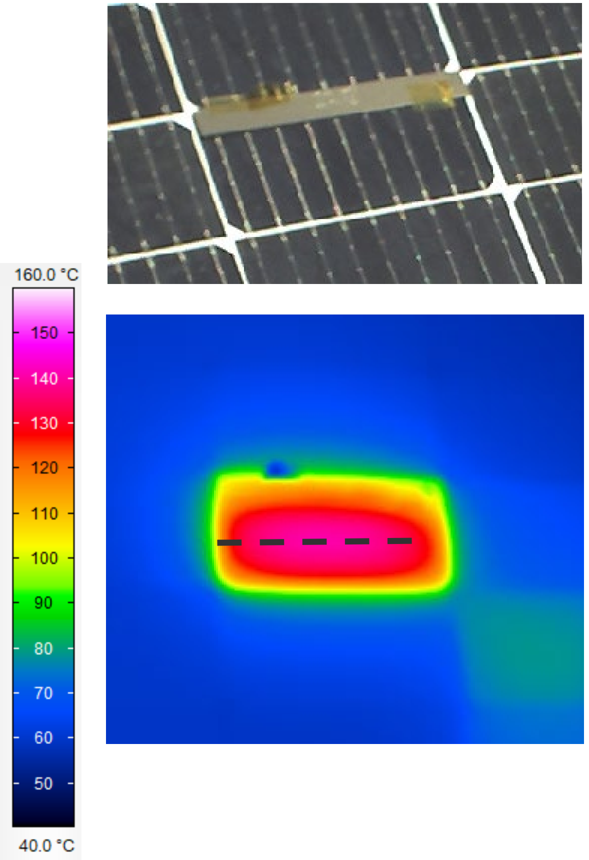


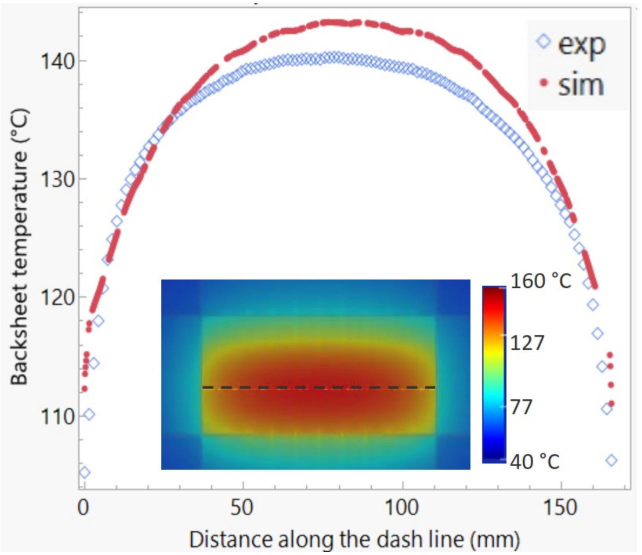
- Our simulation involves many assumptions and approximations.
- Simulate a solar cell with a breakdown voltage Vr of -5V and -20V

Exp. vs Sim.
120 half-cell PERC module (M6 wafers)

- Shading shape A*

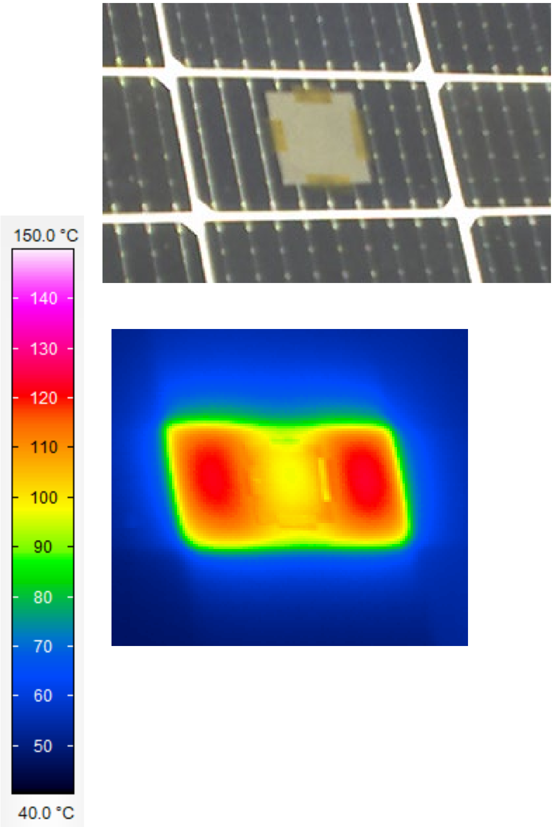
22.5% of a half cell is shaded





- Shading shape B

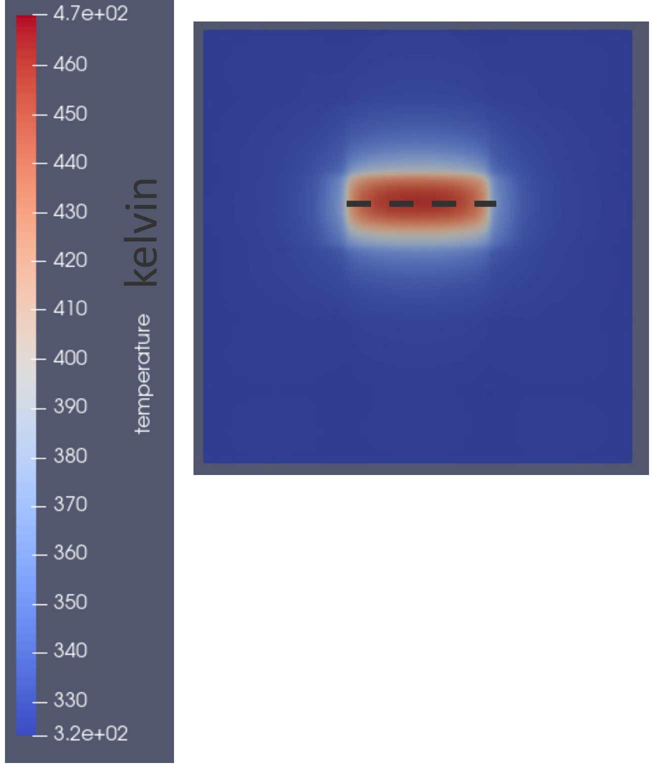
same cell measured on a different date
22.5% of a half cell is shaded



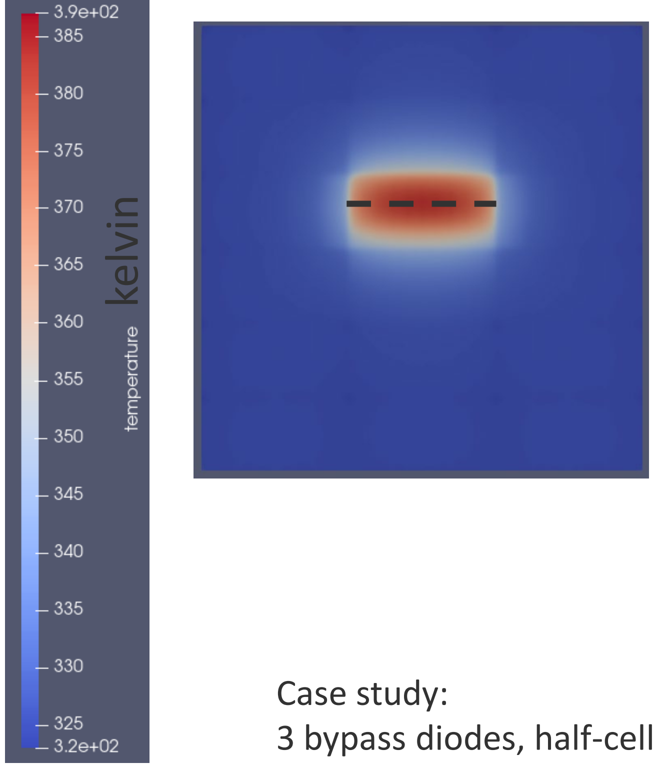
*H. Chu et al., WCPEC-8, 2022, Milan, Italy

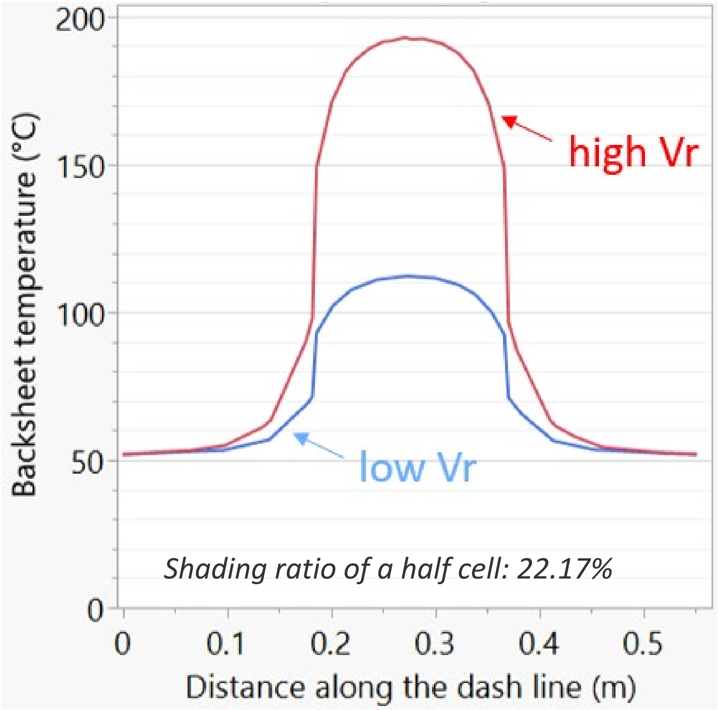
Simulation results: high and low Vr

Cells with high Vr
144 half cell module



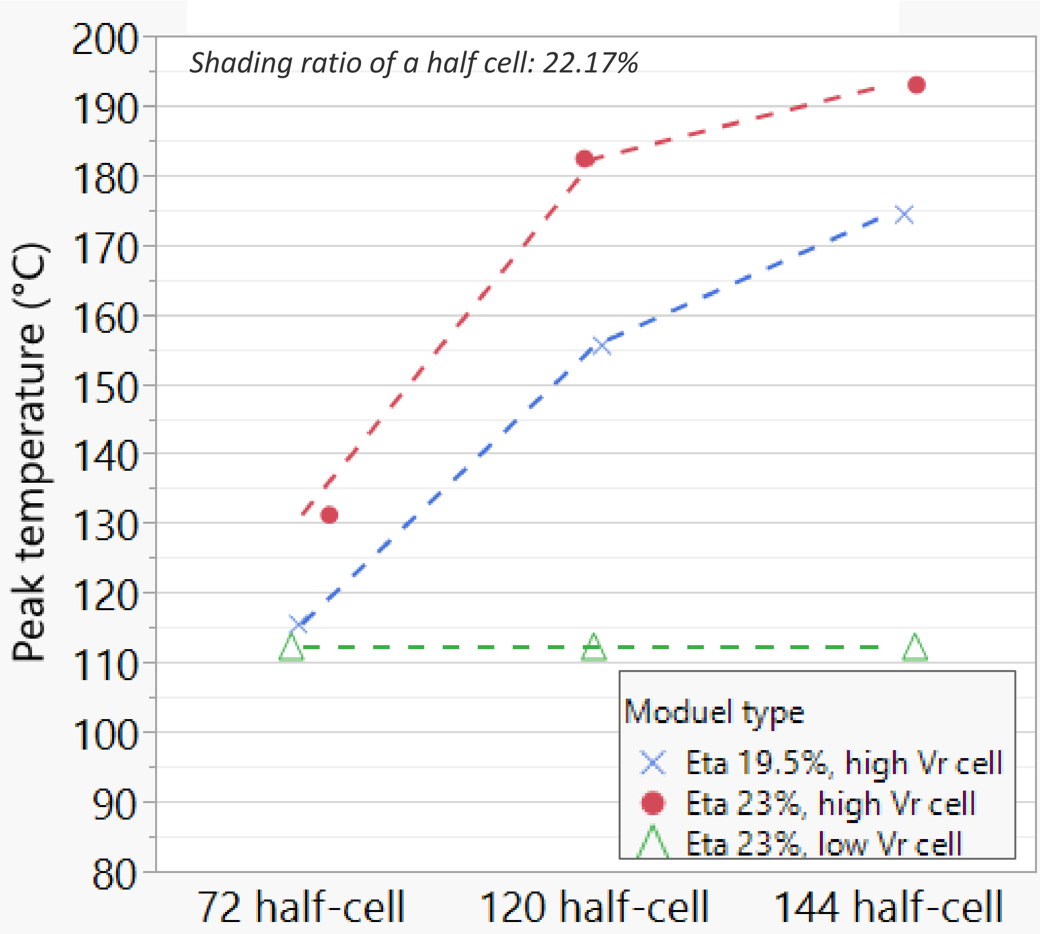
Cells with low Vr
144 half cell module

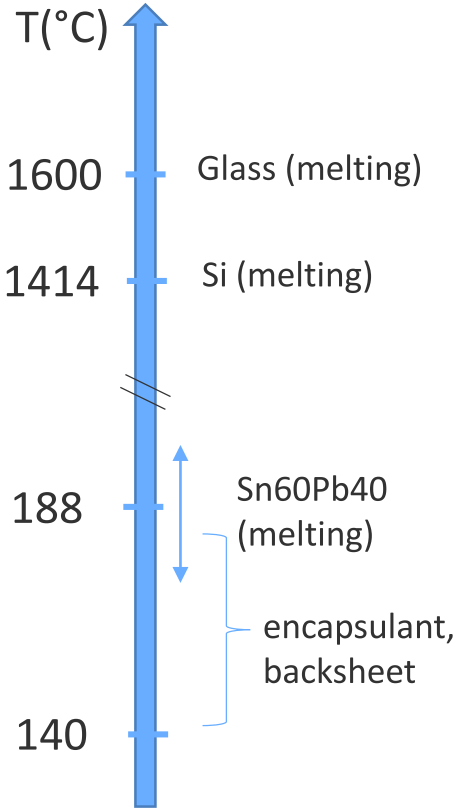




Case study:
3 bypass diodes, half-cell module, Module Eta 23%, M10 wafers
Tair =30 °C, wind speed = 10km/h, One sun illumination
Worst case (current of shaded module = current of unshaded module)

Simulation results: high and low Vr





Temperature coefficient: 0.38%/°C, 0.29%/°C

E. Özkalay et al., EPJ Photovolt., 15 (2024) 7;
C. Reichel et al., Solar enery materials & solar cells (276), 2024;
R. Witteck et al., IEEE Journal of Photovoltaics, vol. 10, no. 6, pp. 1828-1838, 2020;
R. Witteck et al., 38th EUPVSEC 2021 ;
T. Su et al., Solar Energy 230 (2021) 583–590 ;
Maxeon Shading and Hotspot Resilience White Paper, 2024

Step 2: Challenges (hard to be studied by simulation)

- $60x10^9$ c-Si cells / $1x10^9$ modules → 500GW annual capacity

  Simulation study is based on ideal situation (uniform heating under reverse bias condition)

  Variations of cell's and module's processes in mass production

Not clear:

- Influence of reverse bias on solar cell efficiency and influence of long-term reverse bias*
- Hot-spot + Factor "X" (cracks, PID, T and H, solder joints failure) **

**   E. Özkalay et al., EPJ Photovolt., 15 (2024) 7*
***M. Dhimish and A. Tyrrell, npj Materials Degradation (2022) 6,11*
M. Afridi et al., Solar Energy (2023) 249, 467-475

Step 2: Challenges (hard to be studied by simulation)

- Many ways to mitigate this problem:

-less cell per bypass diode

-design of breakdown voltage

-use an inverter that chooses local Pmpp at high-voltage *

- To be bulletproof: regular inspection/maintenance

- Awareness from the general public

* E. Bende et al., EUPVSEC 2014, p2546, Amsterdam, the Netherlands

Summary

- Ideal uniform breakdown can still show high temperature
- High Vr: Tpeak increases with power of the substring
- Low Vr: Tpeak depends on reverse *IV* curve
- Difficult to simulate some factors on the field