Increasing the Lifetime of Power Modules by Smaller Bond Wire Diameters

IMAPS *Wire Bonding Workshop*

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Outline

- Motivation for Testing Different Bond Wire Diameters
- Power Cycling Test Setup
- Devices Under Test
- Test Results & FEM-Analysis
- Conclusion and Discussion

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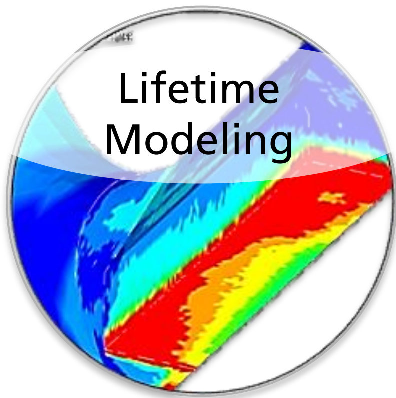

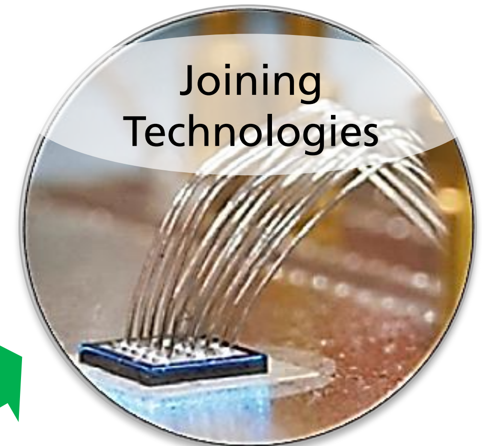

Power Electronics at Fraunhofer IISB

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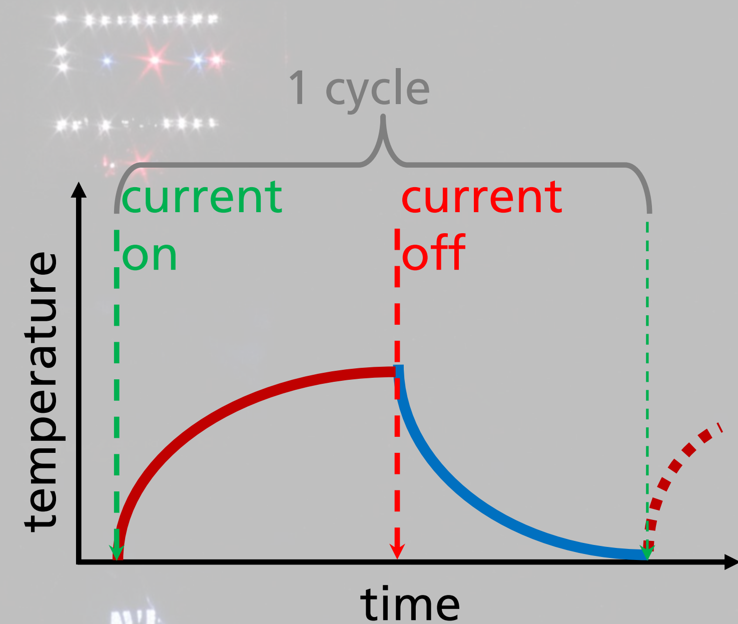
Motivation

- Research Project *Compact and Reliable Electronic integrated in Actuators and Motors (CREAM)*
  - Power Cycling tests with 240 samples
  - SiC-Schottky diodes
  - Silver sintered or soldered
  - **No** bond wire lift offs
  - Failure due to die-attach degradation
- Literature: higher lifetime with smaller bond wires
  - Bayerer in 2008[1]
  - Lu in 2009[2]

1) Bayerer et. Al., Model for Power Cycling lifetime of IGBT Modules - various factors influencing lifetime, CIPS 2008, Nuremberg, Germany
2) Hao Lu, Chris Bailey: Lifetime Prediction of an IBGT Power Electronics Module under Cyclic Temperature Loading Conditions, ICEPT-HDP 2009

What is Power Cycling?

- Active temperature cycles during application
- Semiconductor power losses
- Heating up with current
- Cooling down via a heat sink



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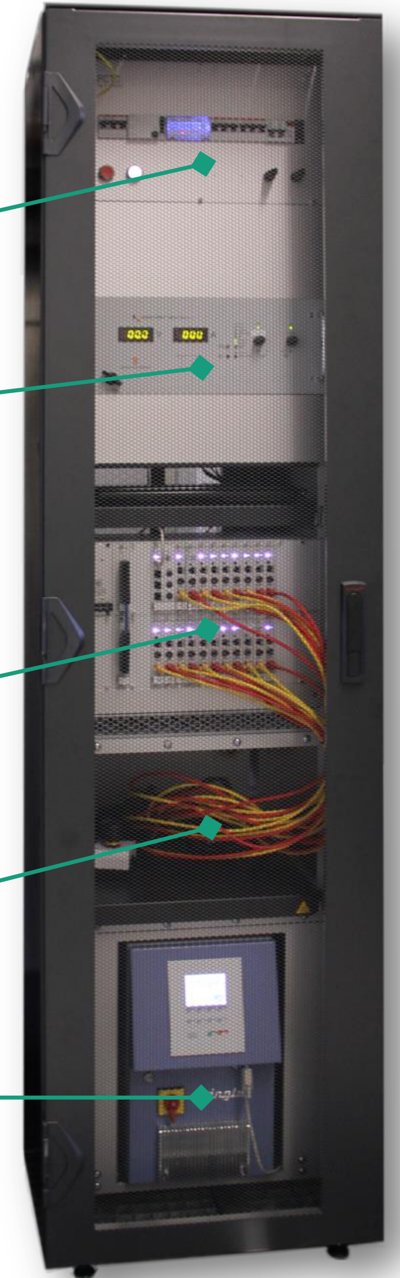
Power Cycling Test Setup

- 6 unique test benches
- Energy Input
- Heat Source
  - 400A / 35V
  - 800A / 15V
  - 2000A / 20V
- PC and Data Logging
- Chamber for up to 20 Devices Under Test
- Temperature Control
  - -76..660°F (-60..350°C)



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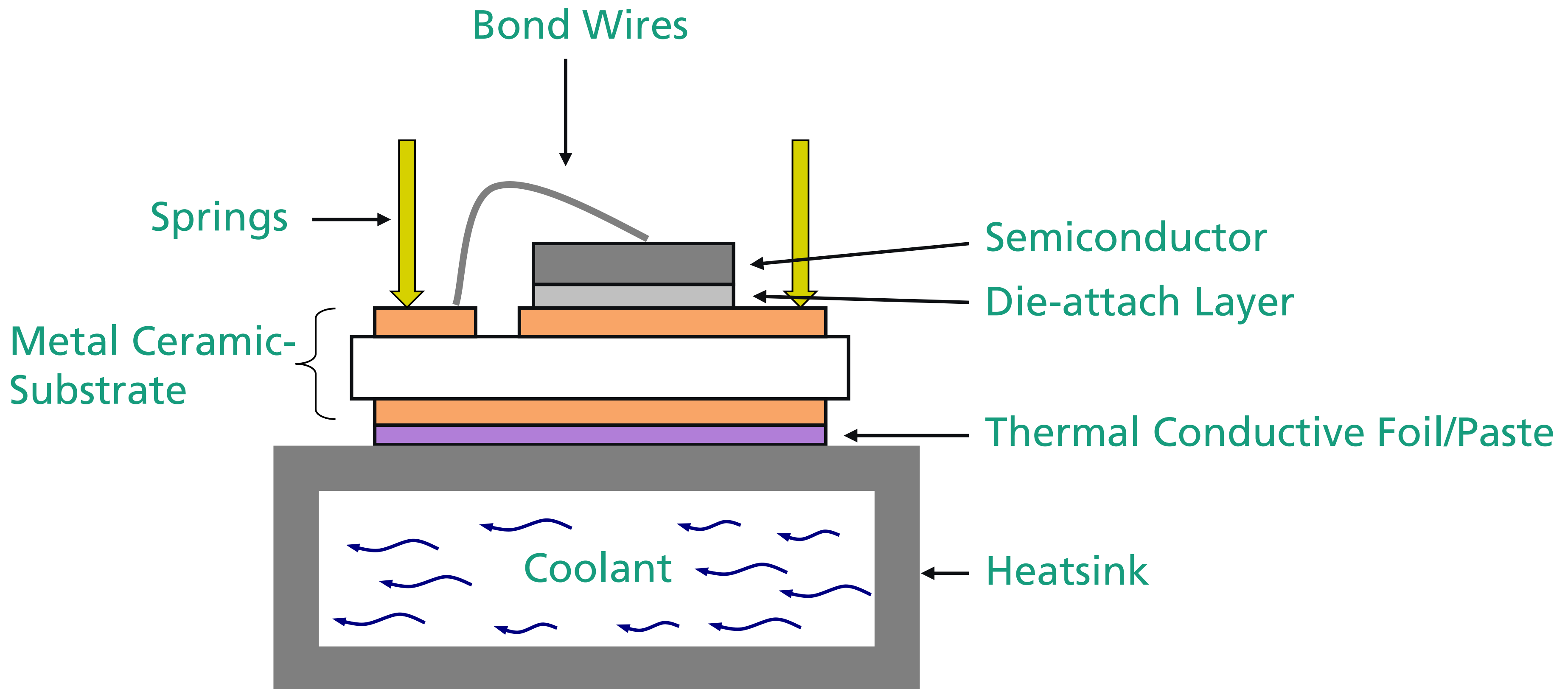
Power Cycling Test Setup



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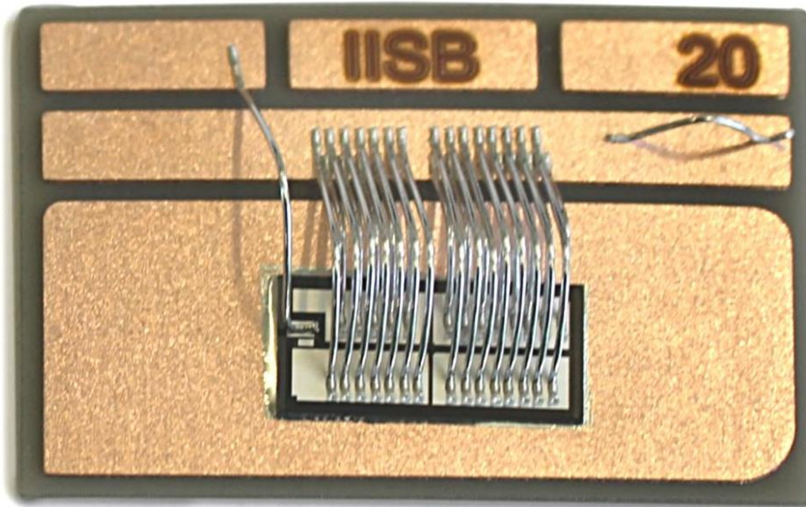
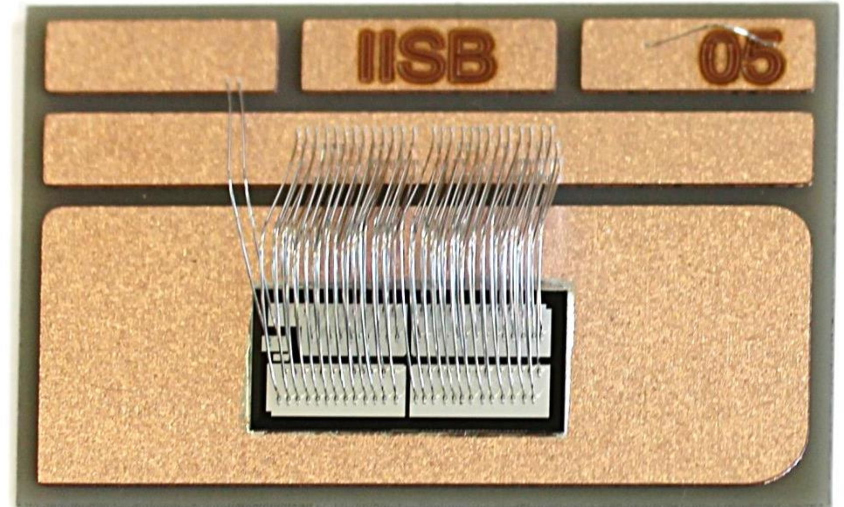
Power Cycling: Devices Under Test





- IGBT4
- Lead-free soldered (Sn96,5Ag3Cu0,5)
- DBC substrate (copper with AlN ceramic)
- Two groups of bond wire diameters (standard Al-wire)
  - Ten samples with 375 µm
  - Ten samples with 125 µm

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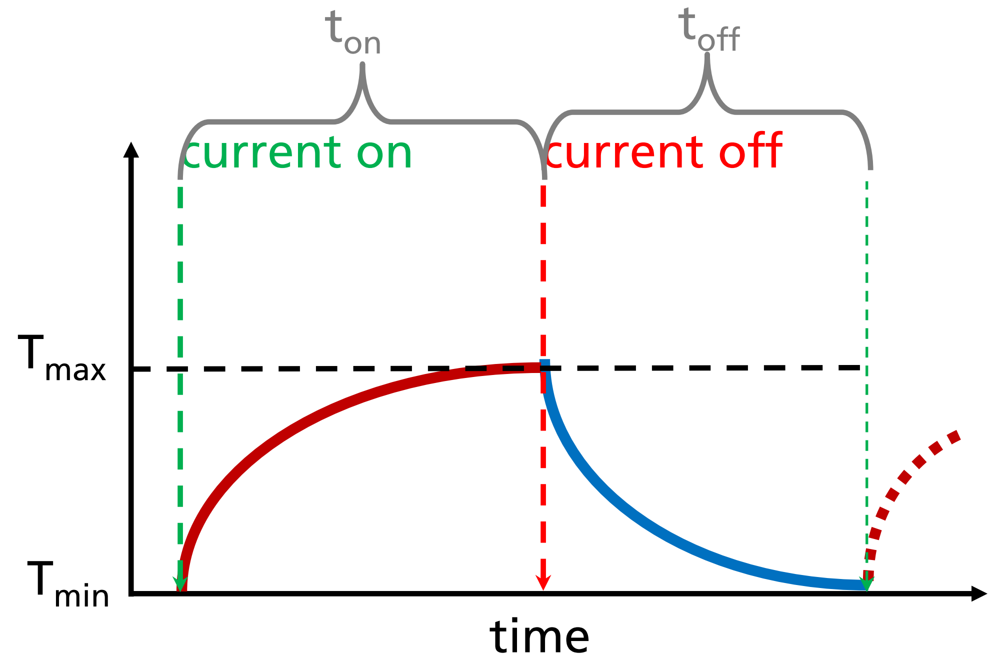
Power Cycling: Devices Under Test

- Heating current: 89 Amps
- Coolant temperature T_{min}: 77°F (25°C)
- Temperature swing ΔT: 130 K
- Maximum temperature T_{max}: 207°F (155°C)
- Cycle time t_{on}/t_{off}: 15s



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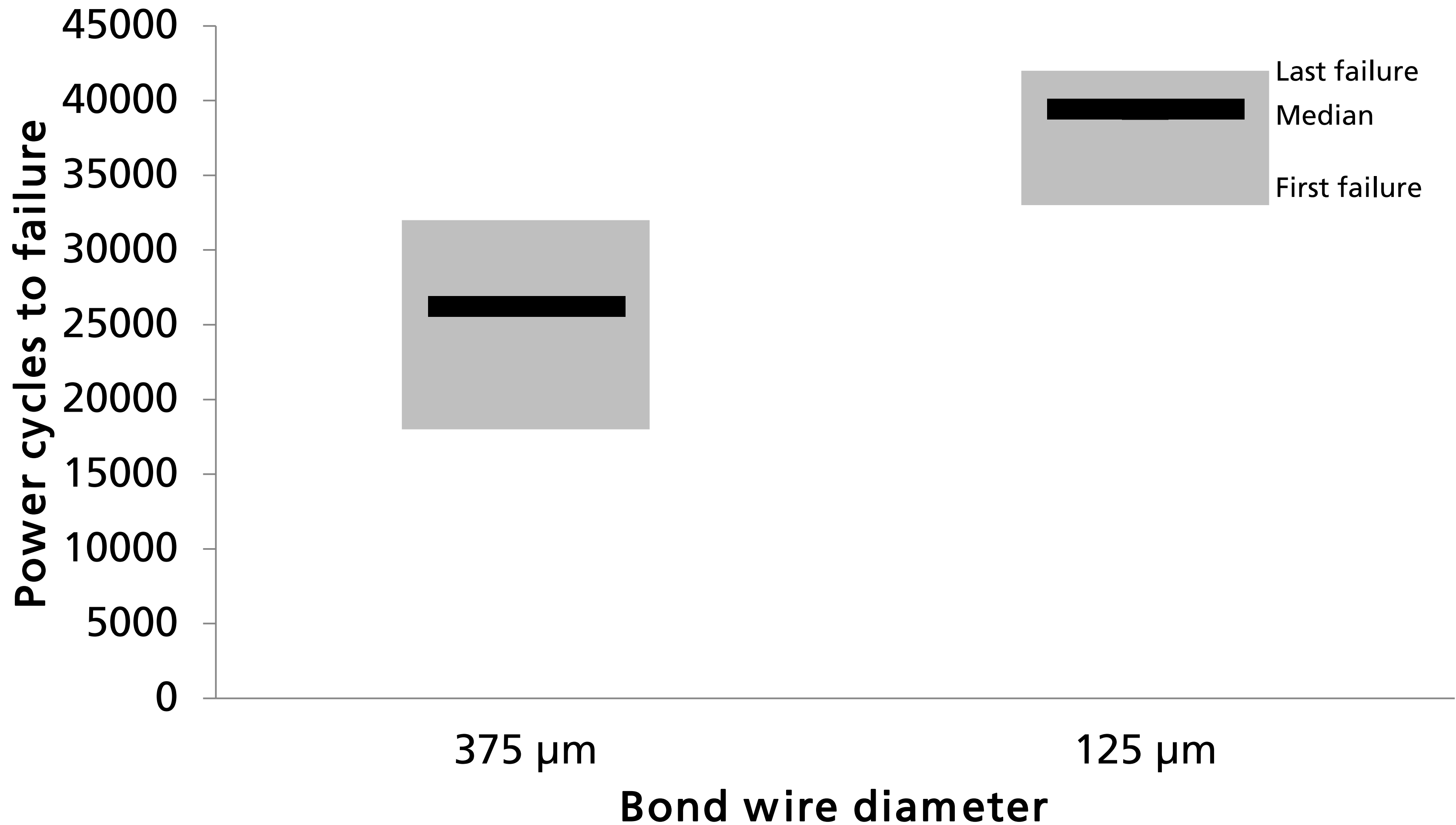
Power Cycling: Test Results



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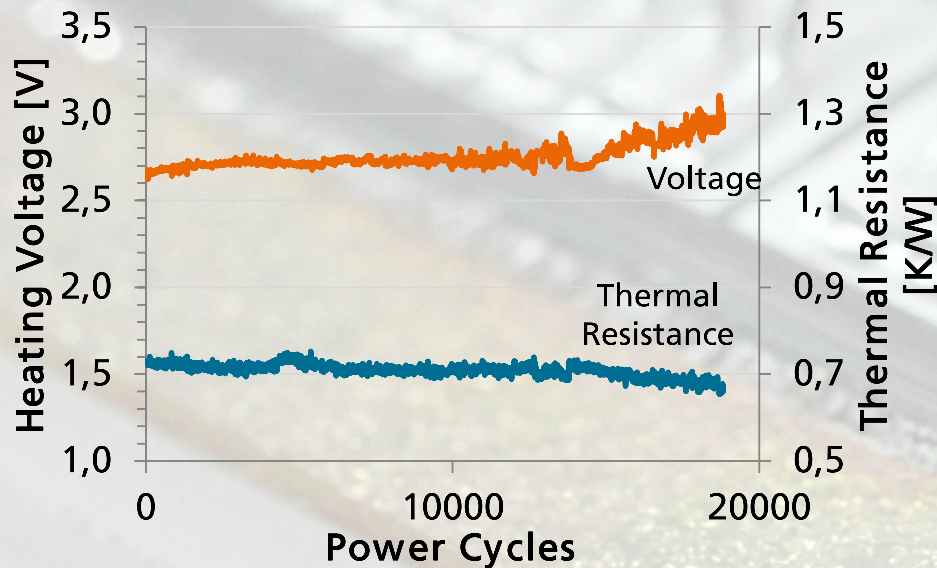
Test Results: 375 µm Wires

- Failure cause: **bond wire lift off**
- No real solder damage
- No increase of thermal resistance
- Increase in heating voltage



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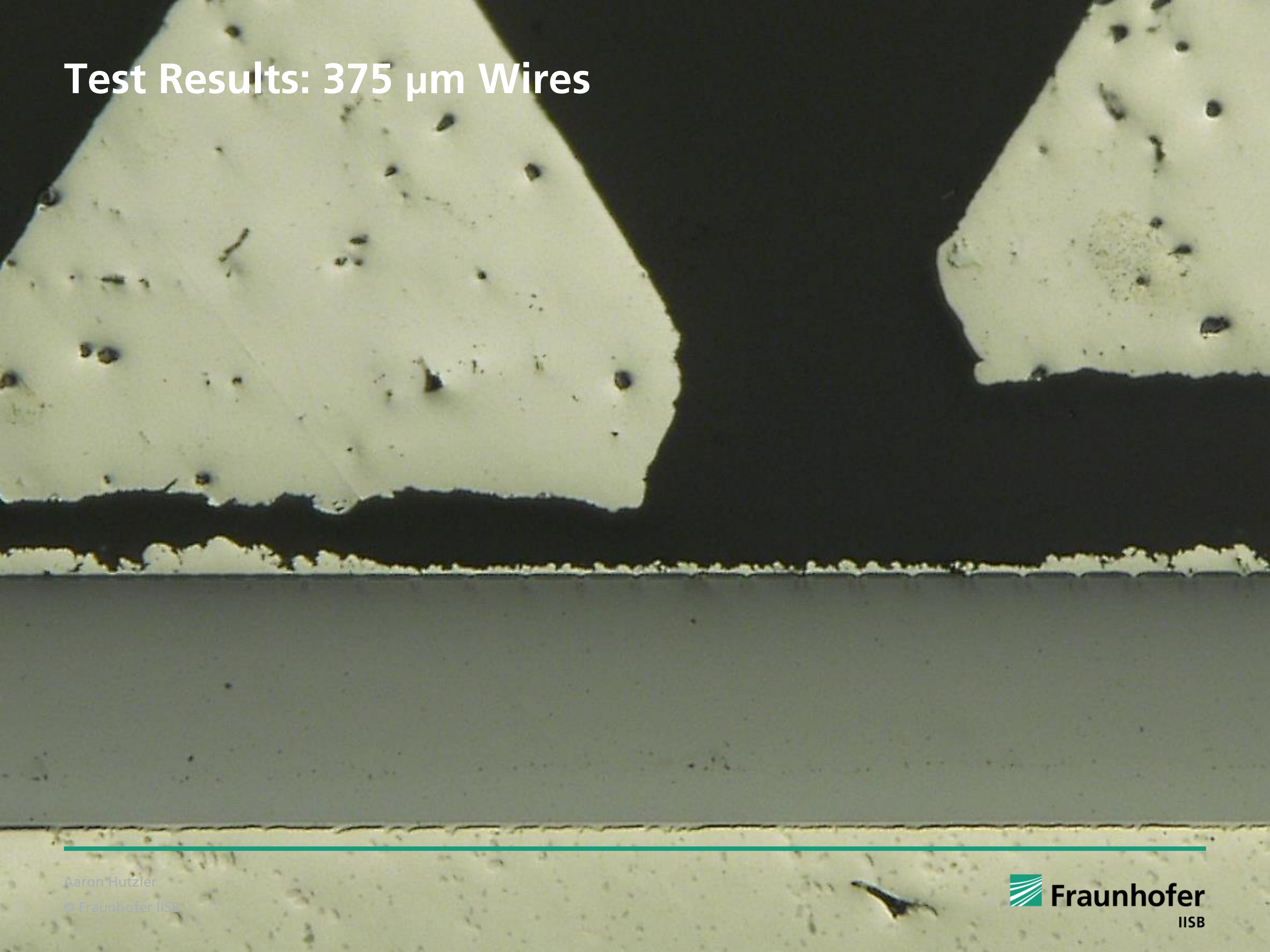
Test Results: 375 µm Wires



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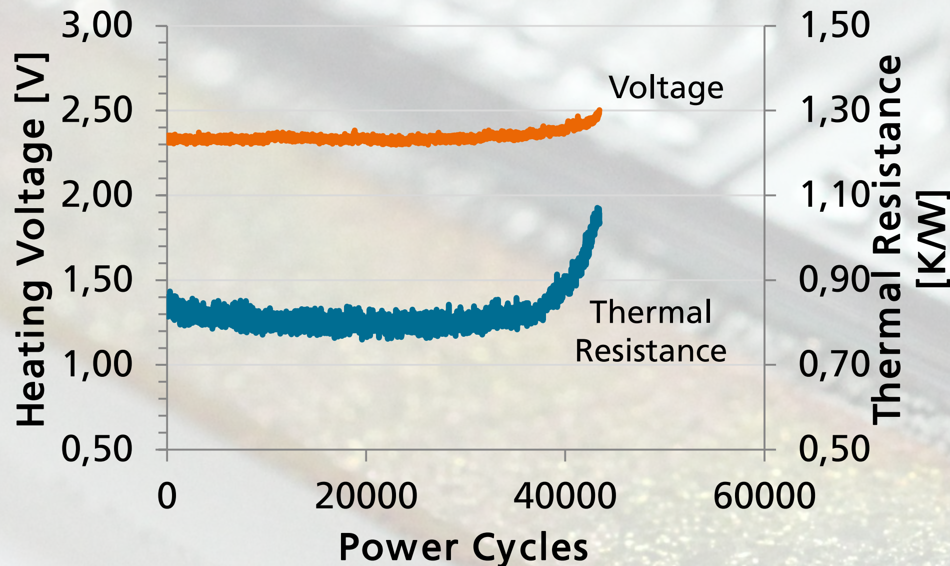
Test Results: 125 µm Wires

- Failure cause: **solder degradation**
- Bond wires were in good condition after test
- Increase of thermal resistance
- Constant heating voltage



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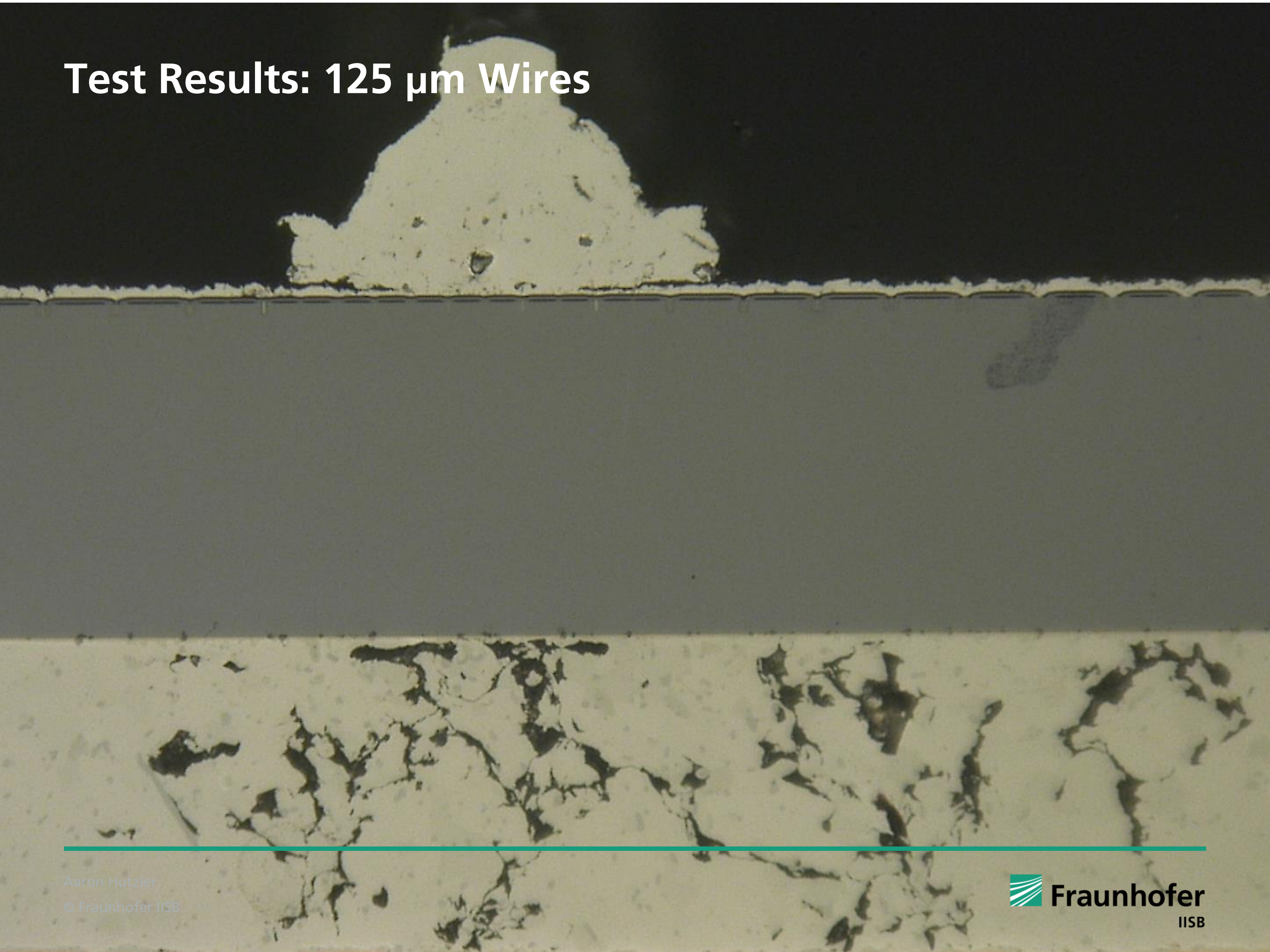
Test Results: 125 µm Wires



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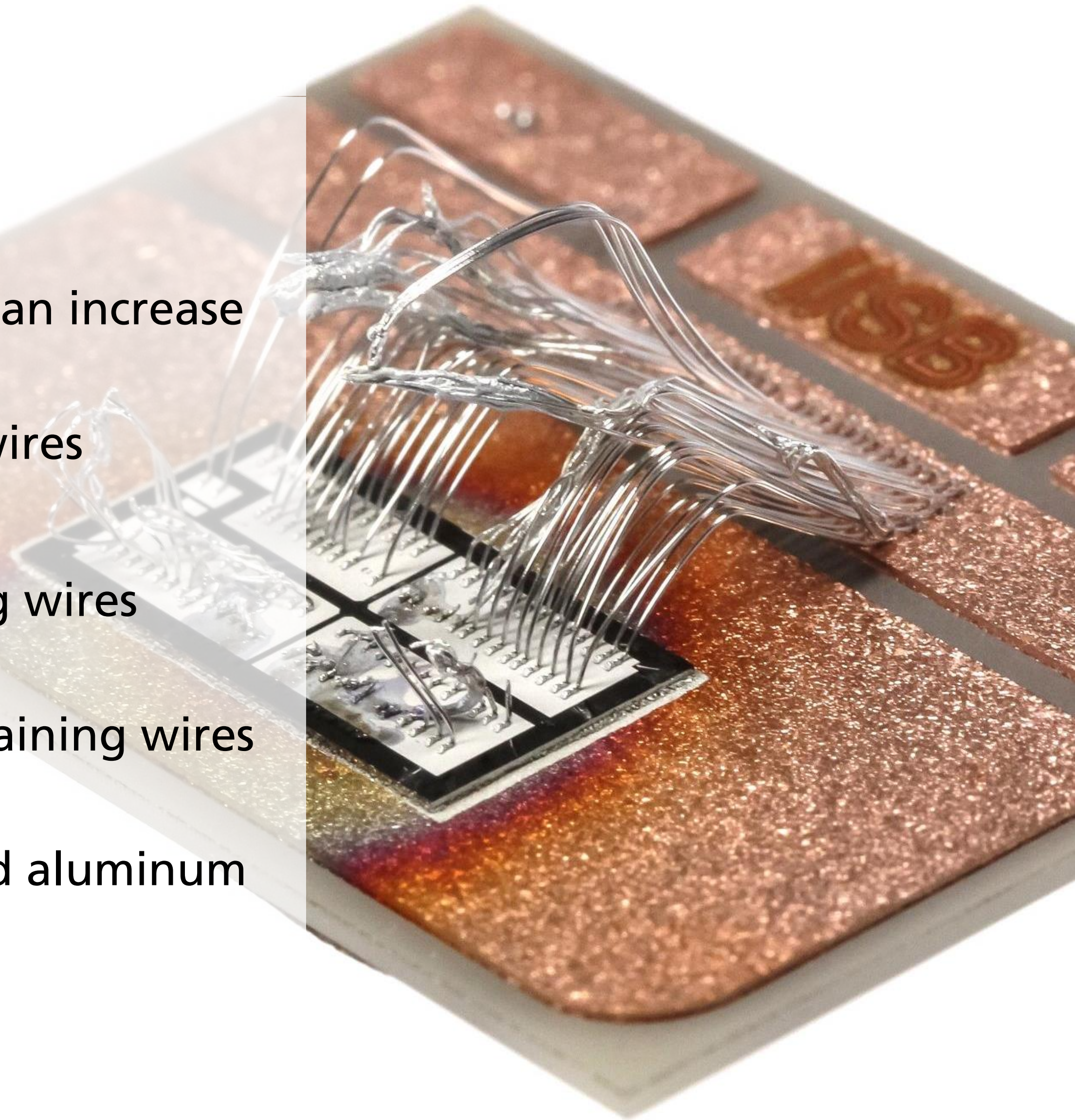
Failure Mechanisms



- Problem: **interactions**
  - Solder degradation effects an increase of chip temperature
  - Increasing stress on bond wires
  - Bond wire lift offs
  - Current stress on remaining wires increases
  - Temperature stress on remaining wires increases
  - Worst case scenario: melted aluminum

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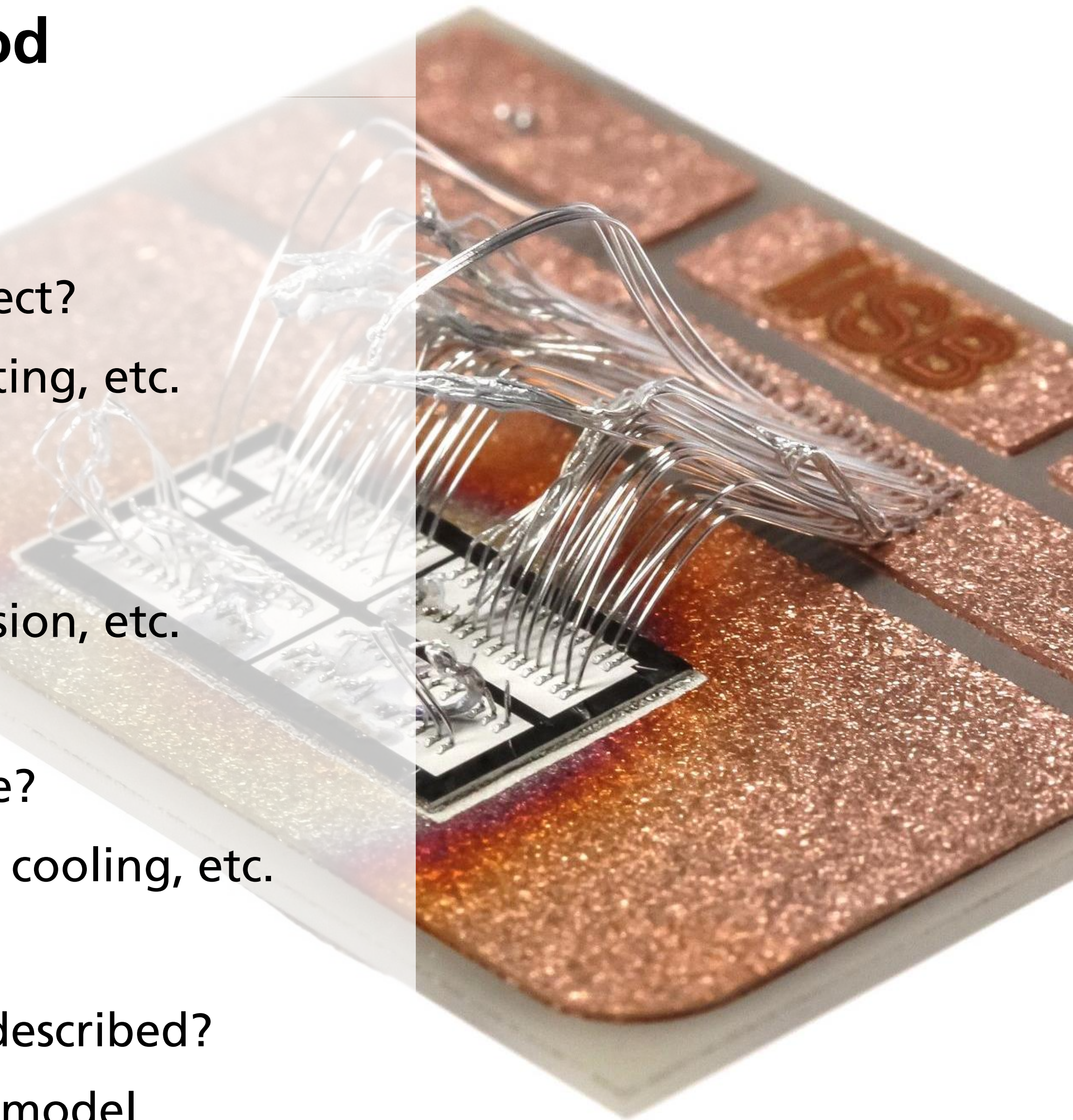
Physics of Failure Method



- Failure-Mode
  - What kind of failure effect?
  - Short circuit, idling, heating, etc.
- Failure-Cause
  - What kind of process?
  - Cracks, migration, corrosion, etc.
- Failure-Mechanism
  - What triggers the failure?
  - Bond wires, solder layer, cooling, etc.
- Failure-Mode
  - How can the failure be described?
  - Mathematical/statistical model

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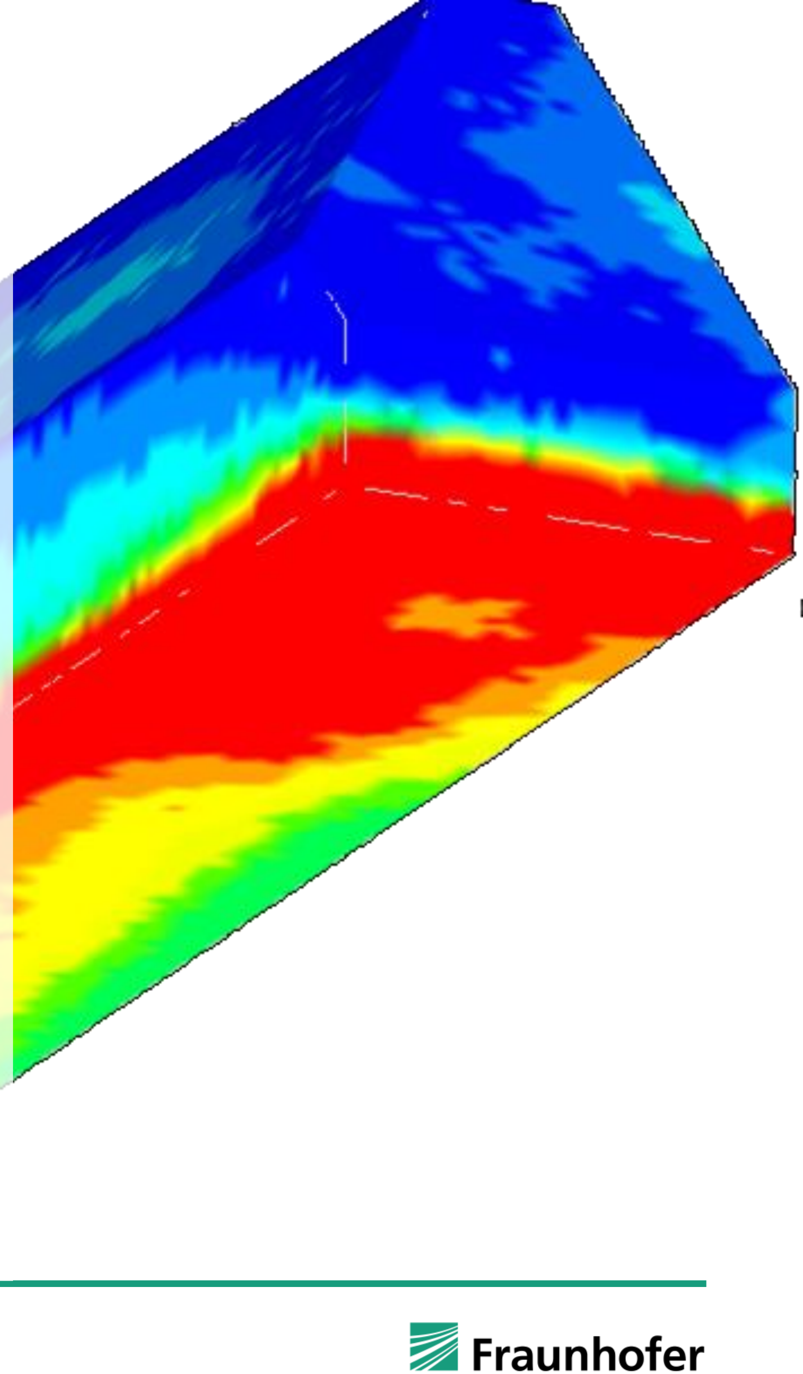
Finite Element Method (FEM)



- Geometry from laser-profilometry and light microscopy
- *Ansys Workbench* with solver *LS-Dyna*
- Temperature cycle from 77°F to 311°F (25°C to 175°C)
- CTE-Mismatch
  - $\Delta l = l_0 \cdot \alpha_{Al} \cdot \Delta T$
- Calculation of plastic strain
- Coffin-Manson Model to predict lifetime
  - $N_f = c_1 \cdot \Delta\varepsilon_{plastic}^{c_2}$

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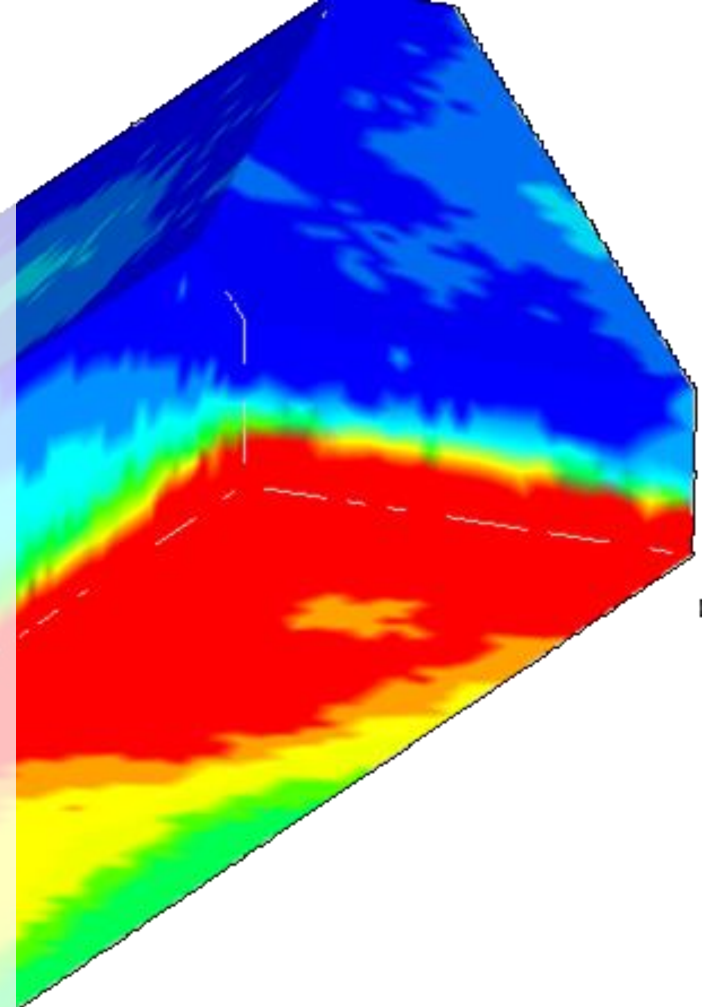
Finite Element Method (FEM)



- Other influences on lifetime of bond wires (375 vs. 125 µm wires)
  - Different current distribution
  - Different surface area
  - Molding compound properties
  - Die-Attach properties
  - …
  - Temperature-dependent material properties
  - Thermal management
- **Result**
  - Different temperatures and stresses
  - Evaluation of simulation via test necessary

Conclusion and Discussion

- New technologies
  - Copper wire bonding
  - Ribbon sintering
- Not state-of-the-art
  - Cost intensive
  - No reliable process

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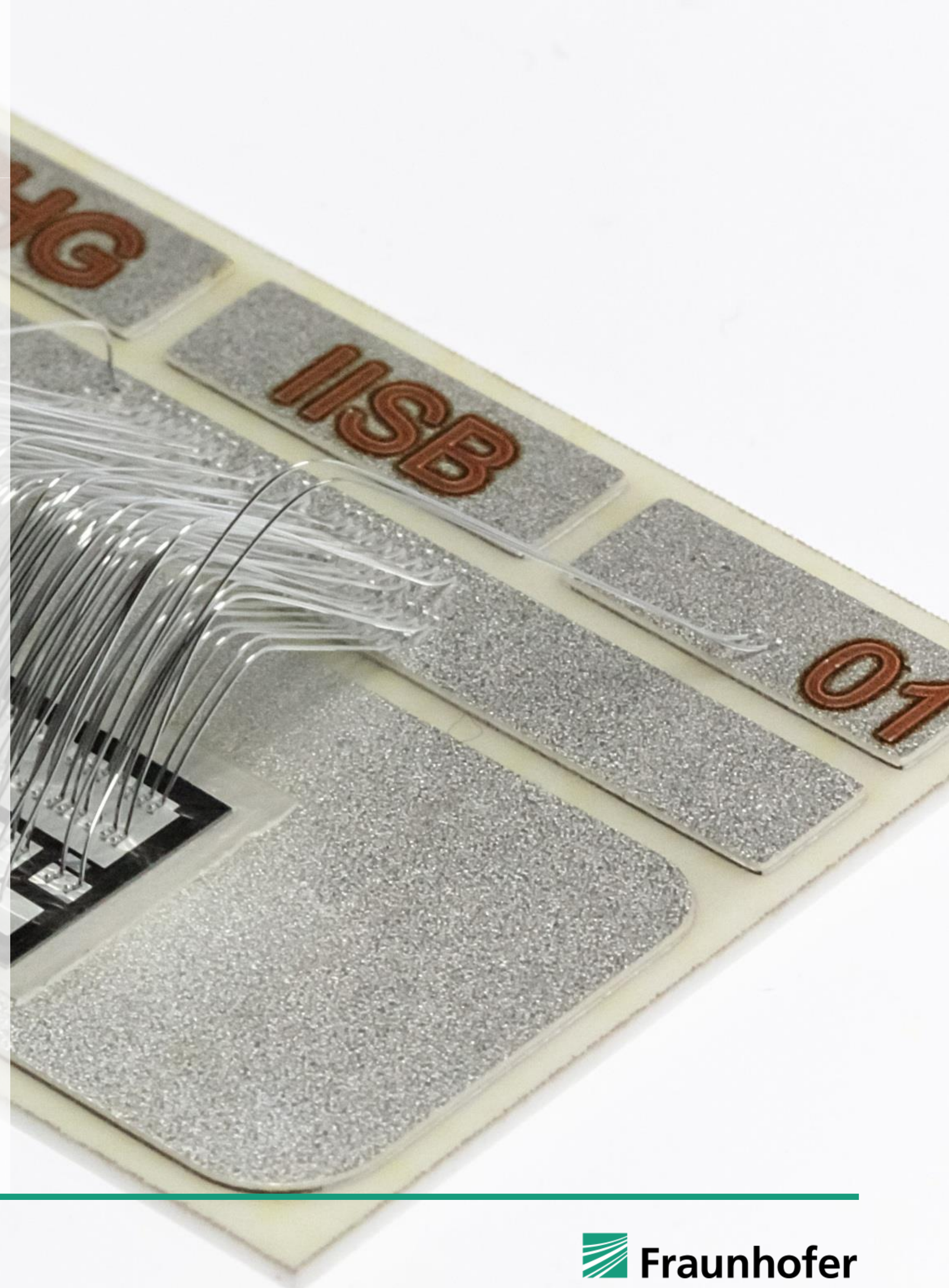
Conclusion and Discussion

- Al wire bonding
  - Still high potential
  - Very reliable process
  - High lifetime possible in combination with silver sintering
- Wire diameters have to be adopted to application



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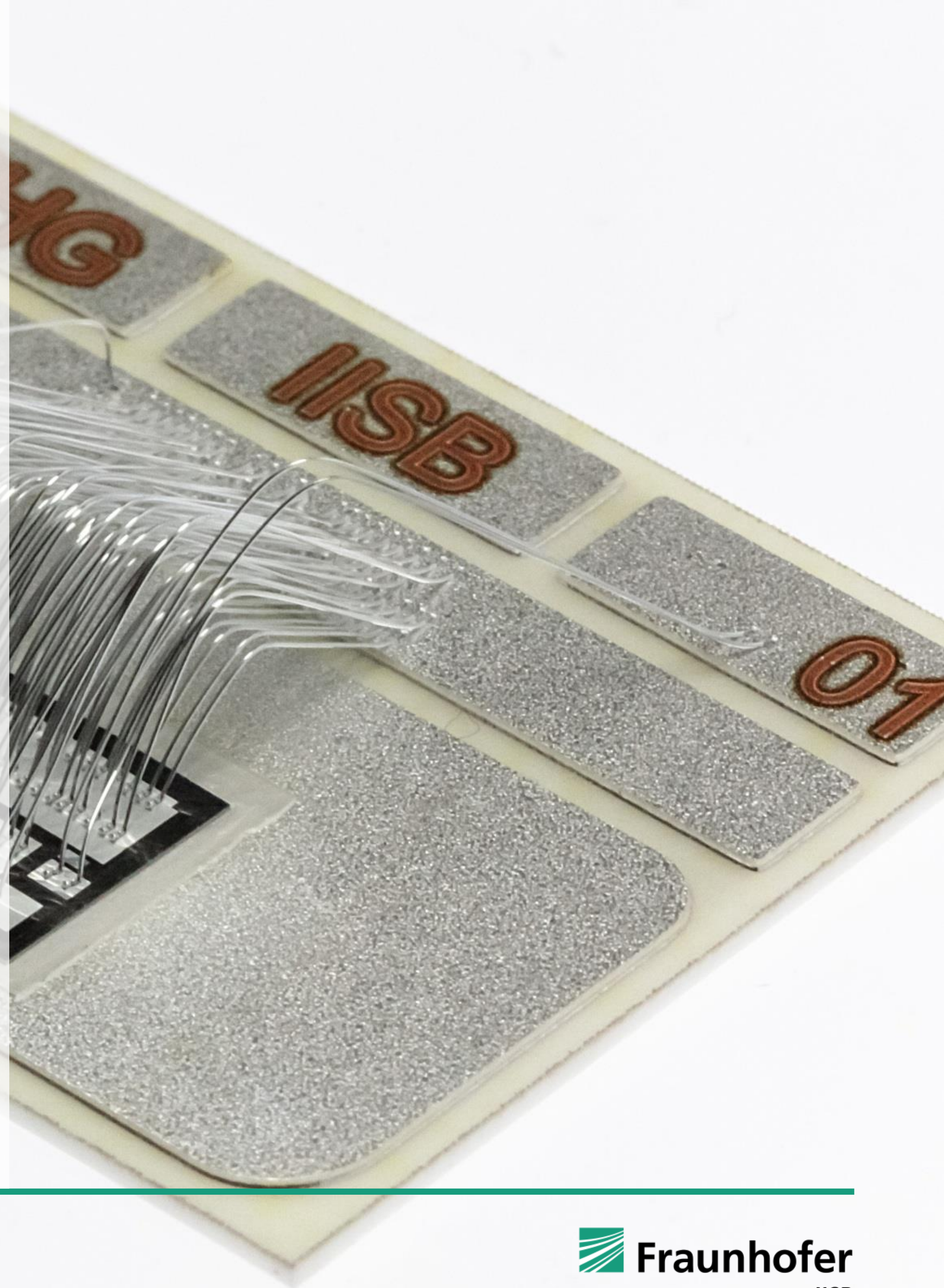
Conclusion and Discussion

- Wire diameters have to be adopted to application
- Depending on
  - Application current
  - Thermal management
  - Bond pad size
  - Power module type

- Flexible and fast bonding machines for small wires are needed



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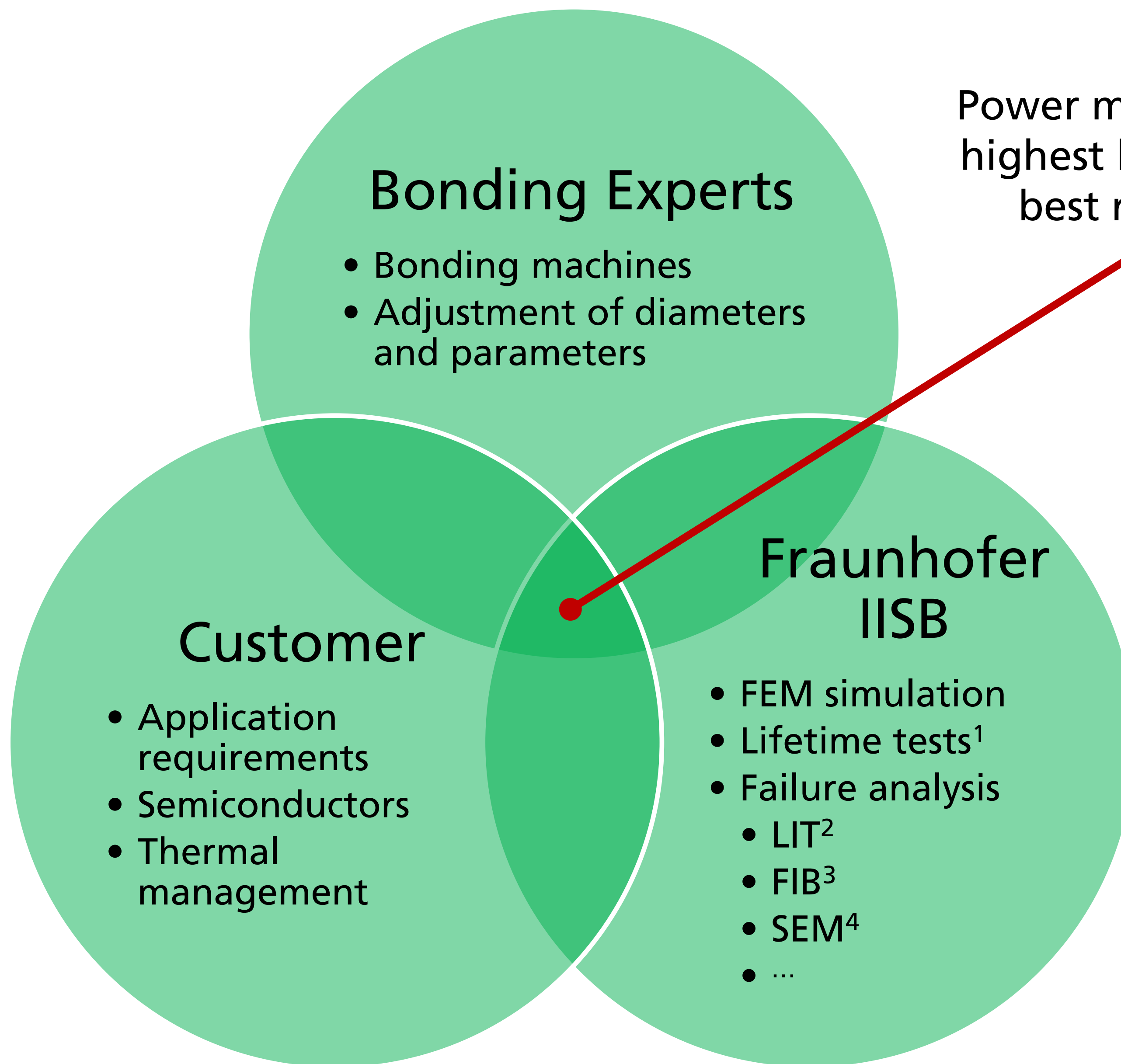

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1) Active power cycling, passive temperature cycling, vibration tests, hot storage, etc.
2) Lock-in Thermography; 3) Focused Ion Beam; 4) Scanning Electron Microcopy

Wire bonding remains hot!

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