University of Stuttgart
Institute for Power Electronics
and Electrical Drives

Power Electronic Systems for Electric Aircraft

E² Flight Symposium, 20th February 2020, Stuttgart

Agenda

Power Electronic Systems for Electric Aircraft

- Voltage- & Power-Levels
- Power Electronic Systems
- Redundancy
- Semiconductors (SiC)
- Electromagnetic Compatibility
- Reliability & Lifetime

Voltage- & Power-Levels

The bus voltage levels differ, regarding:

MORE ELECTRIC AIRCRAFT (MEA)

ALL ELECTRIC AIRCRAFT (AEA)

- DC bus voltage: 270 V, 350 V, 540 V, higher?
- Avionics DC bus: 28 V
- AC bus voltage :
  - 115 V or 230 V
  - 400 Hz fixed or 350-800 Hz variable
- With higher rated powers the bus voltage levels trend to even higher values.

Watch out: Paschen´s Law

With sinking pressure partial discharge occurs at lower voltages!

Key questions:

System architecture?

Insulation strength?

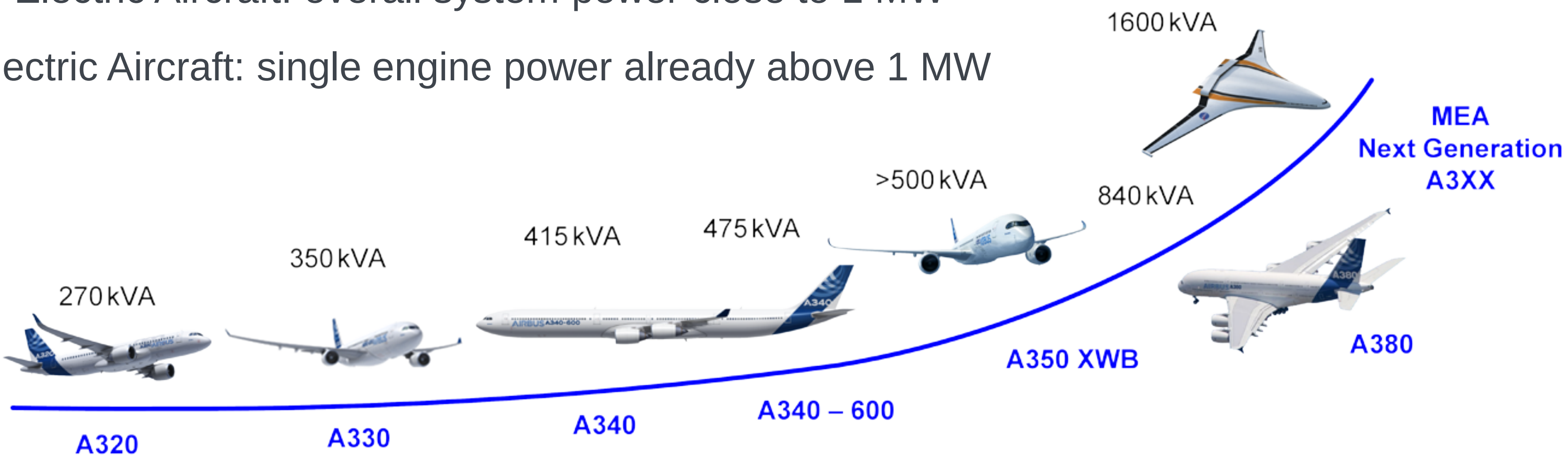
Voltage- & Power-Levels

The power ratings differ, regarding:

MORE ELECTRIC AIRCRAFT (MEA)

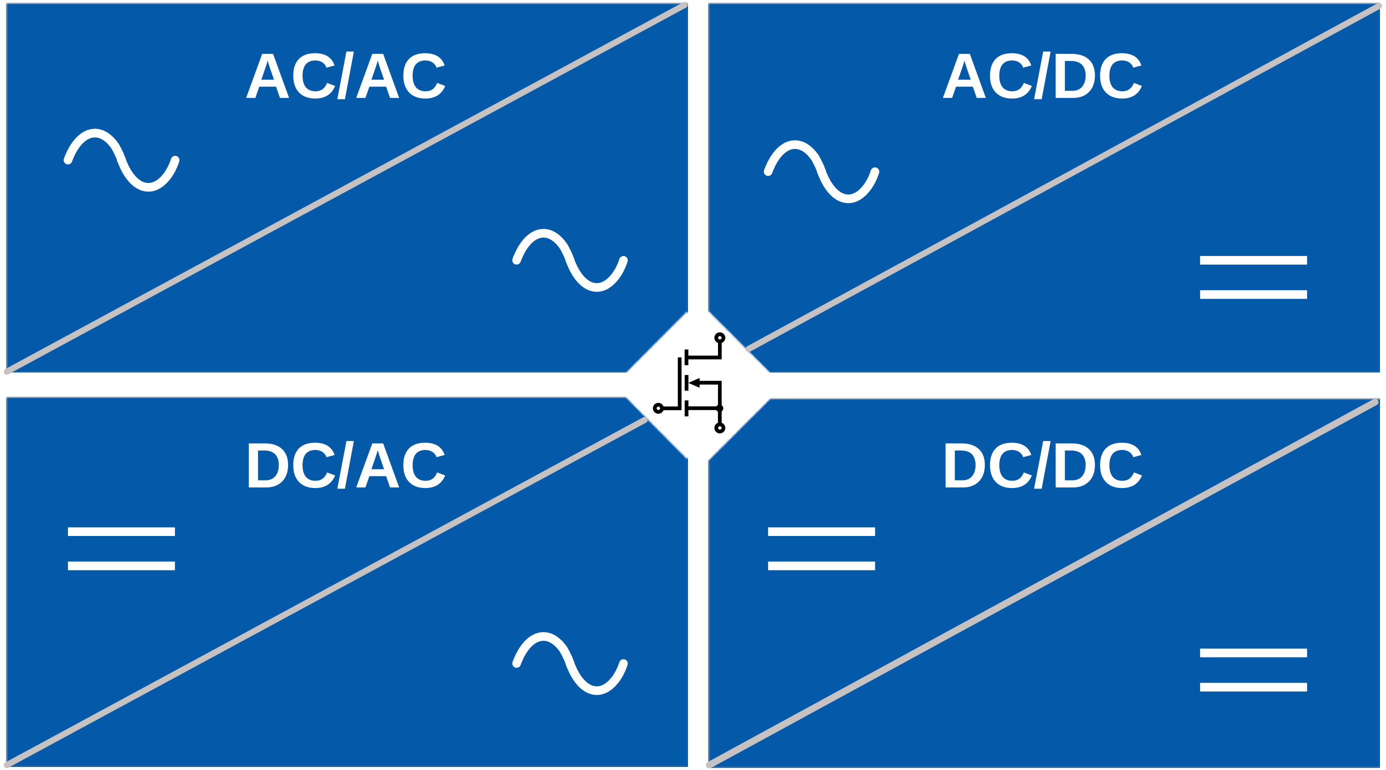
ALL ELECTRIC AIRCRAFT (AEA)

- Trend in electrification of conventional aircraft: radically rising power ratings
- More Electric Aircraft: overall system power close to 1 MW
- All Electric Aircraft: single engine power already above 1 MW



Power Electronics for Electrical Aviation: Overview

Conversion of Voltage & Current: Form, Frequency and Amplitude



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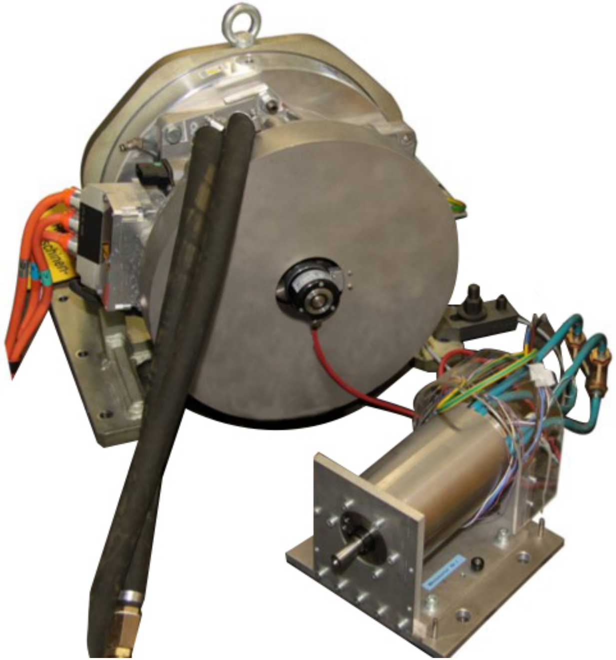
Key challenges for power electronics in electric aircrafts

Redundancy

Scalability of Electrical Motors

- Size of electrical motors decreases dramatically with their speed
- Demand for small and light machines with high power density results in increase of speed

Propeller tip speed ↑
↓
Noise ↑
↓
Smaller propeller ↓
↓
More motors ↑



P_N	=	30 kW
n_N	=	2700 min^{-1}
M_N	=	106 Nm
l	=	240 mm
d	=	400 mm

P_N	=	31 kW
n_N	=	30.000 min^{-1}
M_N	=	10 Nm
l	=	200 mm
d	=	120 mm

Redundancy

Distributed Electric Propulsion

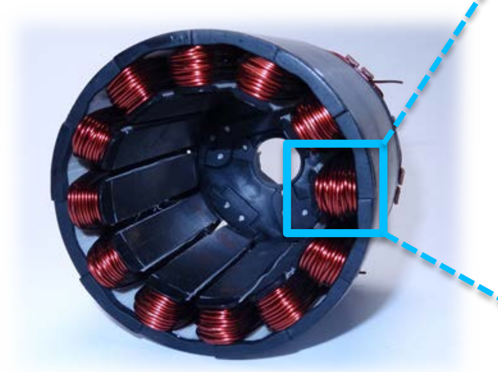
- Creates Redundancy
- Improves propulsive efficiency
- Gives more degrees of freedom in terms of
  - Aerodynamic design
  - Control
  - Flight strategy
  - Power distribution

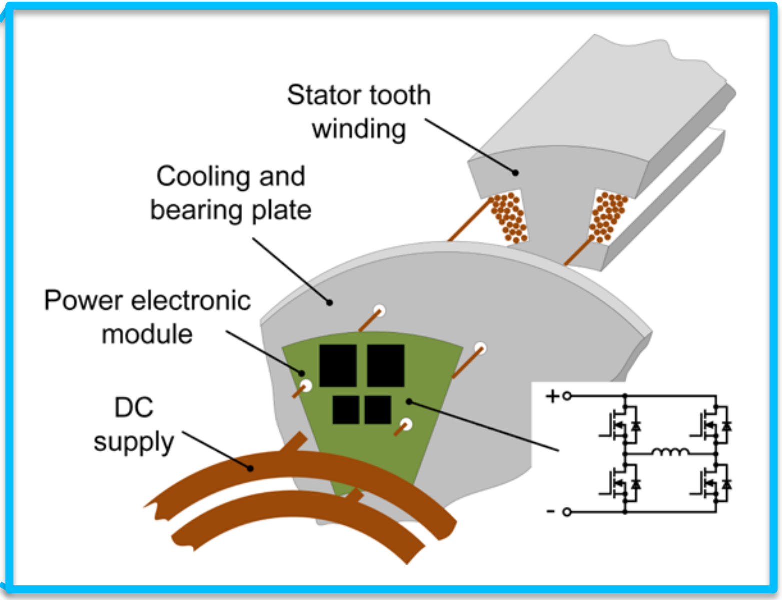
- Raises the complexity of
  - Power electronic system
  - Central control unit
  - Energy distribution
  - Fault management

➢ **Demands for modular and scalable power electronic components**

Redundancy
Multiphase Motors

- Use of multi phase motors gives more degrees of freedom in design and control
- Modular and integrated power electronic blocks distribute power flow and create redundancy
- Universal PE blocks simplify maintenance and certification





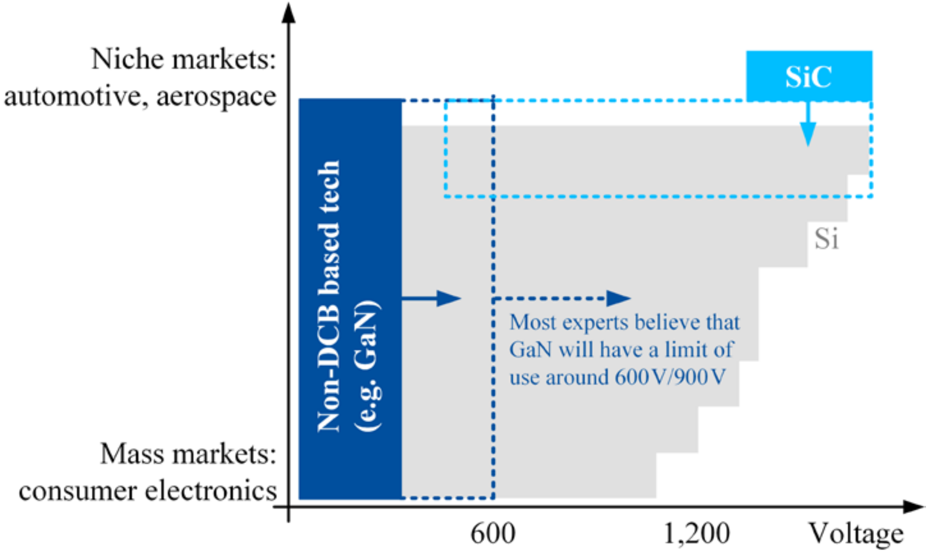
Project „mi48ETA“ funded by the Vector Stiftung: https://vector-stiftung.de/projekte/modularer-integrierter-48-v-elektrotraktionsantrieb-mi48eta/

Semiconductors

Wide Bandgap (WBG) Power Semiconductors

- Development of WBG materials leads to innovations in semiconductor market
- Silicon carbide (SiC) and gallium nitride (GaN) promise many advantages

- SiC & GaN power semiconductors are still under development and not as well researched as silicon semiconductors
- Shift in technologies and market segments can be expected

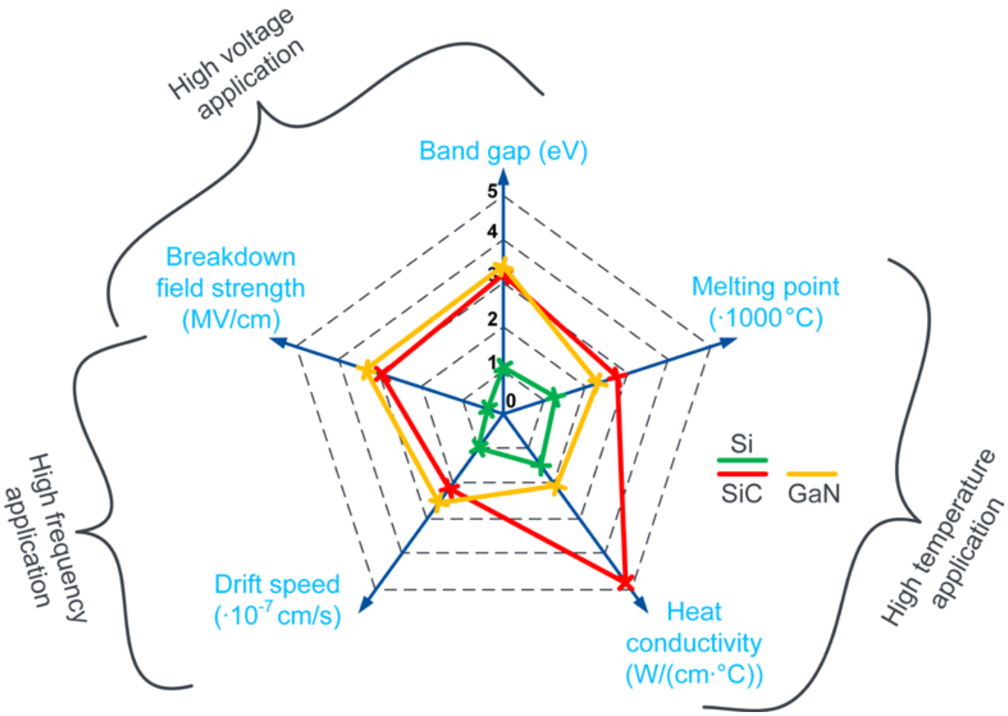


Based on source: Roland Berger

Semiconductors

SiC in Electric Aviation Applications

- SiC semiconductor devices:
  - Higher switching frequency
  - Smaller chip area
  - Less switching & conduction losses
- Advantages:
  - Higher power and current density of PE
  - Lighter and smaller cooling systems
  - More robust against cosmic radiation
- Challenges:
  - Electromagnetic compatibility
  - Reliability



Electromagnetic Compatibility

Motor Winding Stress

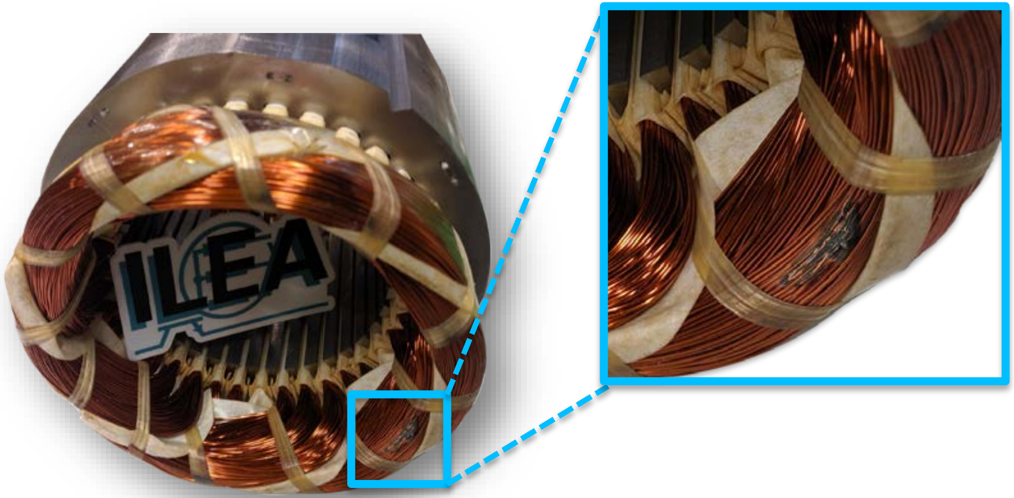
- High bus voltages
- Fast switching semiconductors

High voltage change rates in the motor winding

↑ $\frac{dV}{dt}$

- Motor winding insulation system:
  - High voltage capability
  - High temperature capability
  - Thin film for high power density

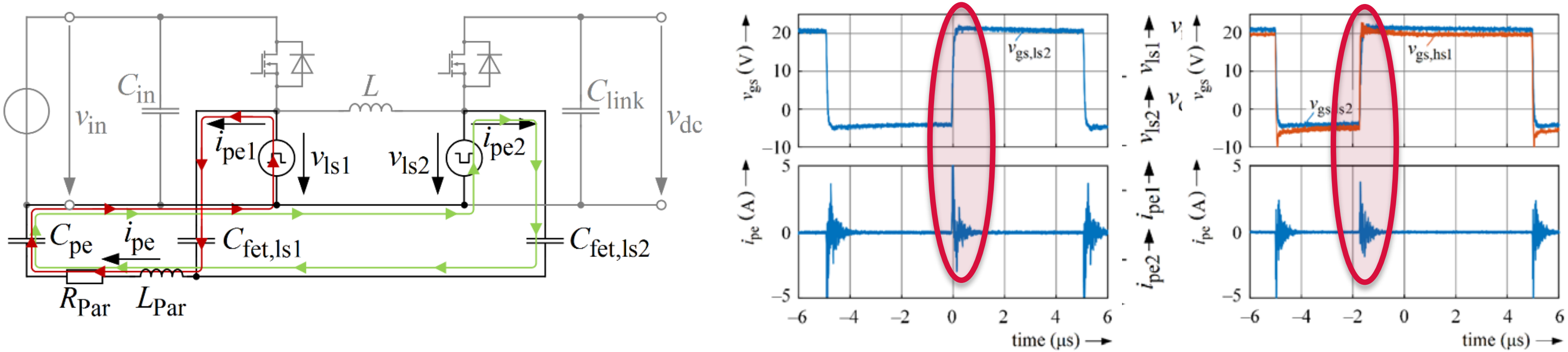
- Bearing currents!



Electromagnetic Compatibility

Active EMC

- Passive filters for EMC are bulky and heavy
- Active EMC: usage of “counter-switching cycles” to reduce leakage currents



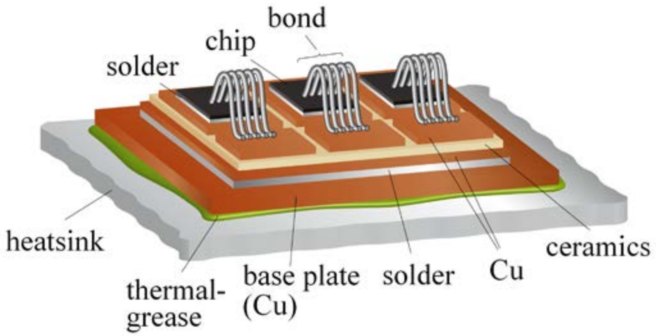
- Disadvantage: more effort and cost. However, possible if available anyway due to redundancy

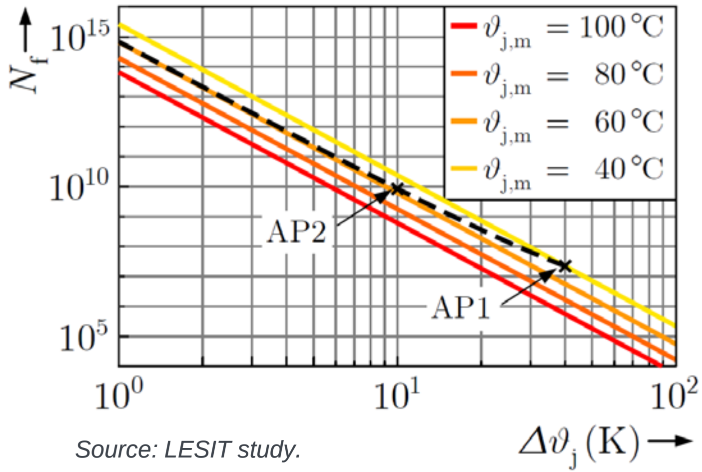
Source: M. Zehelein, J. Portik, M. Nitzsche, P. Marx and J. Roth-Stielow, "Reduction of the Leakage Currents by Switching Transition Synchronization for a Four-Switch Buck-Boost Converter," 2019 10th ICPE 2019 - ECCE Asia, Busan, Korea (South), 2019, pp. 2217-2223.

Reliability & Lifetime

Main Influence: Temperature Cycle

- Material layers have different coefficients of thermal expansion
- Load variations lead to change in temperature
  - Mechanical stresses between the layers
  - Aging / damage to the power transistor
  - Accelerated aging / enlarged damage if
    - $\vartheta_{j,m} \uparrow$
    - $\Delta\vartheta_j \uparrow$
    - $\Delta\vartheta_j / \Delta t \uparrow$



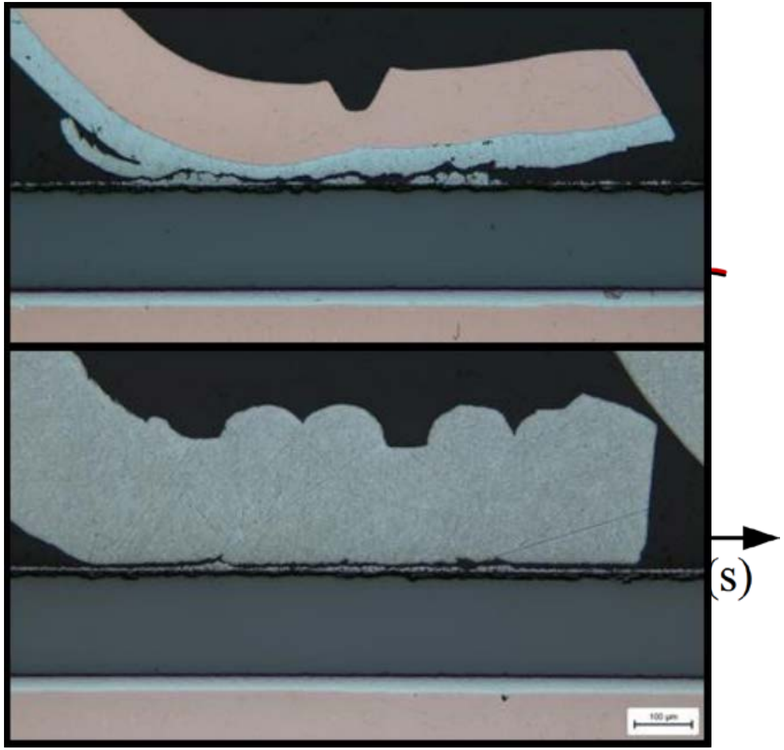


Source: LESIT study.

Reliability & Lifetime

Consequences & Solutions

- Degradation of chip, bonding and thermal path
  - Heel crack, bond wire lift off, substrate fracture
- Solutions:
  - Homogenous distribution of power – on system level as well as on device level
  - Temperature dependent control of PE
  - Application-oriented power cycling for realistic reliability data and certification



Source: Wagner, F.; Reber, G.; Rittner, M.; Guyenot, M.; Nitzsche, M.; Wunderle, B. (2020): Power Cycling of SiC MOSFET Single-Chip Modules with Additional Measurement Cycles for Life End Determination. In: CIPS 2020, IEEE.

Joint project "SiCeff" with Bosch, Porsche, Fraunhofer IZM, Unimicron and University of Stuttgart (ILEA & ILH)

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Some solutions are already available.

Many solutions are being researched.

We need to work together to make electric aviation happen!

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Thank you!

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Perhaps we can´t design planes…

… but we can power them!

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