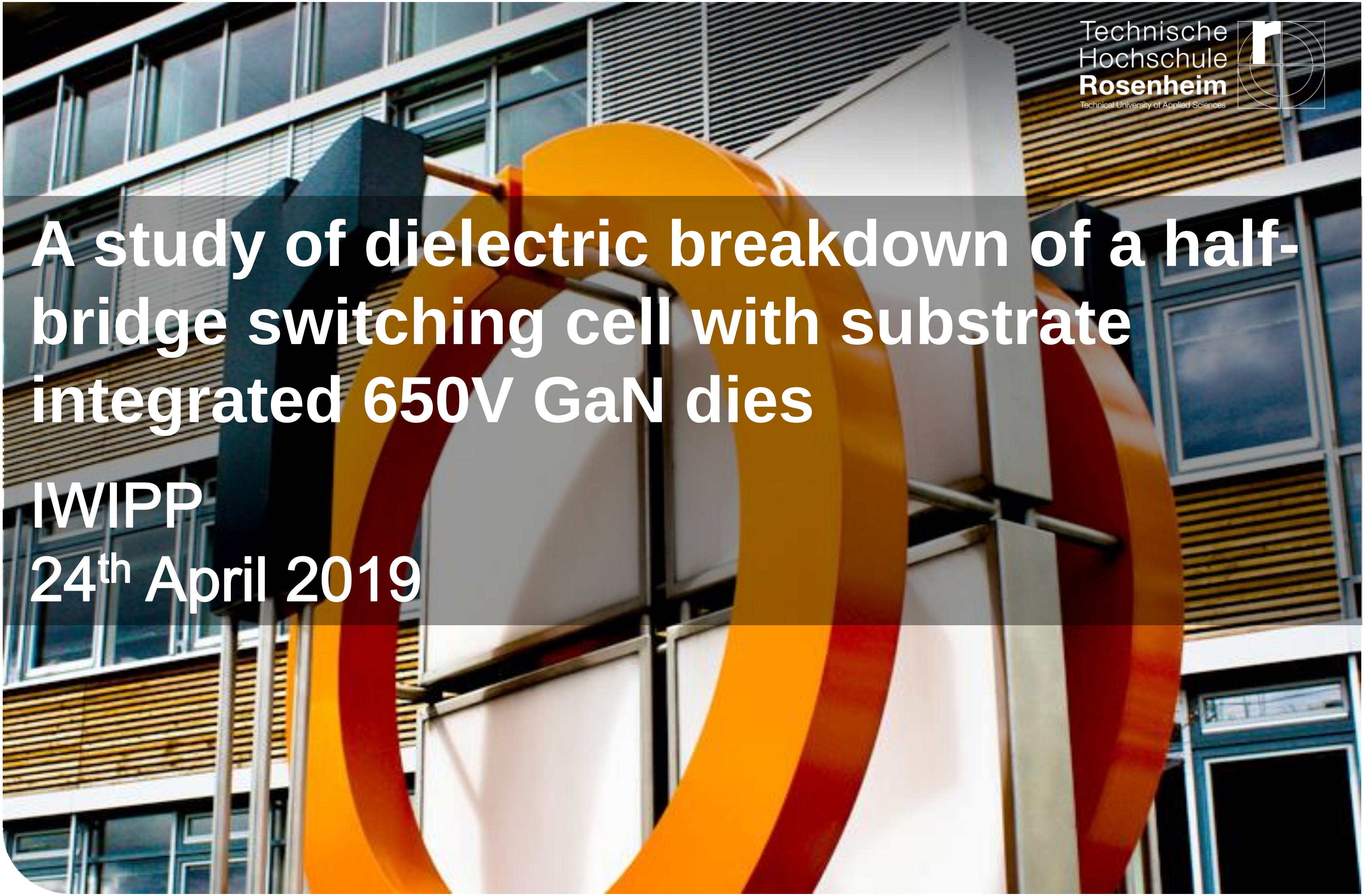


Technische Hochschule Rosenheim
Technical University of Applied Sciences

A study of dielectric breakdown of a half-bridge switching cell with substrate integrated 650V GaN dies

IWIPP

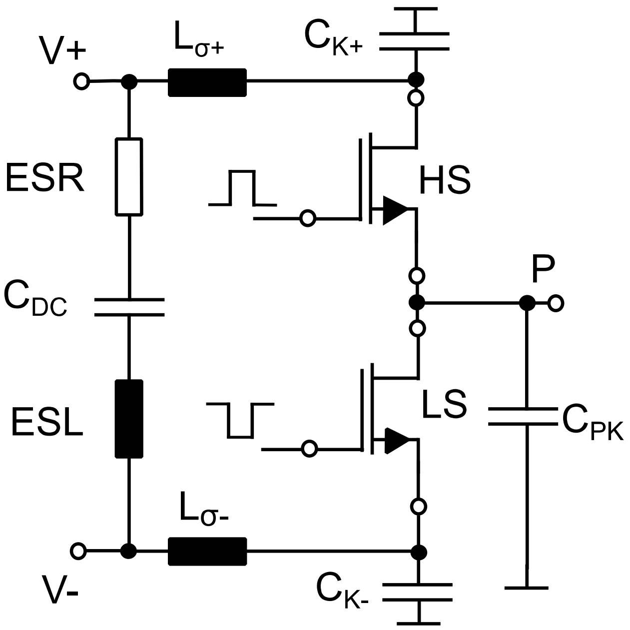
24th April 2019

Agenda

Technische Universität München

Technische Hochschule Rosenheim
Technical University of Applied Sciences

- Design of the switching cell
  - Manufacturing process
  - Implementation
- Electrical performance of the switching cell
- Electrical field modelling of the switching cell
- Experimental analysis of the DC breakdown voltage
  - Breakdown voltage of the switching cell
  - Influence of the temperature
  - Effects of aging
- Conclusion



Main steps in the integration process of the bare dies into the PCB

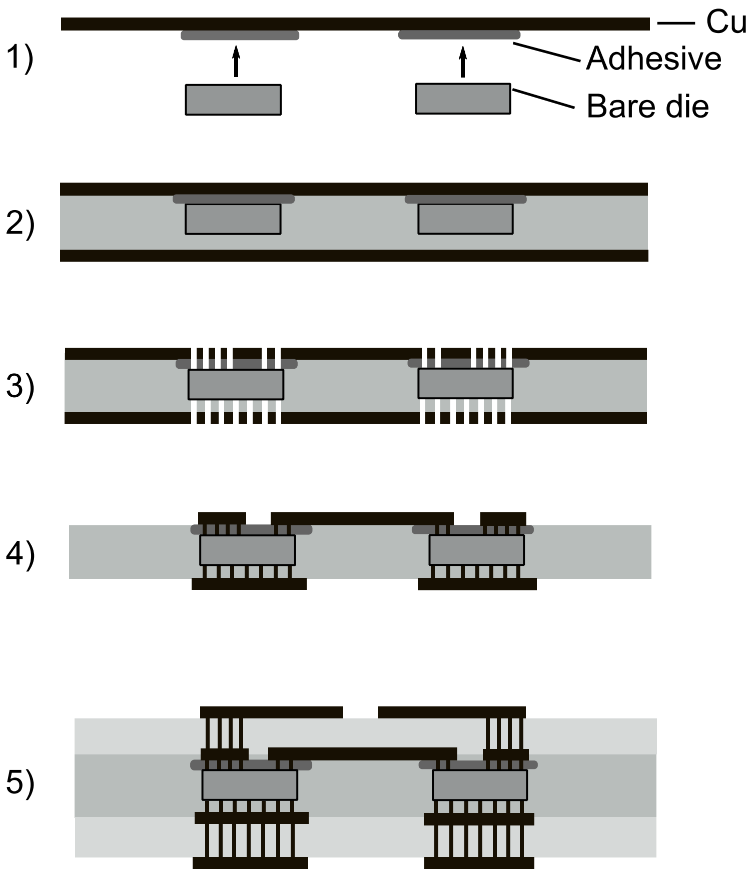
1) Glueing of the bare dies on a Cu foil

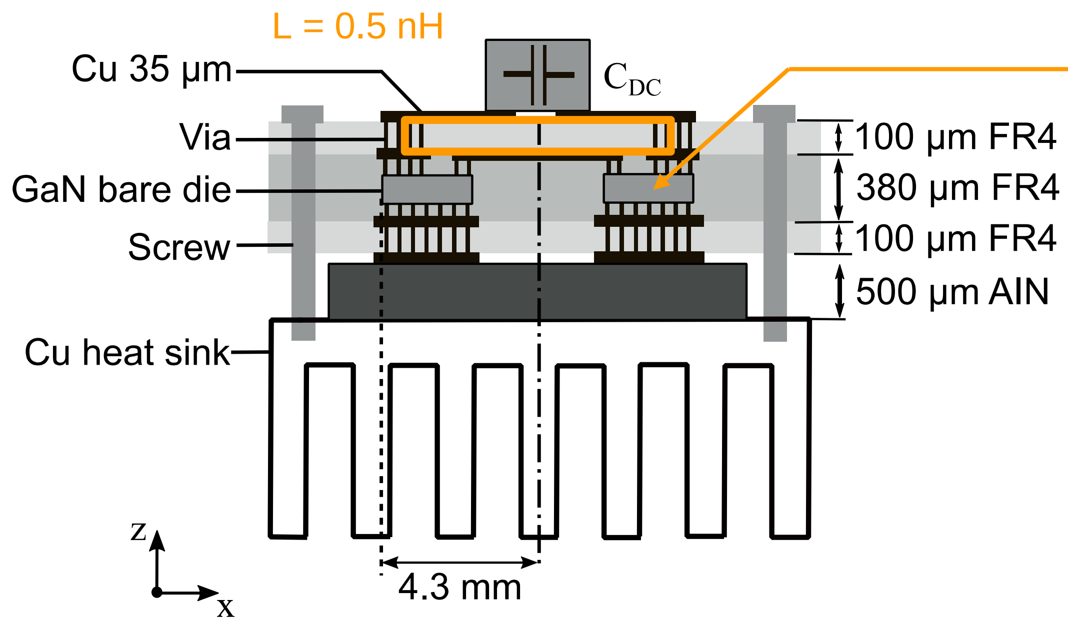
2) Laminating of the inner core

3) Laser drilling of chip contacts

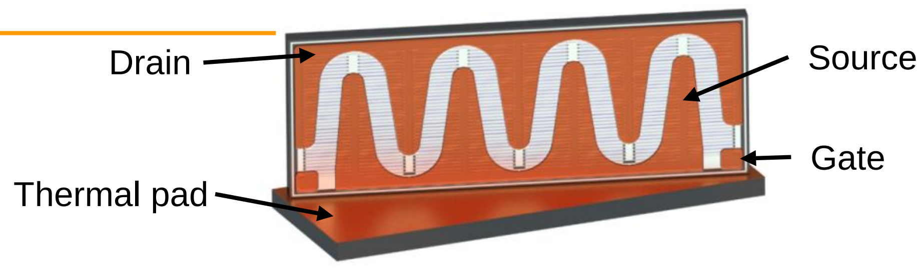
4) Electrical connection between chip and PCB traces with standard copper electroplating and structuring processes

5) Multilayer lamination and structuring of the outer layer





GaN Systems GS66508D



Parameter	Value
V_{DS}	650 V
I_D	30 A
Dimension	5.9 mm x 2.2 mm
Height	0.265 mm

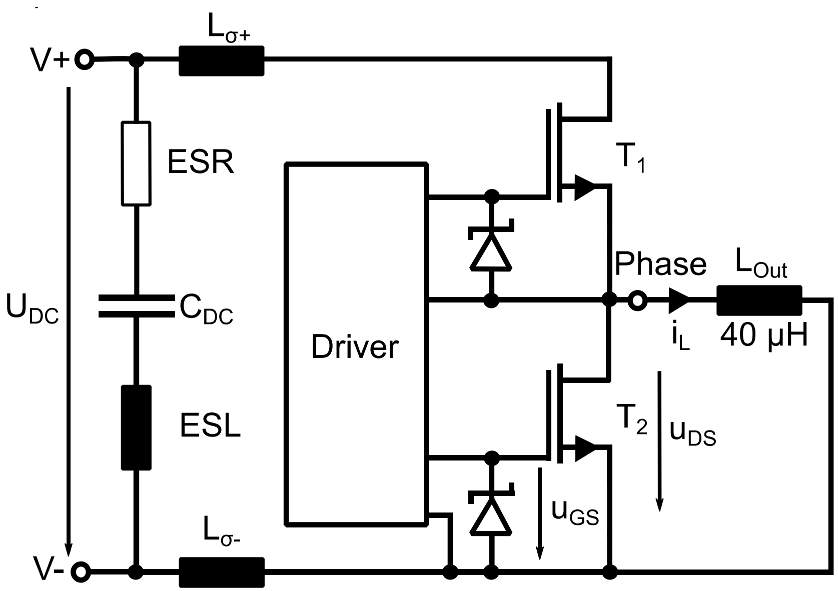
Characteristics

- 100 µm distance between drain and source
- Commutation loop inductance of 0.5 nH
- Aluminiumnitride (AlN) ceramics as isolation material between the Cu heat sink and PCB
- FR4 Material NPG-B 2116MR 40 kV/mm

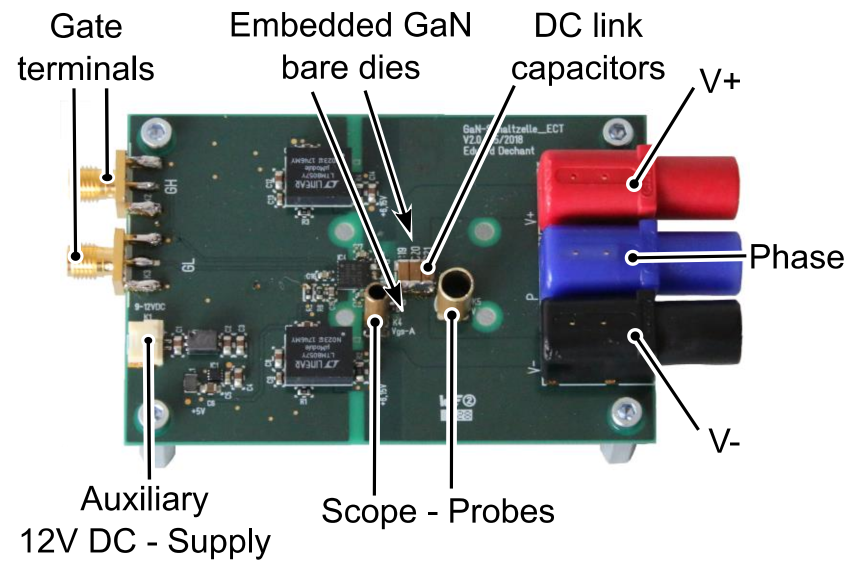
Performance of the switching cell

Double pulse test

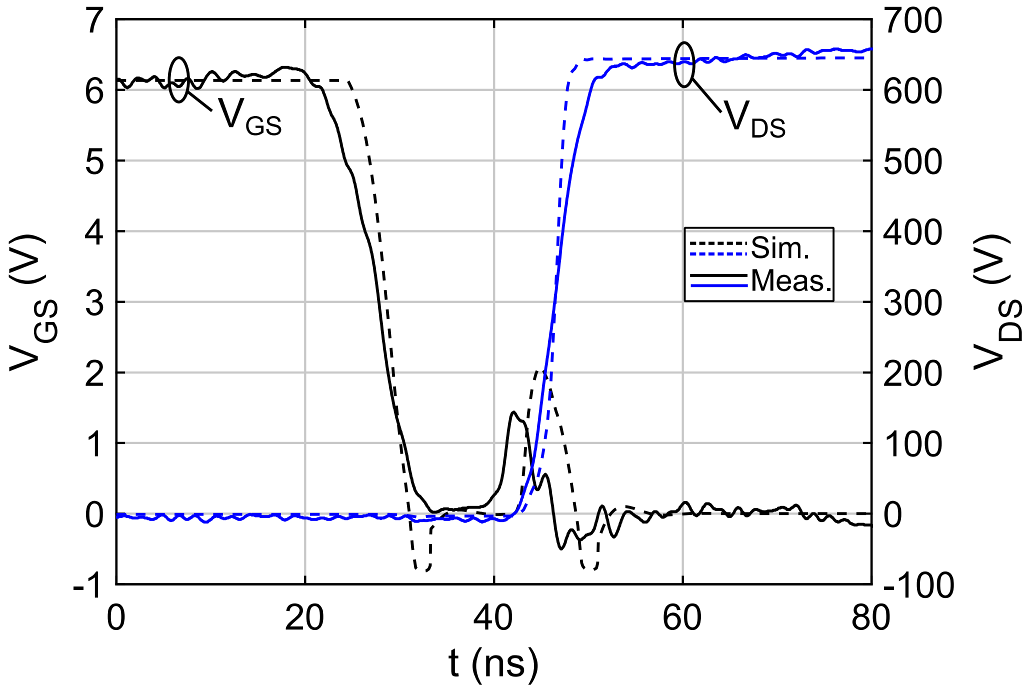
Schematic of the double pulse test



Experimental setup



The gate circuit contains no external gate resistor. The gate resistance consists only of the internal resistance of the driver (2.7 Ω) and the internal resistance of the GaN semiconductor (1.1 Ω).



Notes

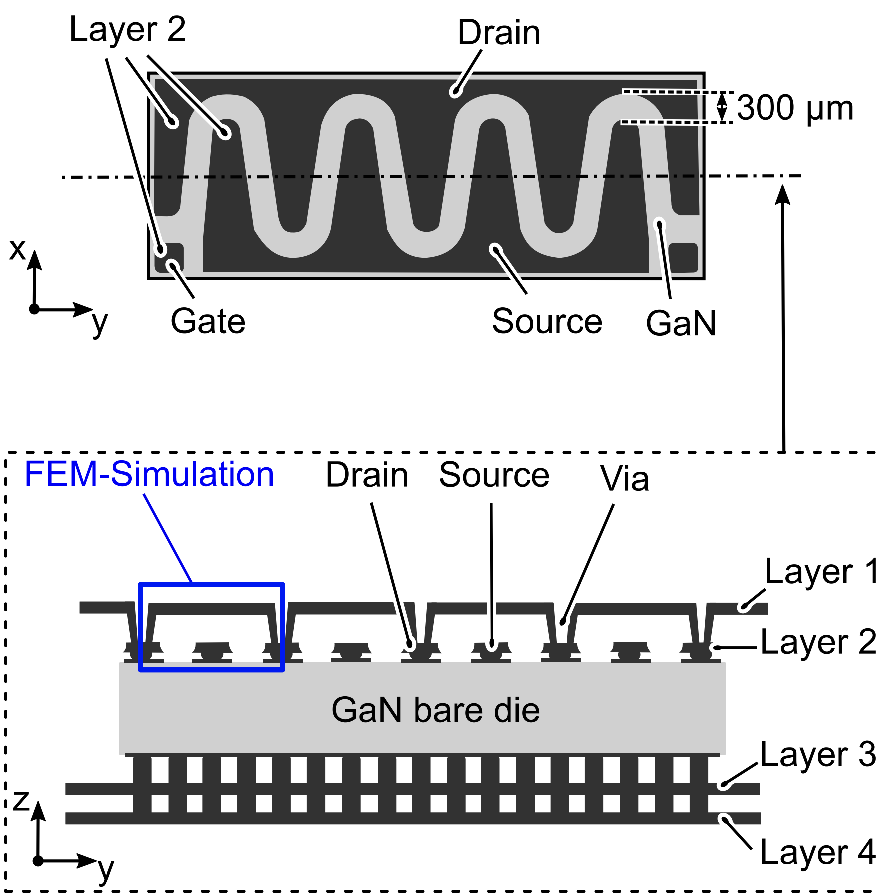
- 15 A turn off drain current I_D
- Simulation software LTspice

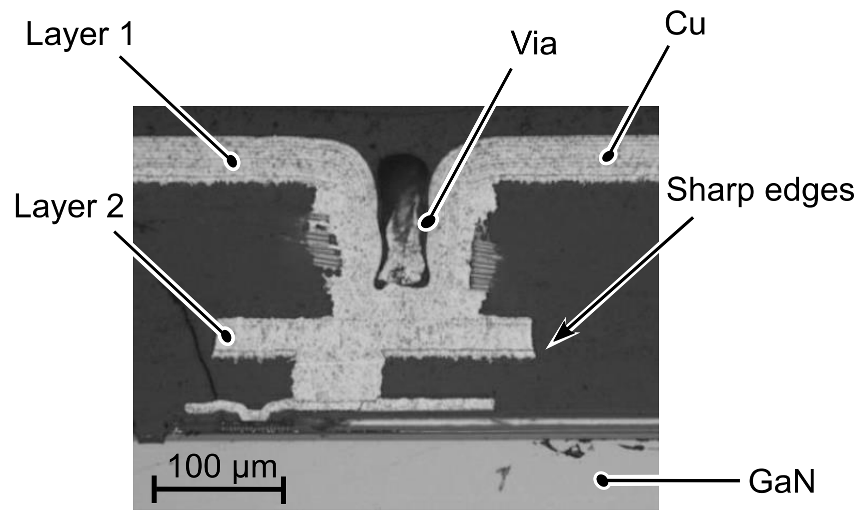
Results

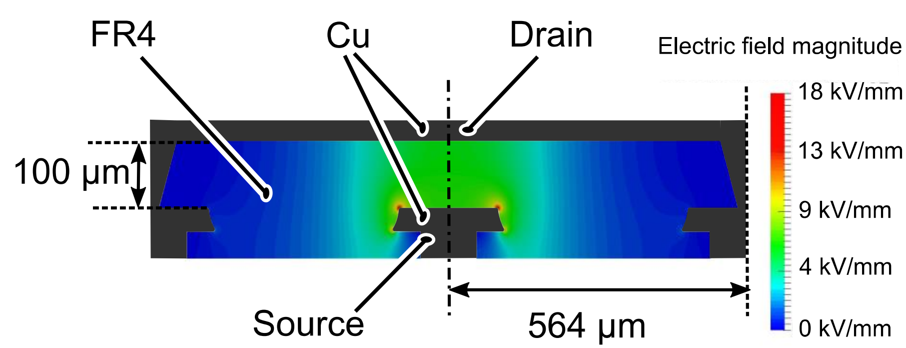
- In the turn-off switching process of the drain source voltage V_{DS} is no voltage overshoot visible
- The low short voltage spike at the voltage V_{GS} leads only to a small spurious turn on time of the low side GaN semiconductor
- The simulation fits very well the measurement

Electrical field modelling of the switching cell

Analysis of critical paths







Experimental analysis of the DC breakdown voltage
Two plates

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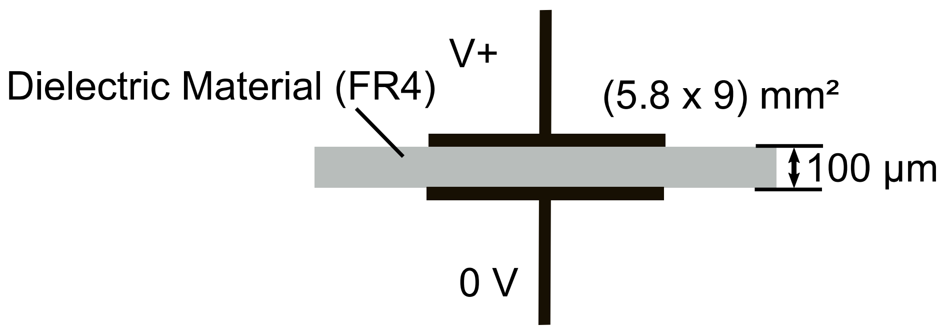
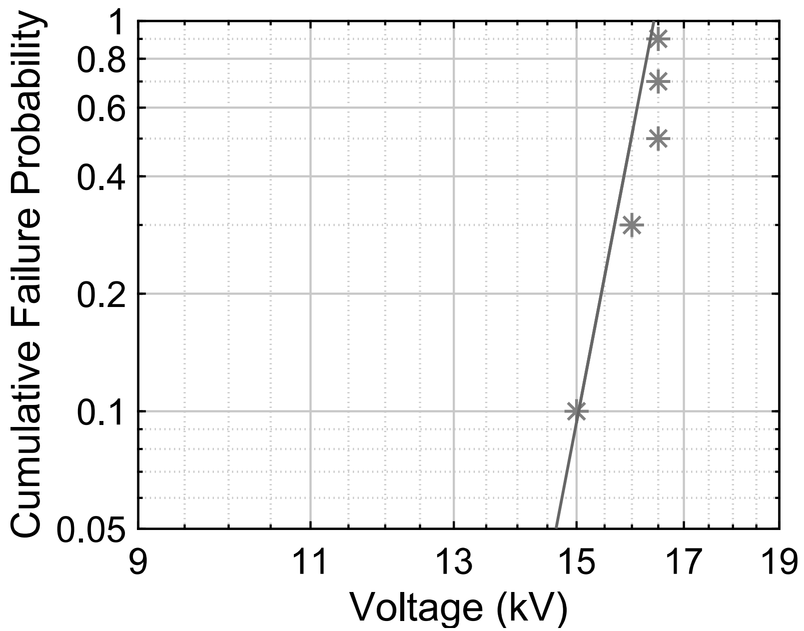
Two plates test structure



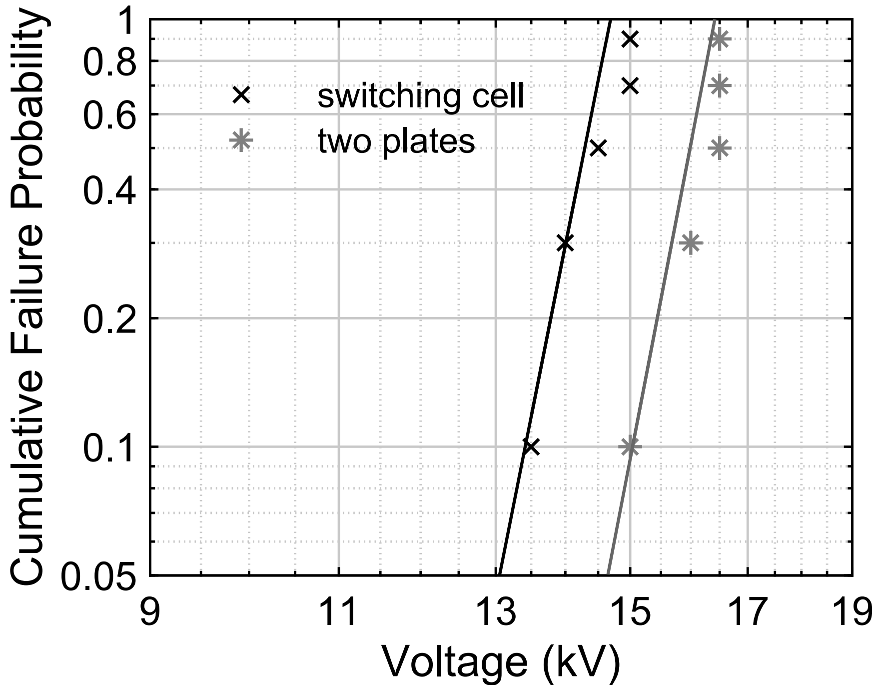
Result of the Measurement



Results

- Characteristic life η (63% failure) 16.4 kV
- Quantil value (10% failure) 15 kV
- By assuming of a homogeneous electric field between the two plates, the electric field strength corresponds to $E_{10\%}$= 150 kV/mm

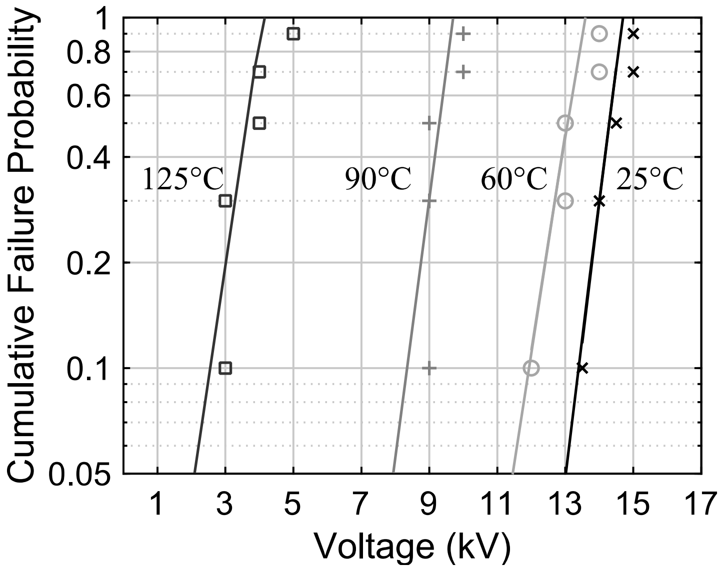
Breakdown voltage of the switching cell

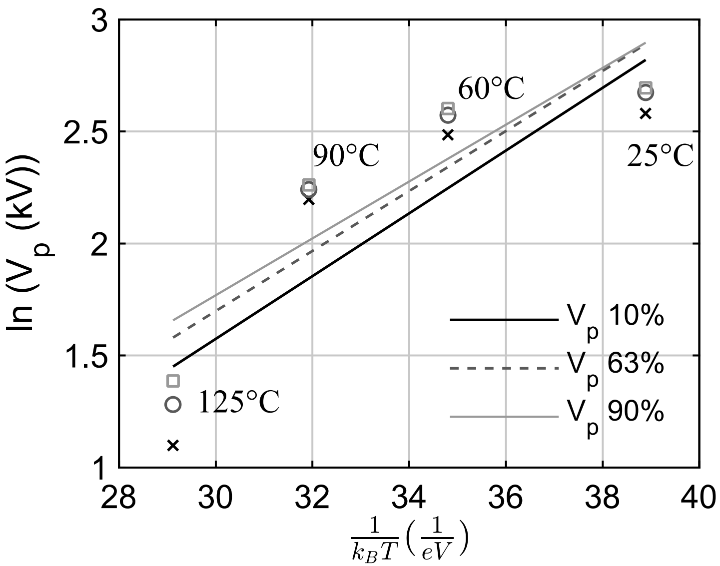


Results

- Characteristic life η (63% failure) 14.7 kV
- Quantil value (10% failure) 13.5 kV

- Electric field components $\vec{E} = (Ex, Ey, Ez)$ in all directions, gives a local higher magnitude $|\vec{E}|$ as the one-dimensional field in the parallel plate structure
- The increased field strength leads to a reduction of the breakdown voltage in the switching cell structure





Results

- Characteristic life η (63% failure) at 125 °C decreases to 3.6 kV
- Quantil value (10% failure) at 125 °C decreases to 3 kV

  ➡ This corresponds to a reduction by 77 %

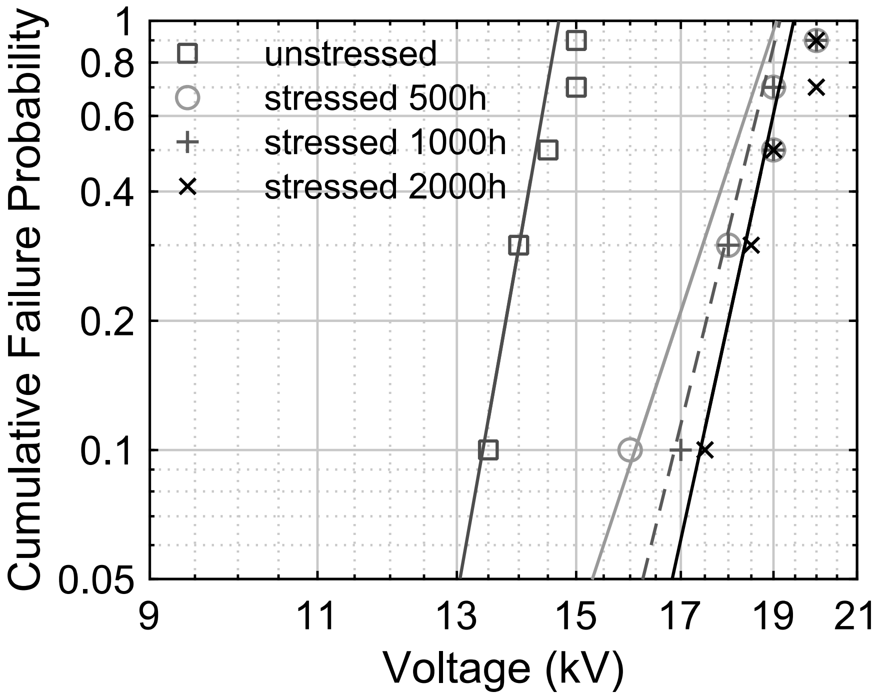
Arrhenius failure model

$$V_P = A_P \cdot e^{\frac{E_A}{k_B \cdot T}}$$

- Identical activation energies $E_A = 0.15\ \mathrm{eV}$ at different failure probabilities
- The physical failure mechanism does not change up to the T_g temperature

Experimental analysis of the DC breakdown voltage

Effects of aging



Test conditions

- High temperature storage below the T_g temperature at 125 °C
- The measurements were carried out at room temperature

Results

- After the high temperature storage the breakdown voltage increases
- A densification of the FR4 material leads to a recovery effect of material flaws
- For longer storage times chemical degradation of the material will deteriorate the dielectric electric strength of the epoxy material

Summary

- The ultra low inductance switching cell with integrated bare dies indicates in the double pulse test no voltage overshoot
- The small vertical insulation thickness of 100 µm between the drain and source and the sharp conductor edges cause enhanced electric field strengths
- The characteristic life of the drain to source voltage breakdown is 14.7 kV
- Experiments with samples at elevated temperatures indicate a significant decrease of the breakdown voltage
- Material recovery effects were observed after high temperature storage at 125 °C up to 2000 h