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# Next generation 4.5 kV IGBT StakPak module and FRD for 8GW HVDC application

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# Personal Introduction

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| **Speaker:** | Jeremy Jones |
| **Company:** | Hitachi Energy, Switzerland, joined 2018 |
| **Departement:** | R&D BiMOS, Product Evaluation and Qualification |
| **Position:** | Senior R&D Engineer |
| **Alma mater:** | ETH Zurich, Electrical Engineering and Information Technology, BSc. |

# Outline

- Introduction: Motivation and goal
- Power semiconductor devices
- IGBT chip technology: Improvements and results
- Discrete FRD technology
- 8 GW HVDC system simulation
- Summary and conclusion
- Q & A

# Introduction

**Motivation**

- HVDC transmission is critical technology in the energy transition with trend toward 8 GW VSC-HVDC systems
- Power semiconductors are key components of HVDC systems
- Demand for increased capability of power semiconductors

**Goal**

- Best in class IGBT and FRD for VSC-HVDC MMC topology
- Device design
    - $I_{nom}$ up to 5 kA
    - Operating temperature up to $T_{vj}$=150°C
    - Low on-state and switching losses
    - Maintain excellent SOA capability
    - Strong surge current capability

# Power semiconductor devices

**StakPak 4.5 kV IGBT:**

- Fully IGBT module for higher current rating
- Scalable up to 5 kA
- Presspack, mounting force 60-110 kN

**4.5 kV IGBT-only**
**Submodule**

**4.5 kV / 2.5 kA IGBT-only**
**3-pocket**
**5SMA2500L450300**

**4.5 kV / 5 kA IGBT-only**
**6-pocket**
**5SMA5000L450300**

**Fast recovery diode:**

- Discrete diode offers high surge current capability
- Scalable platform 4-5 kA, three housing types
- Mounting force: 90 kN

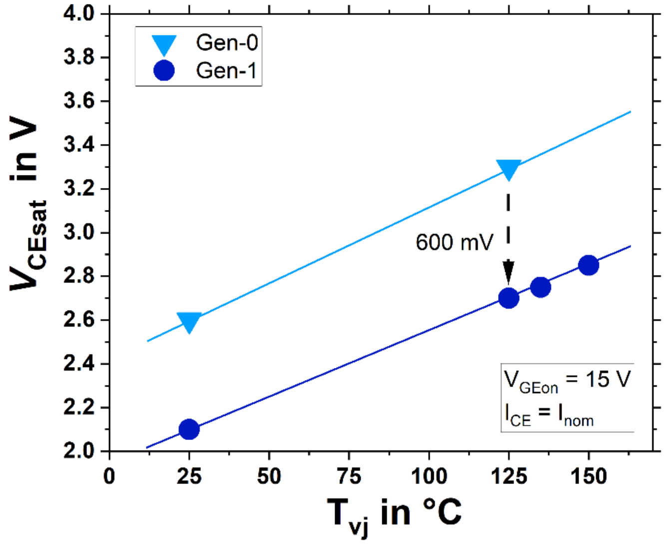
Pole piece 110 mm
(PP110)

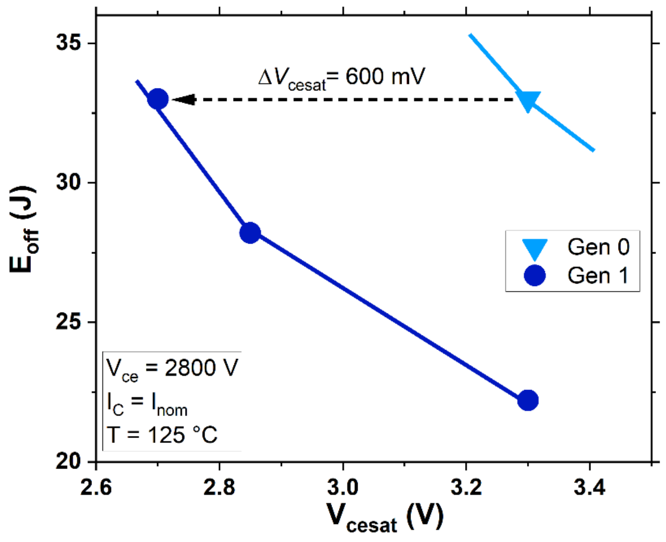
Pole piece 119 mm
(PP119)

Pole piece 143 mm
(PP143)

# IGBT chip technology: Improvements and results

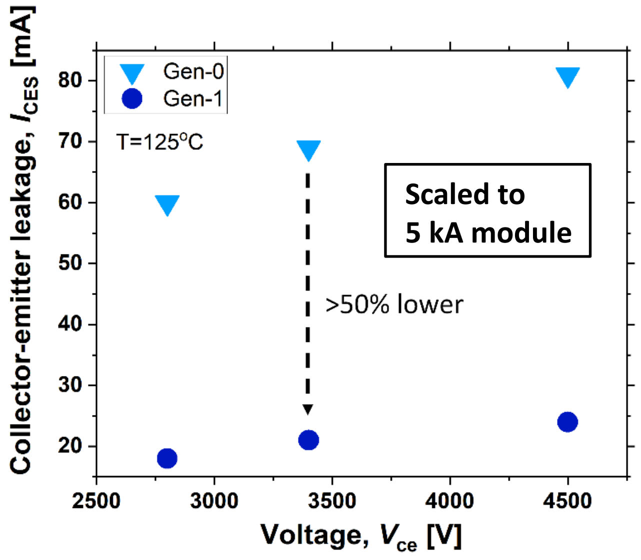
- Enhanced planar cell concept (SPT++) as reference technology (Gen-0)
- Optimized chip (Gen-1)
- Optimized for on-state losses
  - On-state losses dominate in HVDC transmission
  - Reduction of $V_{CEsat}$ by 600 mV
  - Enhanced injection efficiency of the backside collector
  - Higher channel density
- Improved technology trade-off curve
  - Improved (shorter) termination design for more active area
  - Reduced thickness of Si drift region
  - No adverse affect on turn-off losses
- Turn-on losses improved close to 40%
  - Higher channel density

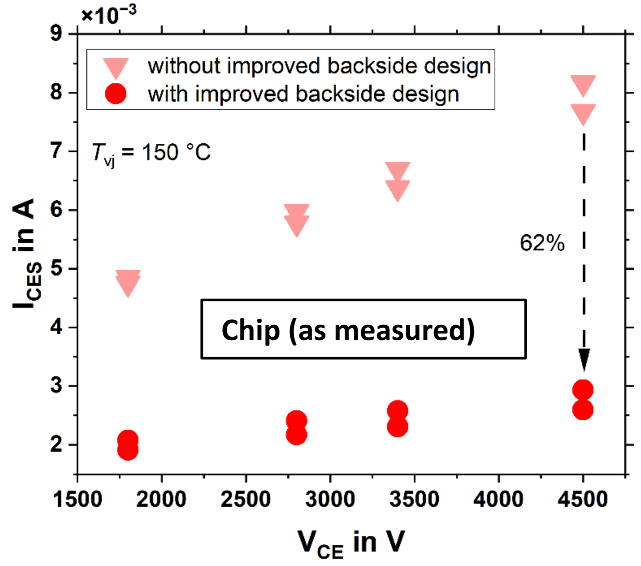


# IGBT chip technology: Improvements and results

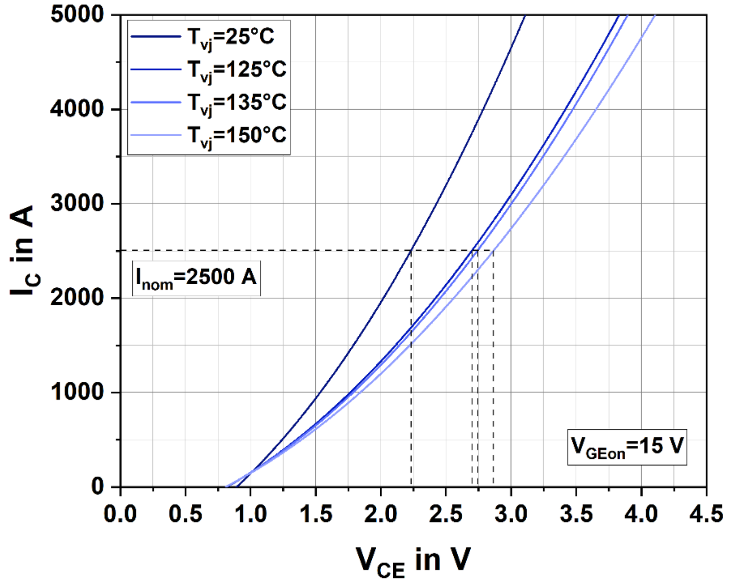
- Advanced backside technology for lower collector-emitter leakage
- Over 50% reduced collector-emitter leakage current between generations at $T_{vj}$=125°C
- Gen-1 with vs. without new backside: 62% lower collector-emitter leakage at $T_{vj}$=150°C and VCE=4500 V
- HTRB 1000 h (80% $V_{CES}$) test successfully passed at $T_{vj}$=150°C
- Cosmic ray 100 FIT successfully passed with margin for target $V_{CES}$=2.8 kV



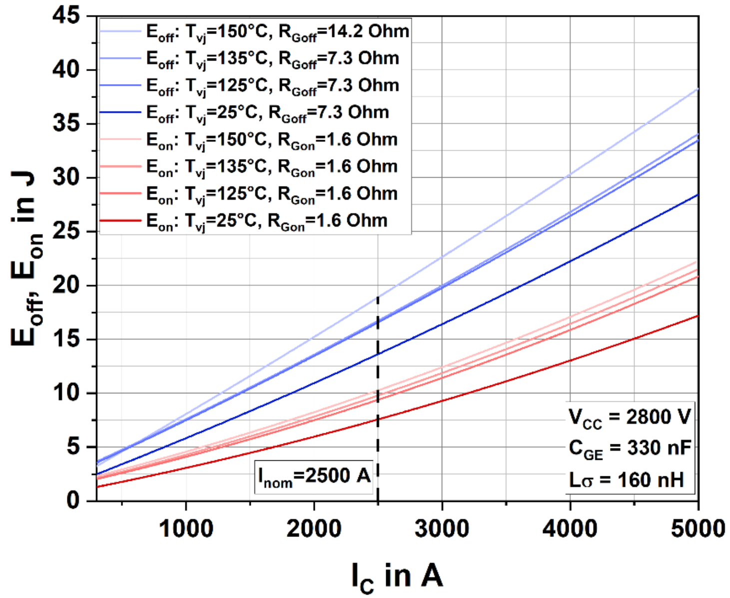
# IGBT 2.5 kA and 5 kA module results

## 2.5 kA Module (as measured)



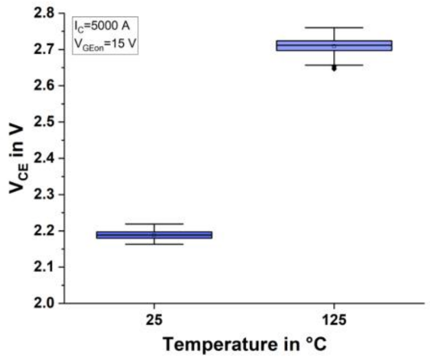

- Nominal on-state voltage $V_{CEsat}$< 3 V at all temperatures
- Positive temperature coefficient of resistivity

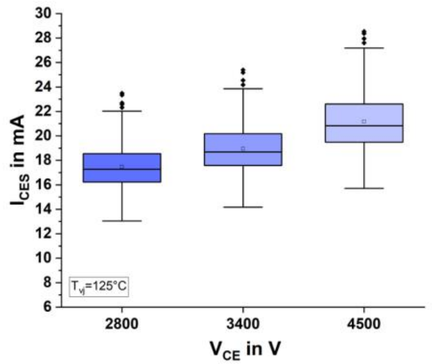
## 2.5 kA Module (as measured)




- Nominal turn-off switching losses Eoff < 20 J for all temperatures (< 40 J scaled to 5 kA module)
- $L_\sigma$=160 nH
- Low turn-on losses

## 5 kA Module (as measured)

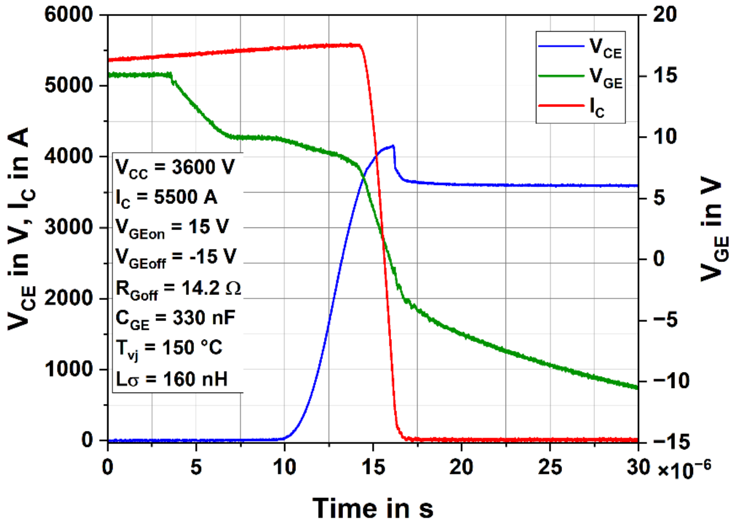



- 5 kA production data, $T_{vj}$=125°C
- Losses and collector emitter leakage current in accordance with 2.5 kA results
- Qualification of 5 kA IGBT ongoing

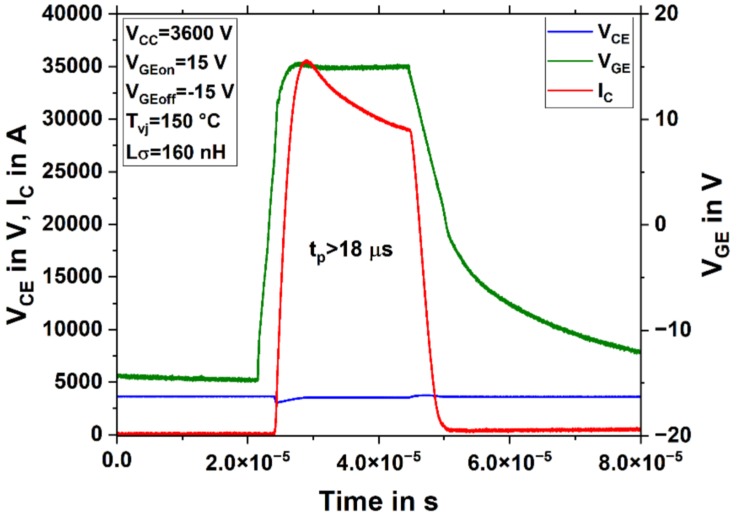
# IGBT 2.5 kA and 5 kA module results

## 2.5 kA Module (as measured)



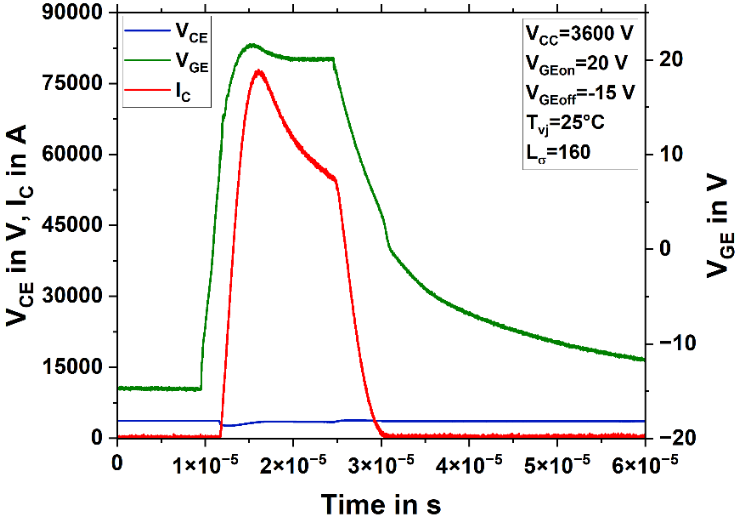

- Extended RBSOA
- $V_{CC}$=3.6 kV, $T_{vj}$=150°C, $L_{\sigma}$=160 nH
- $I_C > 2 \times I_{nom}$

## 5 kA Module (scaled from submodule measurement)




- Short-circuit SOA pulse
- $V_{CC}$=3.6 kV, $T_{vj}$=150°C, $L_{\sigma}$=160 nH
- $t_p$ > 18 µs

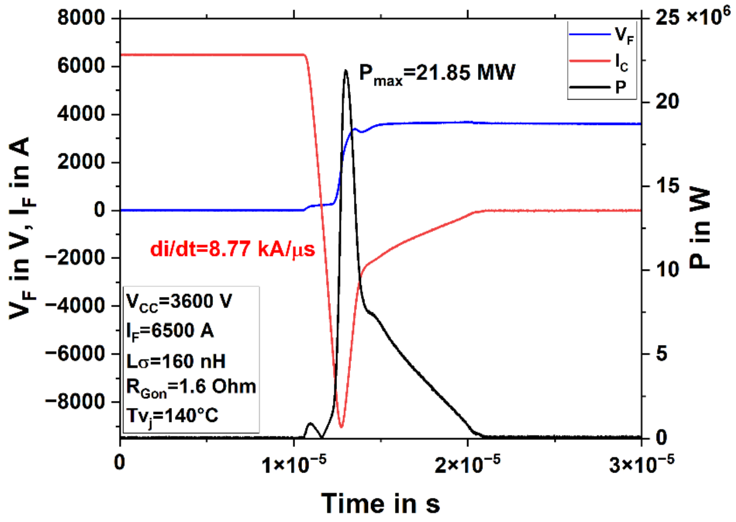
## 5 kA Module (scaled from submodule measurement)

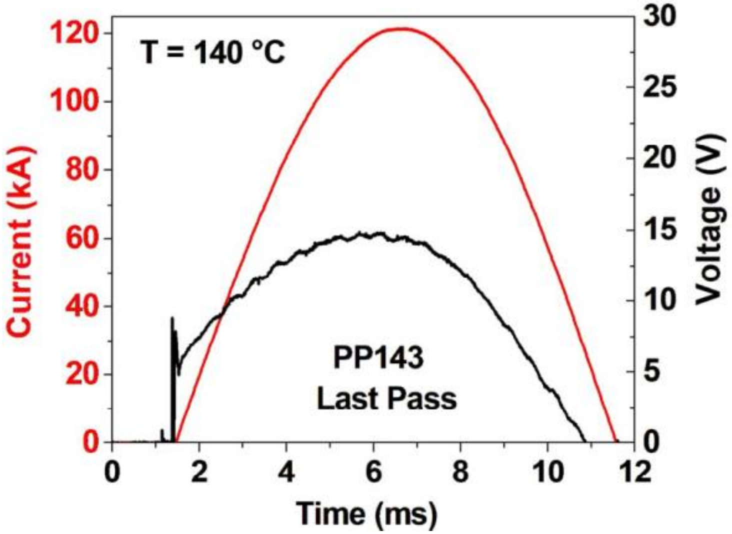



- Short-circuit SOA pulse
- $V_{CC}$=3.6 kV, $T_{vj}$=25°C, $V_{GEon}$>19 V, $t_p$=10 µs, $L_{\sigma}$=160 nH
- $I_{cmax}$ capability > 75 kA

# Discrete FRD technology

- Typical $V_F$=1.8 V / 2.7 V for $I_F$=2.5 / 5.5 kA at $T_{vj}$=140°C for all diode sizes
- Cosmic ray withstand capability:
  - 0.1 FIT up to 3.4 kV
  - 400 FIT up to 3.6 kV
- Diode SOA
  - $V_{CC}$=3.6 kV, $I_F$=6.5 kA, $T_{vj}$=140°C, $L_\sigma$=160 nH
  - Pmax approx. 22 MW
  - *di/dt* close to 9 kA/µs
- Surge current
  - $t_p$=10 ms, $T_{vj}$=140°C
  - Data sheet $I_{FSM}$ 75 kA, 80 kA and 100 kA
  - Last pass $I_{FSM}$ 85 kA, 95 kA, 117 kA
- Snapiness
  - $V_{CC}$=3.6 kV, low current, $T_{vj}$=25°C, $L_\sigma$=160 nH
  - Provoked voltage spikes as high as 7 kV without destruction

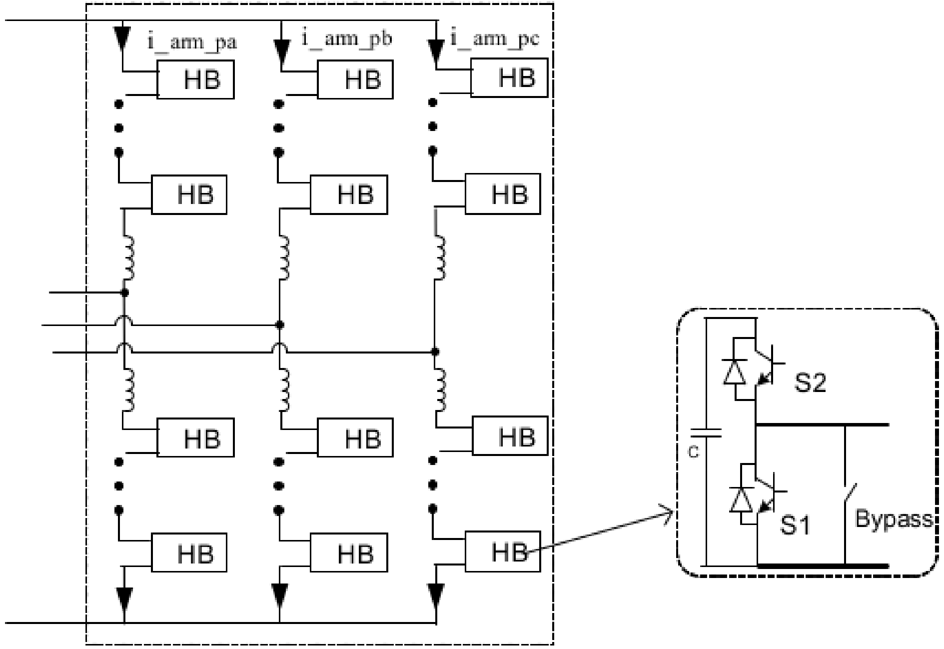


# 8 GW HVDC system simulation

**Operating conditions**

- IGBT module: 4.5 kV / 5 kA Gen-1 StakPak
- FRD: 4.5 kV / 5 kA FRD
- DC voltage: ±800 kV DC voltage
- Cell voltage: $V_{CC}$=2800 V
- AC side current: $I_{rms}$=6670 A
- Cooling liquid temperatures $T_W$=60°C
- Switching frequency $f_{sw}$=96 Hz
- DC power above 8 GW




| Operating mode | $T_{vj}$ IGBT [˚C] | $T_{vj}$ Diode [˚C] | Losses [%] |
|---|---|---|---|
| Inverter | 143.3 | 93.3 | 0.99 |
| Rectifier | 128.9 | 107.5 | 0.95 |

# Summary and conclusion

Improved SPT++ IGBT platform
(4.5 kV / 2.5 kA, 5 kA)

## Operating temperature $T_{vj}$=150°C

**Losses**
- Reduction of $V_{CEsat}$ by 600 mV compared to SPT++ technology
- Nominal $V_{CEsat}$ below 3 V
- Superior technology curve
- $E_{off}$ below 20 J / 40 J for 2.5 kA / 5 kA IGBT

**SOA**
- RBSOA: $V_{CC}$=3.6 kV and $I_C$ > 2 x $I_{nom}$
- SCSOA: $t_p$ > 10 µs
- SCSOA ($T_{vj}$=25°C): $I_{SCmax}$ > 75 kA

**HTRB**
- 1000 h at $T_{vj}$=150°C

FRD platform
(4.5 kV / 4-5 kA)

## Operating temperature $T_{vj}$=140°C

**Losses**
- 1.8 V / 2.7 V at $I_F$=2.5 kA / 5.5 kA

**Cosmic ray**
- 0.1 FIT up to 3.4 kV and 400 FIT up to 3.6 kV

**SOA**
- 22 MW peak power
- 9 kA/µs di/dt

**Surge current**
- $I_{FSM}$ at 75, 80 and 100 kA

Hitachi Energy continues to build on its extensive experience to push the limits of power semiconductors. The new devices will help establish the next generation of VSC-HVDC systems rated at 8 GW.

# Q & A

## Do you have any questions?

Thank you 谢谢

Visit the Hitachi Energy booth F08, Hall 11

Further reference:
“A 4.5 kV Fast Recovery Diode Platform for High-Current IGBTs” - Dr. J. Vobecky - PCIM Europe 2024
“Novel MOS-cell Engineered 4.5 kV Enhanced-planar IGBT Device for Improved Short-Circuit Capability” - Dr. G. Gupta - PCIM Europe 2023