pcim ASIA Hybrid Platform

High dV/dt Controllability of 1.2-kV TCIGBT through Dynamic Avalanche Elimination

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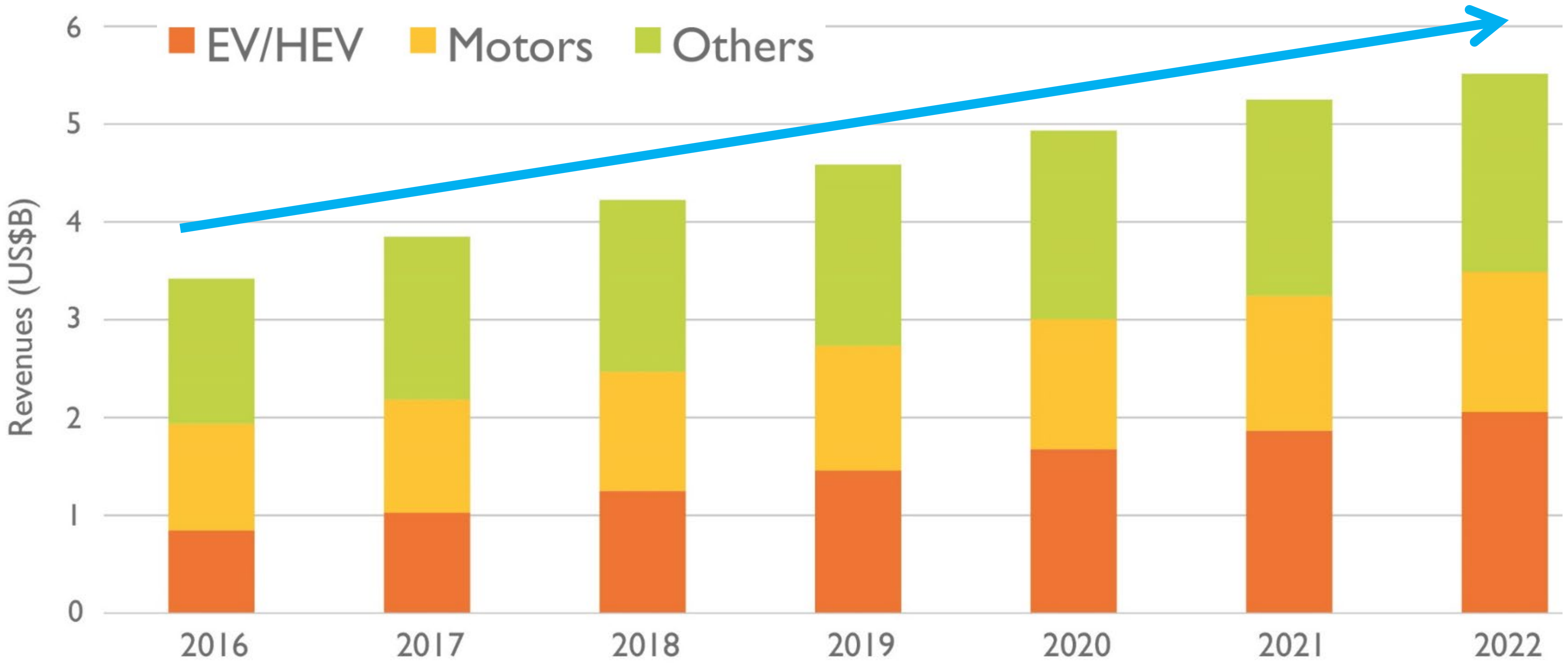
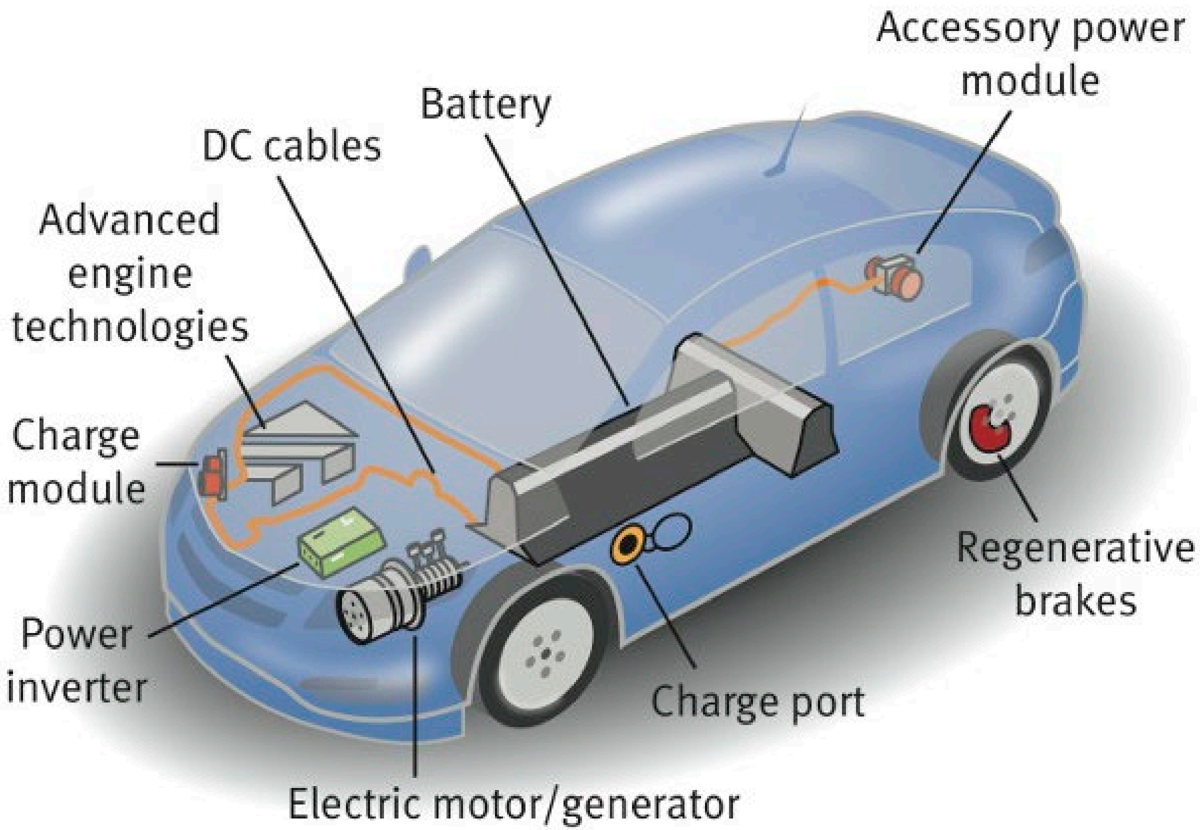
I. IGBT Market Evolution by Applications



(Source: IGBT Market and Technology Trends, Yole Développement, 2017)

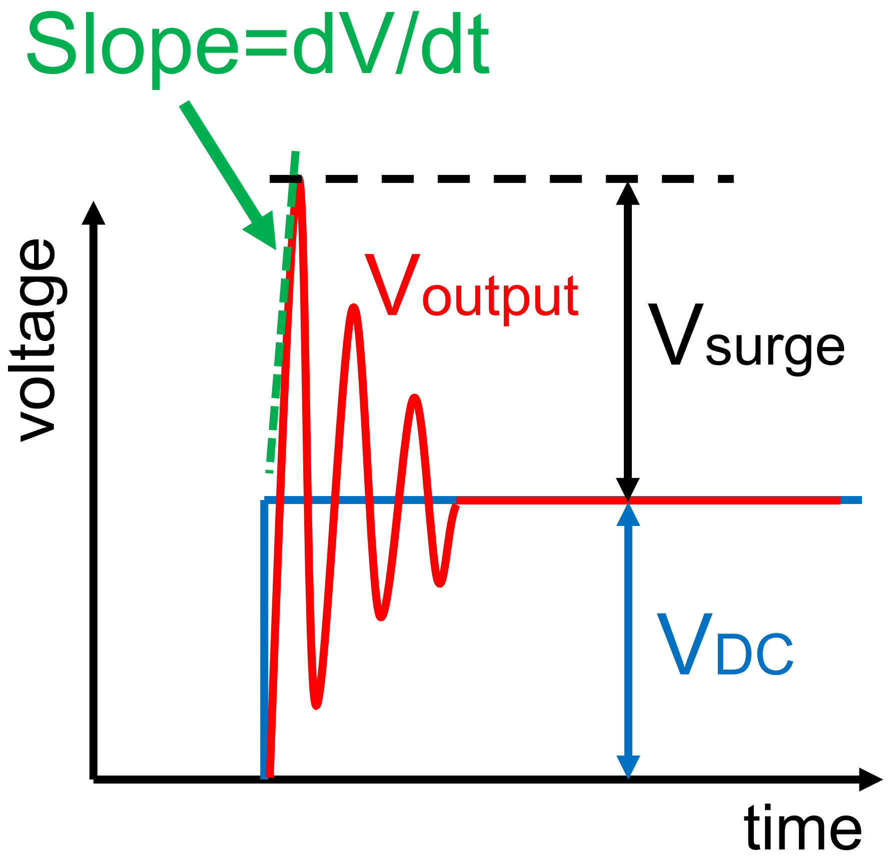
- IGBTs are widely used in ***EV, motor drives*** *and* ***transportations***.
- The global IGBT market is expected to reach ***>$5B USD by 2022***.

What are the requirements for future IGBTs?



- Higher energy efficiency:
  - *Eoff-Vce(sat)* trade-off
- Higher power density:
  - Higher operating current density
  - Higher operating temperature
- Higher dV/dt controllability:
  - To suppress EMI noise
  - To increase switching frequency
- Long-term reliability & high robustness

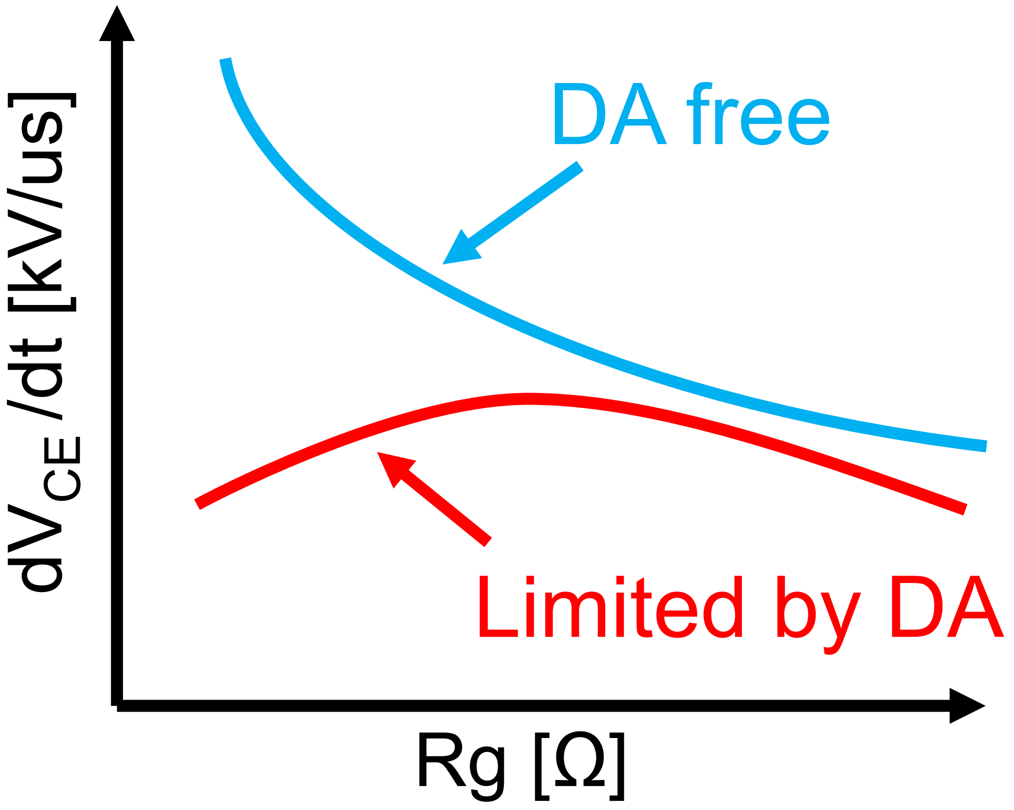
Why dV/dt controllability is important for IGBTs?



Example of an output voltage curve

- Most important application for IGBT modules is variable speed drives.
- One major topic in drive applications is limitation of dV/dt due to requirement of insulation system.
- High dV/dt can result in:
  - Low power loss ✓
  - High frequency operation ✓
  - EMI noise ✗
  - Motor insulation failures ✗

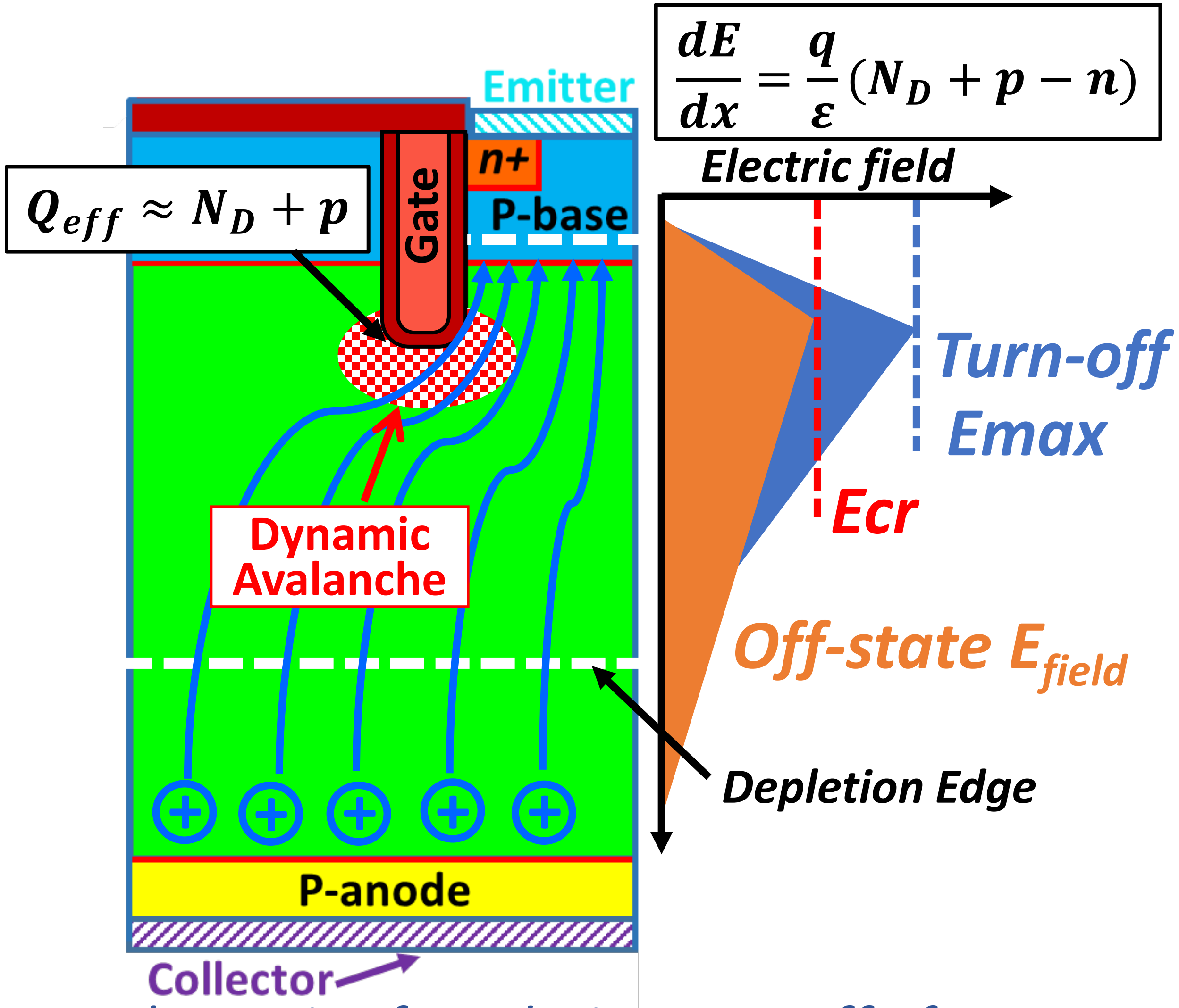
How to control the dV/dt of IGBTs?



Example of dV/dt versus Rg

- One common method to control the dV/dt is adjustment of gate resistance (*Rg*).
- However, the dV/dt controllability is limited by Dynamic Avalanche (DA).

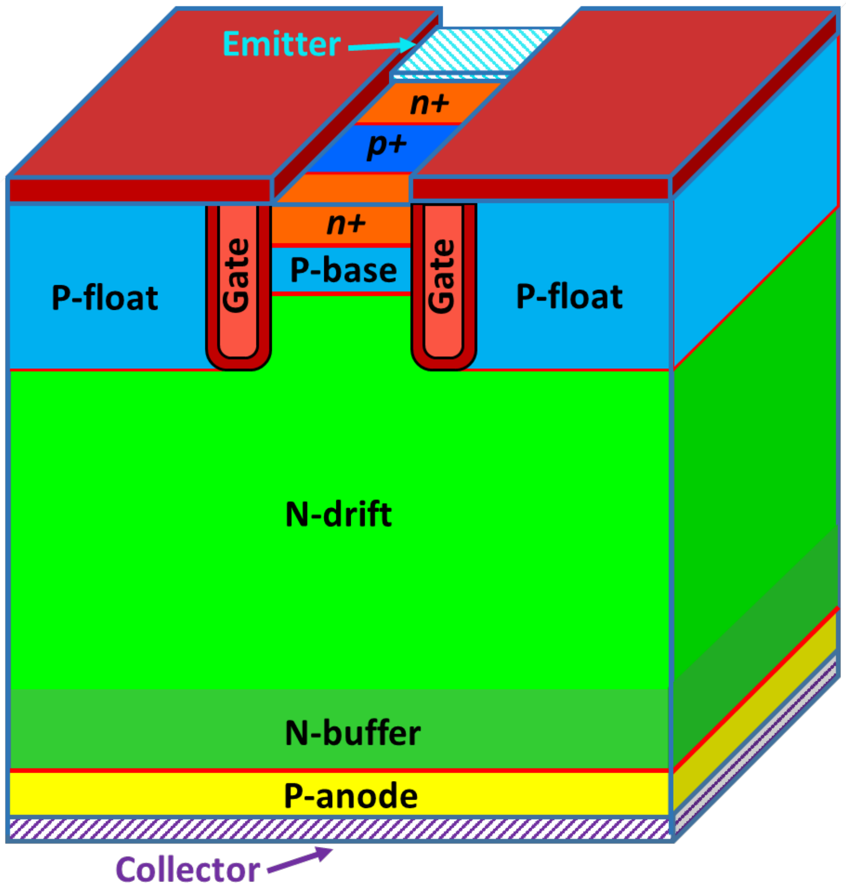
II. What is Dynamic Avalanche (DA) in TIGBTs?



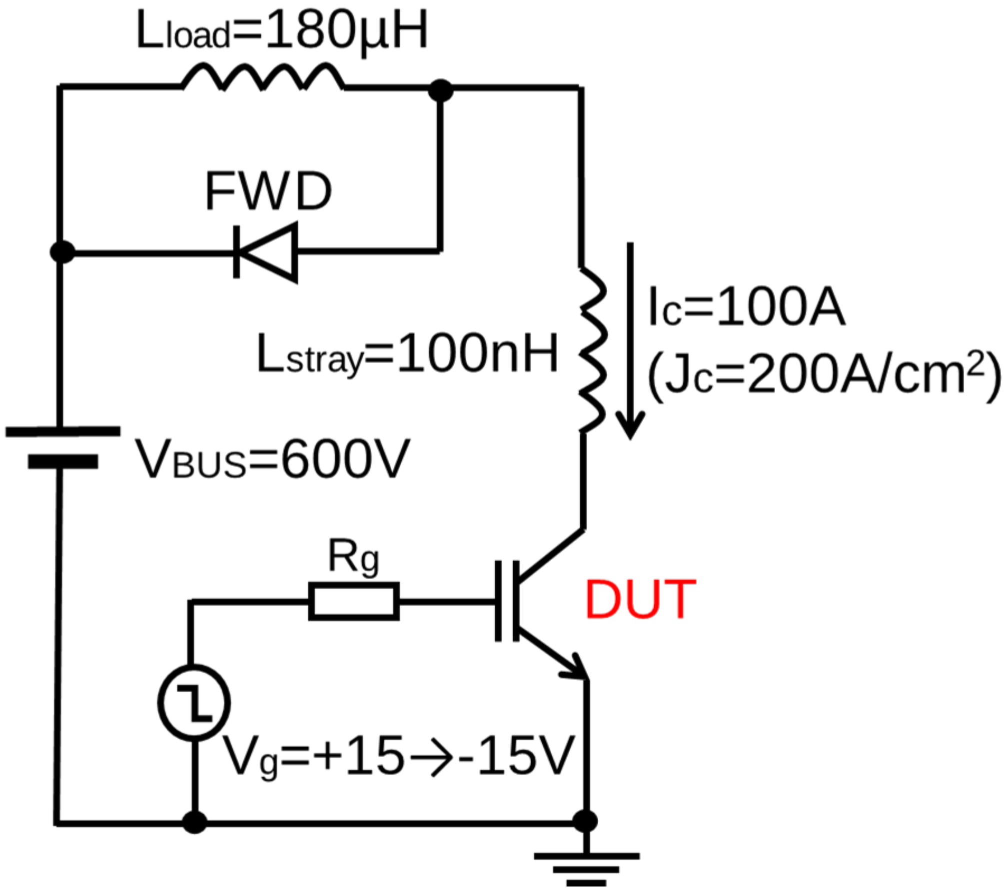
*Schematic of DA during **turn-off** of TIGBTs*

- DA can be triggered by:
  - High current density
  - High dV/dt
  - Current filamentation
- DA poses fundamental limits on:
  - Operating current density
  - Turn-off energy loss
  - dV/dt controllability
- Therefore DA must be eliminated.

Test circuit to analyze DA in TIGBTs

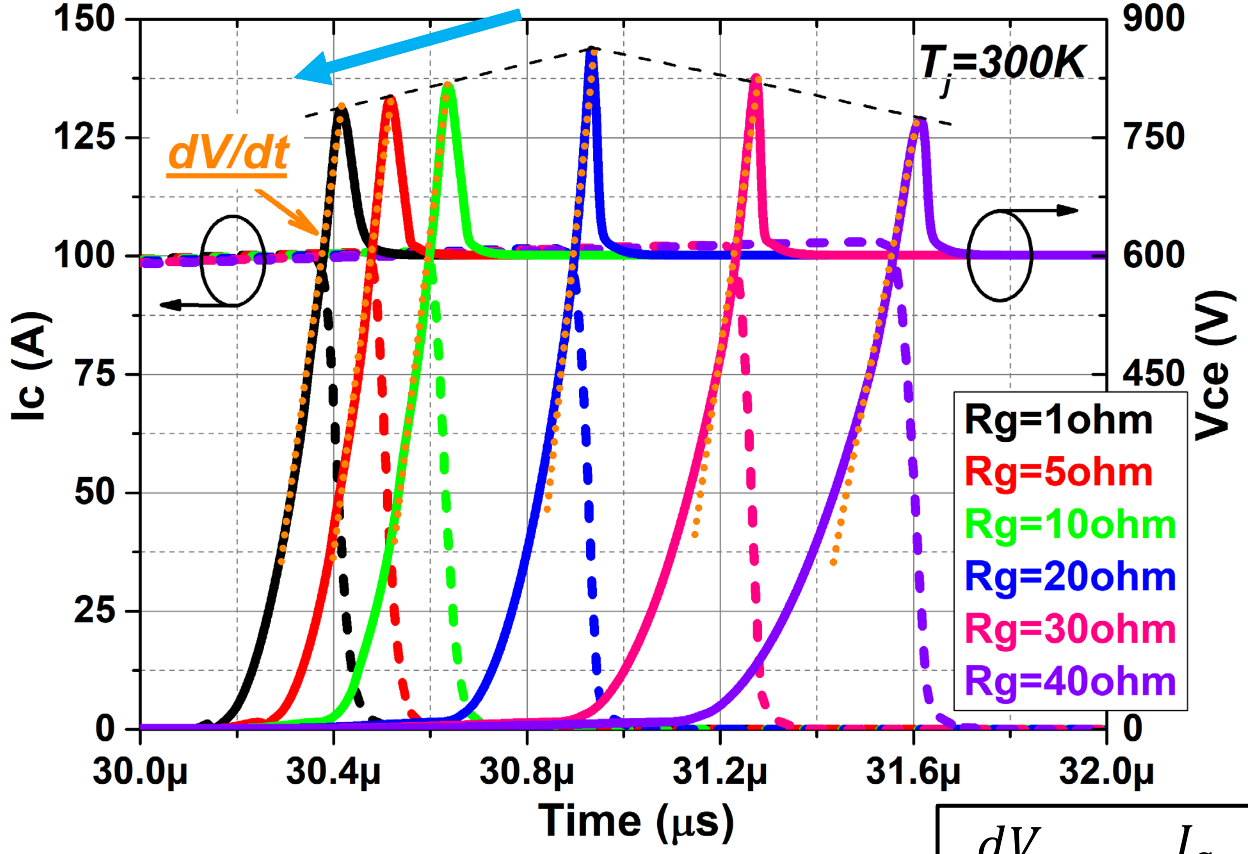


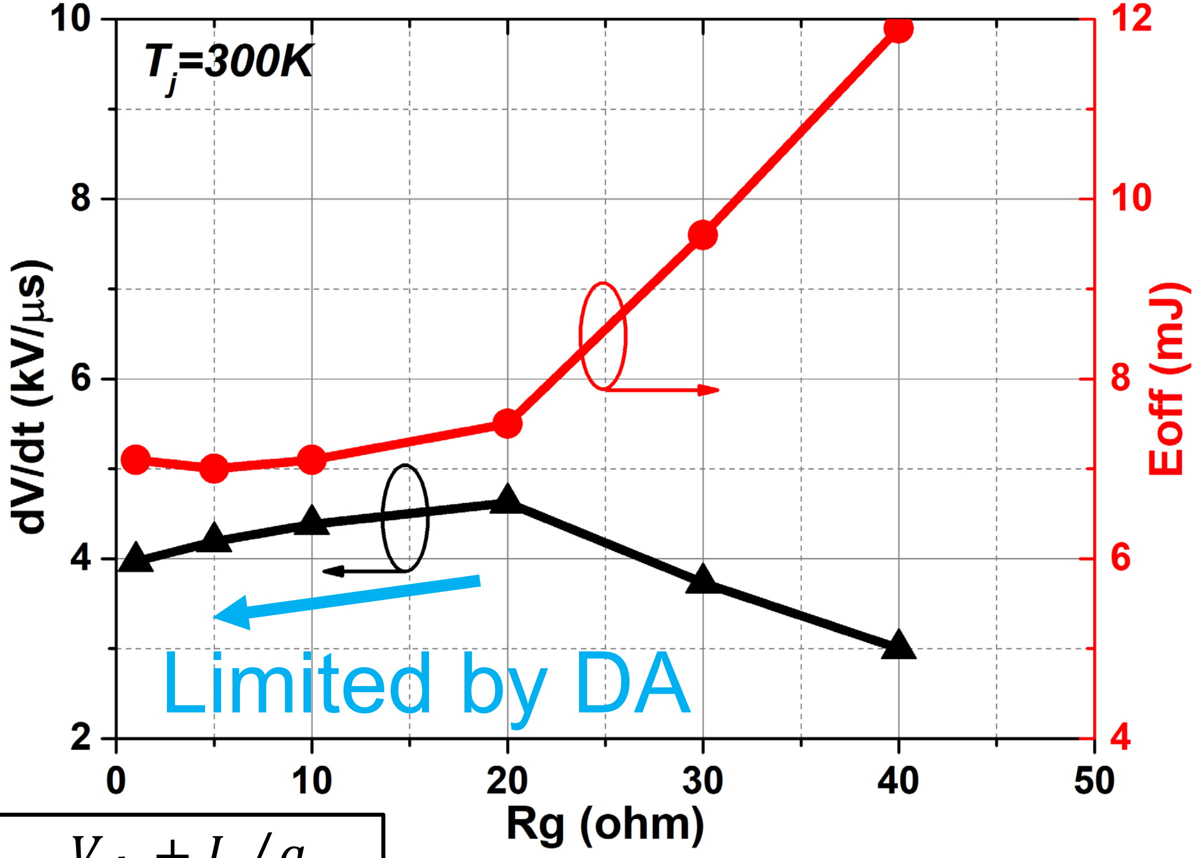
3-D cross-section of a 1.2kV TIGBT



Test circuit configuration

III. Impact of DA on dV/dt Controllability of IGBTs

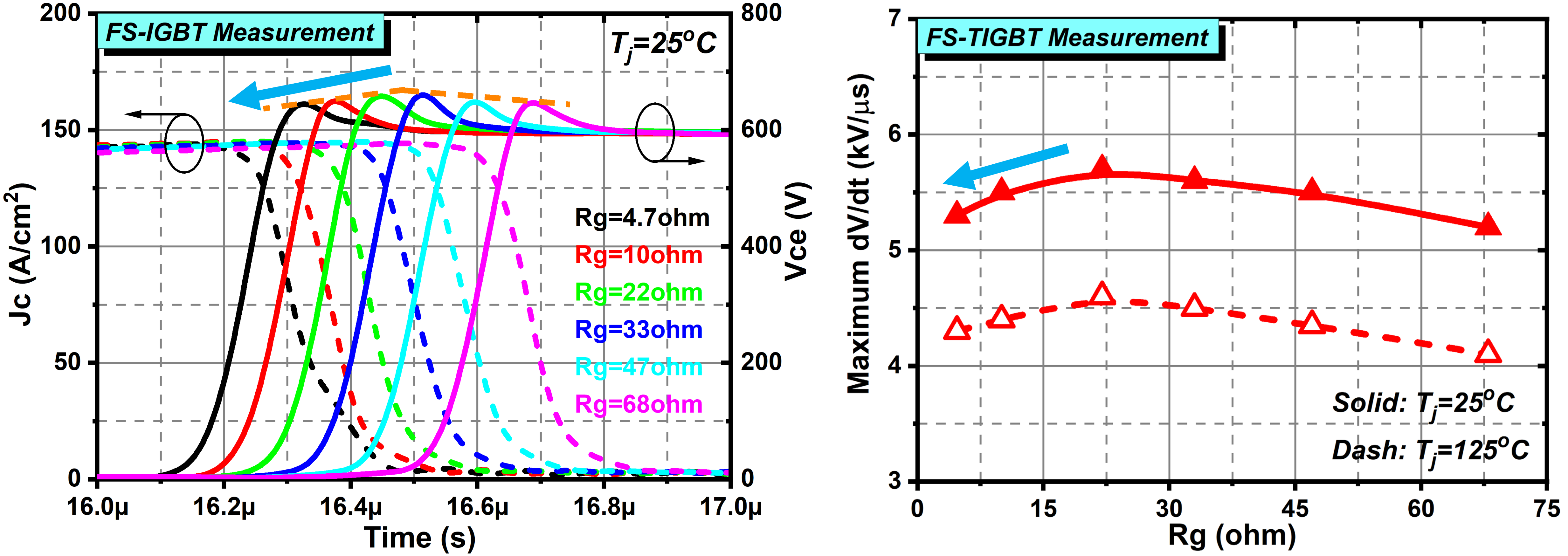




$$\frac{dV_{ce}}{dt} = \frac{I_g}{C_{GC}} = \frac{V_{th} + I_c/g_m}{R_g \times C_{GC}}$$

- In practice, smaller *Rg* → higher Vsurge & dV/dt.
- However, DA occurs at small *Rg* and limits dV/dt controllability.

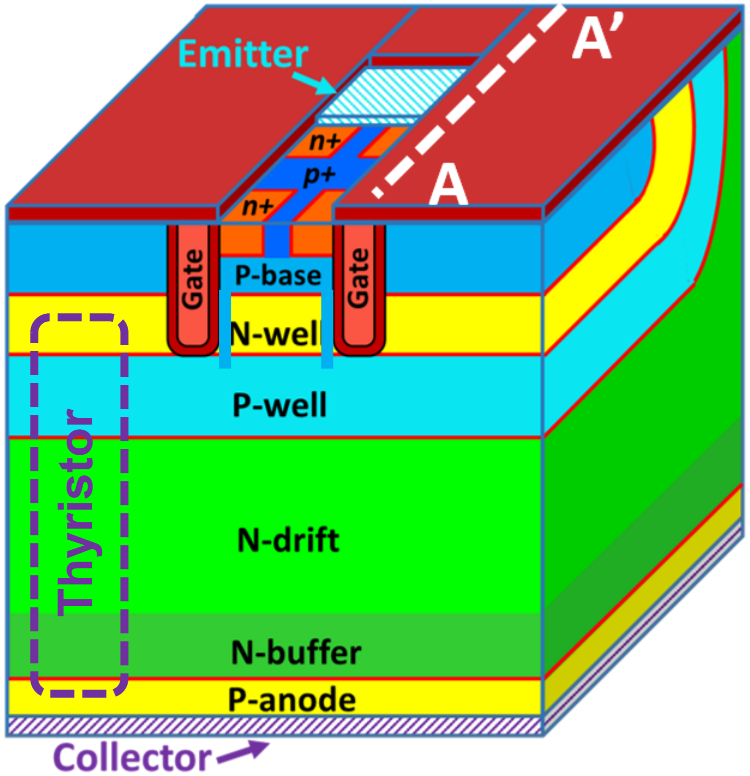
Experimental Results - DA in TIGBTs



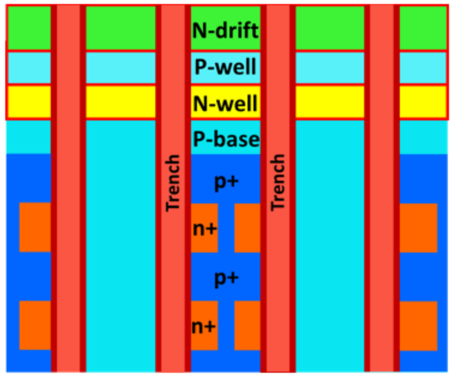
(Source: P. Luo, et. al, "Turn-off dV/dt Controllability in 1.2kV MOS-Bipolar Devices," in *IEEE Transactions on Power Electronics.*)

- Experiments confirm that DA limits the dV/dt controllability of TIGBTs.

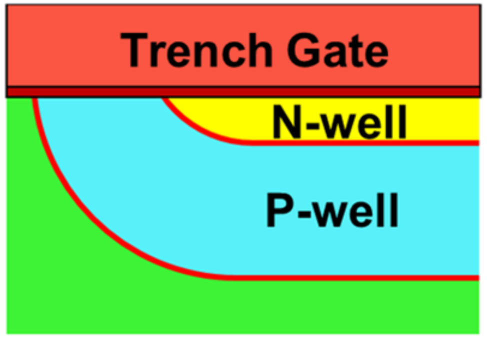
IV. DA Free Design – Trench Clustered IGBT



3D-Trench CIGBT



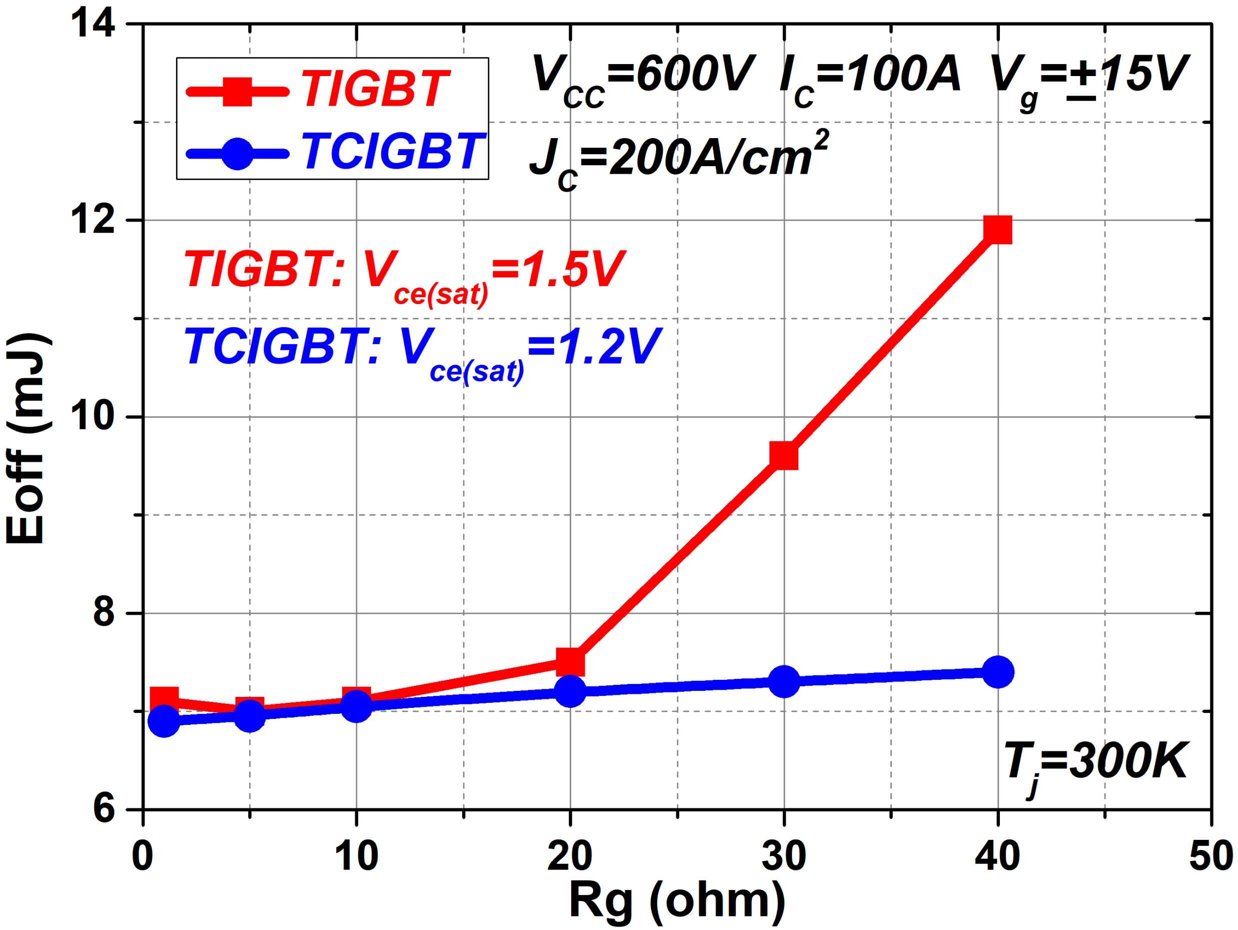
Top-view

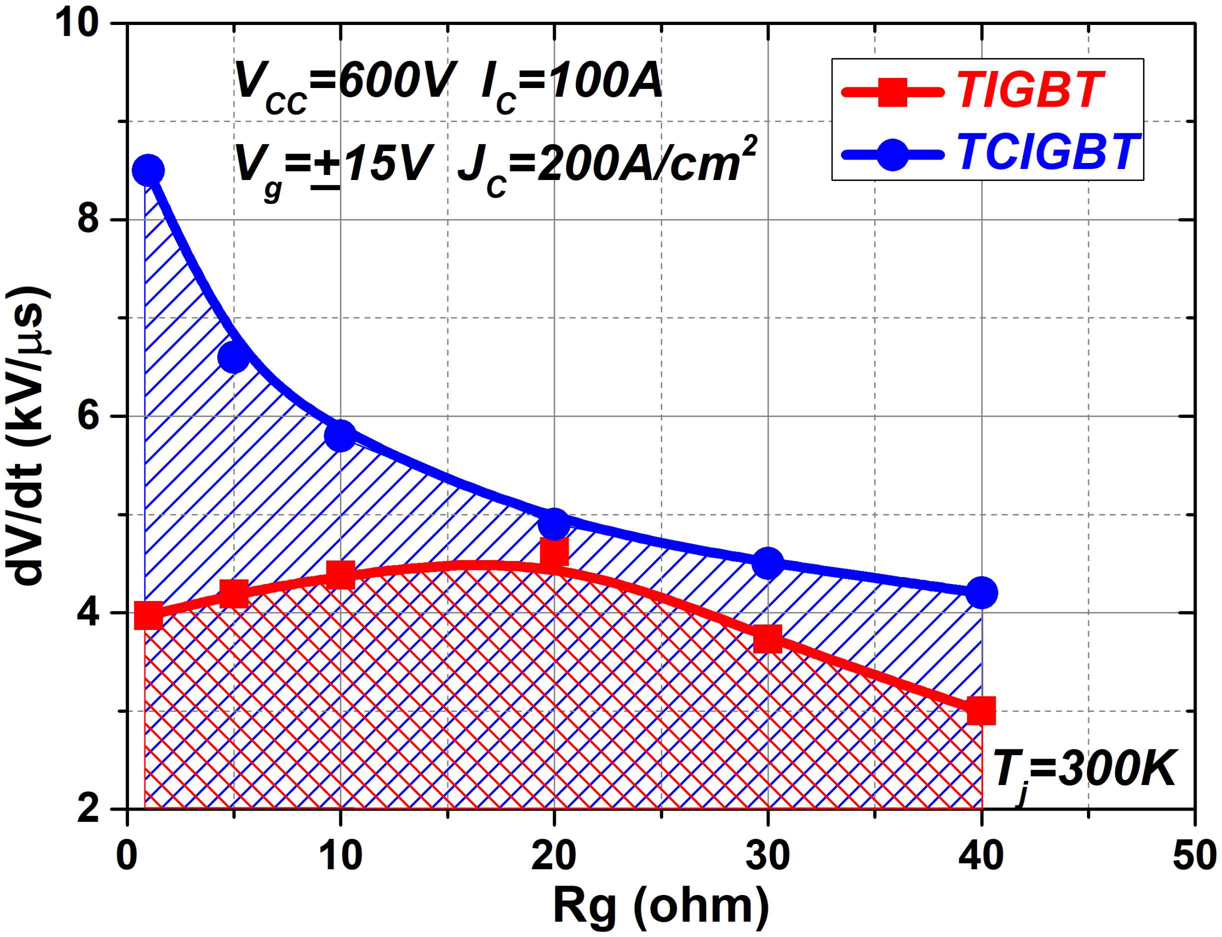


Cut-line A-A'

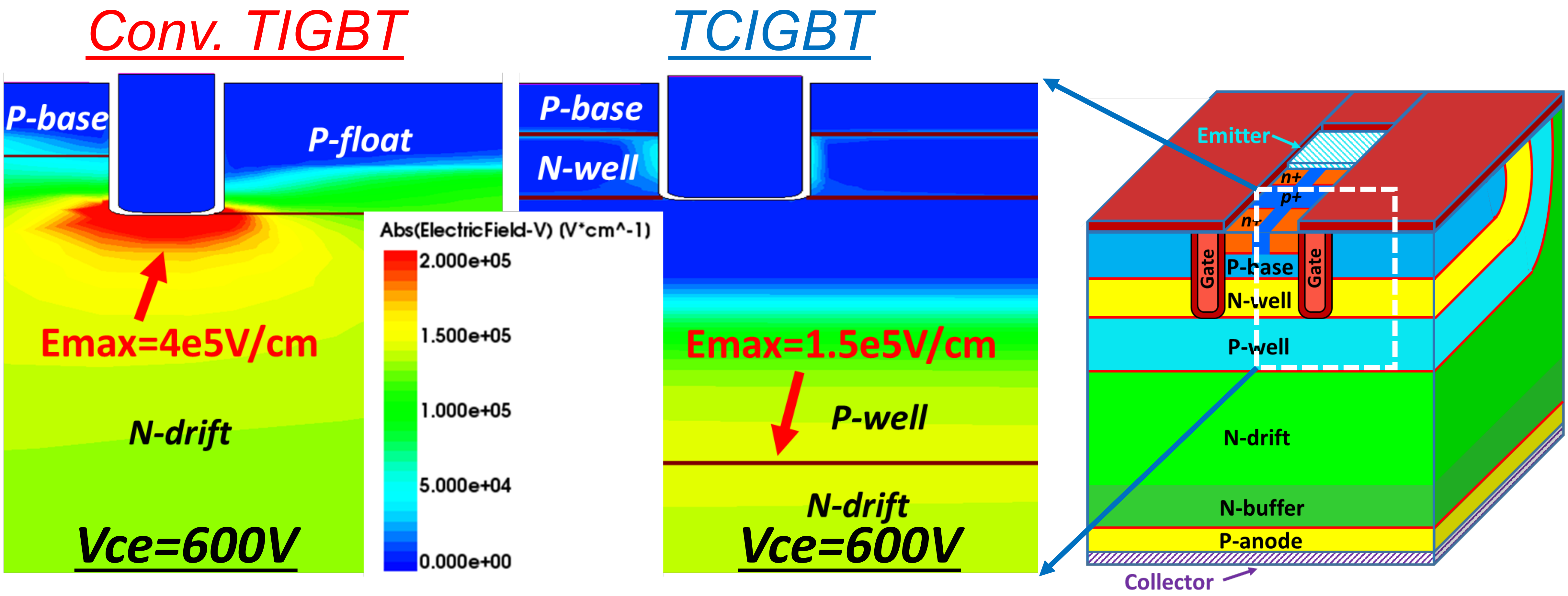
- 3-terminal MOS-controlled thyristor device:
  - *P-anode/N-drift/P-well/N-well*
  - Low on-state voltage drop
- Self-clamping feature:
  - Lower saturation current density
  - Trench gates are protected from high electric field
- PMOS actions:
  - Lower *Eoff*

High dV/dt Controllability due to DA Free





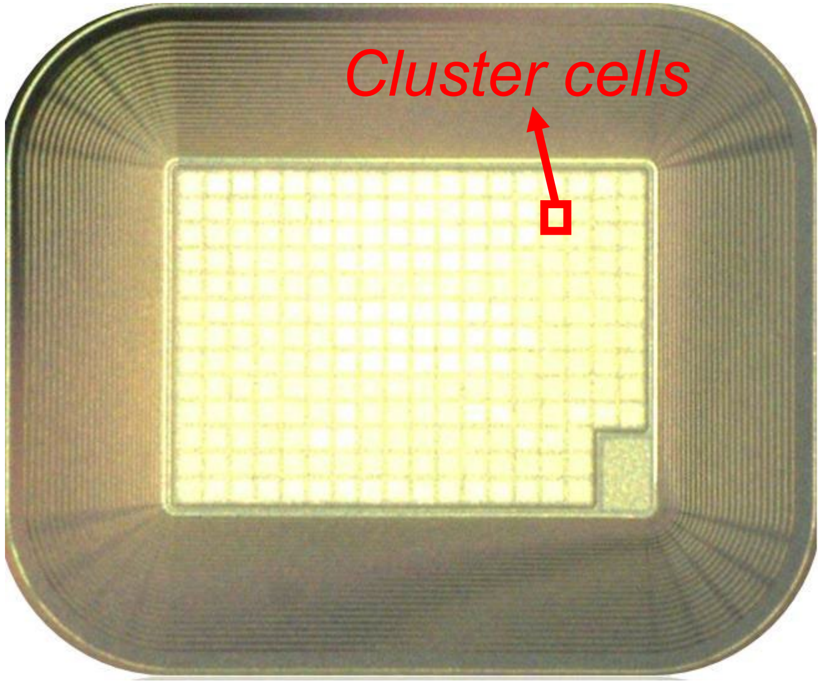
Essence of DA Free – E-field Management



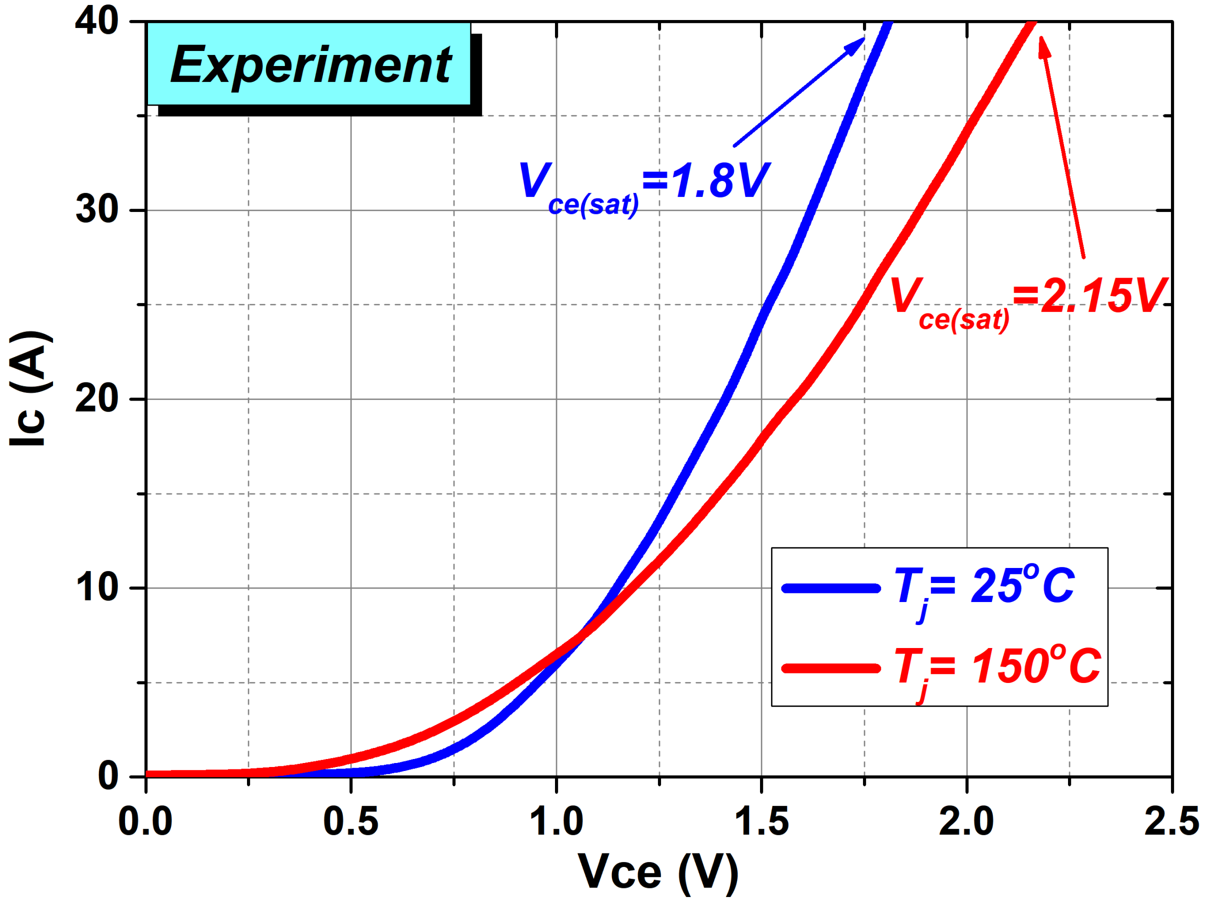
- No electric field crowding in the TCIGBT.
- Trench gates are protected from peak electric field.

V. Experimental Results – TCIGBT*

(H. Long et al, PCIM Asia - 2015)

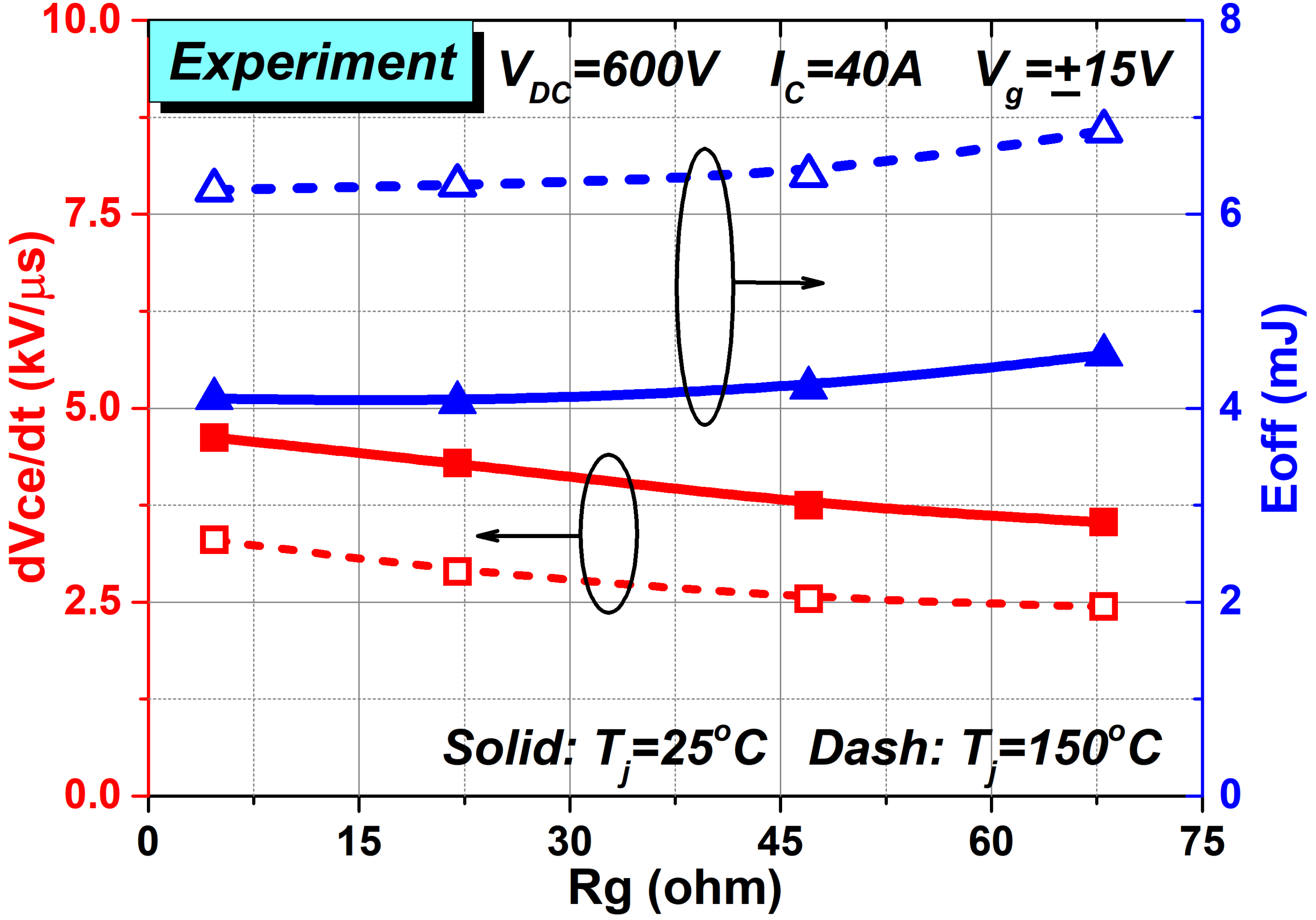


Fabricated 1.2 kV, 8 A (140 A/cm²)
NPT Trench CIGBT on 6" wafers



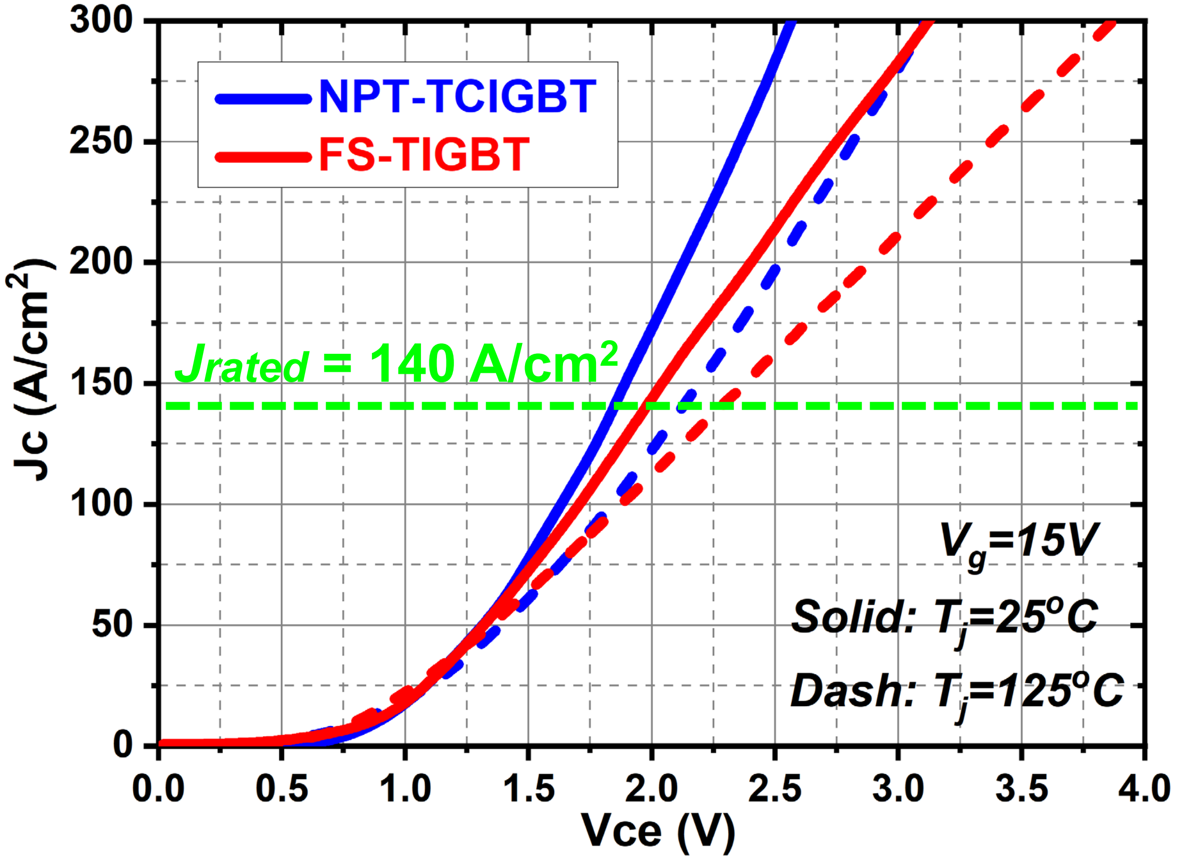
*Thanks to ECO Semiconductors Ltd for providing the samples.

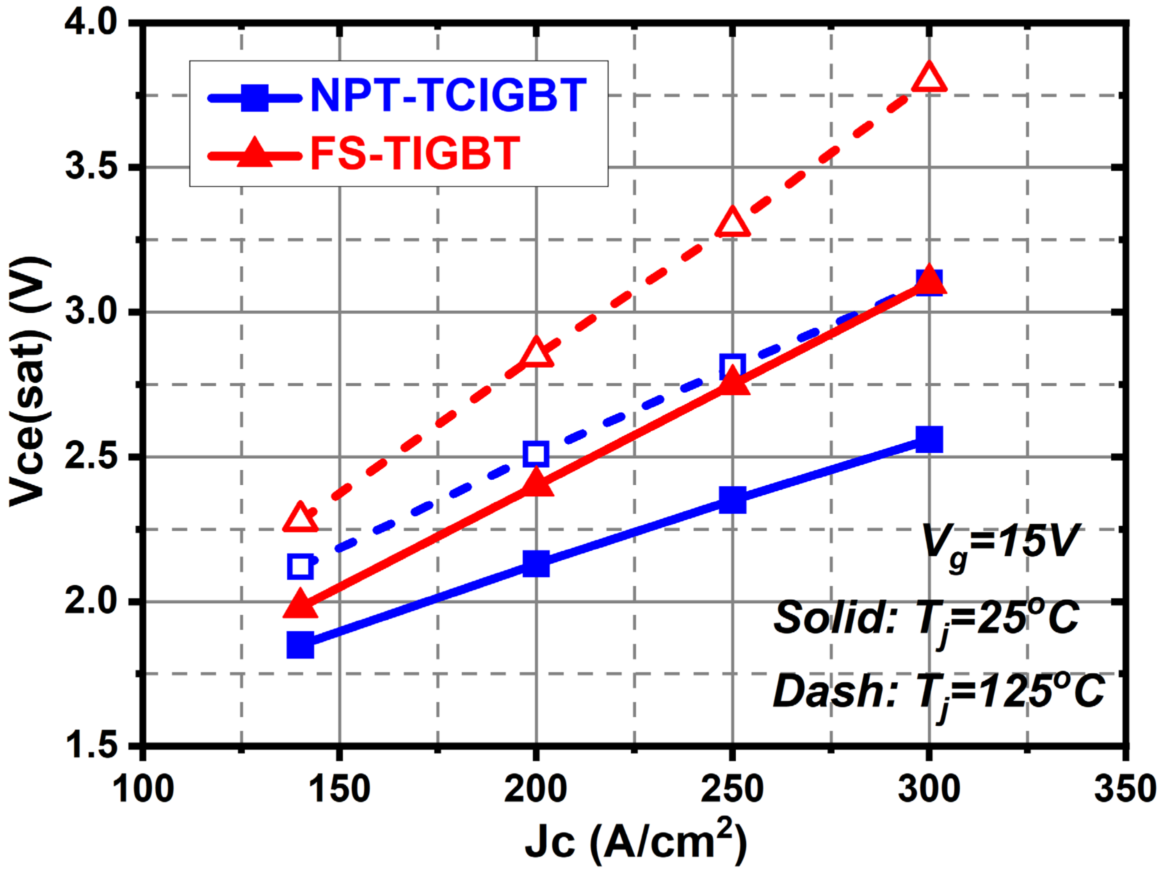
Experimental Results – TCIGBT is DA free



- The turn-off dV/dt shows a linear increase with reducing *Rg*.
- The Eoff shows a linear decrease with reducing *Rg.*
- TCIGBT is DA free.

VI. Comparison between TCIGBT and TIGBT

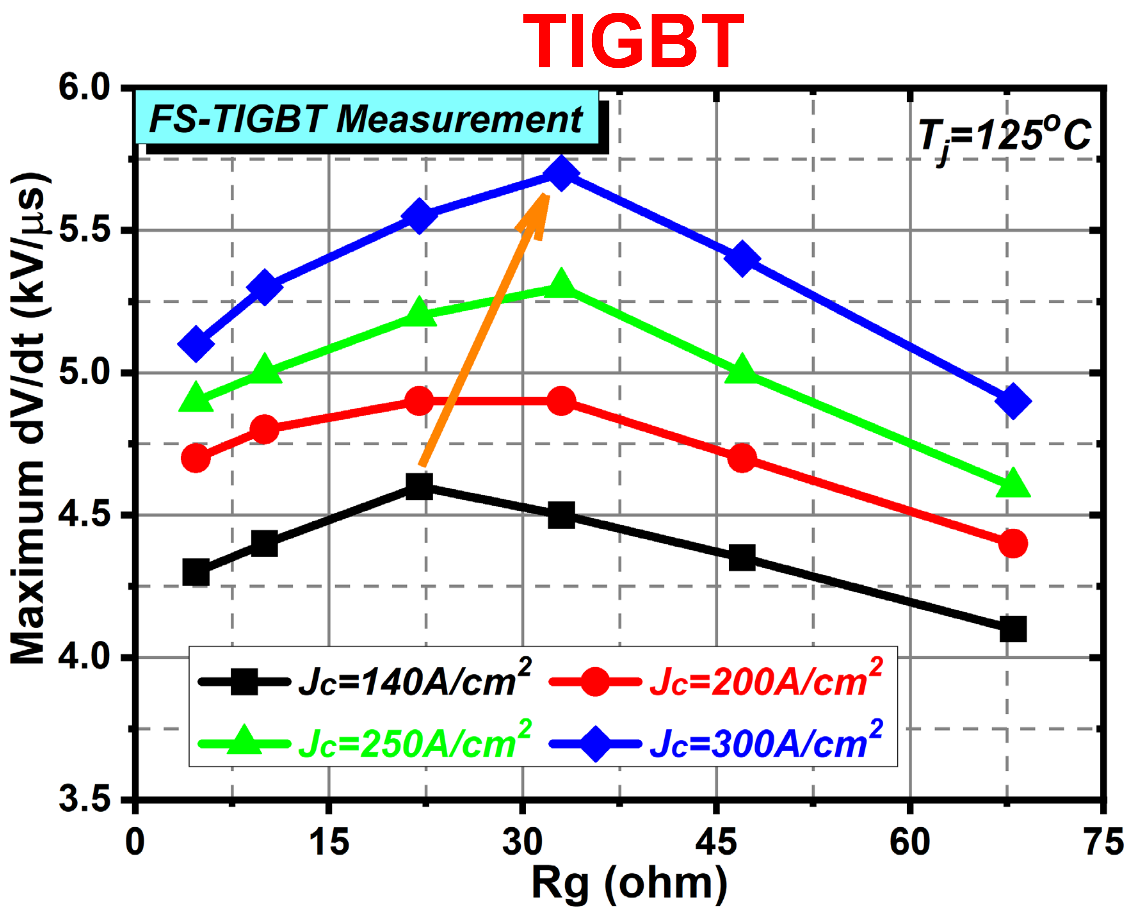


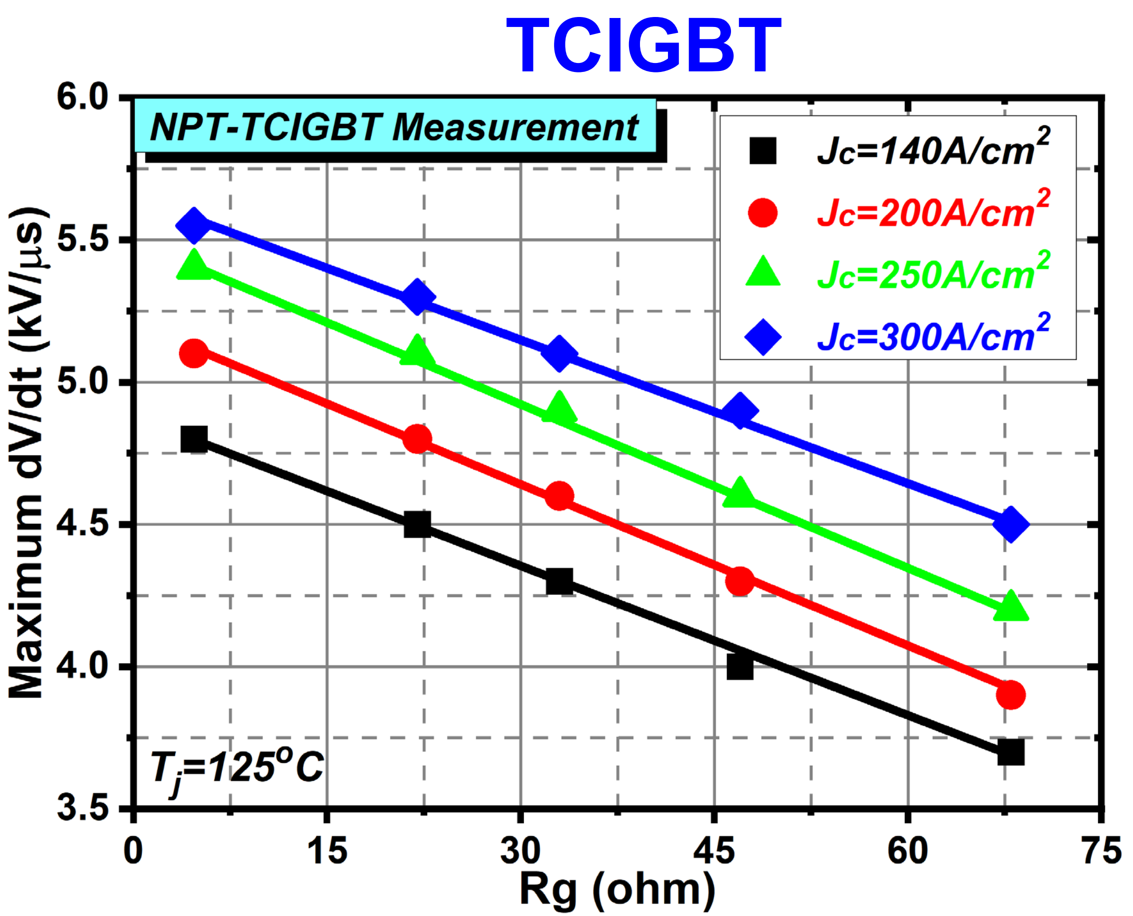


(Source: P. Luo, et. al, "Turn-off dV/dt Controllability in 1.2kV MOS-Bipolar Devices," in *IEEE Transactions on Power Electronics.*)

- TCIGBT shows superior on-state performance at both rated current density and high current densities.

Experiments - High Current Density Operation

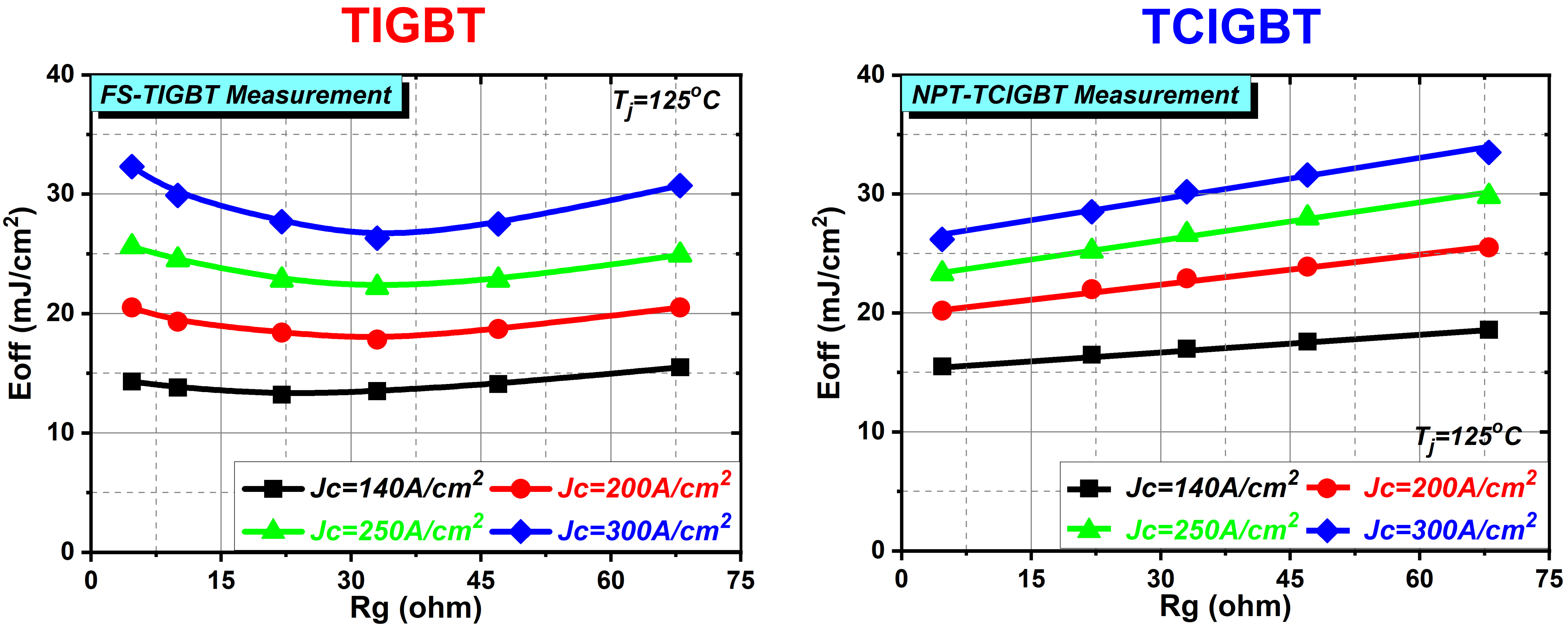




(Source: P. Luo, et. al, "Turn-off dV/dt Controllability in 1.2kV MOS-Bipolar Devices," in *IEEE Transactions on Power Electronics.*)

- DA is enhanced at high current densities in the TIGBT.
- However, TCIGBT can remain DA free at 300A/cm^2.

Experiments - High Current Density Operation



(Source: P. Luo, et. al, "Evaluation of Dynamic Avalanche Performance in 1.2-kV MOS-Bipolar Devices", in *IEEE Transactions on Electron Devices.*)

VII.Conclusions

- DA limits the operation current density, switching loss and dV/dt controllability of TIGBTs.
- Management of the electric field beneath trench gates is the key to minimize the DA.
- A DA free design enabled by TCIGBT shows high dV/dt controllability through experiments and simulations.
- Experimental results confirm that TCIGBTs can remain DA free performance at high current densities and provide high dV/dt controllability and high design flexibility.

Thank you for your kind attention.