Solitronics, LLC

NC STATE UNIVERSITY

SPEC

Development of High Voltage SiC Emitter Turn-Off Thyristor (ETO)

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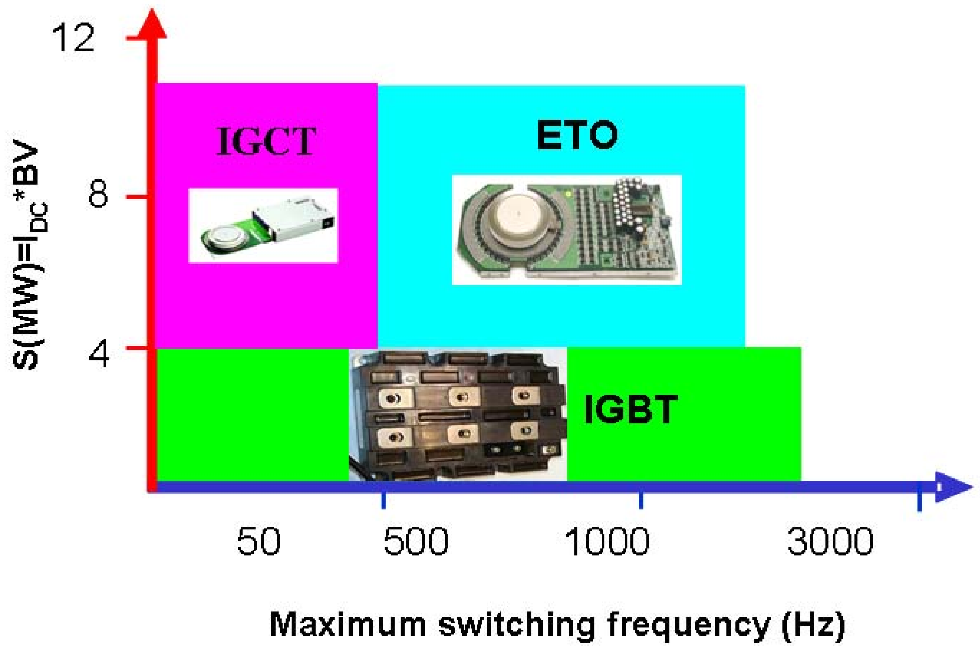
Problem statement:

Low cost, reliable, high efficiency power control and storage technologies are needed to handle increasing levels of power flow in distribution and sub-transmission applications including integration of renewable energy resources.

How to address this problem:

- **10 kV-12 kV SiC Emitter Turn-off (ETO) Thyristor**
- **5 kHz switching capability**
- **100 A current rating.**
- **Large current module using multichip module packaging (MCM)**
- **Superior to Si IGBT and MOSFET**
    - **Higher frequency operation**
    - **Lower conduction losses**
    - **Lower switching losses**

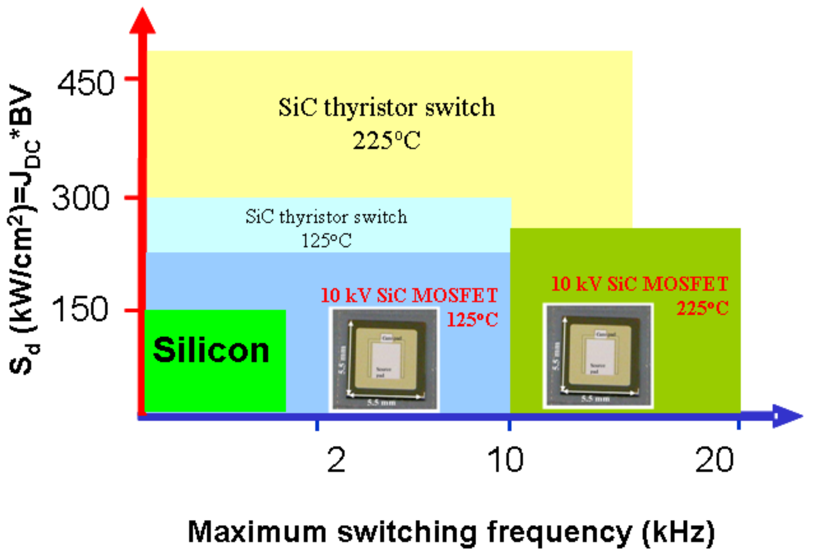
Limit of Si Power Devices



Si high power devices are approaching its physical limit:

- Voltage rating below 6.5 kV
- Operation frequency below 1 kHz
- Normal operation junction temperature is below 125 ^{O}C.

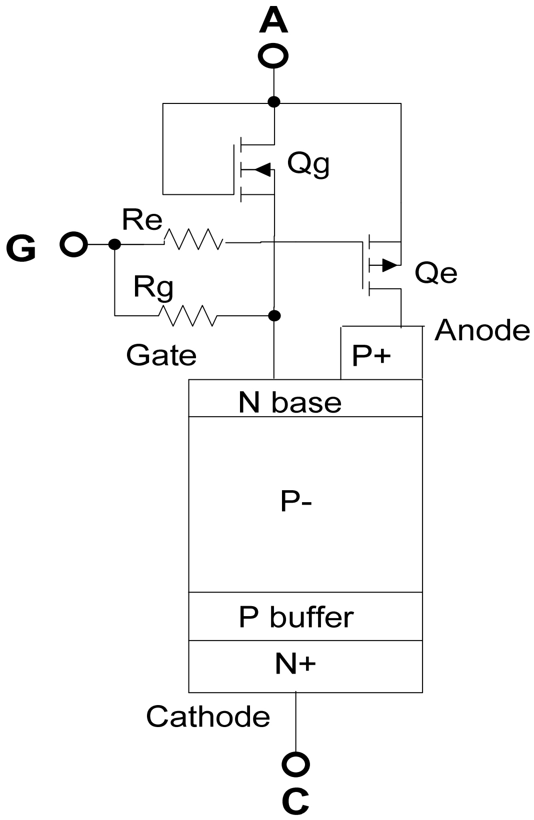
Motivation of SiC ETO

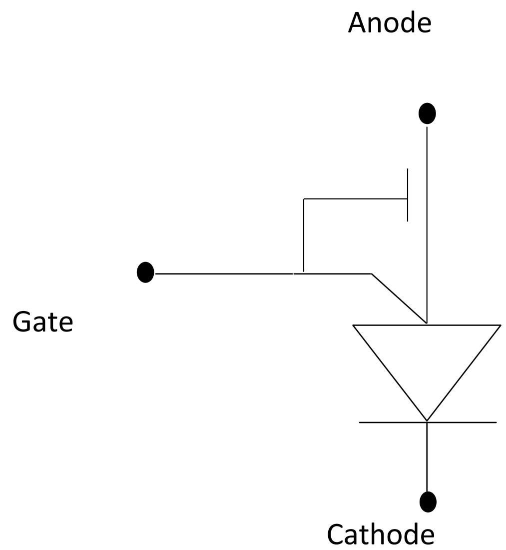


Advantages of SiC ETO:

- Improved switching speed
- High temperature operation capability
- Gate control.
- Better SOA

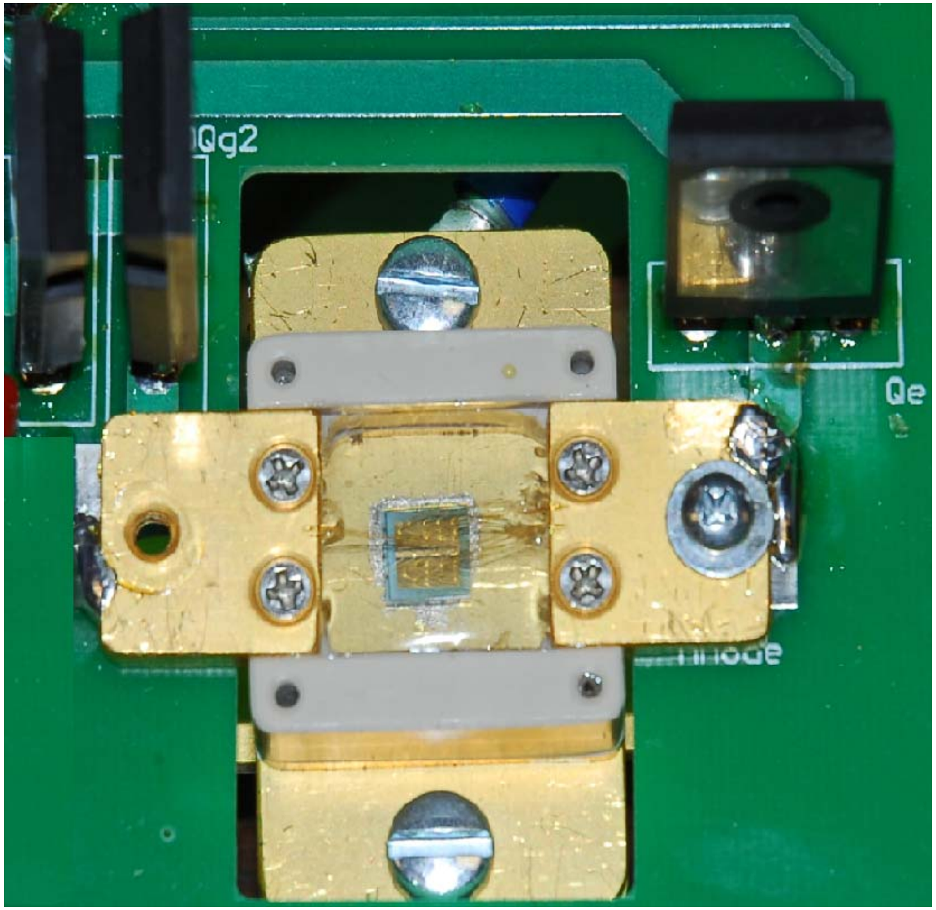
Schematic of p type SiC ETO



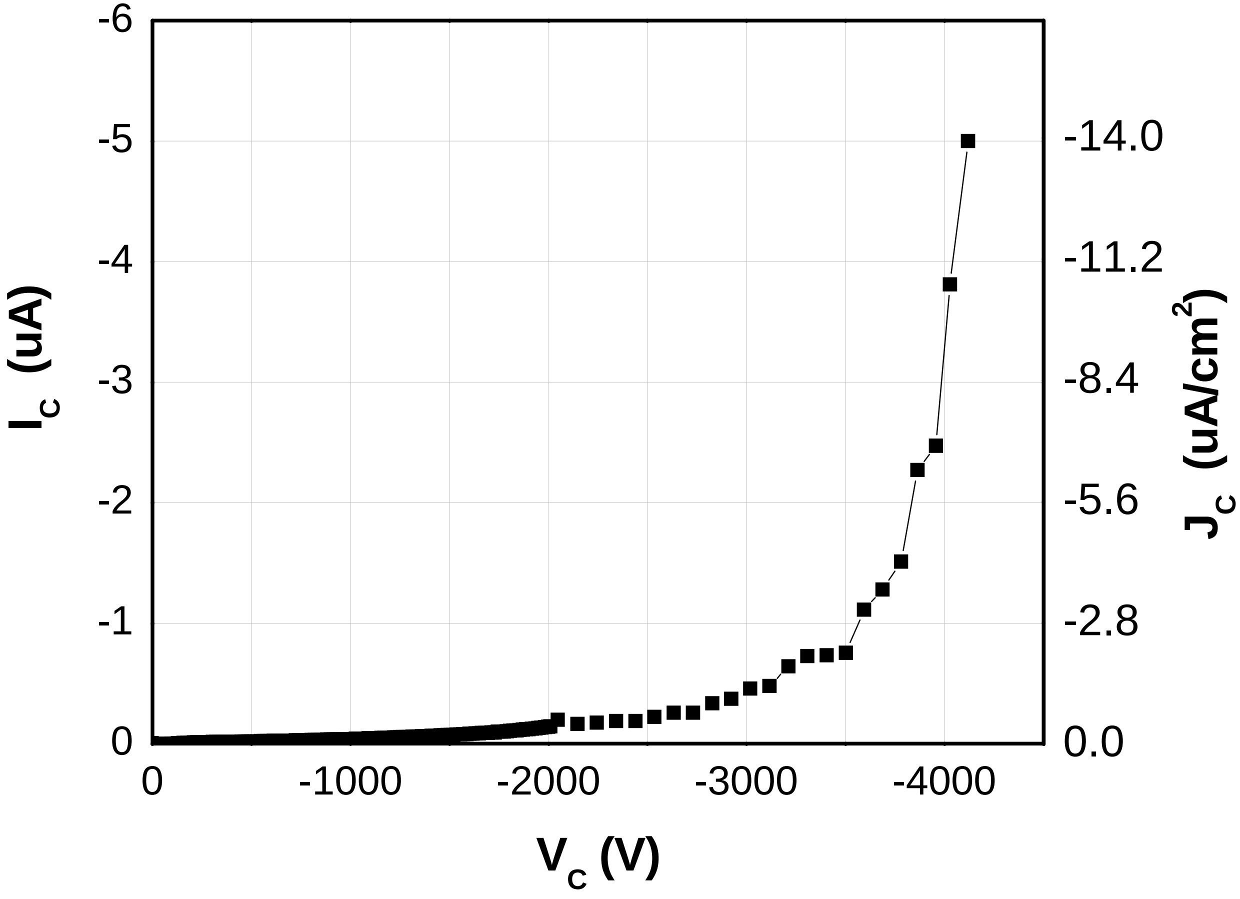


(a) p-type ETO equivalent circuit; (b) corresponding ETO symbol.

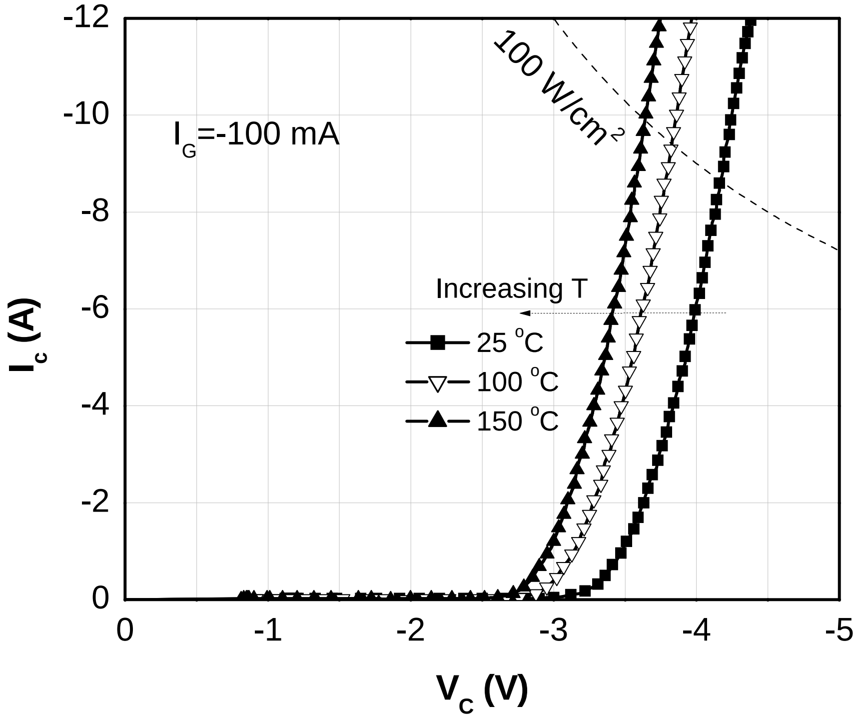
World’s first SiC ETO



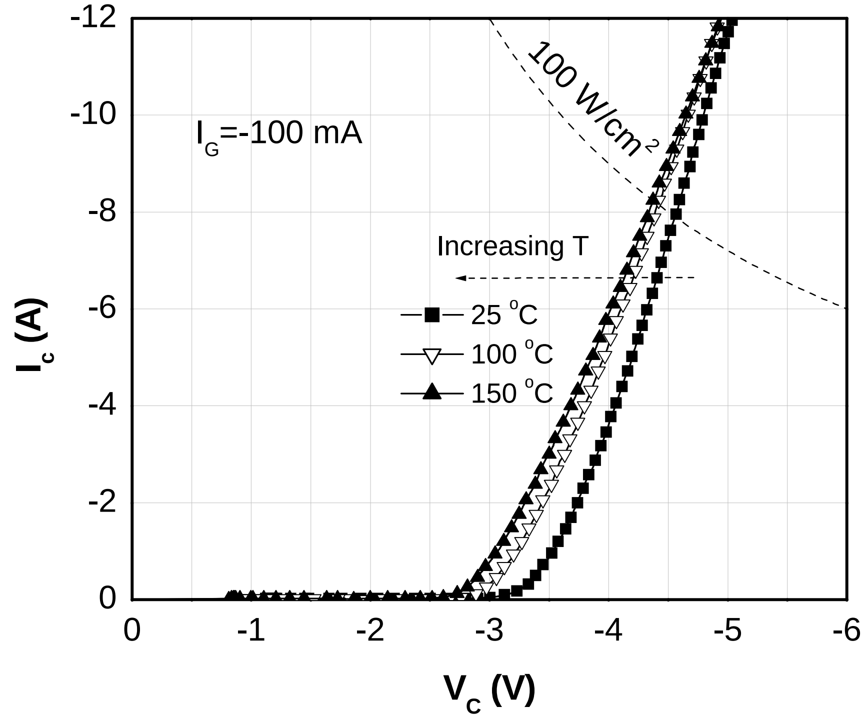
Blocking Characteristics of SiC GTO



DC Forward Characteristics of SiC GTO and ETO

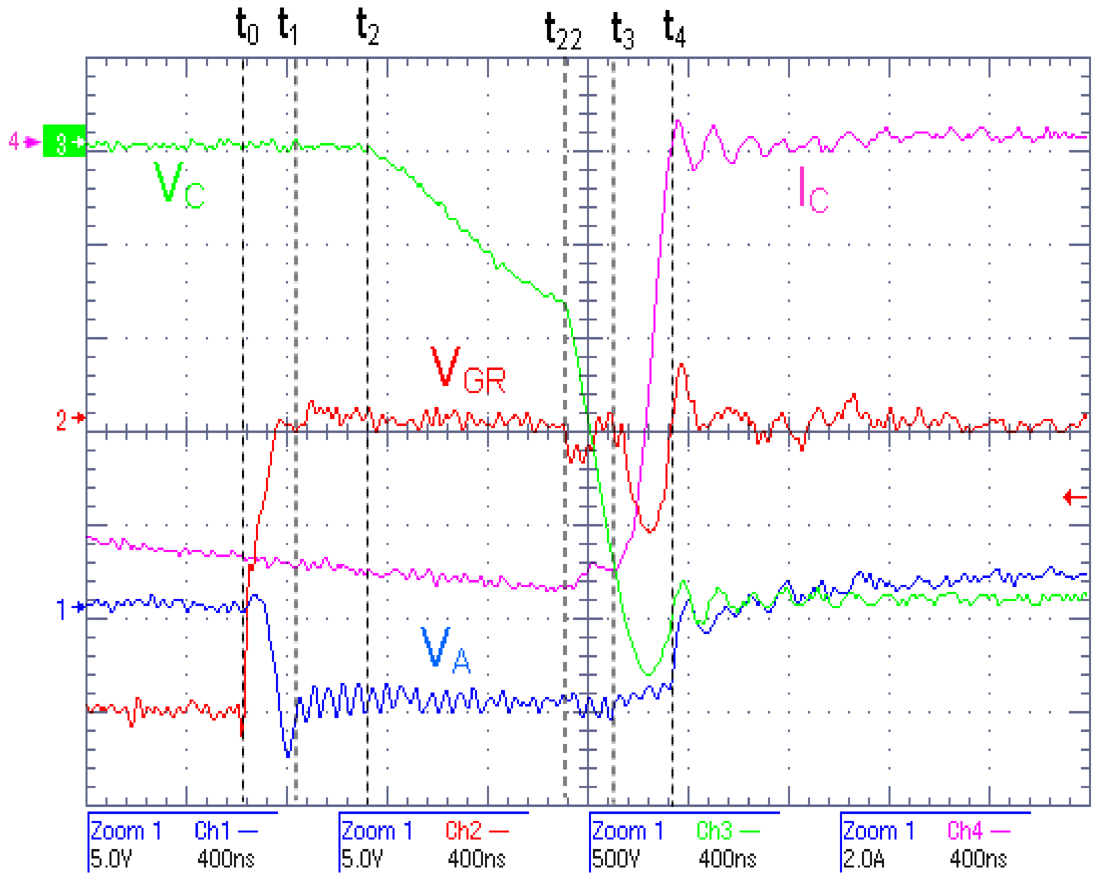


(a) SiC GTO



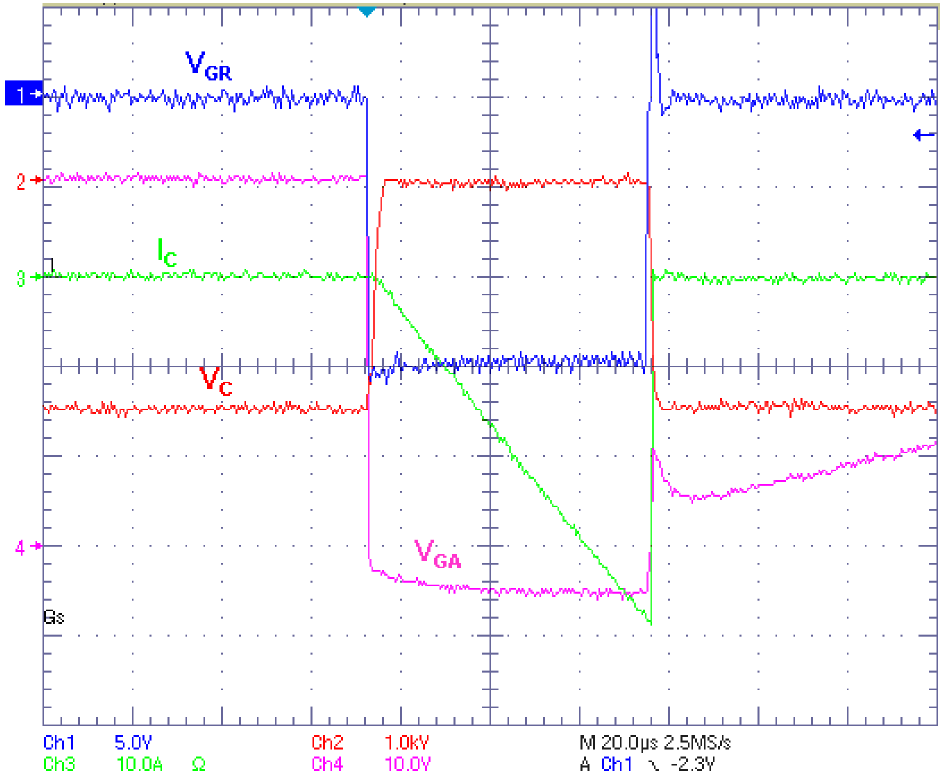
(b) SiC ETO

Transient Characteristics of SiC ETO



E_{off} = 9.88mJ for 36 mm^2 SiC GTO, capable 8 kHz switching at 200 ^{O}C.

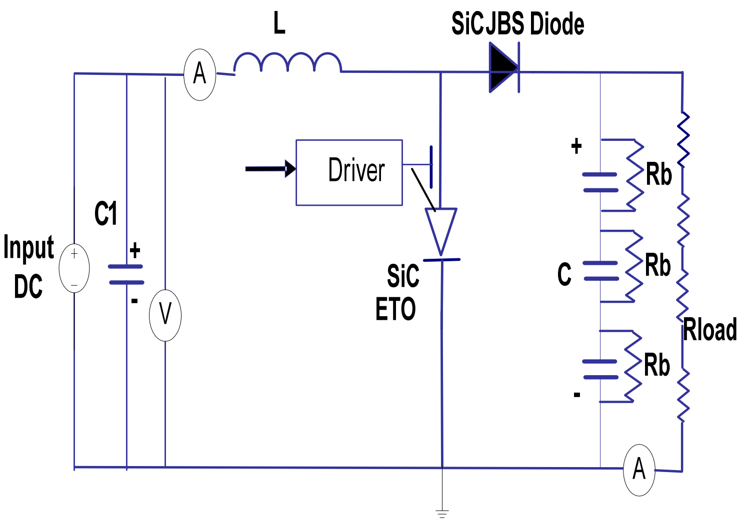
RBSOA study of SiC ETO

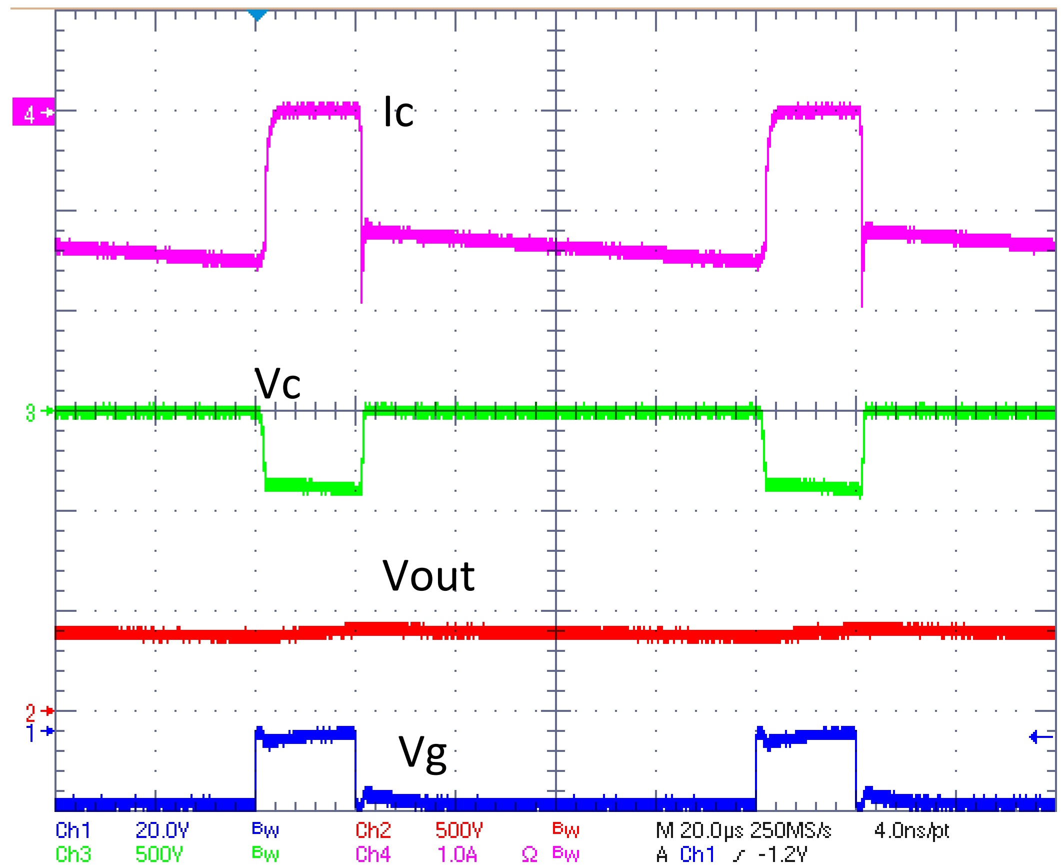


$V_{DC\text{-}link}$=2.5 kV

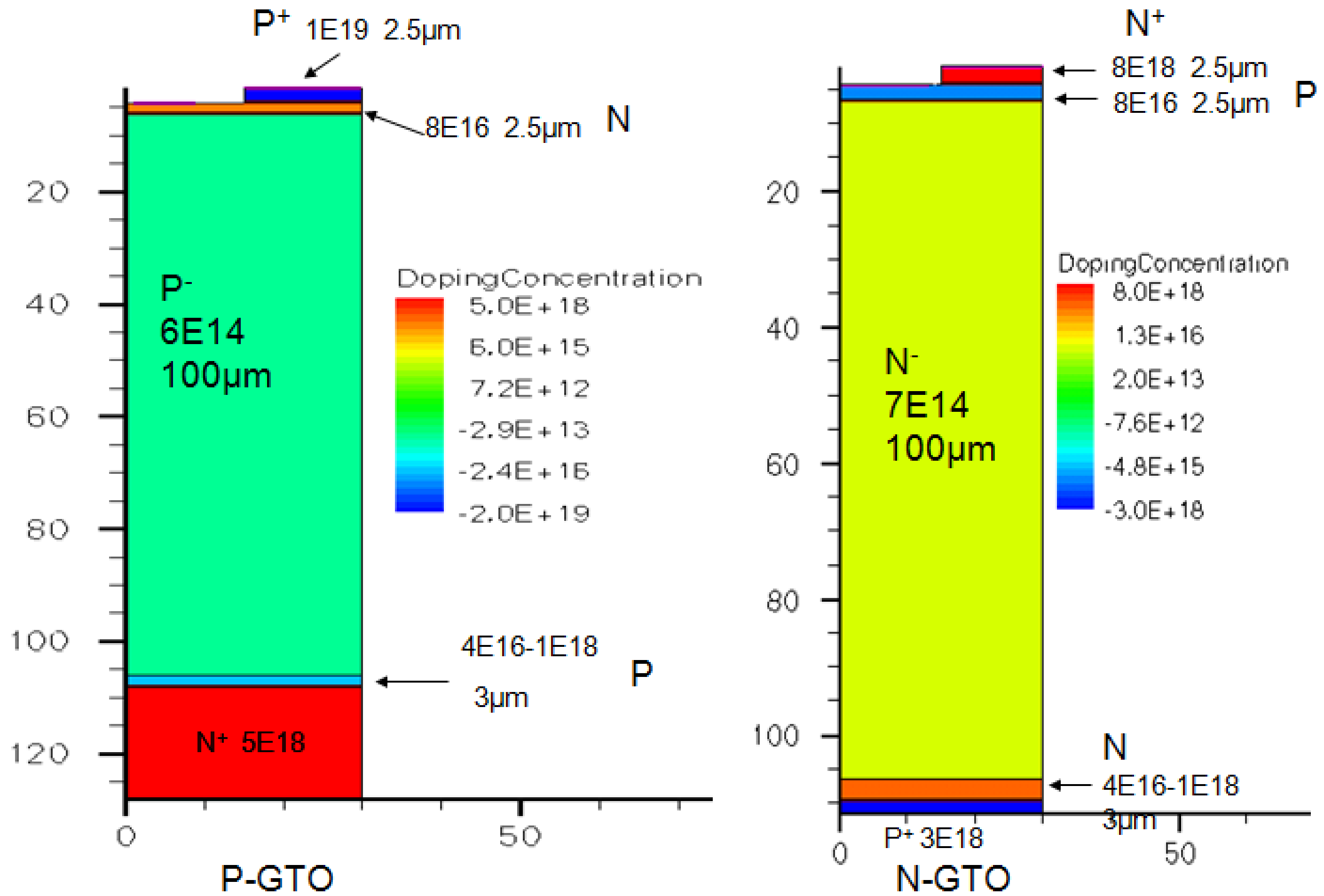
J_C=100 A/cm^2

SiC ETO Based Boost Converter Demo

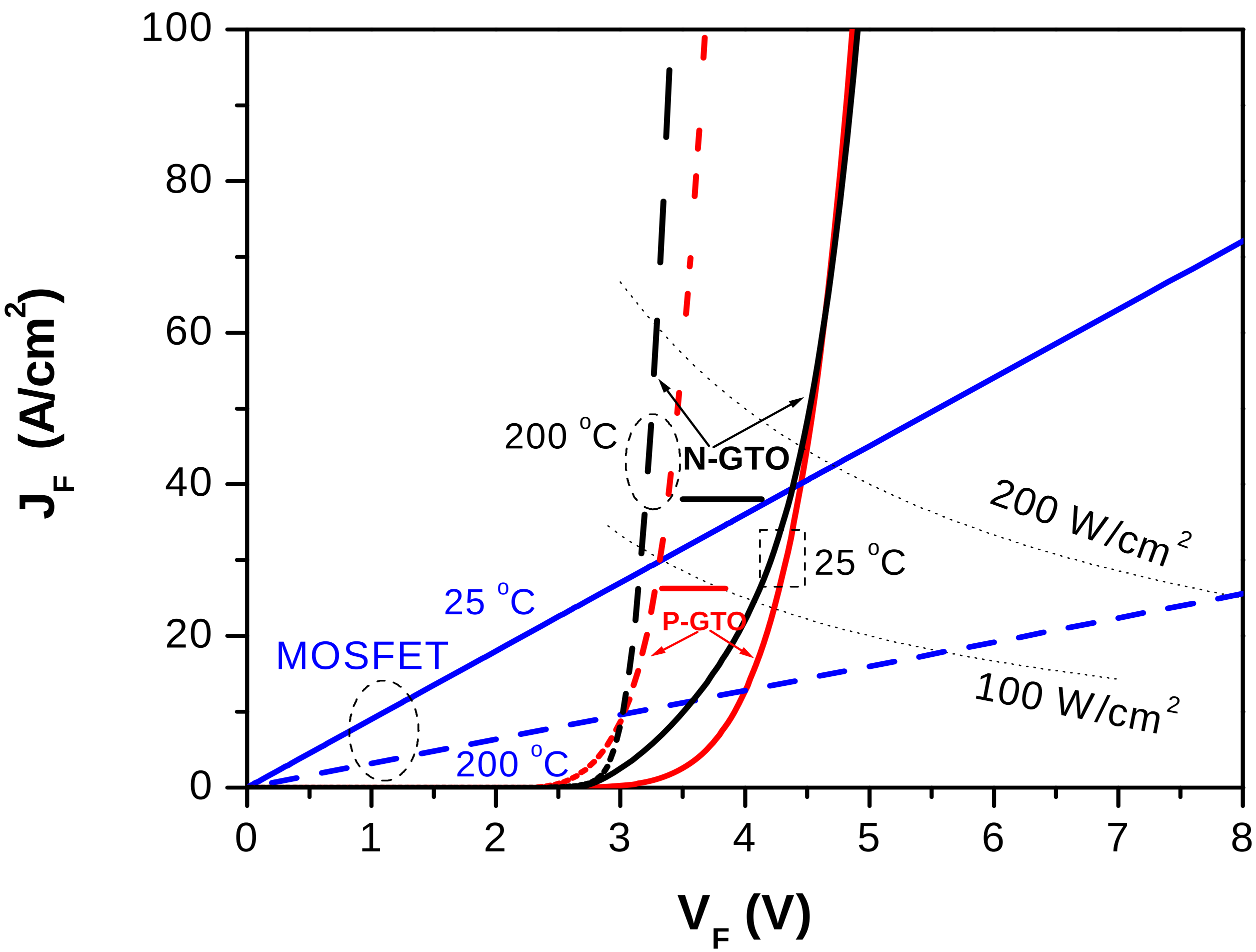




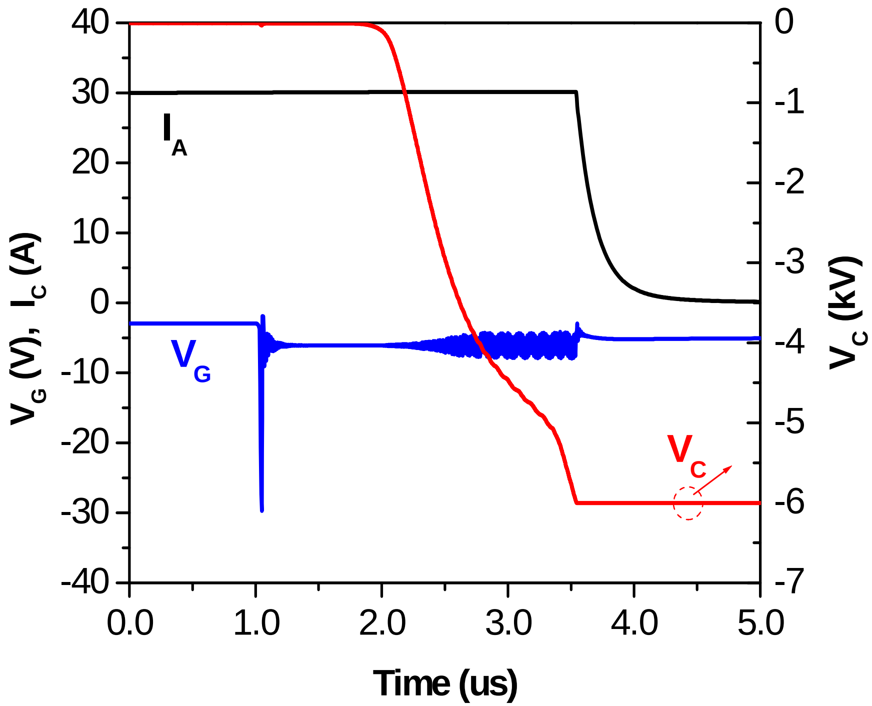
Design of High Voltage (10-kV) SiC GTO

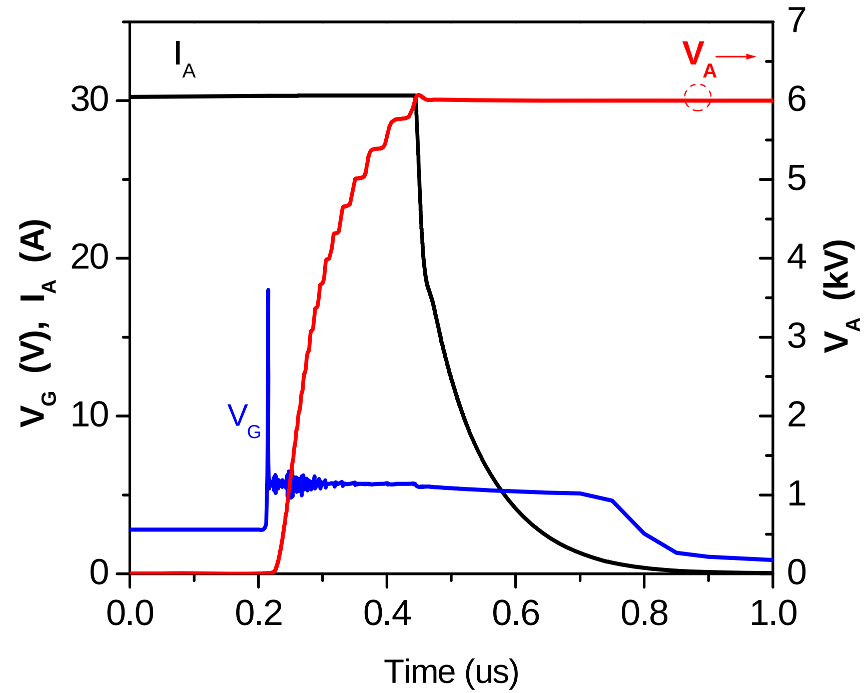


Simulated DC Characteristics



Simulated Transient Characteristics





p-ETO

t_{off}=2.9 µs

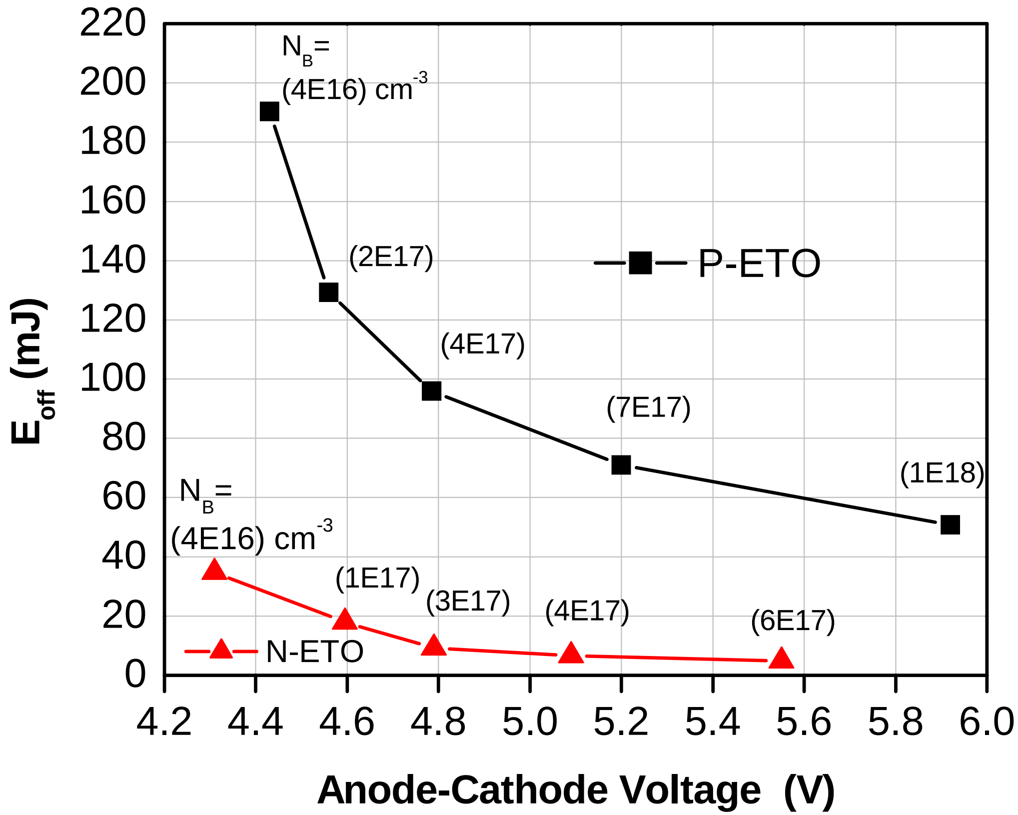
E_{off}=190 mJ

n-ETO

t_{off}=0.52 µs

E_{off}=34 mJ

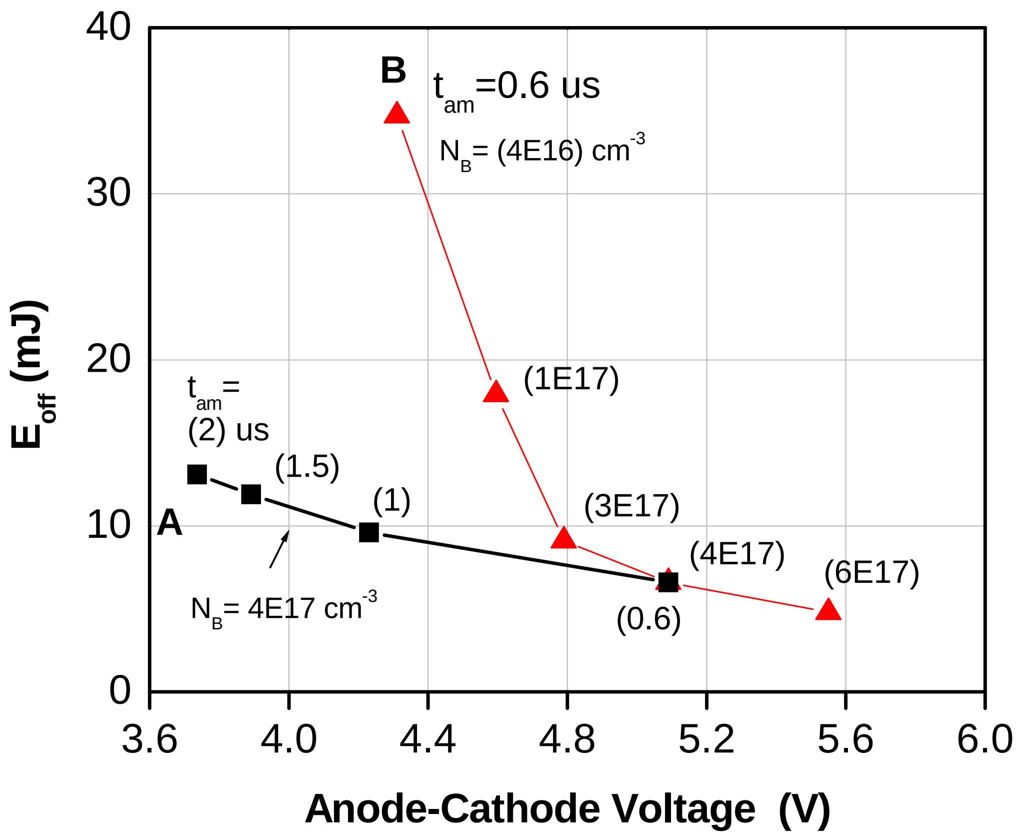
Effect of Buffer Layer in SiC GTO



1) n-ETO can achieve about 8 time smaller turn-off energy, $E_{off,}$ than p-ETO due to a small lower transistor current gain

2) E_{off} reduces by 81% (6.6 mJ) and V_F increases by 18% (5.05 V)when N_D increases form 4E16 cm^3 to 4E17 cm^3 for n type SiC ETO

Effect of Drift Layer Carrier Lifetime in SiC n-GTO



The n type SiC GTO with a long drift layer carrier lifetime is superior to those with a short drift layer carrier lifetime for the trade-off between on-state voltage and turn-off losses.

Summary

- We demonstrate the world's first 4.5 kV SiC ETO
- The fast switching speed and low loss of the 4.5 kV SiC ETO indicates the attractive potential of high voltage (>5 kV) SiC ETO especially for high voltage high frequency applications.
- Theoretical comparisons of 10 kV SiC n and p type SiC ETO shows the superiority of n type ETO, such as faster switching, due to very low switching losses and wide RBSOA.
- Further improvement of n type ETO can be made by the optimization of buffer layer and drift layer lifetime of SiC GTO

Further Work

- <u>*Development of 10 kV SiC n type ETO*</u>

  1) fabrication of 10 kV SiC n-GTO

  2) Characterization of 10 kV SiC n-ETO

  3) Application of 10 kV SiC n-ETO

- <u>*Study of Si/SiC heterostructure to reduce the turn-on knee voltage of SiC pn junction (~3 V)*</u>

  1) Theoretical analysis

  2) Experimental study

Questions ?

Thank you