Novel SiC MOS-Bipolar Switches for >10 kV Applications

Ranbir Singh
GeneSiC Semiconductor Inc.
25050 Riding Plaza, Suite 130-801, South Riding, VA 20152
571-265-7535 (ph), 703-373-6918 (fax), ranbir@ieee.org (email).

MOS-based gate control is considered a necessity for the applicability of a switch to pulse-width modulation (PWM) circuits used in high voltage power conversion. Also, bipolar-mode switches offers low conduction losses in >10 kV SiC devices as compared to unipolar devices. This paper introduces and compares novel device structures and configurations that allow the integration of MOS based control to bipolar Silicon Carbide power devices.

Thyristor-based devices offer the lowest on-state drop due to high level of minority carrier injection into the low doped voltage blocking region. A novel method of incorporating MOS control into a SiC-based thyristor is the Emitter Switched Thyristor (EST), as shown in Figure 1. This device is realized when a low voltage (low resistance) Si MOSFET is placed in series with the SiC GTO Thyristor. A positive gate voltage pulse turns ON the device by inducing a transient current into the Thyristor through a gate input capacitor, and simultaneously turning ON the Si MOSFET. Since the current flows through both these devices, the on-state voltage drop of the EST is the sum of on-state drop of both the Thyristor and the MOSFET. As in Si, IGBTs may be ideal candidates for PWM applications but face many fabrication and reliability challenges for implementation in SiC such as availability of suitable substrates, MOS channel mobility, reliability, contact resistance, and cost.

In contrast, a SiC MOS-Bipolar Transistor is a high voltage MOSFET in Darlington connection with a high voltage BJT, as shown in Figure 3 and Figure 4. It features the following advantages: 1) the n-channel MOSFET provides a higher transconductance than a p-channel MOSFET and the npn bipolar transistor has a higher current gain and BV_{CEO} than the pnp counterpart; 2) when compared to the IGBT, it does not have a four-layer parasitic thyristor that creates latch-up and thus has a better forward-biased SOA; 3) the hole ionization coefficient is larger than the electron coefficient in SiC, thus the npn is more rugged than the pnp; and 4) the MBT uses an n+ substrate, which is available in a much lower resistivity and higher quality than the p+ substrate of an n-channel IGBT in SiC. Another new promising approach uses a high voltage SiC bipolar Field Controlled Thyristor in a cascode configuration with a low voltage Si MOSFET as shown in Figure 5. An FCT behaves similar to a PiN diode in the forward conduction and switching operation, with the addition of a gate grid near the Anode to control the flow of current. However, it faces the challenge of low voltage gain (V_{Anode}/V_{Gate}), due to the precision required in the control of voltage blocking layer doping near the Anode region.

This paper will analyze the trade-offs of these SiC switches with respect to their functionality and performance; reliability; and cost considerations. These metrics includes their breakdown voltage/on-state drop performance, switching speed, high temperature operation, complexity of integration, as well as materials & fabrication costs.

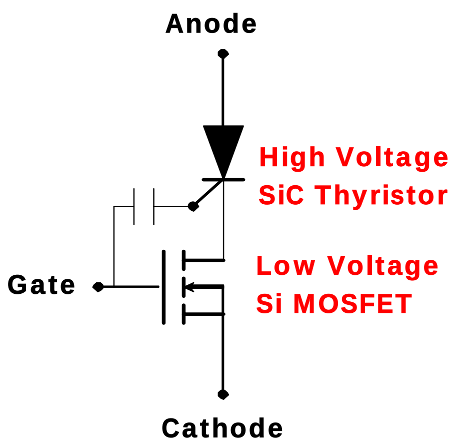

Figure 1: Emitter Switched Thyristor (EST) with ultra-high voltage SiC Thyristor and low voltage Si MOSFET.

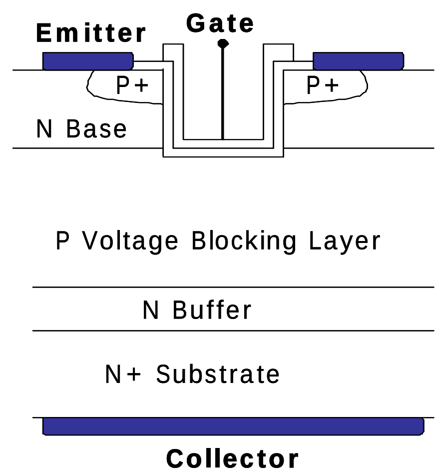

Figure 2: p-channel IGBT using conventional N+ Substrate.

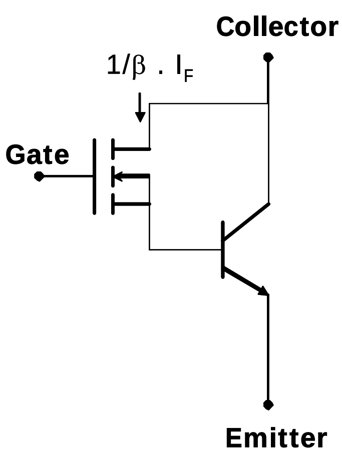

Figure 3: Discrete MOSFET/BJT implementation of MBT.

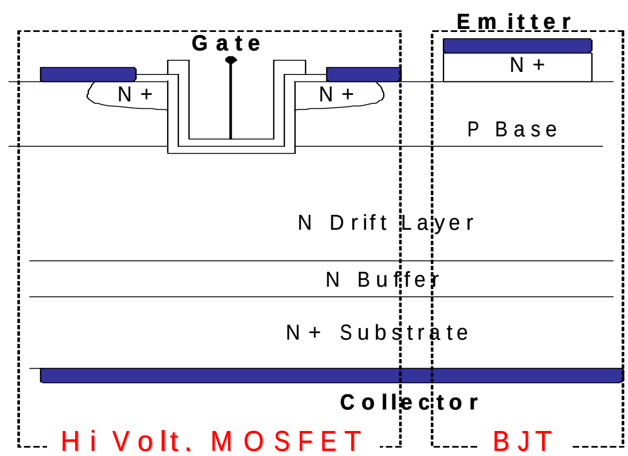

Figure 4: Integrated MBT in SiC may offer lower on-state voltage drop because of minority carriers in MOSFET.

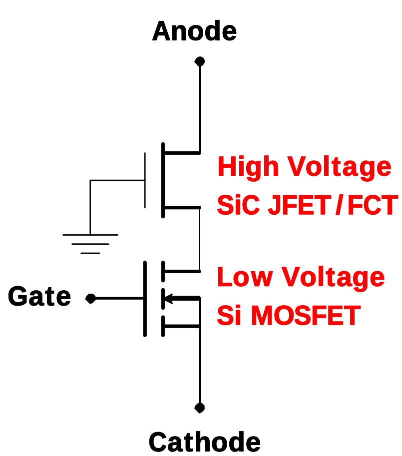

Figure 5: Cascode configuration of low voltage Si MOSFET with high voltage field controlled thyristor (FCT).

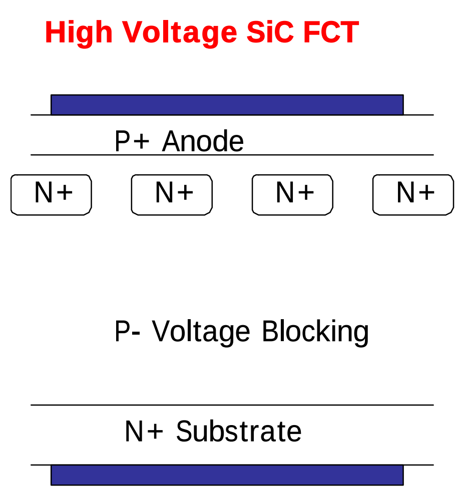

Figure 6: A possible structure of high voltage SiC FCT.