5.8kV SiC PiN Diode for Switching of High-Efficiency Inductive Pulsed Plasma Thruster Circuits

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Inductive Pulsed Plasma Thruster (IPPT) pulse circuits, such as those needed to operate the Pulsed Inductive Thruster (PIT), are required to quickly switch capacitor banks operating at a period of μs while conducting current at levels on the order of at least 10 kA. [1,2] For all iterations of the PIT to date, spark gaps have been used to discharge the capacitor bank through an inductive coil. Recent availability of fast, high-power solid state switching devices makes it possible to consider the use of semiconductor switches in modern IPPTs. In addition, novel pre-ionization schemes have led to a reduction in discharge energy per pulse for electric thrusters of this type, relaxing the switching requirements for these thrusters. [3,4] Solid state switches offer the advantage of greater controllability and reliability, as well as decreased drive circuit dimensions and mass relative to spark gap switches.

The use of solid state devices such as Integrated Gate Bipolar Transistors (IGBTs), Gate Turn-off Thyristors (GTOs) and Silicon-Controlled Rectifiers (SCRs) often involves the use of power diodes. These semiconductor devices may be connected antiparallel to the switch for protection from reverse current, or used to reduce power loss in a circuit by clamping off current ringing. In each case, higher circuit efficiency may be achieved by using a diode that is able to transition, or 'switch,' from the forward conducting state ('on' state) to the reverse blocking state ('off' state) in the shortest amount of time, thereby minimizing current ringing and switching losses.

Silicon Carbide (SiC) PiN diodes offer significant advantages to conventional fast-switching Silicon (Si) diodes for high power and fast switching applications. A wider band gap results in a breakdown voltage 10 times that of Si, so that a SiC device may have a thinner drift region for a given blocking voltage. [5] This leads to smaller, lighter devices for high voltage applications, as well as reduced forward conduction losses, faster reverse recovery time (faster turn-off), and lower-magnitude reverse recovery current. In addition, SiC devices have lower leakage current as compared to their Si counterparts, and a high thermal conductivity, potentially allowing the former to operate at higher temperatures with a smaller, lighter heatsink (or no heatsink at all). [6]

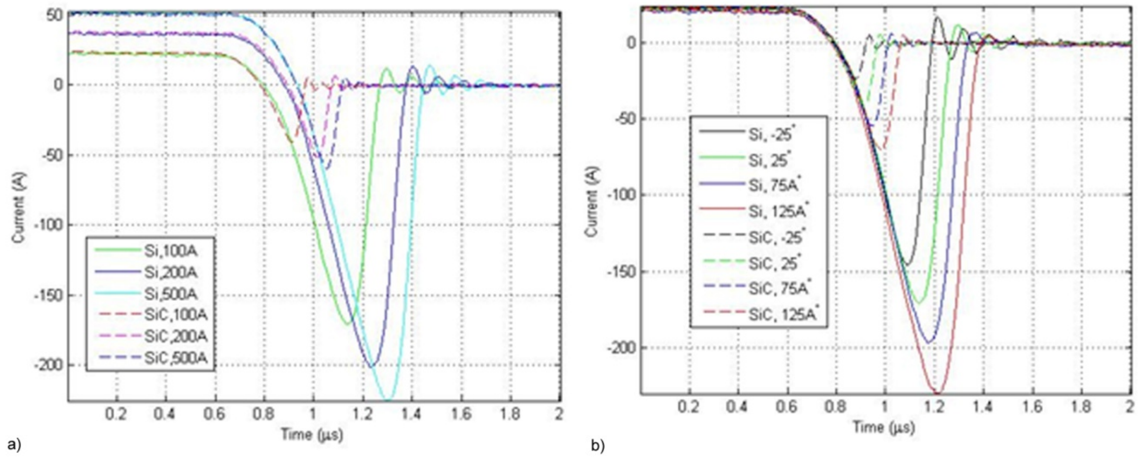

Figure 1: Measured reverse recovery waveforms for 5.8kV SiC PiN diode and 5.5kV Si fast diode. a) Fixed ambient temperature of 25°C, varying diode current. b) Fixed diode current, varying ambient temperature.

Reverse recovery waveforms were collected for a prototype 5.8kV SiC PiN diode from Cree, Inc. and for a 5SDF 02D6004 5.5kV fast-switching Si diode from ABB (Fig. 1). In Fig. 1a, the temperature is held at a constant 25°C using a SunSystems thermal chamber, while the current through the diode under test is varied. In Fig 1b, the current through the diode is fixed, and data is collected at ambient temperatures of -25°C, 25°C, 75°C, and 125°C. In each case, it can be seen that the peak reverse recovery current, reverse recovery time, and total recovery energy are all significantly lower for the SiC device than for the Si device.

Notably, the peak reverse recovery current for SiC at -25°C is a factor of 6 lower than for Si at the same temperature, while the reverse recovery time and total reverse recovery energy are reduced by factors of approximately 3 and 15, respectively. These data demonstrate the fast turn-off of the SiC device relative to a conventional fast-swtiching Si diode. This makes it desirable for use in high-efficiency IPPT drive applications, in which the main switch must be opened as soon as possible after the first current half-cycle in order to minimize energy loss in the drive circuit due to current ringing. [7,8]

A flat-plate IPPT developed at NASA Marshall Space Flight Center has been designed and constructed to serve as a test-bed for solid state components that will allow for repetitive operation mode testing. [9] The SiC and Si diodes will be integrated in turn into the thruster assembly, and waveforms collected to compare performance and switching efficiency. The results are compared to simulated waveforms generated using a physics-based Simulink model of the Si and SiC PiN diodes.

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