2.6 Post-Silicon Devices

Year 10 Projects and Participants			
Project Number	**Project Title**	**Participants**	**Institution**
Y10.FS.1	SiC MPS Rectifiers	Baliga	NCSU

2.6.1 Intellectual Merit and Impact

The Post-Silicon Device (PSD) was created from the inception of the FREEDM Sytems Center to support enhancements in performance of the solid-state-transformers (SST) and fault-interruption-devices (FID). During the first year, we demonstrated that 10-kV SiC power MOSFETs are more suitable than 10-kV SiC IGBTs due to the high switching speed goals set for the SST. Based up on this effort, 10-kV SiC power MOSFETs were acquired from CREE and successfully used in the Gen-2 and Gen-3 SSTs to increase the efficiency and size/weight.

We identified switching losses in the 10-kV SiC P-i-N fly-back diodes as a major component on the primary side of the SST. Based up on this conclusion, we proposed the development of a novel 10-kV SiC Merged-PiN-Schottky (MPS) rectifier. We were successful in fabricating the first 10-kV SiC MPS rectifiers in Year 6-7 and demonstrating reduced power losses due to improved reverse recovery behavior. In Year 8-9, we were able to enhance the performance of the SiC MPS rectifiers to achieve efficient operation at 175 ^{o}C. This enables reducing the heat sink size/weight. **The 10-kV SiC MPS rectifier developed in the FREEDM Systems Center is a new SiC power device component that can be commercialized by the industry for utility scale applications (executive summary).**

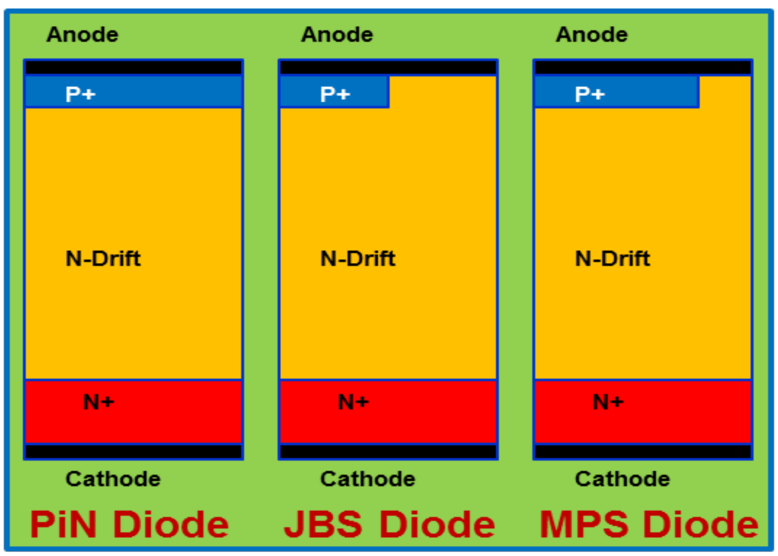

Fig. 1: SiC MPS Rectifier compared with available PiN and Schottky Rectifiers

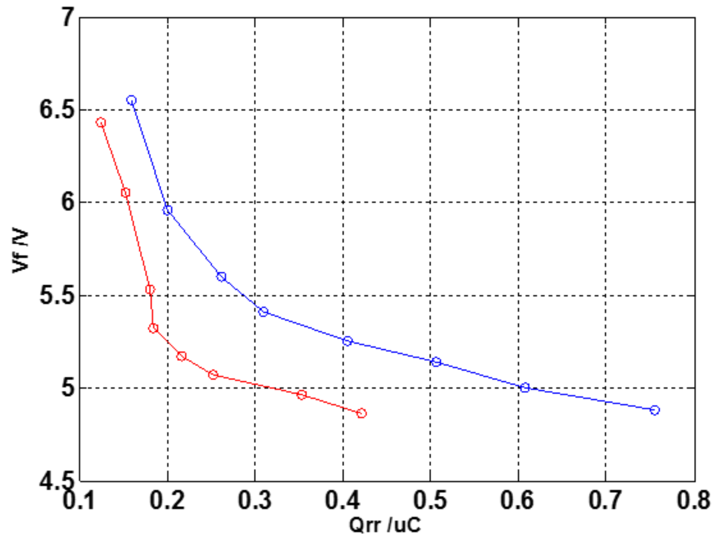

Fig. 2: Improved power loss trade-off curve demonstrated using 10-kV SiC MPS Rectifier (red) compared with PiN Rectifiers (blue).

10-kV 4H-SiC Junction Field Effect Transistors (JFETs) and Field Controlled Diodes (FCDs) with bidirectional voltage blocking capability were investigated for the FID application on the enabling technology plane. We were successful in demonstrating the first high performance 10-kV SiC JFETs with blocking gains above 50. We also proposed and demonstrated a novel orthogonal bevel edge termination to achieve high voltage bi-directional blocking capability. This is the first and only method proposed and demonstrated for creating bi-directional blocking SiC power devices.

2.6.2 Technical Approach

The development of the 10-kV MPS rectifiers required innovations in edge terminations to achieve the very high blocking voltage capability and creating a process to simultaneously form a low leakage Schottky contact to the N-drift region and ohmic contact to the P^+ shielding regions. Our process enabled achieving Schottky barrier heights of 1.7 eV on 4H-SiC using Ni as contact metal.

2.6.3 Unique Approaches

A unique multiple-floating-zone junction-termination-extension (MFZ-JTE) edge termination was created during the FREEDM System Center research. It was demonstrate to have excellent breakdown voltage close to the ideal value and to be highly tolerant to process variations when compared with previously reported method.

2.6.4 Scientific Breakthroughs

A major scientific breakthrough achieved in our work was to achieve injection from the P-N junction of the SiC MPS rectifier with a low Schottky barrier height in spite of the large band gap of SiC. This was made possible by using a very narrow opening for the Schottky contact so that a potential barrier was formed under it.

2.6.5 Technology Innovations

Interactions with the developers of the SST on the enabling technology plane allowed the PSD effort to recommend the development of 10-kV SiC Power MOSFETs which were then procured and used for the successful development of Gen 2 and Gen 3 SSTs.

The motivation for development of the novel 10-kV SiC MPS rectifier in the fundamental sciences plane was provided by understanding the needs of the SST in the enabling technology plane. This interaction was also responsible in encouraging the development of 10-kV SiC MPS rectifiers with high temperature operating capability to reduce the heat sink size and weight. During our research, we discovered that the performance of 10-kV SiC MPS rectifiers becomes even superior to that of the previously used 10-kV SiC PiN rectifiers at elevated temperatures.

2.6.6 References

The effort on 10-kV MPS rectifiers was published in numerous papers:

1. “A Novel Edge Termination Technique for High Voltage Devices in 4H-SiC – Multiple Floating Zone Junction Termination Extension (MFZ-JTE)”, IEEE Electron Device Letters, Vol. 32, pp. 880-882, 2011.

2. “10-kV SiC MPS Diodes for High Temperature Applications, IEEE Int. Symp. On Power Semiconductor Devices and ICs, pp. 43-46, 2016.

3. “Performance Improvement of 10-kV 4H-SiC MPS Rectifiers with High Schottky Barrier Height”, Electronic Materials Conference, 2017.

4. “Electrical Characteristics of 10-kV 4H-SiC MPS Rectifiers with High Schottky Barrier Height”, Journal of Electronic Materials, Vol. 47, pp. 927-931, 2017.

2.6.7 Intellectual Property (Licensing and Patents)

None in the PSD Thrust