Radiation Hardening of Silicon Carbide Power Devices for Lunar Applications.

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Introduction: High-voltage DC buses are essential to obtain power efficiencies needed for electric vehicles on the lunar surface. Currently the target power bus voltage is around 1000 V or greater. Silicon carbide transistors can easily achieve this voltage and much higher for power converters in the terrestrial environment, but in space are susceptible to single-event burnout (SEB) and single-event leakage current (SELC) degradation because of solar and galactic energetic ions on the lunar surface. An SEB event is a permanent failure of the power device and a possible short on the power bus. The SELC events are small permanent increases in the leakage current that over time lead to significant off-state leakage current that exceeds the manufacturer specification and impacts the power converter efficiency.

Statement of Problem: The SEB and SELC effects are typically plotted with the device bias under radiation on the vertical axis, and the linear energy transfer from the ion on the horizontal axis (LET, in units of MeV/mg/cm^2), as shown in Fig. 1. The figure illustrates that the SEB boundary is well below the rated voltage of the various devices shown, on the order of 0.3 to 0.4 of the rated voltage. Consequently the full capability of the devices cannot be currently used in space. However, the SEB boundary does seem to scale somewhat with the voltage capability of the device, e.g., the 3300 V MOSFET has a significantly higher boundary than the 1200 V MOSFET, and may be used as the prototype for obtaining a device with an SEB boundary greater than 1kV.

Previous Research Effort: The majority of this research team participated in a NASA Early Stage Innovation (ESI) grant exploring the impact of radiation on silicon carbide devices from 2017 through 2019. We achieved several advancements that should contribute to developing SiC power device technology that will survive the harsh radiation environment to be encountered on the Lunar surface.

Statement of Work: The NASA LuSTR 2020 SiC program is focused on developing a radiation-hardened MOSFET survivable at 600 V minimum and a radiation-hardened diode survivable at 1000 V, while maintaining useful electrical specifications. This effort will leverage the efforts from the NASA ESI program. As noted above, using a higher rated breakdown voltage device provide substantial increases in SEB tolerance when compared to lower rated devices.

Consistent with the observation that higher voltage rated SiC parts tend to have higher SEB boundaries, the core activity in this project is first to measure the SEB performance of GE SiC high voltage MOSFETs and diodes rated at 1.7kV and 3.3 kV. The initial ion-beam experiment will be with existing GE parts. After the measurement, GE and VU will work together to determine measures that can harden the parts. The GE team will then fabricate new 3.3 kV devices modified to improve their radiation hardness. At the end of the fab cycle, the VU team will measure the hardness of the hardened parts at the same heavy-ion accelerator test facility. Both SELC and SEB will be characterized.

Additionally, failure analysis (inspection of the device/die for material property changes during radiation) has been limited to date, particularly for ion-induced degradation in which the device is still functioning. The goals of the LuSTR program are to advance the state of the art in understanding the SEB tolerance of higher rated devices, the magnitude and frequency of ion-induced degradation, and fundamental material changes due to radiation.

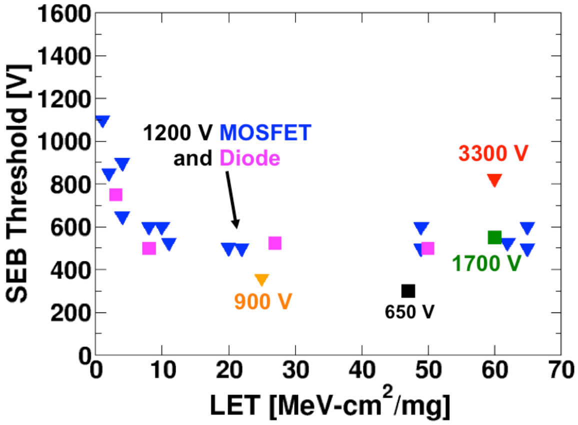

Fig. 1. An SEB boundary plot for several different SiC diodes and MOSFETs.

References:

[1] D.R. Ball, et al, IEEE Trans. on Nucl. Sci., vol. 67, no. 1, pp. 22-28, Jan. 2020.