Operation of Silicon Carbide Power Diodes under Lunar Night Temperatures

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Introduction: Silicon Carbide (SiC) power devices offer important advantages for next-generation power converters. In comparison with Si power devices, SiC power devices feature higher breakdown electric field, lower specific on-resistance, faster switching speed, and higher junction temperature capability. These material properties are favorable for the efficiency, power density, specific power, and reliability of power converters [1]. It is essential to understand the performance of SiC devices at low temperatures if they are to be used in lunar applications such as Lunar Surface Utility Systems since the average ambient temperature (T_A) on the Moon can be as low as 100 K at night [2].

Temperature Considerations for Lunar Surface Power: Two aspects related to temperature must be considered to facilitate the creation of power infrastructure for the Lunar surface. Firstly, device parameters such as turn-on voltage (V_F) varies with the junction temperature (T_J) at which the device operates, calculated as:

$$T_J = T_A + (\theta_{JA} \times P_d)$$

where θ_{JA} is the junction-to-ambient thermal resistance and P_d is the power dissipated. Therefore, to ensure good thermal management and a longer device life-cycle, T_J must remain well below T_{Jmax}, the maximum temperature a device can tolerate while guaranteeing reliable operation [3]. Secondly, the power thermally radiated to space during the switching of the devices can be characterized following an approximation of the Stefan-Boltzmann Law:

$$P_R = \sigma_{SB} T_J^4$$

where P_R is the radiated power and σ_{SB} is the Stefan-Boltzmann constant. This radiated power will be on the order of kW_e when generating 40 kW_e power in a lunar fission PMAD system at 97.5% efficiency.

SiC Diode Operation under Lunar Night Temperatures: Commercially available SiC diodes have significant challenges for operation at very low temperatures during Lunar night, two of which were discussed in the previous section. The diode turn-on voltage increases significantly with decreasing temperature because of the reduced carrier generation rate [4]. I-V sweep tests were performed with 3.3 kV SiC diodes from GE using a temperature chamber from 200-300 K and the curve was linearly extrapolated to derive the V_F at 100 K as shown in Fig. 1. V_F at 100 K is about 400 mV higher than at room temperature which means the SiC diodes will have more switching losses during Lunar night, but these losses are still much lower than Si power diodes.

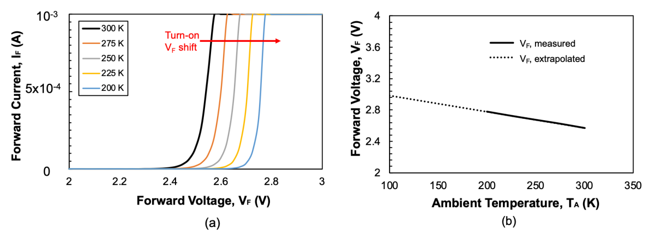

Fig. 1. (a) Forward I-V sweep of GE 3.3.kV SiC diode at temperatures 200 K to 300 K, and (b) Forward voltage (V_f) vs Ambient Temperature (T_A), measured using Test Equity I40 Temp. Chamber at 200 K to 300 K and extrapolated till 100 K.

Proper system shielding needs to be used to stabilize the temperature in a power converter and optimize the device operation. Radioisotope Power Systems (RPS) can be an option to be used here, which uses thermo-electrics to change that dissipated heat into usable electrical power [5].

Conclusion: To facilitate power management, distribution and control of Lunar surface power systems using SiC diodes, it is essential to regulate the operating temperature of the diodes by using appropriate device packaging and system shielding. These measures will optimize the turn-on voltage V_F of the devices, resulting in acceptable efficiency of the power converter.

References

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