Silicon Carbide Power Device Performance Under Heavy-Ion Irradiation

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Abstract: Heavy-ion induced degradation and catastrophic failure in SiC power MOSFETs and diodes are examined to provide insight into the challenge of single-event effect hardening of SiC power devices.

Introduction

This work presents heavy-ion data for several SiC power MOSFETs and diodes in order to increase the body of knowledge that will enable single-event effect (SEE) hardening of this technology. Specifically, dose data and MOSFET current data under different threshold biases, temperatures, and beam conditions are presented for devices from different manufacturers or different generations within a single manufacturer, and the emerging patterns are discussed.

Analysis of the performance benefits of SiC power devices (Fig. 1) and the high tolerance of commercial SiC components to normalizing electron (LET) (10^-4) to determine the allure of SiC technology in the aerospace community. To date, however, SiC power devices have not performed well under heavy-ion irradiation, suffering permanent degradation in various SEE conditions (Fig. 2, modified from [4] [6]).

The mechanisms of heavy-ion induced degradation and failure are actively researched in various research centers (see [5]).

Test Methods and Devices

Table I: Summary of Data Submitted for Testing

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Technology</th>
<th>Package</th>
<th>Maximum Bias</th>
<th>Onset Bias</th>
<th>Min VR</th>
<th>Max VR</th>
<th>Voltage Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDMOS</td>
<td>Vertical, planar gate double-diffused power MOSFET</td>
<td>7/4</td>
<td>1200 – 3300</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SBD</td>
<td>Schottky Barrier Diode</td>
<td>3/3</td>
<td>650 – 1200</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PiN</td>
<td>Pinsort</td>
<td>2/1</td>
<td>1200 – 3300</td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Results

Table II: MOSFET Single-Event Effect Testing

<table>
<thead>
<tr>
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Discussion

Several conclusions emerge from Tables II & IV:

- The overall outlier of device performance is found in the SiC device under heavy-ion irradiation.
- SiC devices exhibit a broader range of performance compared to Si-based devices.
- The performance of SiC devices is highly sensitive to irradiation conditions and device processing.

Several implications are derived from the results:

- Further investigation into the mechanisms of heavy-ion induced degradation in SiC devices is necessary.
- Development of hardening strategies for SiC devices is critical to their successful implementation in space applications.

References


Discussion Cont’d

In silicon power MOSFETs, SEE susceptibility in military testing is often reduced by elevated temperature and/or the addition of a dose ramp to the irradiation to accelerate the degradation and suppress second breakdown. In two of the SiC power MOSFETs studied here, elevated temperature tests did not impact current degradation or sudden SEB onset, suggesting different experimental methodologies are involved in SiC power devices.

Small sample size limits the conclusions that can be drawn from Fatal failure rates associated with SEE in SiC devices are rare and non-existent. Most space applications will require SiC power devices with low failure rates that are robust to SEE.

From the work presented here and performed by others, it can be clear that SiC power MOSFETs and diodes are rare and non-existent. Most space applications will require SiC power devices with low failure rates that are robust to SEE.

All commercial SiC power devices evaluated here exhibited inexcusable catastrophic SEBs at biases below 40% of their rated irradiation voltage, and experimental results demonstrate degraded electrical performance (i.e., SEE hardness requirement conditions). The SEE safe operating area falls within the range of biases at which catastrophic SEB occurs and, therefore, SEE-induced damage cannot be established for space applications. This limitation is compounded by the unknown mechanisms governing SEE in SiC devices. Much work remains to be done to better investigate SiC technology into space applications.

Acknowledgments

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