National Aeronautics and Space Administration

Investigation of the Semicoa 2N7616 and 2N7425 and the Microsemi 2N7480 for Single-event Gate Rupture and Single-event Burnout

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NASA Electronic Parts and Packaging (NEPP) Program
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EXECUTIVE SUMMARY

Single-event-effect test results for hi-rel total-dose-hardened power MOSFETs are presented in this report. The 2N7616 and the 2N7425 from Semicoa and the 2N7480 from International Rectifier were tested to NASA test condition standards and requirements.

The 2N7480 performed well and the data agree with the manufacture's data. The 2N7616 and 2N7425 were entry parts from Semicoa using a new device architecture. Unfortunately, the device performed poorly and Semicoa is withdrawing power MOSFETs from it line due to these data.

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1.0 INTRODUCTION

Vertical metal-oxide-semiconductor field-effect transistors (MOSFETs) are the most commonly used power transistor. MOSFETs are typically employed in power supplies and high current switching applications. Due to the inherent high electric fields in the device, power MOSFETs are sensitive to heavy ion irradiation and can fail catastrophically as a result of single-event gate rupture (SEGR) or single-event burnout (SEB). Manufacturers have designed radiation-hardened power MOSFETs for space applications. See [1] through [5] for more information.

The objective of this effort was to investigate the SEGR and SEB responses of two power MOSFETs recently produced. These tests will serve as a limited verification of these parts. It is acknowledged that further testing on the respective parts may be needed for some mission profiles.

2.0 TEST METHOD

Table 2.0-1 lists the devices tested. All single-event effect (SEE) tests were conducted in accordance with the guidelines in [6].

Table 2.0-1. Parts Used in this study.

Part Number	Voltage Rating [V]	RDSon [Ω]	Current Rating [A]	Type	Number Tested	Package
2N7480	60	0.03	22	N	3	TO5
2N7616	60	0.08	20	N	50	SMD-0.5
2N7425	100	0.05	35	P	50	SMD-1

2.1 SEE Beam Parameters

Devices under test (DUTs) were irradiated at the Texas A&M Cyclotron. All irradiations were performed at normal incidence.

2.2 Device Characterization Prior to Irradiation

Prior to any irradiation, the devices were electrically characterized using a Tektronix 371b curve tracer or HP4156 parametric analyzer. Non-destructive electrical measurements were performed on all devices, specifically, the threshold voltage (V_{th}) and the transconductance (gm). If either of these parameters were not in specification, the part was excluded from the test population. Parts were de-lidded with a micro-mill and remeasured after de-lidding to verify no damage occurred in this process.

2.3 Experimental Setup

Figure 2.3-1 shows the schematic of the experimental setup used during the SEE testing. All devices were biased and measured with the HP4142B Modular DC Source/Monitor Unit (SMU) connected to a personal computer (PC) via a general-purpose instrument bus (GPIB). SMUs were used with 24-in coaxial cables that could source current with a current limit of 10 mA, with no stiffening capacitance or choke inductance added into the test circuit. The type of SEE (gate-to-drain SEGR, gate-to-source SEGR, or SEB) was noted, as well as the fluence at the voltage in which the SEGR/B occurred and the total fluence the part endured. The current and voltage changes were measured at approximately 100 ms increments; the maximum current resolution of the SMU was 1 nA. Background noise in a virgin device typically had an amplitude of <10 nA.

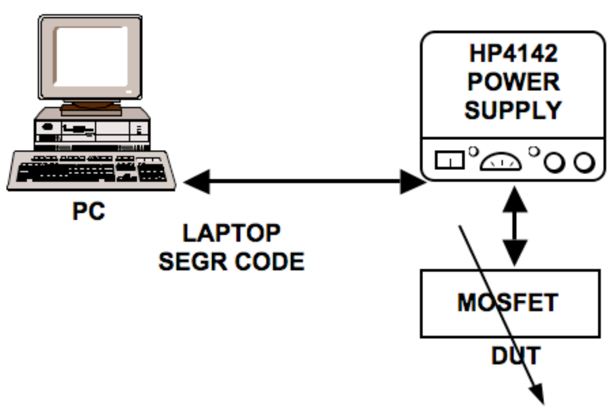

Figure 2.3-1. Schematic of experimental setup.

2.4 Failure Condition

SEGR was defined as the drain-to-source voltage at which the current from gate-to-drain or gate-to-source permanently exceeded 1 μA; this variable is defined as V_{SEE}. The mean V_{SEE} value was determined by computing the arithmetic average of the V_{SEE} value and the previous voltage. Since the definition of the SEGR voltage is the average voltage at which the DUT exhibited an SEE and the voltage of the previous irradiation, a valid data point is one where the DUT exhibited no failures (SEGR or SEB) for at least one complete irradiation run.

An SEGR can occur from the gate-to-source or from the gate-to-drain, and for an SEB the current path is drain-to-source. In all cases, the HP4142 system can measure the resulting leakages, but since the charge injection and resulting charge transport for SEB and SEGR are in the same area of the transport, the resulting damage of both may be the same. Therefore, discriminating between SEGR and SEB by the resulting current leakage is not completely reliable. In cases where a single current leakage path is solely extant, the SEE mode can be identified. These observations are stated in the results of this test.

2.4.1 Error Bars

The error bars associated with each data point on the safe operating area (SOA) curve were computed by taking the square root (SR) of the sum of the squares of the uncertainty in each measurement and the standard deviation (SD) of all measurements on multiple device samples performed at the specific VDS and VGS bias condition.

3.0 RESULTS

Overall, the parts performed comparably to previous part types. Part-to-part variation was an issue for both parts, but not more than typically seen in other similar parts.

3.1 2N7480

These parts performed better than others of this device rating. The 2N7480 is an n-channel 60 V power MOSFET based on the /703 slash sheet. The parts tested here were fabricated on the new RH2 process development. These parts performed much better than parts tested from the previous fabrication lines. The test ion was undegraded 41 MeV-cm^2/mg silver. Figure 3.1-1 presents the results.

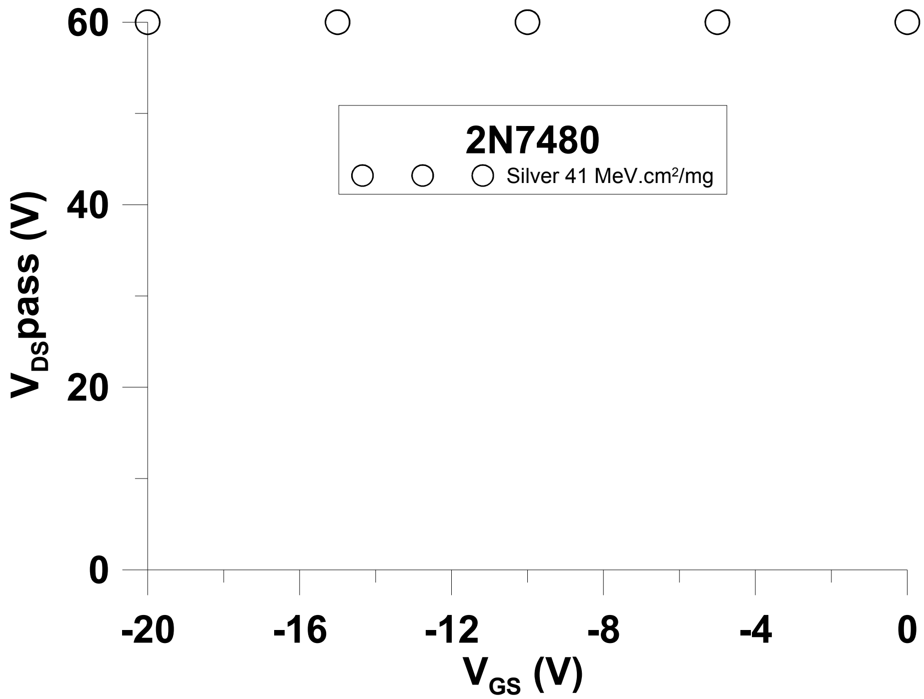

Figure 3.1-1. SEE response of the Microsemi 2N7480 for silver ions.

3.2 2N7616

Figures 3.2-1 through 3.2-13 present the test results for the Semicoa 2N7616. The parts tested here were first generation parts for Semicoa's line, which is an epitaxial-based process, produced with a rad-hard process developed for products from 100 V to 500 V. The SEE response of these parts is comparable to other 500 V rated parts. Four different wafer splits were tested. Wafer split is the primary production lot for Semicoa. Split 5 had the best performance, but Split 5 demonstrated Single Event Gate Rupture and Burnout. Almost 89% of failures were during the ion exposures and only 11% from PIGS; this is completely reversed from previous testing and could be due to the improved oxide quality. All of the failures from Split 4 and 5 were during the ion runs. The limited PIGS failures were only from Split 1 (13) and 3 (3).

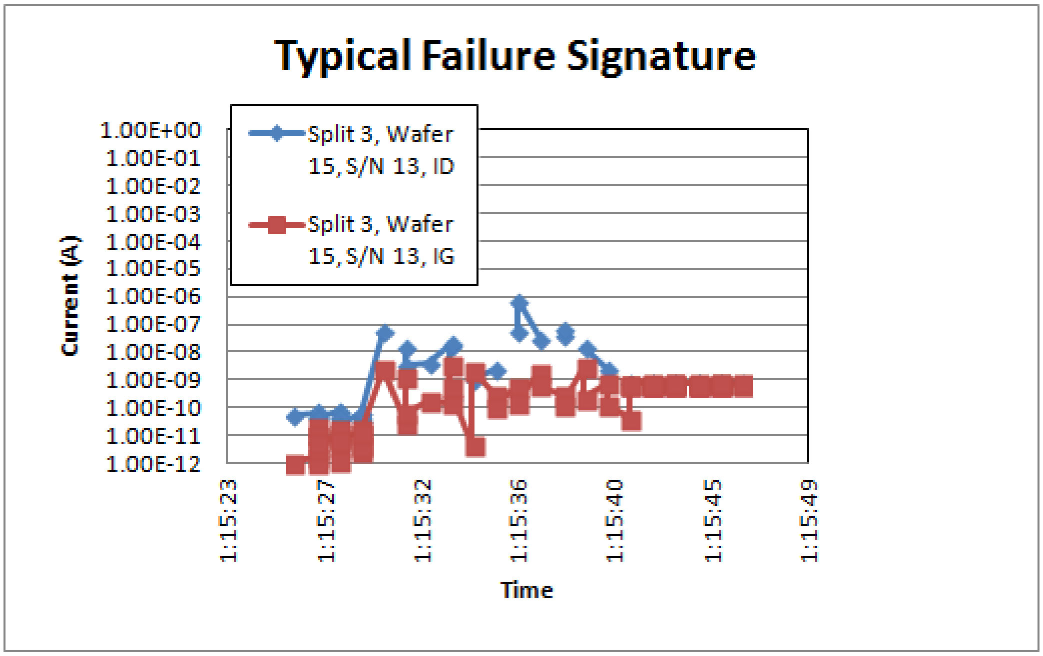

Figure 3.2-1. Part shows no problems during exposure but fails the Gate Stress Test after the run.

Gate Stress Test Initial Measurement (01:15:54 12-21-2012)				

Gate	-10.01	-2.03E-06		
Drain	0	-7.60E-13		
Source	0	2.08E-06		

Figure 3.2-2. 100× Increase in IG during run could be the precursor of failure.

Drain Stress Test Initial Measurement (01:16:08 12-21-2012)				

Gate	0	-7.04E-10		
Drain	48	8.97E-10		
Source	0	-7.58E-11		

Figure 3.2-3. SEE test results for 2N7616 for xenon at 2865 MeV (wafer 13).

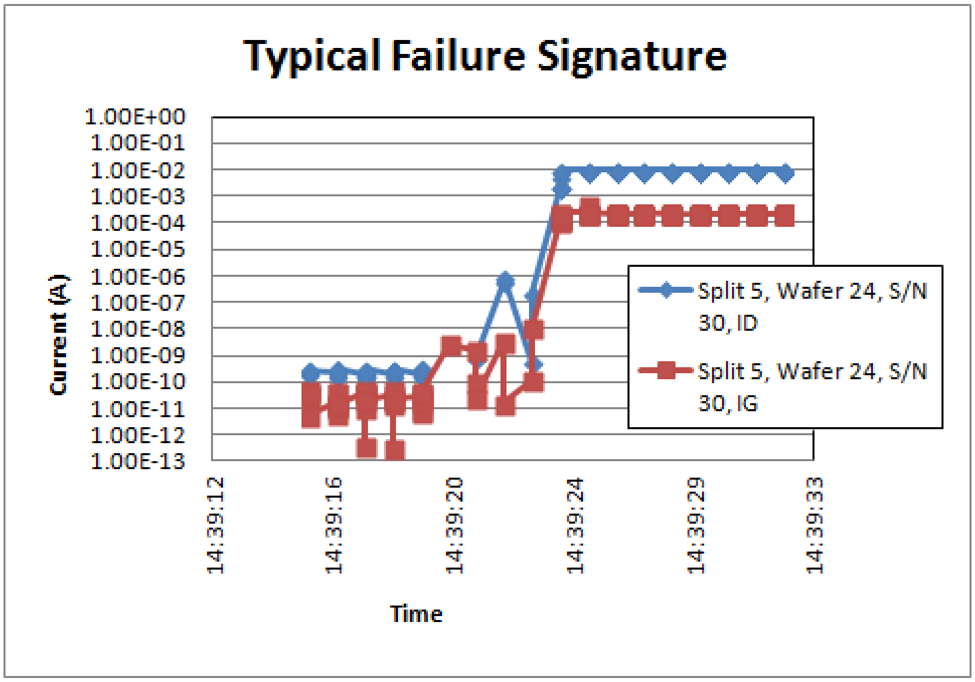

Figure 3.2-4. IG and ID during exposure and at some point the part breaks and exceeds specification. In this test, 51.7% of failures were this type

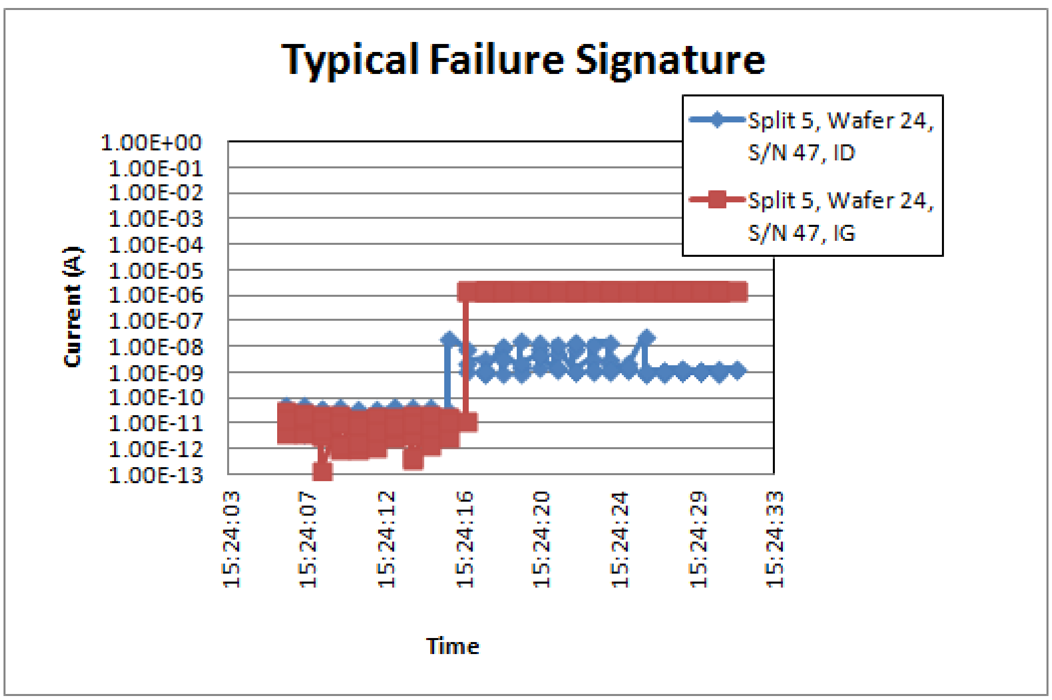

Figure 3.2-5. Both the Drain and Gate become leaky but only IG fails its spec. this test, 40.6% of failures were this type.

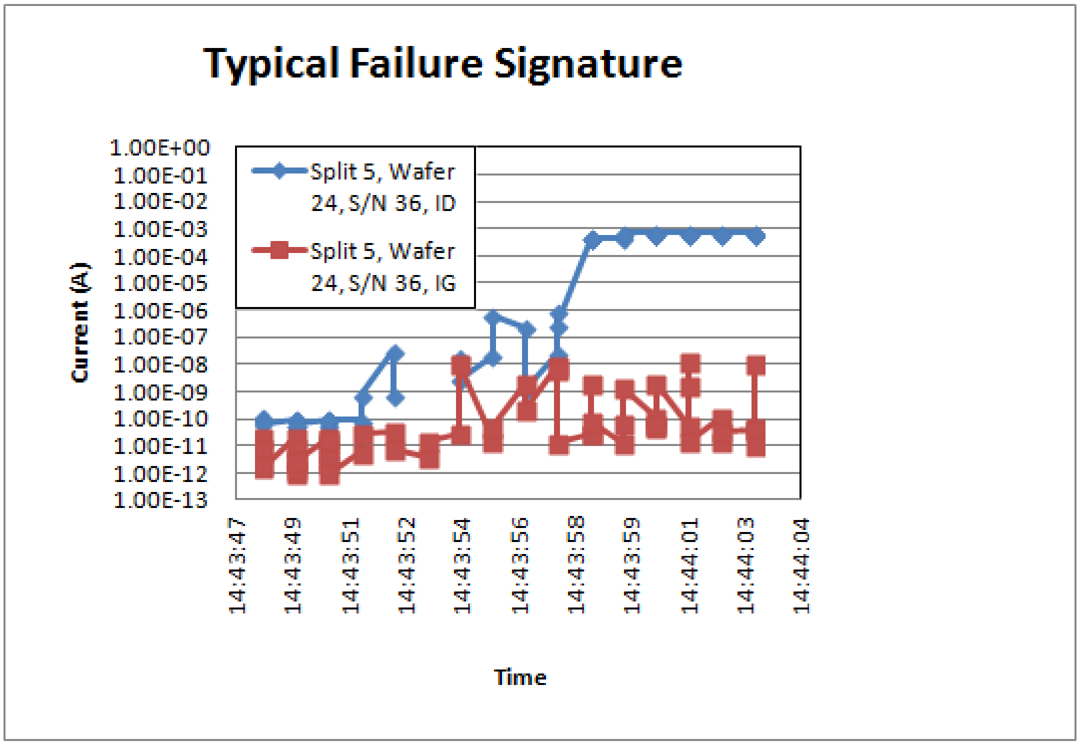

Figure 3.2-6. This is a Single Event Burnout, the Gate is not ruptured. There were 11 of these failures – two in Split 4 and nine in Split 5. In this test, 7.7% of failures were this type

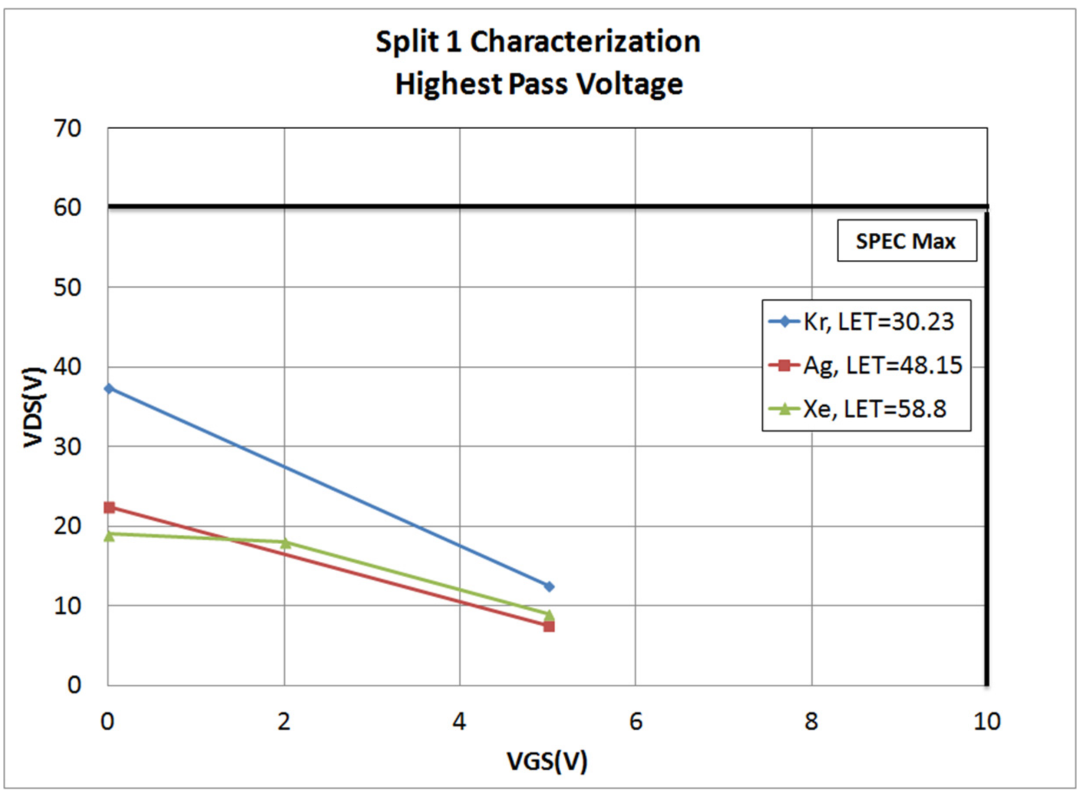

Figure 3.2-7. SEE response of split 1.

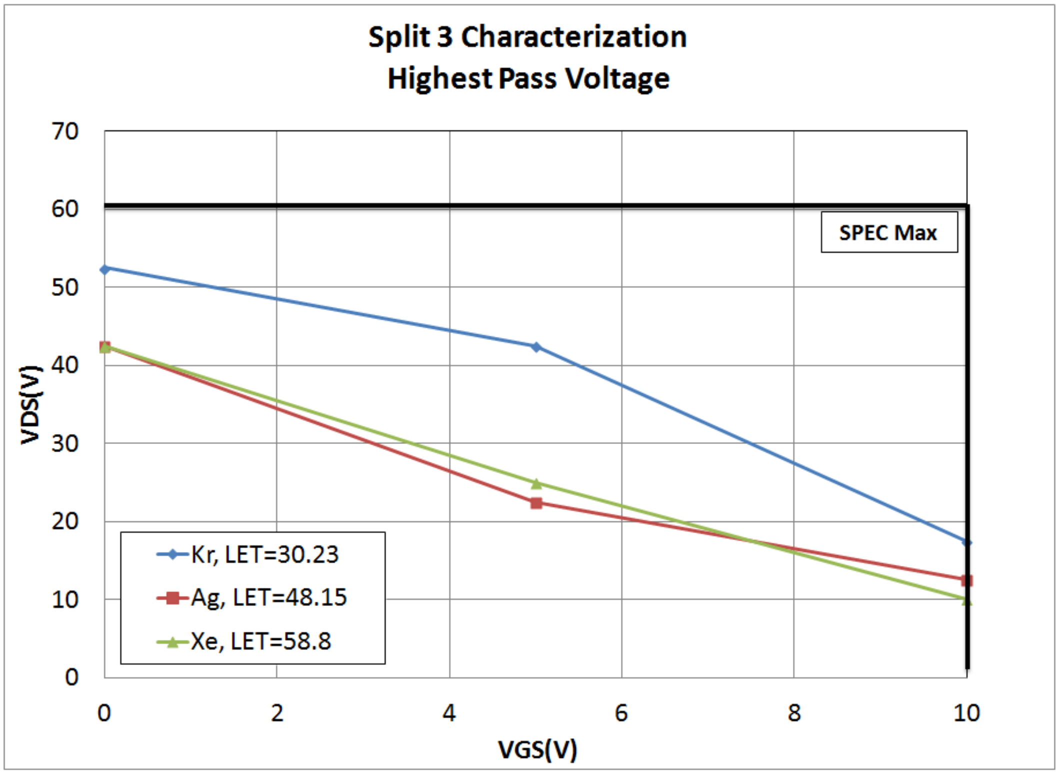

Figure 3.2-8. SEE response of split 3.

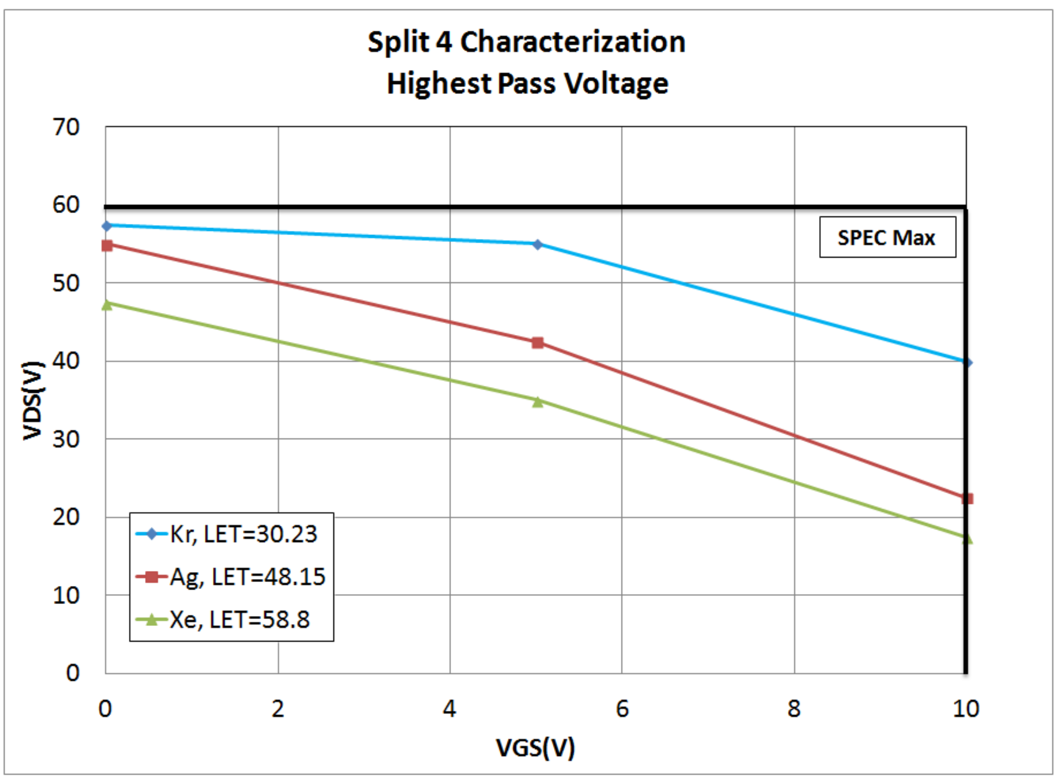

Figure 3.2-9. SEE response of split 4.

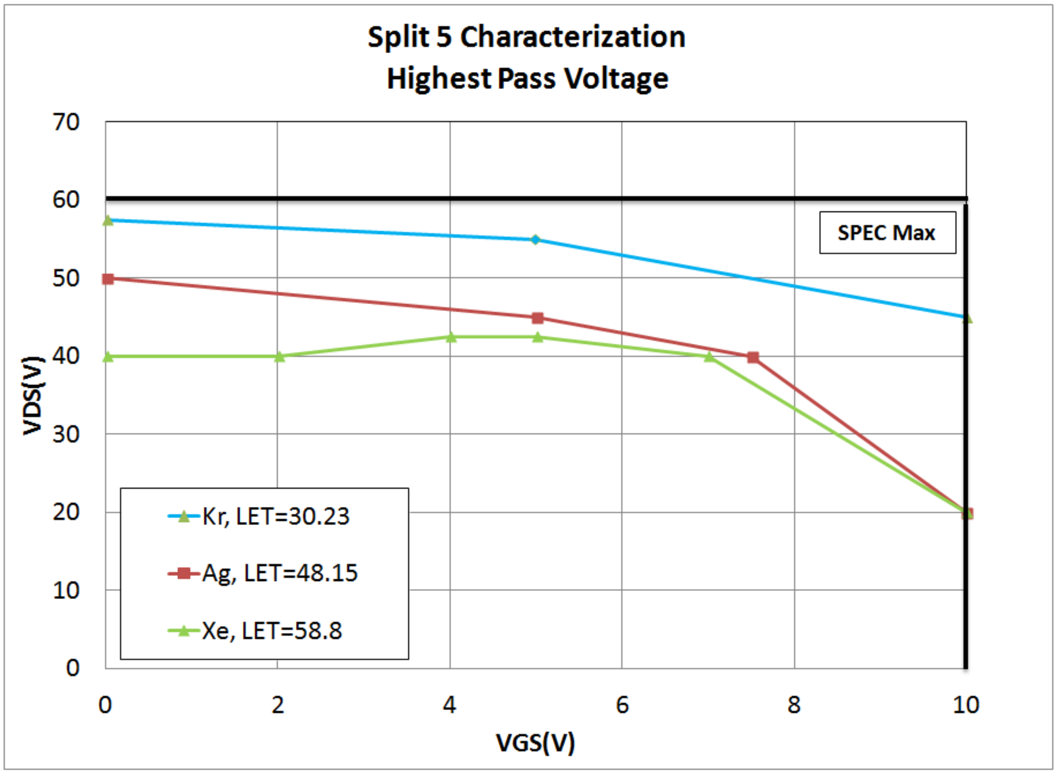

Figure 3.2-10. SEE response of split 5.

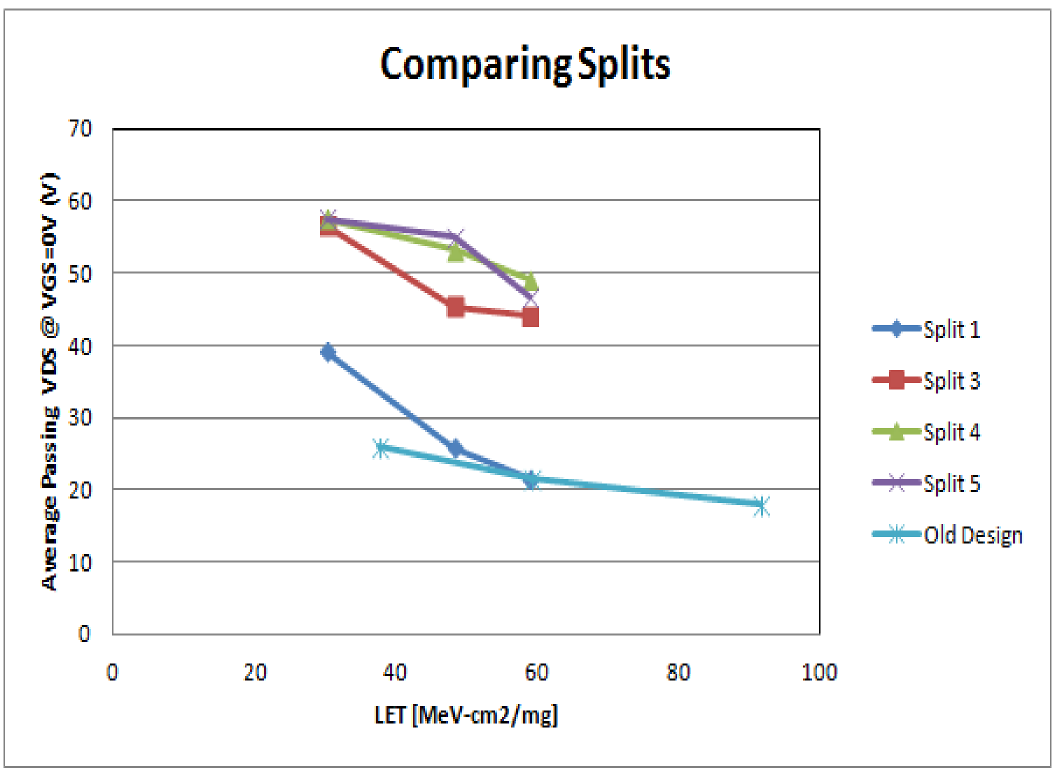

Figure 3.2-11. Graph shows performance for all four splits tested with V_G=0 V.

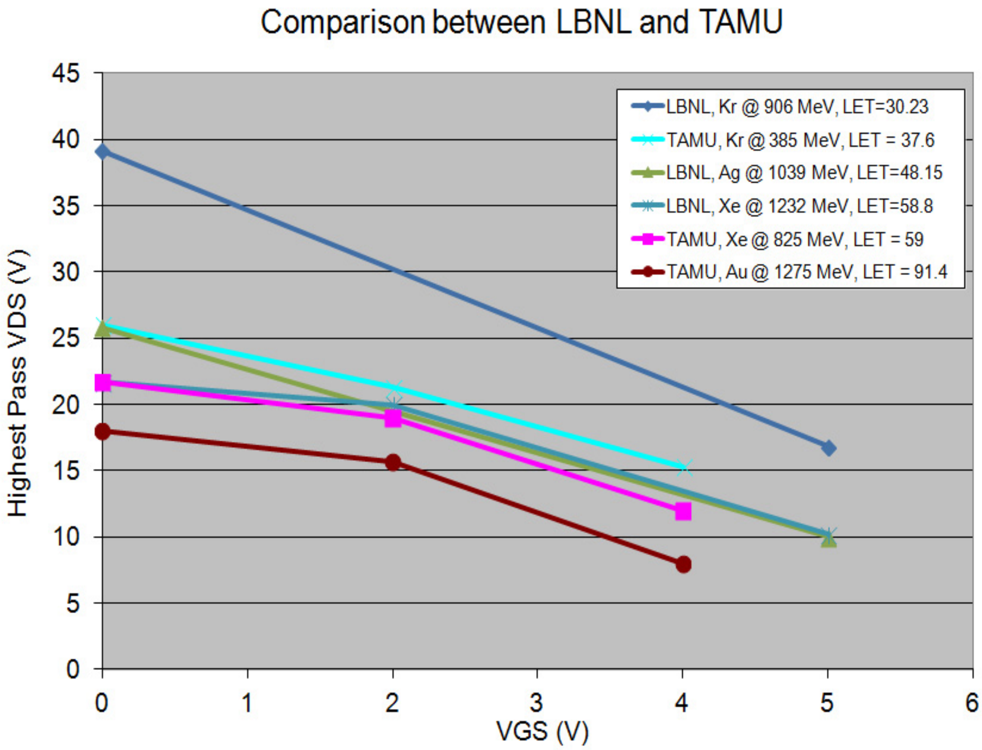

Figure 3.2-12. Testing at both heavy ion facilities. The TAMU data tuned the Bragg Peak to the epi/substrate interface.

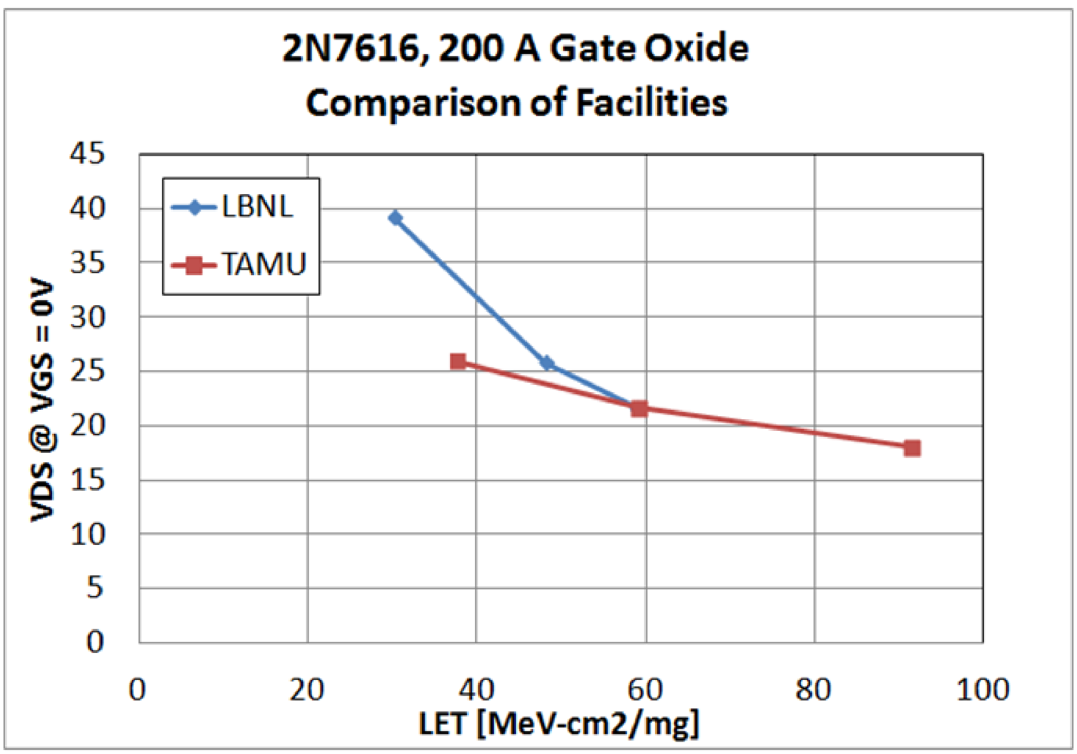

Figure 3.2-13. Testing at both heavy ion facilities. The TAMU data tuned the Bragg Peak to the epi/substrate interface.

3.3 2N7425

Figure 3.3-1 presents the test results for the Semicoa 2N7425. The 2N7425 is an n-channel 450 V, 11 A device. The parts tested here were first generation parts for Semicoa's line, which is an epitaxial-based process, produced with a rad-hard process developed for products from 100 V to 500 V. The beam was degraded to place the Bragg Peak at the Epi/Substrate interface. Tested device was 2N7425, 100 V P-Channel MOSFET, Wafer Lot J36753.3. Three ion species were used: Ag @ 550 MeV with surface LET was 51.7 MeV-cm^2/mg, Ho @ 1,050 MeV with surface LET was 75.8 MeV-cm^2/mg, and Au @ 1,425 MeV with surface LET was 90.4 MeV-cm^2/mg. Tested a sample size of three at each VGS and VDS point. Performed a posttest gate/drain stress test per MIL-STD-750, Test Method 1080.1.

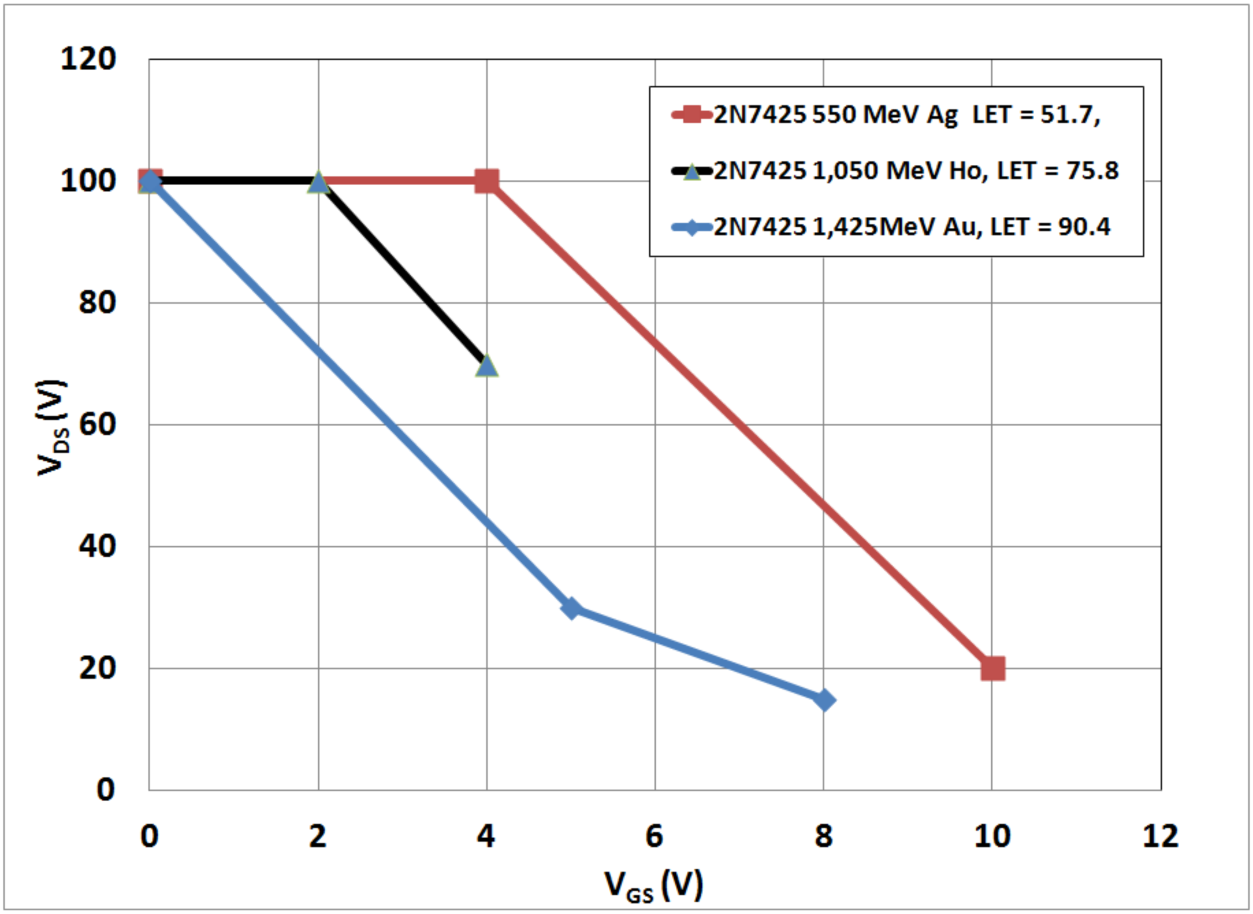

Figure 3.3-1. SEE results for 2n7425 (N-Channel). Note VDS is negative in the graph above.

4.0 CONCLUSION

The limited Microsemi samples for test did show the process is as strong as other rad-hard manufactures, and the process appears to be well-managed. Semicoa parts, however, performed very poorly and Semicoa has withdrawn all MOSFETs from the market indefinitely.

4.1 Recommendation

It is recommended that all devices from Microsemi be screened for SEE as the independently verified data on them is sparse.

Acknowledgment

The author would like to thank Brian Triggs of Semicoa for help in testing and much of the analysis. Also the contribution of Dennis Thorbourn, Michael O'Connor, and Gregory Allen of JPL cannot be overstated.

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