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Investigation of the Semicoa SCF9550 and the International Rectifier IRHM57260SE for Single-Event Gate Rupture and Single-Event Burnout

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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 SCF9550 from Semicoa and the IRHM57260SE from International Rectifier were tested to NASA test condition standards and requirements.

The IRHM57260SE performed much better when compared to previous testing. These initial results confirm that parts from the Temecula line are marginally comparable to the El Segundo line. The SCF9550 from Semicoa was also tested and represents the initial parts offering from this vendor. Both parts experienced single-event gate rupture (SEGR) and single-event burnout (SEB). All of the SEGR was from gate to drain.

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

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 (Vth) 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 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.

Table 1. Parts Used in this study.

Part Number	Voltage Rating [V]	RDSon [Ω]	Current Rating [A]	Type	Number Tested	Package
IRHM57260SE	200	0.06	31	N	25	SMD-1
SCF9550	450	0.08	20	N	25	SMD-0.5

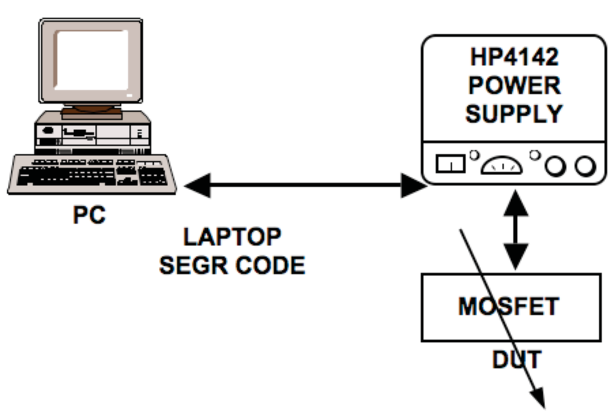

Figure 1. Schematic of experimental setup.

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 VSEE. The mean VSEE value was determined by computing the arithmetic average of the VSEE 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 can 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 V_{DS} and V_{GS} bias condition.

3.0 RESULTS

Overall, the parts performed comparable 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 IRHM57260SE

These parts performed better than others of this device rating. The IRHM57260SE is an n-channel 200 V power MOSFET with an RDSon of 0.038 ohm. The parts tested here were fabricated on the new line in Temecula using International Rectifiers' (IR's) R5 technology. These parts performed much better than parts tested from the previous fabrication line. The 37 MeV.cm^2/mg was not degraded while the 59 MeV.cm^2/mg xenon had an energy of 824 MeV at the surface of the die. Figure 3 presents the results.

3.1.1 Comparison to El Segundo Parts

Figure 3 shows the data from the El Segundo line tested by JPL. The results from the Temecula line demonstrate a much more robust part.

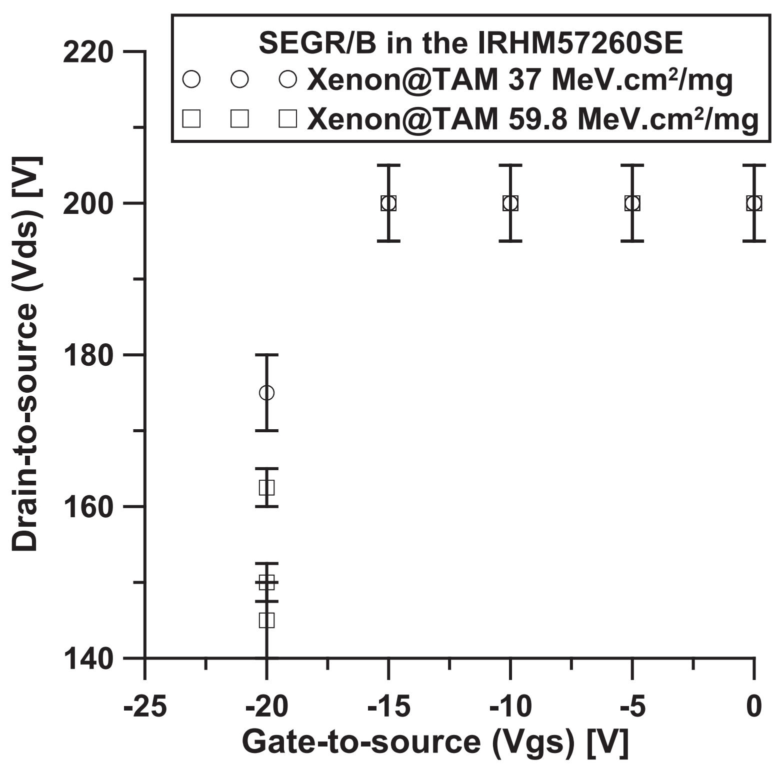

Figure 2. SEE response of the IRHM57260SE for xenon ions.

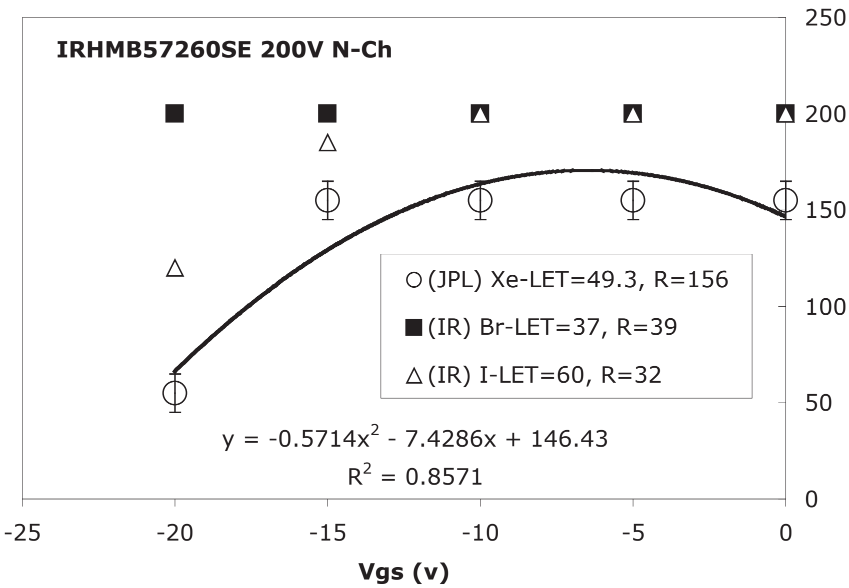

Figure 3. SEE results for IRHMB57260SE (N-Channel) from the El Segundo line.

3.2 SCF9950

Figures 4 though 9 present the test results for the Semicoa SCF9550. The SCF9550 is an n-channel 450 V, 11 A power MOSFET with an RDSon of 0.45 ohm. 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 epitaxial thickness is 55 µm and the total device thickness is 200 µm. The SEE response of these parts is comparable to other 500 V rated parts. Three different wafer lots were tested. Wafer lot 15 (Figure 4 and Figure 5) is the primary production lot for Semicoa. Wafer lots 13 (Figure 6) and 16 (Figure 7) were tested to investigate changing the epitaxial doping with SEE; none was seen.

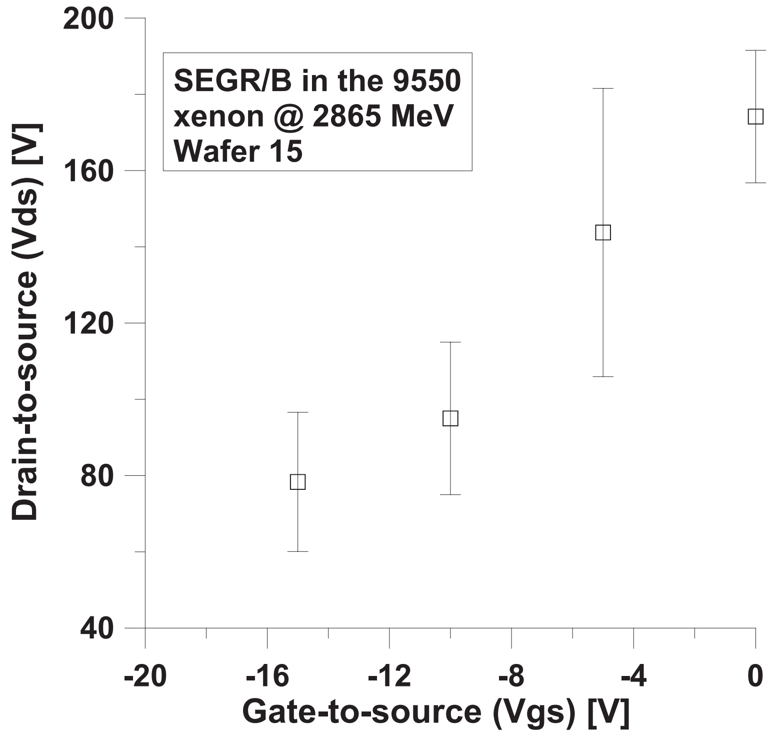

Figure 4. SEE test results for SCF9550 for xenon at 2865 MeV (wafer 15).

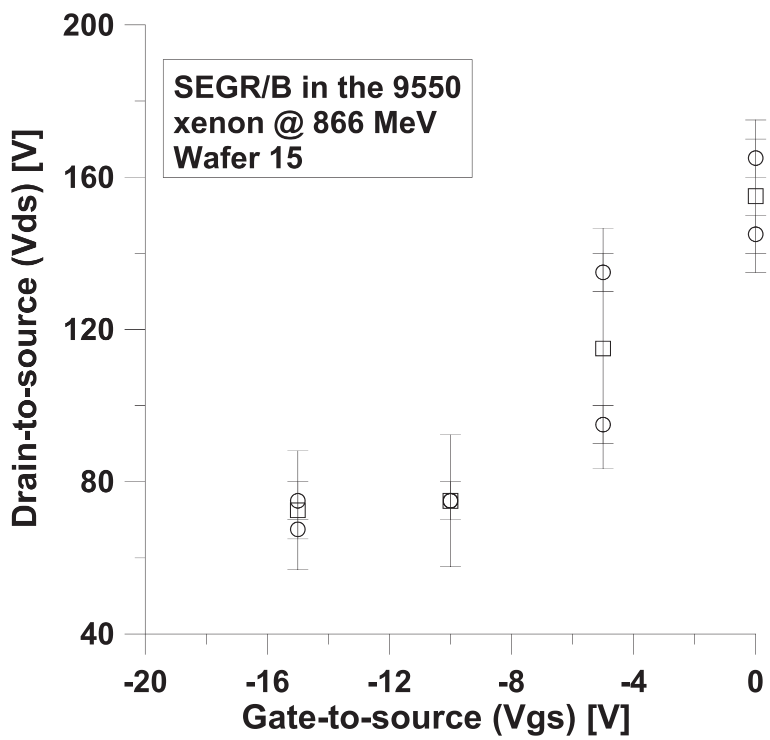

Figure 5. SEE test results for SCF9550 for xenon at 866 MeV (wafer 15).

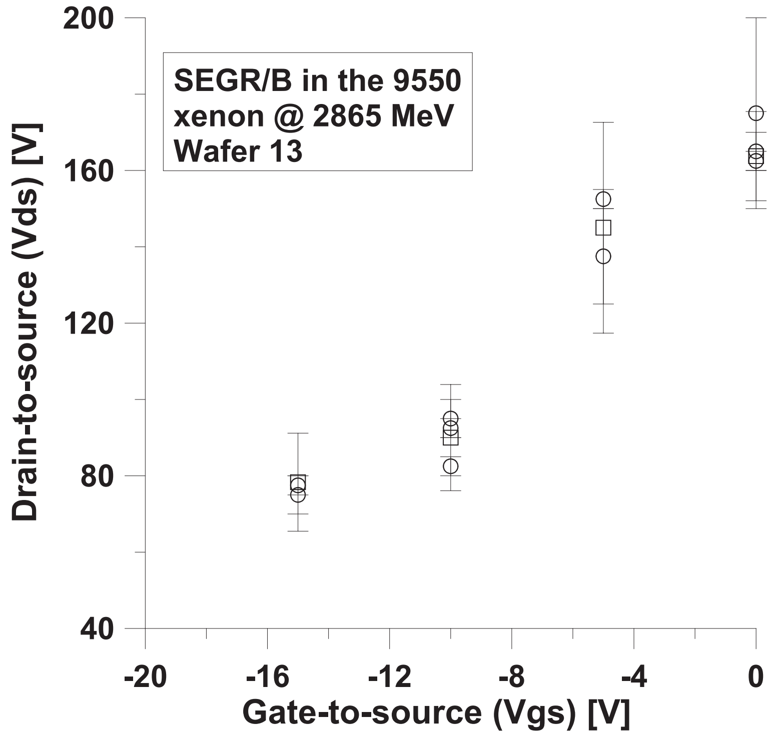

Figure 6. SEE test results for SCF9550 for xenon at 2865 MeV (wafer 13).

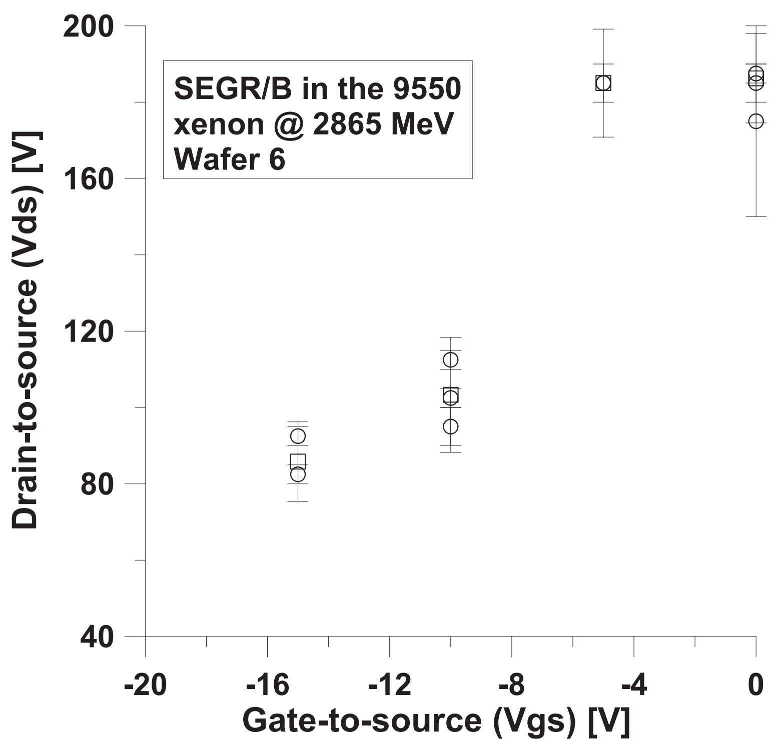

Figure 7. SEE test results for SCF9550 for xenon at 2865 MeV (wafer 6).

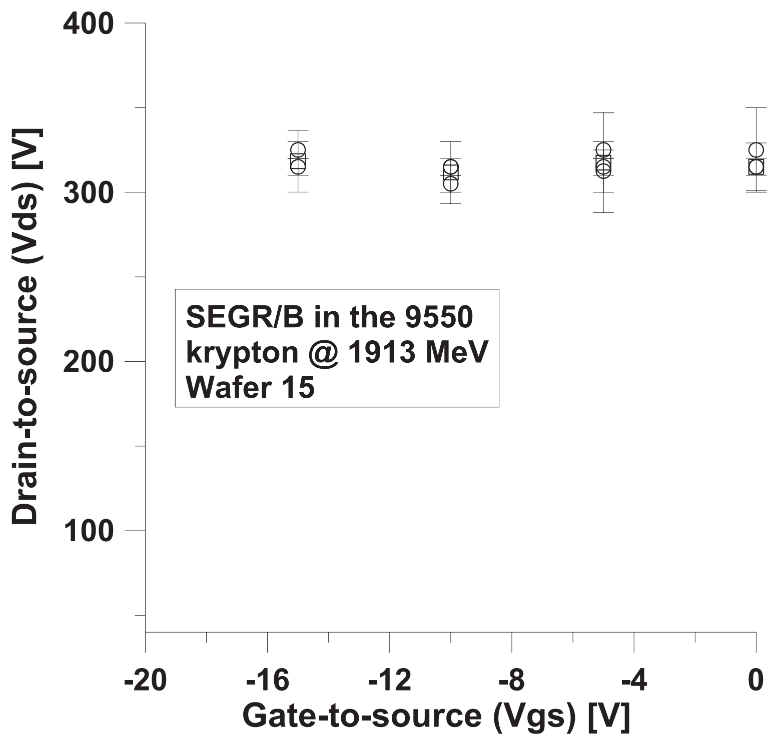

Figure 8. SEE test results for SCF9550 for krypton at 1913 MeV (wafer 15).

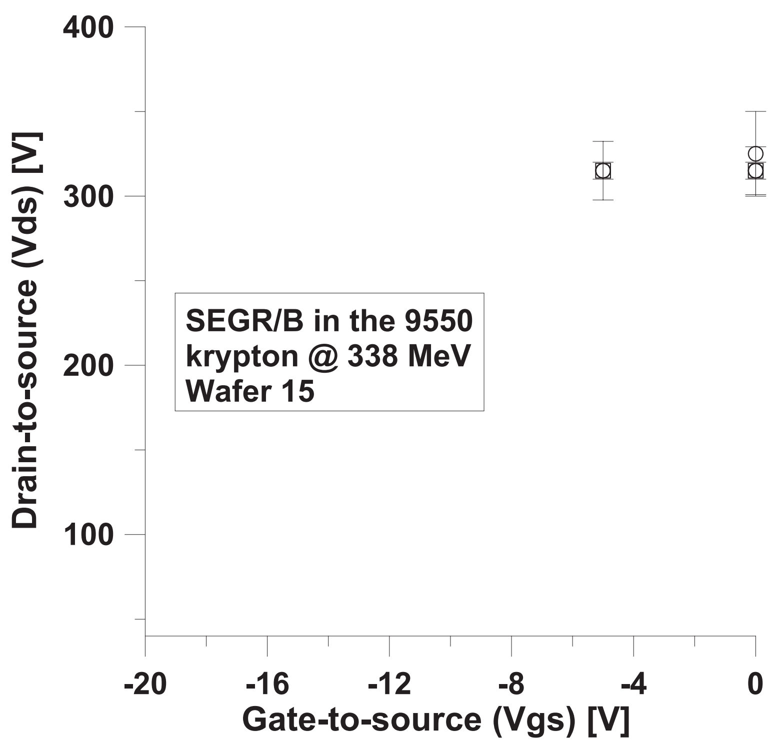

Figure 9. SEE test results for SCF9550 for krypton at 338 MeV (wafer 15).

3.2.1 *Failure Analysis of the SCF9550*

Two devices were selected to undergo failure analysis on the SCF9550. S/N 1301 was a completely destroyed device, while S/N 1304 still functioned as a transistor (although it was very leaky). Figures 10–12 show the infrared, optical, and SEM inspection of S/N 1301, respectively. The damage to the device is shown near the gate region; although, largest power dissipation is in the wire bond region. The "leaky" part, S/N 1304, did not show a "hot spot" under infrared inspection; however, damage was seen in the gate source region as shown in Figures 13 and 14.

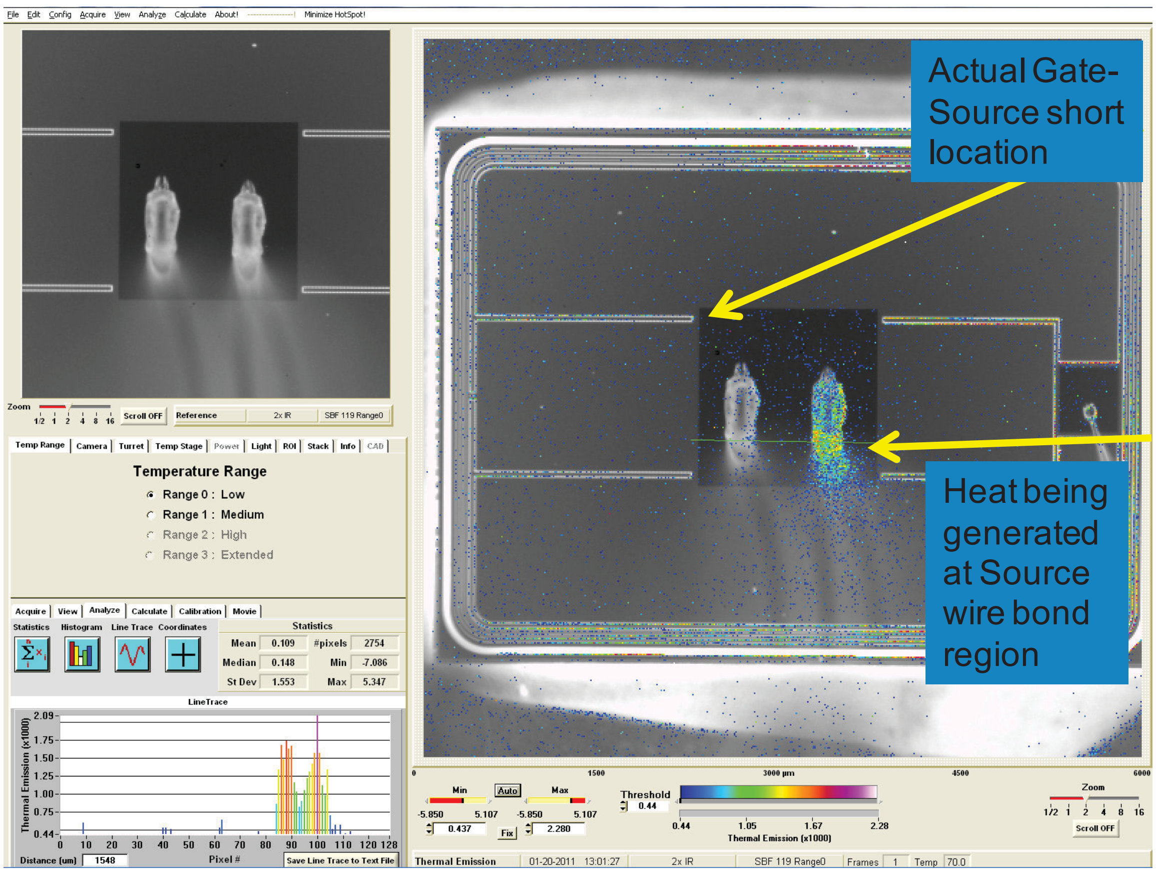

Figure 10. The infrared image shows heat being dissipated at the source wire bond region but gate-source short is at a different location. Part S/N was 1301.

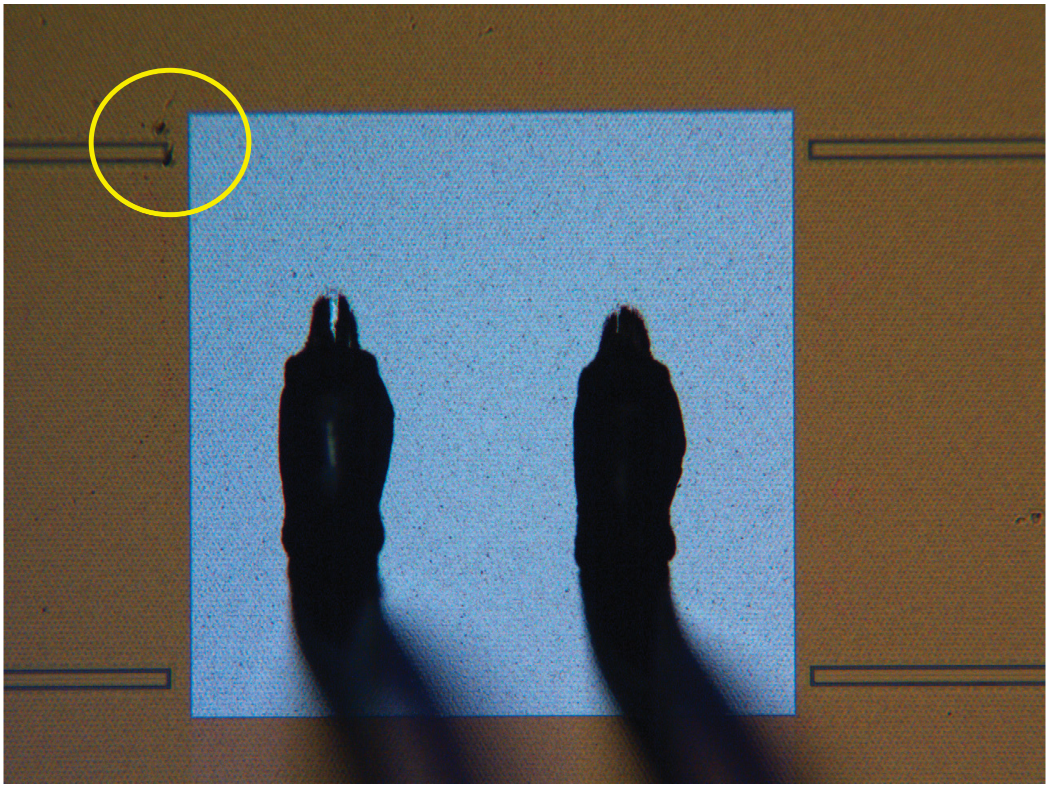

Figure 11. S/N 1301 optical image with anomaly at gate-source region.

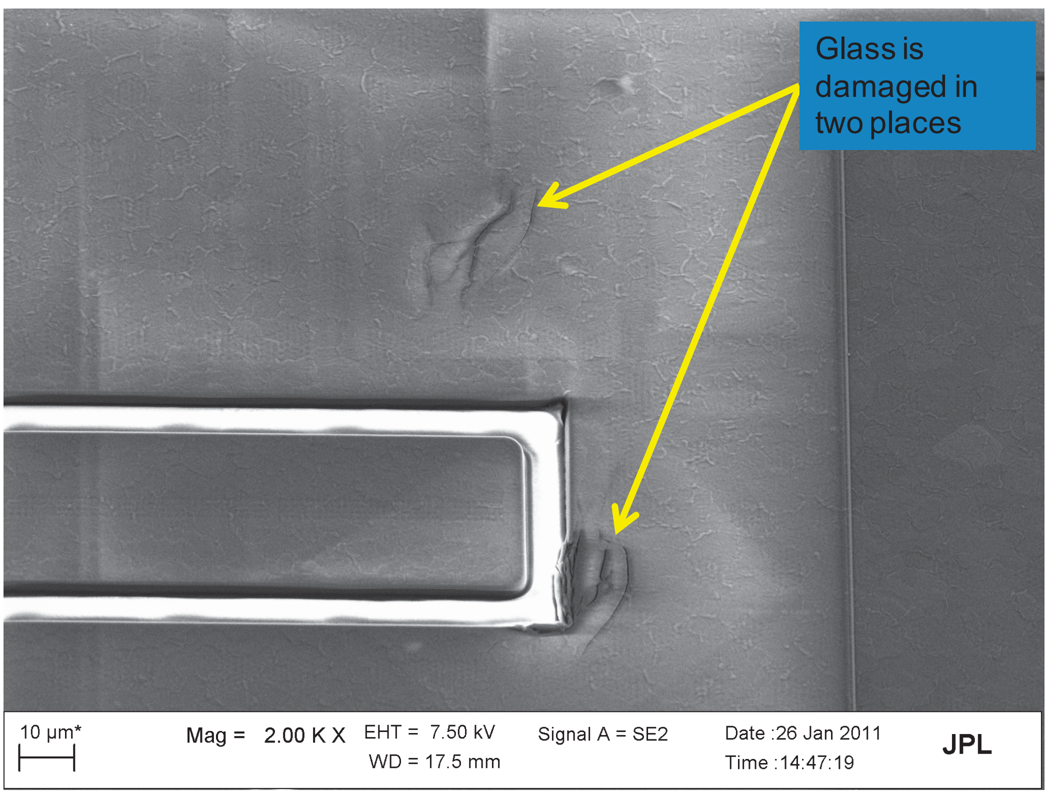

Figure 12. S/N 1301 magnified SEM Image of the gate-source short. Damage to glass is most likely related to metal having been stressed below the passivation.

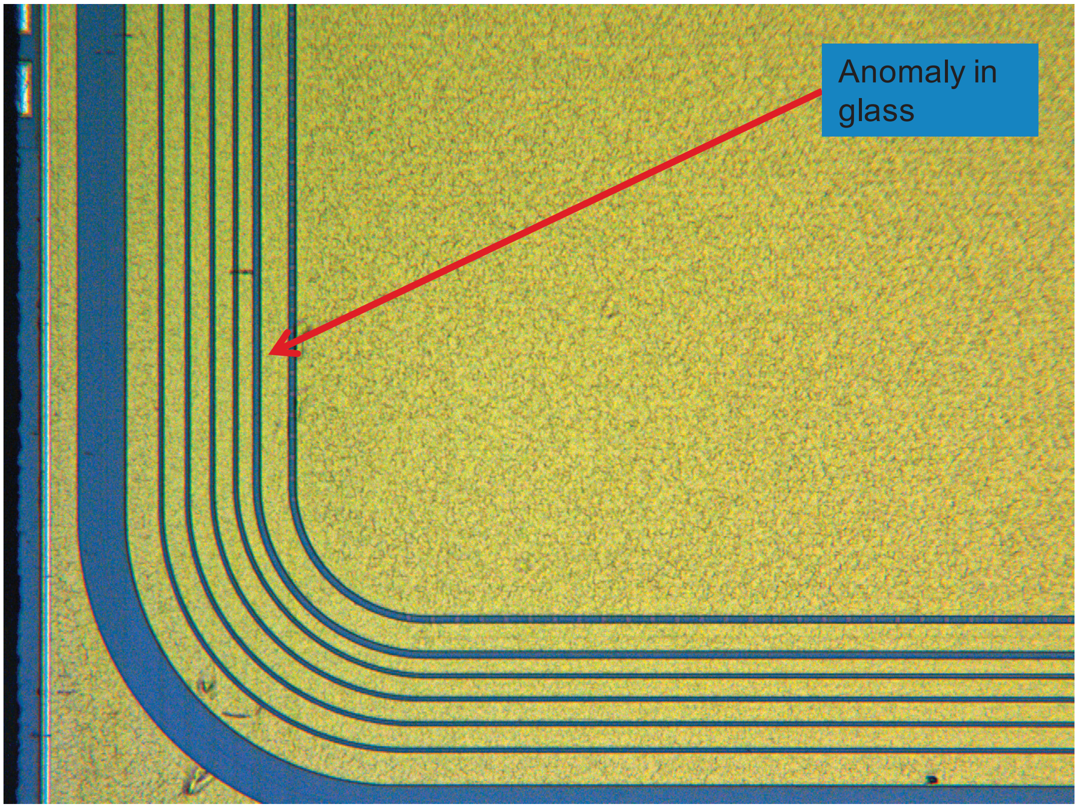

Figure 13. S/N 1304 optical image with anomaly at gate-source region.

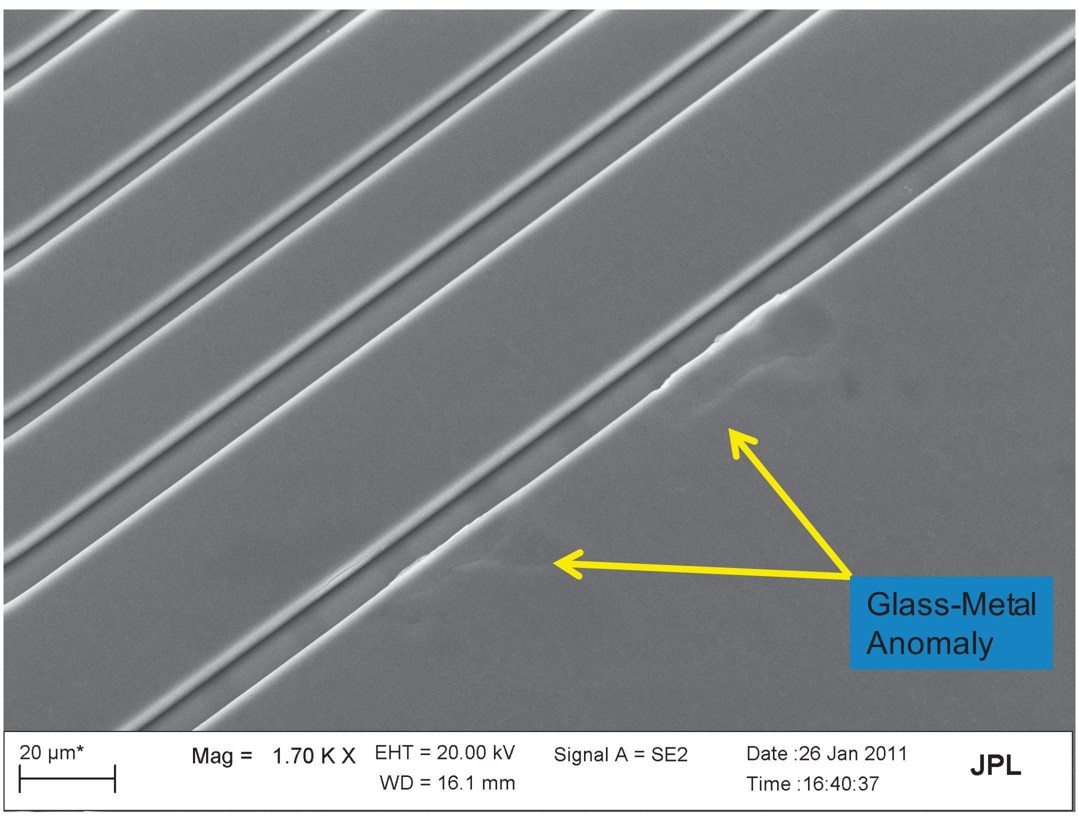

Figure 14. S/N 1304 SEM image of gate-source anomaly. Glass is disturbed possibly by defect beneath metal.

3.2.2 Comparison to Similar Parts

As a comparison to the results from these tests, the SEE response of a similarly rated IR part is shown in Figure 15. The krypton was adjusted for some measurements to match the surface linear energy transfer (LET) of the ion used in IR's previous testing. The Semicoa part performed at least as well as the IR parts.

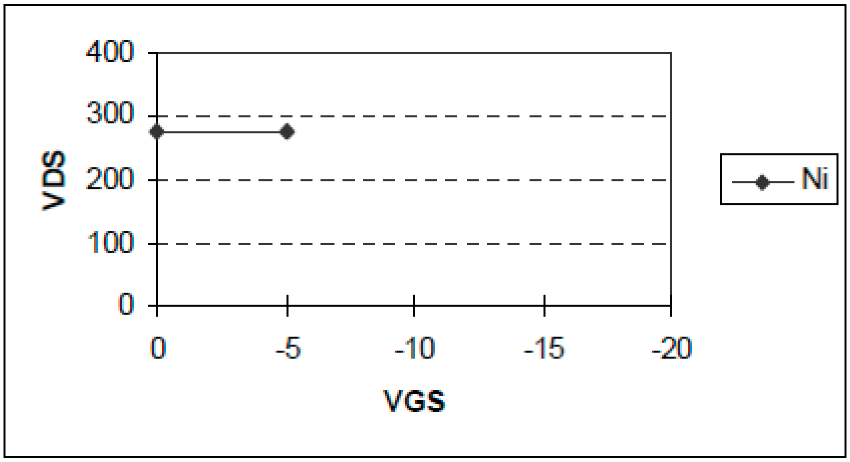

Figure 15. SEE results for SCF9550 (N-Channel) from the El Segundo line.

4.0 CONCLUSION

Recent testing of emerging power MOSFETs shows that the technology performs at least as well as other technologies of similar specifications. Testing of the IR Temecula device confirms, at least for this device, that this line can be as capable as the El Segundo line. The Semicoa part has similar performance to non-Single Event hardened, total dose radiation hard devices. The ion penetration depth is critical to testing the SEE phenomenon correctly. Testing approach also has an effect on the SEGR response of devices. Proper use of support circuitry and test procedure allow for a complete investigation of SEE in power MOSFETs.

4.1 Recommendation

It is recommended that all devices from both fabrication lines (IR and Semicoa) be screened for SEE.

5.0 REFERENCES

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