Recent power MOSFET test results

Leif Z. Scheick, *Member, IEEE*, Michael Gauthier, Brian Gauthier, and Brian Triggs

***Abstract*—The results of recent Single Event Effect (SEE) testing of newly available power MOSFETS are presented.**

I. Introduction

INCREASING demand for radiation hard power solutions in space has brought several new options for power MOSFETs. Power MOSFETs are the most widely used for power management solutions due to the readiness of the technology. Thus, the radiation hardening of these devices has also advanced. However, power MOSFETs, even with radiation hardening, experience catastrophic SEEs: Single Event Gate Rupture (SEGR) and Single Event Burnout (SEB). This work presents SEE testing of newly available power MOSFETs.

SEGR in a vertical power MOSFET is the breakdown of the gate oxide caused by charge injection under the gate region. The normally accepted model of SEGR is that at threshold bias conditions, accumulation of charge in the silicon at the Si-SiO_2 interface in the gate-drain overlap region (i.e., the neck region) and reduced resistivity in the epitaxial layer can result in sufficiently high electric fields across the gate oxide. In addition, the charge generated in the oxide reduces the electric field required to breakdown the oxide. When the field magnitude in the oxide is greater than this reduced breakdown field of the oxide, oxide breakdown will occur and be assisted by thermal runaway. This effect manifests as an increase in the leakage current from the drain-to-gate or gate-to-source.

SEB is the triggering of a forward bias condition in the parasitic NPN bipolar transistor from injected charge. At a threshold voltage, the injected charge will be sufficient to induce burnout in the power MOSFET structure. To illustrate both SEE mechanisms, Fig. 1 depicts a conceptual case for SEB (left ion track) and SEGR (right ion track). Note in laboratory testing, as well as Galactic Cosmic Rays striking the device in space, ions will not always penetrate the entire device, and the effect of the ion range on SEE is an important measurement for assuring power MOSFETs. Therefore, inducing SEGR in a laboratory setting poses several challenges to applying test data to mission applications. Since previous work has shown that ion range and test circuitry has an effect on the SEGR voltage, careful attention must be paid to the testing of thicker devices with adequate range, test equipment, and methods [1]-[17].

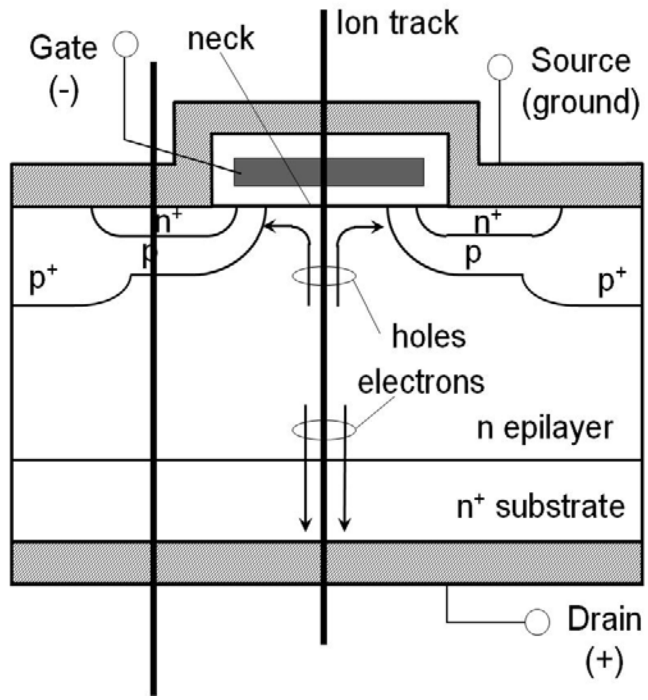

Fig. 1. 2D cross section of a vertical Power MOSFET during an ion strike to the SEB (left ion track) and SEGR sensitive sites (right ion track).

II. Procedure and Setup

Tested devices were the SCF9550 from Semicoa, the IRHM57133SE from International Rectifier, the IRHN57250SE from International Rectifier, and the IRHM57260SE from International Rectifier (see Table I). The test sites were the Texas A&M University (TAMU) Cyclotron Facility and Brookhaven National Laboratory (BNL). The ions used were xenon, krypton, gold and bromine. Various energies were selected to evaluate device responses to ion test conditions. Some of the ion energies were selected so the results of this study can be compared to other data [3], [9], [16]. The devices were electrically characterized prior to irradiation to verify no damage to the parts had occurred prior

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L. Z. Scheick is with the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Ca (telephone: 818-354-3272, e-mail: leif.z.scheick@jpl.nasa.gov).
M. Gauthier is with the Semicoa Corporation Costa Mesa, CA 92626 USA, (telephone: 714-852-6319, email: MGauthier@semicoa.com).
B. Gauthier is with the Semicoa Corporation Costa Mesa, CA 92626 USA, (telephone: 714-852-6324, email: BGauthier@semicoa.com).
B. Triggs is with the Semicoa Corporation Costa Mesa, CA 92626 USA, (telephone: 714-242-3029, email: BTriggsr@semicoa.com).

to irradiation or de-packaging. The following were measured with a Tektronix 371b curve tracer and HP4156: threshold voltage, transconductance, reverse breakdown voltage, and on-resistance. The devices were de-encapsulated using a milling machine. Parts that were measured to be out of manufacture specification during any point in the preparation were rejected from the test lot.

Table I. List of devices used in this study.

Rating (V)	Device	Man.	Ions tested
130	IRHN57133SE	IR	Br, Xe, Kr
200	IRHJ57260SE	IR	Br, Xe, Kr
200	IRHN57250SE	IR	Xe, Kr
450	SCF9550	Semicoa	Xe, Kr

The NASA SEGR and SEB testing guideline [15] was used as the testing standard. A high-voltage source-measurement unit (a HP4142 SMU) controlled through a personal computer (PC) via a general-purpose instrument bus (GPIB) was used to force voltages and read currents. The time resolution of the measurements was ~100ms. The current resolution of the SMU was 1nA, while the typical off-state leakage current in a virgin device is 10nA. During irradiation, devices were monitored for increases in current through the gate, source, and drain pins while at a constant gate-to-source voltage (V_{GS}) and a constant drain-to-source voltage (V_{DS}). Between irradiations, a post irradiation gate stress (PIGS) test was done to screen for latent damage. If the DUT showed no damage, i.e., no increase in current, the voltage was increased and the device was irradiated again.

SEGR was defined as a permanent increase in the gate-to-drain or gate-to-source current from the pre-irradiation measurement, while SEB was defined as the increase in drain-to-source current. In some tests, because of the damage to the device from the local heating of the SEE, the device failed such that all three current parts showed damage. In these cases, the event was noted as being SEB and/or SEGR. The SEE voltage (V_{SEE}) value for each run was determined by computing the mean of the "last pass" voltage and the voltage at which failure had occurred. Therefore, a valid data point is one where the DUT no SEGR or SEB for at least one complete irradiation run. For each irradiation, typical run parameters were $1x10^5$ ions/cm^2 at a flux of ~$1x10^4$ ions/cm^2 per second, thus each irradiation run was about 10 seconds long.

III. Results

The safe operating area (SOA) is the range of voltages (or domain space) found on the [Vds, Vgs] plane in which a MOSFET operates without SEGR and/or SEB for a given ion of a particular energy.

A. IRHNJ57133SE

The IRHNJ57133SE is an n-channel 130V power MOSFET with an RDSon of 0.1 ohm. The parts tested here were fabricated on the new line in Temecula using IR's R5 technology. The device performed slightly worse than previous tests [16]. Both of these beams were degraded; the 49 MeV.cm^2/mg xenon had an energy of 1756 MeV at the surface of the die, while the 59 MeV.cm^2/mg xenon had an energy of 824 MeV at the surface of the die. Fig. 2 presents the results.

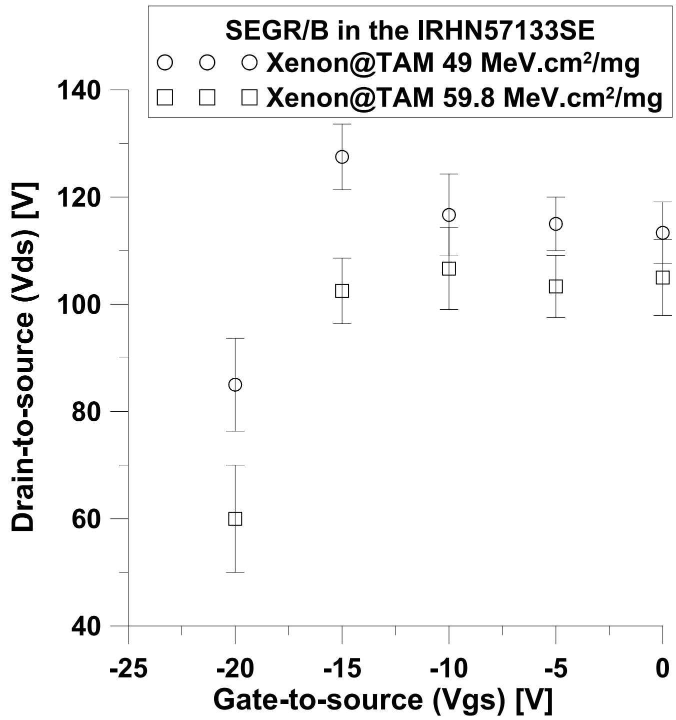

Fig. 2. SEE test results for IRHM57133SE for xenon.

B. IRHM57260SE

The IRHN57260SE is an n-channel 200V power MOSFET with an RDSon of 0.038 ohm. The parts tested here were fabricated on the new line in Temecula using IR's R5 technology. These parts also performed much better than parts tested from the previous fabrication line [16]. 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. Fig. 3 presents the results.

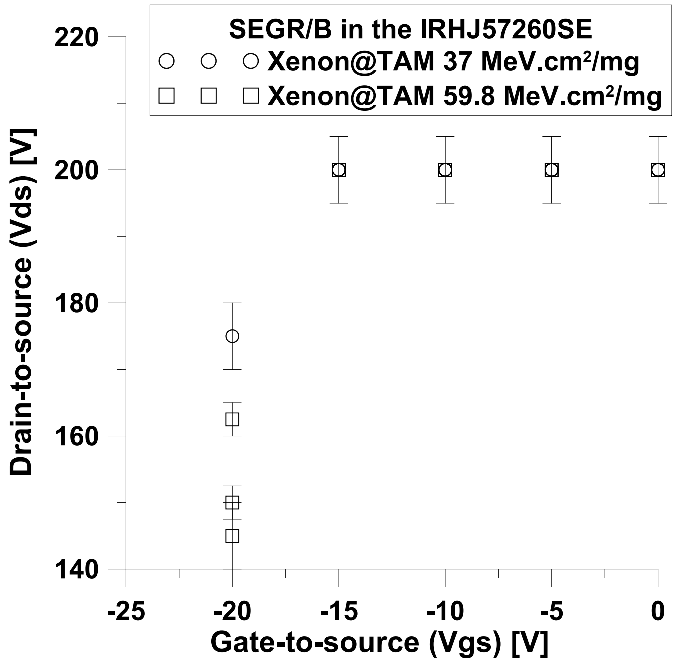

Fig. 3. SEE test results for IRHM57260SE.

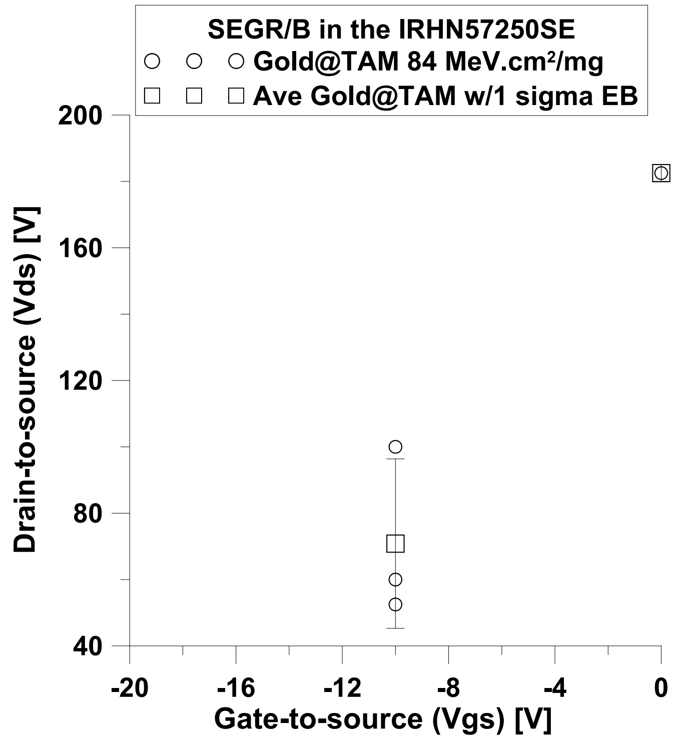

Fig. 4. SEE response curve of the IRHN57250SE. Tests with Bromine at BNL (41.3 MeV.cm^2/mg) result in SEGR outside the absolute maximum ratings of the device.

C. *IRHN57250SE*

The IRHN57250SE is an n-channel 200V power MOSFET with an RDSon of 0.06 ohm. The parts tested here were fabricated on the new line in Temecula using IR's R5 technology. The device performed much better than parts tested from the previous fabrication line [16]. These parts also performed very similarly to the IRHJ57260SE as shown in Fig. 4. For some devices, the gold ion energy was varied to explore the variation in SEE. Fig. 5 and Fig. 6 are the results. In Fig. 5, the drain-to-source voltage was held constant at 50 V, and the Vcrit of the Vgs was measured, while in Fig. 6, the gate-to source voltage was zero volts, and the Vds Vcrit was measured. In both cases, the part-to-part variability was quite large; however, Fig. 5 where Vcrit of Vgs was measured intimates an increasing susceptibility to increasing particle energy, however, no consistent trend can be inferred due to large variation of Vds. These results disagree in part or in whole with several previous publications on this effect [1]-[10]. These devices are made on the manufacturer's most current process line, so the technology may have a different dependence than previous part architectures. Regardless, the ability to trend the Vcrit response for Vds or Vgs as a function of particle energy should be carefully vetted. These devices exhibit both SEB and SEGR, and results shown here plot the average for both SEE types. However, the both the SEB and SEGR results follow the same trend.

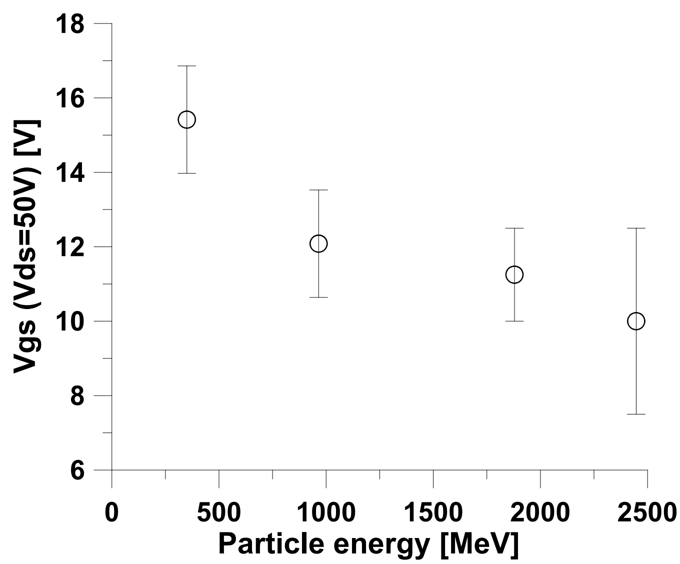

Fig. 5. Variation of the Vcrit of Vgs in the IRHN57250SE with gold ion energy at Vds=50 V.

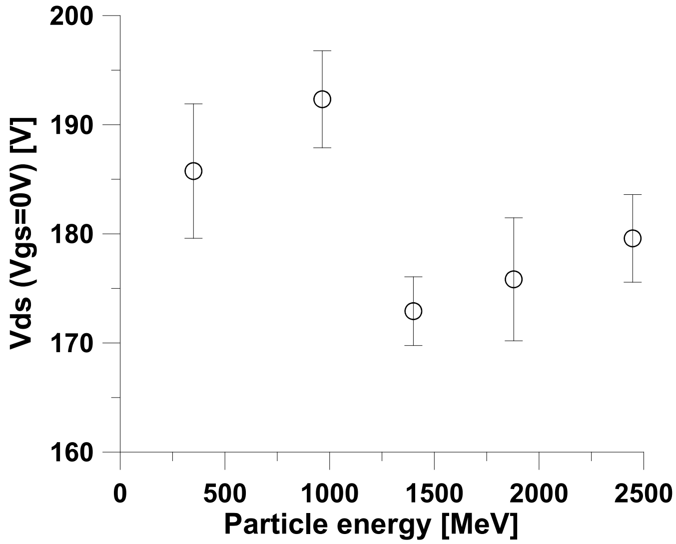

Fig. 6. Variation of the Vcrit of Vds in the IRHN57250SE with gold ion energy at Vgs=0 V.

D. *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 100V to 500 V. The epitaxial thickness is 55 µm and the total device thickness is 200 µm. The parts are currently available per Source Control Drawings and soon to be available to DSCC Specifications at the JANS Level (MIL-PRF-19500). The SEE response of these parts is comparable to other 500 V rated parts [11]-[14].

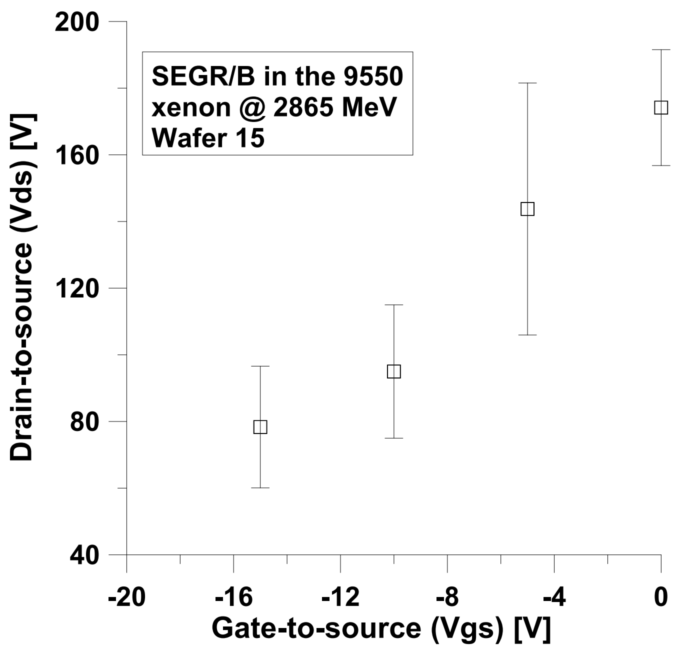

Fig. 7. SEE test results for SCF9550 for xenon at 2865 MeV.

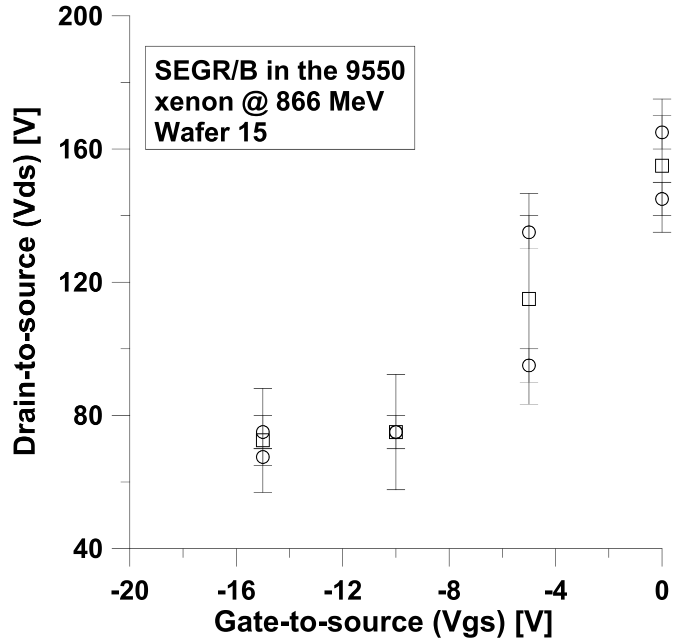

Fig. 8. SEE test results for SCF9550 for xenon at 866 MeV.

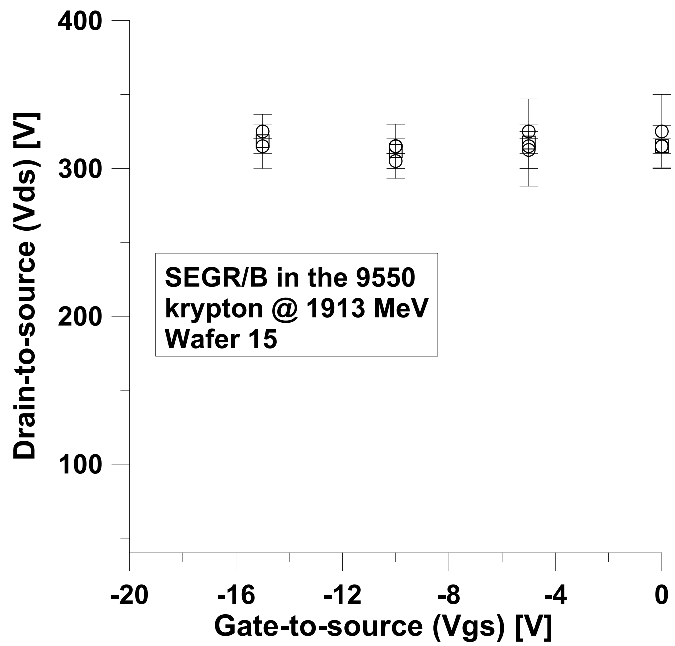

Fig. 9. SEE test results for SCF9550 for Krypton at 1913 MeV.

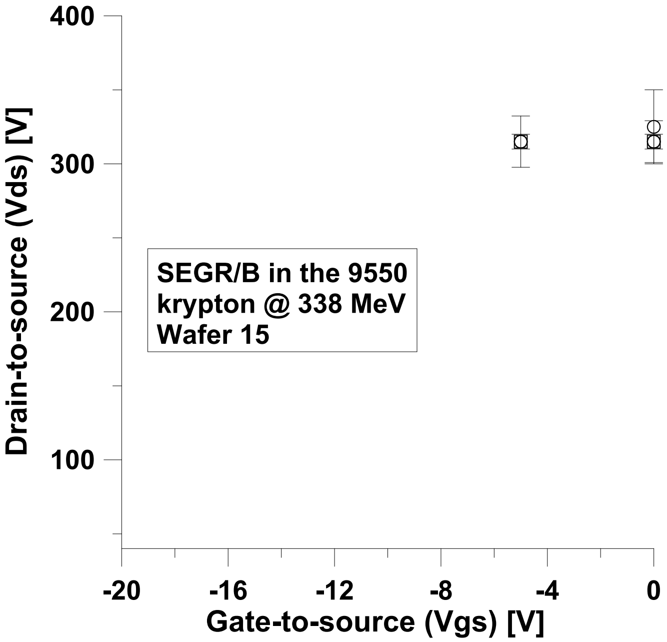

Fig. 10. SEE test results for SCF9550 for Krypton at 338 MeV.

1). Failure Analysis of the SCF9550

Two devices were selected to undergo failure analysis on the SCF9550. The S/N 1301 was a completely destroyed device, while S/N 1304 still functioned as a transistor, although it was very leaky. Fig. 11, Fig. 12 and Fig. 13 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 loss is in the wire bond region. The "leaky" part, S/N 1304, did not show a "hot spot" under IR inspection, however, damage was seen in the gate source region as shown in Fig. 15 and Fig. 15.

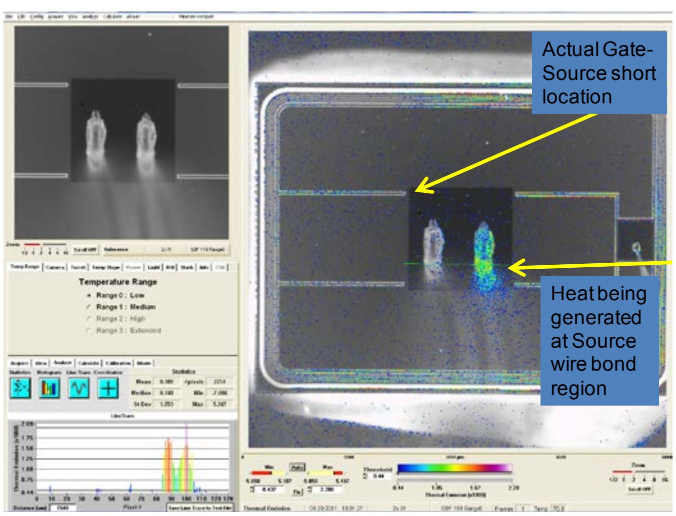

Fig. 11. The infrared image shows heat being dissipated at the source wire bond region but gate-source short is at a different location. Part S/N was 1301.

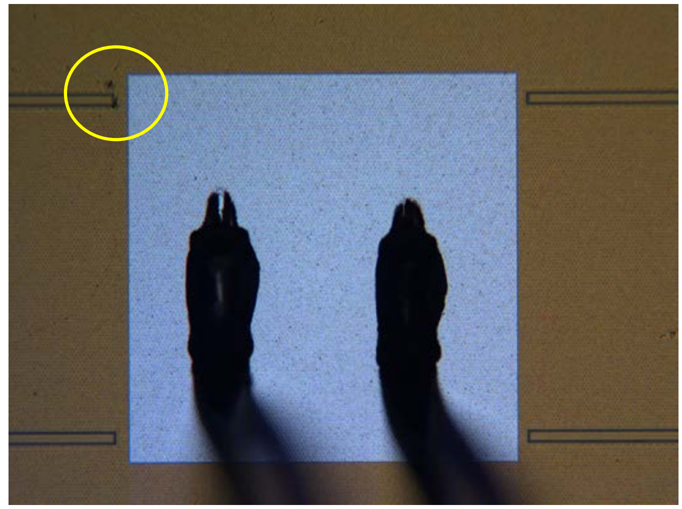
Fig. 12. S/N1301 Optical Image with Anomaly at Gate-Source Region

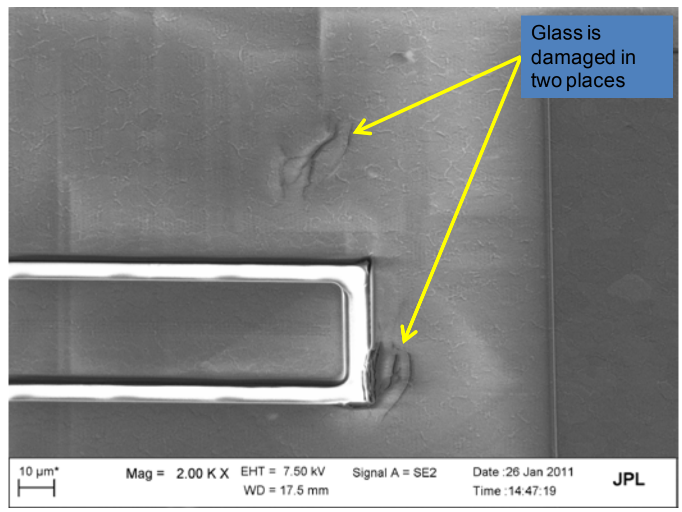

Fig. 13. S/N 1301 Magnified SEM Image of the Gate-Source Short, Damage to glass is most likely related to metal having been stressed below the passivation

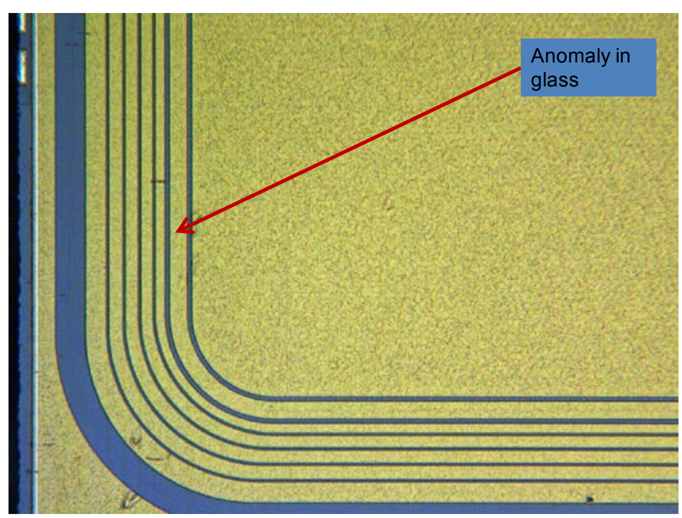

Fig. 14. S/N1304 Optical Image with Anomaly at Gate-Source Region

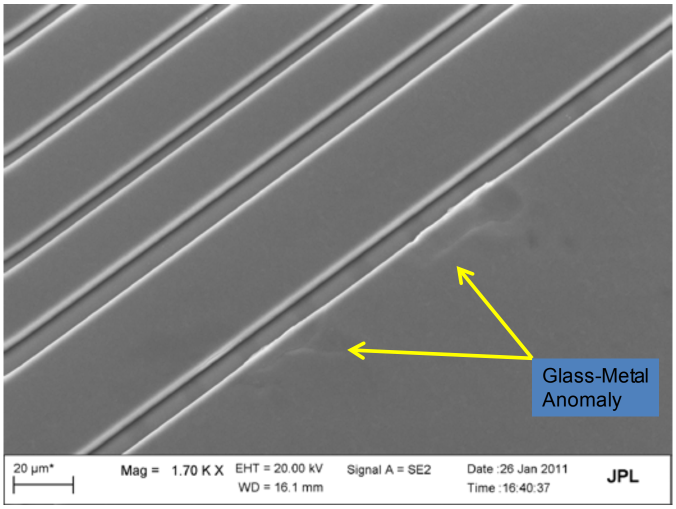

Fig. 15. S/N 1304 SEM Image of Gate-Source Anomaly, Glass is disturbed possibly by defect beneath metal

IV. Discussion and Conclusion

Recent testing of emerging power MOSFETs is showing that the technology performs at least as well as other technologies of similar specifications.

V. Acknowledgment

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