ISL70023SEH, ISL73023SEH, ISL70024SEH, ISL73024SEH

Overview

The intense proton and heavy ion environment encountered in space applications can cause a variety of Single Event Effects (SEE) in electronic circuitry, including Single Event Upset (SEU), Single Event Transient (SET), Single Event Functional Interrupt (SEFI), Single Event Gate Rupture (SEGR), and Single Event Burnout (SEB). SEE can lead to system-level performance issues including disruption, degradation, and destruction. For predictable and reliable space system operation, individual electronic components should be characterized to determine their SEE response. This report discusses the results of SEE testing performed on the ISL70023SEH and ISL70024SEH enhancement mode GaN FETs. This report also applies to the ISL73023SEH (which is the same die as the ISL70023SEH) and ISL73024SEH (which is the same die as the ISL70024SEH) parts, which are offered with radiation assurance screening to only 75krad(Si) at 10mrad(Si)/s.

Product Description

The ISL70023SEH and ISL70024SEH are 100V and 200V, respectively, N-channel enhancement mode GaN power transistors packaged in Hermetic Ceramic four pad Surface Mount Device (SMD) packages. The die packaged into the SMD are manufactured by Efficient Power Conversion Company (EPC). The base EPC parts are the EPC2922 (100V, 60A) and the EPC2919 (200V, 8.5A) devices, respectively. The EPC parts are bare die solder bumped to be flip-chip mounted. The die used in the SMD (the EPC2919 and EPC2922) have high temperature solder bumps to allow soldering of the SMD without demounting the die already mounted inside the package. The commercial equivalents of EPC products are the EPC2019 and EPC2022.

Related Literature

For a full list of related documents, visit our website

- ISL70023SEH, ISL73023SEH, ISL70024SEH, and ISL73024SEH product pages

1. Test Description

1.1 SEE Test Objectives

The testing described characterizes the constituent die of the ISL70023SEH and ISL70024SEH (EPC2922 and EPC2919) transistors for energetic heavy ion irradiation impact on IDSS (two terminal blocking current) when the parts were irradiated in the blocking mode. Of primary concern was Single Event Burnout (SEB) typified by a sudden large increase in IDSS during irradiation. Of secondary interest was the gradual increase in IDSS with irradiation fluence noted during previous preliminary testing. The testing was intended to provide a safe operating area (for both VDSS and irradiation Linear Energy Transfer, LET) for SEB and to quantify the rate of the gradual increase of IDSS with fluence, VDSS, and LET.

1.2 SEE Test Facility

Testing was performed at the Texas A&M University (TAMU) Radiation Effects Facility of the Cyclotron Institute heavy ion facility. This facility is coupled to a K500 super-conducting cyclotron, which is capable of generating a wide range of particle beams with the various energy, flux, and fluence levels needed for advanced radiation testing. Further details on the test facility can be found at the website. The Devices Under Test (DUTs) were located in air at 30mm to 50mm from the aramica window for the ion beam. Ion LET values are quoted at the DUT surface. Signals were communicated to and from the DUT test fixture through 20 foot cables connecting to the control room. The testing reported here was conducted on August 29, 2016. The ion species used in the testing reported here and the approximate ion parameters are as listed in Table 1. The values in are Table 1 are taken from the TAMU Cyclotron Institute on-line beam characteristics information.

Table 1. Ion Species and Approximate Parameters Used in Testing the EPC2922 and EPC2919

Species	Initial Total Energy (GeV)	Surface LET in Si After Window and Air Path (MeV·cm^2/mg)	Range to Bragg Peak in Si (µm)
Kr	1.259	28	115
Ag	1.634	43	91
Pr	2.114	60	85
Au	2.954	86	63

1.3 SEE Test Set-Up

To make the device side of the devices accessible for ion irradiation, the flip-chip devices were mounted with the solder bumped side exposed away from the printed circuit board (PCB) to which the parts were physically attached. The connections from the devices to the PCB traces were made by soldering fine wires from the PCB traces to the device solder bumps. The parts were wired for testing in a two terminal configuration with drain biased against the gate, source, and substrate (wired together at the device). Appendix A and Appendix B provide diagrams of the wire mounting.

For irradiation testing, four devices mounted on a PCB inside the ion beam diameter of one inch were biased with a single voltage supply (VDSS) through four separate current meters, one for each Device Under Test (DUT). This allowed the current, IDSS, to be monitored on each DUT. One set of four DUTs was used for each combination of part type (2), irradiation species (4), and test voltage (3) resulting in 24 separate irradiations runs.

Before and after each irradiation, the current was logged for irradiation VDSS biasing without the ion beam. The IDSS current was also measured for the absolute maximum voltage ratings (100V for the EPC2922 and 200V for the EPC2919) before and after each irradiation. The measurements and irradiations were carried out at ambient temperature (~25°C) to a fluence of 2.5×10^6ion/cm^2 at a flux of approximately 1×10^4ion/(cm^2-s). This brings the total fluence for each device type at each species and VDSS combination to 1×10^7ion/cm^2.

Each combination of ion species (4) and VDSS (3) was tested on four fresh DUTs with the sequence of events outlined in Table 2. The IDSS current of each DUT was monitored and logged during each row entry in Table 2. The VDSS during irradiation for the EPC2922 took values of 60V, 80V, and 100V. In the case of irradiation with VDSS = 100V the first and last rows of Table 2 became redundant and were dropped so the resulting sequence had only three rows.

Table 2. Sequence of Events for IDSS Logging Using the First VDSS Voltage for the EPC2922

Flux (ion/(cm^2·s))	Fluence (ion/cm^2)	VDSS (V)	Time (s)
0	0	100	30
0	0	60	30
$1x10^4$	$2.5x10^6$	60	250
0	0	60	30
0	0	100	30

1.4 Pre-Irradiation Characterization

After mounting 48 units of each type (three groups of four units per PCB), the devices were characterized to verify their proper mounting and operation with regards to IDSS. Each grouping of four parts was tested for IDSS of each unit during approximately a one minute interval (IDSS logged every 0.788 seconds) at 25°C and maximum VDSS for the part type. The testing methodology and equipment was the same as that used at TAMU. The last 30 measurements for each part where then used to characterize the parts' IDSS as represented in Figure 1 and Figure 2. Except for one part at a 12µA median (#42), all the EPC2922 parts ranged between 1µA and 7µA median IDSS at 100V. The range for each part was within 1µA. Because the SEB testing plan is to use a different four DUTs for each condition it is important that the parts for testing represent a homogeneous population, and with a single exception the EPC2922 population appears to be homogeneous with respect to IDSS at 100V. For the EPC2919 the median IDSS varied between 0.1µA and 2.3µA. Again, the measurement range about the median was generally within 1µA with a single part (#16) exceeding that range. The population of EPC2919 parts appears homogeneous with respect to IDSS at 200V.

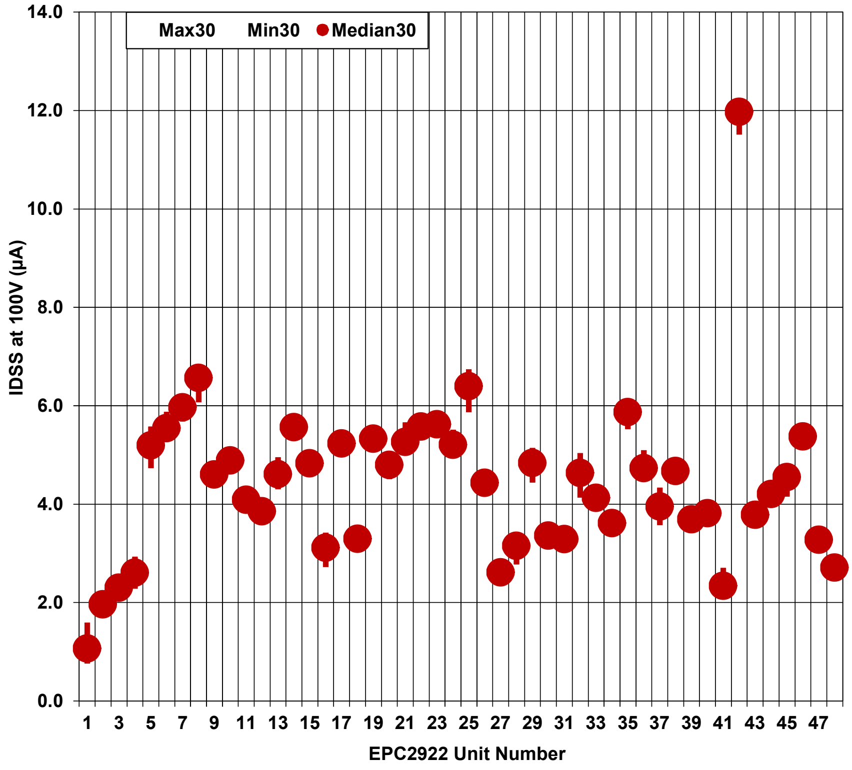


Figure 1. Initial IDSS Characterization Data on the EPC2922 Devices Taken for Irradiation Testing

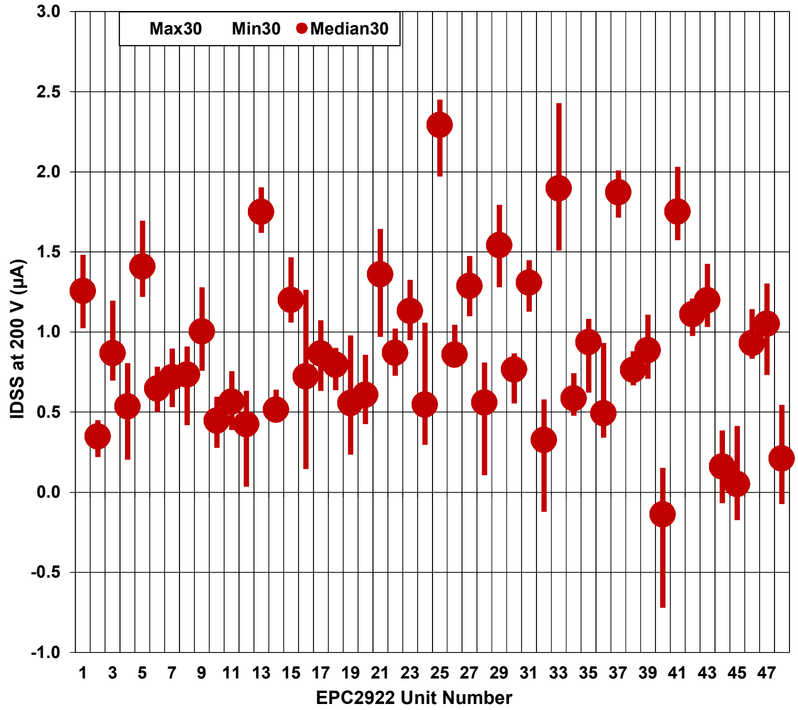


Figure 2. Initial IDSS Characterization Data on the EPC2919 Devices Taken for Irradiation Testing

The logged IDSS data was then used to calculate the last 30 sequential changes in the IDSS measurements. These sequential changes give a representation of the nominal error associated with the measurements. A histogram of the measurement changes is presented in Figure 3. The standard deviation for all the measurement changes (both part types) was 75nA. The minimum and maximum changes were -332nA and 305nA. This sets the bounds on the normal variation in the IDSS measurements.

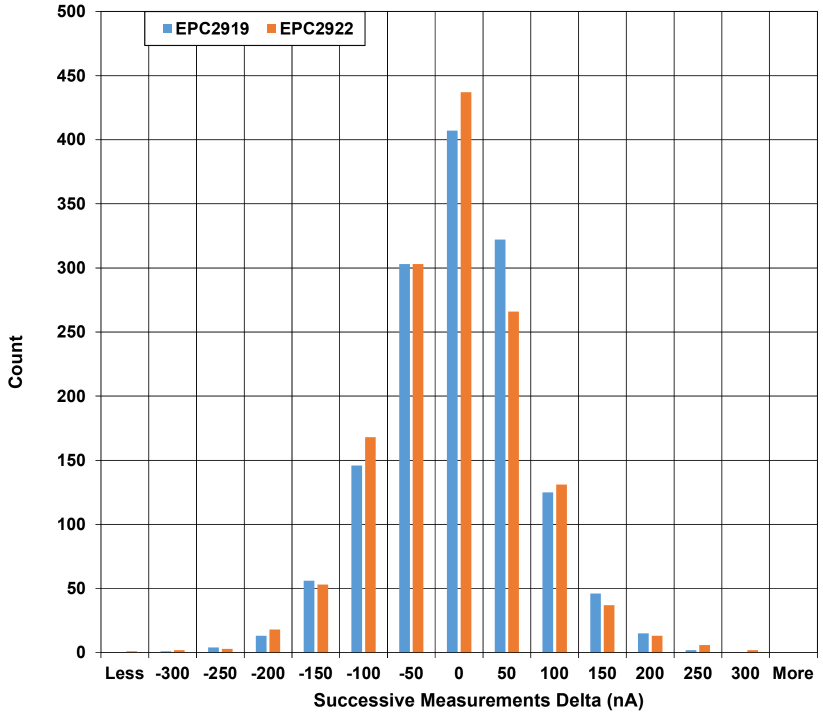


Figure 3. Histogram of the Last 30 Sequential Changes in IDSS Measurements for the Pre-irradiation Characterization of the Set of Parts Going to SEB Testing

1.5 EPC2922 Testing Results

The IDSS for each EPC2922 part was logged for 30s at 100V and for 30s at the irradiation VDSS (60V, 80V, or 100V) immediately before irradiation. Then IDSS was logged during irradiation at the selected VDSS. After irradiation, IDSS was again logged for 30s at the irradiation VDSS and then for 30s at 100V.

The IDSS data collected during the irradiation was used to calculate the step changes in IDSS between measurements. For each grouping of four units irradiated together, the minimum and maximum steps were found. This IDSS step data by irradiation condition appears in Table 3. Each irradiation was done on four device to 2.5×10^6ion/cm^2 and the extreme IDSS steps of the group are reported here. Only thee irradiation treatments yielded positive steps in excess of 1µA at 1.02, 1.20, and 1.39µA. The irradiations yielding these statistically significant events were VDSS = 80V and VDSS = 100V at LET = 86MeV•cm^2/mg(Si) and VDSS = 100V at 60MeV•cm^2/mg(Si).

Although these events are statistically significant, they represent very small perturbations in the blocking current. It is interesting to note that these irradiation conditions also provided the largest negative steps in IDSS at -0.54, -1.15, and -1.26µA.

Table 3. EPC2922 IDSS Step Extremes During Irradiation by Irradiation Treatment.

EPC2922 IDSS Irradiation Step Extremes in µA				
LET in Si (MeV•cm^2/mg)	Step	VDSS During Irradiation		
		60V	80V	100V
28	Min	-0.25	-0.27	-0.26
	Max	0.29	0.26	0.28
43	Min	-0.23	-0.31	-0.30
	Max	0.27	0.41	0.31
60	Min	-0.26	-0.29	-1.15
	Max	0.57	0.29	1.02
86	Min	-0.26	-0.54	-1.26
	Max	0.37	1.20	1.39

The EPC2922 parts did exhibit a gradual growth of IDSS, measured at VDSS = 100V, with irradiation for conditions with LET at 60MeV•cm^2/mg(Si) or 86MeV•cm^2/mg(Si). The minimum IDSS measured at 100V before irradiation was subtracted from the maximum IDSS registered after irradiation for each part to establish the IDSS deltas over the irradiation. The change in µA was then divided by 2.5 to yield an IDSS rise per 1x10^{6}ion/cm^2. These numbers are reported in Table 4. The first two rows (green) do not show a significant change in IDSS. The last two rows (yellow) do show significant changes in IDSS. LET is listed in units of MeV•cm^2/mg(Si).

Table 4. EPC2922 Change in IDSS (µA) at VDSS = 100V per Irradiation with 1x10^{6}ion/cm^2 by DUT

LET	Change in IDSS in µA at VDSS = 100V per Irradiation to 1x10^6 ion/cm^2											
	VDSS = 60V				VDSS = 80V				VDSS = 100V			
	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4
28	0.08	0.09	0.08	-0.09	-0.56	-0.28	-0.33	-0.22	-0.14	-0.08	0.32	-0.06
43	0.06	-0.23	0.07	0.24	-0.11	-0.30	0.12	-0.20	0.23	-0.12	0.03	0.20
60	1.18	-0.17	1.20	1.32	-0.21	0.54	-0.05	-0.04	1.72	1.94	1.17	0.78
86	1.16	1.57	3.06	2.85	3.73	4.17	4.63	2.78	3.15	3.07	1.46	5.88

The greatest IDSS rise, 5.88µA per 1x10^{6}ion/cm^2, was registered for the most extreme conditions of VDSS = 100V and LET = 86MeV•cm^2/mg(Si). The IDSS evolution for this case is presented in Figure 4. In this figure, changes in test conditions are marked by spikes in data beyond 20µA. Clearly the irradiation caused a gradual rise in IDSS composed of many small increments. The two largest positive steps in IDSS (1.39 and 1.26µA) occurred in DUT4, which performed somewhat worse than the other three DUTs.

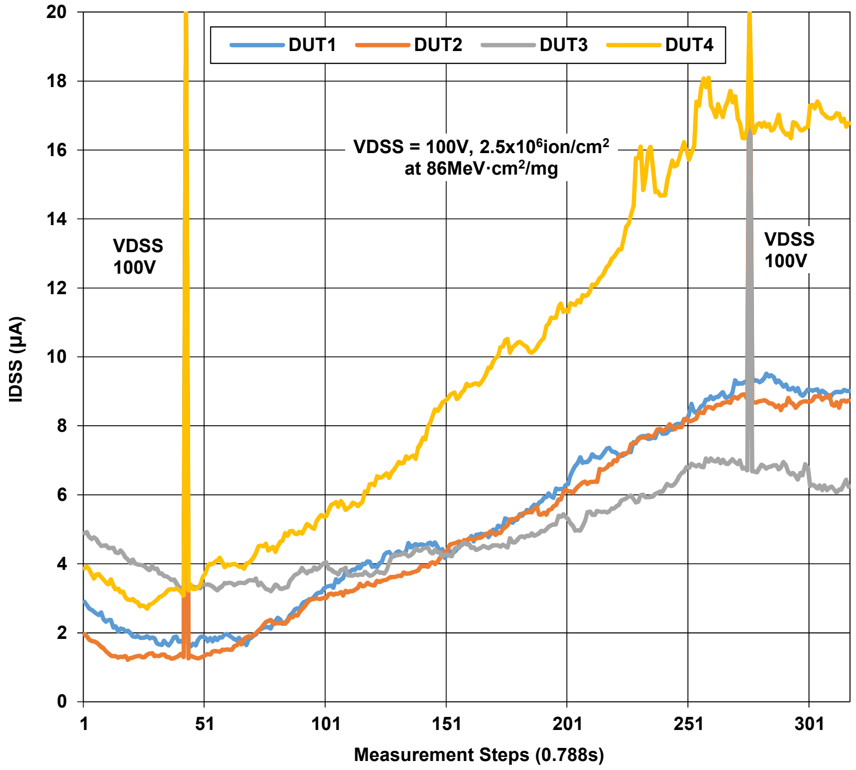


Figure 4. IDSS Behavior for the EPC2922 100V GaN FET at VDSS = 100V and LET = 86MeV·cm^2/mg(Si)

1.6 EPC2919 Testing Results

The IDSS for each EPC2919 was logged for 30s at 200V and for 30s at the irradiation VDSS (120V, 160V, or 200V) immediately before irradiation. Then IDSS was logged during irradiation at the selected VDSS. After irradiation IDSS was again logged for 30s at the irradiation VDSS and then for 30s at 200V.

The IDSS data collected during the irradiation was used to calculate the step changes in IDSS between measurements. For each grouping of four units irradiated together, the minimum and maximum steps were found. This IDSS step data by irradiation condition appears in Table 5. Each irradiation was done on four devices to 2.5x10^{6}ion/cm^2 and the extreme IDSS steps of the group are reported here. The most extreme irradiation condition, VDSS = 200V and LET = 86MeV•cm^2/mg(Si), resulted in all four test devices exhibiting catastrophic failure with 100mA current steps (equipment limited). These events are viewed as single event burnout (SEB) in this report. Of the remaining eleven irradiation treatment cells, only those three for LET = 28MeV•cm^2/mg(Si) did not register IDSS steps greater than 1µA. The steps peaked at 5.12µA (for the case of 120V and 60MeV•cm^2/mg)(Si), so a criteria of 10µA for SEB would leave only the one irradiation condition generating SEB.

Table 5. EPC2919 IDSS Step Extremes During Irradiation by Irradiation Treatment

EPC2919 IDSS Irradiation Step Extremes in µA				
LET in Si (MeV·cm^2/mg)	Step	VDSS During Irradiation		
		120V	160V	200V
28	Min	-0.25	-0.24	-0.25
	Max	0.24	0.30	0.47
43	Min	-0.49	-0.30	-0.81
	Max	3.81	1.00	4.65
60	Min	-0.82	-0.56	-1.15
	Max	5.12	1.17	2.01
86	Min	-0.83	-2.05	NA
	Max	1.13	1.98	1.00E+05

The EPC2919 parts did exhibit a gradual growth of IDSS, measured at VDSS = 200V, with irradiation for conditions with LET at or above 43MeV•cm^2/mg(Si). The minimum IDSS measured at 200V before irradiation was subtracted from the maximum IDSS registered after irradiation for each part to establish the IDSS deltas over the irradiation. The change in µA was then divided by 2.5 to yield an IDSS rise per 1x10^6 ion/cm^2.

These numbers are reported in Table 6. The first row (green) did not show a significant change in IDSS. The next two rows and the first two voltages of the last row (yellow) show significant IDSS increase. The four devices represented in the lower right (red) entries exhibited catastrophic failures. LET is listed in units of MeV•cm^2/mg(Si).

Table 6. EPC2919 Change in IDSS (µA) at VDSS = 200V per Irradiation with 1x10^6 ion/cm^2 by DUT

LET	Change in IDSS in µA at VDSS = 200V per Irradiation to 1x10^6 ion/cm^2											
	VDSS = 120V				VDSS = 160V				VDSS = 200V			
	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4
28	0.14	-0.19	-0.47	0.02	0.12	-0.02	0.04	0.28	0.16	-0.06	-0.07	0.05
43	2.00	0.27	0.61	0.50	0.86	0.59	0.89	0.86	2.50	6.70	2.91	3.70
60	1.24	5.08	2.71	7.40	3.14	2.45	2.56	2.61	7.11	9.52	10.45	15.26
86	7.30	8.87	8.61	6.78	14.51	32.37	28.14	11.73	SEB	SEB	SEB	SEB

The greatest IDSS rise, 32.37µA per 1x10^6 ion/cm^2, was registered for the condition of VDSS = 160V and LET = 86MeV•cm^2/mg(Si). The IDSS evolution for this case is presented in Figure 5. In this figure, changes in test conditions are marked by spikes in data beyond 90µA. Although it is not apparent on the scale of Figure 5, fifteen IDSS steps were in excess of 1µA, the largest being 1.98µA. These do not reach the largest step of 5.12µA seen for 120V and 60MeV•cm^2/mg(Si).

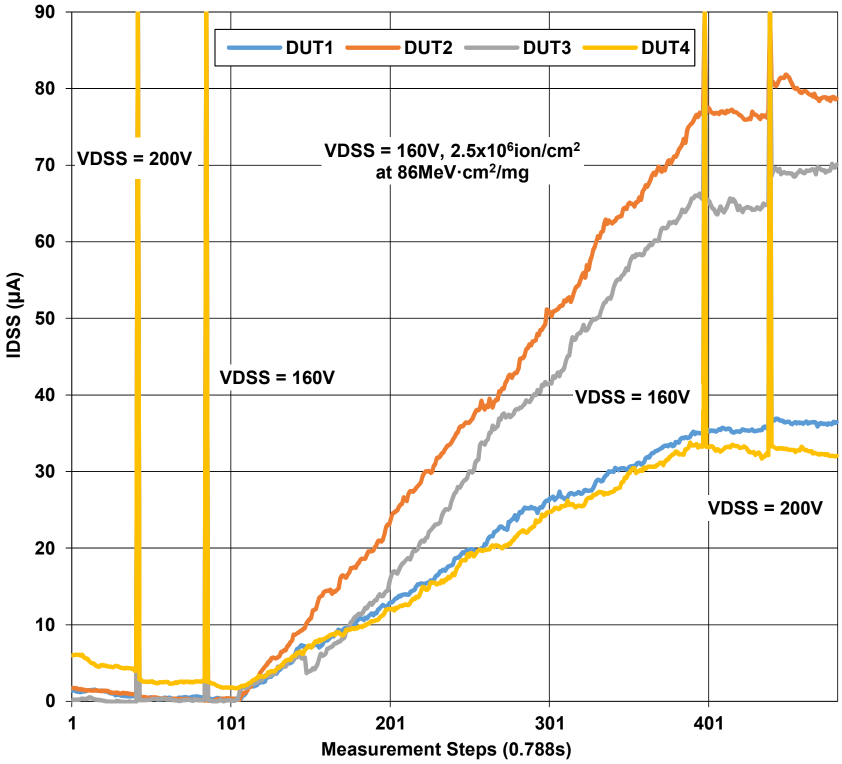


Figure 5. IDSS Evolution for EPC2919 Exhibiting the Largest IDSS Rise with Irradiation

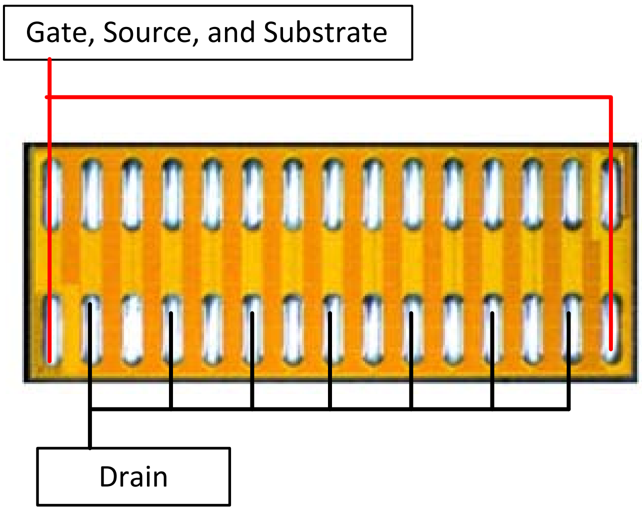
2. Discussion and Conclusions

The ISL70023SEH (EPC2922) devices exhibited two forms of IDSS behavior over the range of twelve irradiation conditions tested (VDSS = 60V, 80V, and 100V with LET = 28, 43, 60, and 86MeV•cm^2/mg(Si) at 25°C). For the two lower LET no apparent changes in IDSS during irradiation or at VDSS = 100V were found. The conclusion is that these irradiation conditions (VDSS 100V and LET 43MeV•cm^2/mg(Si)) define an unconditional Safe Operating Area (SOA). At higher LET (60 and 86MeV•cm^2/mg(Si)) the IDSS did register a gradual increase with irradiation. This increase rate grew with both VDSS during irradiation and with the LET of the irradiation. At the most extreme conditions (VDSS = 100V and LET = 86MeV•cm^2/mg(Si)) the increase reached 5.88µA/1x10^{6}ion/cm^2. However, no IDSS steps greater than 2µA were noted in any cases. Depending upon the interpretation of the gradual IDSS rise, a conditional SOA can be defined for these conditions.

The ISL70024SEH (EPC2919) devices exhibited three forms of IDSS behavior over the range of twelve irradiation conditions tested (VDSS = 120V, 160V, and 200V with LET = 28, 43, 60, and 86MeV•cm^2/mg(Si) at 25°C). For the lowest LET no apparent changes in IDSS during irradiation or at VDSS = 200V were found. The conclusion is that these irradiation conditions clearly define an unconditional SOA. At the most extreme irradiation condition (VDSS = 200V and 86MeV•cm^2/mg(Si)) catastrophic failure of all four test devices was encountered. This clearly defines a region outside of any SOA. At intermediate LET (43, 60MeV•cm^2/mg(Si)) as well as at the highest LET (86MeV•cm^2/mg(Si)) at the lower two voltages (VDSS = 120V and 160V) the IDSS did register a gradual increase with irradiation. At the conditions of VDSS = 160V and LET = 86MeV•cm^2/mg(Si) the rate of IDSS rise reached 32.37µA/1x10^{6}ion/cm^2. However, no IDSS steps greater than 6µA were noted in the rising IDSS cases. Depending upon the interpretation of the gradual IDSS rise, a conditional SOA can be defined for these conditions.

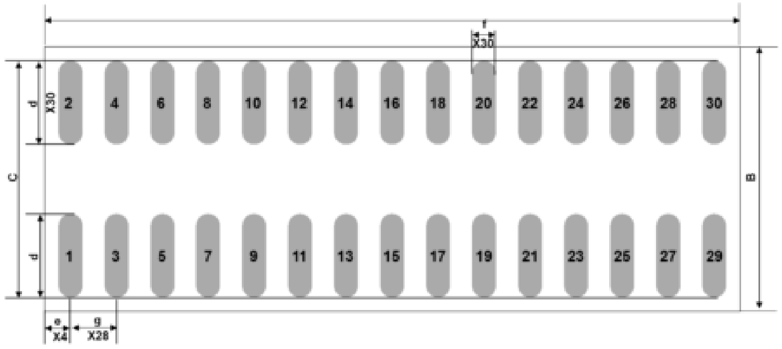
Appendix A

The following figures show a dead-bug view of the EPC2922 (taken from the EPC2022 datasheet) and connections for SEB testing.



DIE OUTLINE

Solder Bar View



DIM	MICROMETERS		
	MIN	Nominal	MAX
A	6020	6050	6080
B	2270	2300	2330
c	2047	2050	2053
d	717	720	723
e	210	225	240
f	195	200	205
g	400	400	400

Pad 1 is Gate

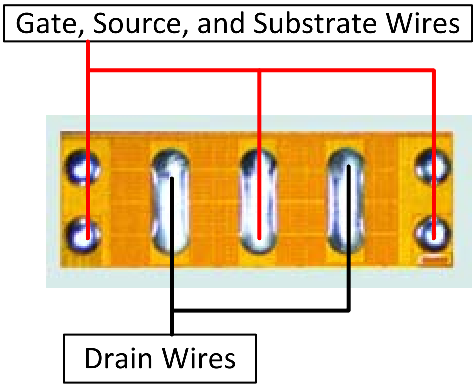
Pads 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, and 29 are Source

Pads 3, 4, 7, 8, 11, 12, 15, 16, 19, 20, 23, 24, 27, and 28 are Drain

Pad 30 is Substrate

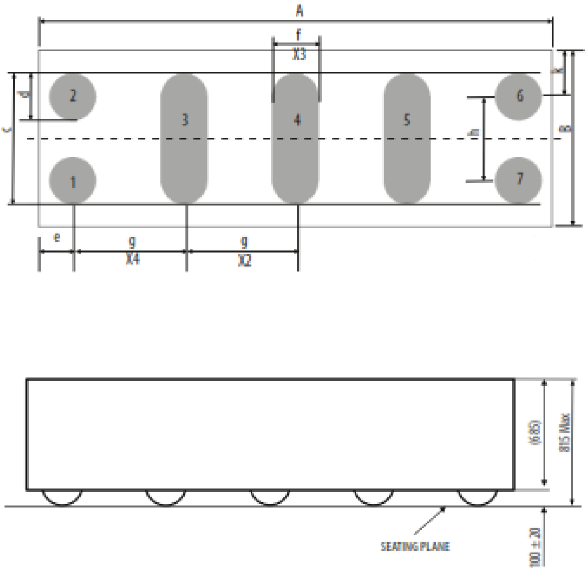
Appendix B

The following figures show a dead-bug view of the EPC2919 (from the EPC2019) datasheet) and connections for SEB testing.



DIE OUTLINE
Solder Bar View

Side View



DIM	MICROMETERS		
	MIN	Nominal	MAX
A	2736	2766	2796
B	1057	950	980
c	697	700	703
d	247	250	253
e	168	183	198
f	245	250	255
g	600	600	600
h	450	450	450
i	235	250	265

Pad no.1 is Gate

Pad no. 3, 5 are Drain

Pad no. 2, 4, 6 are Source

Pad no. 7 is Substrate

3. Revision History

Rev.	Date	Description
1.01	Mar 28, 2024	Clarified that LETs were calculated using a silicon target substrate.
1.00	Nov 28, 2022	Applied new template. Added ISL73023SEH and ISL73024SEH information to page 1.
0.00	Dec 5, 2017	Initial release

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Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

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