ISL73033SLHM

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, characterize individual electronic components to determine their SEE response.

Because the ISL73033SLHM is a co-package of a ISL73040SEH driver die and two EPC2016C, gallium nitride (GaN), 100V, N-channel enhancement mode FETs, the SEE report for the ISL73033SLHM is broken into two separate reports. The separate reports are necessary because the constituent die cannot readily be SEE tested in the co-packaged configuration. The first report, the ISL70040SEH, ISL73040SEH SEE test report, is for the ISL73040SEH low-side driver. This second report examines the results of destructive SEE testing performed on the constituent GaN FET die of the ISL73033SLHM, the EPC2016C.

Contents

1. Product Description

The EPC2016C is a 100V, N-channel enhancement mode GaN power transistor co-packaged in the ISL73033SLHM. The GaN FET die are manufactured by EPC (Efficient Power Conversion Company). The EPC parts are bare die solder bumped to be flip-chip mounted.

2. Single Event Effects Test

2.1 Objective

The testing described here was intended to characterize the constituent transistor die of the ISL73033SLHM (EPC2016C) for energetic heavy ion irradiation impact on I_{DSS} (two-terminal blocking current) when the parts were irradiated in the blocking mode. The primary concern was SEB typified by a sudden large increase in I_{DSS} during irradiation. The secondary interest was the gradual increase in I_{DSS} with irradiation fluence noted during testing of other GaN FET parts. The testing provided a safe operating area (for both V_{DSS} and irradiation Linear Energy Transfer (LET) for SEB) and quantifies the rate of the gradual increase of I_{DSS} with LET, fluence, and V_{DSS}.

2.2 Facility

The testing was done at the Texas A&M University (TAMU) Radiation Effects Facility of the Cyclotron Institute. This facility is coupled to a K500 superconducting cyclotron that is capable of generating a wide range of particle beams with various energy and flux levels needed for advanced single event testing. The ion species used in the testing reported here and the approximate ion parameters are as listed in Table 1. The testing was done on October 1, 2019.

Table 1. Ion Species and Approximate Parameters Used in Testing the EPC2016C[1]

Species	Initial Total Energy (GeV)	Surface LET 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. Taken from TAMU Cyclotron Institute on-line beam characteristics information.

2.3 Setup and Method

To ensure the device side of the EPC2016C was 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). The Appendix provides a diagram of how the wire mounting was done.

For irradiation testing, four devices mounted on a PCB inside the ion beam diameter of one inch were biased with a single voltage supply (V_{DSS}) through four separate current meters, one for each Device Under Test (DUT). This set up allowed the monitoring of the current (I_{DSS}) on each DUT. One set of four DUTs was used for each combination of four irradiation species (Kr, Ag, Pr and Au) and three test voltages (VDSS of 60V, 80V and 100V). In total, 48 EPC2016 GaN FET die were tested.

Before, after, and during each irradiation, the current was logged from the current meters and stored for later analysis. The I_{DSS} current was measured for the absolute maximum voltage ratings (100V) 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 the device type at each species and V_{DSS} combination to 1×10^7ion/cm^2.

Each combination of ion species (4) and V_{DSS} (3) was tested on four fresh DUTs with the sequence of events outlined in Table 2. The I_{DSS} current of each DUT was monitored and logged during each row entry in Table 2. The V_{DSS} during irradiation for the EPC2016C took the values 60V, 80V, and 100V. In the irradiation with V_{DSS} = 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 I_{DSS} Logging Using the First V_{DSS} Voltage for the EPC2016C

Flux (ion/(cm^2-s))	Fluence (ion/cm^2)	V_{DSS} (V)	Time (s)
0	0	100	30
0	0	60	30
1.0E+04	2.50E+06	60	250
0	0	60	30
0	0	100	30

2.4 Pre-Irradiation Characterization

Prior to irradiation each part had its I_{DSS} measured at 100V V_{DSS} for approximately 30 seconds at a sampling time of about 0.21 seconds. The measurements produced for each part were then used to characterize the I_{DSS} of the parts as represented in Figure 1. DUT 3 is not shown because it exhibited an anomalously high current and was purged from further analysis. The last eight DUTs also exhibited somewhat higher currents than the bulk of the population, but not so much as to disqualify them from testing. Because the SEB testing plan was to use a different set of DUTs (4) for each condition it is important that the parts for testing represent a homogeneous population. The total population registered a mean I_{DSS} value of 0.33µA between extremes of -0.03µA and 4.79µA (DUT 3).

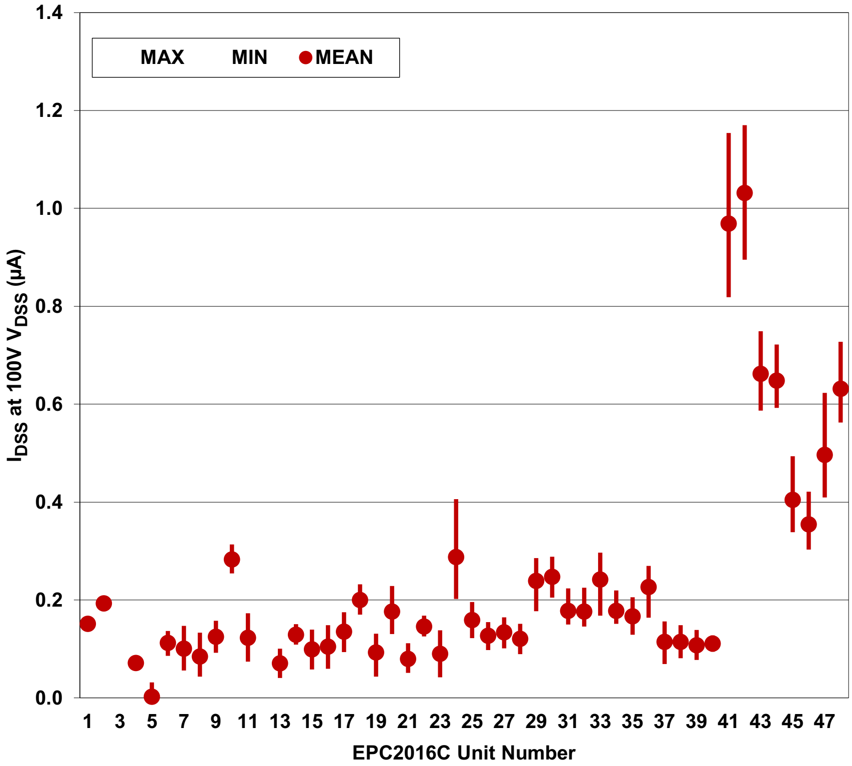


Figure 1. Initial I_{DSS} at 100V Characterization Data on the EPC2016C Devices Taken Before Irradiation Testing

The logged I_{DSS} data was then used to calculate the sequential changes in the I_{DSS} 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 2. The mean and standard deviation for all the measurement changes were 220pA and 37nA. The minimum change was -200nA and the maximum change was 92nA. This sets the bounds on the normal variation in the I_{DSS} measurements.

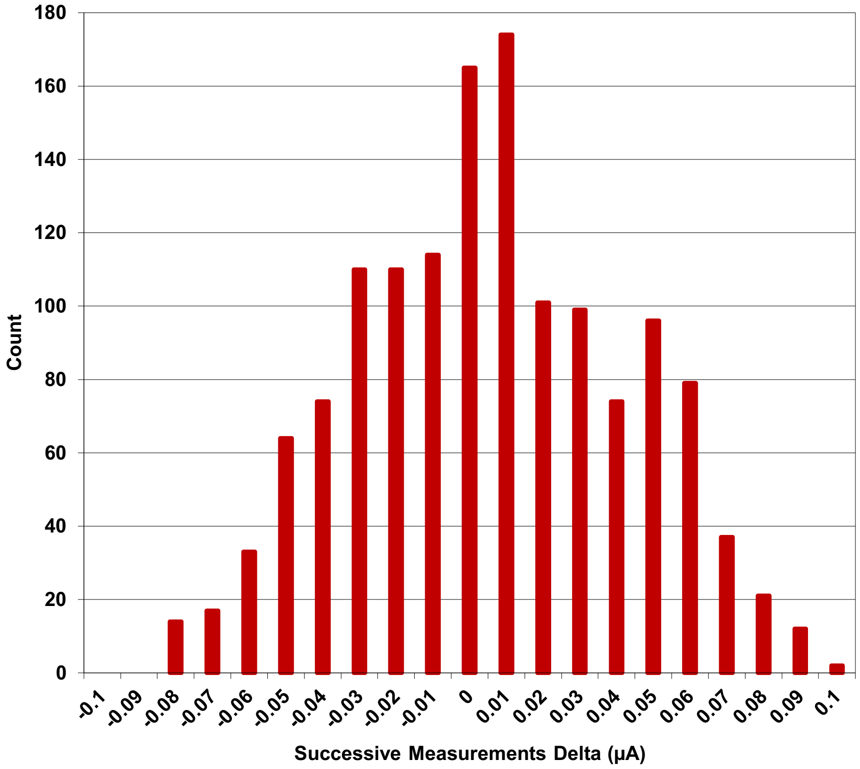


Figure 2. 30 Sequential Changes in I_{DSS} Measurements at 100V for the Pre-Irradiation Characterization of the Parts Set Going to SEB Testing

3. Results

The I_{DSS} for each EPC2016C part was logged for 30s at 100V and 30s at the irradiation V_{DSS} (60V or 80V) immediately before irradiation. Next, I_{DSS} was logged during irradiation at the selected V_{DSS}. After irradiation, I_{DSS} was again logged for 30s at the irradiation V_{DSS} and 30s at 100V.

The I_{DSS} data collected during the irradiation was used to calculate the step changes in I_{DSS} between measurements. The average, minimum, and maximum steps were found for each grouping of four units irradiated together. This I_{DSS} step data by irradiation condition appears in Table 3. The data for the case of 60V and LET = 28MeV·cm^2/mg (irradiation with Kr) was suspect for being too small and has been omitted. The largest positive step was 502nA occurring for the case of 100V and LET = 86MeV·cm^2/mg. This irradiation condition also produced the largest negative step at -362nA.

Table 3. EPC2016C IDSS Step Statistics During Irradiation by Irradiation Treatment[1]

EPC2016C I_{DSS} Irradiation Step Statistics in nA				
		V_{DSS} During Irradiation		
LET (MeV·cm^2/mg)	**Step**	**60V**	**80V**	**100V**
28	Mean	na	0	0
	Min	na	-85	-122
	Max	na	86	123
43	Mean	0	0	0
	Min	-85	-86	-130
	Max	86	86	202
60	Mean	0	1	1
	Min	-299	-105	-199
	Max	351	204	444
86	Mean	1	6	8
	Min	-178	-354	-362
	Max	274	369	502

1. Each irradiation was done on four devices to 2.5x10^{6}ion/cm^2 and the statistics on the I_{DSS} steps of the group are reported here.

The EPC2016C parts did exhibit a gradual growth of I_{DSS}, measured at V_{DSS} = 100V, for irradiation conditions with LET at 86MeV·cm^2/mg and 60MeV·cm^2/mg. The minimum I_{DSS} measured at 100V before irradiation was subtracted from the maximum I_{DSS} registered after irradiation for each part to establish the I_{DSS} deltas over the irradiation. The change in µA was then divided by 2.5 to yield an I_{DSS} rise per 1x10^{6}ion/cm^2. These numbers are reported in Table 4. It is worth noting that the time in orbit to accumulate 1X10^{6}ion/cm^2 of ions with LET greater than or equal to 28MeV·cm^2/mg is greater than one hundred thousand years. Therefore, the current increases given in Table 4 have no practical application in normal usage as the fluence encountered in a mission is much too small to yield meaningful increases.

Table 4. EPC2016C Change in I_{DSS} (µA) at V_{DSS} = 100V per Irradiation with 1x10^{6}ion/cm^2 by DUT

	Change in I_{DSS} in µA at V_{DSS} = 100V per Irradiation to 1x10^{6}ion/cm^2											
	V_{DSS} = 60				V_{DSS} = 80[1]				V_{DSS} = 100[1]			
LET	**DUT1**	**DUT2**	**DUT3**	**DUT4**	**DUT1**	**DUT2**	**DUT3**	**DUT4**	**DUT1**	**DUT2**	**DUT3**	**DUT4**
28[2]	na	na	na	na	**-0.31**	**-0.31**	**-0.18**	**-0.19**	0.02	**-0.04**	0.03	na
43[2]	0.04	0.02	0.03	0.03	0.03	0.04	0.03	0.03	0.04	0.05	0.04	0.48
60[3]	0.29	0.18	0.25	0.20	0.71	0.31	0.18	0.57	0.18	0.82	0.45	0.34
86[3]	0.86	0.80	0.57	1.03	2.65	2.96	3.61	3.08	4.62	5.16	2.98	2.98

1. Negative changes are indicated in bold text.
2. The blue cells indicate groupings that did not show a significant increase in I_{DSS} over the irradiations.
3. The orange cells indicate cases that did exhibit I_{DSS} growth with irradiation.

The changes registered in Table 4 show a tendency to grow with increasing stress, with higher voltage or higher LET during irradiation. Only the two highest LET, 60 and 86, show a clear propensity for increased current. The I_{DSS} evolution for the highest stress case is presented in Figure 3. The irradiation caused a gradual rise in I_{DSS} composed of many small increments. The largest positive step in I_{DSS} (502nA) occurred in DUT2 which performed slightly worse than the other three DUTs. A three-sigma bound on the increase is 7.31μA over 1x10^6ions/cm^2 at 86MeV·cm^2/mg and a bias of 100V. The three-sigma bound on the case of an 80V bias at 86MeV·cm^2/mg to 1x10^6ion/cm^2 is 4.27μA.

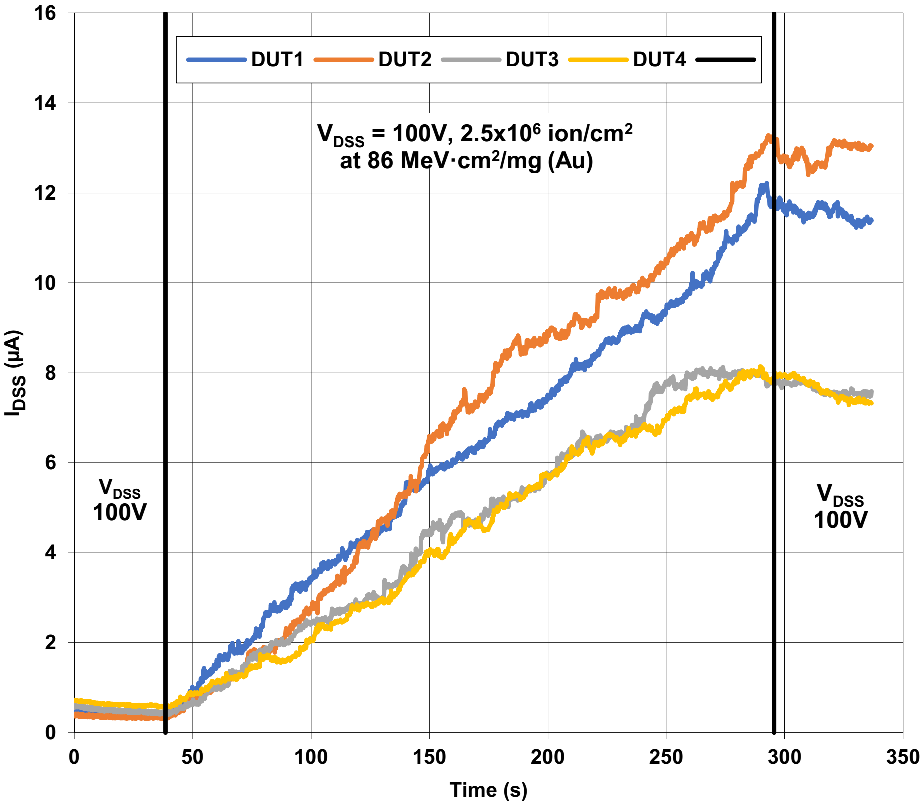


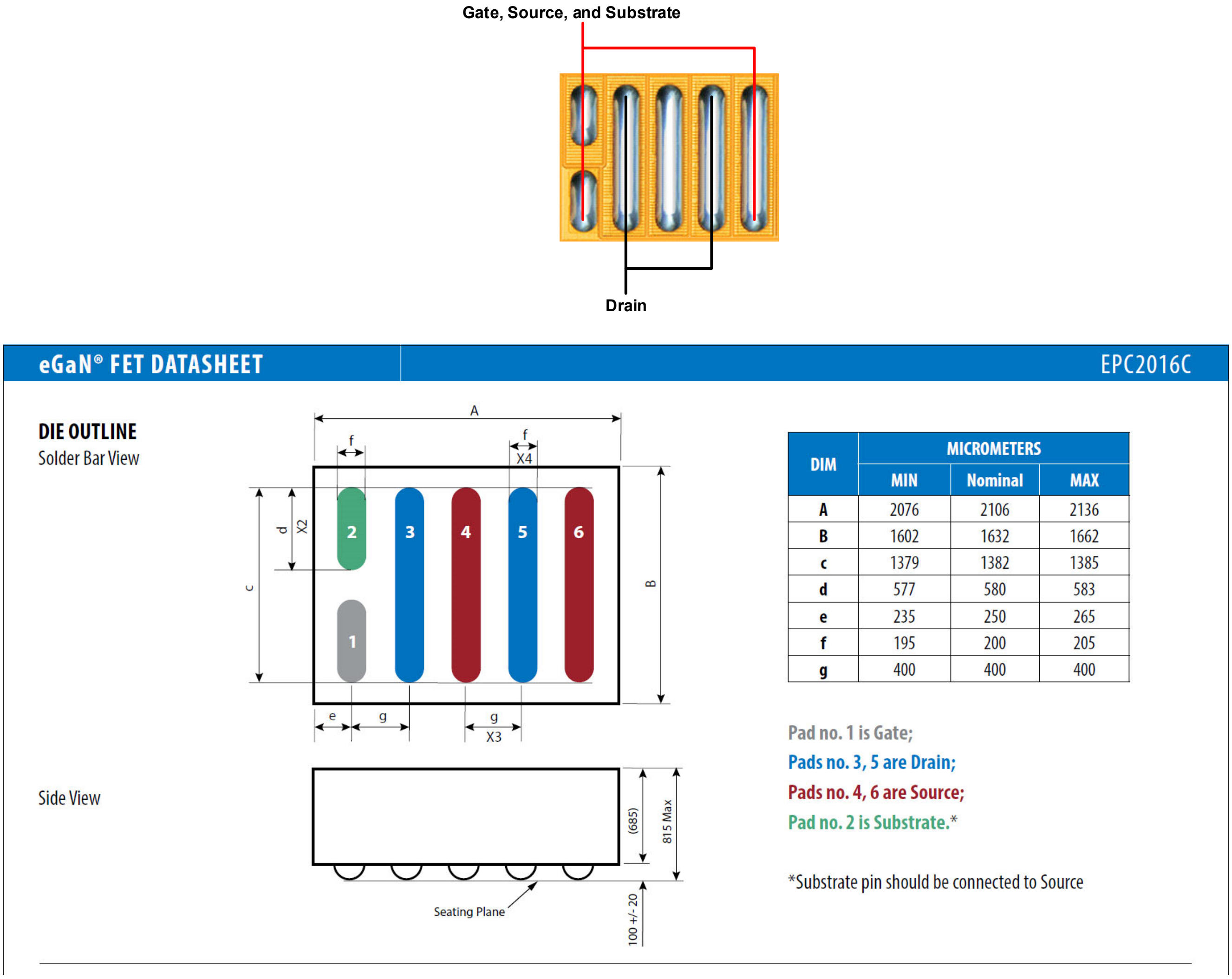
Figure 3. I_{DSS} Behavior for the EPC2016C 100V GaN FET at V_{DSS} = 100V and LET = 86MeV·cm^2/mg to 2.5x10^6ion/cm^2

4. Discussion and Conclusions

The EPC2016C devices exhibited two forms of I_{DSS} behavior over the range of twelve irradiation conditions tested (V_{DSS} = 60V, 80V, and 100V with LET = 28, 43, 60, and 86MeV·cm^2/mg at 25°C). For the two lower LETs, no apparent changes in I_{DSS} during irradiation at V_{DSS} = 100V were found. The conclusion is that these irradiation conditions (V_{DSS} ≤100V and LET ≤ 43MeV·cm^2/mg) define an unconditional Safe Operating Area (SOA). At LET = 60MeV·cm^2/mg, there appears to be a small tendency toward increasing current regardless of bias voltage. At LET=86MeV·cm^2/mg, there appears to be an I_{DSS} increase that grows with increasing voltage. No current steps greater than 502nA were registered even for these evolving I_{DSS} conditions. These higher conditions can be interpreted as conditional SOA. **Important:** Even in this conditional SOA the fluences needed to cause any significant I_{DSS} increase are more than fifty thousand times than expected in a twenty-year orbit mission of Earth.

No occurrences of catastrophic I_{DSS} increase were registered for any irradiation conditions. Therefore, even at a 100V bias and irradiation with 86MeV·cm^2/mg gold ions, there were no catastrophic failures indicative of SEB for the devices tested. The testing amounted to 1x10^7ions/cm^2 at 86MeV·cm^2/mg distributed over the four parts.

Appendix



eGaN® FET DATASHEET EPC2016C

DIE OUTLINE
Solder Bar View

Side View

DIM	MICROMETERS		
	MIN	Nominal	MAX
A	2076	2106	2136
B	1602	1632	1662
c	1379	1382	1385
d	577	580	583
e	235	250	265
f	195	200	205
g	400	400	400

Pad no. 1 is Gate;
Pads no. 3, 5 are Drain;
Pads no. 4, 6 are Source;
Pad no. 2 is Substrate.*

*Substrate pin should be connected to Source

Figure 4. Dead-Bug View of EPC2016C (from datasheet) and Connection for SEB Testing

5. Revision History

Rev.	Date	Description
1.0	Apr 6, 2021	Initial release

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