ISL70020SEH. ISL73020SEH

Introduction

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 destructive SEE testing performed on the constituent die of the ISL70020SEH GaN transistor. This report also applies to the ISL73020SEH part, which is the same die offered with radiation assurance screening to only 75krad(Si) at 10mrad(Si)/s.

Product Description

The ISL70020SEH is a 40V N-channel enhancement mode GaN power transistor packaged in hermetic Ceramic Leadless Chip Carriers (CLCC). The die packaged into the CLCC by Renesas are manufactured by EPC (Efficient Power Conversion Company). The EPC parts are bare die solder bumped to be flip-chip mounted. The die used by Renesas in the CLCC, the EPC2924, have high temperature solder bumps to allow soldering of the CLCC without de-mounting the die already mounted inside the package. The commercial equivalent of EPC product is the EPC2024 (40V, 90A).

Related Literature

For a full list of related documents, visit our website:

- ISL70020SEH, ISL73020SEH device page

1. Single Event Effects Test

1.1 Objective

The testing described here was intended to characterize the constituent die of the ISL70020SEH transistor 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 was intended to provide a safe operating area (for both V_{DSS} and irradiation Linear Energy Transfer (LET) for SEB) and to quantify the rate of the gradual increase of I_{DSS} with fluence, V_{DSS}, and LET.

1.2 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 December 5, 2018.

Table 1. Ion Species and Approximate Parameters Used in Testing the EPC2024[1]

Species	Initial Total Energy (GeV)	Surface LET in Si after window and air path (MeV·cm²/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.

1.3 Setup and Method

To make the ISL70020SEH's device side 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 provides diagrams 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 allowed the current (I_{DSS}) to be monitored on each DUT. One set of four DUTs was used for each combination of irradiation species (4), and test voltage (3) resulting in twelve separate irradiation runs.

Before and after each irradiation the current was logged for irradiation V_{DSS} biasing without the ion beam. The I_{DSS} current was also measured for the absolute maximum voltage ratings (40V) 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 EPC2024 took values of 24V, 32V, and 40V. In the case of irradiation with

V_{DSS} = 40V, 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 EPC2024

Flux (ion/(cm^2-s))	Fluence (ion/cm^2)	V_{DSS} (V)	Time (s)
0	0	40	30
0	0	24	30
1.0E+04	2.50E+06	24	250
0	0	24	30
0	0	40	30

1.4 Pre-Irradiation Characterization

Prior to irradiation each part had its I_{DSS} measured at 40V V_{DSS} for approximately 30 seconds at a sampling time of about 0.78 seconds. The measurements produced for each part were then used to characterize the parts' I_{DSS} as represented in Figure 1. 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 5.51µA between extremes of 1.45µA and 12.54µA and an overall standard deviation of 2.50µA.

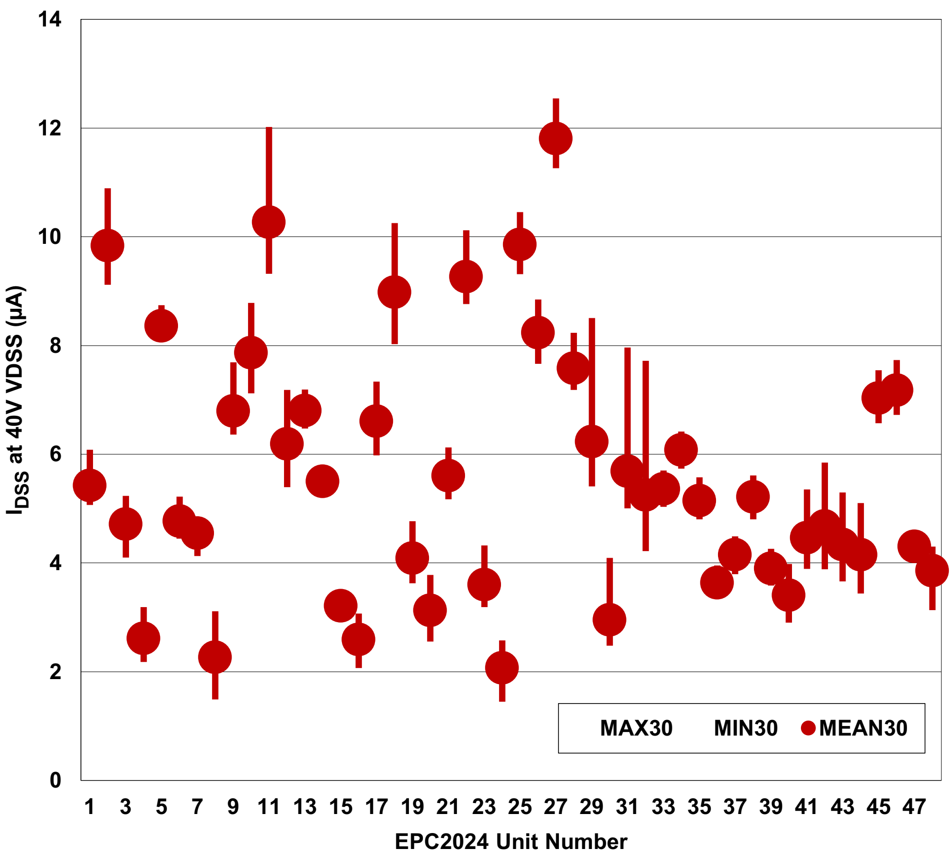


Figure 1. Initial I_{DSS} at 40V Characterization Data on the EPC2024 Devices Taken Before Irradiation Testing

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 standard deviation for all the measurement changes was 82nA. The minimum and maximum changes were -502nA and 310nA, respectively. This sets the bounds on the normal variation in the I_{DSS} measurements.

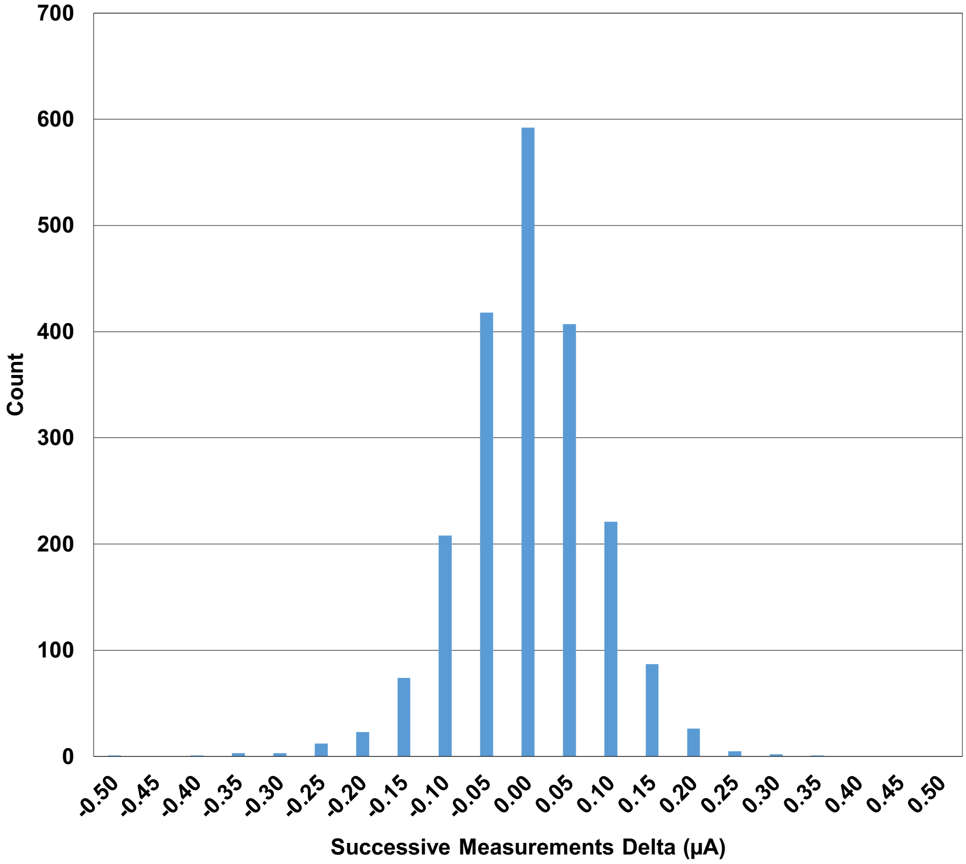


Figure 2. 30-Second Sequential Changes in I_{DSS} Measurements at 40V for the Pre-Irradiation Characterization of the Part Set Going to SEB Testing

2. Results

The I_{DSS} for each EPC2024 part was logged for 30s at 40V and for 30s at the irradiation V_{DSS} (24V or 32V) 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 for 30s at 40V.

The I_{DSS} data collected during the irradiation was used to calculate the step changes in I_{DSS} between measurements. The minimum, maximum, and average steps were found for each grouping of four units irradiated together. This I_{DSS} step data by irradiation condition appears in Table 3. Only one irradiation treatment yielded a positive step in excess of 1µA at 1.44µA. The irradiation yielding this result was V_{DSS} = 40V at LET = 86MeV·cm^2/mg(Si). Although these events are statistically significant, they represent small perturbations in the blocking current. Note, the irradiation condition also provided the largest negative step in I_{DSS} at -0.81. The adjacent irradiation of 32V at 86MeV·cm^2/mg(Si) had the second highest maximum step at 0.63µA.

Table 3. EPC2024 IDSS Step Statistics During Irradiation by Irradiation Treatment

EPC2024 I_{DSS} Irradiation Step Statistics in µA[1]				
LET in Si ($MeV \cdot cm^2/mg$)	Step	V_{DSS} During Irradiation		
		24V	32V	40V
28	Mean	0.0013	-0.0013	-0.0045
	Min	-0.34	-0.36	-0.31
	Max	0.31	0.26	0.53
43	Mean	0.0003	0.0011	0.0003
	Min	-0.43	-0.38	-0.39
	Max	0.34	0.33	0.30
60	Mean	0.0028	0.0010	0.0021
	Min	-0.26	-0.25	-0.42
	Max	0.37	0.31	0.48
86	Mean	0.0023	0.0302	0.0476
	Min	-0.36	-0.50	-0.81
	Max	0.35	0.63	1.44

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 EPC2024 parts did exhibit a gradual growth of I_{DSS}, measured at V_{DSS} = 40V for irradiation conditions with LET at $86MeV \cdot cm^2/mg(Si)$ and $60MeV \cdot cm^2/mg(Si)$. The minimum I_{DSS} measured at 40V 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 $28MeV \cdot cm^2/mg(Si)$ is greater than one hundred thousand years. Therefore, the current increases given in Table 4 really have no practical application in normal usage as the fluence encountered in a mission is much too small to yield meaningful increases.

Table 4. EPC2024 Change in I_{DSS} (µA) at V_{DSS} = 40V per Irradiation with $1x10^6 ion/cm^2$ by DUT

	Change in I_{DSS} in µA at V_{DSS} = 40V per Irradiation to $1x10^6 ion/cm^2$ [1]											
	V_{DSS} = 24				V_{DSS} = 32				V_{DSS} = 40			
LET	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4	DUT1	DUT2	DUT3	DUT4
28	**-0.30**	**-0.26**	**-0.28**	0.11	**-0.61**	**-0.76**	**-0.96**	**-0.73**	**-0.34**	**-0.82**	**-0.49**	**-0.59**
43	**-0.46**	**-0.80**	**-0.36**	**-0.40**	**-0.45**	**-0.49**	**-0.24**	0.04	**-0.12**	**-0.06**	**-0.10**	0.11
60	**-0.21**	0.29	**-0.39**	**-0.38**	**-0.14**	**-0.23**	**0.03**	**-0.06**	0.10	0.04	**-0.72**	0.40
86	**-0.13**	**-0.30**	**-0.08**	**-0.09**	4.76	5.36	2.32	1.92	5.48	8.97	1.97	5.97

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

With the exception of the three higher stresses ($86MeV \cdot cm^2/mg(Si)$ at 32V and 40V, and $60MeV \cdot cm^2/mg(Si)$ at 40V) the changes in I_{DSS} show a negative trend. The three higher stresses do show a positive change trend. The I_{DSS} evolution for the highest stress case is presented in Figure 3 (*Note:* Changes in test conditions are marked by spikes in data to 30µA). Clearly the irradiation caused a gradual rise in I_{DSS} composed of many small increments. The largest positive step in I_{DSS} (1.44µA) occurred in DUT2 which performed somewhat worse than the other three DUTs. A three sigma bound on the increase is 14.2µA over 1×10^6ions/cm^2 at 86MeV·cm^2/mg(Si) and a bias of 40V. The three sigma bound on the case of a 32V bias at 86MeV·cm^2/mg(Si) to 1×10^6ion/cm^2 is 8.8µA. At the 40V bias at 60MeV·cm^2/mg(Si) the three sigma bound on the increase drops to 1.4µA.

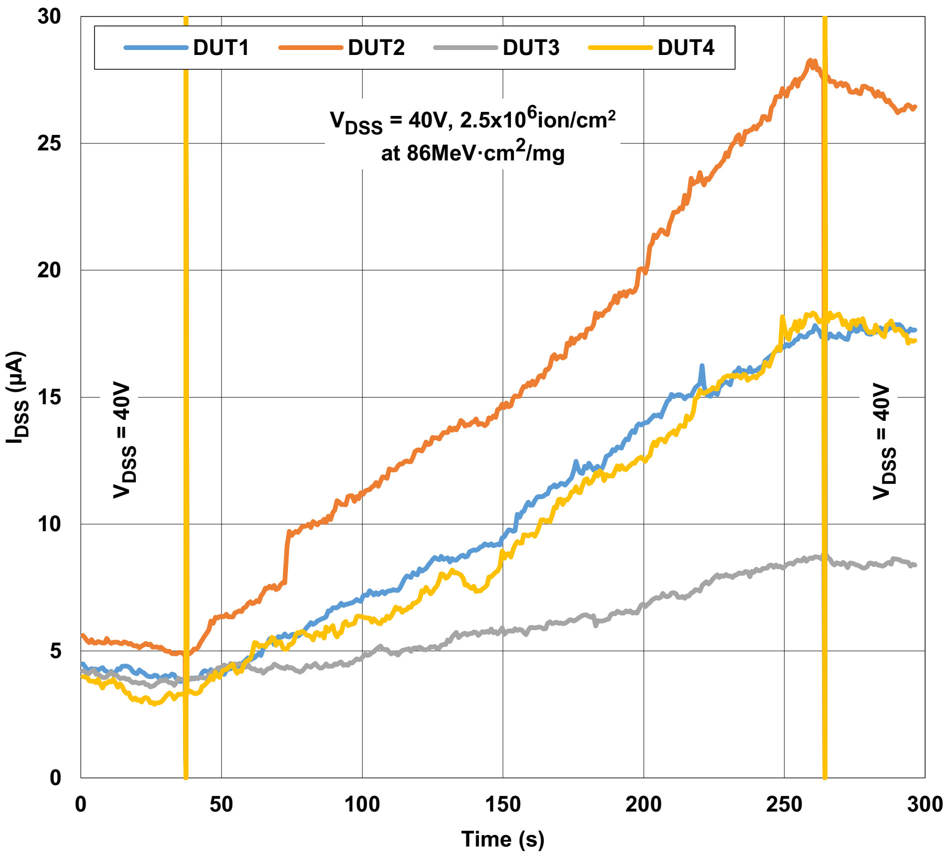


Figure 3. I_{DSS} Behavior for the EPC2024 40V GaN FET at V_{DSS} = 40V and LET = 86MeV·cm^2/mg(Si) to 2.5×10^6ion/cm^2

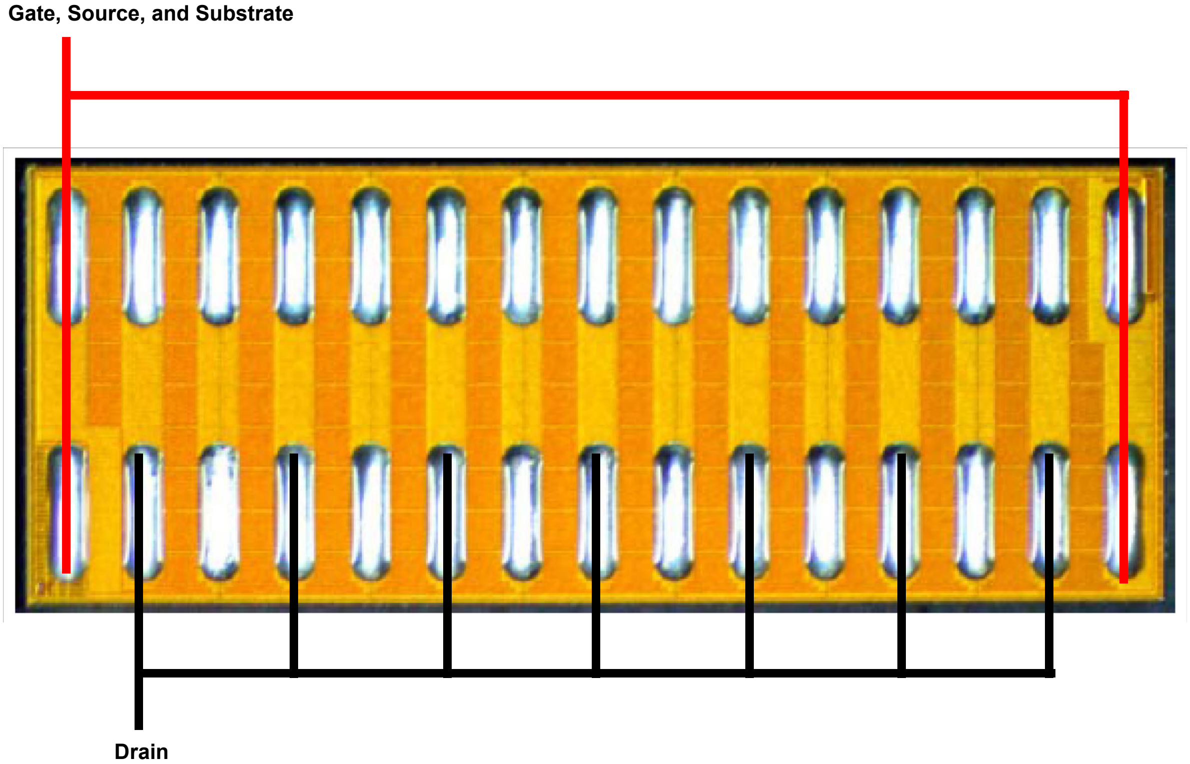
3. Discussion and Conclusions

The ISL70020SEH (EPC2024) devices exhibited two forms of I_{DSS} behavior over the range of twelve irradiation conditions tested (V_{DSS} = 24V, 32V, and 40V with LET = 28, 43, 60, and 86MeV·cm^2/mg(Si) at 25°C). For the two lower LET, no apparent changes in I_{DSS} during irradiation at V_{DSS} = 40V were found. The conclusion is that these irradiation conditions (V_{DSS} ≤40V and LET ≤ 43MeV·cm^2/mg(Si)) define an unconditional Safe Operating Area (SOA). At LET = 60MeV·cm^2/mg(Si), the two lower voltages (24V and 32V) did not show any apparent increase in I_{DSS} at 40V. However, at a 40V bias and LET = 60MeV·cm^2/mg(Si), there did appear to be some gradual I_{DSS} increase during the irradiation. At LET=86MeV·cm^2/mg(Si) the lowest voltages (24V) did not show any apparent increase in I_{DSS} when measured at 40V; however, at 32V and 40V biases at this LET, there appeared to be significant I_{DSS} increase. No current steps greater than 1.44µA were registered even for these evolving I_{DSS} conditions. These higher conditions can be interpreted as conditional SOA. It is important to note that even in this conditional SOA the fluences needed to cause any significant I_{DSS} increase are more than fifty thousand times that expected in a twenty year earth's orbit mission.

No occurrences of catastrophic I_{DSS} increase were registered for any irradiation conditions. Therefore, even at a 40V bias and irradiation with 86MeV·cm^2/mg(Si) gold ions, there were no catastrophic failures indicative of SEB for the devices tested. The testing amounted to 1×10^7ions/cm^2 at 86MeV·cm^2/mg(Si) distributed over four parts.

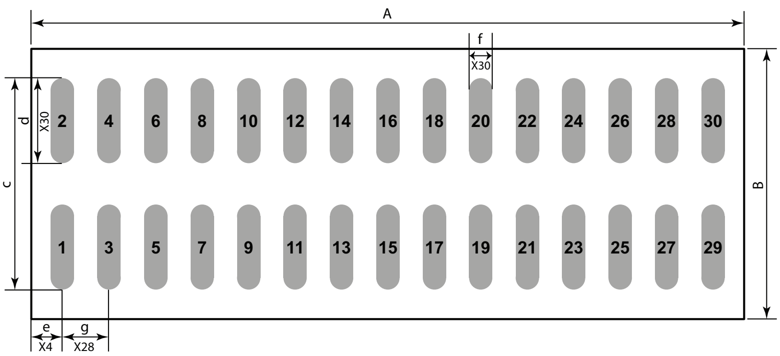
4. Appendix A

Dead-Bug View of EPC2924 (from EPC2024 datasheet) and Connection 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 no. 1 is Gate
Pads 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, 29 are Source
Pads 3, 4, 7, 8, 11, 12, 15, 16, 19, 20, 23, 24, 27, 28 are Drain
Pad 30 is Substrate

5. Revision History

Rev.	Date	Description
1.02	Mar 28, 2024	Clarified that LETs were calculated using a silicon target substrate.
1.01	Nov 28, 2022	Applied new template. Added ISL73020SEH information.
1.00	May 14, 2019	Initial release

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