National Aeronautics and Space Administration

Single-event Effect Report for EPC Series eGaN FETs: The effect of load conditions on destructive SEE

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1.0 EXECUTIVE SUMMARY

Recent testing of Enhanced Power Conversion (EPC) Efficient Power Conversion Corporation (eGaN) FET devices design for power use has shown that the devices are susceptible to single-event effects (SEE) that degrade or destroy the device. The exact mechanism of the SEE is not known. The testing so far has been in the static condition, in the fully off condition, and with minimal load conditions. These conditions may not be worst case. This report presents the results of a study that tests some of the load conditions for SEE. The EPC2012 and EPC1012 were chosen for the test. The tests were performed at the Texas A&M University (TAMU) radiation effects facility in May and June of 2013. The effect of increased capacitive load results in lowered V_{see} (the V_{ds} voltage at which SEE occurs) and increased the magnitude of SEE in the devices such that the device suffers catastrophic failure at lower voltage and less fluences. The load capacitance appears to supply enough current in the local circuit that transients induced by the heavy ions allow for more current to flow through the test device that increase the chance for damage.

2.0 PURPOSE

The purpose of this testing was to characterize the effect of load conditions on eGaN FETs from EPC for radiation effects from heavy ions. The primary interest in these devices is for use in high-efficiency buck converters, which will have varying load, and the effect of the load condition on SEE is a critical parameter to the deployment of this device in NASA missions. Figure 2.0-1 shows the typical test circuit in MIL-STD-750 Method 1080 for measuring SEE. The capacitor in parallel with the drain and source connection is called the load capacitor. This study applied various load capacitor values as SEE was tested.

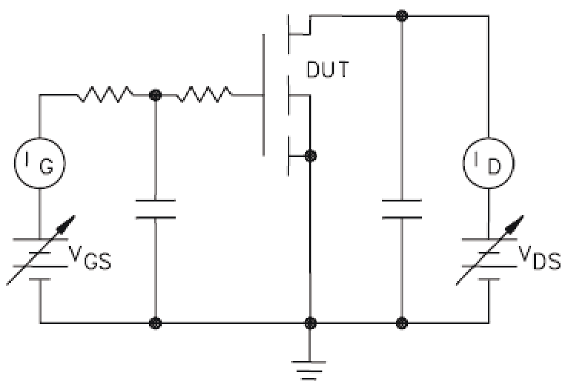

FIGURE 1080–1. Basic SEB/SEGR test circuit.

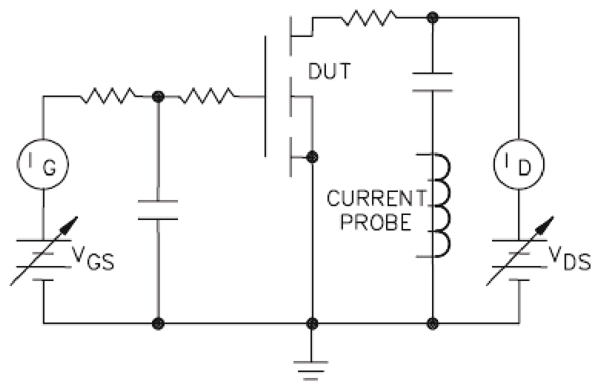

FIGURE 1080–2. SEB circumvention and monitoring circuit.

Figure 2.0-1. The test setup used in this study was identical to the Method 1080 circuit.

3.0 TEST SAMPLES

The DUT listed in Table 3.0-1 were acquired commercially and stored under flight ESD conditions per D-57732. The EPC1012 and EPC2012 devices were selected for testing since they are the smallest die, which minimized the area for damage investigations, and the largest voltage rating, which maximized the sensitivity to SEE.

Table 3.0-1. List of devices that were tested.

Manufacturer	Part Number	VDS rating (max) [V]	Channel	LDC	Package
EPC	EPC1012	200	N	NA	Custom
EPC	EPC2012	200	N	NA	Custom

4.0 PROCEDURE/SETUP

The general test procedure adhered to “The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [JPL Publication 08-10 2/08]. Parts were serialized (if not already done), with controls marked prominently to distinguish them from test samples. Exposures were performed at ambient laboratory temperature. Since the packages from EPC were atypical, the DUTS had to be remounted in a dead-bug configuration for ion testing and testing with the ATE. Devices were verified to be functional after mounting on the test carrier, see Figure 4.0-1. The equipment used in this effort is listed in Table 4.0-1.

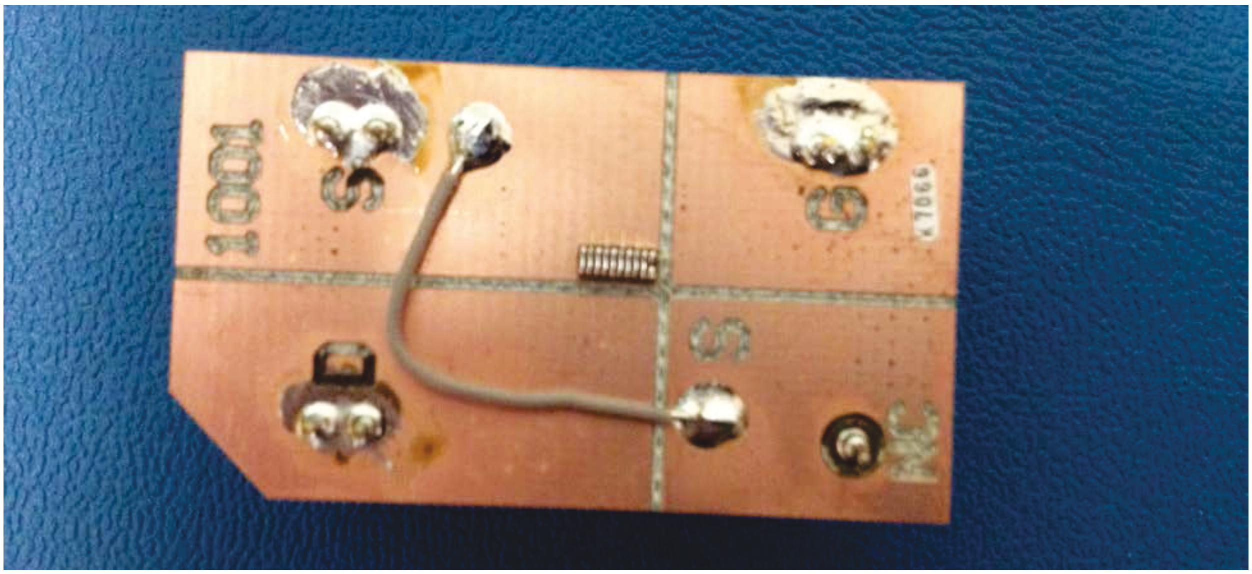

Figure 4.0-1. Dose testing carrier.

Table 4.0-1. Equipment used in this effort.

Unit	Function	Make	Calibration	JPL SN
HP4156	Parametric ATE	Agilent	20091219	TDB
HP4142	SEE ATE	Agilent	20111013	887633
B1500	SEE ATE	Agilent	20111013	TBD
Laptop	SEE control PC	Toshiba	NA	2220673

4.1 Electrical Tests

Electrical tests were performed in accordance with “The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [JPL Publication 08-10 2/08]. All devices were verified to work by testing with a HP4156/B1500. The transfer and characteristic curves of each device were acquired to a maximum current of 10 mA on any terminal of the device.

4.2 Failure Criteria

Failure criteria were classified in accordance with “The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [PL Publication 08-10 2/08]. However, any change in device parameters was noted for this exploratory effort.

4.3 Setup

Failure criteria were classified in accordance with “The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [PL Publication 08-10 2/08]. Figure 4.3.1 shows the setup used in this experiment. An HP4142/B1500 forced the voltage and read a current with three independent SMUs. The background current on the board with no DUT was recorded to be ~0.5 nA in each device location.

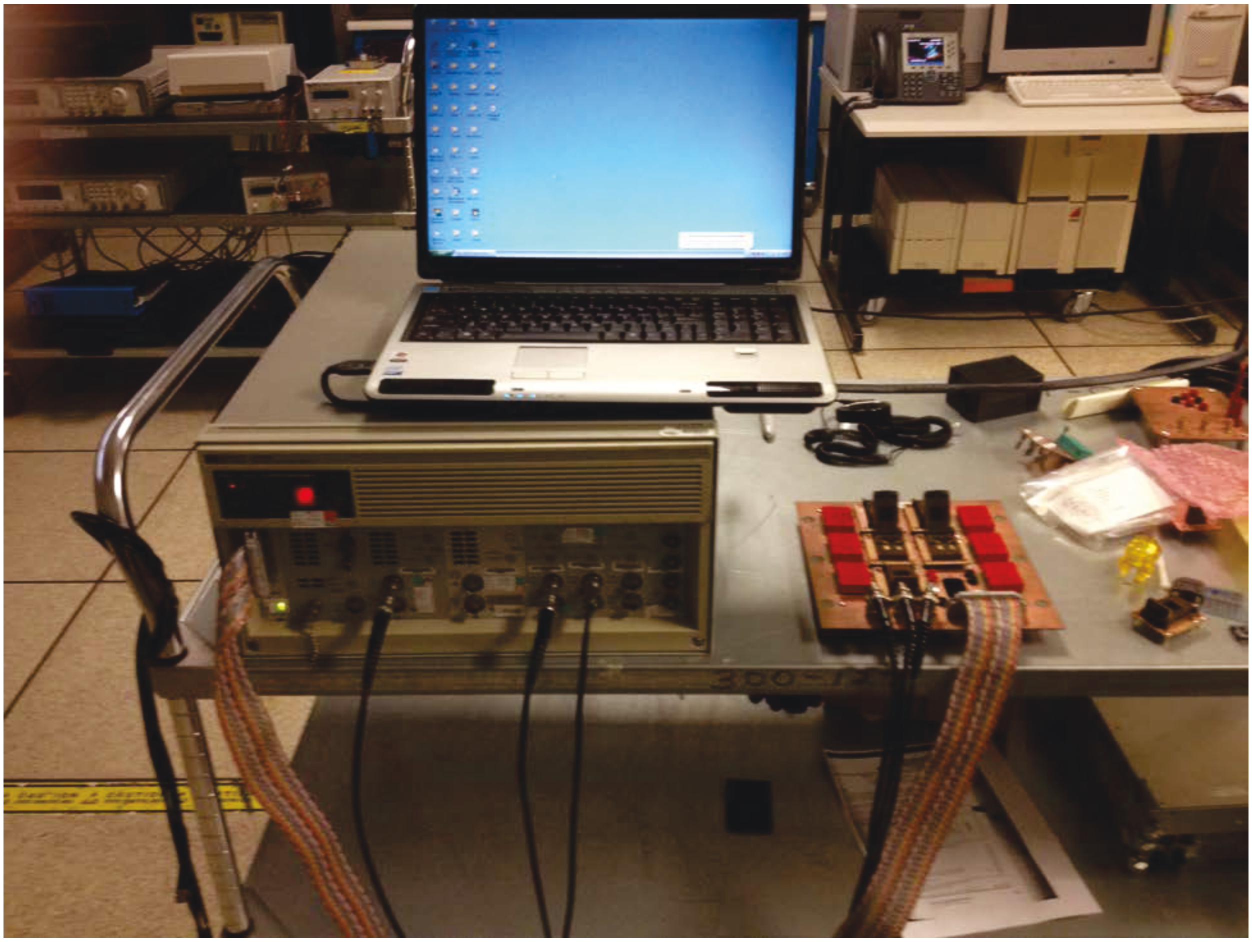

Figure 4.3-1. Setup used for SEE testing. The entire system is transported to a heavy ion site. A B1500 is electrical similar and has replaced the HP4142 on testing since June 2013.

5.0 SOURCE REQUIREMENTS

The ion source was the TAMU cyclotron. The ions must be able to penetrate at 100 μm past the surface of the device to assure a space-like SEE response.

6.0 BIAS CONDITION/FIXTURES

Bias condition during the biased irradiations were in accordance with “The Test Guideline for Single Event Gate Rupture (SEGR) of Power MOSFETs” [PL Publication 08-10 2/08]. Unbiased parts were exposed in a manner that protects them against ESD.

7.0 RESULTS

7.1 Gross SEE response to Cl

The first battery of tests was designed to observe the gross response of SEE with various load capacitors on the DUT. The test device was the EPC2012. Figures 7.1-1 and 7.1-2 show the SEE test strip chart for a capacitive load (Cl) of 0 μF. Figures 7.1-3 and 7.1-4 show the SEE test strip chart for a Cl of 10 μF. Figures 7.1-5 and 7.1-6 show the SEE test strip chart for a Cl of 100 μF. All the tests were done with V_{gs} = 0 V and V_{ds} = 200 V to enhance the SEE effect. The device tends to fails by burning out and then melting the drain to source boundary as seen in Figures 7.1-1, 7.1-3, 7.1-5, and 7.1-6. The higher Cl may induce more damage, however a 0.2 W drop in the device cause severe melting of the die. Looking at Figure 7.1-4 and Figure 7.1-5, we see higher Cl to large spikes in current and drops in the voltage. These are assumed to be SEE that are assisted by the load capacitor. They have not been seen in any previous DC testing with no Cl.

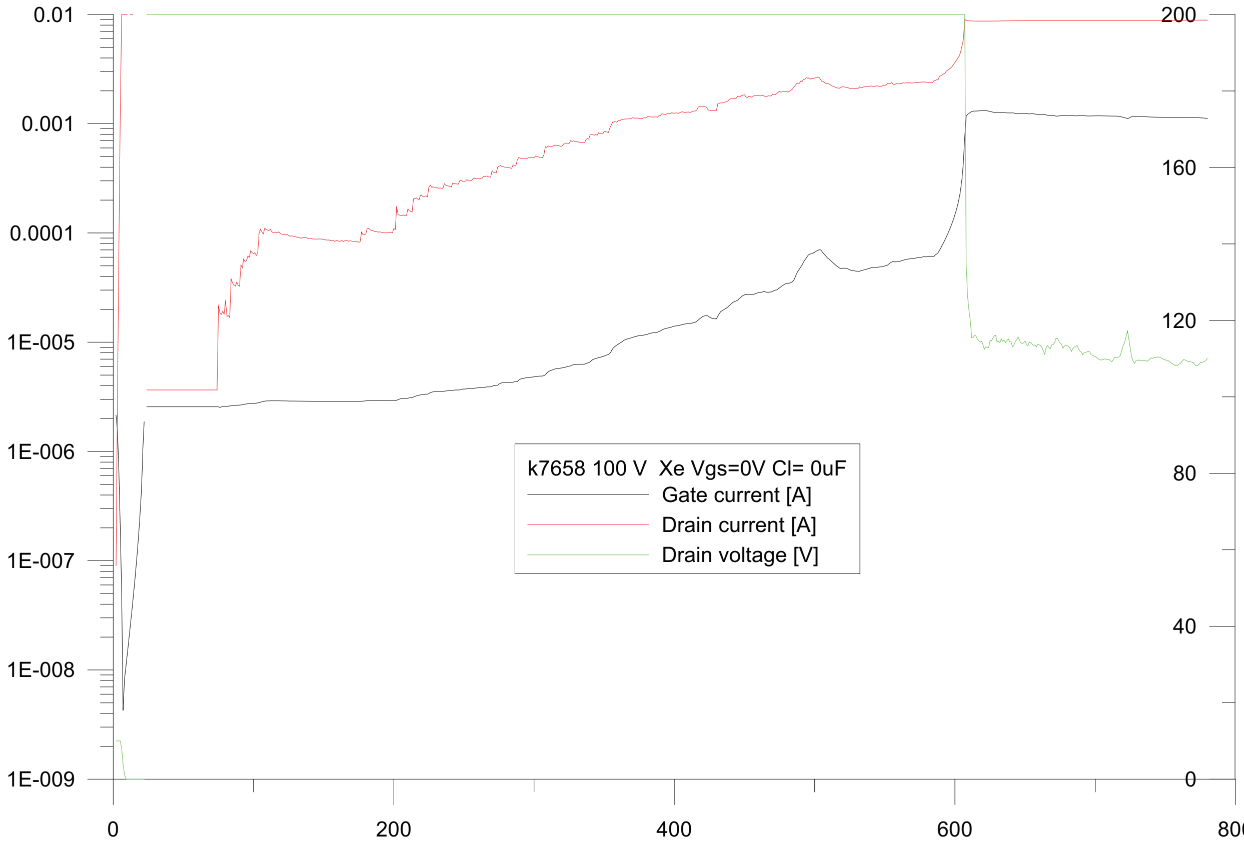

Figure 7.1-1a. Heavy ion response of the EPC2012, K7658. Ion flux was 2E4 cm^{-2}-s^{-1}. The first irradiation was 1E7 cm^{-2}, the rest were for 1E6 cm^{-2}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. Note the failure of the device is the gradual increase drain current that results in melting of the source to drain area.

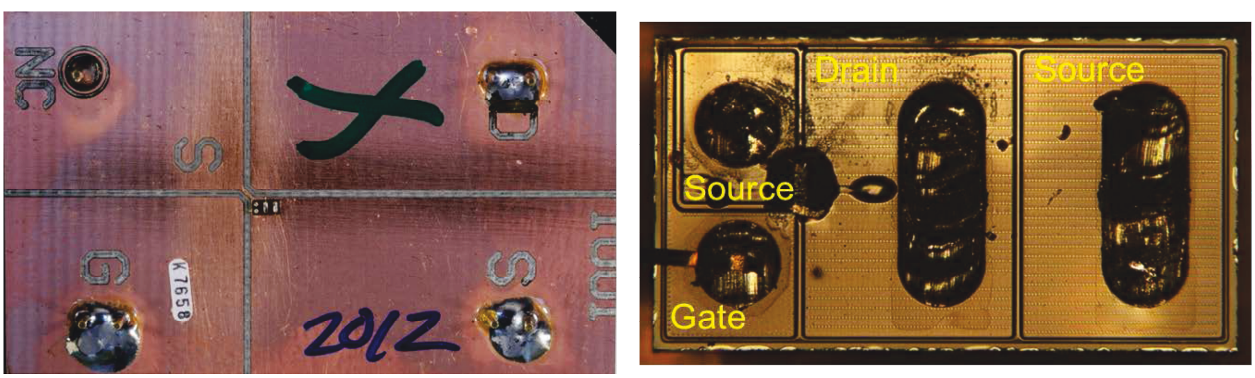

Figure 7.1-1b. Device picture after irradiation.

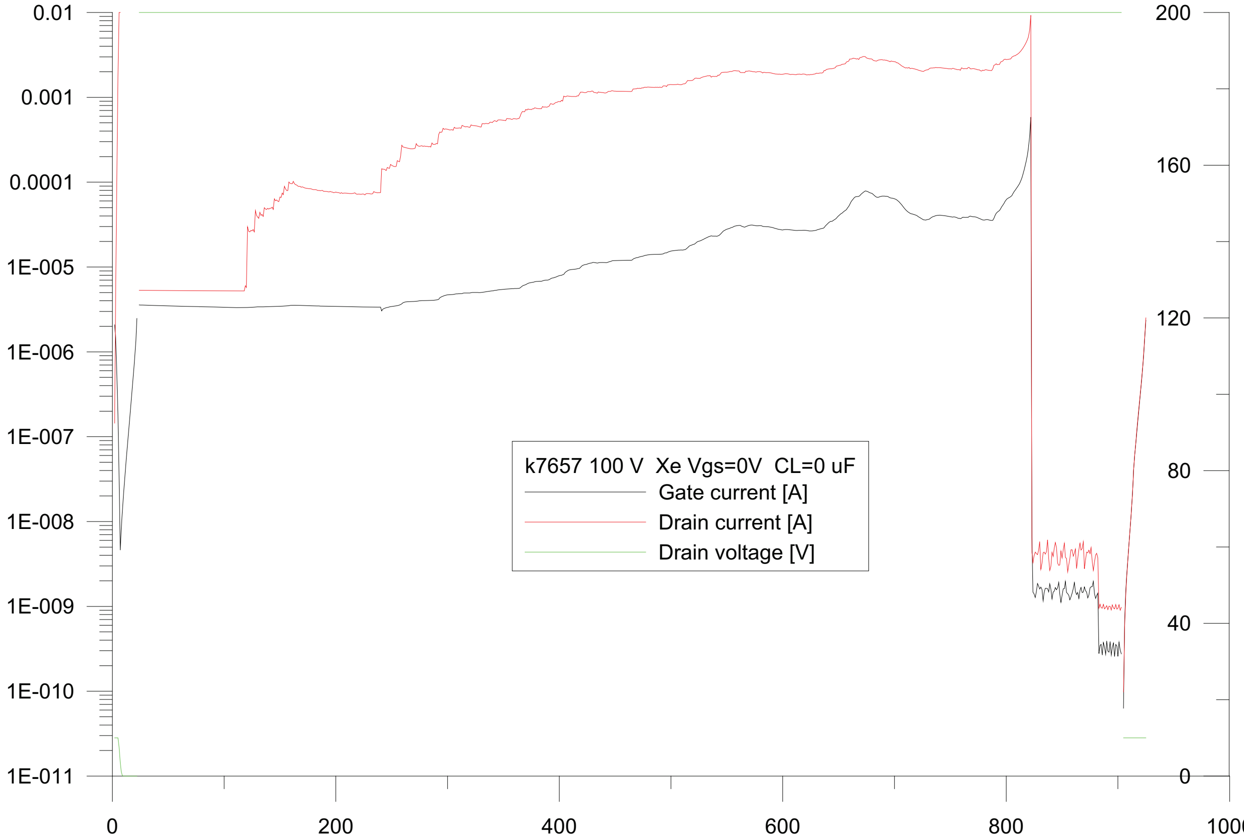

Figure 7.1-2a. Heavy ion response of the EPC2012 200V/3A. Ion flux was 1E5 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. This device also caused failed by increase in drain current. Note the failure of the device is the gradual increase drain current that results in melting of the source to drain area.

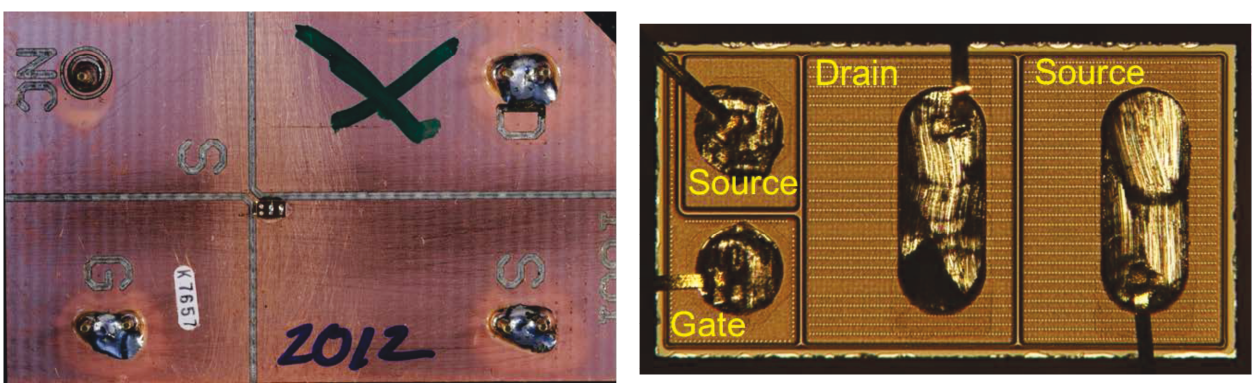

Figure 7.1-2b. Device picture after irradiation.

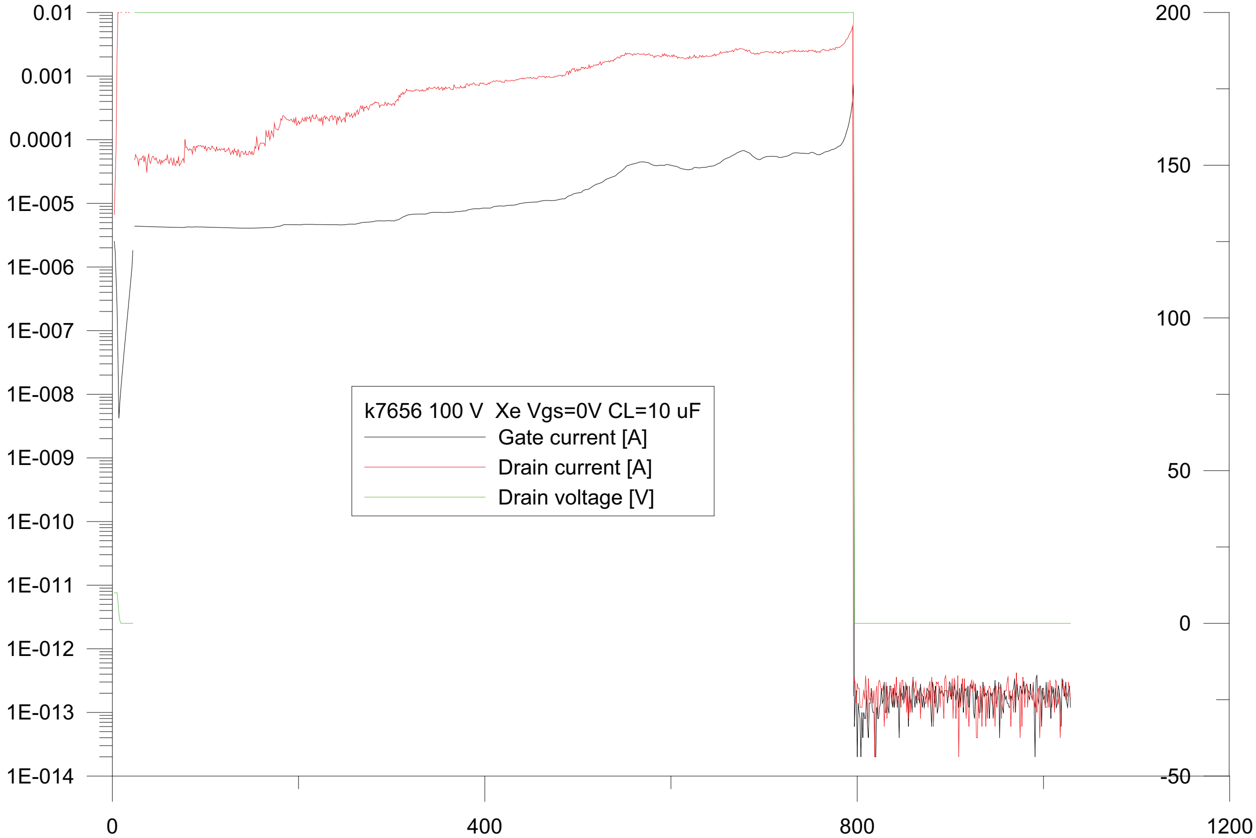

Figure 7.1-3a. Heavy ion response of the EPC2012 200V/3A. Ion flux was 1E5 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. Note the failure of the device is the gradual increase drain current that results in melting of the source to drain area.

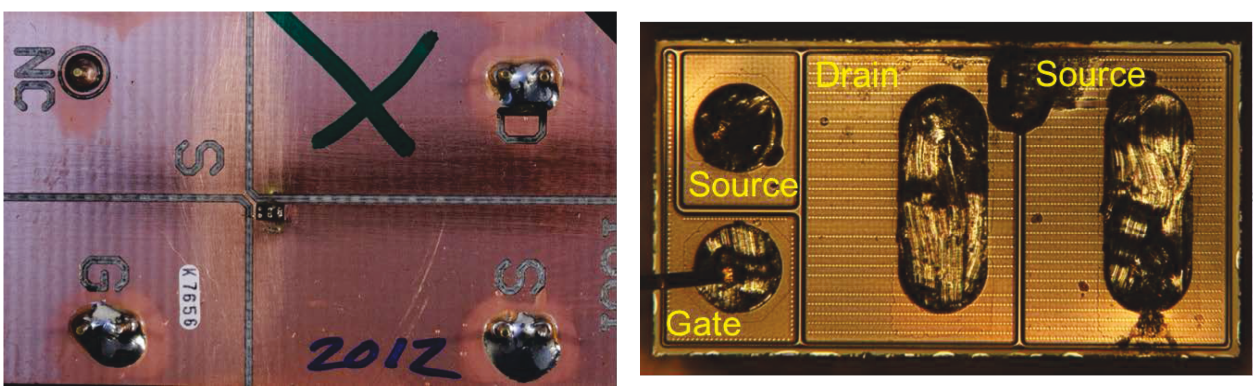

Figure 7.1-3b. Device picture after irradiation.

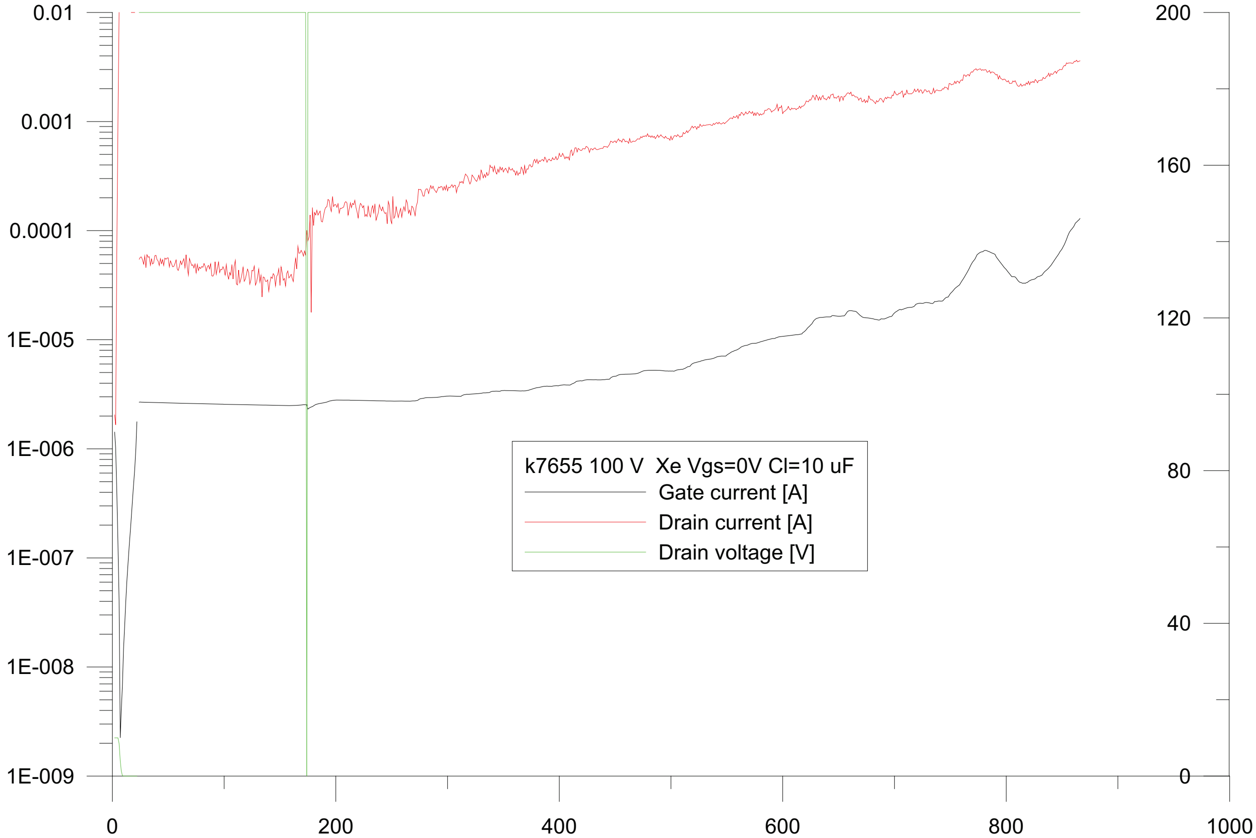

Figure 7.1-4a. Heavy ion response of the EPC2012 200V/3A. Ion flux was 1E5 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. Note the transient voltage dip that indicates a rapid influx of current from the load capacitor.

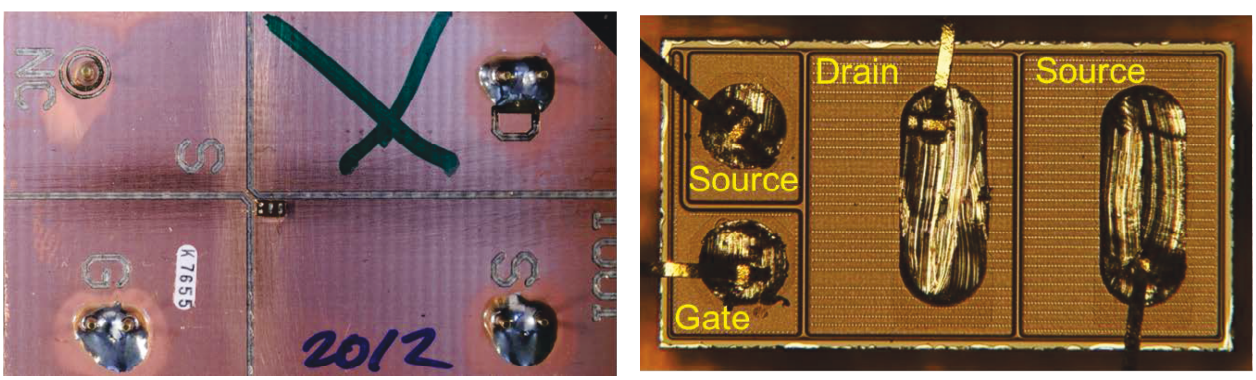

Figure 7.1-4b. Device picture after irradiation.

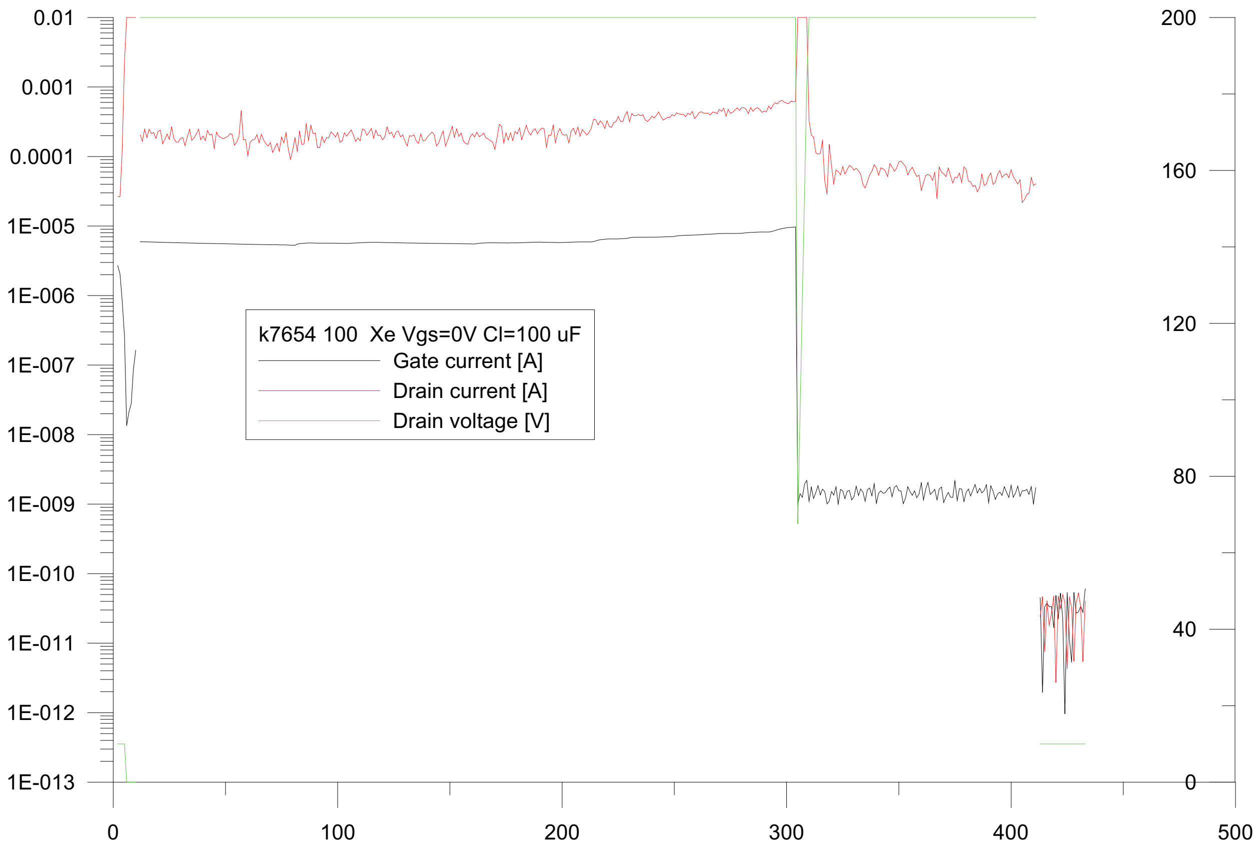

Figure 7.1-5a. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. This device failed catastrophically only due to an SEE induced transient. That is, the device melted at the source to drain boundary without a gradual increase in drain current.

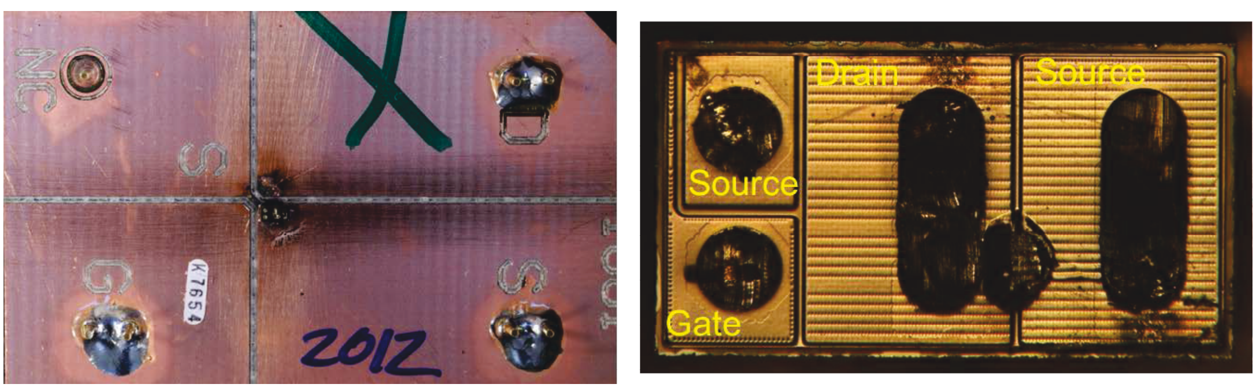

Figure 7.1-5b. Device picture after irradiation.

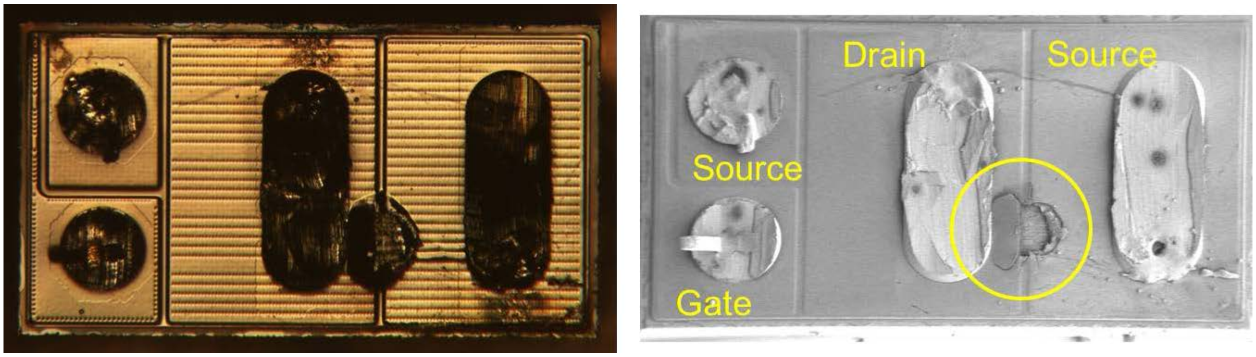

Figure 7.1-5c. Device picture after irradiation.

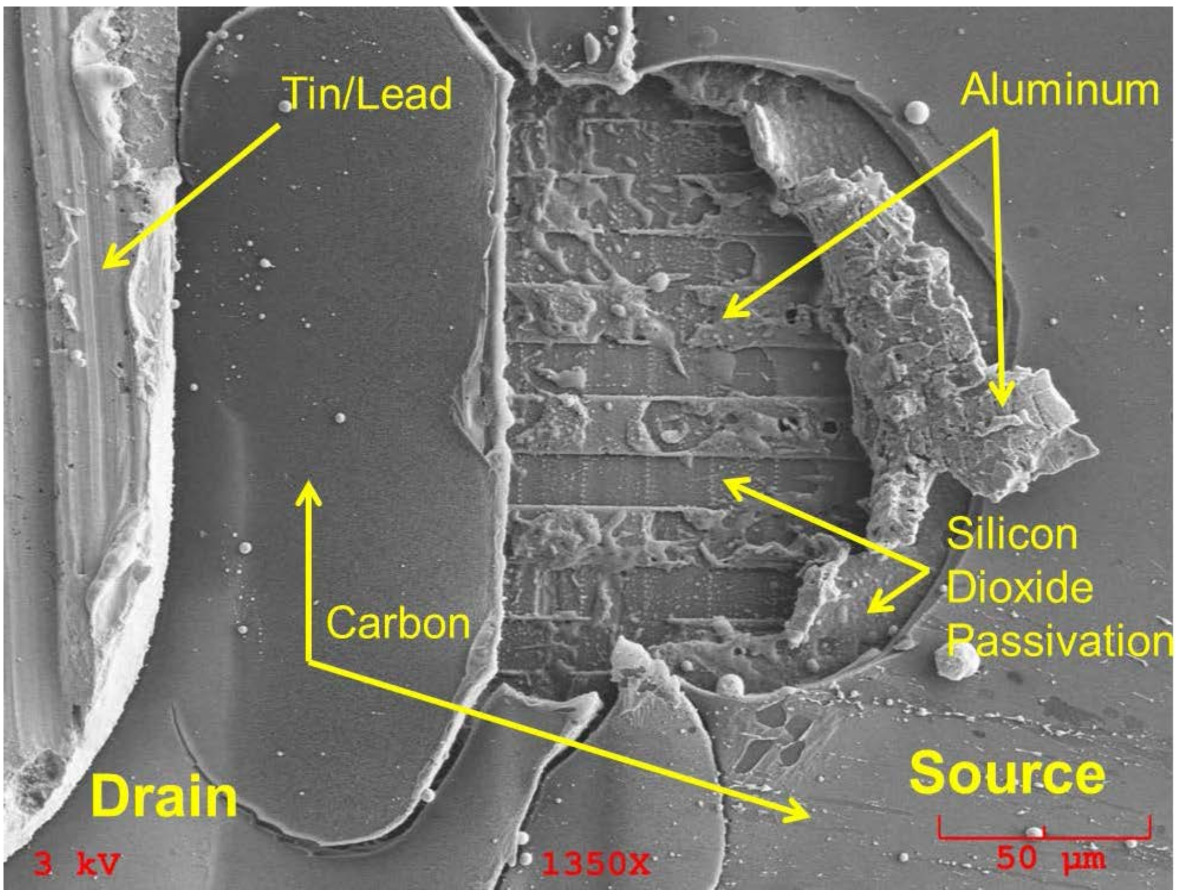

Figure 7.1-5d. Device picture after irradiation.

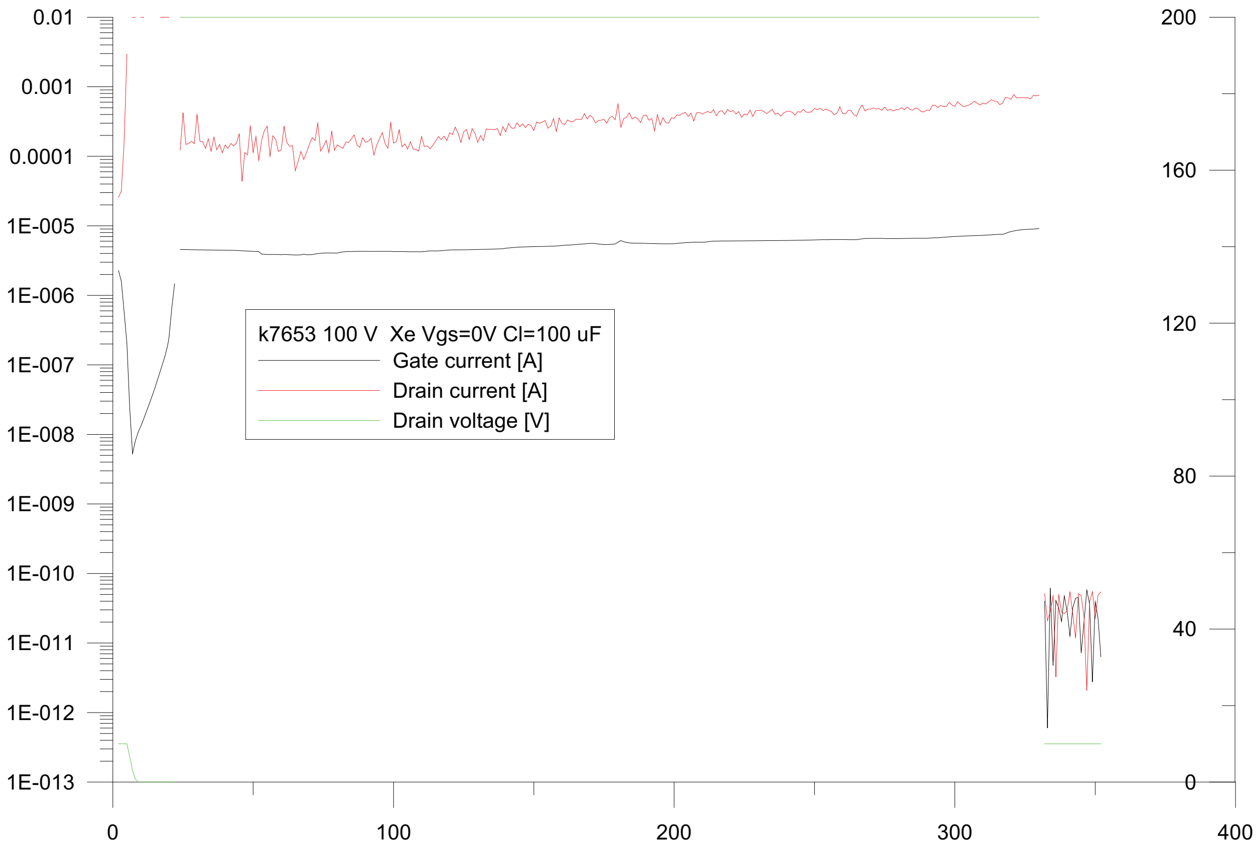

Figure 7.1-6a. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. This device failed catastrophically only due to an SEE induced transient. That is, the device melted at the source to drain boundary without a gradual increase in drain current.

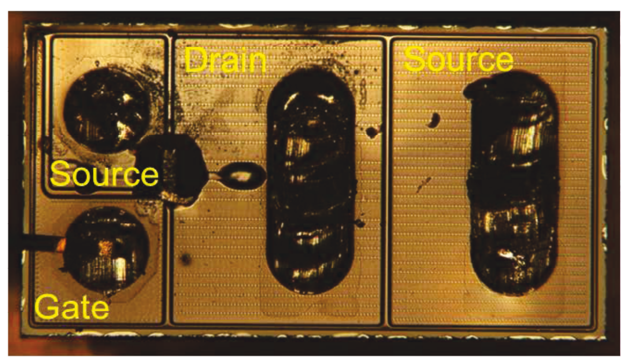

Figure 7.1-6b. Device picture after irradiation.

7.2 VSEE response to Cl

The second battery of tests were designed to observe the gross response of V_{see} (the voltage at which the damage first occurs) as a function of Cl. The gate to source voltage is 0 V for all tests. Figures 7.2-1 and 7.2-2 show the SEE test strip chart for a capacitive load (Cl) of 0 μF. Figure 7.2-3 shows the SEE test strip chart for a Cl of 10 μF. Figures 7.2-4 and 7.2-5 show a typical SEE test strip chart for a Cl of 22 μF. Figure 7.2-6 shows the SEE test strip chart for a Cl of 100 μF. All the tests were done with V_{gs} = 0 V and V_{ds} increased until SEE occurs. The V_{see} decreases with Cl as shown in 7.2-7.

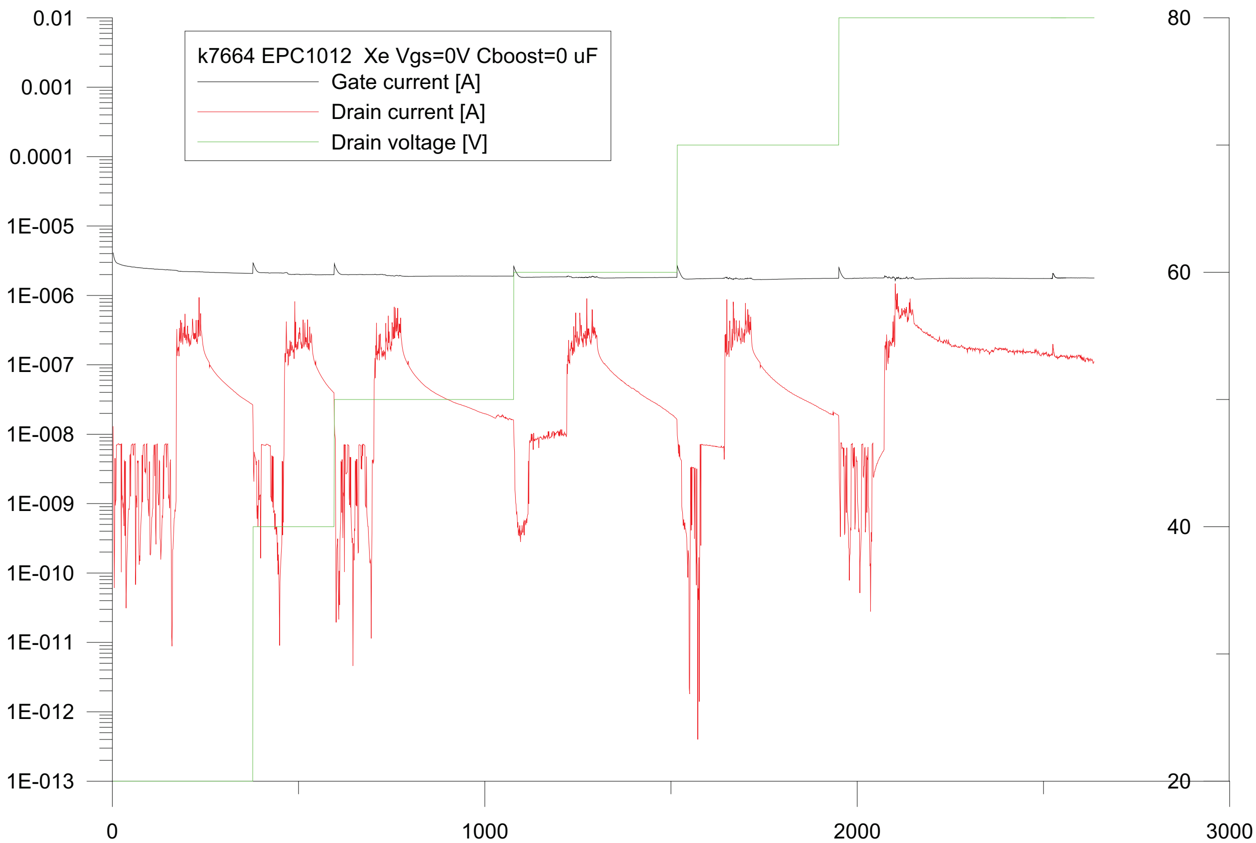

Figure 7.2-1. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 0 μF. The V_{see} was determined to be between 70 and 80 V, and defined as the average of 75 V.

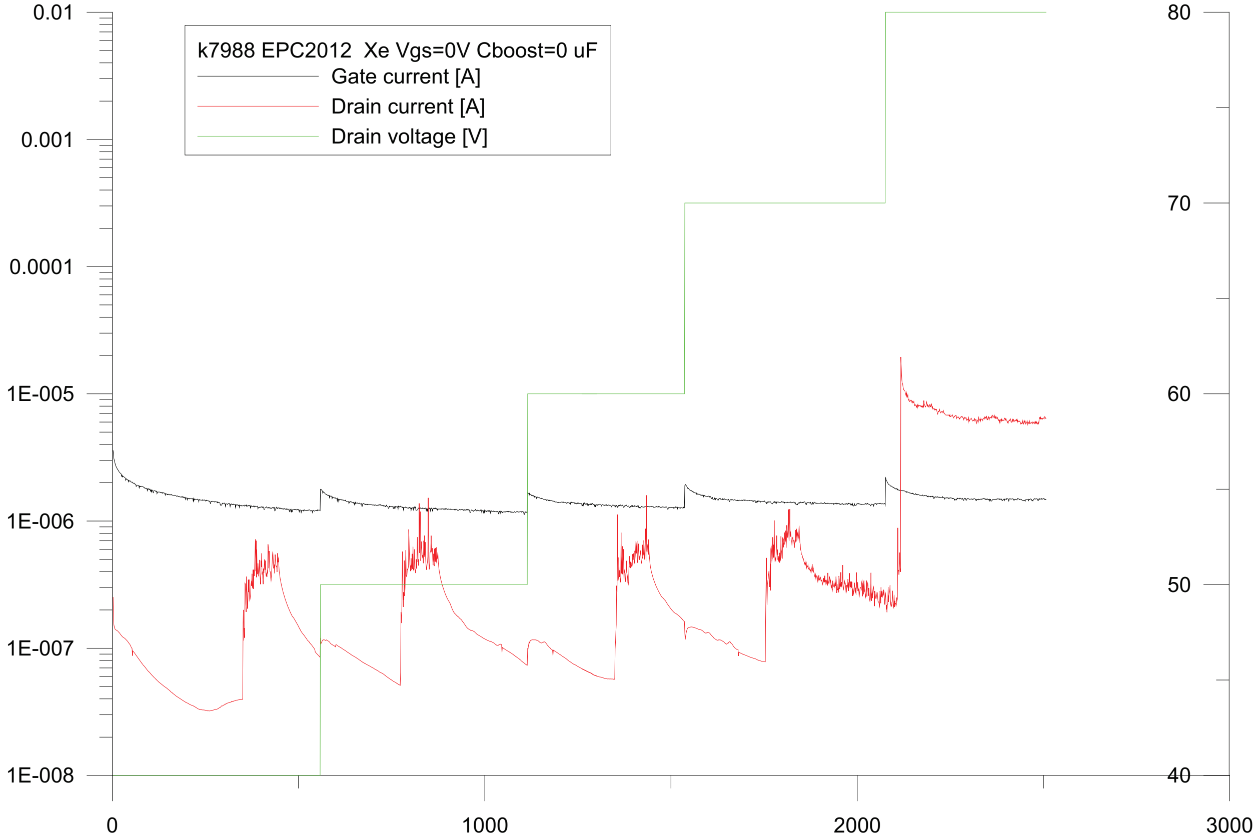

Figure 7.2-2. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 0 μF. The V_{see} was determined to be between 70 and 80 V, and defined as the average of 75 V.

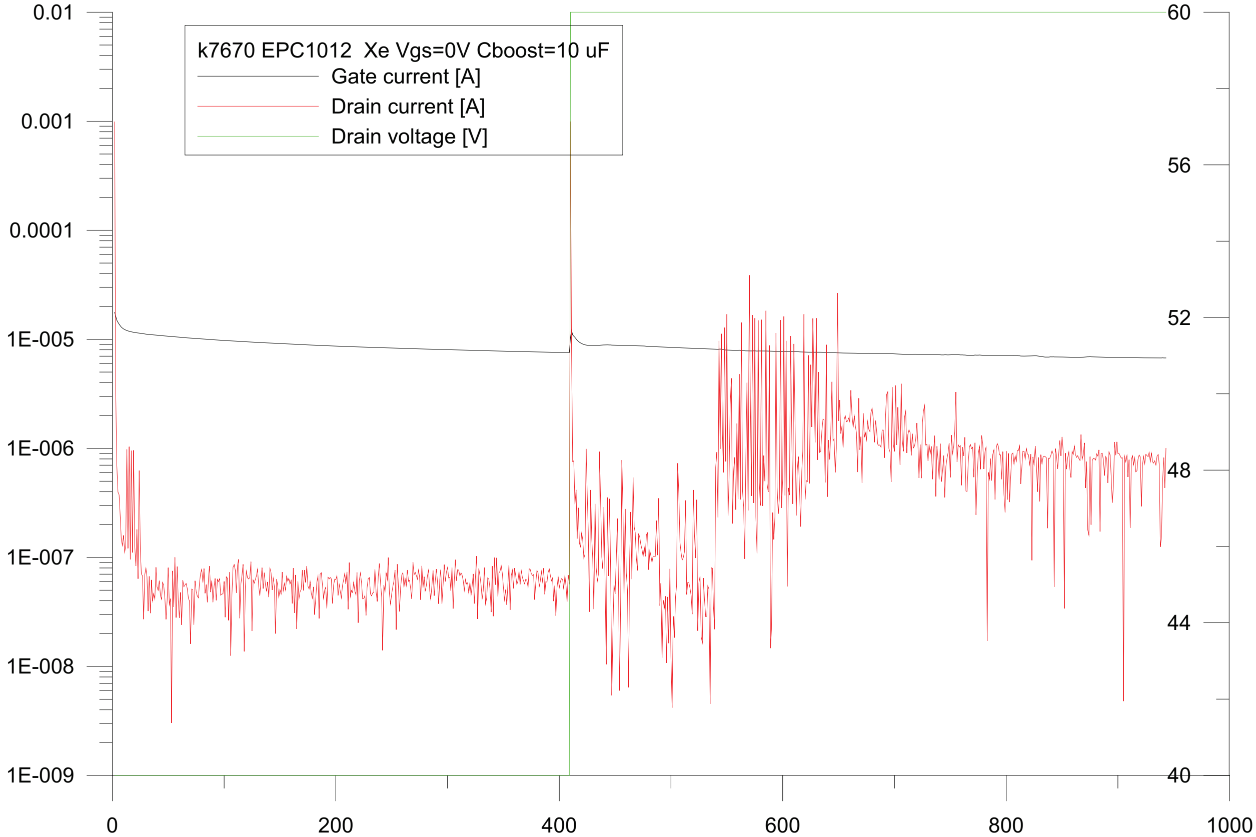

Figure 7.2-3. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 10 μF. The V_{see} was determined to be between 40 and 60 V, and defined as the average of 50 V.

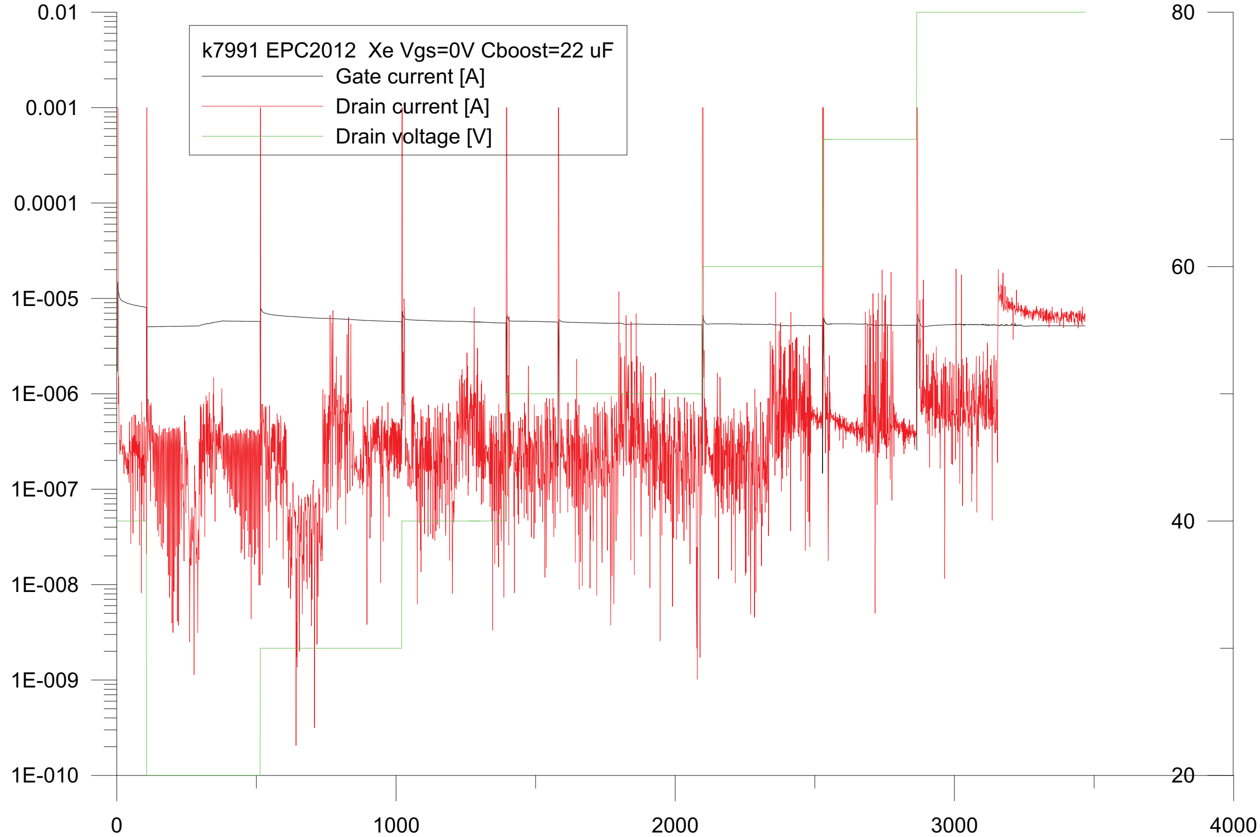

Figure 7.2-4. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 22 μF. The V_{see} was determined to be between 70 and 80 V, and defined as the average of 75 V.

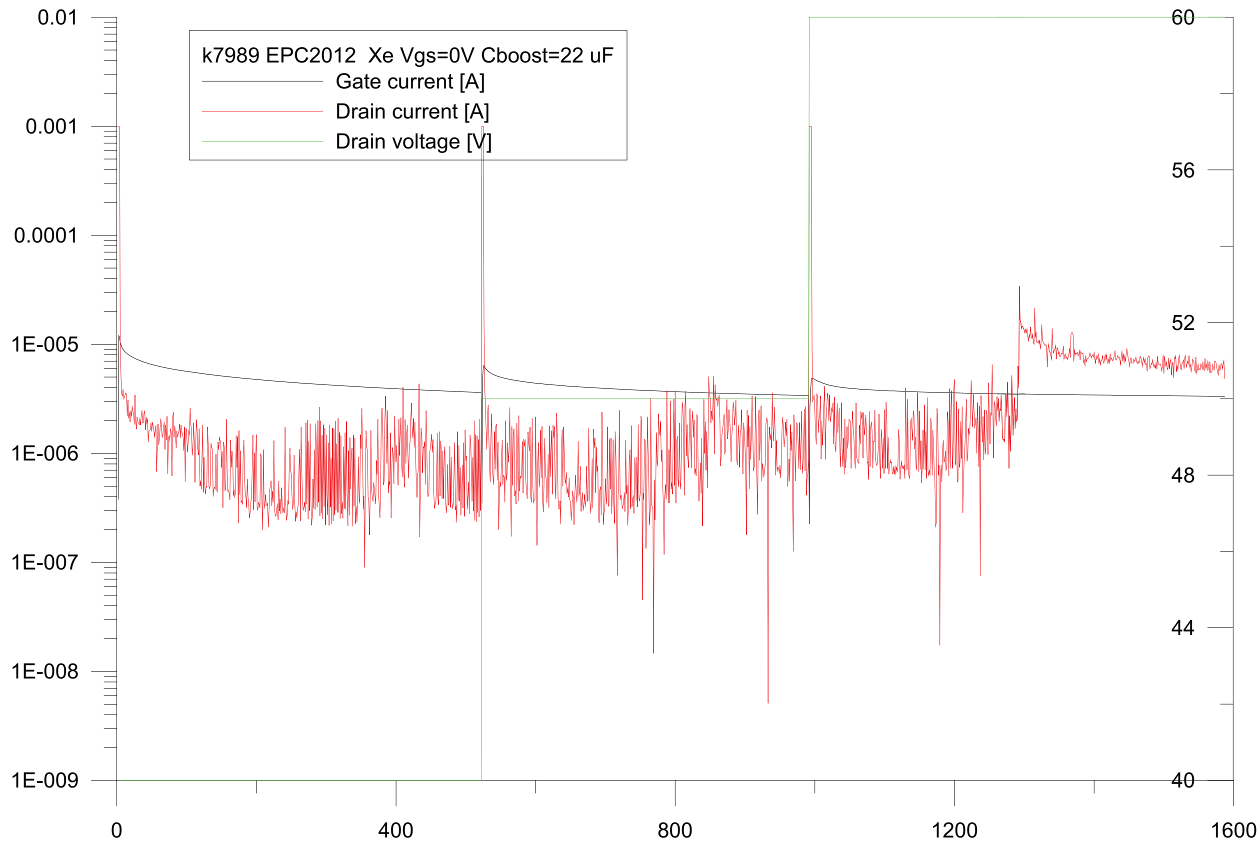

Figure 7.2-5. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 22 μF. The V_{see} was determined to be between 50 and 60 V, and defined as the average of 55 V.

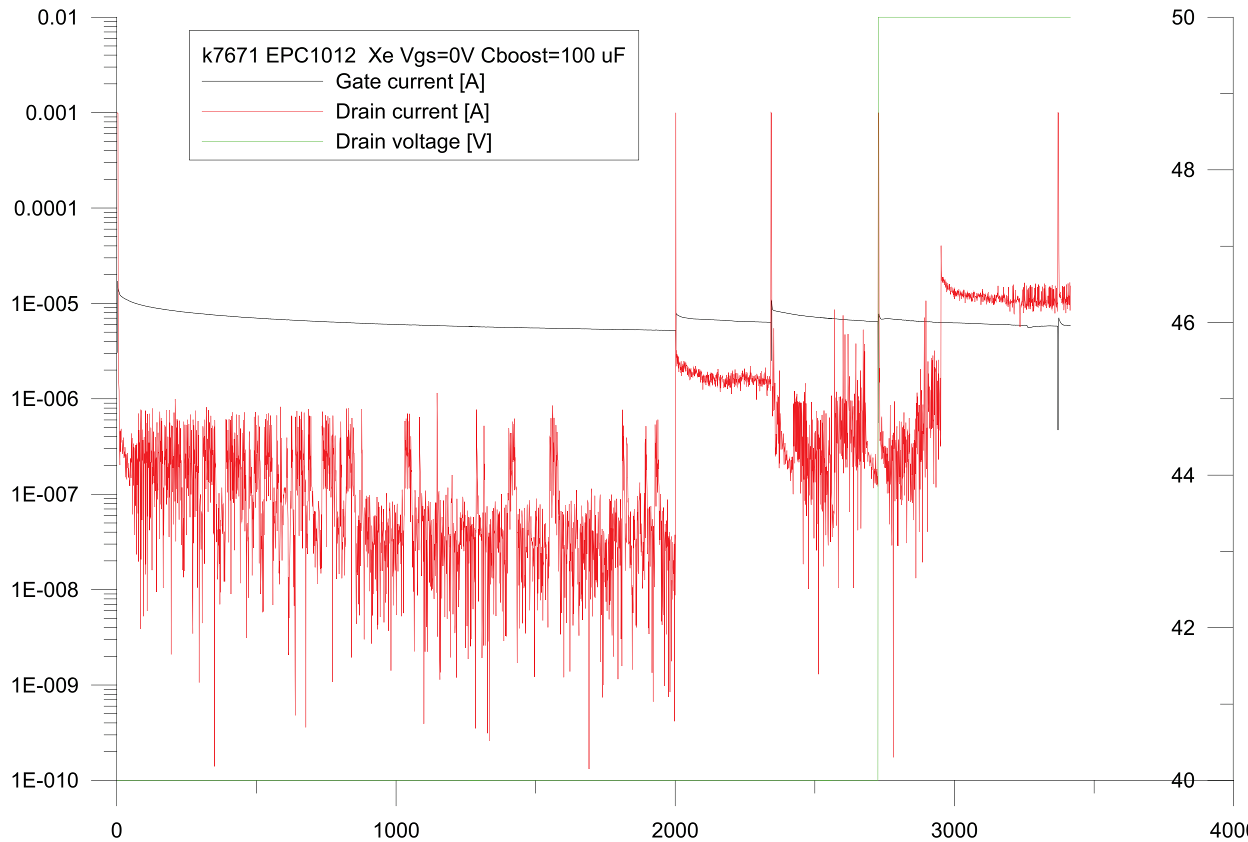

Figure 7.2-6. Heavy ion response of the EPC2012 200V/3A. Ion flux was 2E4 cm^{-2}-s^{-1}. Red line is drain voltage; gate voltage is zero volts. Black line is drain current and green line is gate current. The load capacitor was 0 µF. The V_{see} was determined to be between 40 and 50 V.

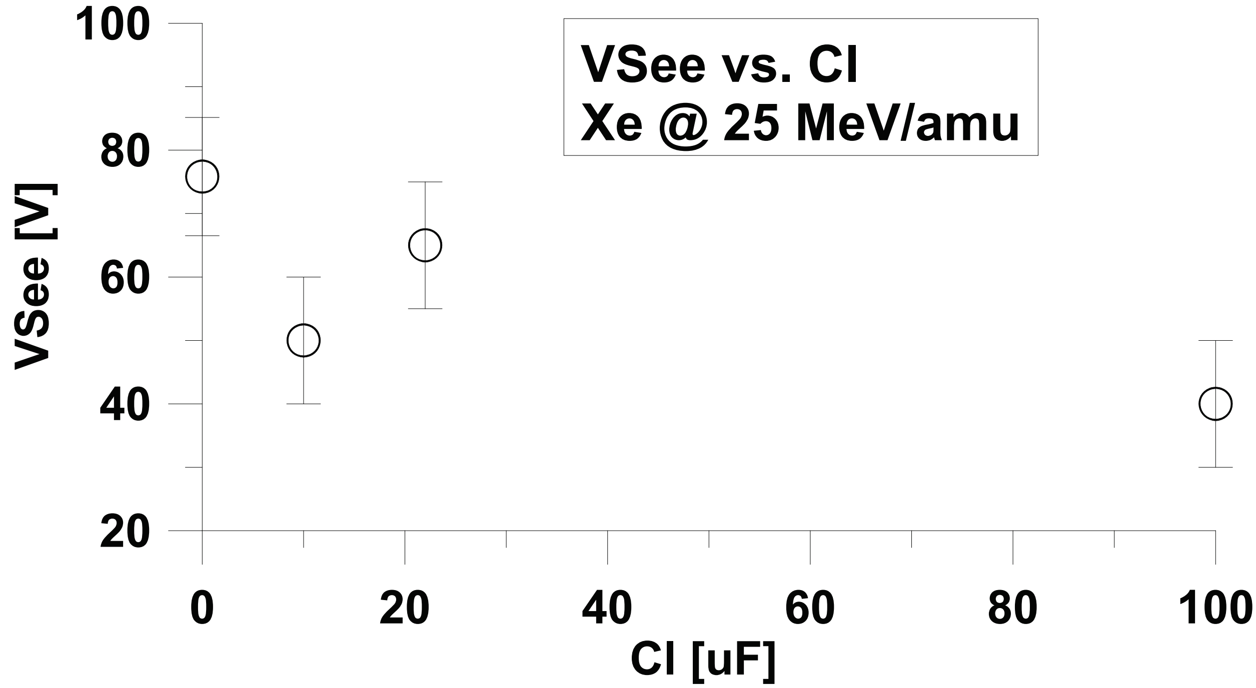

Figure 7.2-7. Heavy ion response of the EPC2012 200V/3A as a function of Cl.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Recent testing of Enhanced Power Conversion (EPC) eGaN FET devices design for power use has shown that the devices are susceptible to Single-Event Effects (SEE) that degrade or destroy the device. The exact mechanism of the SEE is not known. The testing so far has been in the static condition, in the fully off condition, and with minimal load conditions. These conditions may not be worst case. This report presents the results of a study that tests some of the load conditions for SEE. The EPC2012 and EPC1012 were chosen for the test. The tests were performed the TAMU radiation effects facility in May and June of 2013.

15. SUBJECT TERMS

Single-event effect, SEE, Enhanced Power Conversion, EPC, Single Event Gate Rupture, SEGR, Texas A&M University, TAMU, Efficient Power Conversion Corporation, eGaN, FET, load conditions

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