NAVSEA Crane Radiation Test Report

B053102_IRL110

Test Report No.: NSWC C6054-IRL110-0001-SEGR

Program: NASA Goddard		**Report Date:** 06/03/2002
Generic Part No.	**Part Description:**	**Manufacturer:**
IRLL110	100-V, N-Channel MOSFET	International Rectifier
Package Type:	**Date Code:**	**Package Markings**
SOT-223	2000 42nd week	LL110 IR 042 4X4NC
Detailed Test Specification:	**General Test Requirements:**	**Performance Specifications:**
	VDS > 32 V Acceptable (Nickel)	IRLL110 Specification Sheet
Serial Number: Manually assigned numbers		**Radiation Test Results** (see Appendix B)

1.0 Summary.

NAVSEA Crane was tasked to evaluate the single event (SEE) performance of a 100-volt, N-channel power MOSFET (IRLL110) to conditions specified by Ray Ladbury at NASA-GSFC, Code 561, Greenbelt MD 20771. Prior to the test, Jeffrey Titus (NAVSEA) contacted Ray Ladbury about the selected bias conditions. A tentative SEE Test Plan was determined as follows (See Table I):

Table I: IRLL110 SEE Test Plan (05/29/2002)

Condition	Ion Species	Drain	Gate
1	Nickel	5V < VDS < 100V	0 V
2	Bromine	5V < VDS < 100V	0 V
3	Silver	5V < VDS < 100V	0 V
4	Iodine	5V < VDS < 100V	0 V

* Minimum acceptable drain voltage (VDS) is 64 volts.

NAVSEA Crane was tasked to perform these tests: Electrical Measurements (I_{GSS} & I_{DSS}) were made immediately prior to, during, and after each ion exposure. I_{GSS} was used to determine if SEGR or SEB was present during the test. A pre-and post-test (VDS=100V and VGS=-10V) was employed to verify functionality. Some devices were monitored using a Tektronix CT-2 current probe inserted in the drain node to monitor for the possibility of SEB. The CT-2 output was fed into a frequency counter to obtain any SEB events. For these tests, the external capacitors were removed to prevent the device from actually destroying if an SEB event occurred. The drain voltage was incremented after each exposure to obtain a drain voltage response curve to SEGR and SEB. Ion exposures were performed using a fluence of $3x10^5$ ions/cm^2 at a flux of approximately 10^4 ions/cm^2•s. The IRLL110 was exposed to 265-MeV Nickel (LET=26), 278-MeV Bromine (LET=37), 307-MeV Silver (LET=53), and 320-MeV Iodine (LET=60).

Test results of the IRLL110 indicated that single event gate rupture was the dominant failure mode. Single event burnout was not observed during these tests. For 265-MeV Nickel, SEGR was recorded on a total of four samples (VDS = 82.5V, 92.5V, 92.5V at VGS = 0V and VDS = 30V at VGS = -17.5V). For 278-MeV Bromine, SEGR was recorded on a total of three samples (VDS = 55V, 55V, and 54.5V at VGS = 0V). For 307-MeV Silver, SEGR was recorded on one sample (VDS = 42V at VGS = -1V). For 320-MeV iodine, SEGR was recorded on all three test samples (VDS = 37.5V VGS = 0V, VDS = 20V at VGS = -7.5V, and VDS = 30V at VGS = -5V). A saturated cross section was not actually measured for these samples because the test was catastrophic. The SEGR cross section must be lower than the measured die area. The IRLL110 die area is approximately 0.034 cm^2 and the saturated cross section is approximately 75% of this die area or 0.025 cm^2. Since the device passed above the operating VDS of 35 volts (Nickel, Bromine, Silver, and Iodine), the IRLL110 is considered acceptable. Detailed radiation data are provided in Appendix B. Note, SEGR was not observed.

2.0 Applicable Documents and References:

The major applicable documents, used to construct and perform these SEE tests, are listed here

a.) IRLL110 Performance Specification N-Channel MOSFET

b.) NAVSEA INST 4734.1 NAVSEA Metrology and Calibration Program

while major applicable references are listed here.

1) Titus and Wheatley, IEEE Trans Nuc Sci, Apr 96, p 2492-2499.
2) Titus, et al, IEEE Trans Nuc Sci, Dec 98, p 2492-2499.
3) Titus, et al, IEEE Trans Nuc Sci, Dec 99, p 1640-1651.

3.0 Background:

NAVSEA Crane was requested to evaluate the single event response of a commercial non-radiation hardened power MOSFET, manufactured by International Rectifier, the IRLL110. Commercial power MOSFETs exhibit two types of SEE failures, single event burnout and single event gate rupture. Both can be catastrophic. Power MOSFETs have been observed to exhibit SEB at voltages as low as 30% of a device's rated breakdown voltage; whereas SEGR is very dependent upon the thickness of the gate oxide. Additional information on SEB and SEGR can be found in reference 1. Additional resources are available in the literature, mainly the IEEE TNS after 1987, which address SEB and SEGR effects in power MOSFETs. Given that the IRLL110 is a commercial power MOSFET and that the maximum gate voltage was specified at 10V , there was concern that this device might exhibit SEB and/or SEGR. Therefore, to alleviate this concern and possible risk of using this devices in a space deployed system, multiple test samples were delivered to NAVSEA Crane and were subsequently tested at Brookhaven National Laboratory (BNL) tandem van de Graaff facility.

3.1 Package Description

The IRLL110 uses a plastic encapsulated package referred to as a SOT223. Prior to Heavy ion exposure, this plastic was removed to expose the bare die using standard etching techniques. No problems were encountered in this process.

3.1 Device Description

The IRLL110 is a vertical, n-channel 100-volt power MOSFET manufactured by International Rectifier. This MOSFET has a measured die area of 0.216 cm by 0.157 cm (equates to 0.034 cm^2). Figure 1 depicts a cross sectional representation of a generic power MOSFET.

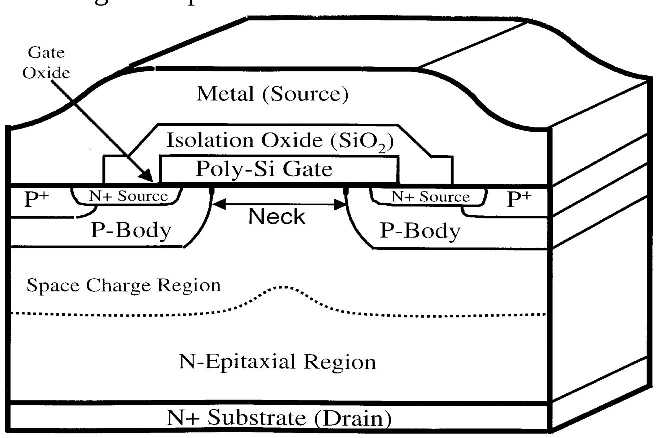

Fig. 1 Cross Sectional View of Power MOSFET Structure

4.0 Test Setup

An 18-socket SEB/SEGR test board was utilized. It was custom designed and built to perform SEB and SEGR type of tests. A top view of this DUT board is given in Appendix A. These eighteen sockets are arranged in three columns of six sockets. Figure 2 depicts a generic test circuit to detect SEGR/SEB and replicated for each of the 18 sockets. A Tektronix CT-2 current probe was inserted in series with the drain on one test sample for each ion beam. The CT-2 output was connected to a frequency counter to detect and log the number of SEB events. Note, the drain stiffening capacitors were removed to minimize permanent damage during an SEB event.

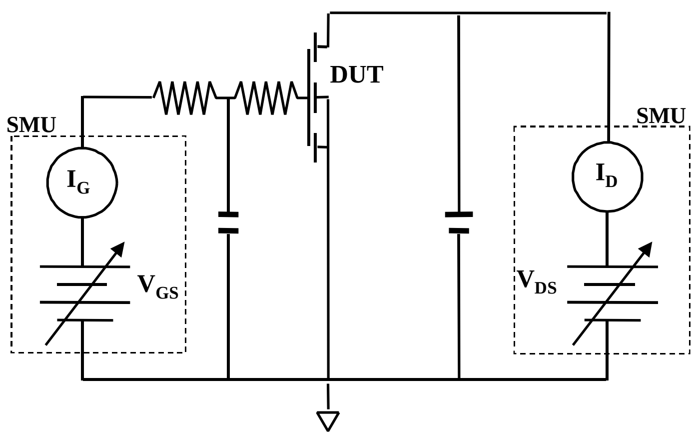

Fig. 2 Generic SEB/SEGR test circuitry used in this experiment

Two Keithley SMUs provided the necessary bias and current measurement. One is used to bias and monitor the drain current (IDSS) and the other is used to bias and monitor the gate current(IGSS). The source is placed at common ground potential. The gate and drain biases are connected to a switch box using TRIAX cable, which are then passed through the vacuum chamber to the test board using 40-pin ribbon cable. The switch box permits the user to select the appropriate DUT using a mechanical switch without breaking the vacuum.

4.1 Test Equipment

To perform this test, a customized test system was employed to perform the necessary electrical measurements and bias conditions. A detailed list of the equipment is provided here.

(a) Keithley 237 (NSWC #10000128468000)
(b) Keithley 237 (NSWC #10000128467000)
(c) Custom-Designed 18-socket SEB/SEGR test board
(d) Custom-Designed 18-position Switch Box
(e) Portable COMPAQ Computer with Custom Software Package
(f) Four 40 Pin Ribbon Cables
(g) Tektronix CT-2 current probe
(h) Handheld Multimeter (used to verify system is operational)
(i) PM6669 Universal Frequency Counter

5.0 BNL Heavy Ion Test Facility

Brookhaven National Labs (BNL) heavy ion test facility is capable of generating heavy ion beams with ion energies up to approximately 15 MeV per amu. An integrated exposure system is available, which includes the vacuum chamber, x-y-z stepper motors, laser alignment system, dosimetry system, and a computer controller. The x-y-z stage allows the device under test to be moved into position remotely (observed while under a vacuum using the remote camera and laser system). The operators provide the requested ion, energy and flux within the constraints of the facility.

5.1 Heavy Ion Beam Diagnostics

When the test board was mounted in the fixture, the beam spot location was determined using a laser system, which was reflected down the beam line through the beam iris allowing the position of each device under test (DUT) to be mapped and stored in the facility's computer. The beam intensity and its energy were determined using dosimetry methods provided by the facility. Once the DUT were mapped, the board was easily moved to the desired DUT socket. The beam diameter was adjusted using a mechanical iris located between the beam exit port and the DUT. The beam diameter was approximately one inch, which was centered over the die under test. The ion, energy, flux, fluence, and uniformity were all recorded.

5.2 BNL Fixture

Testing was performed using a specially designed vacuum chamber integrated directly with the heavy ion beam line. The chamber employed a mechanical x-y-z stage to allow DUT alignment. The mechanical x-y system allows a working area of approximately 7 inches by 9 inches to mount multiple DUTs. The mounting frame accommodates test boards that do not exceed dimensions of approximately 10 inches by 14 inches. The vacuum chamber is also equipped with six 40-pin ribbon cable connectors allowing electrical connection between the test board inside the chamber to the test equipment located outside the chamber. An iris was used to define the beam spot size at the DUT. Final alignment of the DUT was achieved by the laser system. Each DUTs was positioned using the x-y-z stage and that position stored for subsequent recall during test. Alignment of each DUT was visually checked using the camera.

6.0 Test Results

Tests were performed at Brookhaven National Labs on 31 May 2002 as planned. Four different mono-energetic ion beams (265-MeV Nickel, 270-MeV Bromine, 307-MeV Silver, and 320-MeV Iodine) were employed.

6.1 LET Threshold

The first step was to determine a limited response curve for SEGR. Since this test is destructive each point represents a single device. For each ion, the minimum drain voltage was determined to induce SEGR with a gate voltage of zero volts. Additional tests were performed to examine the role of the gate bias with respect to the drain voltage. The SEGR threshold of these devices was determined so that a risk assessment coul dbe performed. It should be noted that SEGR has been demonstrated to be mainly dependent upon the thickness of the gate oxide, If the devices are pulled from the same wafer or lot, this should help reduce variability within the system population.

The measured SEGR thresholds are shown in Table 1. The test results demonstrated that these tested IRLL110 devices have the following SEGR response.

Table II: Summary of VDS Thresholds

ION	LET	VGS THRESHOLD	VDS THRESHOLD
Nickel	26	0	82.5
Nickel	26	0	92.5
Nickel	26	0	92.5
Nickel	26	-17.5	30
Bromine	37	0	55
Bromine	37	0	55
Bromine	37	0	54.5
Silver	53	-1	< 42
Iodine	60	0	37.5
Iodine	60	-7.5	20
Iodine	60	-5	30

Figure 4 shows the minimum drain voltage for a gate voltage of zero volts as a function of LET.

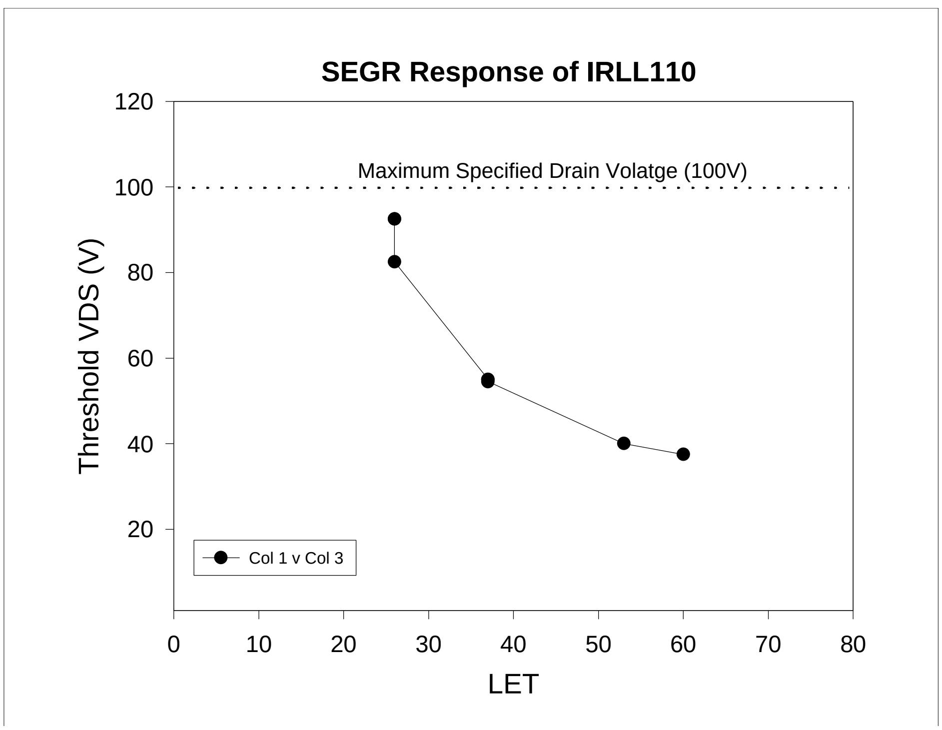

Figure 4. SEGR response curve of IRLL110.

6.2 Effective LET (Angular Response)

The angular response of the SEGR response was not examined. However, all data taken to date on vertical MOSFET have demonstrated that angle causes the SEGR response to improve.

6.3 SEGR Cross Section

The SEGR cross section is useful to estimate the failure rate. Saturated SEGR cross sections can be estimated based upon the die area (See reference 1). Typically the saturated cross section is between 60% to 80% of the total die area. The IRLL110 had a measured die area of 0.034 cm^2. Therefore, the saturated SEGR cross section is expected to be approximately 0.025 cm^2.

Submitted by: ______________________ Approved by: ______________________

Date: ______________________ Date: ______________________

Appendix A: Scanned Image of 18-Socket SEB/SEGR Test Board (Top View)

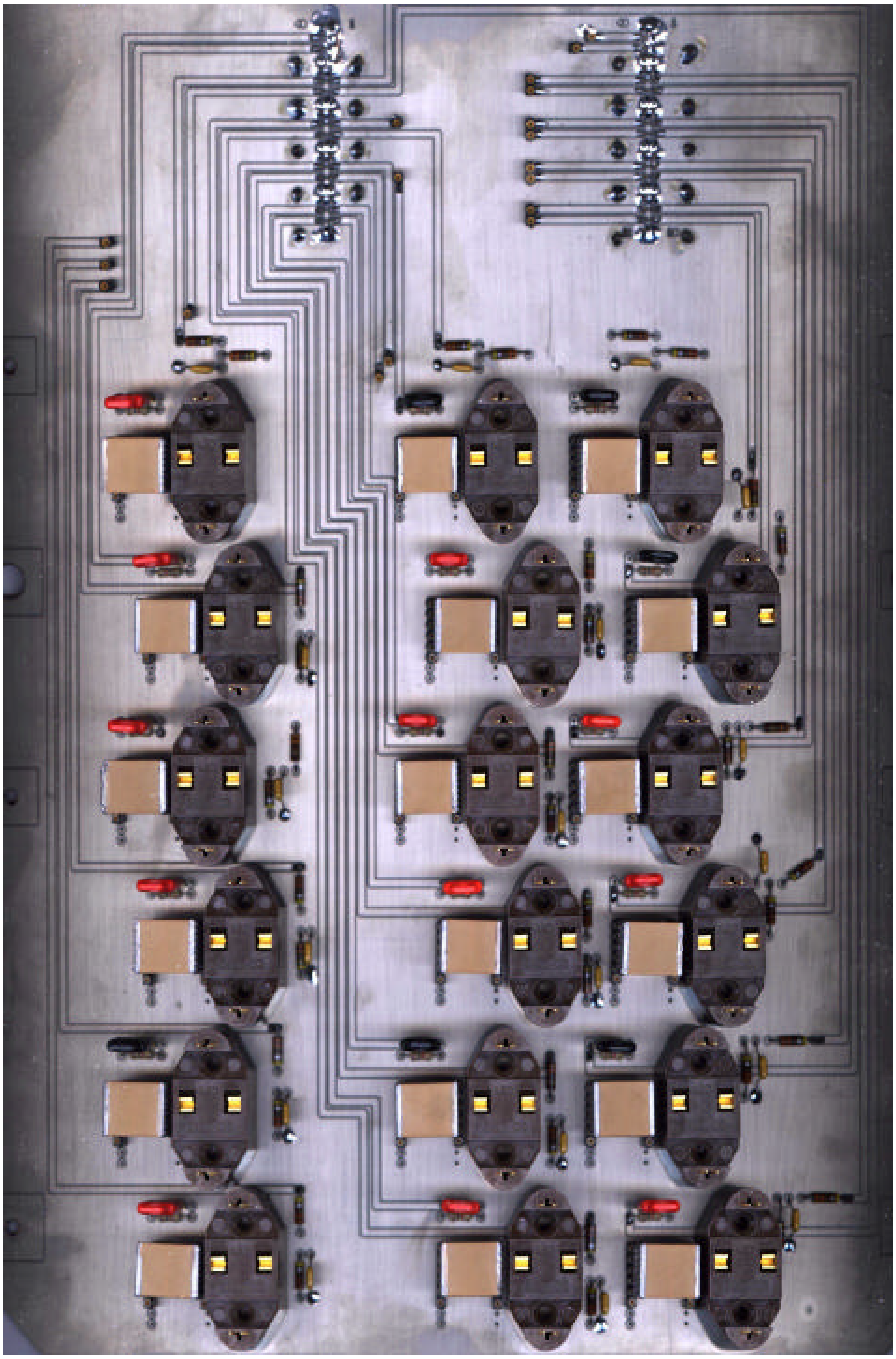

Fig. A. Top View of SEB/SEGR Test Board

Appendix B

Table B1. Iodine (Sample 1)

RUN #	Socket #	Fluence	VDS	VGS	SEB #	SEGR #	Tilt
104	7	3e5	20	0	0	0	0
105	7	3e5	25	0	0	0	0
106	7	3e5	30	0	0	0	0
107	7	3e5	35	0	0	0	0
108	7	3e5	40	0	0	Fail	0
109	8	3e5	20	0	0	0	0
110	8	3e5	20	-5	0	0	0
111	8	3e5	20	-10	0	Fail	0
111	9	3e5	30	0	0	0	0
112	9	3e5	30	-2	0	0	0
113	9	3e5	30	-4	0	0	0
114	9	3e5	30	-6	0	Fail	0

Table B2. Silver (Sample 1)

RUN #	Socket #	Fluence	VDS	VGS	SEB #	SEGR #	Tilt
147	1	3e5	42	-1	0	Fail	0

Table B3. Bromine (Sample 1)

RUN #	Socket #	Fluence	VDS	VGS	SEB #	SEGR #	Tilt
38	12	3e5	30	0	0	0	0
39	12	3e5	35	0	0	0	0
40	12	3e5	40	0	0	0	0
41	12	3e5	45	0	0	0	0
42	12	3e5	50	0	0	0	0
43	12	3e5	50	0	0	0	30
44	12	3e5	50	0	0	0	60
45	12	3e5	54	0	0	0	0
46	12	3e5	56	0	0	Fail	0
56	9	3e5	50	0	0	0	0
57	9	3e5	51	0	0	0	0
58	9	3e5	52	0	0	0	0
59	9	3e5	53	0	0	0	0
60	9	3e5	54	0	0	0	0
61	9	3e5	55	0	0	Fail	0
26	12	3e5	5	0	0	0	0
27	12	3e5	10	0	0	0	0
28	12	3e5	15	0	0	0	0
29	12	3e5	20	0	0	0	0
30	12	3e5	25	0	0	0	0
31	12	3e5	30	0	0	0	0
32	12	3e5	35	0	0	0	0
33	12	3e5	40	0	0	0	0
34	12	3e5	50	0	0	0	0
35	12	3e5	60	0	0	Fail	0
36	12	3e5	70	0	0	0	0

Table B4. Nickel (Sample 1)

RUN #	Socket #	Fluence	VDS	VGS	SEB #	SEGR #	Tilt
73	1	3e5	50	-1	0	0	0
74	1	3e5	55	-1	0	0	0
75	1	3e5	60	0	0	0	0
76	1	3e5	65	0	0	0	0
77	1	3e5	70	0	0	0	0
78	1	3e5	75	0	0	0	30
79	1	3e5	80	0	0	0	60
80	1	3e5	85	0	0	0	0
81	1	3e5	90	0	0	0	0
82	1	3e5	95	0	0	Fail	0
83	1	3e5	100	0	0	Fail	0
84	2	3e5	60	0	0	0	0
85	2	3e5	65	0	0	0	0
86	2	3e5	70	0	0	0	0
87	2	3e5	75	0	0	0	0
88	2	3e5	80	0	0	0	0
89	2	3e5	85	0	0	0	0
90	2	3e5	90	0	0	0	0
91	2	3e5	95	0	0	Fail	0
92	6	3e5	60	0	0	0	0
93	6	3e5	65	0	0	0	0
94	6	3e5	70	0	0	0	0
95	6	3e5	75	0	0	0	0
96	6	3e5	80	0	0	0	0
97	6	3e5	85	0	0	Fail	0
98	12	3e5	80	0	0	0	0
99	12	3e5	30	0	0	0	0
100	12	3e5	30	-5	0	0	0
101	12	3e5	30	-10	0	0	0
102	12	3e5	30	-15	0	0	0
103	12	3e5	30	-20	0	Fail	0