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Single Event Effects Test Report Vishay Siliconix Si7113DN P-Channel 100V MOSFET

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Single Event Effects Test Report Vishay Siliconix Si7113DN P-Channel 100V MOSFET

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1. Introduction and Purpose

This study was undertaken to determine the destructive single event effect and degradation susceptibility of the Si7113DN P-Channel 100V MOSFET from Vishay Siliconix. The device was monitored for destructive single event effects and degradation during exposure to a heavy ion beam at the Berkely Accelerator Space Effects (BASE) Facility at the Lawrence Berkely National Laboratory (LBNL). Gate and drain currents were measured during irradiation and a basic set of electrical characterizations was performed following each fluence exposure to assess heavy ion induced damage. The test date was April 10, 2024. This characterization is application specific.

2. Test Result Summary

Samples passed at -40V drain-source voltage (V_{DS}) under irradiation with 16 MeV/u silver (linear energy transfer (LET) = 48.7 MeV·cm^2/mg) with gate biases of 0V. The minimum V_{DS} at failure occurred at -50V when V_{GS} was 0V. Parts showed a wide range of variability. One part had a maximum last passing V_{DS} of -70V. Two parts failed at -30V drain-source voltage (V_{DS}) under irradiation with 16 MeV/u silver (linear energy transfer (LET) = 48.7 MeV·cm2/mg) with gate biases of 5V and three parts passed at this condition.

Tests were conducted at normal beam incidence (worst-case angle) in air. Data are plotted in Figure 1 as the last passing V_{DS}. Details are provided in the Results section below. Ion range and LET for LBNL beams were determined using SEUSS from the Cyclotron Institute at Texas A&M University.

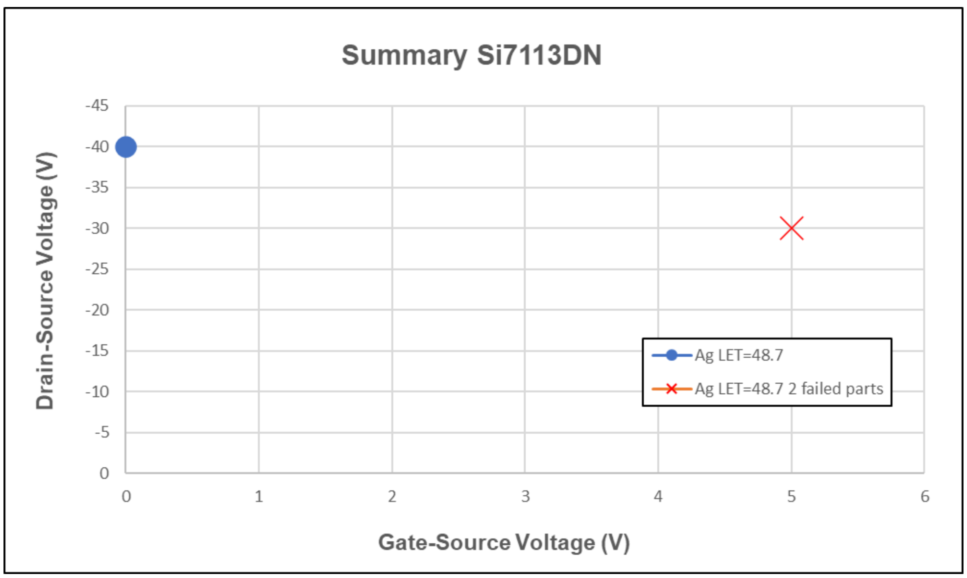

Figure 1. Maximum passing V_{DS} bias as a function of V_{GS} bias during irradiation.

3. Device Description

The Si7113DN is a P-channel 100V MOSFET. Ten devices were prepared for testing by de-lidding the package at the Parts Analysis Laboratory at NASA GFSC. The device is provided in a PowerPAK 1212-8 package. The pieces were mechanically delidded, visually inspected, and electrically characterized at GSFC prior to shipping to test facilities. At the test facilities, a subset of electrical characterizations was performed prior to radiation exposure.

Table I. Part Description

REAG ID	24-002
Part Number	Si7113DN
Manufacturer	Vishay Siliconix
Lot Date Code	NA
Quantity Tested	10, plus 2 controls
Part Function	TrenchP
Part Technology	MOSFET
Package	PowerPAK 1212-8

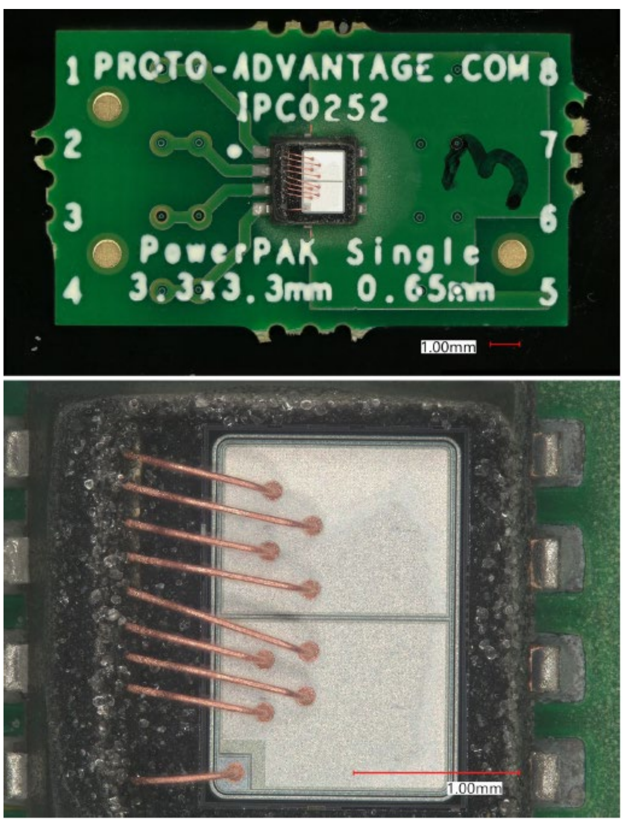

Figure 2. De-lidded Si7113DN

4. Test Setup

The test circuit and block diagram, as shown in Figures 3 and 4, for the power MOSFET contains a Keithley 2400 source meter to provide the gate voltage while measuring the gate current. A filter is placed at the gate node of each device under test (DUT) to dampen noise at the gate. A Keithley 2400 source meter provides the appropriate V_{DS} while measuring the drain current; a 500 Ω resistor is optionally switched into series with the Keithley 2400 to protect it from sudden high-current transients; it is switched out during device characterization tests. Gate current is limited to 1 mA, drain current limited to 10 mA, and both are recorded via ethernet to a desktop computer at approximately 175 ms intervals.

Six DUTs were mounted on the test board via daughter cards and individually accessed via dry Reed relays controlled by an Agilent DAQ 34907A data acquisition/switch unit. All terminals of the devices not under test are then floating. Testing was conducted in air at LBNL with the DUT centered in the beam. Ion exposures was conducted at normal incidence to the DUT.

The test setup is controlled via a custom LabVIEW program written by Alyson Topper and Hak Kim, Science Systems and Applications, Inc. The program controls the source measuring units (SMUs), gate current limit, and gate and drain current sampling and recording. The Keithleys are used to perform a parametric analysis of each DUT prior to irradiation and following each beam run, recording if selected: gate threshold voltage (V_{th}), I_D as a function of V_{GS} at various fixed V_{DS} values for evaluation of total ionizing dose effects, drain-source breakdown voltage (BV_{DSS}), zero gate voltage drain current (I_{DSS}), and I_G and I_D as a function of V_{GS} (post-irradiation gate stress (PIGS) test to test the integrity of the gate dielectric).

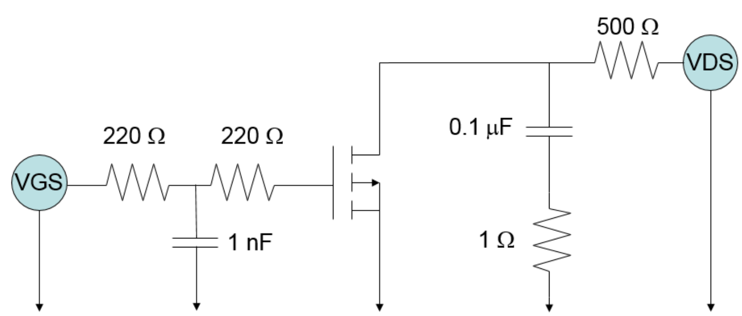

Figure 3. Equivalent Test Circuit for the Si7113DN.

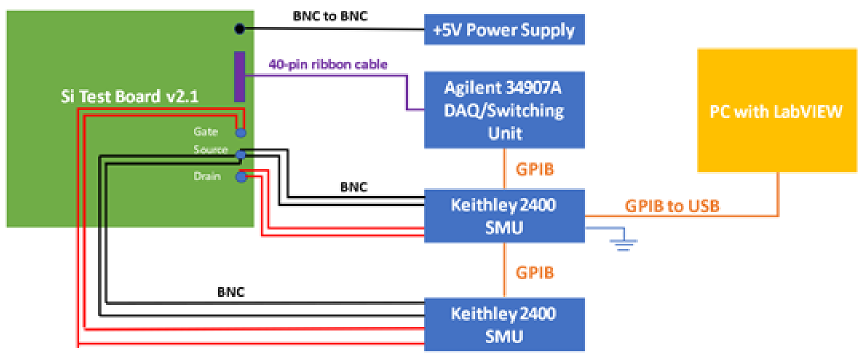

Figure 4. Block Diagram of Test Setup.

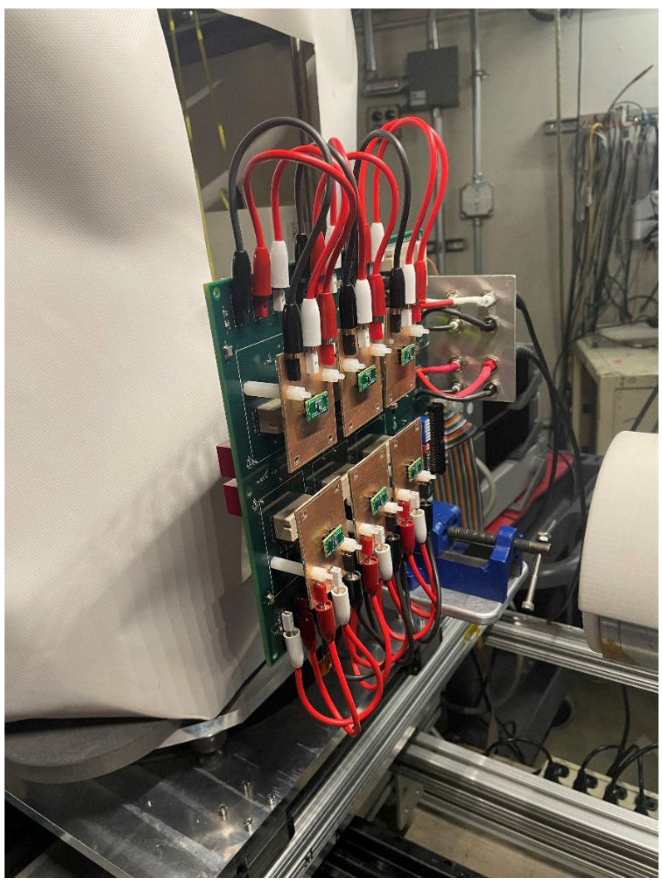

Figure 5. Test Setup.

5. Test Facility

Facility: Lawrence Berkeley National Laboratory (LBNL) Berkeley Accelerator Space Effects (BASE) Facility 88" Cyclotron

Type of Radiation: Heavy ions

Facility Configuration: 16 MeV/amu tune

Flux: 5 x 10^3 ions/cm^2/s to 1.4 x 10^4 ions/cm^2/s.

Fluence: All tests were run to 3x10^5 ions/cm^{-2}.

.Beams / LET: A normal-incidence LET of at least 37 MeVcm^2/mg is required for destructive single event gate rupture testing (SEGR) and single event burnout (SEB).

Ion Species Table II shows surface-incident beam properties

Table II: Notional Energy, Range, and LET* Estimates for Accelerated Ions at 16 MeV/amu*

Ion	Tilt Angle (°)	Energy (MeV)	Range (μm)	Nominal Incident LET (MeV-cm^2/mg)
^{147}Ag	0	1007	87.3	48.7

* LET calculated using Seuss assuming 5.715cm of air and 2 mils of mylar

6. Test Conditions

Temperature: Room

In-Air or Vacuum: In-air

Supply Voltages: See Table III

Table III: V_{GS} and V_{DS} Operating Voltages with Testing Flow

V_{GS}=	0V	5V
V_{DS1} =	-20V	
V_{DS2} =	-30V	-30V
V_{DS3} =	-40V	-40V

A few DUTs were selected to have V_{DS} increased until failure with a V_{GS} of 0V. The V_{DS} was increased in -10V steps until failure.

7. Test Methods and Procedures

Personnel present at the test were Anthony Phan (Science Systems and Application Inc) Lead Test Engineer, and Tom Carstens (NASA/GSFC), Principal Investigator.

The test circuit and block diagram, as shown in Figures 3 and 4, for the power MOSFET contains a Keithley 2400 source meter to provide the gate voltage (set to 0 V and 5 V during irradiation) while measuring the gate current. A filter is placed at the gate node of each device under test (DUT) to dampen noise at the gate. A Keithley 2400 source meter provides the appropriate V_{DS} (between -20V and -40V) while measuring the drain current; a 500 Ω resistor is optionally switched into series with the Keithley 2400 to protect it from sudden high-current transients; it is switched out during device characterization tests. Gate current is limited to 1 mA, drain current limited to 10 mA, and both are recorded via ethernet to a desktop computer at approximately 175 ms intervals.

Prior to the initial beam run and following each run, the zero-gate voltage drain current (I_{DSS}) was measured to test the integrity of the drain-source connection, and a gate stress test was performed in which the gate and drain currents were measured while at a fixed 0 V_{DS}, the gate voltage was swept from 0 V to 20 V, then from 0 V to -20 V, in 2 V increments. The +/- 20V levels were held for 1 s to stress the gate per MIL-STD_750-1 TM1080.1 Condition B. Note that the gate stress test, per TM1080.1, is not performed when the gate is biased ≥ 50% of rated voltage. Failure was defined as the gate current exceeding the manufacturer gate-source leakage current (IGSS) specification of 100 nA during the beam run or during the post-irradiation gate stress (PIGS) test, and/or a sudden, sustained increase in the drain current during the beam run indicative of single event burnout (SEB).

All terminals of the devices not under test were floating. Testing was conducted in air with the DUT centered within the beam diameter. Ion exposures were conducted at 0º tilt angle (normal incidence to the DUT). To meet destructive single event effects threshold LET requirements, 147Ag was used during irradiation.

Initially the V_{GS} was set to 0V, and V_{DS1}=-20V. If no destructive single effect events occur V_{GS} remained at 0V and V_{DS} was increased to V_{DS2}=-30V. V_{DS} was increased according to table III, in -10V increments, until V_{DS} was -40V or failure was observed. During this process V_{GS} was set to 0V. This process was repeated with at least three different DUTs to gather enough data for statistics. A few DUTs were selected to have V_{DS} increased until failure with a V_{GS} of 0V. The V_{DS} was increased in -10V steps until failure.

After this V_{GS} was set to 5V, and V_{DS1}=-30V. If no destructive single effect events occur V_{GS} remained at 5V and V_{DS} was increased to V_{DS2}=-40V. This process was repeated with at least three different DUTs to gather enough data for statistics.

8. Test Results

Prior to the initial beam run and following each run, the zero gate voltage drain current (I_{DSS}) was measured to test the integrity of the drain-source connection, and a gate stress test was performed in which the gate and drain currents were measured while at a fixed 0 V_{DS}, the gate voltage was swept from 0 V to 20 V, then from 0 V to -20 V, in 2 V increments. The +/- 20V levels were held for 1 s to stress the gate per MIL-STD_750-1 TM1080.1 Condition B. Note that the gate stress test, per TM1080.1, is not performed when the gate is biased ≥ 50% of rated voltage. Failure was defined as the gate current exceeding the manufacturer gate-source leakage current (I_{GSS}) specification of 100 nA during the beam run or during the post-irradiation gate stress (PIGS) test, and/or a sudden, sustained increase in the drain current during the beam run indicative of single event burnout (SEB).

The four devices tested under the 16-MeV/u Ag ion beam all passed at -40 V_{DS} with the gate at 0 V. The first DUT failure occurred when V_{DS} was -50V. One DUT was able to function when V_{DS} was -70V. The two devices tested under the 16-MeV/u Au ion beam failed at -30 V_{DS} with the gate biased at 5V. Three devices passed at -30 V_{DS} with the gate biased at 5V. However, all these devices failed when V_{DS} was -40V and V_{GS} was 5V. Time limitations prevented additional testing with Ag. Table IV summarizes the heavy-ion test results for each sample; Figure 1 in Section I plots the bias conditions at which no failures occurred for any DUT. Device electrical specifications are provided in Appendix A, as well as pretest electrical characterizations performed on-site. The run log is given in Appendix B, PIGS test results are in Appendix C.

Table IV: V_{GS} and V_{DS} Operating Voltages with Testing Flow

Ion Species	Surface-Incident Energy (MeV)	Range (mm)	Surface-Incident LET(Si) (MeV·cm²/mg)	Beam Angle of Incidence (degrees)	DUT	V_{GS} (V)	Maximum Last Passing V_{DS} (V)	Minimum V_{DS} at Failure (V)
Ag	1007	87.3	48.7	0	1	0	-40	-50
					7	0	-70	-80
					9	0	-60	-70
					10	0	-40	n/a
					10	5	-30	-40
					11	5	-30	-40
					12	5	n/a	-30
					13	5	n/a	-30
					3	5	-30	-40

9. References

[1] Vishay Siliconix, “P-Channel 100-V (D-S) MOSFET”, Si7113DN datasheet, July 2008.

Appendix A

Table A1. Manufacturer-Specified Electrical Parameters (Partial List)[1]

Parameter	Condition	MIN	TYP	MAX	Units
Gate-Source Threshold Voltage ($V_{GS(th)}$)	$V_{DS} = V_{GS}$, I_D = -250μA	-1		-3	V
Zero Gate Voltage Drain Current (I_{DSS})	V_{DS} = -100 V, V_{GS} = 0 V			-1	μA
Drain-Source Breakdown Voltage (BV_{DS})	V_{GS} = 0 V, I_D = -250 μA	-100			V
Gate-Source Leakage Current (I_{GSS})	V_{DS} = 0 V, V_{GS} = ±20 V			±100	nA
Static Drain-Source Resistance ($R_{DS(on)}$)	V_{GS} = -10 V, I_D =-4 A		0.108	0.134	Ω

Table A2. Pretest Electrical Characterization at LBNL

DUT	$V_{GS(th)}$ (V)	BV_{DSS} (V)	I_{DSS} (nA)	I_{GSS}+ (nA)	I_{GSS}- (nA)
3	-2.05	-100	-92.7	0.554	-0.282
5	-2.14	-100	-93.8	0.759	-0.302
6	-1.98	-100	-89	0.508	-0.309
7	-2.02	-100	-64.7	0.633	-0.243
8	-2.03	-100	-70.2	0.775	-0.293
9	-2.06	-100	-46.9	0.57	-0.235
10	-2.03	-100	-144	0.648	-0.282
11	-2.07	-100	-96.7	0.706	-0.29
12	-2.03	-100	-109	0.511	-0.24
13	-2.08	-100	-93.8	0.535	-0.26

Appendix B: Raw Test Data from April 10, 2024

RUN INFO			DUT SETUP			BEAM DIAGNOSTICS:											Irradiation Results	
Time	Run	DUT	Socket	V_{GS} [V]	V_{DS} [V]	Ion	Energy [MeV/u]	Energy [MeV]	Angle	LET [MeV-cm^2/mg]	Flux [/(cm^2-s)]	Fluence [/cm^2]	Cum Fluence [/cm^2]	Dose [rad(Si)]	Cum. Dose (rad(Si))	run time (sec)	SEE Observed on Run	Event Notes
12:18pm	**1**	**5**	1	0	**-20**	Ag	16.0	1007	0	48.7	2695.2	3.02E+05	3.02E+05	2.35E+02	2.353E+02	1.121E+02		
12:22pm	**2**	**5**	1	5	**-20**	Ag	16.0	1007	0	48.7	2849.0	3.01E+05	6.03E+05	2.35E+02	4.699E+02	1.057E+02		
12:26pm	**3**	**5**	1	0	**-30**	Ag	16.0	1007	0	48.7	3005.9	3.02E+05	9.05E+05	2.35E+02	7.052E+02	1.005E+02		
12:32pm	**4**	**5**	1	5	**-30**	Ag	16.0	1007	0	48.7	#DIV/0!		9.05E+05	0.00E+00	7.052E+02		yes	current spike on the gate, gate broken
12:39pm	**5**	**6**	2	0	**-20**	Ag	16.0	1007	0	48.7	3053.9	3.02E+05		2.35E+02		9.889E+01		
12:43pm	**6**	**6**	2	0	**-30**	Ag	16.0	1007	0	48.7	3136.7	3.02E+05		2.35E+02		9.628E+01		
12:47pm	**7**	**6**	2	0	**-40**	Ag	16.0	1007	0	48.7	3120.8	3.02E+05		2.35E+02		9.677E+01		
12:51pm	**8**	**6**	2	5	**-30**	Ag	16.0	1007	0	48.7	3193.1	3.02E+05		2.35E+02		9.458E+01		
12:58pm	**9**	**8**	4	0	**-20**	Ag	16.0	1007	0	48.7	3228.6	3.02E+05		2.35E+02		9.354E+01		bad socket
1:05pm	**10**	**9**	5	0	**-20**	Ag	16.0	1007	0	48.7	4583.1	3.04E+05		2.37E+02		6.633E+01		
1:09pm	**11**	**9**	5	0	**-30**	Ag	16.0	1007	0	48.7	6515.2	3.04E+05		2.37E+02		4.666E+01		
1:11pm	**12**	**9**	5	0	**-40**	Ag	16.0	1007	0	48.7	6080.0	3.04E+05		2.37E+02		5.000E+01		
1:15pm	**13**	**10**	6	0	**-20**	Ag	16.0	1007	0	48.7	5725.0	3.04E+05		2.37E+02		5.310E+01		
1:18pm	**14**	**10**	6	0	**-30**	Ag	16.0	1007	0	48.7	5951.4	3.04E+05		2.37E+02		5.108E+01		
1:22pm	**15**	**10**	6	0	**-40**	Ag	16.0	1007	0	48.7	6013.8	3.04E+05		2.37E+02		5.055E+01		
1:31pm	**16**	**7**	3	0	**-20**	Ag	16.0	1007	0	48.7	6863.9	3.04E+05		2.37E+02		4.429E+01		
1:34pm	**17**	**7**	3	0	**-30**	Ag	16.0	1007	0	48.7	7368.9	3.05E+05		2.38E+02		4.139E+01		
1:38pm	**18**	**7**	3	0	**-40**	Ag	16.0	1007	0	48.7	7763.0	3.04E+05		2.37E+02		3.916E+01		
1:42pm	**19**	**7**	3	0	**-50**	Ag	16.0	1007	0	48.7	9928.6	3.06E+05		2.38E+02		3.082E+01		
1:45pm	**20**	**7**	3	0	**-60**	Ag	16.0	1007	0	48.7	10062.3	3.07E+05		2.39E+02		3.051E+01		
1:48pm	**21**	**7**	3	0	**-70**	Ag	16.0	1007	0	48.7	6835.5	3.05E+05		2.38E+02		4.462E+01		
1:52pm	**22**	**7**	3	0	**-80**	Ag	16.0	1007	0	48.7	5741.3	3.04E+05		2.37E+02		5.295E+01	yes	failure
1:57pm	**23**	**6**	2	0	**-50**	Ag	16.0	1007	0	48.7	4934.9	3.03E+05		2.36E+02		6.140E+01	yes	failure
2:01pm	**24**	**9**	5	0	**-50**	Ag	16.0	1007	0	48.7	4908.5	3.03E+05		2.36E+02		6.173E+01		
2:05pm	**25**	**9**	5	0	**-60**	Ag	16.0	1007	0	48.7	5047.5	3.03E+05		2.36E+02		6.003E+01		
2:07pm	**26**	**9**	5	0	**-70**	Ag	16.0	1007	0	48.7	5039.9	3.03E+05		2.36E+02		6.012E+01	yes	failure
2:13pm	**27**	**10**	6	5	**-30**	Ag	16.0	1007	0	48.7	4736.0	3.05E+05		2.38E+02		6.440E+01		
2:16pm	**28**	**10**	6	5	**-40**	Ag	16.0	1007	0	48.7	4526.4	3.03E+05		2.36E+02		6.694E+01	yes	failure
2:33pm	**29**	**11**	1	5	**-30**	Ag	16.0	1007	0	48.7	4009.6	3.02E+05		2.35E+02		7.532E+01		
	30	**11**	1	5	**-40**	Ag	16.0	1007	0	48.7	3713.7	3.02E+05		2.35E+02		8.132E+01	yes	gate current spike
2:45pm	**31**	**12**	2	5	**-30**	Ag	16.0	1007	0	48.7	3372.4	3.02E+05		2.35E+02		8.955E+01	yes	gate current spike
2:51pm	**32**	**13**	3	5	**-30**	Ag	16.0	1007	0	48.7	3112.1	3.02E+05		2.35E+02		9.704E+01	yes	bad gate
2:56pm	**33**	**3**	5	5	**-30**	Ag	16.0	1007	0	48.7	2957.6	3.01E+05		2.35E+02		1.018E+02		
3:03pm	**34**	**3**	5	5	**-40**	Ag	16.0	1007	0	48.7	2829.0	3.02E+05		2.35E+02		1.068E+02	yes	bad gate
3:10pm	**35**	**8**	6	5	**-30**	Ag	16.0	1007	0	48.7	1190.7	3.01E+05		2.35E+02		2.528E+02	yes	bad gate

Appendix C: Pre- and Post-Irradiation Gate Stress Test Results

Run #	Pre	5	6	7	23
DUT	6	6	6	6	6
Run Vds (V):	n/a	-20	-30	-40	-50
Run Vgs (V):	n/a	0	0	0	0
Ion Species	n/a	Ag	Ag	Ag	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)
0.0	-2.52E-11	-2.26E-11	-1.87E-11	-2.28E-11	-2.47E-11
-2.0	-1.17E-10	-3.45E-11	-4.15E-11	-4.02E-11	-2.76E-11
-4.0	-1.11E-10	-4.76E-11	-5.62E-11	-5.55E-11	-8.20E-11
-6.0	-1.26E-10	-7.06E-11	-6.94E-11	-8.75E-11	-7.31E-11
-8.0	-1.61E-10	-9.60E-11	-7.77E-11	-8.26E-11	-6.43E-11
-10.0	-1.95E-10	-8.75E-11	-8.24E-11	-7.46E-11	-8.79E-11
-12.0	-1.99E-10	-6.46E-11	-9.50E-11	-9.18E-11	-1.38E-10
-14.0	-2.27E-10	-9.60E-11	-1.06E-10	-1.04E-10	-2.38E-10
-16.0	-2.49E-10	-1.37E-10	-1.09E-10	-1.12E-10	-4.02E-10
-18.0	-2.49E-10	-1.24E-10	-1.20E-10	-1.30E-10	-9.68E-10
-20.0	-3.09E-10	-1.09E-10	-1.29E-10	-1.42E-10	-4.76E-09
2.0	4.07E-10	1.29E-10	1.26E-10	1.31E-10	2.07E-04
4.0	1.52E-10	5.30E-11	6.27E-11	7.37E-11	9.27E-04
6.0	1.36E-10	6.08E-11	5.87E-11	5.52E-11	1.00E-03
8.0	1.72E-10	7.22E-11	5.79E-11	6.14E-11	1.00E-03
10.0	2.09E-10	5.18E-11	5.42E-11	6.38E-11	1.00E-03
12.0	2.00E-10	4.35E-11	5.95E-11	5.78E-11	1.00E-03
14.0	1.79E-10	7.01E-11	6.49E-11	8.62E-11	1.00E-03
16.0	2.26E-10	5.46E-11	7.20E-11	7.89E-11	1.00E-03
18.0	2.17E-10	8.01E-11	8.83E-11	7.23E-11	1.00E-03
20.0	5.08E-10	3.49E-10	3.49E-10	3.41E-10	1.00E-03

Run #	Pre	10	11	12	24	25	26
DUT	9	9	9	9	9	9	9
Run Vds (V):	n/a	-20	-30	-40	-50	-60	-70
Run Vgs (V):	n/a	0	0	0	0	0	0
Ion Species	n/a	Ag	Ag	Ag	Ag	Ag	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)
0.0	-2.83E-11	-1.81E-11	-1.78E-11	-4.01E-11	-1.99E-11	-1.55E-11	-1.99E-11
-2.0	4.42E-11	-4.03E-11	-4.29E-11	-2.56E-11	-4.32E-11	-4.62E-11	-4.19E-11
-4.0	-3.32E-11	-6.44E-11	-6.84E-11	-8.28E-11	-6.64E-11	-6.29E-11	-6.62E-11
-6.0	-2.83E-10	-8.56E-11	-6.73E-11	-7.06E-11	-7.02E-11	-7.94E-11	-7.80E-11
-8.0	-2.66E-10	-8.96E-11	-8.38E-11	-9.88E-11	-8.91E-11	-8.78E-11	-9.44E-11
-10.0	-3.93E-10	-9.26E-11	-1.19E-10	-7.94E-11	-1.09E-10	-1.05E-10	-1.55E-10
-12.0	-4.32E-10	-1.23E-10	-1.65E-10	-1.24E-10	-1.28E-10	-1.16E-10	-4.81E-10
-14.0	-2.36E-10	-1.30E-10	-1.58E-10	-1.72E-10	-1.42E-10	-1.40E-10	-1.14E-09
-16.0	-2.52E-10	-1.50E-10	-1.69E-10	-1.73E-10	-1.36E-10	-1.86E-10	-5.61E-04
-18.0	-2.72E-10	-1.89E-10	-2.08E-10	-1.68E-10	-1.77E-10	-2.16E-10	-6.67E-04
-20.0	-2.35E-10	-1.84E-10	-2.18E-10	-2.36E-10	-2.30E-10	-3.89E-10	-8.59E-04
2.0	4.49E-10	1.40E-10	1.35E-10	1.31E-10	1.30E-10	1.52E-10	7.52E-09
4.0	1.04E-10	7.71E-11	6.77E-11	8.27E-11	7.20E-11	9.71E-11	1.04E-07
6.0	1.81E-10	4.87E-11	7.14E-11	5.99E-11	8.40E-11	7.05E-11	1.39E-05
8.0	1.28E-10	7.24E-11	4.16E-11	7.18E-11	7.34E-11	6.37E-11	1.00E-03
10.0	1.71E-10	1.00E-10	8.66E-11	7.15E-11	7.34E-11	7.52E-11	1.00E-03
12.0	1.87E-10	8.97E-11	6.85E-11	9.07E-11	8.33E-11	8.35E-11	1.00E-03
14.0	2.46E-10	7.80E-11	8.03E-11	8.90E-11	8.98E-11	1.13E-10	1.00E-03
16.0	2.21E-10	9.74E-11	1.04E-10	9.19E-11	1.10E-10	1.27E-10	1.00E-03
18.0	2.79E-10	1.38E-10	1.44E-10	1.20E-10	1.20E-10	1.54E-10	1.00E-03
20.0	5.70E-10	4.30E-10	4.14E-10	4.37E-10	4.39E-10	6.24E-10	1.00E-03

Run #	Pre	13	14	15	27	28
DUT	10	10	10	10	10	10
Run Vds (V):	n/a	-20	-30	-40	-30	-40
Run Vgs (V):	n/a	0	0	0	5	5
Ion Species	n/a	Ag	Ag	Ag	Ag	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)
0.0	-1.18E-11	9.07E-13	-1.84E-11	-3.67E-11	-1.86E-11	-9.57E-12
-2.0	-3.23E-10	-4.75E-11	-6.28E-11	-2.71E-11	-4.46E-11	-5.14E-11
-4.0	-1.06E-10	-4.72E-11	-3.40E-11	-6.39E-11	-5.52E-11	-5.20E-11
-6.0	-1.41E-10	-4.02E-11	-6.94E-11	-5.75E-11	-8.49E-11	-6.60E-11
-8.0	-1.73E-10	-6.95E-11	-8.37E-11	-7.71E-11	-7.72E-11	-8.77E-11
-10.0	-2.22E-10	-1.05E-10	-9.22E-11	-8.95E-11	-8.60E-11	-1.18E-10
-12.0	-2.16E-10	-9.72E-11	-9.98E-11	-9.56E-11	-1.10E-10	-2.31E-10
-14.0	-2.35E-10	-1.05E-10	-1.00E-10	-9.27E-11	-1.22E-10	-6.46E-10
-16.0	-2.31E-10	-1.18E-10	-1.15E-10	-1.09E-10	-1.72E-10	-2.23E-09
-18.0	-2.35E-10	-1.19E-10	-1.16E-10	-1.35E-10	-2.50E-10	-1.00E-03
-20.0	-2.82E-10	-1.26E-10	-1.24E-10	-1.29E-10	-4.99E-10	-1.00E-03
2.0	4.14E-10	1.25E-10	1.19E-10	1.39E-10	1.25E-10	2.45E-05
4.0	2.02E-10	6.56E-11	7.04E-11	5.20E-11	6.53E-11	1.66E-04
6.0	1.65E-10	6.41E-11	7.61E-11	6.25E-11	6.98E-11	9.33E-04
8.0	1.18E-11	6.09E-11	6.29E-11	6.23E-11	5.86E-11	1.00E-03
10.0	1.63E-10	6.84E-11	5.58E-11	5.92E-11	6.69E-11	1.00E-03
12.0	2.24E-10	6.43E-11	6.57E-11	6.22E-11	5.87E-11	1.00E-03
14.0	2.12E-10	6.98E-11	8.57E-11	6.49E-11	8.24E-11	1.00E-03
16.0	2.24E-10	8.02E-11	7.03E-11	8.50E-11	1.18E-10	1.00E-03
18.0	2.55E-10	9.60E-11	1.06E-10	9.12E-11	2.01E-10	1.00E-03
20.0	6.48E-10	4.81E-10	4.75E-10	4.65E-10	7.54E-10	1.00E-03

Run #	Pre	16	17	18	19	20	21	22
DUT	7	7	7	7	7	7	7	7
Run Vds (V):	n/a	-20	-30	-40	-50	-60	-70	-80
Run Vgs (V):	n/a	0	0	0	0	0	0	0
Ion Species	n/a	Ag	Ag	Ag	Ag	Ag	Ag	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)
0.0	-6.67E-11	-1.25E-11	-1.65E-11	-2.16E-11	-1.96E-11	-1.83E-11	-1.71E-11	-2.06E-11
-2.0	-7.57E-11	-4.26E-11	-3.95E-11	-4.21E-11	-3.74E-11	-3.76E-11	-3.77E-11	-3.77E-11
-4.0	-1.27E-10	-3.76E-11	-5.30E-11	-2.88E-11	-5.01E-11	-5.41E-11	-5.04E-11	-6.13E-11
-6.0	-1.41E-10	-5.21E-11	-6.03E-11	-5.78E-11	-5.82E-11	-6.08E-11	-6.22E-11	-2.05E-10
-8.0	-1.74E-10	-6.38E-11	-8.55E-11	-7.96E-11	-7.45E-11	-7.12E-11	-6.69E-11	-1.17E-09
-10.0	-1.62E-10	-8.84E-11	-6.58E-11	-7.62E-11	-8.01E-11	-7.79E-11	-7.69E-11	-6.61E-09
-12.0	-2.05E-10	-8.55E-11	-8.49E-11	-9.29E-11	-6.64E-11	-8.41E-11	-8.03E-11	-2.69E-08
-14.0	-2.20E-10	-7.92E-11	-1.04E-10	-6.90E-11	-8.78E-11	-9.02E-11	-9.11E-11	-6.37E-06
-16.0	-2.54E-10	-9.47E-11	-9.82E-11	-1.04E-10	-1.19E-10	-1.01E-10	-1.04E-10	-1.00E-03
-18.0	-2.55E-10	-1.06E-10	-1.02E-10	-8.23E-11	-9.71E-11	-1.06E-10	-1.20E-10	-1.00E-03
-20.0	-2.43E-10	-1.13E-10	-1.14E-10	-1.13E-10	-1.24E-10	-1.40E-10	-1.56E-10	-1.00E-03
2.0	3.24E-10	1.12E-10	1.12E-10	1.37E-10	1.36E-10	1.16E-10	1.17E-10	3.55E-06
4.0	2.05E-10	5.50E-11	6.69E-11	4.74E-11	6.36E-11	5.09E-11	5.90E-11	1.04E-04
6.0	1.47E-10	6.24E-11	5.41E-11	5.03E-11	3.25E-11	4.82E-11	5.16E-11	8.13E-04
8.0	1.52E-10	4.70E-11	4.49E-11	4.53E-11	5.54E-11	5.52E-11	5.16E-11	1.00E-03
10.0	1.41E-10	5.72E-11	2.66E-11	5.18E-11	5.12E-11	2.99E-11	5.17E-11	1.00E-03
12.0	1.69E-10	4.51E-11	5.10E-11	3.45E-11	2.74E-11	5.00E-11	4.77E-11	1.00E-03
14.0	1.79E-10	5.18E-11	6.07E-11	5.16E-11	6.46E-11	4.06E-11	6.70E-11	1.00E-03
16.0	1.95E-10	5.45E-11	4.13E-11	5.17E-11	6.46E-11	6.00E-11	6.01E-11	1.00E-03
18.0	2.47E-10	7.65E-11	7.54E-11	7.81E-11	6.32E-11	6.44E-11	8.98E-11	1.00E-03
20.0	6.33E-10	4.92E-10	4.90E-10	4.72E-10	5.12E-10	4.96E-10	5.12E-10	1.00E-03

Run #	Pre	29	30	Pre	31	Pre	32
DUT	11	11	11	12	12	13	13
Run Vds (V):	n/a	-30	-40	n/a	-30	n/a	-30
Run Vgs (V):	n/a	5	5	n/a	5	n/a	5
Ion Species	n/a	Ag	Ag	n/a	Ag	n/a	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)	Ig (A)
0.0	-3.57E-11	-1.70E-11	-1.44E-11	-6.12E-11	-2.13E-11	-8.27E-11	-1.92E-11
-2.0	-1.04E-10	-4.10E-11	-3.41E-08	-6.66E-11	-6.83E-11	-2.16E-11	-3.56E-11
-4.0	-1.49E-10	-4.80E-11	-1.17E-07	-1.15E-10	-3.48E-10	-1.53E-10	-4.91E-11
-6.0	-1.54E-10	-6.21E-11	-3.17E-07	-1.28E-10	-5.25E-09	-1.13E-10	-7.59E-11
-8.0	-1.76E-10	-7.62E-11	-8.28E-07	-1.17E-10	-2.54E-08	-1.64E-10	-1.28E-10
-10.0	-2.29E-10	-7.77E-11	-2.01E-06	-1.46E-10	-1.69E-07	-1.63E-10	-4.48E-10
-12.0	-2.08E-10	-1.04E-10	-9.04E-06	-1.93E-10	-8.50E-07	-2.47E-10	-9.44E-09
-14.0	-2.50E-10	-9.52E-11	-1.00E-03	-1.72E-10	-6.64E-04	-2.66E-10	-9.99E-04
-16.0	-2.48E-10	-9.52E-11	-1.00E-03	-2.19E-10	-1.00E-03	-2.61E-10	-1.00E-03
-18.0	-2.84E-10	-9.88E-11	-1.00E-03	-2.42E-10	-1.00E-03	-2.40E-10	-1.00E-03
-20.0	-2.90E-10	-1.14E-10	-1.00E-03	-2.40E-10	-1.00E-03	-2.60E-10	-1.00E-03
2.0	3.50E-10	1.06E-10	1.74E-05	4.43E-10	1.26E-05	3.56E-10	2.42E-07
4.0	1.36E-10	7.92E-11	8.78E-05	2.24E-10	8.24E-05	1.44E-10	3.04E-06
6.0	1.82E-10	5.68E-11	6.85E-04	2.10E-10	3.77E-04	1.50E-10	8.47E-05
8.0	1.59E-10	3.21E-11	1.00E-03	1.32E-10	1.00E-03	2.01E-10	1.00E-03
10.0	1.42E-10	4.25E-11	1.00E-03	1.70E-10	1.00E-03	1.44E-10	1.00E-03
12.0	1.56E-10	6.57E-11	1.00E-03	2.06E-10	1.00E-03	1.67E-10	1.00E-03
14.0	2.20E-10	3.66E-11	1.00E-03	1.85E-10	1.00E-03	1.92E-10	1.00E-03
16.0	2.32E-10	5.72E-11	1.00E-03	2.06E-10	1.00E-03	2.05E-10	1.00E-03
18.0	2.75E-10	1.02E-10	1.00E-03	2.70E-10	1.00E-03	2.23E-10	1.00E-03
20.0	7.06E-10	5.46E-10	1.00E-03	5.11E-10	1.00E-03	5.35E-10	1.00E-03

Run #	Pre	33	34
DUT	3	3	3
Run Vds (V):	n/a	-30	-40
Run Vgs (V):	n/a	5	5
Ion Species	n/a	Ag	Ag
Vgs (V)	Ig (A)	Ig (A)	Ig (A)
0.0	-3.49E-11	-1.85E-11	-2.66E-11
-2.0	-8.44E-11	-4.08E-11	-3.72E-11
-4.0	-1.40E-10	-5.04E-11	-6.50E-11
-6.0	-1.14E-10	-6.04E-11	-6.92E-11
-8.0	-1.51E-10	-7.77E-11	-7.58E-11
-10.0	-1.88E-10	-8.25E-11	-1.39E-10
-12.0	-2.38E-10	-8.23E-11	-2.77E-10
-14.0	-2.22E-10	-9.71E-11	-8.29E-10
-16.0	-2.47E-10	-1.05E-10	-2.92E-09
-18.0	-2.49E-10	-1.13E-10	-1.00E-03
-20.0	-2.82E-10	-1.13E-10	-1.00E-03
2.0	4.24E-10	1.25E-10	1.53E-04
4.0	1.31E-10	6.90E-11	1.00E-03
6.0	1.54E-10	5.78E-11	1.00E-03
8.0	1.71E-10	7.06E-11	1.00E-03
10.0	1.78E-10	6.05E-11	1.00E-03
12.0	1.79E-10	5.42E-11	1.00E-03
14.0	1.94E-10	7.86E-11	1.00E-03
16.0	2.31E-10	7.22E-11	1.00E-03
18.0	2.78E-10	9.77E-11	1.00E-03
20.0	5.54E-10	3.81E-10	1.00E-03