Single Event Latchup (SEL) Report for AP54RHC Product Family

This report covers the Heavy Ion Single Event Latchup (SEL) characterization results for the devices in the AP54RHC product family. The report specifies the measured latch up performance impact to the AP54RHC family up to an effective LET of 80 MeV*cm2/mg. The results show that the AP54RHC product family does not show susceptibility to SEL up to the specified effective LET and maximum rated power supply voltage.

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1 Overview

It is well documented that heavy ion strikes on integrated circuits containing CMOS components can result in Single Event Latchup (SEL), Single Event Burnout (SEB), and Single Event Gate Rupture (SEGR). SEL occurs when the ion passing through the circuit creates a dense track of electron-hole pairs that results in triggering parasitic bipolar structures. For specific circuit layouts, such as illustrated in the device cross section of Figure 1, a circuit with positive feedback is formed. The parasitic junctions necessary to create this feedback loop are created when a NMOS and PMOS are laid out in proximity, as in the well-known case of an inverter. When the distance between these devices (dX2) is small and the well tap distances (dX1 and dX3) are large, positive feedback is possible. This well-known circuit topology is known as a silicon-controlled rectifier (SCR). Once transient currents induced by heavy ion passage turn on the parasitic bipolar transistors in Figure 2, a low impedance path between the power supply (VDD) node and ground (GND) is created. Once the SCR circuit has turned on in the latched state, catastrophic failure is possible and the only way to clear this fault is to cycle the power supply. The AP54RHC family has been optimized to prevent single event latchup from being of concern.

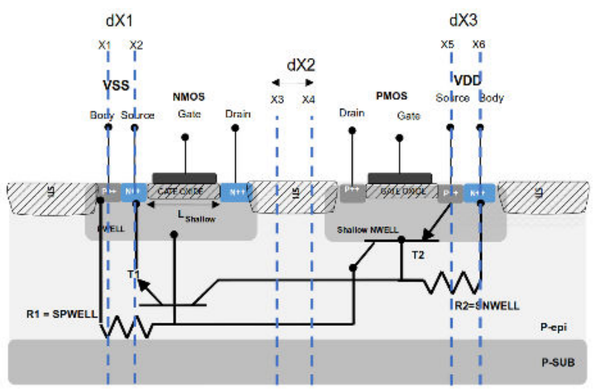

Figure 1: Cross Section of Parasitic SCR

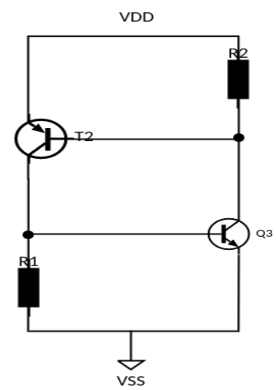

Figure 2: Schematic of SCR

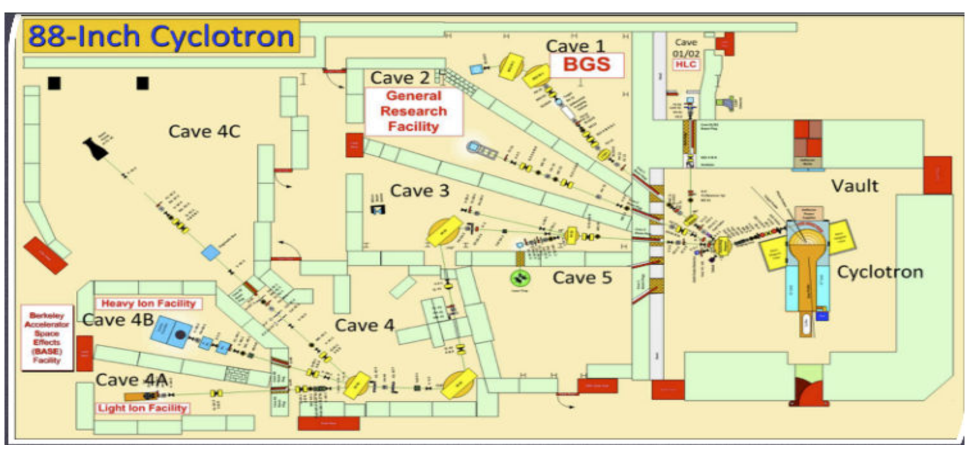

Figure 3: Map of LBNL 88-Inch Facility. SEE Testing Performed in Cave 4B

2 Facilities Description

The single event testing conducted in this report occurred April 10th, 2019 at the Lawrence Berkeley National Laboratories (LBNL) using the 88-inch cyclotron. This facility is managed by the University of California for the United States Department of Energy. Berkeley Accelerator Space Effects (BASE) Facility is home to the 88-Inch Cyclotron. The 88-Inch Cyclotron is a 300-ton, K=140 sector-focused cyclotron with both light- and heavy-ion capabilities. Protons and other light-ions are available at high intensities (10-20 pA) up to maximum energies of 60 MeV (protons), 65 MeV (deuterons), 170 MeV (3He), and 130 MeV (4He).

Ion	Cocktail (AMeV)	Energy (MeV)	Z	A	Chg. State	% Nat. Abund.	LET 0° (MeV/mg/cm2)	LET 60°	Range (Max) (µm)
B	4.5	44.90	5	10	+2	19.9	**1.65**	3.30	78.5
N	4.5	67.44	7	15	+3	0.37	**3.08**	6.16	67.8
Ne	4.5	89.95	10	20	+4	90.48	**5.77**	11.54	53.1
Si	4.5	139.61	14	29	+6	4.67	**9.28**	18.56	52.4
Ar	4.5	180.00	18	40	+8	99.6	**14.32**	28.64	48.3
V	4.5	221.00	23	51	+10	99.75	**21.68**	43.36	42.5
Cu	4.5	301.79	29	63	+13	69.17	**29.33**	58.66	45.6
Kr	4.5	378.11	36	86	+17	17.3	**39.25**	78.50	42.4
Y	4.5	409.58	39	89	+18	100	**45.58**	91.16	45.8
Ag	4.5	499.50	47	109	+22	48.161	**58.18**	116.36	46.3
Xe	4.5	602.90	54	136	+27	8.9	**68.84**	137.68	48.3
Tb	4.5	724.17	65	159	+32	100	**77.52**	155.04	52.4
Ta	4.5	805.02	73	181	+36	99.988	**87.15**	174.30	53.0
Bi*	4.5	904.16	83	209	+41	100	**99.74**	199.48	52.9
B	10	108.01	5	11	+3	80.1	**0.89**	1.78	305.7
O	10	183.47	8	18	+5	0.2	**2.19**	4.38	226.4
Ne	10	216.28	10	22	+6	9.25	**3.49**	6.98	174.6
Si	10	291.77	14	29	+8	4.67	**6.09**	12.18	141.7
Ar	10	400.00	18	40	+11	99.6	**9.74**	19.48	130.1
V	10	508.27	23	51	+14	99.75	**14.59**	29.18	113.4
Cu	10	659.19	29	65	+18	30.83	**21.17**	42.34	108.0
Kr	10	885.59	36	86	+24	17.3	**30.86**	61.72	109.9
Y	10	928.49	39	89	+25	100	**34.73**	69.46	102.2
Ag	10	1039.42	47	107	+29	51.839	**48.15**	96.30	90.0
Xe	10	1232.55	54	124	+34	0.1	**58.78**	117.56	90.0
Au*	10	1955.87	79	197	+54	100	**85.76**	171.52	105.9
He*	16	43.46	2	3	+1	0.000137	**0.11**	0.22	1020.0
N	16	233.75	7	14	+5	99.63	**1.16**	2.32	505.9
O	16	277.33	8	17	+6	0.04	**1.54**	3.08	462.4
Ne	16	321.00	10	20	+7	90.48	**2.39**	4.78	347.9
Si	16	452.10	14	29	+10	4.67	**4.56**	9.12	274.3
Cl	16	539.51	17	35	+12	75.77	**6.61**	13.22	233.6
Ar	16	642.36	18	40	+14	99.600	**7.27**	14.54	255.6
V	16	832.84	23	51	+18	99.750	**10.90**	21.80	225.8
Cu	16	1007.34	29	63	+22	69.17	**16.53**	33.06	190.3
Kr	16	1225.54	36	78	+27	0.35	**24.98**	49.96	165.4
Xe*	16	1954.71	54	124	+43	0.1	**49.29**	98.58	147.9
C	20	240.00	6	12	+5	98.900	**0.72**	1.44	813.1
Ne	20	400.00	10	20	+8	90.480	**2.00**	3.99	504.5
Al	20	540.00	13	27	+11	100.000	**3.36**	6.72	428.7
Ar	20	800.00	18	40	+16	99.600	**6.27**	12.53	356.5
Cu	20	1260.00	29	65	+25	30.830	**14.12**	28.24	288.4
Kr	20	1560.00	36	78	+32	0.350	**22.62**	45.24	221.7
Y	20	1780.00	39	89	+36	100.000	**24.82**	49.64	229.2
Ag	20	2180.00	47	109	+44	48.161	**34.24**	68.48	212.9
Xe	20	2480.00	54	124	+47	0.100	**45.40**	90.80	193.8
N	30	425.45	7	15	+7	0.370	**0.76**	1.52	1370.0
O	30	490.22	8	17	+8	0.04	**0.98**	1.96	1220.0
Ne	30	620.00	10	21	+10	0.27	**1.48**	2.96	1040.0
Ar	30	1046.11	18	36	+17	0.337	**4.87**	9.74	578.1

*Special request only. **Ion isotopes and charge states subject to change without notice.
LETs calculated with SRIM using a silicon target in vacuum.

Figure 4: LBNL Available Beams and Characteristics

For this test, the single event testing (SEE) was conducted in Cave 4B in air. Figure 3 shows a map of the Lawrence Berkeley National Laboratory Cyclotron Facility, including Cave 4B. For dosimetry, five Hamamatsu R647 photomultiplier tubes (PMTs) are used. Four PMTs are placed around the edge of the beam, and one is placed in the middle. These PMTs are calibrated by Cyclotron operations staff. Just before a run, each ion is calibrated using the five PMTs. During the test, the center PMT is removed to permit exposure of the target. All PMTs currently use YAP:Ce crystals that have proven to show minimal, if any, degradation in performance after extended periods of time in high-flux, high-LET beams.

3 Radiation Test Conditions

Apogee's AP54RHC11 Triple Input 3 Channel AND was irradiated using Xe at the devices maximum rated bias condition of VDD = 5.5 V. Although the AP54RHC11 was the only part tested in the AP54RHC family, the remaining parts of the family are qualified by similarity (QBS) given that all parts in the family use the same base silicon layers. A single top-level metal layer is used to set the Boolean functionality and is the only difference between die in the members family, as shown in Figure 6. In addition, during this test, the 4 kV ESD cells used for the AP54RHC product family were also tested to determine if these large, heavily metallized structures would experience SEB/SEGR.

Figure 5: Breakout board in beam

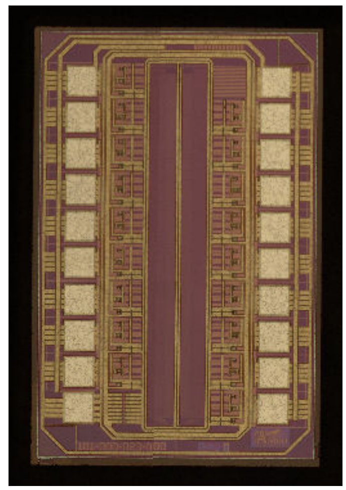

Figure 6: Unbonded die

The material tested was fabricated in TSI Semiconductor's Roseville, California 180 nm HV foundry. The parts used in this testing were built from wafer 12 whose parent wafer lot was RG91V2560B. This wafer went through a backgrind to 11 mils at TSI. The process control monitor (PCM) data was reviewed, was within process control limits, and was deemed to be nominal silicon representative of the technology.

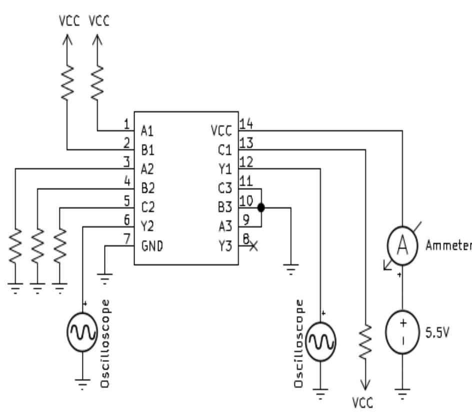

Figure 7: Bias Diagram

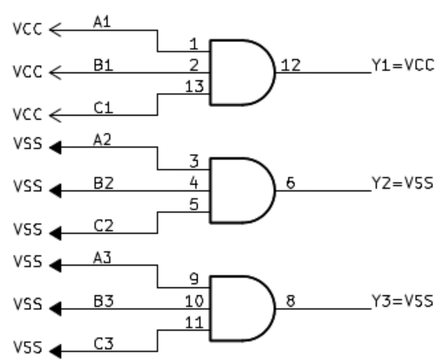

Figure 8: Logical configuration of 3 channels

The Devices Under Test (DUTs) were bonded out in ceramic packages with the lids taped on to allow for exposure of the die to the ion beam. The DUTs were placed in sockets on a breakout board shown in Figure 5 that allowed the pins to be configured as per the bias diagram in Figure 7. During testing, the DUTs were irradiated to a minimum fluence of 1e7 ions/cm2 using the 16 MeV/n beam with a flux that varied from 2.7e4 to 3.5e4 (ions/cm^2-s). To elevate the temperature of the die, a hot air gun was directed at the DUT, as illustrated Figure 5. The table shown in 4 details all of the available beams available at LBNL and their pertinent characteristics. The temperature was remotely monitored from the control room by means of a thermocouple attached to the device under test (DUT). To determine if a latchup event had occurred, the power supply current was remotely monitored and logged. Any sustained deviation above the pre-irradiated supply current level would be counted as a latchup event. If a latchup event were detected, the power supply could be remotely cycled from the control room to reset the DUT.

4 Summary

All circuits were characterized for SEL immunity using Xe at an effective LET of 80 MeV*cm2/mg. The results of the heavy ion testing are shown in Table 1. Two DUTs with serial numbers 1 and 2 were tested for the ESD clamps. Additionally, each DUT had 2 ESD clamps bonded out, which allowed a total of 4 ESD cells to be evaluated. Over the 4 runs, DUTs 1 and 2 were exposed to a maximum effective LET 80 MeV*cm2/mg at 100C with no latch-up events recorded. The second device, labeled Triple 3 AND was the AP54RHC11. During the three runs, the device had its channels biased per the diagram in Figure 8. In aggregate, 9 input buffers and 3 output buffers were exposed to a maximum effective LET 80 MeV*cm2/mg at 100C with no latch-up events recorded. Although, the purpose of this test was to determine if the AP54RHC family was susceptible to latchup, during each run the outputs of the 2 of the 3 AND gates (Biased High and Biased Low) were monitored with an oscilloscope. Although quantitative cross-sectional data was not gathered, during the runs no major transients were noted on either output. This was as expected due to the redundancy in the AP54RHC families I/O cells. The focus of the next test will be to gather broad beam SET statistics on the I/Os.

Table 1: AP54RHC SEL Test Results.

Unit 1 AP54RHC Family ESD 5V and 5V Isolated							
Run #	**Ion**	**LET**	**Temperature**	**VDD**	**Angle**	**Fluence (Ions/cm^2)**	**Result**
109	Xe	80	25°C	5.0V	45°	1.0e+07	Passed/No Latchup
110	Xe	80	95°C	5.0V	45°	1.0e+07	Passed/No Latchup
111	Xe	80	95°C	5.5V	45°	1.0e+07	Passed/No Latchup
Unit 2 ESD 5V and 5V Isolated							
112	Xe	80	100°C	5.5V	45°	1.0e+07	Passed/No Latchup
Unit 1 AP54RHC Family Triple 3 AND (Monitoring 2 IO Outputs Driving High/Low)							
113	Xe	80	25°C	5.0V	45°	1.0e+07	Passed/No Latchup
114	Xe	80	100°C	5.0V	45°	1.0e+07	Passed/No Latchup
115	Xe	80	100°C	5.5V	45°	1.0e+07	Passed/No Latchup

5 Revision History

REVISION	DESCRIPTION	DATE
A00	Initial internal release.	November 5, 2020

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