Single Event Effects

Heavy Ions Test Report

Test type	Single-Event Upset, Single Event Latchup
Part Reference	PC28F00AM29EW
Tested function	NOR Flash Memory
Chip manufacturer	Micron
Test Facility	RADEF, Jyvaskyla, Finland
Test Date	December 2017
Customer	ESA ESTEC

BCE 5524

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DOCUMENTATION CHANGE NOTICE

Issue	Date	Page	Change Item	
01	25/06/2018	All	Original issue	
02		Page 9	In Figure 7 - NOR Flash test sequences Was 450 blocks Is 900 blocks	
		Page 12	Added: “Buffer read error consist in the 16 words of the read buffer in error with data read mainly to “0000” instead of “AAAA” or “5555”.”	
		Page 13	Figure 1: SEU buffer read error static cross-section for X=1 "OFF" sequence. Y axis title changed to Buffer read error cross-section / word” Was Considering the word errors addresses, even not knowing the memory cells array mapping, it is very likely that an ion hit can upset more than 1 word as buffer reads in error are distant of each other. This can be derived from the number of buffer reads in error (on a total of 1 843 200 buffer reads) and the number of words in error, see Table 4. Is For each word error address, the corresponding read buffer number is identified. Considering the word errors addresses, even not knowing the memory cells array mapping, it is very likely that an ion hit can upset more than 1 word as buffer reads numbers are distant of each other. This can be derived from the number of buffer read numbers involved (on a total of 1 843 200 buffer read numbers) and the number of words in error, see Table 4.	
		Page 14	“Due to DUT MLC technology where 2 bits are stored in 1 memory cell (4 states), we can assume than the logic state of a fully charge cell is 00 and the logic state of an erased cell is 11.” added	
		Page 19	Was Figure 2: SEU dynamic word error cross-section for "Erase/Write" sequence. Is Figure 3: logic errors cross-section for "Erase/Write" sequence.	

Contributors to this work

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1 Introduction

This report presents results of SEE test campaign for the Micron NOR Flash Memory PC28F00AM29EW. 6 parts were prepared with 2 parts per test sequence. The test campaigns took place at RADEF, Jyvaskyla, Finland in December 2017.

2 Applicable and Reference Documents

Applicable Documents

AD-1 Micron MX29EW Datasheet, m29ew_256mb_2gb.pdf - Rev. C 9/14 EN

AD-2 PC28F00AM29EW physical analysis HRX/RCA/00114

Reference Documents

RD-1. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100

3 Device Information

Device description

PC28F00AM29EW, NOR Flash Memory

Manufacturer:	Micron
Package:	FBGA-64
Marking:	logo 00AM29EWH M4110131 Z4091BCYA M C 08 e1
Date code	1409
Technology :	CMOS, 65nm multilevel cell (**MLC**) process
Die dimensions :	7.1 mm x 8.2 mm

This 1Gb memory is composed of 1 die of 1024 blocks of 65536 x16 bits words. Write Buffer is 512 words while read buffer is 16 words.

Device and die identification

Figure 4: Package, top.

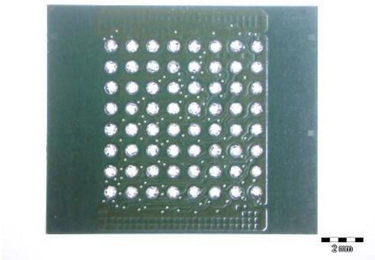


Figure 5: Package, bottom.

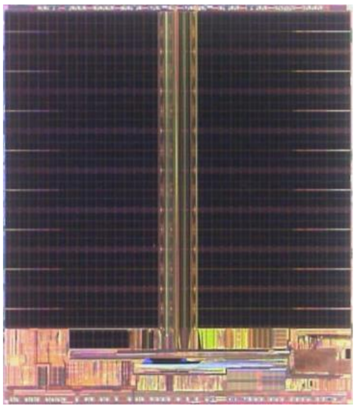


Figure 6: Die view.

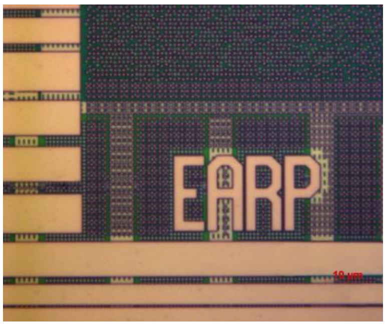


Figure 7: Die marking.

Samples preparation

Samples have been opened chemically and tested for their functionality before the test campaign. 3 daughter boards have been tested for a total of 6 parts.

4 Test Setup

Figure 8 shows the principle of the single event test system.

The test system is based on a Virtex4 FPGA (Xilinx). It runs at 50 MHz. The test board has 271 I/Os which can be configured using several I/O standards.

The test board includes the voltage/current monitoring and the latch-up management of the DUT power supplies up to 24 independent channels.

The communication between the test chamber and the controlling computer is effectively done by a 100 Mbit/s Ethernet link which safely enables high speed data transfer.

SEL event is detected when the supply current is over a configurable threshold (typically 5 to 10 times the nominal current) and processed:

Once detected, SEL state is maintained for typically 1 or 2ms and power supplies are cut off during a wait time of typically 1 s. These times are configurable.

Each power supply under supervision is monitored independently for SEL detection and processing but subsequent cut off is performed on all power supplies.

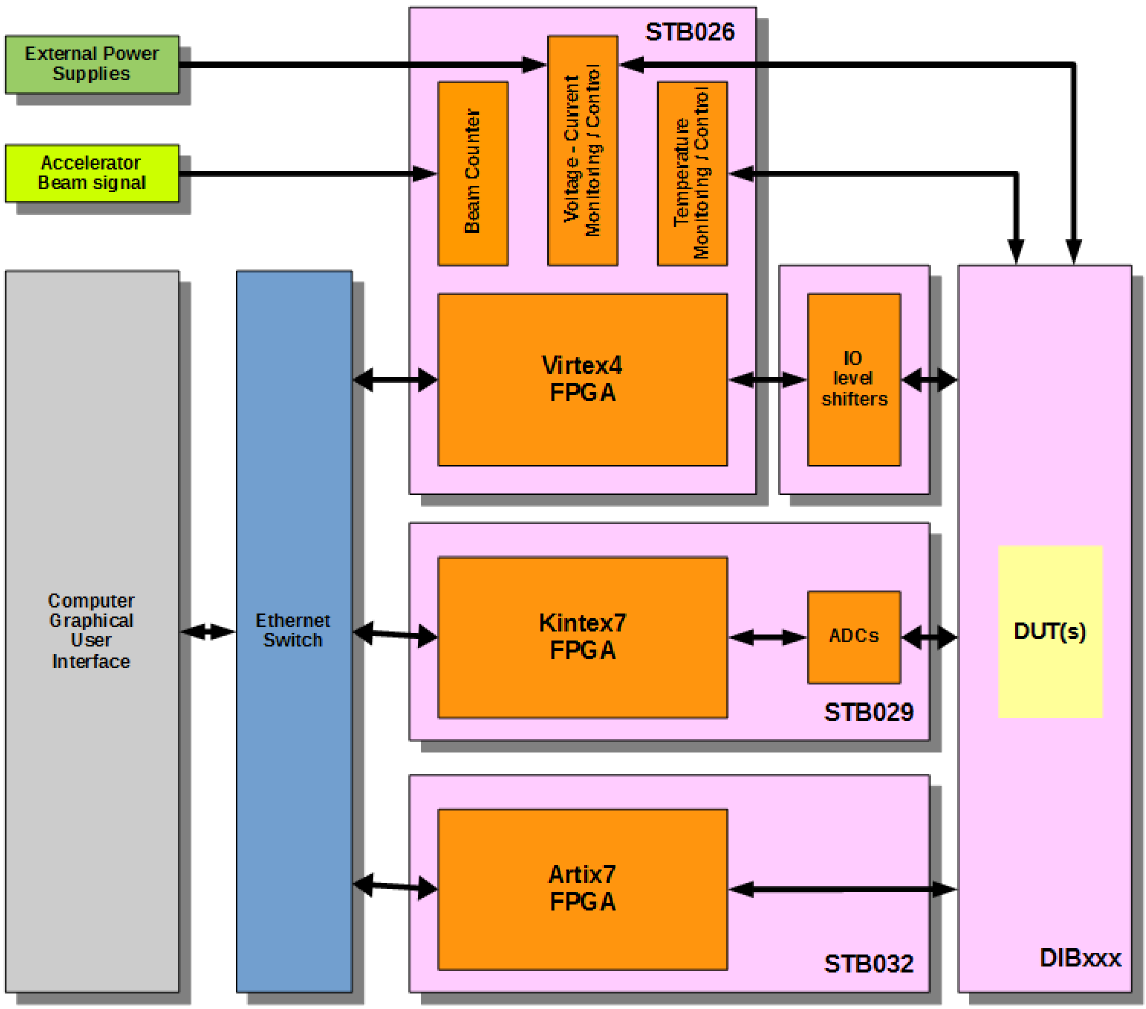


Figure 8: Hirex SEE test setup

A daughter board with 2 samples mounted on it has been designed for this test (DIB294A) and Figure 9 show a picture this board.

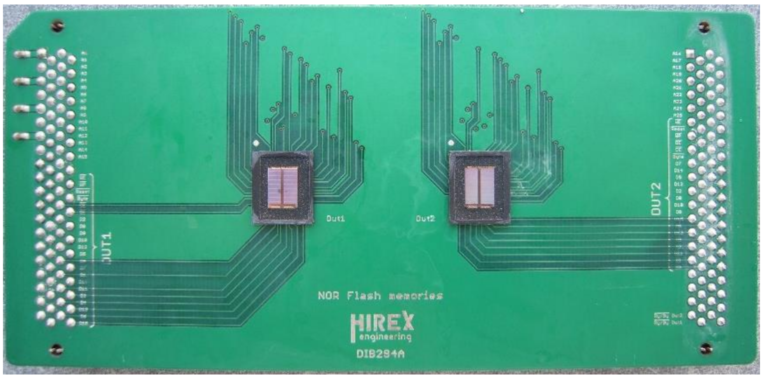


Figure 9 – DIB294A NOR flash daughter board

5 Test sequence

Test modes and their sequence used during the test campaign are summarized in Figure 10. Operations in grey boxes are performed before the irradiation. Operations in white boxes are performed outside the beam when the shutter is closed. Operation in blue boxes are performed under irradiation and operations in yellow boxes are performed once the beam is stopped at the end of the run.

Off sequence

The DUT is turned off after the pre-run. It is then turned back on once the total fluence has been reached and the full chip is read (X=1).

Read sequence

The read sequence (X=3) consists in a loop of a read operation followed by a power-cycle and a second read operation. This sequence focuses on the same 10 blocks of the memory. The pattern used is alternatively 0x66 and 0x99 pattern for this dynamic test.

Both static and dynamic results can be extrapolated based on a single run result. This is done by considering 10 blocks for dynamic behaviour (X=3) and 450 blocks of the chip for static behaviour (X=5).

Erase/Write sequence

During the erase/write (E/W) sequence (X=2), the same 10 blocks are erased and then written under the beam flux. The shutter is then closed to power-cycle the DUT and read twice the blocks outside irradiation. These operations are then looped for the duration of the run.

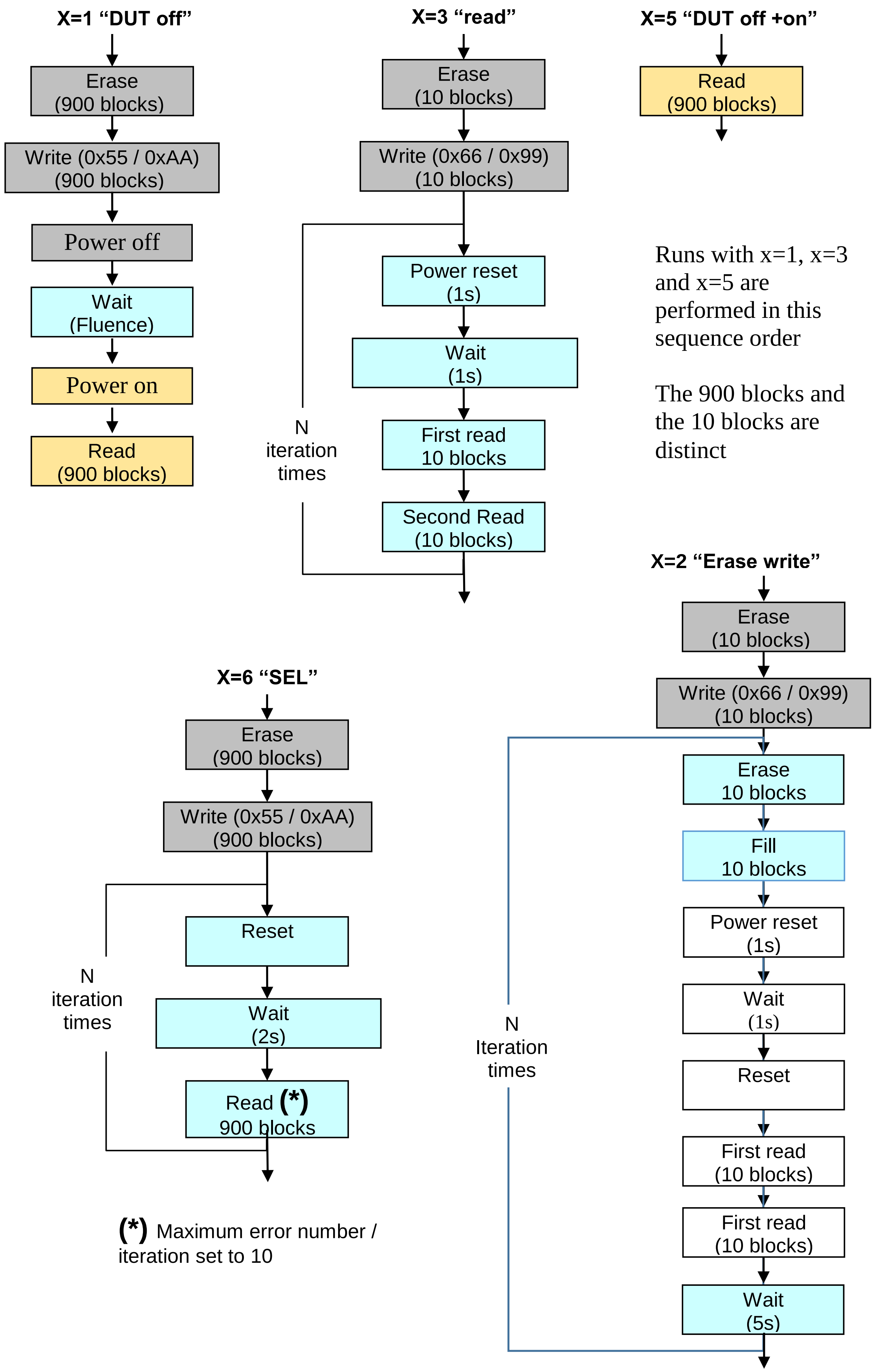


Figure 10 - NOR Flash test sequences

6 RADEF facility

The facility includes a special beam line dedicated to irradiation studies of semiconductor components and devices. It consists of a vacuum chamber including component movement apparatus and the necessary diagnostic equipment required for the beam quality and intensity analysis.

The cyclotron is a versatile, sector-focused accelerator of beams from hydrogen to xenon equipped with three external ion sources: two electron cyclotron resonance (ECR) ion sources designed for high-charge-state heavy ions, and a multicusp ion source for intense beams of protons. The ECR's are especially valuable in the study of single event effects (SEE) in semiconductor devices. For heavy ions, the maximum energy attainable can be determined using the formula,

$$130\ Q^2/M,$$

where Q is the ion charge state and M is the mass in Atomic Mass Units.

Test chamber

Irradiation of components is performed in a vacuum chamber with an inside diameter of 75 cm and a height of 81 cm.

The vacuum in the chamber is achieved after 15 minutes of pumping, and the inflation takes only a few minutes. The position of the components installed in the linear movement apparatus inside the chamber can be adjusted in the X, Y and Z directions. The possibility of rotation around the Y-axis is provided by a round table. The free movement area reserved for the components is 25 cm x 25 cm, which allows one to perform several consecutive irradiations for several different components without breaking the vacuum.

The assembly is equipped with a standard mounting fixture. The adapters required to accommodate the special board configurations and the vacuum feed-throughs can also be made in the laboratory's workshops. The chamber has an entrance door, which allows rapid changing of the circuit board or individual components.

A CCD camera with a magnifying telescope is located at the other end of the beam line to determine accurate positioning of the components. The coordinates are stored in the computer's memory allowing fast positioning of various targets during the test.

Beam quality control

For measuring beam uniformity at low intensity, a CsI(Tl) scintillator with a PIN-type photodiode readout is fixed in the mounting fixture. The uniformity is measured automatically before component irradiation and the results can be plotted immediately for more detailed analysis.

A set of four collimated PIN-CsI(Tl) detectors is located in front of the beam entrance. The detectors are operated with step motors and are located at 90 degrees with respect to each other. During the irradiation and uniformity scan they are set to the outer edge of the beam in order to monitor the stability of the homogeneity and flux.

Two beam wobblers and/or a 0.5 microns diffusion Gold foil can be used to achieve good beam homogeneity. The foil is placed 3 m in front of the chamber. The wobbler-coils vibrate the beam horizontally and vertically, the proper sweeping area being attained with the adjustable coil-currents.

Dosimetry

The flux and intensity dosimeter system contains a Faraday cup, several collimators, a scintillation counter and four PIN-CsI(Tl) detectors. Three collimators of different size and shape are placed 25 cm in front of the device under test. They can be used to limit the beam to the active area to be studied.

At low fluxes a plastic scintillator with a photomultiplier tube is used as an absolute particle counter. It is located behind the vacuum chamber and is used before the irradiation to normalize the count rates of the four PIN-CsI(Tl) detectors.

Used ions

Table 1: Ion beam setting.

Ion	LET^{SRIM} at surface [$MeV.cm^2.mg^{-1}$]	Range [µm]	Beam energy [MeV]
$^{15}N^{4+}$	1.83	202	139
$^{20}Ne^{6+}$	3.63	146	186
$^{40}Ar^{12+}$	10.2	118	372
$^{56}Fe^{15+}$	18.5	97	523
$^{82}Kr^{22+}$	32.1	94	768
$^{131}Xe^{35+}$	60.0	89	1217

SRIM-2003.26

7 Test conditions.

SEU tests were carried out at Vddmin (2.7 V) and room temperature.
Samples for SEL were tested at Vddmax (3.6 V) and a junction temperature of 85°C while performing a dynamic test (read).

8 Results

Detailed results are provided in section 9 with error bars taking into account a 95% confidence level and 10% beam uniformity. For each data set, a Weibull curve has been proposed based on the following equation:

$$F(x) = Sat\left(1 - \exp\left\{-\left[\frac{x - x_0}{W}\right]^S\right\}\right)$$

SEL runs exhibits events on the Vccq line with high current steps around 0.25 A over the detection limit of 100mA. Data and a chronogram example of SEL recorded are presented at the end of section 9. The SEL cross-section at a LET of 60 MeV/mg/cm² is about 4.0E-6 cm²/device.

One DUT failed when tested with Xenon during erase write mode (X=2).

Behavior of MLC cells under heavy ions with 4 states per cell have been observed and described in the words analysis paragraph.

Buffer read errors (16 words) have been observed after “off” or static on conditions.

9 Detailed results

9.1 SEE

X=1 Off sequence

Words errors have been observed as well as buffer read errors.

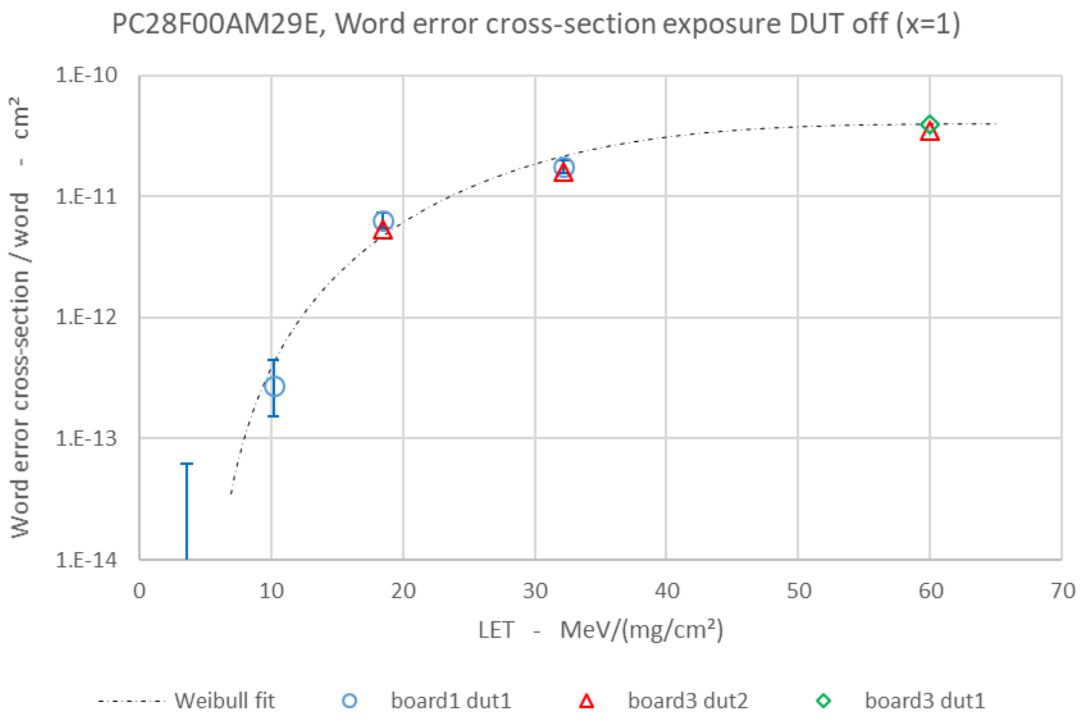
Results for X=1 “off” sequence runs are summarized in Table 2 which gives the number of word errors and buffer read errors recorded once DUT is powered on at the end of each run.

A Buffer read error consists in the 16 words of the buffer in error with data read mainly to “0000” instead of “AAAA” or “5555”.

Table 2: SEE results for X=1 "Off" sequence.

Facility	dut_medium	test_mode	interface_comment	power_config	run_number	Facility_run_number	board_id	DUT_under_beam	temperature	Ion	tilt	Eff. LET	run_duration	entered_fluence	first block	last block	Nb Blocks	Word Capacity under test	Words in error	Buf_read error	Word error cross-section / word	Buffer error cross-section / word
RADEF	vacuum	SEU	x=1	2.7V	1	87	1	1	room	Ar	0	10.20	350	1.00E+06	10	909	900	58982400	16	0	2.7E-13	1.0E-15
RADEF	vacuum	SEU	x=1	2.7V	7	91	1	1	room	Ne	0	3.63	46	1.00E+06	10	909	900	58982400	0	0		
RADEF	vacuum	SEU	x=1	2.7V	55	136	1	1	room	Fe	0	18.50	339	1.01E+06	10	909	900	58982400	379	4	6.4E-12	6.7E-14
RADEF	vacuum	SEU	x=1	2.7V	63	140	1	1	room	Kr	0	32.20	76	1.00E+06	10	909	900	58982400	1053	31	1.8E-11	5.3E-13
RADEF	vacuum	SEU	x=1	2.7V	110	164	3	1	room	Xe	0	60.00	143	1.00E+06	10	509	500	32768000	1284	23	3.9E-11	7.0E-13
RADEF	vacuum	SEU	x=1	2.7V	93	154	3	2	room	Fe	0	18.50	103	1.00E+06	10	909	900	58982400	318	10	5.4E-12	1.7E-13
RADEF	vacuum	SEU	x=1	2.7V	97	156	3	2	room	Kr	0	32.20	124	1.00E+06	10	909	900	58982400	953	26	1.6E-11	4.4E-13
RADEF	vacuum	SEU	x=1	2.7V	107	162	3	2	room	Xe	0	60.00	149	1.00E+06	10	509	500	32768000	1137	24	3.5E-11	7.3E-13

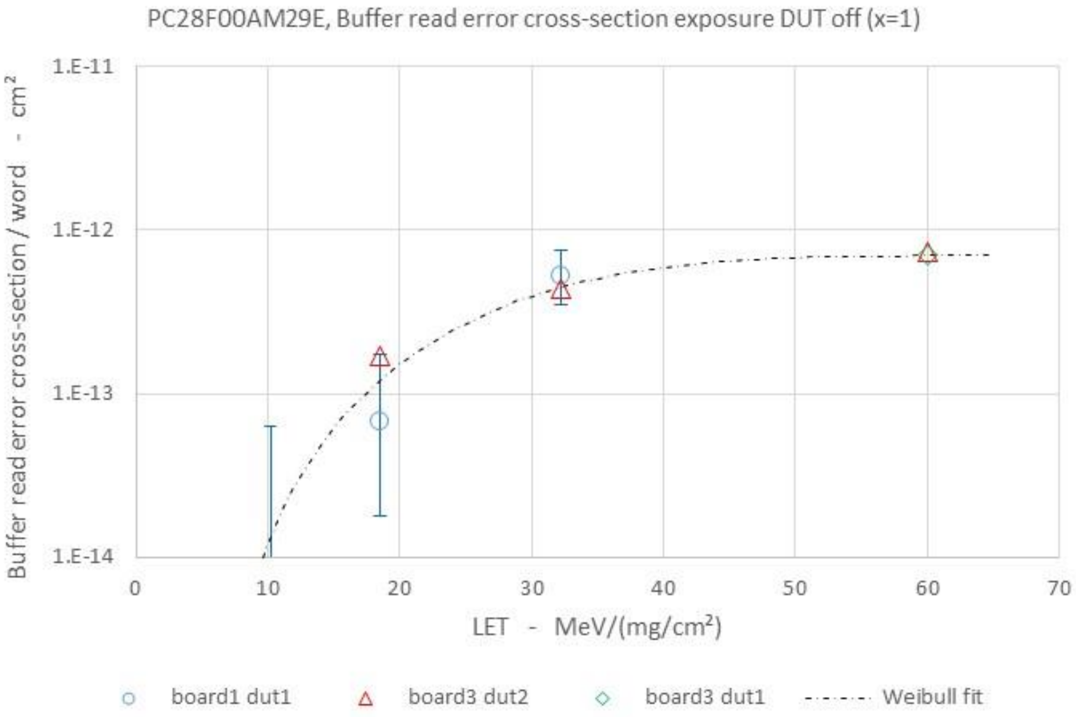
Cross-section results are plotted in Figure 11 for word errors and in Figure 12 for buffer read errors along with a Weibull fit curve.



Weibull parameters

W	30
xo	5
s	2.6
Sat	4E-11

Figure 11: SEU static word error cross-section for X=1 "OFF" sequence.



Weibull parameters

W	27
xo	5
s	2.4
Sat	7.00E-13

Figure 12: SEU buffer read error static cross-section for X=1 "OFF" sequence.

Word errors analysis

SBU and MBU contributions are summarized in Table 3. SBU are counted in the second column (“SBU”), MBU of size 2 are counted in the third column (“mbu2”) and MBU of size 3 are counted in the fourth column (“mbu3”), etc.

Bit error distribution per bit and bit flip transitions are summarised in Table 5: Distribution of 2 consecutive bit flips per transition.

For each word error address, the corresponding read buffer number is identified.

Considering the word errors addresses, even not knowing the memory cells array mapping, it is very likely that an ion hit can upset more than 1 word as buffer reads numbers are distant of each other. This can be derived from the number of buffer read numbers involved (on a total of 1 843 200 buffer read numbers) and the number of words in error, see Table 4.

Considering the bit errors positions inside each word, it appears that many 2 consecutive bits but not always are in error. This is the consequence of the DUT MLC technology where 2 bits are stored in 1 memory cell (4 states) and Table 5 gives the number of 2 consecutive bit errors and the distribution of the two bit transitions.

Table 3: MBU contribution to overall word errors

	SBU	mbu2	mbu3	mbu4	mbu5	mbu6	mbu7	total
run107	501	591	13	30	1	1	0	1137
run097	315	587	15	35	0	1	0	953
run093	44	257	2	14	0	1	0	318
run110	555	665	27	35	0	2	0	1284
run063	426	601	6	18	0	2	0	1053
run055	96	264	2	17	0	0	0	379
run001	1	14	0	0	0	1	0	16
run007	0	0	0	0	0	0	0	0

Table 4: Distribution of bit flips per bit and per bit transition

	Word errors	buffer_read	bit flip	trans 0->1	trans 1->0	bit0	bit1	bit2	bit3	bit4	bit5	bit6	bit7	bit8	bit9	bit10	bit11	bit12	bit13	bit14	bit15
run107	1137	518	1853	712	1141	126	101	110	99	138	116	141	112	109	92	120	104	125	101	148	111
run097	953	429	1680	709	971	114	89	127	89	129	97	114	80	123	87	127	99	124	89	113	79
run093	318	141	626	295	331	49	41	36	33	39	38	36	32	42	42	42	37	47	44	36	32
run110	1284	578	2118	822	1296	158	135	148	107	155	134	135	120	128	99	131	117	156	126	140	129
run063	1053	473	1730	686	1044	138	91	149	100	135	85	112	70	138	84	121	76	123	81	133	94
run055	379	171	698	310	388	53	41	43	33	43	37	39	30	62	44	54	44	51	42	46	36
run001	16	8	35	18	17	3	2	5	5	4	4	2	2	0	0	1	1	1	1	2	2
run007	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5: Distribution of 2 consecutive bit flips per transition.

	nb bits couple n, n+1 n even	transition bit n: 1->0 bit n+1: 0->1	transition bit n: 0-> 1 bit n+1: 1->0
run107	654	594	60
run097	666	616	50
run093	289	256	33
run110	753	700	53
run063	638	583	55
run055	299	274	25
run001	17	16	1
run007	0	0	0

Due to DUT MLC technology where 2 bits are stored in 1 memory cell (4 states), we can assume than the logic state of a fully charge cell is 00 and the logic state of an erased cell is 11.
We can conclude that the loss of charge in the impacted cell is nine times more frequent than an increase of the stored charge.

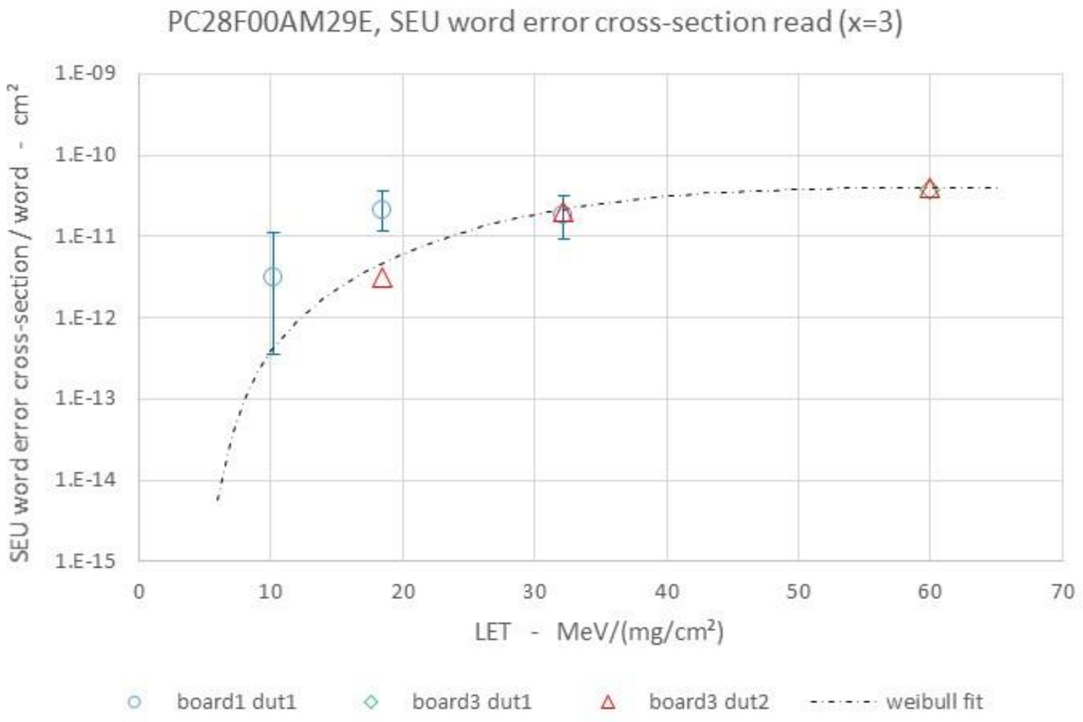
Read sequence

Results for X=3 “read” sequence runs are given in Table 6. The SEU static value is computed from the blocks that are not used during read operation (X=5).

Table 6: SEE results for X=3 "Read" sequence.

Facility	dut_medium	run_number	test_mode	power_config	Facility_run_number	interface_comment	board_id	DUT_under_beam	temperature	Ion	tilt	Eff. LET	run_duration	entered_fluence	bock start	block end	nb blocks	Nb wordes	logic	buf_read	SEU cell	Logic errors Cross-section	SEU error cross-section
RADEF	vacuum	4	SEU	2.7V	90	x=3	1	1	room	Ar	0	10.2	365	1.00E+06	0	9	10	655360	0		2		3.1E-12
RADEF	vacuum	10	SEU	2.7V	94	x=3	1	1	room	Ne	0	3.6	46	1.00E+06	0	9	10	655360	0		0		
RADEF	vacuum	60	SEU	2.7V	139	x=3	1	1	room	Fe	0	18.5	316	1.00E+06	0	9	10	655360	0	1	14		2.1E-11
RADEF	vacuum	64	SEU	2.7V	141	x=3	1	1	room	Kr	0	32.2	73	1.00E+06	0	9	10	655360	3		12	3.0E-06	1.8E-11
RADEF	vacuum	111	SEU	2.7V	165	x=3	3	1	room	Xe	0	60.0	144	1.00E+06	0	9	10	655360	7	1	25	7.0E-06	3.8E-11
RADEF	vacuum	94	SEU	2.7V	155	x=3	3	2	room	Fe	0	18.5	107	1.00E+06	0	9	10	655360	1		2	1.0E-06	3.1E-12
RADEF	vacuum	98	SEU	2.7V	157	x=3	3	2	room	Kr	0	32.2	121	1.00E+06	0	9	10	655360	0		13		2.0E-11
RADEF	vacuum	108	SEU	2.7V	163	x=3	3	2	room	Xe	0	60.0	151	1.00E+06	0	9	10	655360	1	3	26	1.0E-06	4.0E-11

SEU word correspond to 1 a word error detected at each read out of the two consecutive reads.
Buffer read error corresponds to the entire buffer read (16 words) in error at one of the two consecutive reads
Logic error: 1 or several blocks in error either during one read or the two consecutive reads



Weibull parameters:

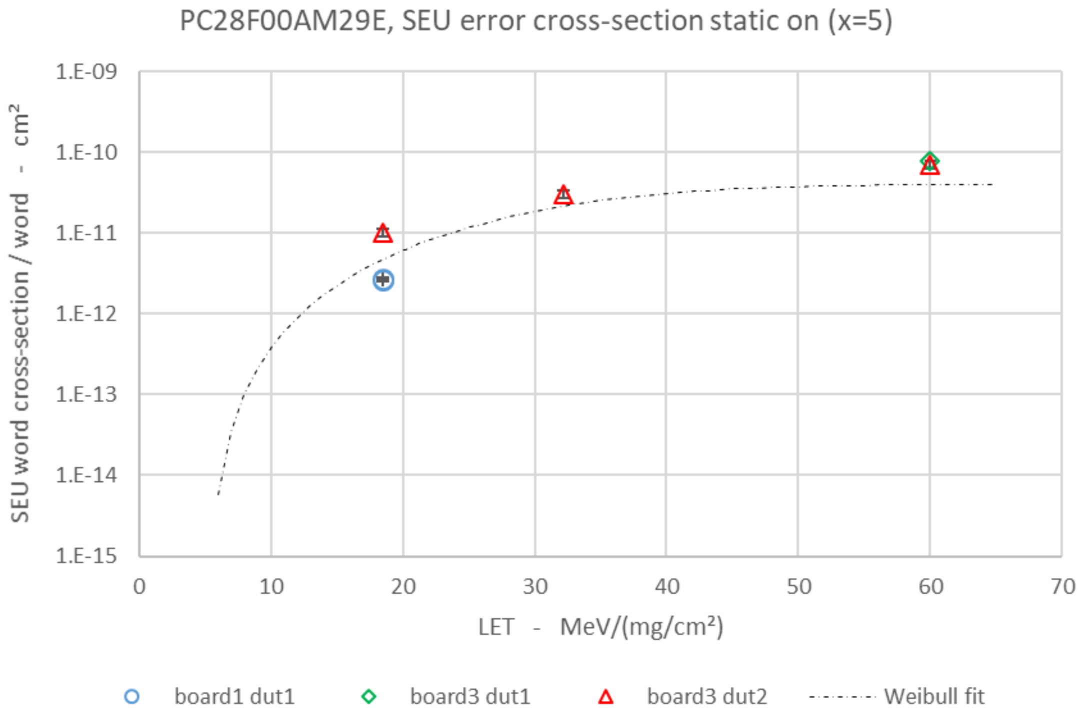
W	30
xo	5
s	2.6
Sat	4E-11

Figure 13: SEU word error cross-section / word for X=3 "read" sequence.

Figure 14: Logic error cross-section / device for X=3 "read" sequence.

Table 7: SEE results for X=5 "Static on" sequence.

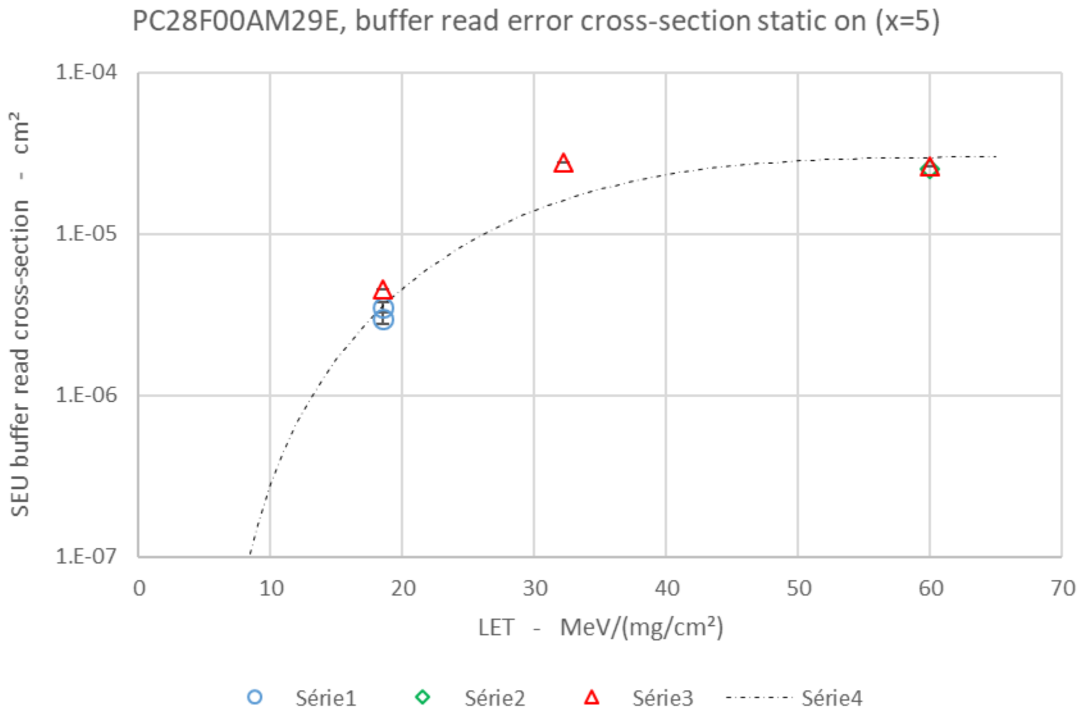
Facility	dut_medium	run_number	Facility_run_number	interface_comment	power_config	test_mode	board_id	DUT_under_beam	temperature	Ion	tilt	Eff. LET	Fluence previous runs x=1 & x=3	first block	last block	Nb Blocks	Word Capacity under test	Words in error	Buf_read in error	SEU cells cross-section	Buffer_read cross-section
RADEF	vacuum	61	-	x=5	2.7V	SEU	1	1	room	Fe	0	18.5	2.00E+06	10	909	900	58982400	323	7	2.7E-12	3.5E-06
RADEF	vacuum	62	-	x=5	2.7V	SEU	1	1	room	Fe	0	18.5	2.00E+06	10	909	900	58982400	304	6	2.6E-12	3.0E-06
RADEF	vacuum	112	-	x=5	2.7V	SEU	3	1	room	Xe	0	60.0	2.00E+06	10	509	500	32768000	5142	51	7.8E-11	2.6E-05
RADEF	vacuum	95	-	x=5	2.7V	SEU	3	2	room	Fe	0	18.5	2.00E+06	10	909	900	58982400	1216	9	1.0E-11	4.5E-06
RADEF	vacuum	99	-	x=5	2.7V	SEU	3	2	room	Kr	0	32.2	2.00E+06	10	909	900	58982400	3639	55	3.1E-11	2.8E-05
RADEF	vacuum	109	-	x=5	2.7V	SEU	3	2	room	Xe	0	60.0	2.00E+06	10	509	500	32768000	4667	52	7.1E-11	2.6E-05



Weibull parameters:

W	30
xo	5
s	2.6
Sat	4E-11

Figure 15: SEU word cross-section / word for X=5 "static on" sequence.



Weibull parameters:

W	30
xo	5
s	2.6
Sat	3.00E-05

Figure 16: buffer read error cross-section / device for X=5 "static on" sequence.

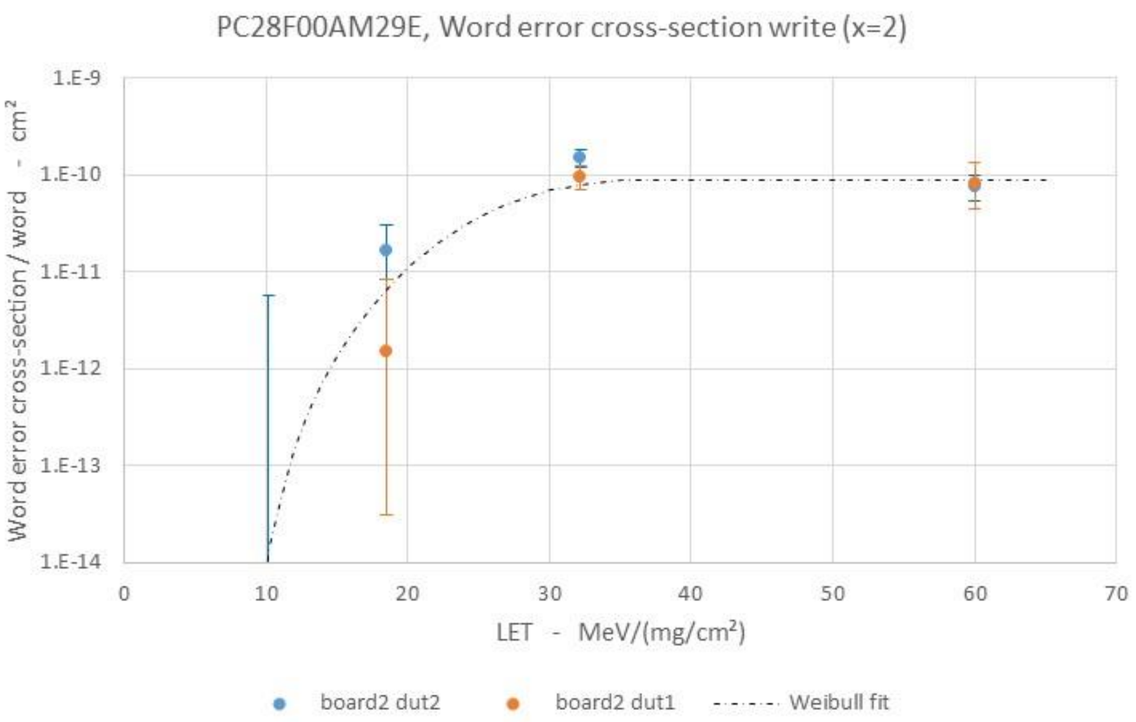
Erase/Write sequence

Results for “Erase/Write” sequence runs are given in Table 8. One device lost its functionality during Xenon test run.

Table 8: SEE results for "Erase/Write" sequence.

Facility	dut_medium	test_mode	power_config	interface_comment	run_number	Facility_run_number	board_id	DUT_under_beam	temperature	Ion	tilt	Eff. LET	run_duration	entered_fluence	bock start	block end	nb blocks	Nb wordes	SEU word	block error	BUF_write	fill error buf_w	erase error block	Total logic	SEU logic X-section	SEU word X-section
RADEF	vacuum	SEU	2.7V	x=2	13	95	2	1	room	Ne	0	3.6	57	1.0E+06	0	9	10	655360	0	0	0	0	0	0		
RADEF	vacuum	SEU	2.7V	x=2	16	104	2	1	room	Ar	0	10.2	246	1.0E+06	0	9	10	655360	0	0	1	0	0	1	1.0E-06	
RADEF	vacuum	SEU	2.7V	x=2	76	148	2	1	room	Fe	0	18.5	137	1.0E+06	0	9	10	655360	0	0	0	0	5	5	5.0E-06	
RADEF	vacuum	SEU	2.7V	x=2	92	153	2	1	room	Fe	0	18.5	139	1.0E+06	0	9	10	655360	11	2	0	1	1	4	4.0E-06	1.7E-11
RADEF	vacuum	SEU	2.7V	x=2	102	159	2	1	room	Kr	0	32.2	188	1.0E+06	0	9	10	655360	98	13	0	0	7	20	2.0E-05	1.5E-10
RADEF	vacuum	SEU	2.7V	x=2	103	160	2	1	room	Xe	0	60.0	267	1.0E+06	0	9	10	655360	49	4	0	0	14	18	1.8E-05	7.5E-11
RADEF	vacuum	SEU	2.7V	x=2	91	152	2	2	room	Fe	0	18.5	149	1.0E+06	0	9	10	655360	1	3	1	0	5	9	9.0E-06	1.5E-12
RADEF	vacuum	SEU	2.7V	x=2	101	158	2	2	room	Kr	0	32.2	157	1.0E+06	0	9	10	655360	62	3	0	2	8	10	1.0E-05	9.5E-11
RADEF	vacuum	SEU	2.7V	x=2	104	161	2	2	room	Xe	0	60.0	70	2.8E+05	0	9	10	655360	15	2	0	0	3	5	1.8E-05	8.3E-11

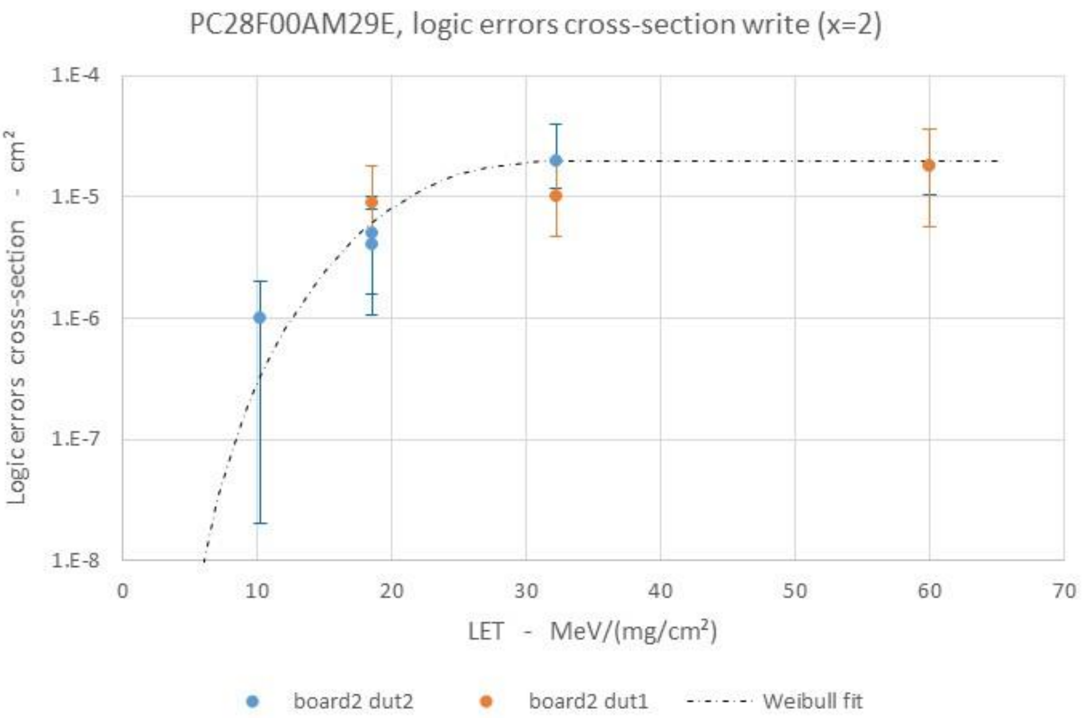
- SEU word correspond to 1-word error detected at each read out of the two consecutive reads.
- Buffer write error corresponds to the entire buffer write (512 words) in error.
- Block corresponds to 1 block in error
- Fill error: 1 or more buffer write fill operation exceeds the allocated time of 10ms.
- Erase error: 1 or more block erase operation exceeds the allocated time of 4s.



Weibull Parameters:

W	20
xo	8
s	4
Sat	9E-11

Figure 17: SEU dynamic word error cross-section for "Erase/Write" sequence.



Weibull Parameters:

W	20
xo	3
s	4
Sat	2.00E-05

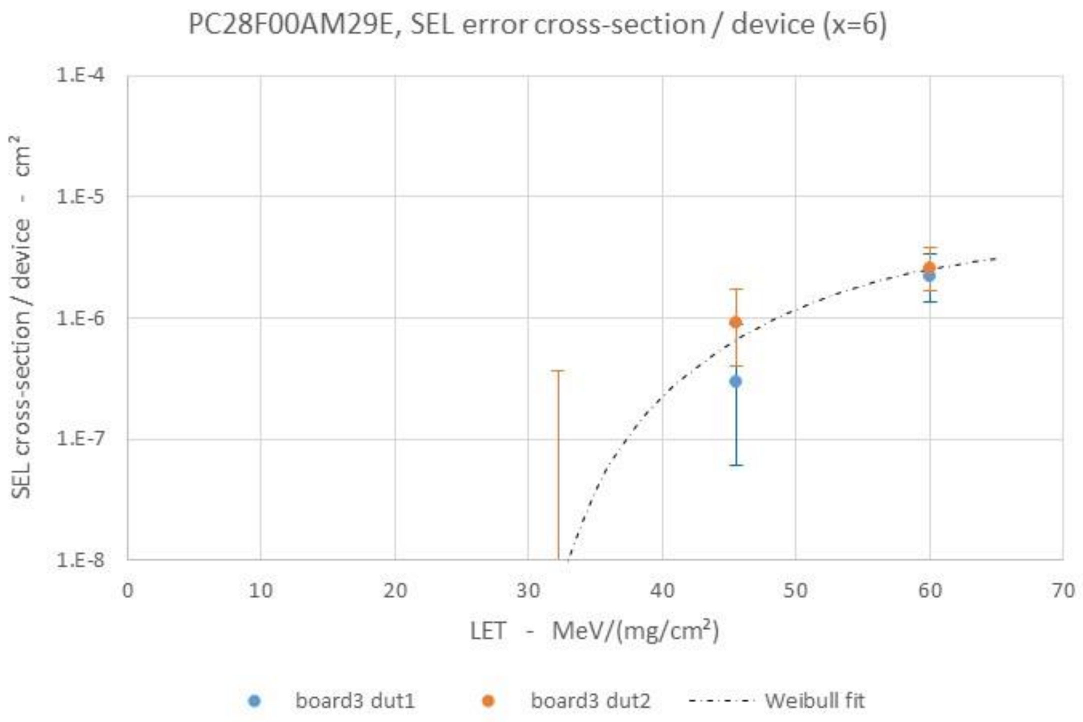
Figure 18: logic errors cross-section for "Erase/Write" sequence.

9.2 SEL tests

Specific runs where carried out at high temperature and Vddmax. During these runs devices are in read mode.
Maximum current spike recorded is about 250mA while current limit was set to100 mA

Table 9: SEL results for PC28F00AM29EW.

Facility	dut_medium	tester_comment	test_mode	power_config	run_number	Facility_run_number	DUT_under_beam	board_id	temperature	Ion	LET	tilt	Eff. LET	run_duration	entered_fluence	Vcc	Vccq	Vccq channel	Vcc channel	X-section Vcc	X-section Vccq
RADEF	vacuum	x=6	SEL	3.6V	113	166	1	3	85	Kr	32.2	0	32.20	353	1.00E+07	0	0	15	16		1.0E-10
RADEF	vacuum	x=6	SEL	3.6V	118	170	1	3	85	Xe	60	0	60.00	249	1.00E+07	0	22	15	16		2.2E-06
RADEF	vacuum	x=6	SEL	3.6V	119	171	1	3	85	Kr	32.2	45	45.54	144	1.00E+07	0	3	15	16		3.0E-07
RADEF	vacuum	x=6	SEL	3.6V	114	167	2	3	85	Kr	32.2	0	32.20	251	1.00E+07	0	0	13	14		1.0E-10
RADEF	vacuum	x=6	SEL	3.6V	117	169	2	3	85	Xe	60	0	60.00	257	1.00E+07	0	26	13	14		2.6E-06
RADEF	vacuum	x=6	SEL	3.6V	120	172	2	3	85	Kr	32.2	45	45.54	149	1.00E+07	0	9	13	14		9.0E-07

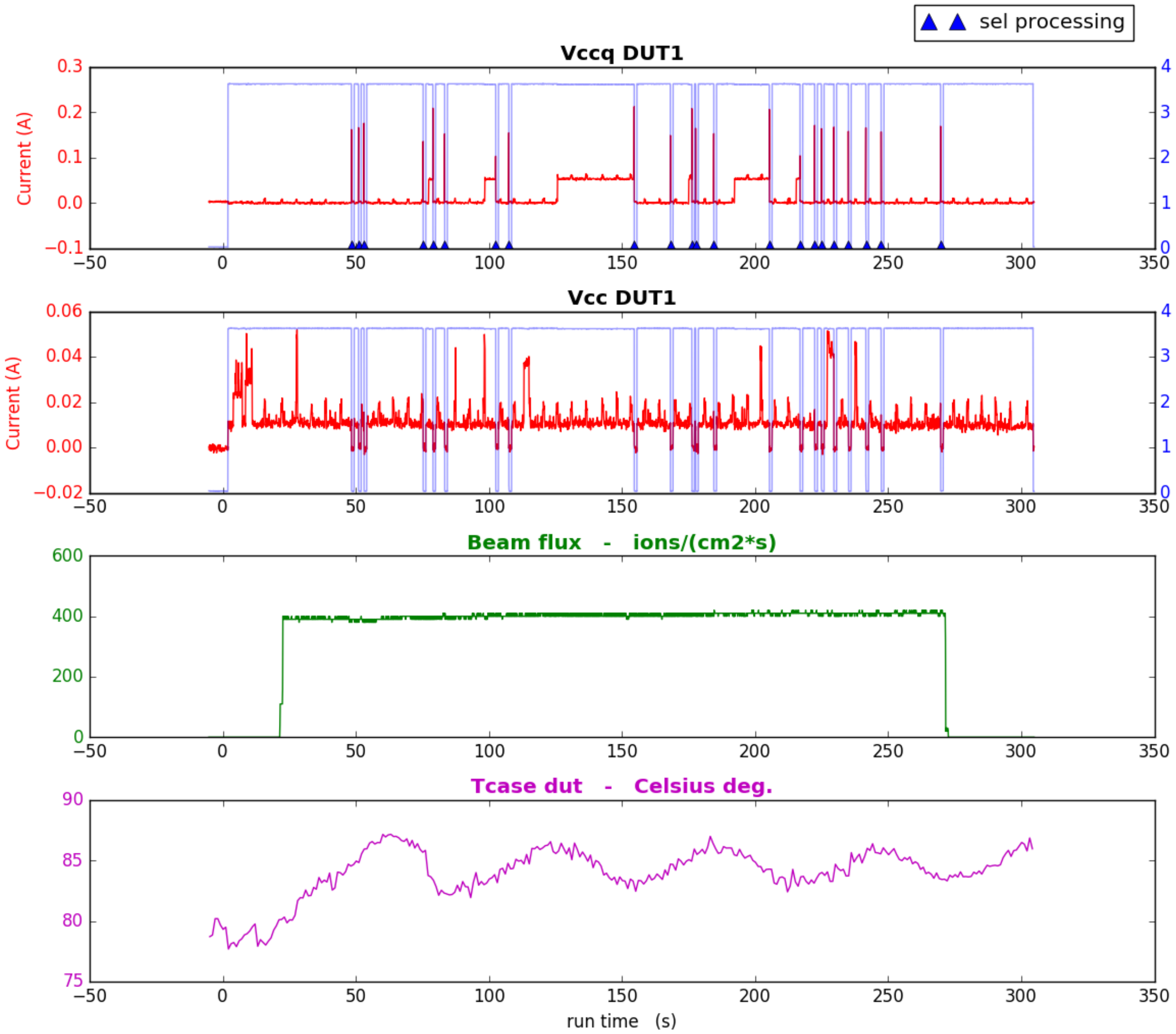


Weibull parameters:

W	30
xo	30
s	2.6
Sat	4.00E-06

Figure 19 – SEL cross-section / device

The chronogram for SEL run number 118 is given in Figure 20. SEL occurred on Vccq line (Iccq current) with no abnormal behaviour on Vcc line. Temperature at die surface was measured with an IR thermometer at 85°C with a monitoring temperature set to 85C for the thermocouple close to DUT case.



RUN118

Figure 20: chronogram for Vccq and Vcc lines along with temperature and flux.

10 Glossary

DUT: Device under test.

Fluence (of particle radiation incident on a surface): The total amount of particle radiant energy incident on a surface in a given period of time, divided by the area of the surface.
In this document, Fluence is expressed in ions per cm^2.

Flux: The time rate of flow of particle radiant energy incident on a surface, divided by the area of that surface.
In this document, Flux is expressed in ions per $cm^2.s$.

Single-Event Effect (SEE): Any measurable or observable change in state or performance of a microelectronic device, component, subsystem, or system (digital or analog) resulting from a single energetic particle strike.
Single-event effects include single-event upset (SEU), multiple-bit upset (MBU), multiple-cell upset (MCU), single-event functional interrupt (SEFI), single-event latch-up (SEL).

Single Event Gate Rupture (SEGR) **/ Single Event Dielectric Rupture (**SEDR**):** Destructive rupture of the gate oxide layer or dielectric layer by a single ion strike. This leads to leakage currents under bias and can be observed as stuck bits in digitals devices

Single-Event Upset (SEU)**:** A soft error caused by the transient signal induced by a single energetic particle strike.

Single-Event Transient (SET): A transient signal induced by a single energetic particle strike.

Single-Event Latch-up (SEL): An abnormal high-current state in a device caused by the passage of a single energetic particle through sensitive regions of the device structure and resulting in the loss of device functionality.
SEL may cause permanent damage to the device. If the device is not permanently damaged, power cycling of the device (off and back on) is necessary to restore normal operation.
An example of SEL in a CMOS device is when the passage of a single particle induces the creation of parasitic bipolar (p-n-p-n) shorting of power to ground.

Single-Event Functional Interrupt (SEFI): A soft error that causes the component to reset, lock-up, or otherwise malfunction in a detectable way, but does not require power cycling of the device (off and back on) to restore operability, unlike single-event latch-up (SEL), or result in permanent damage as in single-event burnout (SEB).
A SEFI is often associated with an upset in a control bit or register.

Error cross-section: the number of errors per unit fluence. For device error cross-section, the dimensions are cm^2 per device. For bit error cross-section, the dimensions are cm^2 per bit.

Tilt angle: tilt angle, rotation axis of the DUT board is perpendicular to the beam axis; roll angle, board rotation axis is parallel to the beam axis

Weibull fit: $F(x) = A (1- \exp\{-[(x-x_0)/W]^s\})$ with:

> x = effective LET in MeV/(mg/cm^2);
> $F(x)$ = SEE cross-section in cm^2;
> A = limiting or plateau cross-section;
> x_0 = onset parameter, such that $F(x) = 0$ for $x < x_0$;
> W = width parameter;
> s = a dimensionless exponent.

Error bars: error bars are computed using a confidence level of 95% and a beam flux uncertainty of +/-10% as recommended by Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100.