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CONTRACT REPORT

ESA/ESTEC Contract No. 11755/95/NL/NB-WO1/CO1

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Title

TC551001BPL-70L, 1 MBIT SRAM FROM TOSHIBA

HEAVY ION & PROTON SEE CHARACTERIZATION TEST REPORT

Summary :

Low Voltage memories were tested under heavy ion and proton irradiation, in order to study the effect of supply voltage on the SEE sensitivity. Additional results including study of operating and temperature effects is also addressed. This report presents the results obtained on 1 Mbit Toshiba SRAMs.

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Document type	**Nb WBS**	**Key Words**

SUMMARY

Test sample characteristics :

Part Name :	TC551001BPL-70L	**Function :**	128K x 8 SRAM
Technology :	CMOS, 0.5µm, 4 T cells	**Package :**	32 pin DIP
Manufacturer :	Toshiba	**Location :**	Japan
Sample size :	4 (H.I. tests) 4 (P. tests)	**Date Code :**	9623

Heavy ion results

The following table summarizes the Heavy ion SEU test results:

	LET Threshold (MeV.cm²/mg)	**Saturated Cross-section (cm²/bit)**
Vcc=3.3V	<1.7	≈1e-07
Vcc=5V	≈1.7	≈3e-08

Heavy ion test conclusion :

The results of these experiments demonstrate that 1 Mbit SRAM TC551001BPL-70L from Toshiba, biased at 3.3V, is highly sensitive to heavy induced SEU : the threshold LET is <1.7 MeV.cm²/mg, and the saturated cross section is about 1e-07 cm²/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity : the threshold LET is 1.7 MeV.cm²/mg, and the saturated cross section is reduced by a factor 3.

Additional heavy ion results:

These devices exhibit no Latch-up sensitivity, up to at least a LET of 34 MeV.cm²/mg.

No effect of frequency (Fmax→Fmax/4) was evidenced on heavy ion cross section values at saturation.

No multiple errors within one 8 bit word were recorded during the heavy ion irradiation.

No Single Hard Error sensitivity was found under the heavy ion irradiation, up to at least a LET of 34 MeV.cm²/mg.

Proton results

The following table summarizes the proton SEE test results:

	Proton Energy Threshold (MeV)	Saturated Cross-section (cm^2/bit)
Vcc=3.3V	<20	≈1e-13
Vcc=5V	<20	≈2e-14

Proton conclusion :

The results of these experiments demonstrate that 1 Mbit SRAM TC551001BPL-70L (70ns) from Toshiba, biased at 3.3V, are sensitive to proton induced SEU : the saturated cross section is approximately 1e-13 cm^2/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity to proton induced SEU : cross section are reduced by a factor of 4. Since the cross section curves are rather flat down to 20 MeV, no effect on Proton energy threshold can be evidenced.

Additional proton results:

These devices exhibit no Latch-up sensitivity, up to at least a proton energy of 60 MeV

No effect of frequency (Fmax→Fmax/4) can be evidenced on proton cross section values at saturation.

No multiple errors within one 8 bit word were recorded during the proton irradiation.

No Single Hard Error sensitivity was found under proton irradiation, up to a proton energy of 60 MeV.

In both heavy ion and proton tests, the 1 to 0 transition error rate is equivalent to the 0 to 1 transition error rate (see results in the annex)

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1. INTRODUCTION

The aim of this work is to investigate radiation effects in low voltage technologies. The study is focused on memory devices, which require lower voltage to achieve higher integration. Parts selected concern SRAM (1 Mbit, 2 types), DRAM (16 Mbit, 2 types), and FLASH memories (8 Mbit, 1 type).

The object of this document is to describe the irradiation performed on the 1 Mbit SRAM TC551001BPL-70L (70 ns) from Toshiba, in order to measure their sensitivity to heavy ion and proton induced SEU. Influence of Supply Voltage, and operating Frequency is also addressed.

Irradiation were performed in November/December 1996 (30th-1st) according to the procedures referenced in the following paragraph.

This work was performed in the frame of the WO1/CO1 for ESTEC Contract n°11755/95/NL/NB.

2. REFERENCE DOCUMENTS

[1] ESA/SCC Basic Specification 25100

[2] Toshiba Manufacturer Data Sheet

[3] "Radiation Prescreening Program On Low Voltage Memories For ESA/ESTEC Contract N°11755/95/NL/NB" MMS Contract WP1 Report Ref. DOF/DEC/TP6.577.

[4] "The Heavy Ion Irradiation Facility at CYCLONE-a dedicated SEE beam line", G. Berger, G. Ryckewaert, R. Harboe-Sorensen, L. Adams, 1996 IEEE Radiation Effects Data Workshop

[5] "Testeur de mémoire haute densité", D. Winkel, TSEU-MAV-PE-000 (MMS report)

[6] Statement of work- QCA/RHS-CDS1.WP-MAR.'95, Issue 1, "Call-Off Order 1, Study and radiation testing of Low voltage Technologies".

3. PART DETAILS

3.1. DEVICE IDENTIFICATION

3.1.1. References

Type	:	TC551001BPL-70L (70 ns)
Manufacturer	:	Toshiba
Place	:	Japan
Packaging	:	32 pin plastic DIP

3.1.2. Function

128K x 8 SRAM (70 ns)

3.1.3. Technology

CMOS, 0.5 µm, 4T cells (See next page for further details)

3.1.4. Part Procurement

Origin	:	Tekelec, France
Level	:	Standard Level
Temperature range	:	0°C, +70°C (Commercial)
Date code	:	9623
Screening	:	/
Sample size	:	4 (heavy ion tests), 4 (proton tests)
Detailed specifications	:	Manufacturer Data sheet

3.1.5. Previous SEE details/history

No radiation data on this device

During this campaign, proton tests were performed prior to heavy ion tests; samples irradiated with heavy ions are different from samples irradiated with protons.

3.2. TECHNOLOGY

The 1 Mbit TC551001BPL-70L SRAM from Toshiba is a 5V supply voltage device, which is also functional at 3.3V. It is not considered as a dual voltage device.

General information

Name	Toshiba TC551001BPL-70L
Package Marking	Toshiba TC551001BPL-70L Japan 9623 HAK
Access time/ns at 5V	70
Temperature range/°C	0,+70
Organisation	128K x 8
Supply Voltage/V	2.7-5.5

Technology

Name	Toshiba TC551001BPL-70L
CMOS	yes
Mask	Mask B
Epitaxial layer	*
Design rules	0.5 µm
Die size	5.07mm x 8.69mm
Cell type	4T cells
Cell size	3.61µm x 5.7 µm

*This missing information was unsuccessfully required to the manufacturer.

A photography of the die is given in the annex.

4. TEST DESCRIPTION

4.1. IRRADIATION FACILITY

Name : Louvain-La-Neuve Cyclotron

Location : Université Catholique de Louvain,
Centre de Recherches du Cyclotron
Chemin du Cyclotron, 2, 1348,
Louvain-La-Neuve, Belgium

4.1.1. Beams currently available

A cocktail of heavy ions can be provided, allowing quick (in a few minutes) changes of ion species. The characteristics of the associated LET are reported in table 1 (**X** in the last column refers to the type of ions used during this campaign) :

Ion	Energy (MeV)	Range [μm Si]	LET (MeV.cm²/mg)	Beam used
^{84}Kr	316	43	34	X
^{40}Ar	150	42	14.1	X
^{20}Ne	78	45	5.85	X
^{15}N	62	64	2.97	
^{10}B	41	80	1.7	X
^{132}Xe	459	43	55.9	

Table 1 Cocktail 1 that can be provided by LLN cyclotron.

- By varying the ion species and angle of incidence, the error Cross-section (σ) can be determined as a function of LET. A controlled flux between 10 and 10^5 (part./cm²)/s is used for heavy ions tests. A complete presentation of the Cyclone Facility SEE beam line is presented in ref [4].

4.1.2. Proton energies available

- Proton energies available at the LLN cyclotron are ranging from 10 to 60 MeV. Low energies are obtained by degrading the 60 MeV beam. For these tests, 2e+07 to 1e+08 (part./cm²)/s proton fluxes were used.

4.2. TEST SET UP DESCRIPTION

4.2.1. Heavy ion test set-up

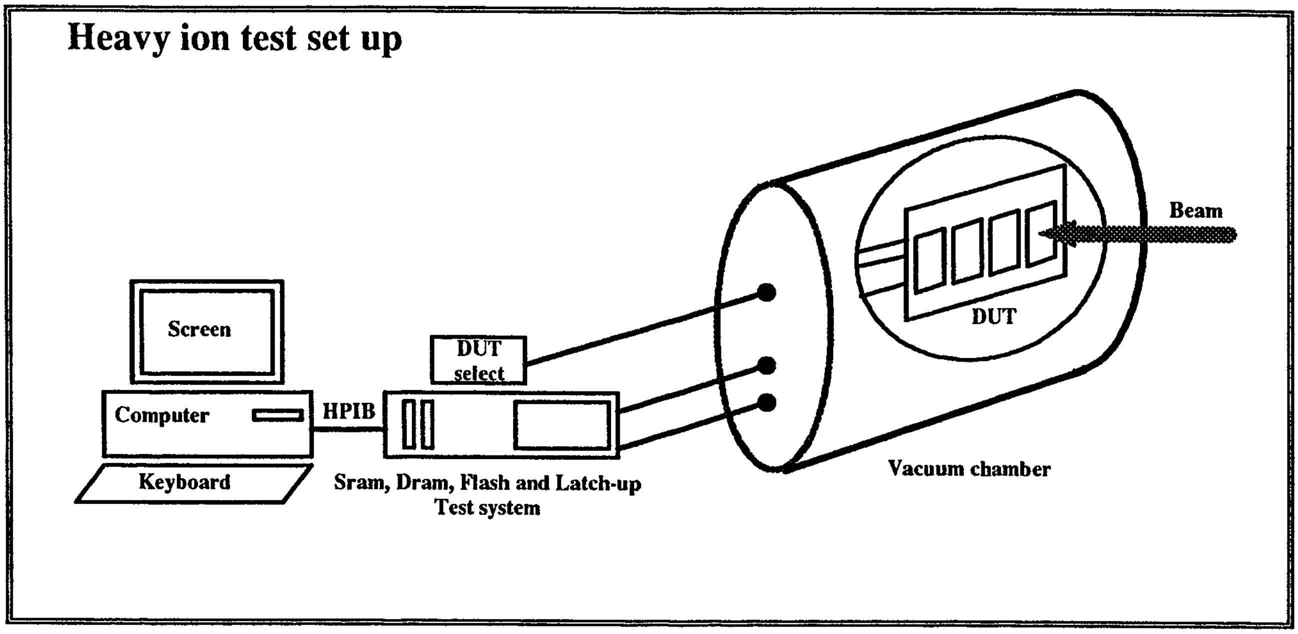


Fig. 1 Description of the heavy ion test set-up.

Comments :

The DUT are mounted on 4 zero-insertion-force sockets. Due to the low heavy ion penetration, parts were delidded for the heavy ion tests.

The tested device is selected by a switching commuter, located outside of the vacuum chamber.

The supply voltage is provided by the memory tester. The memory tester is also located outside of the vacuum chamber. The maximum frequency (Fmax) for tests is 1.25 MHz for SRAMs. This frequency can be divided by 2, 4, or 8. The maximum SEU rate is 625000 SEU/s (errors are systematically counted and recorded with the corresponding address).

The tester also includes a delatcher. The Latch-up detection threshold is programmable (set at 20 mA for the SRAM). The cut-off time is of 10 ms.

A complete description of the memory tester is given in [5].

4.2.2. Proton test set-up

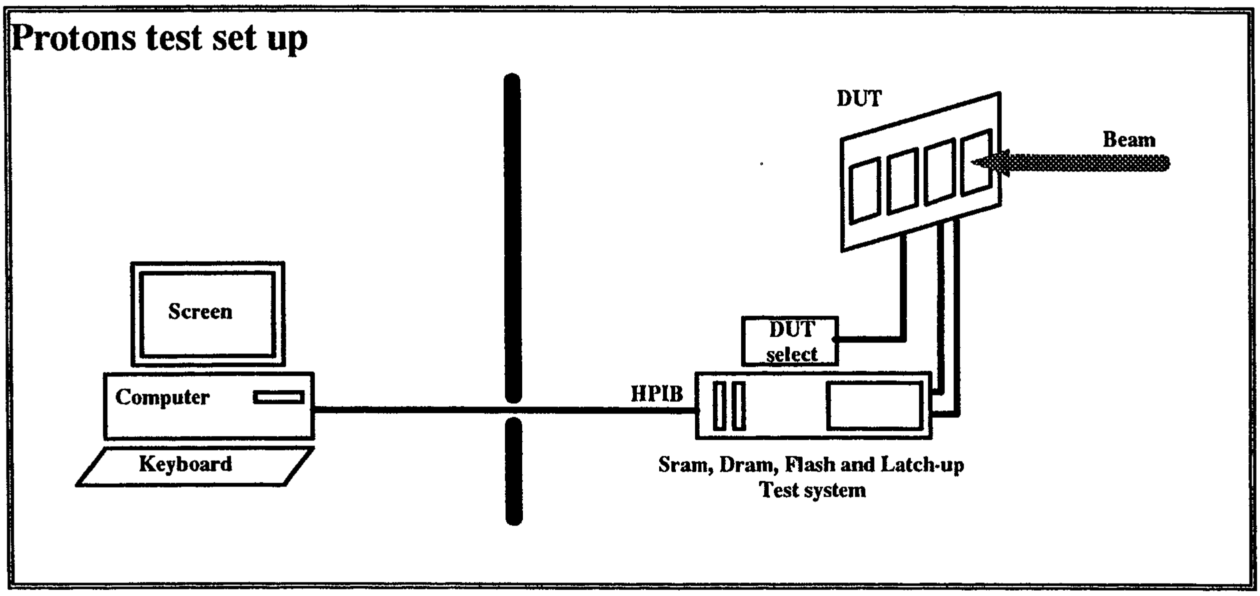
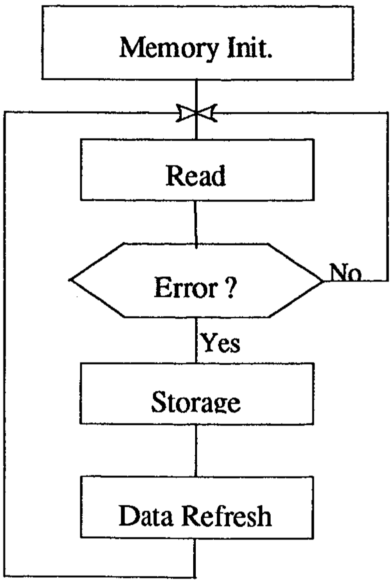


Fig. 2 Description of the proton test set-up

The proton test set-up is the same as the heavy ion test set-up. (see previous page for details). The main difference is that no vacuum chamber is needed for proton tests.

4.2.3. Test sequence



Test sequence flow chart

5. HEAVY ION EXPERIMENTAL RESULTS

5.1. HEAVY ION IRRADIATION TEST SEQUENCE

The heavy ion irradiation test sequence is reported in the following tables. Fluences in column 9 are corrected fluences, according to the tilt (corrected fluences = real fluences x cosθ). The run number refers to the total irradiation test sequence, including all the memories tested during this campaign.

All the devices were tested with a Cb (checkerboard) pattern during irradiation. Since they were also tested with All to 0, All to 1, and /Cb patterns between runs, it was also checked that they were not sensitive to Single Hard Errors (SHE), up to a LET of 34 MeV.cm²/mg (a SHE is a stuck bit, due to deposited dose in the oxide of the cell transistors. It is generally detected when testing a device under a pattern and its complementary pattern : the stuck bit remains in its initial configuration).

ICC+ is the consumption current for 4 memories biased together.

Run	Device	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Time (s)	Fluence [p/cm²]	ICC+ [mA]
1	SN3	3.3V/Fmax	34	0	34	150	92	12190	+12.2
2	SN4	3.3V/Fmax	34	0	34	150	115	10832	+12.7
5	SN3	3.3V/(Fmax/4)	34	0	34	150	182	13743	+8.3
6	SN4	3.3V/(Fmax/4)	34	0	34	150	165	10716	+8.8
30	SN3	3.3V/Fmax	14.1	0	14.1	150	102	28760	+12.2
31	SN3	3.3V/Fmax	14.1	0	14.1	150	32	9089	+12.2
33	SN4	3.3V/Fmax	14.1	0	14.1	150	158	33482	+12.7

Table 2 : Heavy Ion Irradiation Test Sequence : runs 1-41

Run	Device	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Time (s)	Fluence [p/cm²]	ICC+ [mA]
42	SN3	3.3V/Fmax	5.85	0	5.85	1000	61	58520	+12.7
43	SN5	3.3V/Fmax	5.85	0	5.85	1000	67	63226	+12.7
48	SN5	3.3V/Fmax	5.85	54	10	900	47	30723	+12.7
49	SN5	3.3V/Fmax	5.85	54	10	900	56	31455	+12.7
60	SN3	3.3V/Fmax	1.7	0	1.7	4000	182	511194	+12.2
61	SN5	3.3V/Fmax	1.7	0	1.7	4000	100	510109	+12.2
72	SN3	+5V/Fmax	1.7	0	1.7	9000	111	1.0e+6	+14.7
73	SN5	+5V/Fmax	1.7	0	1.7	9000	118	1.0e+06	+14.7
78	SN5	+5V/Fmax	5.85	0	5.85	4000	/	1.79e+05	+14.7
79	SN3	+5V/Fmax	5.85	0	5.85	4000	/	1.80e+05	+14.7
95	SN3	+5V/Fmax	34	0	34	250	/	19448	+14.6
96	SN5	+5V/Fmax	34	0	34	250	/	16062	+14.6

Table 2 (end) : Heavy Ion Irradiation Test Sequence : run 42-96

5.2. ANALYSIS OF HEAVY ION RESULTS: METHOD

5.2.1. Calculation of SEP cross-sections

The cross-sections were calculated as follows :

$$\sigma(\mathrm{LET}) = N/F$$

where :

σ is the SEP Cross-section (cm²/device), expressed as a function of the Heavy Ion LET

LET is the Linear Energy Transfer $\left(\frac{1}{\rho}\frac{dE}{dx}\right)$, in MeV.cm²/mg

N is the total Number of SEP

F = Fluence (part./cm²) (corrected according to the incident angle).

The cross section per bit is obtained by dividing the cross section for the device by the total number of bits of the memory.

The minimum of fluence required is 1e+6 p/cm², if no event detected. By default, a value of 1 for N is used to calculate the cross-section when no event is observed (Cf. statistical treatment).

The LET threshold is defined as the minimum LET value at which no event occurs at a fluence of 10^6 particle/cm².

5.2.2. Statistical treatment

The confidence limits shown in the following tables represent the values of the cross section between which the true value of cross section lies within a 90% probability.

The calculation of the confidence limits is made on the basis of a Poisson distribution for the events. Note that when large numbers of errors are observed, the statistical errors become insignificant. The assumptions made therefore are :

- only one event possible per incident ion
- small probability of event

For an event number > 600, no confidence limit is calculated

5.3. HEAVY ION CROSS SECTION MEASUREMENTS

5.3.1. Tables of heavy ion results

The cross sections are expressed in cm²/bit, obtained by dividing the device cross section by the number of tested bits.

Test Sample	Test n°	SEU	Eff. Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN5	61	71	5.1 e+05	**1.7**	**1.33e-10**	1.08e-10/1.62e-10
SN3	60	71	5.1 e+05	**1.7**	**1.32e-10**	1.07e-10/1.61e-10
SN5	43	474	6.3 e+04	**5.85**	**7.15e-09**	6.61e-09/7.71e-09
SN3	42	433	5.8 e+04	**5.85**	**7.06e-09**	6.51e-09/7.63e-09
SN3	49	534	3.1 e+04	**10**	**1.62e-08**	1.50e-08/1.74e-08
SN5	48	522	3.1 e+04	**10**	**1.62e-08**	1.50e-08/1.74e-08
SN4	33	689	3.3 e+04	**14.1**	**1.96e-08**	/
SN4	31	201	9.0 e+03	**14.1**	**2.11e-08**	1.87 e-08/2.37 e-08
SN3	30	619	2.8 e+04	**14.1**	**2.05e-08**	/
SN4	2	1016	1.1 e+04	**34**	**8.95e-08**	/
SN3	1	1016	1.2 e+04	**34**	**7.95e-08**	/

Table 3 : Cross section measurements for Vcc=3.3V, Fmax

Test Sample	Test n°	SEU	Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN5	73	7	1.0 e+06	**1.7**	**6.68e-12**	3.13e-12/1.25e-11
SN3	72	8	1.0 e+06	**1.7**	**7.63e-12**	3.79e-12/1.37e-11
SN3	79	565	1.8 e+05	**5.85**	**2.99e-09**	2.78e-09/3.21e-09
SN5	78	543	1.8 e+05	**5.85**	**2.89e-09**	2.69e-09/3.10e-09
SN5	96	489	1.6 e+04	**34**	**2.90e-08**	2.69e-08/3.13e-08
SN2	95	524	1.9 e+04	**34**	**2.57e-08**	2.38e-08/2.76e-08

Table 4 : Cross section measurements for Vcc=5V, Fmax

Test Sample	Test n°	SEU	Fluence (part/cm²)	**Effective LET [MeV.cm²/mg]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN3	5	1048	1.3 e+04	**34**	**7.27e-08**	/
SN4	6	818	1.0 e+04	**34**	**7.28e-08**	/

Table 5 : Cross section measurements for Vcc=3.3V, Fmax/4

5.3.2. Heavy Ion Cross Section Curves

The figure 4 exhibits the heavy ion induced cross sections for Toshiba 1 Mbit SRAM.

A complete characterization was performed at Vcc=3.3V

Effect of supply voltage (Vcc=5V) was addressed at LET values of 1.7, 5.85, and 34 MeV.cm²/mg.

Effect of operating frequency (Fmax/4) was addressed at a 34 MeV.cm²/mg LET value.

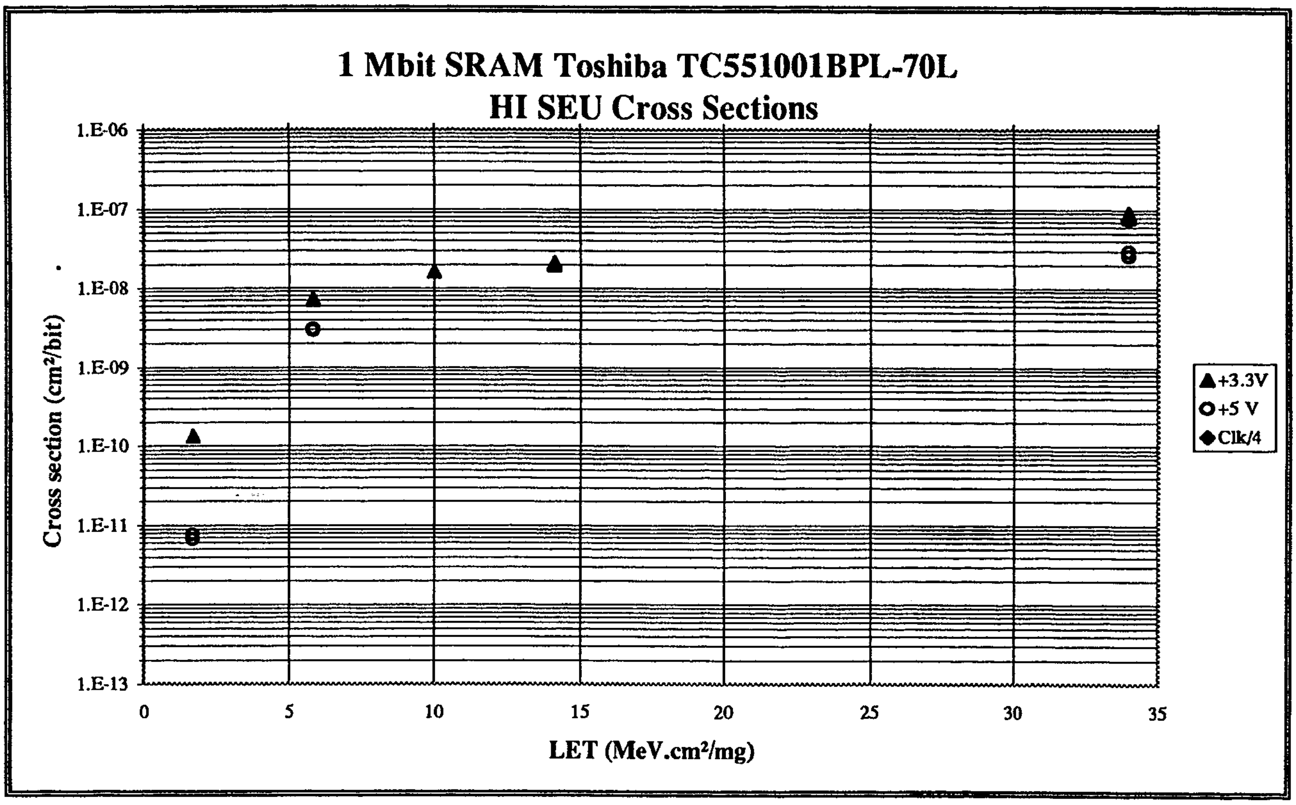


Fig. 4 Heavy ion cross section measurements for TC551001BPL-70L 1 Mbit SRAM fromToshiba

This figure evidences the following results :

<u>Effect of supply voltage</u> :

Biasing the devices at 5V tends to lower the sensitivity of the devices to heavy ion induced SEU : the threshold LET is increased to about 1.7 MeV.cm²/mg; and the saturated cross-section is divided by a factor 3.

<u>Effect of the operating frequency</u> (Fmax→Fmax/4) :

No operating frequency effect is clearly evidenced at 34 MeV.cm²/mg (the only tested LET for this test).

5.3.3. Problems encountered/Discussion

No specific problem was encountered during irradiations.

5.4. HEAVY ION TEST CONCLUSIONS

The results of these experiments demonstrate that 1 Mbit SRAM TC551001BPL-70L from Toshiba, biased at 3.3V, is sensitive to heavy induced SEU : the threshold LET is <1.7 MeV.cm²/mg, and the saturated cross section is about 1e-07 cm²/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity : the LET threshold is close to 1.7 MeV.cm²/mg, and the saturated cross section is reduced by a factor 3.

Additional heavy ion results:

These devices exhibit no Latch-up sensitivity, up to a LET of 34 MeV.cm²/mg.

No effect of frequency (Fmax→Fmax/4) can be evidenced on heavy ion cross section values at saturation.

The 1 to 0 transition error rate is equivalent to the 0 to 1 transition error rate (see results in the annex).

No multiple errors within one 8 bit word were recorded during the heavy ion irradiation. Other multiple errors could not be identified in the absence of bit map.

No Single Hard Error sensitivity was found under the heavy ion irradiation, up to 34 MeV.cm²/mg.

6. PROTON EXPERIMENTAL RESULTS

6.1. PROTON IRRADIATION TEST SEQUENCE

The proton irradiation test sequence is given in the following tables.

The run number refers to the total irradiation test sequence, including all the memories tested during this campaign.

ICC+ is the consumption current for 4 memories biased together.

Run	Device	Vcc/f	Energy (p) [MeV]	Flux [p/cm²/s]	Time (s)	Fluence [p/cm²]	Depos./Cumul. Dose (kRad[Si])	ICC+ [mA]
5	SN1	5V/Fmax	60	2.06e+07	486	1e+10	1.5/3	+15
6	SN2	5V/Fmax	60	2.44e+07	410	1e+10	1.5/1.5	+15
7	SN2	5V/Fmax	60	2.44e+07	409	1e+10	1.5/3	+16
10	SN2	5V/Fmax	40	3.45e+07	290	1e+10	2/7	+16
11	SN4	5V/Fmax	40	3.56e+07	281	1e+10	2/2	+17
16	SN4	5V/Fmax	20	4.02e+07	249	1e+10	3.5/5.5	+16
17	SN2	5V/Fmax	20	4.22e+07	237	1e+10	3.5/10.5	+16
29	SN3	3.3V/Fmax	60	9.62e+07	104	1e+10	1.5/1.5	*
30	SN4	3.3V/Fmax	60	1.02e+08	98	1e+10	1.5/7	*
35	SN4	3.3V/Fmax	40	1.03e+08	97	1e+10	2/9	+13.2
36	SN3	3.3V/Fmax	40	1.04e+08	96	1e+10	2/3.5	+13.2
37	SN3	3.3V/Fmax	20	1.03e+08	97	1e+10	3.5/7	+13.2
38	SN4	5V/Fmax	20	1.01e+08	99	1e+10	3.5/12.5	+13.2
44	SN4	3.3V/(Fmax/4)	60	1.05e+08	95	1e+10	1.5/14	+8.3
45	SN3	3.3V/(Fmax/4)	60	1.08e+08	93	1e+10	1.5/8.5	+8.3

Table 7: Proton Irradiation Test Sequence

*ICC+ values were not measured for these runs (29,30).

6.2. ANALYSIS OF PROTON RESULTS : METHOD

6.2.1. Calculation of SEP cross-sections

The cross-sections were calculated as follows :

$$\sigma(Ep) = N/F$$

where :

σ is the SEP Cross-section (cm^2/device), expressed as a function of the Proton Energy

N is the total Number of SEP

F = Fluence (part./cm^2)

The cross section per bit is obtained by dividing the cross section for the device by the total number of bits of the memory.

The fluence is set at 1e+10 p/cm^2 for all the runs. By default, a value of 1 for N is used to calculate the cross-section when no event is observed (Cf. statistical treatment).

6.2.2. Statistical treatment

The confidence limits shown in the following tables represent the values of the cross section between which the true value of cross section lies within a 90% probability.

The calculation of the confidence limits is made on the basis of a Poisson distribution for the events. Note that when large numbers of errors are observed, the statistical errors become insignificant. The assumptions made therefore are :

- only one event possible per incident proton
- small probability of events

For an error rate > 600, no confidence limit is calculated

6.3. PROTON CROSS SECTION MEASUREMENTS

6.3.1. Tables of proton results

The cross sections are expressed in cm²/bit, obtained by dividing the device cross section by the number of tested bits.

Test Sample	Test n°	SEU	Fluence (part/cm²)	**P. Energy [MeV]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN3	29	677	1.0 e+10	**60**	**6.46e-14**	/
SN4	30	799	1.0 e+10	**60**	**7.62e-14**	/
SN3	35	752	1.0 e+10	**40**	**7.17e-14**	/
SN3	36	705	1.0 e+10	**40**	**6.72e-14**	/
SN3	37	247	1.0 e+10	**20**	**2.36e-14**	2.11e-04/2.61e-04
SN4	38	343	1.0 e+10	**20**	**3.27e-14**	2.98e-04/3.57e-04

Table 8 : Cross section measurements for Vcc=3.3V

Test Sample	Test n°	SEU	Fluence (part/cm²)	**P. Energy [MeV]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN1	5	115	1.0 e+10	**60**	**1.10e-14**	1.28e-14/9.34e-11
SN2	7	94	1.0 e+10	**60**	**8.96e-15**	1.06e-14/7.49e-13
SN2	10	121	1.0 e+10	**40**	**1.15e-14**	9.87e-15/1.34e-14
SN4	11	210	1.0 e+10	**40**	**2.00e-14**	1.78e-14/2.24e-14
SN4	16	62	1.0 e+10	**20**	**5.91e-15**	4.73e-15/7.30 e-15
SN2	17	70	1.0 e+10	**20**	**6.68e-15**	5.41e-15/8.14e-15

Table 9 : Cross section measurements for Vcc=5V

Test Sample	Test n°	SEU	Fluence (part/cm²)	**P. Energy [MeV]**	**X-Section [cm²/bit]**	90% Conf. Limits [cm²/bit]
SN3	45	750	1.0 e+10	**60**	**7.15e-14**	/
SN4	44	876	1.0 e+10	**60**	**8.35e-14**	/

Table 10 : Cross section measurements for Vcc=3.3V, Fmax/4

6.3.2. Proton Cross Section Curves

The figure 5 exhibits the proton induced SEU cross sections for Toshiba 1 Mbit SRAM.

A characterization was performed at Vcc=3.3V for 3 proton energies (20 MeV, 40 MeV, 60 MeV)

Effect of supply voltage (Vcc=5V) was also addressed at these 3 proton energy values.

Effect of operating frequency was addressed at 60 MeV.

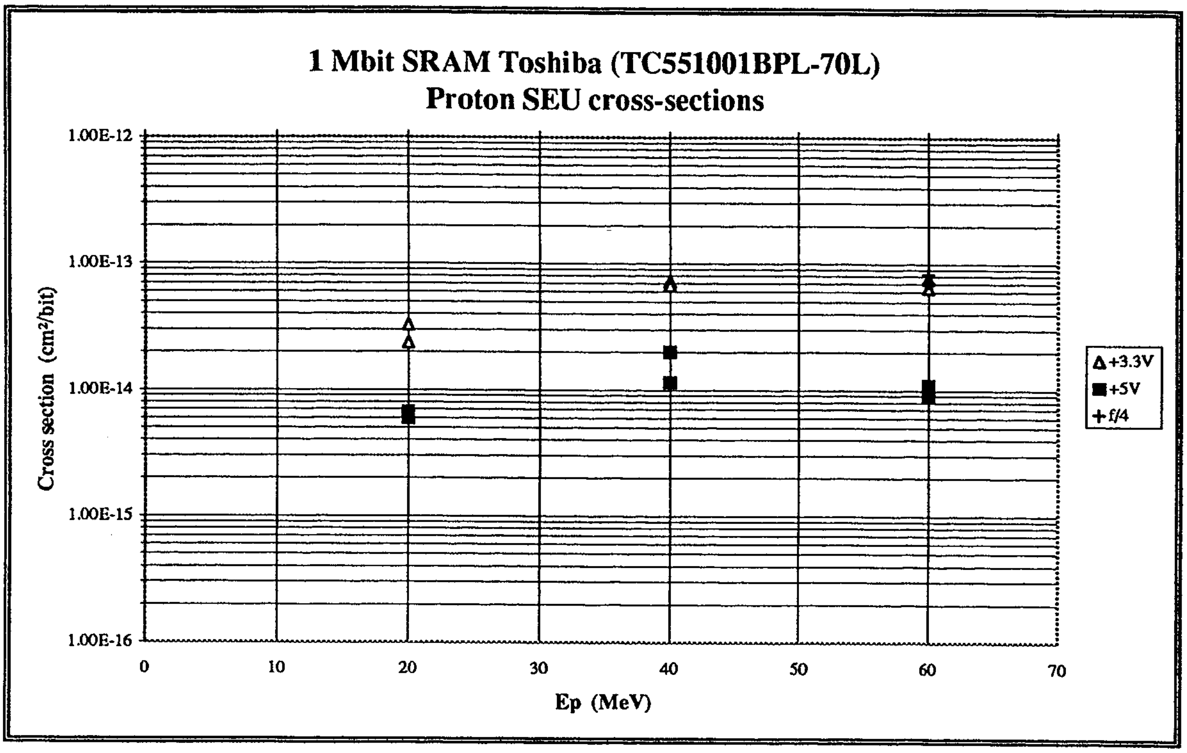


Fig. 5 Proton cross section measurements for Toshiba SRAM 1 Mbit

This figure evidences the following results :

Effect of supply voltage :

The SEU susceptibility of the devices is higher at 3.3V than at 5V : the saturated cross-section is increased by a factor 6.

Effect of the operating frequency (Fmax→Fmax/4) :

No operating frequency effect was evidenced : at the 60 MeV energy (the only investigated energy for operational frequency effects), a comparison of the SEU cross-section measured at Fmax and Fmax/4 exhibits no difference.

6.3.3. Problems encountered/Discussion

No specific problem was encountered during irradiation.

6.4. PROTON TEST CONCLUSIONS

The results of these experiments demonstrate that 1 Mbit SRAM TC551001BPL-70L (70ns) from Toshiba, biased at 3.3V, are sensitive to proton induced SEU : the saturated cross section is approximately 1e-13 cm^2/bit. When biased at Vcc=5V, these devices exhibit a lower sensitivity to proton induced SEU : cross section are reduced by a factor of 6. Since the cross section curves are rather flat down to 20 MeV, no effect on Proton energy threshold can be evidenced.

Additional proton results:

These devices exhibit no Latch-up sensitivity, up to a proton energy of 60 MeV

No effect of frequency (Fmax→Fmax/4) can be evidenced on proton cross section values at saturation.

The 1 to 0 transition error rate is equivalent to the 0 to 1 transition error rate (see results in the annex)

No multiple errors were recorded during the proton irradiation. Other multiple errors could not be identified in absence of a bitmap.

No Single Hard Error sensitivity was found under proton irradiation, up to a proton energy of 60 MeV.

7. CONCLUSIONS

Heavy ion and proton SEU tests were performed on the 1 Mbit SRAM TC551001BPL-70L (70ns) from Toshiba, with complete characterization at 3.3V, and additional points at 5V, and at a lower operating frequency. Results are summarized in the following tables.

	LET Threshold (MeV.cm²/mg)	Saturated Cross-section (cm²/bit)
Vcc=3.3V	<1.7	≈1e-07
Vcc=5V	≈1.7	≈3e-08

Summary of heavy ion results

	Proton Energy Threshold (MeV)	Saturated Cross-section (cm²/bit)
Vcc=3.3V	<20	≈1e-13
Vcc=5V	<20	≈2e-14

Summary of proton results

Analysis of the results showed that no effect of operating frequency was evidenced on the heavy ion and proton cross sections.

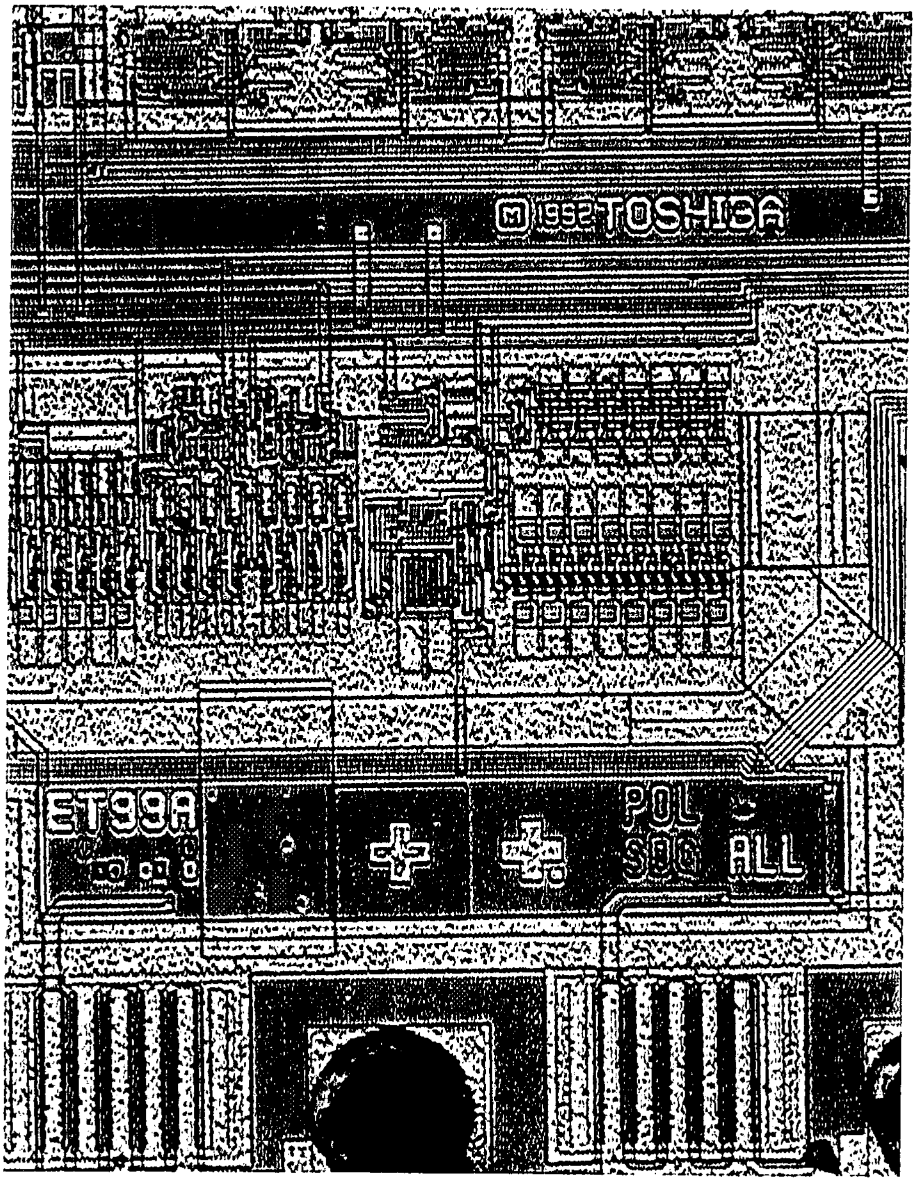
Effect of supply voltage tends to modify the SEU sensitivity of the devices : the SEU susceptibility is higher at 3.3V than at 5V :

- Heavy ion threshold LET is higher at 5V than at 3.3V, and the cross section at saturation is reduced by a factor 3.

- Proton cross sections are divided by a factor 6, at all proton energies.

8. ANNEX

8.1. DIE PHOTOGRAPHY



Photography of the die marking

8.2. DETAILS OF RESULT ANALYSIS

Heavy ion additional test results

The following tables exhibit the heavy ion SEU results separating the 1 to 0 transitions from the 0 to 1 transitions, and comparing with the "total" results. These tables clearly show that the sensitivity of the device is not dependent on the bit transition type. Figures a-1 and a-2 also exhibit these results.

Toshiba Vcc=3.3V

RUN	SN	Upsets			Size	Eff. Fluence	Eff. LET	Cross Sect. (cm²/bit)		
		0→1	1→0	Total	(bits)	(part/cm²)	(MeV.cm²/mg)	0→1	1→0	Total
1	3	523	493	1016	1048576	12190	34	**8,18E-08**	**7,71E-08**	**7,95E-08**
2	4	471	545	1016	1048576	10832	34	**8,29E-08**	**9,60E-08**	**8,95E-08**
30	3	333	286	619	1048576	28760	14,1	**2,21E-08**	**1,90E-08**	**2,05E-08**
31	4	105	96	201	1048576	9089	14,1	**2,20E-08**	**2,01E-08**	**2,11E-08**
33	4	322	367	689	1048576	33482	14,1	**1,83E-08**	**2,09E-08**	**1,96E-08**
48	5	233	289	522	1048576	30723	10	**1,45E-08**	**1,79E-08**	**1,62E-08**
49	3	273	261	534	1048576	31455	10	**1,66E-08**	**1,58E-08**	**1,62E-08**
42	3	232	201	433	1048576	58520	5,85	**7,56E-09**	**6,55E-09**	**7,06E-09**
43	5	226	248	474	1048576	63226	5,85	**6,82E-09**	**7,48E-09**	**7,15E-09**
60	3	36	35	71	1048576	511194	1,7	**1,34E-10**	**1,31E-10**	**1,32E-10**
61	5	36	35	71	1048576	510109	1,7	**1,35E-10**	**1,31E-10**	**1,33E-10**

Table a-1 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V

Toshiba Vcc=5V										
RUN	SN	Upsets			Size	Fluence	LET	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(part/cm^2)	(MeV.cm^2/mg)	0→1	1→0	Total
95	3	312	212	524	1048576	19448	34	**3,06E-08**	**2,08E-08**	**2,57E-08**
96	5	257	232	489	1048576	16062	34	**3,05E-08**	**2,75E-08**	**2,90E-08**
78	5	259	284	543	1048576	179000	5,85	**2,76E-09**	**3,03E-09**	**2,89E-09**
79	3	343	222	565	1048576	180000	5,85	**3,63E-09**	**2,35E-09**	**2,99E-09**
72	3	5	3	8	1048576	1000000	1,7	**9,54E-12**	**5,72E-12**	**7,63E-12**
73	5	4	3	7	1048576	1000000	1,7	**7,63E-12**	**5,72E-12**	**6,68E-12**

Table a-2 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=5V

Toshiba Vcc=3.3V f/4										
RUN	SN				Size	Fluence	LET	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(part/cm^2)	(MeV.cm^2/mg)	0→1	1→0	Total
5	3	568	480	1048	1048576	13743	34	**7,88E-08**	**6,66E-08**	**7,27E-08**
6	4	379	439	818	1048576	10716	34	**6,75E-08**	**7,81E-08**	**7,28E-08**

Table a-3 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

These results clearly show that the sensitivity of the device is not dependent on the transition type.

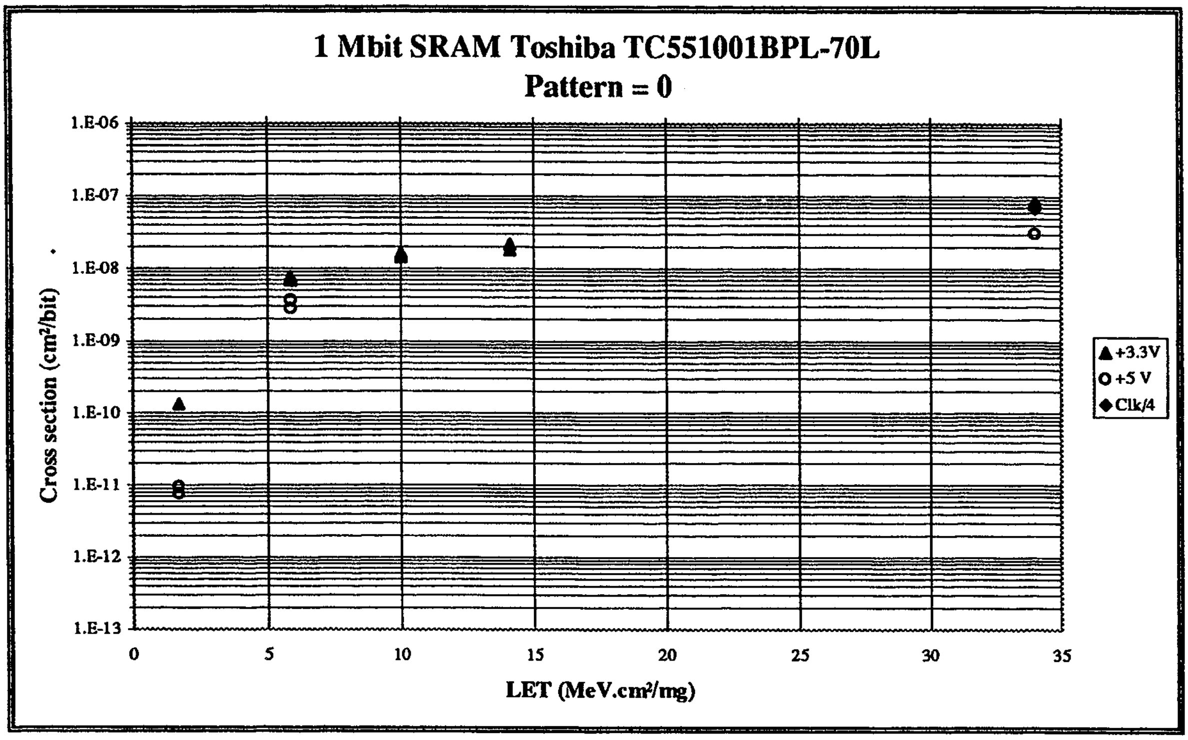


Fig. a-1 Heavy Ion SEU Cross section measurements for 0 to 1 transitions

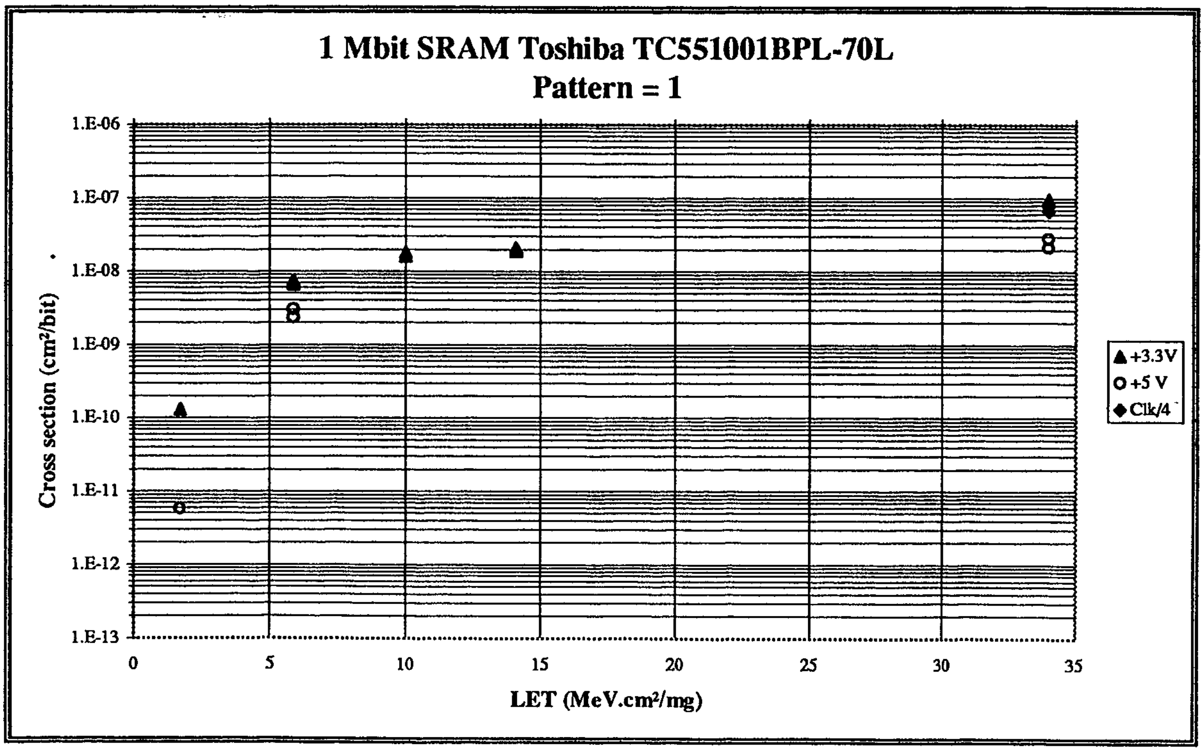


Fig. a-2 Heavy ion SEU Cross section measurements for 1 to 0 transitions

Proton additional test results

The following tables exhibit the proton SEU results, separating the 1 → 0 from the 0 → 1 transition results, and comparing with the "total" results. These tables clearly show that the sensitivity of the device is not dependent on the bit transition type. Figures a-3 and a-4 also exhibit these results.

Toshiba Vcc=3.3V										
RUN	SN	Upsets			Size	Fluence	E	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(p/cm^2)	(MeV)	0→1	1→0	Total
29	3	273	404	677	1048576	1,00E+10	60	**5,21E-14**	**7,71E-14**	**6,46E-14**
30	4	336	463	799	1048576	1,00E+10	60	**6,41E-14**	**8,83E-14**	**7,62E-14**
35	4	304	448	752	1048576	1,00E+10	40	**5,80E-14**	**8,54E-14**	**7,17E-14**
36	3	287	418	705	1048576	1,00E+10	40	**5,47E-14**	**7,97E-14**	**6,72E-14**
37	3	111	136	247	1048576	1,00E+10	20	**2,12E-14**	**2,59E-14**	**2,36E-14**
38	4	151	192	343	1048576	1,00E+10	20	**2,88E-14**	**3,66E-14**	**3,27E-14**

**Table a-4 Separation of 1 → 0 from the 0 → 1 transitions,
and comparison with total error results, at Vcc=3.3V**

Toshiba Vcc=5V										
RUN	SN	Upsets			Size	Fluence	E	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(p/cm^2)	(Mev)	0→1	1→0	Total
5	1	76	39	115	1048576	1,00E+10	60	1,45E-14	7,44E-15	1,10E-14
6	2			94	1048576	1,00E+10	60			8,96E-15
7	2	62	32	94	1048576	1,00E+10	60	1,18E-14	6,10E-15	8,96E-15
10	2	77	44	121	1048576	1,00E+10	40	1,47E-14	8,39E-15	1,15E-14
11	4	99	111	210	1048576	1,00E+10	40	1,89E-14	2,12E-14	2,00E-14
16	4	21	41	62	1048576	1,00E+10	20	4,01E-15	7,82E-15	5,91E-15
17	2	41	29	70	1048576	1,00E+10	20	7,82E-15	5,53E-15	6,68E-15

Table a-5 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

Toshiba Vcc=3.3V f/4										
RUN	SN	Upsets			Size	Fluence	E	Cross Sect. (cm^2/bit)		
		0→1	1→0	Total	(bits)	(p/cm^2)	(MeV)	0→1	1→0	Total
44	4	363	513	876	1048576	1,00E+10	60	6,92E-14	9,78E-14	8,35E-14
45	3	308	442	750	1048576	1,00E+10	60	5,87E-14	8,43E-14	7,15E-14

Table a-6 Separation of 1 → 0 from the 0 → 1 transitions, and comparison with total error results, at Vcc=3.3V, f/4

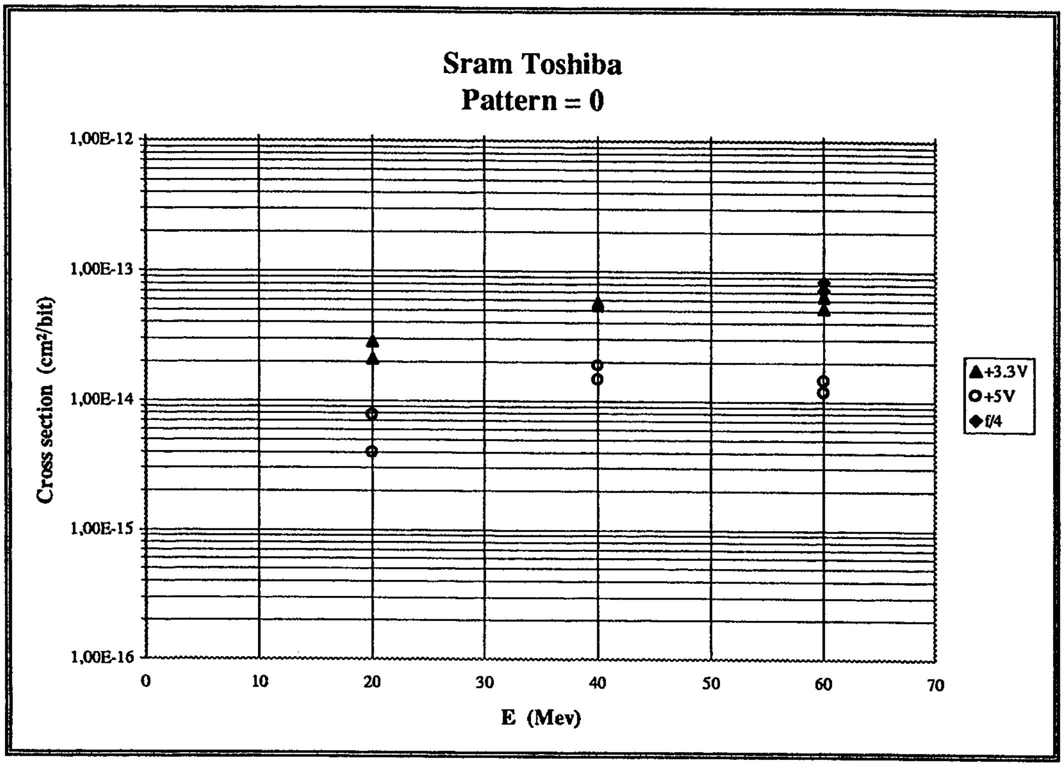


Fig. a-3 Proton SEU Cross section measurements for 1→0 transitions

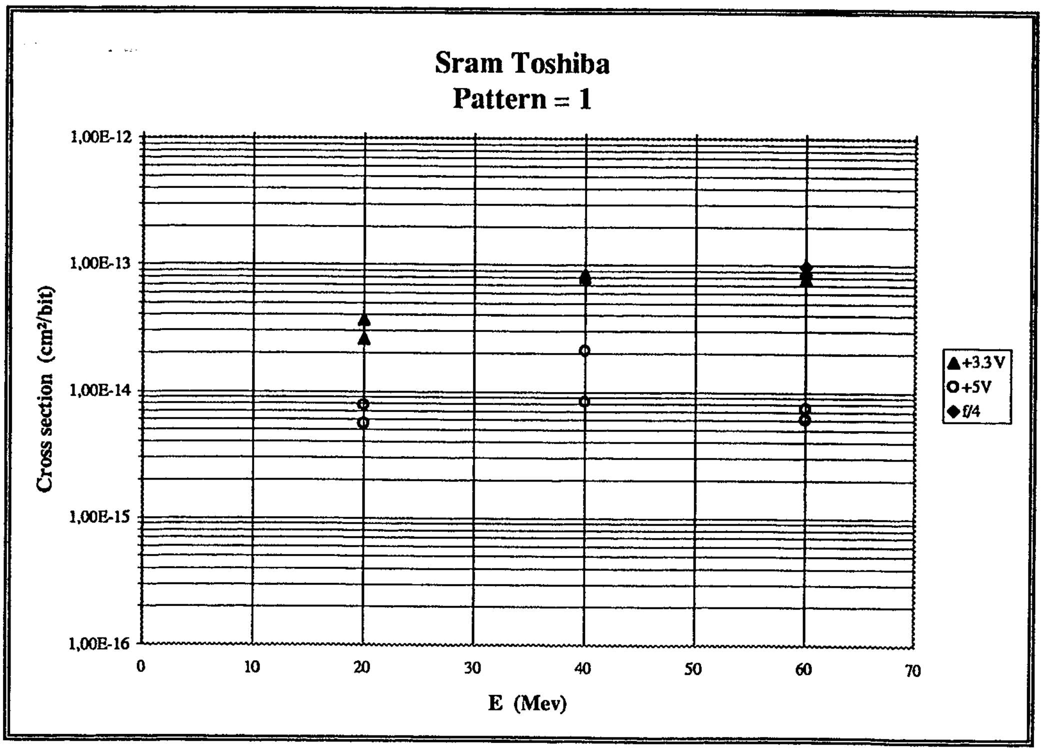


Fig. a-4 Proton SEU Cross section measurements for 1→0 transitions