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EUROPEAN SPACE AGENCY
CONTRACT REPORT

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

The work described in this report was done under ESA contract.
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Title

MT4LC4M4B1D28M, 16 MBIT DRAM (MICRON)

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 16 Mbit MICRON DRAMs.

	Name and Function	Date	Signature
Prepared by :	DOUCIN B.	08/97	
Verified by :	CARRIERE T.	08/97	
Approved by :	CARLOTTI C.	6/08/97	
Authorized by :	HARBOE-SØRENSEN R., ESTEC Technical Officer	/97	

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SUMMARY

Test sample characteristics :

Part Name :	MT4LC4M4B1D28M	**Function :**	4 x 4M DRAM
Technology :	CMOS, 0.35 µm	**Package :**	26 pin plastic SOJ
Manufacturer :	Micron	**Location :**	USA
Sample size :	2 (H.I), 2 (P)	**Date Code :**	***

Heavy ion results

The following table summarizes the Heavy ion SEU test results:

	LET Threshold (MeV.cm²/mg)	**Cross-section (cm²/dev) at LET=34 MeV.cm²/mg**	**Cross-section (cm²/bit) at LET=34 MeV.cm²/mg**
Vcc=3.3V	<1.7	≈4e-1	≈3e-8
Vcc=4.5V	≈1.7	≈4e-1	≈3e-8

Summary of SEU heavy ion results

	LET Threshold (MeV.cm²/mg)	**Saturation Cross-section (cm²/dev.)**
Vcc=3.3V	10<LETth<14.1	≈8e-5
Vcc=4.5V	>34	not estimated

Summary of row error heavy ion results

Heavy ion test conclusion :

The results of these experiments demonstrate that 16 Mbit DRAM MT4LC4M4B1D28M from Micron are highly sensitive to heavy ion induced SEE : for parts biased at 3.3V, the cross section at LET=34 MeV.cm²/mg is about 3e-8 cm²/bit, and the threshold LET is <1.7 MeV.cm²/mg. Parts biased at 4.5V are moderately less sensitive than parts biased at 3.3 V : the cross section at 34 MeV.cm²/mg is comparable, but the threshold LET is slightly higher (≈1.7 MeV.cm²/mg). The main difference is observed on multiple errors (row errors) : they were only observed during the tests at Vcc=3.3V.

Document controlled by :

Additional heavy ion results:

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

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

The initial memory content does not influence the cross section.

The devices exhibited no Single Hard Error sensitivity.

Proton results

The following table summarizes the proton SEE test results:

	Proton Energy Threshold (MeV)	Saturated Cross-section (cm²/bit)
Vcc=3.3V	<20	≈5e-15
Vcc=5V	<20	≈2.8e-15

Summary of proton results

Proton test conclusion :

The results of these experiments demonstrate that 16 Mbit MT4LC4M4B1D28M from Micron, biased at 3.3V, are sensitive to proton induced SEU. The cross section, at the maximum proton energy of 60 MeV, is approximately 5e-15 cm²/bit. When biased at Vcc=4.5V, these devices exhibit a lower sensitivity to proton induced SEU : cross sections are reduced by a factor 2.

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.

No effect of temperature (T room→T 65°C) can be evidenced on proton cross section values at saturation. The initial memory content has no effect on the cross section value.

These devices exhibited no proton Single Hard Error sensitivity.

No multiple errors (row or column errors) were recorded during the proton irradiations. Other multiple error types could not be identified in absence of a bitmap.

DOCUMENT CHANGE LOG

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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 (8Mbit, 1 type).

The object of this document is to describe the irradiation of 16 Mbit DRAM MT4LC4M4B1D28M from Micron, in order to measure their sensitivity to heavy ion and proton induced Single Event Effects (SEE).

Irradiation were performed in November/December 1996 (30^{th}-1^{st}) 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] Micron Manufacturer Data Sheet

[3] "Radiation Prescreening Programme 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]Radiation data trends on high integrated memories for ESTEC Contract N°11755/95/NL/NB; Bruno Doucin (MMS report, ref DOF/GER/NT6.612)

[7] "Space Radiation Evaluation of 16 Mbit DRAMs for Mass Memory Applications", P. Calvel, P. Lamothe, C. Barillot, R. Ecoffet, S. Duzellier, E. G. Stassinopouloss, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL 41, N0 6, Dec. 94

[8] 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	:	MT4LC4M4B1D28M
Manufacturer	:	Micron
Place	:	USA
Packaging	:	26 pin plastic SOJ

3.1.2. Function

16 Mbit DRAM

3.1.3. Technology

CMOS

3.1.4. Part Procurement

Origin	:	Micron US (Idaho), MMS Procurement from REP'TRONIC
Level	:	/
Temperature range	:	0°C, +70°C
Date code	:	/
Screening	:	No screening
Sample size	:	2 (H.I.), 2 (P.)
Manufacturer Marking	:	No marking
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 Micron MT4LC4M4B1D28M 16 Mbit DRAM has no internal regulator to maintain the internal voltage at 3.3V, when supply voltage is higher. Therefore, when the device is biased at 4.5V, the internal voltage is also 4.5V.

General information

Name	Micron MT4LC4M4B1D28M
Die Mark	No
Access time/ns	Not measured
Temperature range/°C	0, +70°C
Organisation	4Mx4Bit
Supply Voltage/V	3.0-4.6

Technology

Name	Micron MT4LC4M4B1D28M
CMOS	yes
Design rules	0.35 µm, (Mask D28)**
Epitaxial layer	No (bulk)
Die size	5.6 mm x 10.2 mm
Cell size	0.875 µm x 1.75 µm

**Two other versions followed the D28 version : D42, and D52 (0.3µm). The D28 version is no longer commercialized.

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	DUT 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, ion energy 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 ion tests. A complete presentation of the Cyclotron 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:

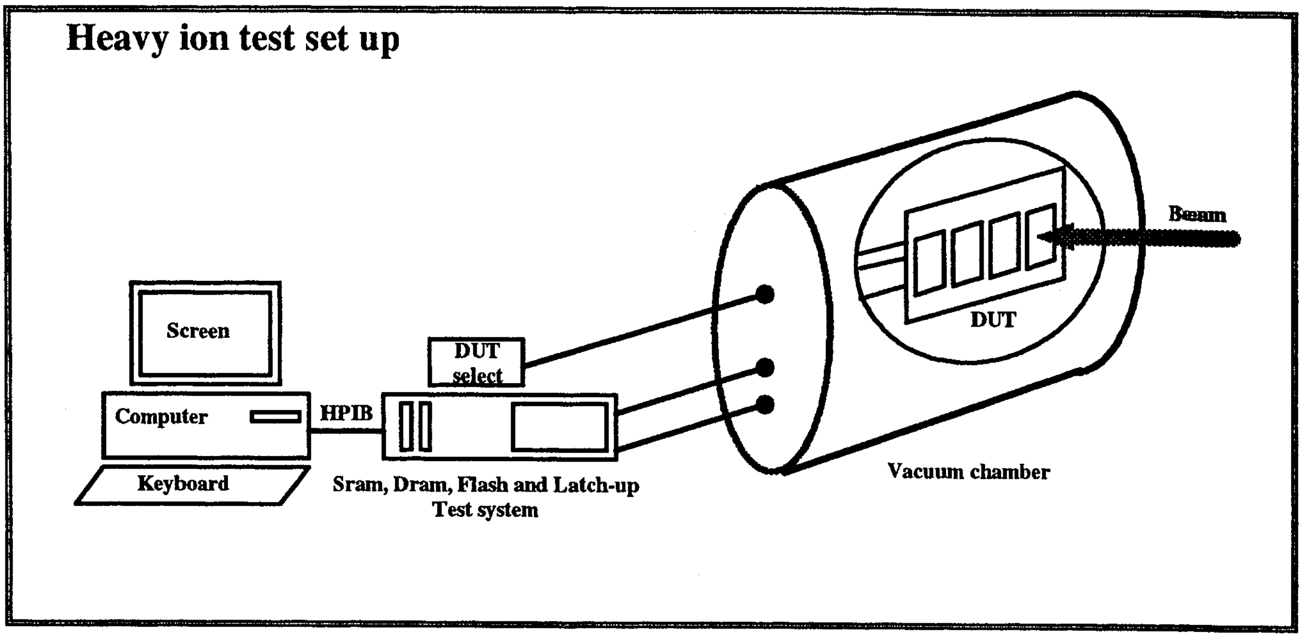


Fig. 1 Description of the heavy ion test set-up.

Comments :

The DUT are mounted on 4 zero-insertion-force sockets.

A switching commutator is located outside of the vacuum chamber, aloowing to select the tested device. The memory tester is also located outside of the vacuum chamber. The tester also includes a delatcher. The Latch-up detection threshold is programmable. The cut-off time is of 10 ms.

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 0.77 MHz for DRAMs. This frequency can be divided by 2, 4, or 8. The maximum SEU rate is 335000 SEU/s for a DRAM, (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. Protons test set-up:

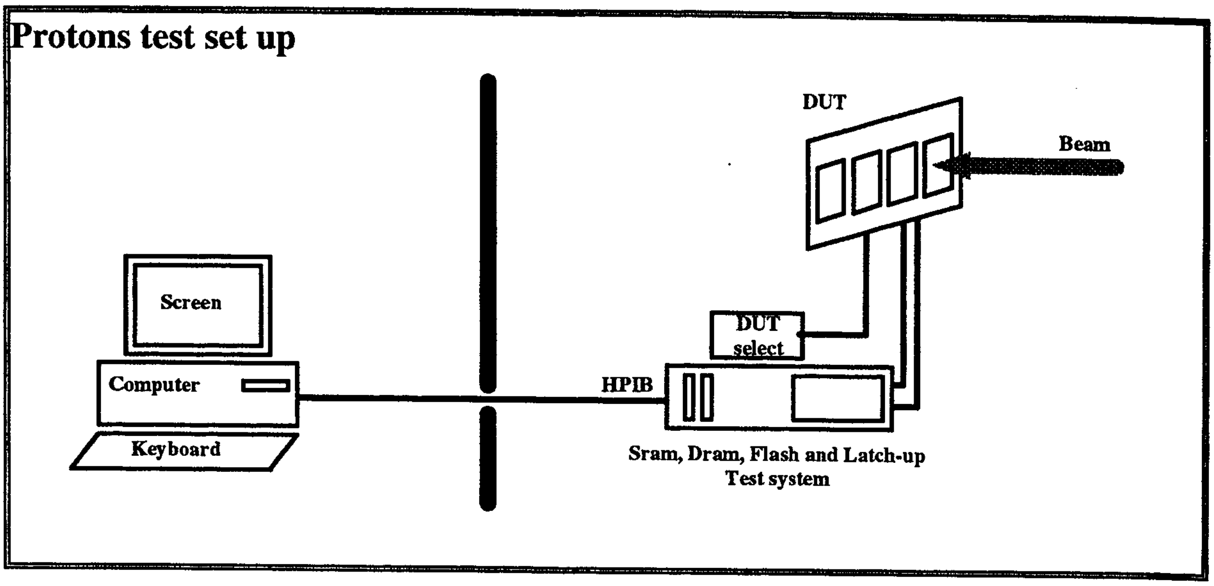
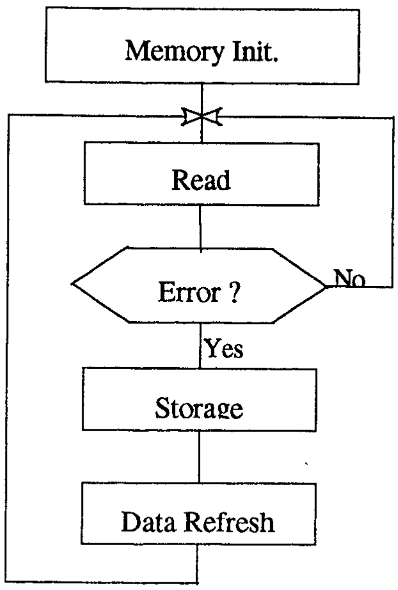


Fig. 2 Description of the proton test set-up

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 LET=10 is an effective LET which is obtained by using the ^{20}Ne ion at an incidence of 54°. 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 irradiations. 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 oxyde 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	Dev.	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Fluence [p/cm²]	ICC+ [mA]
11	SN3	3.3V/fmax	34	0	34	150	23316	+22.5
12	SN3	3.3V/fmax	34	0	34	150	13038	+22.5
13	SN4	3.3V/fmax	34	0	34	150	13094	+22.9
14	SN4	3.3V/fmax	34	0	34	150	13698	+22.9
23	SN4	3.3V/(fmax/4)	34	0	34	150	21072	15.6
24	SN4	3.3V/(fmax/4)	34	0	34	150	20321	15.6
25	SN3	3.3V/(fmax/4)	34	0	34	150	21009	15.6
26	SN3	3.3V/(fmax/4)	34	0	34	150	15673	15.6
27	SN3	3.3V/(fmax/4)	34	0	34	150	12297	15.6

Table 2 : Heavy Ion Irradiation Test Sequence

Run	Device	Vcc/f	LET (Si) [MeV.cm²/mg]	Tilt [°]	Eff. LET (Si) [MeV.cm²/mg]	Flux [p/cm²/s]	Fluence [p/cm²]	ICC+ [mA]
36	SN3	3.3V/(fmax)	14.1	0	14.1	270	28257	+22.5
37	SN4	3.3V/(fmax)	14.1	0	14.1	270	25980	+23.9
50	SN3	3.3V/fmax	5.85	0	5.85	350	11478	+22.5
51	SN4	3.3V/fmax	5.85	0	5.85	350	12611	+22.5
56	SN4	+5V/fmax	5.85	54	10	1000	180518	+23
57	SN3	+5V/fmax	5.85	54	10	1000	91917	+23
64	SN3	3.3V/fmax	1.7	0	1.7	6000	1.0e+06	22.5
65	SN4	3.3V/fmax	1.7	0	1.7	6000	1.0e+06	22.5
68	SN3	4.5V/fmax	1.7	0	1.7	9000	1.0e+06	35.7
69	SN4	4.5V/fmax	1.7	0	1.7	9000	1.0e+06	35.7
80	SN3	4.5V/fmax	5.85	0	5.85	1000	1.1e+05	/
81	SN4	4.5V/fmax	5.85	0	5.85	1000	8.6e+04	+37.1
92	SN4	4.5V/fmax	34	0	34	250	1.52e+03	+37.1
93	SN3	4.5V/fmax	34	0	34	250	9.90e+03	+37.1
94	SN3	4.5V/fmax	34	0	34	250	1.74e+03	+37.1

Table 2 (end) : Heavy Ion Irradiation Test Sequence

5.2. ANALYSIS OF HEAVY ION RESULTS: METHOD

5.2.1. Calculation of SEP cross-sections

The cross-sections were calculated as follows :

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

where :

σ is the SEP Cross-section (cm^2/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.$cm^2$/mg

N is the total Number of SEP

F = Fluence (part./cm^2) (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.

1. For multiple error treatment, see detailed explanation in 5.3.3 page 15.
2. The minimum of fluence required is 1e+6 p/cm^2, 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/cm^2.

When multiple upsets are observed during a run due to row or column errors, these errors minus one are substracted from the total number of errors.

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 error rate > 600, no confidence limit is calculated

5.3. HEAVY ION CROSS SECTION MEASUREMENTS

5.3.1. Tables of heavy ion results

Results in tables 3, 4 and 5 are obtained after substraction of multiple errors (row errors).

Test Sample	Test n°	SEU	Fluence (part/cm²)	Effective LET [MeV.cm²/mg]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN4	65	36	1.0 e+06	**1.7**	**2.15 e-12**	1.59e-12/2.83e-12
SN3	64	33	1.0 e+06	**1.7**	**1.97 e-12**	1.43e-12/2.63e-12
SN4	51	699	1.3 e+04	**5.85**	**3.30 e-09**	/
SN3	50	658	1.1 e+04	**5.85**	**3.42 e-09**	/
SN3	57	9579	9.2 e+04	**10**	**6.21 e-09**	/
SN4	56	10126	1.8 e+05	**10**	**3.34 e-09**	/
SN4	37	5169	2.6 e+04	**14.1**	**1.19 e-08**	/
SN3	36	5132	2.8 e+04	**14.1**	**1.08 e-08**	/
SN4	14	6480	1.4 e+04	**34**	**2.82 e-08**	/
SN4	13	6289	1.3 e+04	**34**	**2.86 e-08**	/
SN 3	12	5598	1.3 e+04	**34**	**2.56 e-08**	/
SN3	11	9348	2.3 e+04	**34**	**2.39 e-08**	/

Table 3 : Cross section measurements for Vcc=3.3V

Test Sample	Test n°	SEU	Fluence (part/cm²)	Effective LET [MeV.cm²/mg]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN4	69	2	1.0 e+06	**1.7**	**1.19 e-13**	2.11e-14/3.75e-13
SN3	68	4	1.0 e+06	**1.7**	**2.38 e-13**	8.14e-14/5.45e-13
SN4	81	3962	8.6 e+04	**5.85**	**2.76 e-09**	/
SN3	80	4024	1.1 e+05	**5.85**	**2.52 e-09**	/
SN5	94	135	1.7 e+03	**34**	**4.62 e-10***	3.99e-10/5.33e-10
SN5	93	3912	9.9 e+03	**34**	**2.36 e-08**	/
SN4	92	229	1.5 e+03	**34**	**8.98 e-09***	8.02e-09/1.00e-08

Table 4 : Cross section measurements for Vcc=4.5V

***See 5.4, result analysis**

Test Sample	Test n°	SEU	Fluence (part/cm²)	Effective LET [MeV.cm²/mg]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN4	24	8073	2.0 e+04	**34**	**2.37 e-08**	/
SN3	27	5584	1.2 e+04	**34**	**2.71 e-08**	/

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

5.4. HEAVY ION RESULT ANALYSIS

The figure 4.a) exhibits the heavy ion induced cross sections for MICRON DRAM 16 Mbit MT4LC4M4B1D28M. Multiple errors were subtracted for SEU calculations.

A complete characterization was performed at Vcc=3.3V

Effect of supply voltage (Vcc=4.5V) was studied at 1.7, 5.85, and 34 MeV.cm²/mg.

Effect of operating frequency was studied at a LET value of 34 MeV.cm²/mg.

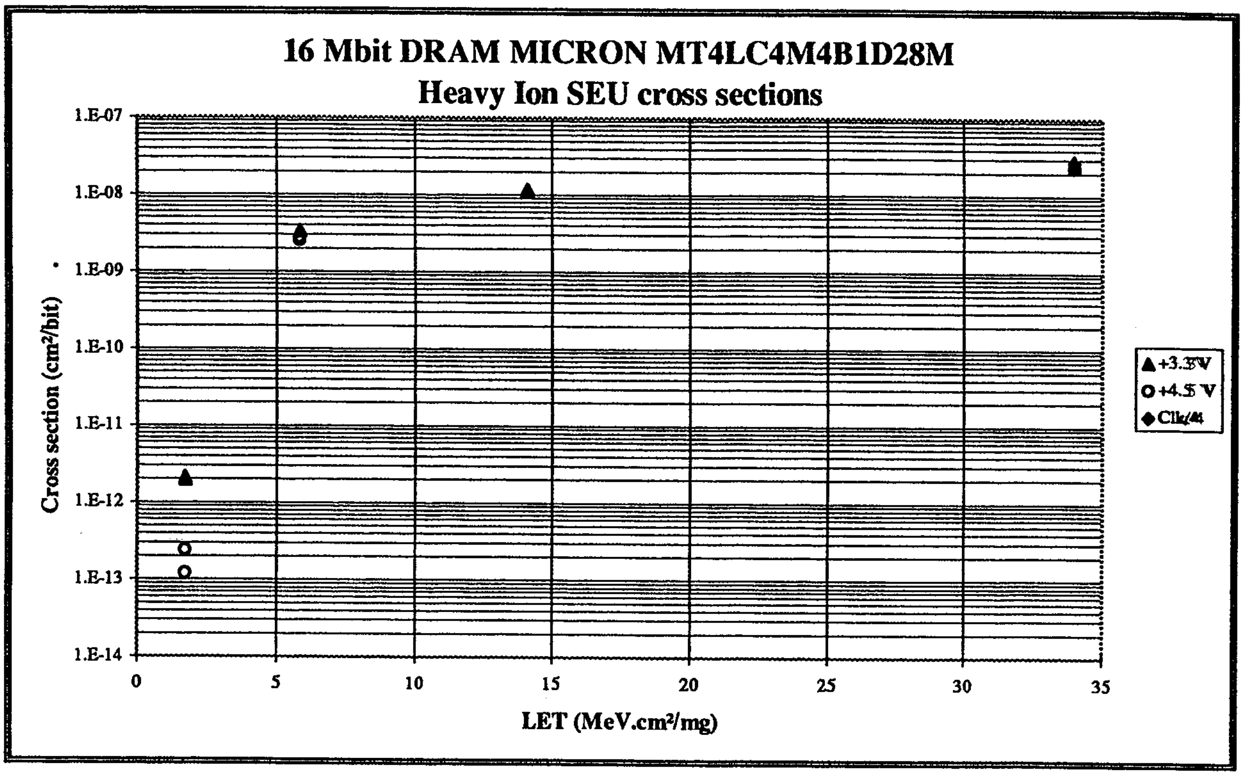


Fig. 4 Heavy ion cross section measurements for MICRON DRAM 16 Mbit

Effect of supply voltage :

The cross section decreases at Vcc=4.5V around the LETth. Only run 93 is considered at maximum LET, since for the other runs (92,94), not all the memory content was investigated. Cross sections are very close at both supply voltage : no effect at high LET is evidenced.

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

No effect of operating frequency is clearly evidenced.

Effect of the initial memory content:

The cross section does not vary with the initial content of the memory.

5.4.1. Multiple errors

Multiple errors were observed during heavy ion irradiation. At the high LET, 1 row error per test was observed but no column errors. When such an error occurs the tester finds 512 errors. When a multiple error is identified by address value analysis, the number of errors is subtracted from the total number and 1 error is counted in row errors. Row errors were only observed at low Vcc voltage (3.3V). No clear influence of the test frequency on multiple error rate was observed, due to the low occurrence rate.

Figure 4.b) gives a comparison between row error cross-sections and SEU cross sections at 3.3V. Results are expressed in cm²/device. At all LET values, the results exhibit a much lower row error sensitivity.

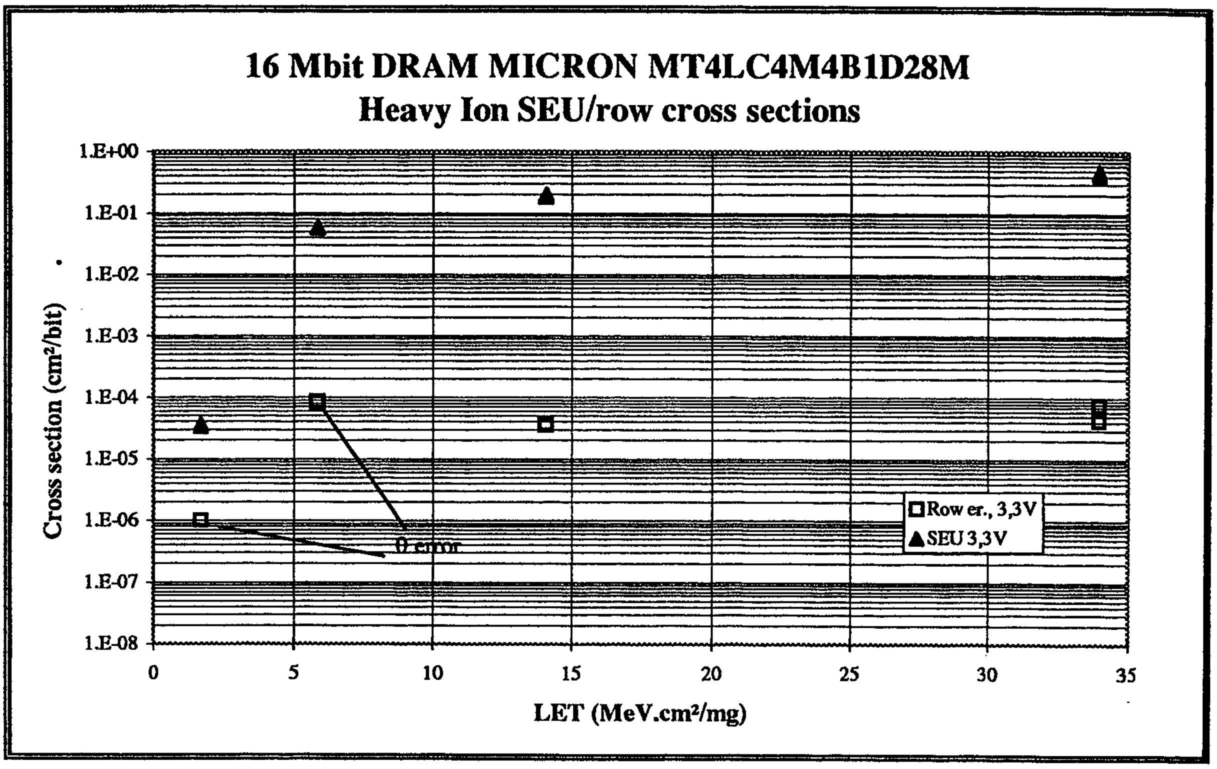


Fig. 4. b) Heavy ion cross section measurements for MICRON DRAM 16 Mbit at 3.3V : comparison between row error and SEU error cross sections.

5.4.2. Problems encountered/Discussion

No specific problem was encountered during irradiation. When analyzing results of run 56 (eff LET=10 MeV.cm²/mg, tilted), it was found out that the row errors systematically stopped at address 3fe: it is believed that the memory was only partially irradiated.

The cross sections obtained at LET=10 MeV.cm²/mg are generally lower than expected. This is probably due to the vertical geometry of the DRAM sensitive volume (a smaller amount of charge can be collected in the sensitive volume with a tilt). It was decided not to plot in Fig.4.a) the data corresponding to this LET value.

5.5. HEAVY ION CONCLUSIONS

The results of these experiments demonstrate that 16 Mbit DRAM MT4LC4M4B1D28M from Micron, biased at 3.3V are highly sensitive to heavy ion induced SEE : the cross section at LET=34 MeV.cm²/mg is about 3e-8 cm²/bit, and the threshold LET is <1.7 MeV.cm²/mg. When biased at 4.5V, the sensitivity is slightly lowered : the cross section at 34 MeV.cm²/mg is comparable, but the threshold LET is slightly higher (≈1.7 MeV.cm²/mg).

Additional heavy ion results:

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

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

The initial memory content does not influence the cross section.

Multiple errors (row errors) were observed during the tests but only at Vcc=3.3V.

The devices exhibited no Single Hard Error sensitivity.

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]	Fluence [p/cm²]	Depos./cumul. dose (kRad[Si])	ICC+ [mA]
18	SN1	4.5V/fmax	60	7.04e+07	1e+10	1.5/1.5	+35.6
19	SN2	4.5V/fmax	60	8.70e+07	1e+10	1.5/1.5	+36
25	SN1	5V/fmax	40	8.7e+07	1e+10	2/3.5	+36
26	SN2	5V/fmax	40	9.52e+07	1e+10	2/3.5	+36
27	SN2	5V/fmax	20	9.8e+07	1e+10	3.5/7	+36
28	SN1	5V/fmax	20	8.47e+07	1e+10	3.5/7	+36.5
46	SN1	3.3V/fmax	60	1.09e+08	1e+10	1.5/8.5	+21.5
47	SN2	3.3V/fmax	60	9.17e+07	1e+10	1.5/8.5	+22.5
52	SN2	3.3V/fmax	40	1.19e+08	1e+10	2/10.5	+21.5
53	SN1	3.3V/fmax	40	1.19e+08	1e+10	2/10.5	+21.5
54	SN2	3.3V/fmax	20	1.09e+08	1e+10	3.5/14	+22.4
55	SN2	3.3V/fmax	20	1.12e+08	1e+10	3.5/17.5	+22.4
60	SN2	3.3V/(fmax/4)	60	1.15e+08	1e+10	1.5/19	+22.4
61	SN1	3.3V/(fmax/4)	60	1.16e+08	1e+10	1.5/12	+22.4
62	SN1	3.3V/(fmax/4)	60	1.11e+08	1e+10	1.5/13.5	+21
63	SN2	3.3V/(fmax/4)	60	1.33e+08	1e+10	1.5/20.5	+21

Table 7: Proton Irradiation Test Sequence

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 (cm²/device), expressed as a function of the Proton Energy

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 fluence is set at 1e+10 p/cm² 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

Test Sample	Test n°	SEU	Fluence (part/cm²)	P. Energy [MeV]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN1	46	776	1.0 e+10	**60**	**4.6 e-15**	/
SN2	47	862	1.0 e+10	**60**	**5.1 e-15**	/
SN2	52	621	1.0 e+10	**40**	**3.7 e-15**	/
SN1	53	697	1.0 e+10	**40**	**4.2 e-15**	/
SN1	54	257	1.0 e+10	**20**	**1.5 e-15**	1.69e-15/1.37e-15
SN2	55	344	1.0 e+10	**20**	**2.1 e-15**	2.24e-15/1.87e-15

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]
SN1	18	417	1.0 e+10	**60**	**2.5 e-15**	2.69e-15/2.28e-15
SN2	19	471	1.0 e+10	**60**	**2.8 e-15**	3.02e-15/2.59e-15
SN1	25	316	1.0 e+10	**40**	**1.9 e-15**	2.06e-15/1.71e-15
SN2	26	361	1.0 e+10	**40**	**2.2 e-15**	2.34e-15/1.96e-15
SN2	27	93	1.0 e+10	**20**	**5.5 e-16**	6.58e-16/4.63e-16
SN1	28	105	1.0 e+10	**20**	**6.3 e-16**	7.36e-16/5.28e-16

Table 9 : Cross section measurements for Vcc=4.5V

Test Sample	Test n°	SEU	Fluence (part/cm²)	P. Energy [MeV]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN2	60	798	1.0 e+10	**60**	**4.8 e-15**	/
SN1	61	793	1.0 e+10	**60**	**4.7 e-15**	/

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

Test Sample	Test n°	SEU	Fluence (part/cm²)	P. Energy [MeV]	X-Section [cm²/bit]	90% Conf. Limits [cm²]
SN1	62	806	1.0 e+10	**60**	**4.8 e-15**	/
SN2	63	844	1.0 e+10	**60**	**5.0 e-15**	/

Table 11 : Cross section measurements for Vcc=3.3V, T=65°C

6.3.2. Proton result analysis

The figure 5 exhibits the proton induced cross sections for MICRON 16 Mbit DRAM.

A complete characterization was performed at Vcc=3.3V and Vcc=4.5V.

Effect of supply voltage (Vcc=4.5V) was adressed at the three proton energies.

Effect of operating frequency at low Vcc was adressed at a 60 MeV proton energy.

Effect of operating temperature was adressed at a 60 MeV proton energy.

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

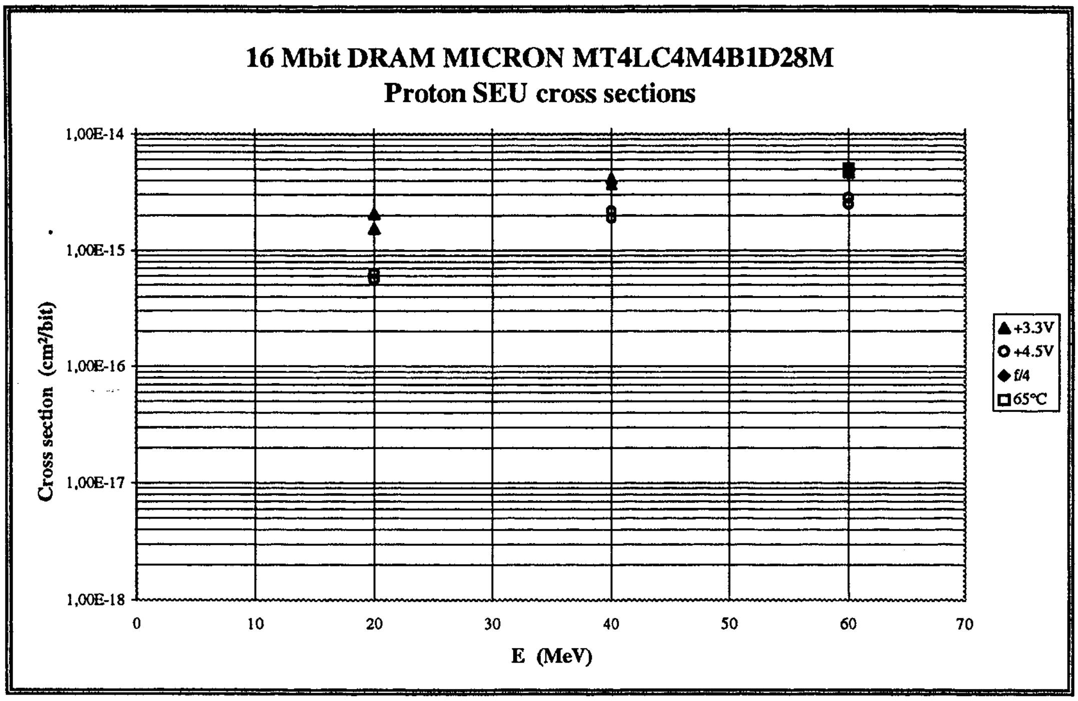


Fig. 5 Proton cross section measurements for MICRON 16 Mbit DRAM

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

The devices biased at 4.5V have a lower sensitivity to proton induced SEU than devices biased at 3.3V : at the 3 proton energies, the average saturated cross-section is divided by a factor of 2.

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

No specific effect was evidenced at the 60 MeV proton energy.

<u>Effect of the operating temperature</u> (T room →T 65°C) :

No specific effect was evidenced at the 60 MeV energy

6.3.3. Problems encountered/Discussion

No specific problem was encountered during irradiations.

6.4. PROTON CONCLUSIONS

The results of these experiments demonstrate that 16 Mbit MT4LC4M4B1D28M from Micron, biased at 3.3V, are sensitive to proton induced SEU. The cross section, at the maximum proton energy of 60 MeV, is approximately 5e-15 cm^2/bit. When biased at Vcc=4.5V, these devices exhibit a lower sensitivity to proton induced SEU : cross section are reduced by a factor 2.

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.

No effect of temperature (T room→T 65°C) can be evidenced on proton cross section values at saturation. The initial memory content has no effect on the cross section value.

These device exhibited no proton Single Hard Error sensitivity.

No multiple errors (row or column errors) were recorded during the proton irradiation. Other multiple error types could not be identified in absence of a bit map.

7. CONCLUSION

Heavy ion and proton SEU characterizations were performed on the 16 Mbit MT4LC4M4B1D28M from Micron, at 3.3V. Effects of supply voltage and operating frequency on the SEE sensitivity was also studied. Results are summarized in the following tables.

	LET Threshold (MeV.cm²/mg)	Cross-section (cm²/dev) at LET=34 MeV.cm²/mg	Cross-section (cm²/bit) at LET=34 MeV.cm²/mg
Vcc=3.3V	<1.7	≈4e-1	≈3e-8
Vcc=4.5V	≈1.7	≈4e-1	≈3e-8

Summary of SEU heavy ion results

	LET Threshold (MeV.cm²/mg)	Saturation Cross-section (cm²/dev.)
Vcc=3.3V	10<LETth<14.1	<8e-5
Vcc=4.5V	>34	not estimated

Summary of row error heavy ion results

	Proton Energy Threshold (MeV)	Saturated Cross-section (cm²/bit)
Vcc=3.3V	<20	≈5e-15
Vcc=5V	<20	≈2.8e-15

Summary of proton results

Analysis of the results shows that no important effect of operating frequency was evidenced on heavy ion and proton cross section measurements.

Effect of supply voltage (from 3.3V to 4.5V) is stronger on the proton SEU cross section sensitivity than on the heavy ion SEU sensitivity.

Multiple errors were observed with heavy ion irradiation, at Vcc=3.3V. These errors are only row errors (no column error or block error were found).

No multiple errors were found with proton irradiation.

These device exhibited no heavy ion or proton Single Hard Error sensitivity.

8. ANNEX

8.1. DIE PHOTOGRAPHY

Photography of the die marking

8.2. DETAILS OF RESULT ANALYSIS

Row Errors:

Row errors were only observed for Vcc=3.3V with a maximum of 1 row error per test.

The cross section is expressed in cm^2/device.

MICRON		Vcc=3.3V				
RUN	**SN**	**Row Err.**	**Size (bits)**	**Fluence (part/cm²)**	**LET (MeV.cm²/mg)**	**Cross. Sec. (cm²/device)**
11	3	0	16777216	23316	34	<4,28E-05
12	3	1	16777216	13038	34	7,66E-05
13	4	1	16777216	13094	34	7,63E-05
14	4	0	16777216	13698	34	<7,30E-05
36	3	0	16777216	28257	14.1	<3,53E-05
37	4	1	16777216	25980	14.1	3,84E-05
56	4	0	16777216	180518	10	<5,53E-06
57	3	0	16777216	91917	10	<1,08E-05
50	3	0	16777216	11478	5.85	<8,71E-05
51	4	0	16777216	12611	5.85	<7,92E-05
64	3	0	16777216	1000000	1.7	<1E-06
65	4	0	16777216	1000000	1.7	<1E-06

Table a-1 Row errors at Vcc=3.3V

MICRON		f/4				
RUN	**SN**	**Row Err.**	**Size (bits)**	**Fluence (part/cm²)**	**LET (MeV.cm²/mg)**	**Cross. Sec. (cm²/device)**
24	4	1	16777216	20321	34	4,92E-05
27	3	0	16777216	12297	34	< 8,13E-05

Table a-2 Row errors at Vcc=3.3V