HEAVY ION SINGLE EVENT EFFECTS RADIATION TEST REPORT

Part Types : AT28C010

EEPROM - 1-megabit (128K x 8) Paged Parallel

Manufacturers : ATMEL

Report Reference : ESA_QCA0209S_C

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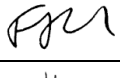
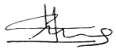
Checked by :	F.X GUERRE		Date :	January 23, 2003
Approved by :	J. F. MOUNES		Date :	January 23, 2003

Heavy ion SEE characterization of AT28C010, 1-megabit (128K x 8) Paged Parallel EEPROM from ATMEL

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1 Abstract

Under ESA Contract No 13528/99/NL/MV COO-14 covering "Radiation Evaluation of COTS Semiconductor Components: SEE Radiation Evaluation of PROMs & SDRAMs", two different types EEPROM memories from ATMEL, were radiation Single Event Effects (SEE) assessed. Results from these assessments covering the AT17LV010 can be found in ESA_QCA0208S_C whereas here, in ESA_QCA0209S_C, the AT28C0110E will be covered.

2 INTRODUCTION

This report presents the results of a Single Event Effects (SEE) test program carried out on the AT28C010, a 1M-bit Paged Parallel EEPROM from ATMEL.
Test was conducted on samples delivered by ATMEL.
These devices were used for heavy ion test at the European Heavy Ion Irradiation Facility (HIF) at Cyclone, Université Catholique de Louvain, Belgium.
This work was performed for ESA/ESTEC under ESA Contract No 13528/99/NL/MV COO-14.

3 REFERENCE DOCUMENTS

RD-1. AT28C010 datasheet
RD-2. Single Event Effects Test method and Guidelines ESA/SCC basic specification No 25100
RD-3. The Heavy Ion Irradiation Facility at CYCLONE, UCL document, Centre de Recherches du Cyclotron (IEEE NSREC'96, Workshop Record, Indian Wells, California, 1996)

4 DEVICE INFORMATION

Relevant detailed device identification information is presented here after.

4.1 AT28C010E

Part type:	AT28C010E
Manufacturer:	ATMEL
Package:	32-pin CERDIP
Quality Level:	Military
Date Code:	0013
Top Marking:	AT28CO10E 15DM/883C 9C0013B
Die Size:	9.3 mm x 6.2 mm approximately
Die marking	ATMEL 19506
Serial number	SN1, SN2 (attributed by Hirex)

The AT28C010 is a high-performance Paged Parallel EEPROM. Its one megabit of memory is organized as 131,072 words by 8 bits.
The device contains a 128-byte page register to allow writing of up to 128-bytes simultaneously.
Die identification is provided in Figure 1.

4.2 Samples preparation

AT28C010E packages could be mechanically opened.

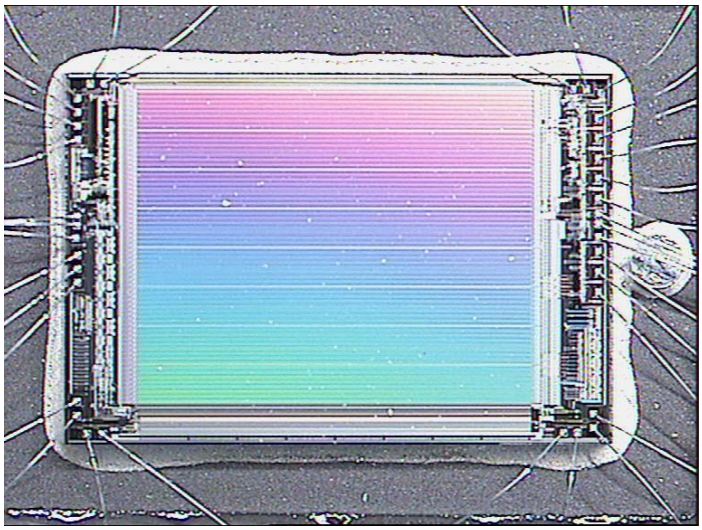

Photo 1

Die, full view

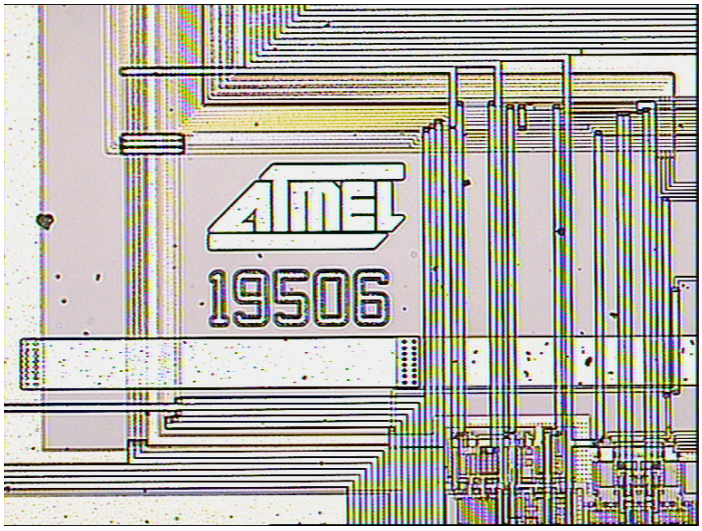

Photo 2

Die marking

Figure 1 - AT28C010E die identification

5 Test Definition

5.1 Test Set-up

Hirex test equipment is composed of a modular rack coupled with a generic memory test board:

This modular rack is derived from Hirex BILT modular instrumentation system and presents 8 slots for modular instruments.
In addition to the existing power supply modules which cover the SEE test needs for precision measurements, remote control, LU detection, data storage, scope observation, etc, a specific modular board has been designed to provide:

- A high speed communication link with the test board under vacuum (up to 500 ko/s)
- Management of DUT positioning (mover)
- Particle and test time counting

Dedicated to the test of memories, the generic test board is based on a 12 MIPs on-board processor which controls the test sequence and the communication with the rack.
The board includes programmable logic circuits with a total capacity of 30000 cells and 960 macrocells. This logic circuitry can work at high speed (up to 100 MHz) while being compatible with thermal requirements imposed by vacuum environment.
Today, the board has a capacity of 80 pin-drivers, using transceivers able to interface memory devices with voltage supply requirements between 1 and 7 volts. The DUT can have two different power supplies.

5.2 Tests Configuration

Supply Voltage : 5V as specified in the AT28C010E datasheet.

Test Temperature : room temperature

Three different sets of test conditions were used:

Static ON :

- Prior to exposure, write the entire memory with a given pattern (moving test pattern)
- Exposure
- After exposure, read all the pages of the memory

Continuous Read :

- Prior to exposure, write the entire memory with a given pattern (moving pattern)
- During exposure, read continuously all the memory

Continuous Read/Write (R/W) :

- Prior to exposure, write the entire memory but the pages which will be continuously cycled under exposure. (in the present case, 100 pages are selected out of a total of 1024 pages)
- During exposure, continuously read, erase and write the selected 100 pages.
- After exposure, check the other pages for eventual data corruption.

Test principle is based on the use of a repetitive pattern, which allows checking that at each cycle, every word has been effectively rewritten with new data.

The table here below provides, for each group of 4 bits, the 14 words repetitive pattern.

	It k	It k+1	It k+2	It k+3	It k+4	It k+5	It k+6	It k+7	It k+8	It k+9	It k+10	It k+11	It k+12	It k+13	It k+14
address n	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000
address n+1	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010
address n+2	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101
address n+3	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111
address n+4	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001
address n+5	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110
address n+6	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101
address n+7	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000
address n+8	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010
address n+9	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101
address n+10	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111
address n+11	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001
address n+12	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110
address n+13	1010	0101	0110	1010	1001	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010
address n+14	0000	1111	0101	0101	0110	1010	1001	0000	1111	1010	0101	0110	1010	1001	0000

Table 1 – Test pattern

5.3 Errors reporting

For each memory read cycle, the total number of words in error (one bit flip minimum) is recorded.

In addition the following information is recorded for each word in error with an upper limit of 6500 errors.

- Cycle iteration number
- Word address
- Awaited word pattern
- Word data in error

DUT power supply module is monitored and each time the current consumption exceeds a programmable threshold, a power reset cycle is done and latch-up error counter is incremented.
In addition the use of fast latch-up detection with a high speed comparator avoids the counting of SEU errors which could be induced by the latch-up condition.

6 TEST FACILITIES

6.1 UCL

Test at the cyclotron accelerator was performed at Université de Louvain (UCL) in Louvain-La-Neuve (Belgium) under HIREX Engineering responsibility.

6.1.1 Beam Source

In collaboration with the European Space Agency (ESA), the needed equipment for single events studies using heavy ions was built and installed on the HIF beam line in the experimental hall of Louvain-La-Neuve cyclotron.
CYCLONE is a multi particle, variable energy, cyclotron capable of accelerating protons (up to 75 MeV), alpha particles and heavy ions. For the heavy ions, the covered energy range is between 0.6 MeV/AMU and 27.5 MeV/AMU. For these ions, the maximal energy can be determined by the formula:

$$110\ Q^2/M,$$

where Q is the ion charge state, and M is the mass in Atomic Mass Units.
The heavy ions are produced in a double stage Electron Cyclotron Resonance (ECR) source. Such a source allows producing highly charged ions and ion "cocktails". These are composed of ions with the same or very close M/Q ratios. The cocktail ions are injected in the cyclotron, accelerated at the same time and extracted separately by a fine tuning of the magnetic field or a slight changing of the RF frequency. This method is very convenient for a quick change of ion (in a few minutes) which is equivalent to a LET variation.

6.1.2 Dosimetry

The current UCL Cyclotron dosimetry system and procedures were used.

6.2 Beam set-up

The different ions used are listed in the tables below.
The LET range is obtained by changing the ion species, energy and changing the angle of incidence between the beam and the chip.
For each run, the following information is given in the detailed results tables provided in the next paragraph (paragraph 7) :

- Ion species
- Ion energy
- LET
- Range in Si
- Tilt angle
- Effective LET
- Averaged flux
- Fluence
- Equivalent dose received by the DUT sample

6.3 UCL Ion sources

The ions used at the HIF facility:

Ion Specie	Energy	LET	Range
	(MeV)	(MeV.cm²/mg)	µm
15-N	62	2.97	64
20-Ne	78	5.85	45
40-Ar	150	14.1	42
84-Kr	316	34	43

Table 2 – HIF ions

Tilting the DUT up to 60º, will result in effective LET values in-between the listed values.

7 RESULTS

The main findings are first summarised, then an analysis of the results per run is provided in Table 3.

7.1 Main findings AT28C010E

Most errors consist in random words errors which were found to persist whatever the test configuration used, Static ON, Continuous read or Continuous Read/Write. LET threshold for these errors was found to be between 4.35 and 5.85 MeV/(mg/cm²).
For the low LET values these errors were mostly SEUs while with higher LET values, MBUs could also be detected.
Analysis of the run errors log files show that for each word data in error, some bits were more sensitive (bit1 for instance) and that each bit in the word should present a preponderant switch transition (1 to 0 or 0 to 1 depending on the bit position inside the word).
A power-off /on cycle allows for recovering the data integrity (read memory cycle with no error)

In addition, using the Continuous Read/Write test condition, page errors have been observed when tested with Argon at 14 MeV/(mg/cm²) as well as functional errors which could affect (erase / write) not only the pages under test (100 pages out of a total of 1024 pages) but the whole memory.

Lastly with Continuous Read test condition, a functional error was observed with Krypton at 34 MeV/(mg/cm²).

In all cases, after the DUT power was switched off and on, the devices were fully functional again.

7.2 Detailed Results and Analysis per Run

Run #	S/N	Test	Ion	Energy (MeV)	LET MeV/(mg/cm²)	Range (µm)	Angle (deg.)	Eff_LET MeV/(mg/cm²)	Time (s)	Flux (ions/cm².s)	Fluence (ions/cm²)	Comment
R31	1	Static ON	15-N	62	2.97	64	0	2.97	99	10100	1.00E+06	No error
R32	1	Continuous Read	15-N	62	2.97	64	0	2.97	100	10000	1.00E+06	No error
R33	1	Continuous Read/write	15-N	62	2.97	64	0	2.97	98	10200	1.00E+06	No error
R34	1	Static ON	15-N	62	2.97	64	47	4.35	139	7190	1.00E+06	No error
R35	1	Continuous Read	15-N	62	2.97	64	47	4.35	138	7250	1.00E+06	No error
R36	1	Continuous Read/write	15-N	62	2.97	64	47	4.35	132	7580	1.00E+06	No error
R14	1	Static ON	20-Ne	78	5.85	45	0	5.85	58	5590	3.24E+05	post exposure, persistent word errors After DUT power-off, no error anymore.
R15	1	Static ON	20-Ne	78	5.85	45	0	5.85	299	3340	1.00E+06	post exposure. persistent SEU word errors, A write memory does not cure the errors, after DUT power-off, no error anymore.
R16	1	Continuous Read/write	20-Ne	78	5.85	45	0	5.85	449	2230	1.00E+06	2 SEU word errors at the same address but at different (not consecutive) iterations (it585 and it620). After exposure and DUT power off, no error in the memory outside the 100 pages.
R07	1	Continuous Read	40-Ar	150	14.1	42	0	14.1	164	6100	1.00E+06	No error
R12	1	Static ON	40-Ar	150	14.1	42	0	14.1	137	6620	1.00E+06	After exposure, word errors at random addresses. Several reads show that errors are persistent. Post run analysis showed that in a word, each bit is switching preponderantly in one direction only (1 to 0 or 0 to 1) and that bit sensitivity is not identical, bit1 is more sensitive. After DUT power off, no error anymore.
R13	1	Continuous Read/write	40-Ar	150	14.1	42	0	14.1	199	4940	9.84E+05	7 pages errors and persistent word errors. After exposure, the pages other than the100 ones tested under exposure, are all in error (all words to FF). After DUT power-off, device is fully functional.
R40	1	Static ON	84-Kr	316	34	43	0	34	137	7300	1.00E+06	No error
R37	2	Static ON	15-N	62	2.97	64	47	4.35	132	7580	1.00E+06	No error
R38	2	Continuous Read	15-N	62	2.97	64	47	4.35	124	8060	1.00E+06	3 read errors at the same it.
R39	2	Continuous Read/write	15-N	62	2.97	64	47	4.35	129	7750	1.00E+06	No error
R17	2	Static ON	20-Ne	78	5.85	45	0	5.85	422	2370	1.00E+06	5 persistent SEU word errors (similar to previous runs)
R18	2	Continuous Read	20-Ne	78	5.85	45	0	5.85	410	2170	8.90E+05	1799 iterations. Same behaviour than run09 with Argon: persistent errors read at each iteration. Log file not recorded: In fact the flux of data in the control board FIFO was too high every second: it has induced a programme crash
R19	2	Continuous Read	20-Ne	78	5.85	45	0	5.85	220	1960	4.32E+05	Same behaviour as the previous run: persistent SEU word errors (~3 errors at each it.)
R20	2	Continuous Read/write	20-Ne	78	5.85	45	0	5.85	548	1820	1.00E+06	3 SEU word errors which occur periodically (same bit error at the same address) during the Read/Write iterations. After exposure and DUT power off, no error in the memory outside the 100 pages.

…/…

Run #	S/N	Test	Ion	Energy (MeV)	LET MeV/(mg/cm²)	Range (um)	Angle (deg.)	Eff_LET MeV/(mg/cm²)	Time (s)	Flux (ions/cm².s)	Fluence (ions/cm²)	Comment
R08	2	Continuous Read	40-Ar	150	14.1	42	0	14.1	117	5960	6.97E+05	381 read cycles have been performed during the run. 13 word errors at different page addresses are detected at the read cycle iteration No 316 . These errors are continuously detected at the subsequent read iterations. In addition, some other word errors at different addresses are detected periodically or only at one iteration. After exposure, it is observed that the errors are still present. Post run analysis of the errors showed that in a word, each bit is switching preponderantly in one direction only(1 to 0 or 0 to 1) and that bit sensitivity is not identical, bit1 is more sensitive. After a DUT power off, no error is detected anymore.
R09	2	Continuous Read/write	40-Ar	150	14.1	42	0	14.1	63	6530	4.12E+05	With this test configuration, 100 pages out of the 1024 pages are selected (H3200 to H6400) before exposure and a continuous read/write cycle is performed for these pages under exposure. 1 page write error (the128 words in error) at two different cycle iterations and at a different address, first error corresponding to a pattern offset, the second error corresponding to all bits to zero (00). Then at the next iteration after the second error, the 100 pages written with all bits to 1 (FF). After exposure, the entire memory (the 1024 pages) are in error: all words with all bits to 1 (FF). After DUT power off, the device recovers its functionality.
R41	2	Static ON	84-Kr	316	34	43	0	34	133	7520	1.00E+06	No error
R42	2	Continuous Read	84-Kr	316	34	43	0	34	31	10500	3.24E+05	Persistent MBU/SEU word errors. At last, the whole memory is in error which induced a functional error and then a stop of the run

Table 3 - AT28CO10E SEE detailed results per run

8 CONCLUSION

Heavy ion tests were conducted on samples of AT28C010E 1M-bit Paged Parallel EEPROM memories from ATMEL, using the heavy ions available at the European Heavy Ion Irradiation Facility (HIF) at Cyclone, Université Catholique de Louvain, Belgium.

Three test configurations were used ‘Static ON’, ‘Continuous Read’ and 'Continuous Read/Write (100 pages)' running the EEPROM at 5 Volt. Errors were observed from a LET of 5.85 MeV/(mg/cm²). These errors were found to be persistent.
A power-off/on of the memory allows for recovering the data integrity.

Functional error were also observed from a LET of 14.1 MeV using 'Continuous Read/Write (100 pages)' test configuration with loss of data even outside the 100 pages under test (total number of memory pages is 1024).