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2025 Seville, Spain
25 - 27 March

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SESSION:
COTS RADIATION TEST DATA

Co-Chairs

César Boatella
ESA

José Largaespalda
ALTER

11:30 -11:55	Evaluation of Spin transfer Torque DDR MRAM in Space Environment - TAS (Anthony Berne)
11:55 - 12:10	Radiation Data Compendium: Evaluation of COTS optocouplers and HiRel solutions for space applications - CNA (Amor Romero Maestre)
12:10 - 12:30	Heavy ion testing of COTS components at CERN: recent results and facility development - CERN (Andreas Waets)
12:30 - 12:50	Advancements in Radiation-Hardened Analog ICs: Qualification of αRD139A and αRD1567 under ESA GSTP - RD ALFA Microelectroncs (Lev Lapkis)
12:50 - 13:10	Evaluation of DAC and ADC for science instrument. BGF_ESA (Silvia Massetti)
13:10 – 13:20	Lunch

EVALUATION OF SPIN-TRANSFER TORQUE DDR MRAM IN SPACE ENVIRONMENT

ESA CONTRACT NO. 4000135378/21/NL/GLC/OV

ACCEDE | ESCCON

2025 Seville - Spain
25 to 27th March

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Date: 02/04/2025
Ref: 0005-0018026533

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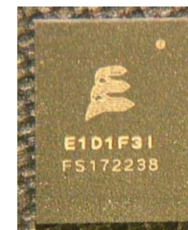
Date: 02/04/2025
Ref: 0005-0018026533

INTRODUCTION

/// Scope and purpose

- MRAM technology is very interesting for space use since:
  - Could replace both non-volatile and volatile memories
  - Has a very high endurance
  - Is known to have a good withstanding in radiation (both TID and SEE)
- COTS MRAM evaluated in radiation in the frame of this study are quite bigger that the one available in Hirel :

Type	Manufacturer	Part Number	Size	Evaluated in
STT-DDR3 MRAM	EVERSPIN Technologies	EMD3D256M16G2-150CBS1	256Mb	TID
STT-DDR4 MRAM	EVERSPIN Technologies	EMD4E001G16G2-150CAS2	1Gb	SEE and TID
STT-xSPI MRAM	EVERSPIN Technologies	EM064LXQADG13IS1T	64Mb	SEE



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METHODOLOGY

/// SEE Testing

- SEE testing has been performed at RADEF Heavy ion test facility by TRAD.
  - Runs were performed:
    - Up to a fluence of 1E+7 cm-2 with only SEL monitoring.
    - Up to a fluence of 1E+6 cm-2 for the SEU, MBU, Burst and SEFI detection.

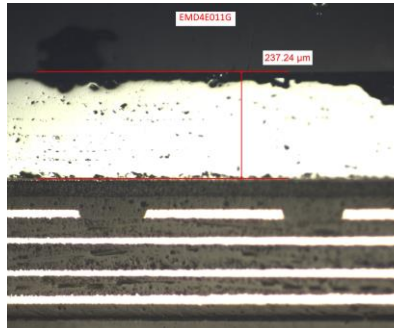
- Type of SEE events evaluated :
  - **SEU:** Any mismatch of data reading with expected data is at first considered to be a SEU and the data is sent to the computer. A counter is incremented accordingly. This process is repeated from address 0 to the last address of the memory. An SEU is an isolated upset in the data array of a memory. At normal flux under beam (until 5000 part./s.cm²), the number of SEUs induced by heavy ions in the memory should not exceed a few events (less than 10 events).
  - **MBU:** An MBU is detected when several bits change from state 0 to 1 or from state 1 to 0 in a single word.
  - **Burst:** If the SEU/MBU error counter reach more than 10 events and less than 500 events of SEU before the last address is reached, then a Burst is considered.
  - **SEFI:** If the error counter reach more than 500 events of SEU before the last address is reached, then a SEFI is considered and a power cycle is applied to the memory.

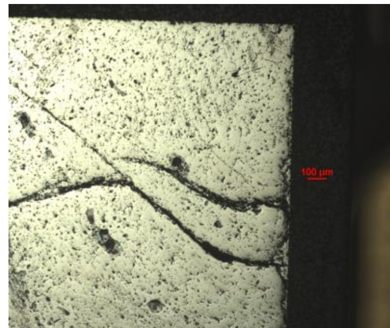
STT-DDR4 MRAM OPENING ISSUES

/// Delidding and backlapping

STT-DDR4 MRAM

- This part is a flip-chip die in FBGA-96 package that means that parts should be delidded and backlapped in order to be tested with standard Heavy ions at RADEF
- Unfortunately, it has not be possible to keep the components functional after delidding and backlapping. As soon as the backlapping start, the die is beginning to break in the corner.





- So the STT-DDR4 MRAM have just been delidded and a high-range cocktail under vacuum has been used :

Ion	Energy (MeV)	Range (µm(Si))	Effective LET (MeV.cm²/mg)
$^{83}Kr^{29+}$	1826	274	39.48
$^{57}Fe^{20+}$	1254	283	23.58
$^{17}O^{6+}$	374	797	1.37

Table 4: RADEF heavy ion list

RESULTS

/// SEE Testing

STT-DDR4 MRAM

- **SEL :**
  - No SEL was observed with LET of 39.48 MeV.cm²/mg, Krypton heavy ion.
- **SEU_READ :**
  - SEU were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.
  - MBU were observed with a minimum LET of 23.6 MeV.cm²/mg, Iron heavy ion.
    - No MBU was observed with LET of 1.4 MeV.cm²/mg, Oxygen heavy ion
  - Burst were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.
  - SEFI were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.
- **SEU_WRITE :**
  - SEU were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.
  - MBU were observed with a minimum LET of 23.6 MeV.cm²/mg, Iron heavy ion.
    - No MBU was observed with LET of 1.4 MeV.cm²/mg, Oxygen heavy ion
  - Burst were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.
  - SEFI were observed with a minimum LET of 1.4 MeV.cm²/mg, Oxygen heavy ion.
    - No lower LET was tested during this test campaign.

Cross-section in SEU_Read for SEU, MBU, SEFI and Burst:

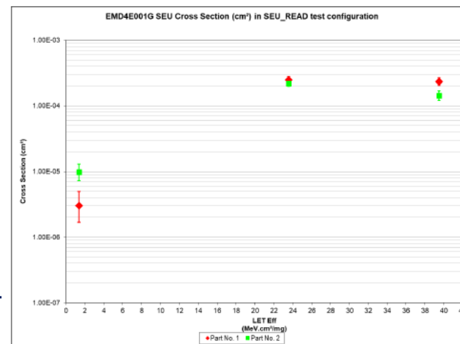


Figure 12: EMD4E001G SEU cross section curve in SEU_READ test configuration

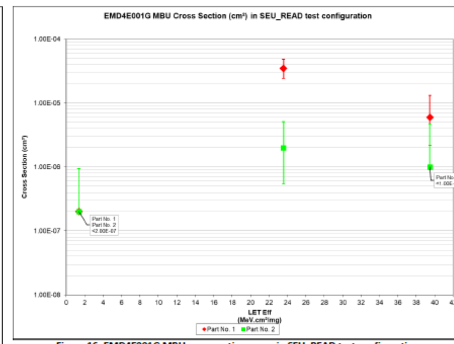


Figure 16: EMD4E001G MBU cross section curve in SEU_READ test configuration

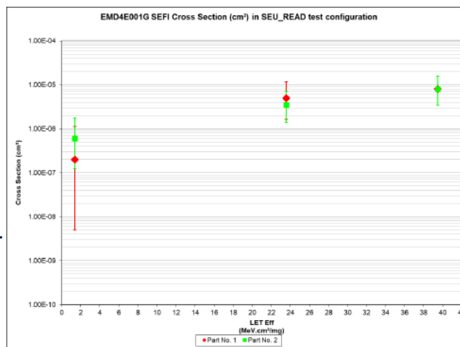


Figure 18: EMD4E001G SEFI cross section curve in SEU_READ test configuration

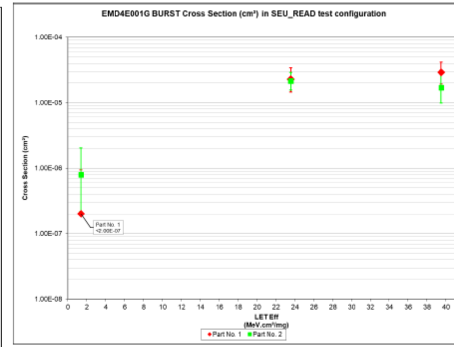


Figure 20: EMD4E001G Burst cross section curve in SEU_READ test configuration

RESULTS

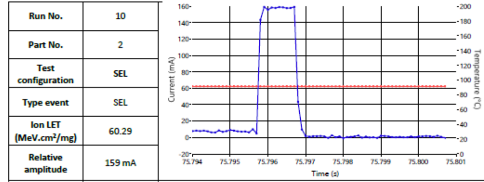
Ion	Energy (MeV)	Range (µm (Si))	LET (MeV.cm²/mg)
$^{126}Xe^{44+}$	2059	88	60.29
$^{83}Kr^{29+}$	1358	125	28.96
$^{57}Fe^{20+}$	941	150	15.45
$^{40}Ar^{14+}$	657	202	8.05

/// SEE Testing

/ STT-xSPI MRAM

- SEL :
  - SEL were observed with a minimum LET of 28.96 MeV.cm²/mg, Krypton heavy ion.
    - No SEL was observed with LET of 15.45 MeV.cm²/mg, Iron heavy ion.

The worst amplitude SEL observed on VCC occurred during run No. 10 on part No. 2.



Run No.	10
Part No.	2
Test configuration	SEL
Type event	SEL
Ion LET (MeV.cm²/mg)	60.29
Relative amplitude	159 mA

Figure 13: SEL worst case

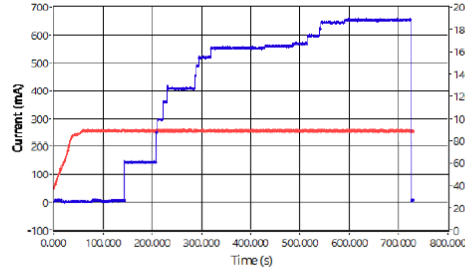


Figure 14: Current consumption monitoring during destructive test run

- SEU_READ :
  - SEU were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
    - No lower LET was tested during this test campaign.
  - No MBU was observed with a maximum LET of 60.29 MeV.cm²/mg, Xenon heavy ion.
  - BURST were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
    - No lower LET was tested during this test campaign.
  - SEFI were observed with a minimum LET of 8.05 MeV.cm²/mg, Argon heavy ion.
    - No lower LET was tested during this test campaign.

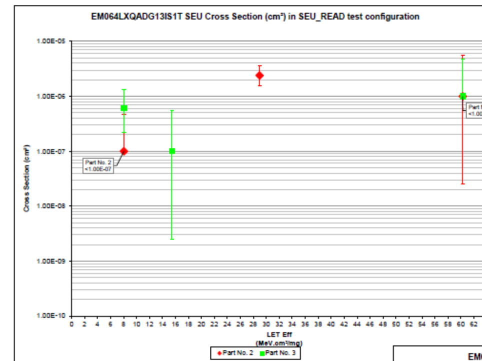
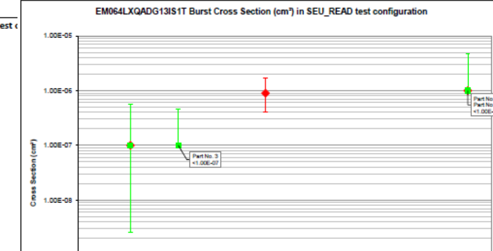
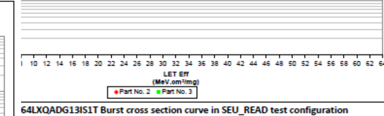


Figure 15: EM064LXQADG13IS1T SEU cross section curve in SEU_READ test c

Cross-section in SEU_Read for SEU, Burst and SEFI :





64LXQADG13IS1T Burst cross section curve in SEU_READ test configuration

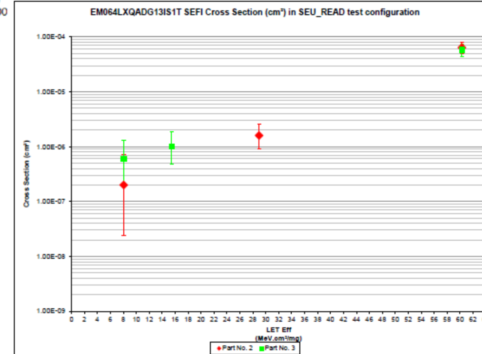


Figure 18: EM064LXQADG13IS1T SEFI cross section curve in SEU_READ test configuration

METHODOLOGY

/// TID Testing

- TID testing has been performed at GAMRAY facility in Toulouse (France) by ALTER. In this irradiation facility, a Cobalt 60 source is used with the possibility to vary the dose rate by simply adjusting the distance to the source.
  - During the dose exposures, devices under test have been irradiated in an ambient temperature of 24°C ±6°C.
  - During annealing step at 100°C±5°C, the temperature was controlled and monitored by using an external monitoring system.
  - A total ionizing dose verification test has been performed with an accumulated dose of about 49 krad(Si) at a dose rate of 221 rad(Si)/hour

- In each case, 6 samples plus one control sample were used during testing
  - 3 ON
  - 3 OFF
  - 1 control sample

RESULTS

/// TID Testing

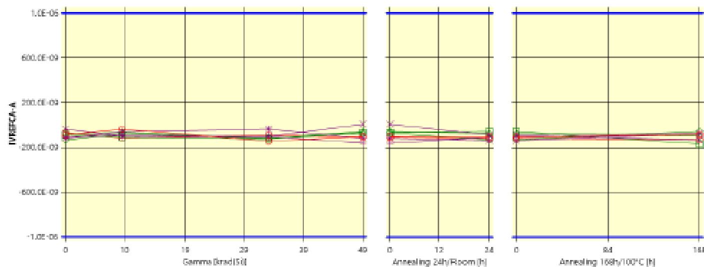
STT-DDR4 MRAM

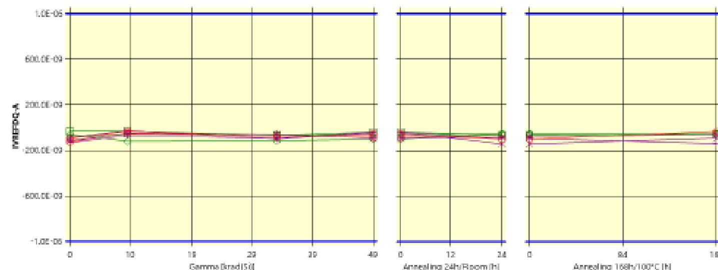
- 6 samples plus one control sample were used during testing. They were exposed to radiation using a dose rate of 221 rad(Si)/hour at room temperature with an accumulated dose of about 49 krad(Si).
- All parameters remained within specification limits all along testing.

STT-DDR3 MRAM

- 6 samples plus one control sample were used during testing. They were exposed to radiation using a dose rate of 221 rad(Si)/hour at room temperature with an accumulated dose of about 49 krad(Si).
- All parameters remained within specification limits all along testing.

Some examples of data collected :





CONCLUSIONS AND PERSPECTIVES

/// Conclusions

- No destructive events seen on both memories tested (STT-DDR4 MRAM and STT-xSPI MRAM)
  - Non-destructive events (High-current events detected on the STT-xSPI MRAM)
- SEU, MBU, SEFI and burst events detected on STT-DDR4 MRAM and STT-xSPI MRAM
- No drift in TID up to 49krad on the both MRAM tested (STT-DDR4 MRAM and STT-DDR3 MRAM)

/// Perspectives

/ Complementary campaigns may be advised in order to deeper evaluate these parts :

- TID campaign for the STT xSPI MRAM
- Heavy ions campaign with additional samples and higher energy for the STT-DDR4 MRAM
- Heavy ions campaign to define and try potential mitigation techniques if needed