D/TOS-QCA Final Presentation Day 2002. ESA/ESTEC, Tuesday April 9th, 2002

- **Heavy ion Radiation Evaluation of FLASH Memories**.
- **Final Presentation of ESTEC Contract No. 13528/99/NL/MV, COO-7.**
  - Evaluation objectives
  - Devices tested
  - Test set-up
  - Test conditions
  - Error detection
  - Heavy ions source
  - DUT responses observed
  - Results per device
  - Conclusion

- Evaluation objectives
  - NAND Flash memories are potential candidates for mass data storage
    (in the present evaluation, the devices were not specifically considered for a given project)
  - Aim of this evaluation was to :
  - First define a set of adequate test conditions
  - Identify the different types of device responses to SEU
  - Compare the sensitivity of a variety of devices (size, die revision)

- **NAND Flash Memories**

- **The following devices have been provided by ESA for this evaluation exercise**

Part type	Manufacturer	Size	Package	Date Code
K9F6408U0A-TCB0	Samsung	8Mx8	TSOP2	028
K9F6408U0B-TCB0	Samsung	8Mx8	TSOP2	121
K9F2808U0B-YCB0	Samsung	16Mx8	TSOP1	130
K9F5608U0A-YCB0	Samsung	32Mx8	TSOP1	043, 103
K9F1208U0M-YCB0	Samsung	64Mx8	TSOP1	130
TC58256FT	Toshiba	32Mx8	TSOP1	0011

Nand Flash Characteristics

- Voltage Supply : 3V3
- Memory array organized in blocks of pages of 528 (512 + 16) bytes
- Page register of 528 (512 +16) bytes for data transfer
- All devices were Single Level Cell (SLC) and 1 die per package (no stack)
- Multiplexed 8-bit bus for command, address and data
- Write Protection (WP)
- Reset
- Sequential read mode (not used, address is provided for each page)
- Multi plane Page/Block program / Erase/ for the K9F1208U0M-YCB0 (not used)

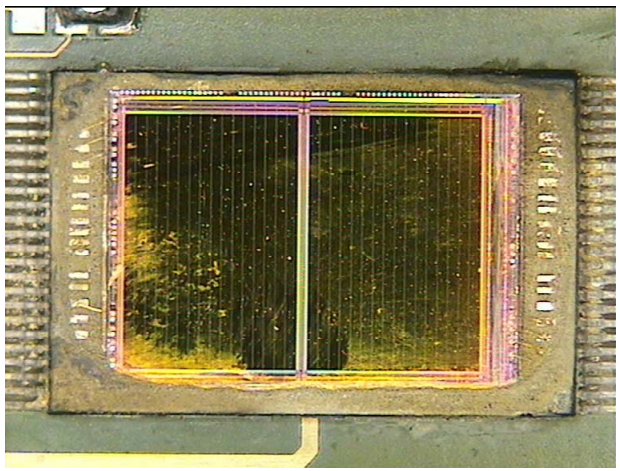
Memory Organization

		Blocks	Pages /Block	Bytes /Page
K9F6408U0A-TCB0	(8M + 256K) x 8bit	1024	16	528
K9F6408U0B-TCB0	(8M + 256K) x 8bit	1024	16	528
K9F2808U0B-YCB0	(16M + 512K) x 8bit	1024	32	528
K9F5608U0A-YCB0	(32M + 1024K) x 8bit	2048	32	528
TC58256FT	(32M + 1024K) x 8bit	2048	32	528
K9F1208U0M-YCB0	(64M + 2048K) x 8bit	4096	32	528

- These devices may be delivered with invalid blocks which have to be excluded during the test.

Sample preparation

- Chemical etch of the package epoxy
- 2 functional samples per device have been prepared
- Main difficulty was the ratio of the die size to the package dimensions
- Photo of prepared sample K9F1208U0M-YCB0



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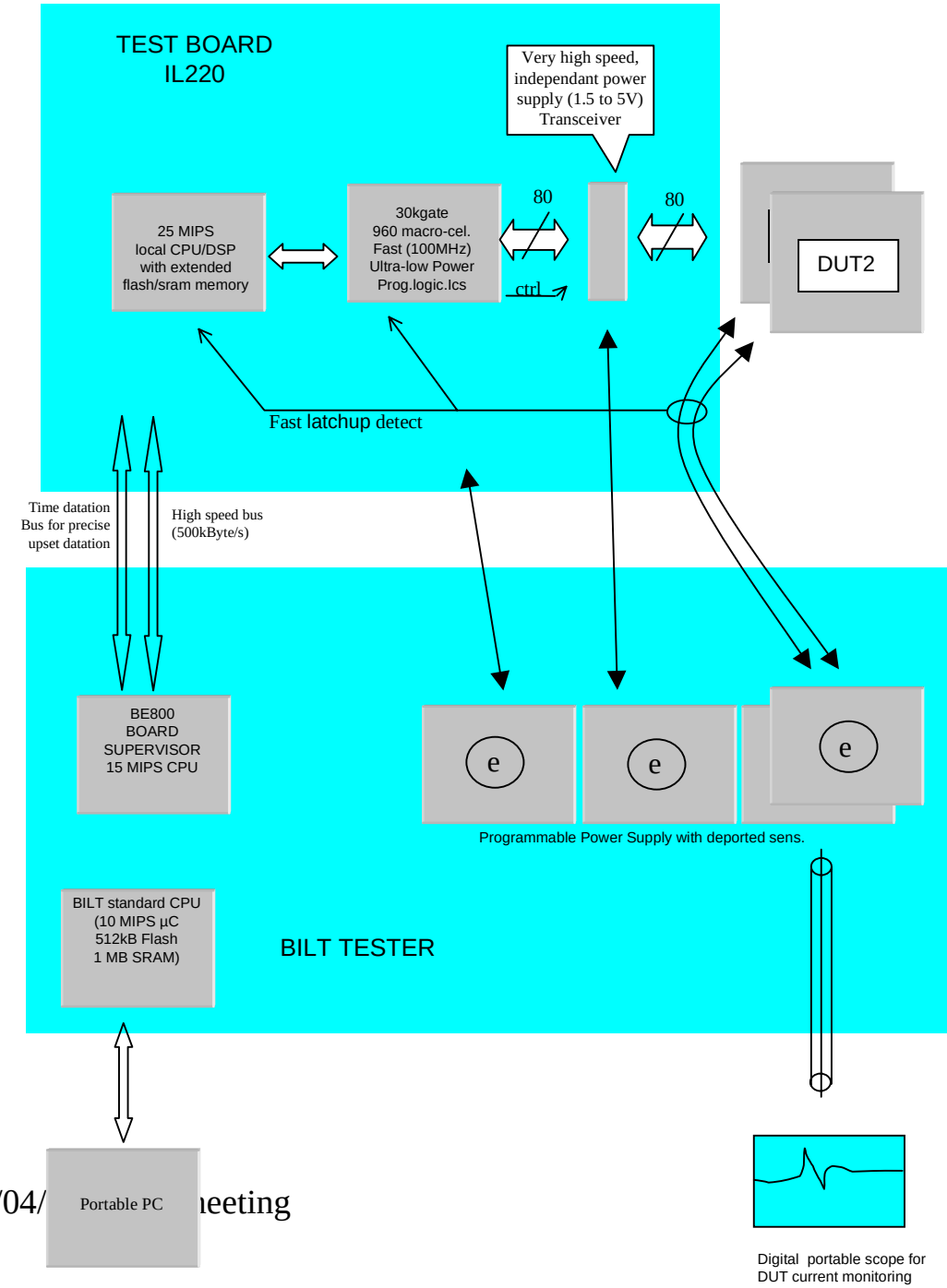
Schematic of the test set-up



Test configurations

- Power off, Power on
  - Prior to exposure, write the memory with a given pattern
  - After exposure, Read all the pages of the memory

- Write/Read/Read (W/R/R) test condition
  - Prior to exposure, write the memory with a given pattern
  - During Exposure, perform continuously the following cycle on 10 given blocks (randomly selected before the test)
  - erase the block
  - write each page of the block
  - read each page of block and if one error repeat the read of the page
  - After exposure, read all the pages of the memory (less the 10 blocks)
- Read/Read
  - Prior to exposure, write the memory with a given pattern
  - During Exposure, perform continuously the following cycle on all blocks
  - read each page of block and if one error repeat the read of the page
  - After exposure, eventually read all the pages of the memory

  – Possibility to active WP for read operation and to reset the device at each cycle

Error detection

– Upsets : the total number of words in errors for each read block at each cycle iteration
– In addition, the following information is recorded (with a limit of 6500 lines maximum)

- Cycle iteration number
- Plan Number (if relevant)
- Block Number
- Page Number
- Column Number
- Spare column number
- Awaited word pattern
- Mask error

– The following errors are also detected :
  • Max time erase error
  • Max time write error
  • Erase Error (DUT read status)
  • Write Error (DUT read status)

Heavy Ions source

- The European Heavy Ions Facility of Louvain La Neuve has been used for this evaluation
- Ions actually used in the course of the present evaluation

Ion Specy	Energy (MeV)	LET (MeV/(mg/cm²))	Range µm
20-Ne	78	5.85	45
40-Ar	150	14.1	42
84-Kr	316	34	43
132-Xe	459	55.9	43

- The use of a tilt angle allows for additional effective LET values

DUT responses observed (1/2)

- Stuck bits :
- These errors have been seen after power off, power on and Read/Read test conditions
- After exposure above a given LET, some bits, randomly, remains stuck to 1(erased). The number of stuck bits decrease with time. However a read of the memory two hours after exposure could lead to detect half the initial number of stuck bits.
- A write operation clear all the stuck bits in a given block.
- SEU
- During W/R/R 10 blocks test condition, these errors could be either read errors or write errors and correspond to 0->1 or 1->0 transitions.
- During R/R operation, idem read errors only.
- These errors very likely occurred inside the data transfer page register.

– DUT responses observed (2/2)

– Page /Block error

– These errors correspond to a complete page / Block with all bits read/written in error.

– Depending of the device type, these errors can occur inside the block addressed or in an other block

– Array error

– The complete array is in error (> 10^6 words errors)

– Max time erase

– Max time write

– Erase Error (detected by the DUT itself)

– Write Error (detected by the DUT itself)

– Latch-up

Results per device

K9F1208U0M-YCB0 64Mx8

Main findings

- First stuck bit errors (0->1) detected at an LET of 34 MeV/(mg/cm²) (Krypton, Tilt 0 deg)
- Device sensitive to Latch-up at an LET of 34MeV/(mg/cm²), (Krypton, Tilt 0 deg)
- W/R/R 10 blocks test configuration
  - First page / block error at an LET of of 8.3 MeV/(mg/cm²) (Neon, Tilt 45 deg)
  - All these page / block errors were detected after beam exposure **outside** the blocks which were addressed during exposure
  - First SEUs detected at an LET of 8.3 MeV/(mg/cm²) (Neon, Tilt 45 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between $5\ 10^{-5}$ cm² and $5\ 10^{-4}$ cm²

K9F5608U0A-YCB0 32Mx8

Main findings

- First stuck bit errors (0->1) detected at an LET of 11.7 MeV/(mg/cm²) (Neon, Tilt 60 deg)

- W/R/R 10 blocks test configuration

  - No page / Block error detected up to an LET of 28.2 MeV/(mg/cm²) (Argon, Tilt 60 deg) inside (during exposure) or outside (post exposure) the 10 blocks.

  - Write and Erase errors (DUT control signals) detected at LET of 28.2 MeV/(mg/cm²) (Argon, Tilt 60 deg)

  - First SEUs detected during at an LET of 5.8 MeV/(mg/cm²) (Neon, Tilt 0 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between $5\ 10^{-5}$ cm² and $5\ 10^{-4}$ cm²

K9F2808U0M-YCB0 16Mx8

Main findings

- First stuck bit errors (0->1) detected at an LET of 34 MeV/(mg/cm²) (Krypton, Tilt 0 deg)

- W/R/R 10 blocks test configuration
  - First SEUs detected during at an LET of 5.8 MeV/(mg/cm²) (Neon, Tilt 0 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between $5\ 10^{-5}$ cm² and $5\ 10^{-4}$ cm²
  - 2 Erase errors (DUT control signals) detected at LET of 11.7 MeV/(mg/cm²) (Neon, Tilt 60 deg)
  - First page / block errors at an LET of of 28.2 MeV/(mg/cm²) (Argon, Tilt 60 deg) (one read and one write) under exposure (within the 10 blocks)
  - No page / block errors were detected under beam exposure **outside** the blocks which were addressed during exposure

- Page R/R test configuration
  - With Krypton, LET= 34 MeV/(mg/cm²)
  - SEUs Read errors and occurrence of stuck bits are observed.
  - Occurrence of 3 full memory array errors (into 3 different runs), two times memory has recovered at the next read cycle, a third time the device need to be reprogrammed.

K9F6408U0A-TCB0 8Mx8

Main findings

- W/R/R 10 blocks test configuration

  - First SEUs detected at an LET of 5.8 MeV/(mg/cm²) (Neon, Tilt 0 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between 5 10^{-5} cm² and 5 10^{-4} cm²
  - First page / block error at an LET of of 5.8 MeV/(mg/cm²) (Neon, Tilt 0 deg) (one page write) under exposure (within the 10 blocks)
  - No page / block errors were detected after beam exposure **outside** the blocks which were addressed during exposure
  - First Max time write errors (DUT control signals) observed with an LET of 14.1 MeV/(mg/cm²) (Argon, Tilt 0 deg)

K9F6408U0B-TCB0 8Mx8

Main findings

- No stuck bit errors (0->1) detected up to an LET of 34 MeV/(mg/cm²) (Krypton, Tilt 0 deg)

- W/R/R 10 blocks test configuration
  - First SEUs detected during at an LET of 5.8 MeV/(mg/cm²) (Neon, Tilt 0 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between 5 10^{-5} cm² and 5 10^{-4} cm²
  - First page / block error at an LET of of 34 MeV/(mg/cm²) (Krypton, Tilt 0 deg) (one page read) under exposure (within the 10 blocks)
  - No page / block errors were detected under beam exposure **outside** the blocks which were addressed during exposure
  - One erase error (DUT control signals) observed at an LET of of 28 MeV/(mg/cm²) (Argon, Tilt 60 deg)
- Page R/R test configuration
  - With Krypton, LET= 34 MeV/(mg/cm²)
  - SEUs Read errors.
  - Page / block errors (few page read errors)

TC58256FT 32Mx8

Main findings

- Few stuck bit errors (0->1) detected at an LET of 55.9 MeV/(mg/cm²) (Xenon, Tilt 0 deg) (power off test condition)

- **W/R/R 10 blocks test configuration**

  - First page / block error observed at an LET of of 11.7 MeV/(mg/cm²) (Neon, Tilt 60 deg) (one block erased) after exposure (**outside** the 10 blocks) while no error was detected under exposure.
  - First SEUs detected during at an LET of 14.1 MeV/(mg/cm²) (Argon, Tilt 0 deg)
  - Either Read SEUs or Write SEUs, SEU device error cross-section between 5 10^{-5} cm² and 5 10^{-4} cm²

Conclusion

- Evaluation has been carried out on 6 different part types
- Several Flash test configurations have been experimented and the corresponding errors detected, have been identified.
- From the devices tested, the major concern is bound to the errors generated in the control part of the device, as for instance erasing of a different block than the block being addressed.
- Large variations in the responses of the different part types suggest that a test on the devices considered for a specific project should be performed to fully characterize the device responses to heavy ions