

Radiation effects in the PowerPC7448 Microprocessor

Damien Lambert¹, Xavier Vega¹, Dan Alexandrescu², and Bruno Azais³

¹EADS Nuclétudes, BP117, Les Ulis, 91944 Courtaboeuf Cedex, France dlambert@nuclétudes.com
²iRoC Technologies, Grenoble, France
³DGA, Bagneux, France

Abstract

Total Ionizing Dose and upset susceptibility are measured for the PowerPC MPC7448 microprocessor. SEE XS for protons (7 to 65 MeV) and neutrons (thermal and 14 MeV) have been tested for registers and data caches. Main characteristics of susceptibility are given.

I Main Characteristics of the MPC7448

- > A 90 nm SOI technology
- > 90 millions of transistors
- > Die dimensions: 8 mm x 7.3 mm x 0.86 mm
- > Package type: 360 HTCE (High Coefficient of Thermal expansion) RoHS BGA
- > Supply voltage 1.0 V ± 50 mV for the core and 2.5 V ± 50 mV for the I/O
- > Frequencies used: 10 MHz for the BUS system and 200 MHz for the core
- > Tested memories:
 - L1 Data Cache: 32 ko
 - L1 Instruction Cache: 32 ko
 - L2 Data Cache: 1 Mo
 - Register (GPR, VR, SR, SPR, CR, MSR, FPR) : 10944 bit

II Experimental Method

- > A special test platform developed by iRoC Technologies
 - o Minimal environment to operate: clock, reset and control signals, interfaces to tester-provided memory blocks and a program memory
 - o Tests controlled by the COP (Common On-chip Processor) with the JTAG port and a few others status and monitoring signals
 - o Power and current supplies and the component temperature measured and recorded
- > Test operations:
 1. Initialization:
 - Supply on and reset operations done by the test platform
 2. Cache memory writing:
 - Write operation of the L1 and L2 caches by reading an external memory on the test platform with the "checkerboard" pattern
 3. Register writing:
 - Write operation of the register (GPR, VR and VR) with the "checkerboard" pattern, done directly with the JTAG interface (not possible for the cache memories). SPR & FPR registers tested by comparison between their values after initialization and after irradiation
 4. Stand-by (during irradiation):
 - Processor stopped; no instructions executed
 5. Reading of cache and register memories:
 - Reading with JTAG interface ⇒ no problems with hangs during stand-by operation and irradiation

III Total Ionizing Dose Test Results

- > 60Co SAND source at EADS Nuclétudes
- > 3 components tested up to 100 krad(Si) at 10 rad(Si)/s
- > Test equipment behind a lead shield
- > Iterative cycle during irradiation test:
 1. Write "checkerboard" pattern – stand-by – read (50 s)
 2. Write "opposite checkerboard" pattern – stand-by – read (50 s)
- > Fully functional up to 100 krad(Si)
 - No error during read/write operations
 - Increase of the current control of 250 mA and increase of the chip temperature from 20°C to 30°C ⇒ Increase of power dissipation of ~5% due to the irradiation at 100 krad(Si)

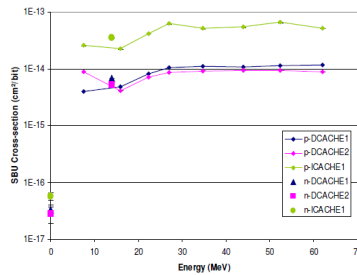
Summary

- > Total Ionizing Dose: fully operational up to 100 krad(Si)
- > Neutron and proton SEE investigations:
 - No error observed on register memories
 - ⇒ registers seem to be a weak parameter for the MPC7448 radiation sensitivity
 - Sensitive part: the cache memories
 - A limited thermal neutron influence (<10⁻¹⁶ cm²/bit)
 - 14 MeV neutron and proton XS in good agreement
 - The L1 data cache XS and the L2 data cache XS : close
 - The instruction cache L1 memory ~4 more sensitive than the data cache L1.
 - Special word signatures with high statistics in the instruction cache L1.
 - Suggestion: SEE in the microprocessor core which writes some special word at random address
 - Seems to be sensitive to direct proton ionization

IV SEE Test Results

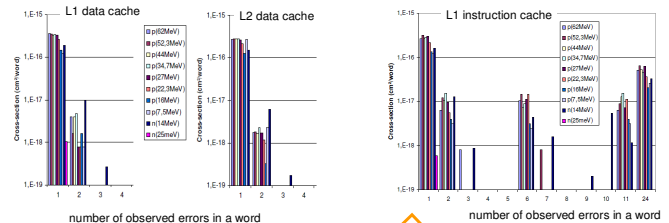
- > Irradiations done from the back of the die ("flip-chip" packaging)
- > 3 components for each test
- > Tests in stand-by mode
- > 14 MeV neutron tests
 - SAMES beam at CEA-Valduc
 - Tests up to >10¹² / cm² at ~2 x 10⁸ /cm²/s
 - Test equipment protected behind a polythene shield
 - No error in registers ⇒ register SBU XS < 2.5 x 10⁻¹⁷ cm²/bit
 - L1 data and L1 instruction cache SBU XS : 6.7 x 10⁻¹⁵ and 3.5 x 10⁻¹⁴ cm²/bit
 - L2 cache SBU XS : 6.2 x 10⁻¹⁵ cm²/bit
- > Thermal neutron tests
 - ORPHEE beam at CEA-Saclay
 - Tests up to 10¹² n(25 meV)/cm² at 4.1 x 10⁸ n(25 meV)/cm²/s
 - Test equipment protected behind a bore shield
 - No error in registers ⇒ the register SBU XS < 3.1 x 10⁻¹⁷ cm²/bit
 - L1 data and L1 instruction cache SBU XS : 3.3 x 10⁻¹⁷ and 5.7 x 10⁻¹⁷ cm²/bit
 - L2 cache SBU XS: 2.8 x 10⁻¹⁷ cm²/bit
- > Proton tests
 - LIF (Light Ion Facility) at CYCLONE of Université Catholique de Louvain (Belgium)
 - 8 energies from 7.5 MeV to 62 MeV up to 5 x 10¹⁰ /cm² at a ~5 x 10⁸ /cm²/s
 - TID : ~115 krad(SiO2) ⇒ We assume that the proton dose has no effect on SEE XS
 - Test equipment 2 meters outside the proton beam and protected by a lead wall
 - No error in registers ⇒ register SBU XS < 6.1 x 10⁻¹⁶ /cm²

SBU cross-sections



- > XS in agreement with XS of literature
- > XS of L1 and L2 data cache close
- > Instruction L1 cache XS ~5 times above the cache XS. In Agreement with heavy ions tests on MPC7447 [Bellin CHSE 2008]
- > No latchup observed
 - ⇒ compliant with SOI design
- > No error observed in register. Small register size. ⇒ Register memory not a main factor of the MPC7448 radiation sensitivity

SBU repartitions



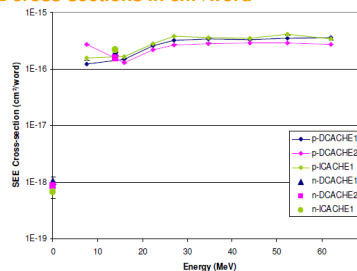
same shape : MBU + fluence

special shape & special signature (starting from an 0x55555555 initial content):
 • 0x7D555555 (2 bit flips)
 • 0x7D555671 (6 bit flips)
 • 0x76AA5555 (11 bit flips)
 • 0xEEEEEEEE (24 bit flips)

Several hypothesis:

- SEE fault causes an internal block of the CPU (the cache memory controllers, MMU, etc) to alter the content of the cache memory by a wrong access
- An error occurs in the instruction cache memory, detected by a watch process which could activate a correction process
 - Require a deep knowledge (data not available in userguides) of the microprocessor working and the implementation of the internal memory controllers

SEE cross-sections in cm²/word



- With a SEE XS in cm²/word, the XS of data L1, instruction L1 and data L2 cache memories: considered equal
- Below 10 MeV, no decrease of the proton XS. 90 nm SOI technology
 - ⇒ probably sensitive to direct proton ionization