An Evaluation of Single Event Upset by Heavy Ion Irradiation on Atom Switch ROM/FPGA

原子スイッチROM/FPGAへの重粒子照射によるシングルイベントアップセットの評価

概 要

"Normally-off computing" featuring a next generation non-volatile memory, which enables to shut the power down whenever not being used, is one of the most promising methodologies to reduce the power consumption in LSI and electronic devices. In this work, we investigate a radiation tolerance of the new memory to achieve "Normally-off computing" in aerospace. NanoBridge (a.k.a. Atom switch) as the nonvolatile memory/switch is subject to be irradiated in a radiation facility, and Single Event Upset (SEU) cross-section against high LET heavy ion was evaluated.

衛星システムにおいて電力消費の爆発的な増加は深刻な問題となっている。この問題を解決する方法の一つとして、待機状態で完全に電源遮断を行う「ノーマリーオフコンピューティング」が提案されている。本研究では、不揮発性技術の一つである原子スイッチメモリ及びFPGAを用い重粒子照射試験によりシングルイベント効果の一つであるシングルイベントアップセット(SEU)の反転断面積を評価した。

Introduction

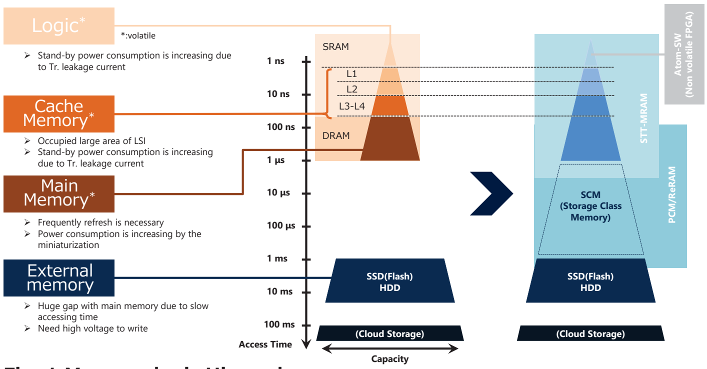


Fig. 1 Memory-logic Hierarchy

The wide spread of mobile IT devices, cloud computing and Internet of the Things (IoT) would increase energy consumption. Japanese government predicts that the energy consumption of IT devices in 2025 will be approximately 5 times as much as that in 2006 [1]. To reduce the dynamic and static energy consumption, "Normally-off computing" which is to shut the power down whenever not being used, and ultra-low power operation are strongly desired [2]. An effective way to satisfy the requirements is to replace the conventional technology with a new non-volatile technology in a memory-logic hierarchy (Fig. 1). Magneto-resistive Random access memory (MRAM), Resistive RAM (ReRAM) and Phase Change Memory (PCM) are the candidates for the future memory. Without these non-volatile technology, we would not be able to deal with the explosion of energy consumption in the terrestrial, as well as in the space.

In this work, a radiation test results were presented as the a preliminary evaluation for applying these technologies in space.

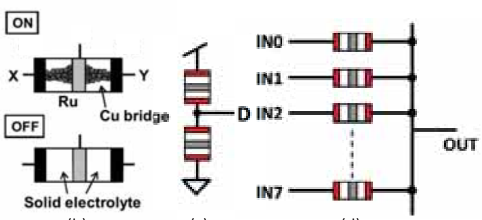
Atom Switch

Atom switch is a nano-scale switch which controls connection/disconnection of Cu bridge electrochemically. Atom switch has Ru/Polymer solid electrolyte (PSE)/Cu sandwich structure. Formation/annihilation of Cu ion bridge causes Low/High resistance states which corresponds each digital states, therefore it is classified as ReRAM. Since atom switch has the high on/off ratio , that enables the low-voltage memory operation without a sense amplifier and routing switches in field programmable gate array (FPGA) as complementary atom switch (CAS) [4-5] as well.

Fig. 2 shows table of typical characteristics (a), schematic image of CAS which is connected Atom switches in series with opposite direction (b), Illustrations of CAS-based memory (c) and multiplexer (d), which are part of the configurable logic block in FPGA. Comparing to the SRAM-based FPGA, 60 % lower power consumption and 3 times faster operation are achieved with this CAS-based programmable logic cell array [4].

Feature	Typical
Set/Reset voltage	2.0V
Set/Reset speed	100ns
ON resistance	1kΩ
OFF resistance	10MΩ
Retention	10years
Cycle endurance	>10^3cycle

(a)



(b) (c) (d)

Fig. 2 (a)Typical characteristics of Atom switch, (b)Schematic image of CAS which shows ON and OFF states, (c)Illustration of CAS-based memory which is used as LUT in FPGA (d) Illustration of CAS-based multiplexer(MUX)[4-5].

Experimental setup

The radiation tolerance of both Atom switch read only memory (ROM) and CAS FPGA were evaluated by using the Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) in the National Institutes for Quantum and Radiological Science and Technology (QST). Atom switch ROM and CAS FPGA were initially developed by Low-power electronics Association & Project (LEAP) and now NEC continues to develop them as NanoBridge®.

The chips were irradiated by Xe ion. Linear energy transfer (LET) of Xe was calculated to be 68.9 MeV/(mg/cm^2) at Si surface (by SRIM [6]). Radiation and test conditions are shown in Table 1 and 2.

Table 1 Radiation conditions

Ion	$^{129}Xe^{25+}$
Net Energy [MeV]	398
LET at Si surface [MeV/(mg/cm^2)]	68.9
Range in Si [μm]	35.0
Fluence [p/cm^2]	10^7

Table 2 Test conditions

Item	Atom switch	
	ROM	LUT in FPGA
Total Atom switch	131 [kbit]	819.2 [kbit] (204.8k CAS)
Voltage Condition to each cell	"not" applied	applied
Written data /CAS condition	All "A"	state "0" & "1" by half
Cell area	1.5×10^{-11} [cm^2]	
Actual ion hits [particle]	19	122

Results and Discussion

No single event upset (SEU or bit flip) was observed through experiment. Atom switch was programmed for either ON or OFF state and validated before and after the radiation test by LSI tester. Since actual cell area of Atom switch is 1.5×10^{-11} cm^2, about 19 or 122 particles were expected to hit somewhere in Atom switches on ROM or FPGA respectively. Fig. 3 shows estimated SEU cross section against Xe ion which has 69.8 MeV/(mg/cm^2) in LET. In-house Cf-252 data[7] was also plotted in 30 MeV/(mg/cm^2) in Fig. 3.

It was revealed that SEU cross sections against heavy ions are much smaller than the Atom switch cell itself irrespective of voltage conditions or cell states.

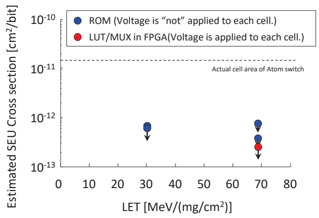


Fig. 3 Estimated SEU cross section and actual cell area of Atom switch. Down arrow represents the each estimated value is expected less than the point in the figure.

A Particle that has energy greater than 68.9 [MeV/(mg/cm^2)] would come flying in every about 188 year in geostationary earth orbit (calculated by CRÈME[8]). It would say that Atom switch itself has tolerance against heavy ions.

On the other hand, Single event transient (SET) pulse caused by ions hit to the CMOS circuit which is not hardened to radiation were observed. SET cross-section was about 10^5 times larger than atom switch itself, and it had LET dependency (Not shown). Even though Atom switch would be fine, Logic status might be failed by SET. Radiation hardening by design (RHBD) technique is required for CMOS logics, in order that CAS FPGA will work in space application.

Conclusion

The radiation tolerance against SEU of atom switches was demonstrated with an LET of up to 68.9 MeV/(mg/cm2), irrespective of the voltage conditions or logic states of the cells. Other evaluations, such as total ionizing dose(TID) or displacement damage(DD) evaluations, would be required to get further information. A hardening technique to radiation must be required to conventional CMOS circuits, in order to use Atom switch ROM and CAS FPGA in space.

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[7] K. Takeuchi et al., "Feasibility study for the ultra-low energy consumption, high speed, non-volatile technology", poster material, MEWS28, Oct. , 2015
[8] CRÈME(https://creme.isde.vanderbilt.edu/)

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