Radiation-Induced Pulse Noise in SOI CMOS Logic

D. Kobayashi, K. Hirose, H. Ikeda, and H. Saito
Institute of Space and Astronautical Science
Japan Aerospace Exploration Agency

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Outline

Radiation-Induced Pulse Noise in SOI CMOS Logic

1. How serious radiation problems are
2. Merits and demerits of SOI
3. Pulse-noise problems in logic gate
4. Summary
An example of basic radiation effects

Drain current behavior of 0.2-μm FD-SOI nMOSFET

Standing by in OFF state @VDS=1.8V

Radiation strike (single Kr ion)

Makino (JAEA) et al., RASEDA 2010

ON current

Smoothed Waveform

Signal Observed

Time (ns)

Current (mA)
Basic parameters of studied SOI tech.

Commercial 0.2-μm FD-SOI

- $t_{SOI} = 50$ nm
- $t_{ox} = 5$ nm
- $L_g = 0.2$ μm
- $t_{BOX} = 100$ nm

8-inch bond-and-etch-back SOI wafer
Google scholar result (May 2, 2011): number of publications with keywords in anywhere in the articles and patents including citations

- "soft error"
- SE & neutron
- SE & logic

"Logic" and "Neutron"
It may not lessen Toyota's woes to hear that the problems the company has been having with faulty gas pedals could be blamed on cosmic rays from space. Sound unbelievable? The concept is actually a lot more plausible than you might think.

Acceptable concept (Real reason is unknown)

ECC is already essential in cache memories for enterprise servers...

Intel developed rad-hard Itanium processor already...
Our living space is filled up with neutrons

Galactic cosmic rays
10GeV, 10/cm²·s

Supernova

Solar flare
1GeV, 1E5/cm²·s

Nuclear reactions

Atmosphere

secondary cosmic rays
π

n

Earth

Terrestrial neutrons
10/cm²·h @ sea level

Terrestrial: Ziegler (IBM) et al., IBM J. Research and Development 40, 1996 p3
How strong are they?

Linear Energy Transfer (LET), explains ionizing ability

LET 10 MeV·cm²/mg

SOI is known as a strong technology to radiation. Now is a time to show our stuff!
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In the bulk case, noise charge in the deep substrate region can reach the signal (drain) terminal but not in the SOI case because of the BOX layer.
That’s not so simple

Small parasitic capacitance results in high sensitivity to noise signals

Parasitic bipolar structure can amplify noises

1. noise charge is deposited in body
2. holes are confined
3. npn-BJT turns on

Large noise

How large?
Bipolar amplification effect

Makino (JAEA) et al., RASEDA 2010

~200 fC

x10 larger than charge deposited (20 fC)

Important to suppress this amplification effect
FD-SOI SRAM is harder than bulk but not enough. BT is effective to suppress parasitic bipolar amp. effect.
Rad-hard SRAM for space


Original FD SOI SRAM

+ Body tie

+ RC filter

Threshold LET for bit upset in MeV\textit{\cdot}cm^2/mg

3.6

9.0

40

Original

T. neutrons

G. cosmic rays

RC filter is used for space applications

Combined use of BT + RC is important

Only RC requires a really large RC value, practically unacceptable
Cell library is available

Hirose (ISAS) et al., 日本航空宇宙学会誌 58(683), 2010 p365 (in Japanese)

All memory elements such as SRAM, latches are protected by optimized RC + BT

Mitsubishi Heavy Industries, Ltd. SoC for space applications
- 32-bit CPU (100MIPS) with FPU
- Cache memory
- SpaceWire Interface
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Pulse-noise problems in logic gate

For now this SET effect is negligible
But many predictions say it becomes serious soon
Original pulse information is essential

Transient noise pulse = SET

Radiation

propagation

Logic gate network

Stored bit information

VO – VDD

Time

i. On-chip pulse-width measurement

ii. Full-waveform observation technique

iii. Physics-based analytical model
On-chip pulse width measurement

Yanagawa (ISAS) et al., IEEE Trans. Nucl. Sci. 53(6) 2006 p3575

Target logic gates

Radiation SET

input

12 NOR gates

SNAPSHOT A
(Time-to-digital converters)

digitize & record

111100011111

read & decode
World-first experimental demonstration

Yanagawa (ISAS) et al., IEEE Trans. Nucl. Sci. 53(6) 2006 p3575

NORs (w/o BT) under irradiation with LET 40 MeV·cm²/mg

Decoding accuracy is not guaranteed.
Comparison with bulk

Makino (ISAS) et al., IEEE Trans. Nucl. Sci. 56(6), 2009 p3180

1. Lower sensitivity than bulk
2. Shorter pulse (←?)
Pulse can be broadened

Propagation-induced pulse broadening (PIPB)

Floating body effect: dynamic VT change leads to pulse broadening during propagation
Wei (MIT) et al., IEEE Electron Device Lett. 17, 1996, p391
Comparison with bulk

Makino (ISAS) et al., IEEE Trans. Nucl. Sci. 56(6), 2009 p3180

Precise pulse-width comparison requires further study
Original pulse information is essential

Transient noise pulse = SET

Radiation

propagation

Logic gate network

Stored bit information

i. On-chip pulse-width measurement

ii. Full-waveform observation technique

iii. Physics-based analytical model
Full-waveform observation

Waveform of SET experimentally observed in advanced CMOS tech.
Original pulse information is essential

Transient noise pulse = SET

VO

VDD

Time

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Saturation tendency

Dodd (Sandia National Lab) et al., IEEE Trans. Nucl. Sci. 51, 2004 p3278

Numerical device simulation results

What makes this saturation tendency? Mechanics was unknown
Stating point of modeling

Numerical device simulation result


What mechanics is behind this plateau?
BJT operates in saturation during the plateau bottom.

Turn-off behavior of saturated BJT

Sze and Ng, Physics of Semiconductor Devices 2007

Forward Biased (F.B.)

Radiation effect = delta-function-like current injection
Demonstration


\[ t^* = \tau_0 \ln \left( \frac{Q_{\text{DEP}}}{I_p(\text{ON}) \tau_0} \right) + \tau_1 + \frac{C_L |V_{T_P}|}{I_p(\text{ON})} \]

Bottom (storage time)  Recovery

Good agreement
Saturation = log behavior
1. How serious radiation problems are
   Need to protect memory elements.
   Not only in space but also on the ground.

2. Merits and demerits of SOI
   BOX suppresses noise charge collection. Need a special care about increase in sensitivity due to small parasitic capacitance, bipolar amplification effect, and propagation-induced broadening

3. Pulse-noise problems in logic
   Logic gates need to be protected in near future. Characterization techniques such as pulse-width measurement, full-waveform observation technique, and physics-based analytical models are developed.