2012 12th International Conference on Control, Automation and Systems
Oct. 17-21, 2012 in ICC, Jeju Island, Korea

The Study of the transient radiation effects on electronic devices caused by pulsed high energy gamma-ray

Seung-Chan Oh[1*], Nam-Ho Lee[1] and Heung-Ho Lee[2*]

[1] Korea Atomic Energy Researcher Institute, Daejeon, South Korea
(Tel : +82-42-868-2245; E-mail: sech0502@kaeri.re.kr)
[2] Department of Electrical Engineering, Chungnam University, Daejeon, South Korea
(Tel : +82-10-4431-5656; E-mail: leehh@cnu.ac.kr) * Corresponding author

Abstract: In this study, we carried out SPICE simulation and transient radiation tests for identify failure situation by a transient radiation effect on electronic devices due to high energy ionizing radiation pulse induced on electronic devices. This experiments were carried out using a 60 MeV electron beam pulse of the LINAC(Linear Accelerator) facility in the Pohang Accelerator Laboratory. In this experiment test, we has found that a serious failure as a burn-out effect due to overcurrent on the partial electronic devices. Also we has found that a temporary error due to ionizing effect on the other electronic devices. Similar to these experimental results, the result of SPICE Simulation in NAND gate has found that the latch-up phenomena could be checked in more than 7.0×10^{11}W/cm^2.

Keywords: CMOS Integrated circuits, Gamma-ray burst, Burn-out

1. INTRODUCTION

Electronic systems can be cause various serious failures due to ionizing effect when exposed to a prompt high-energy gamma-ray pulse. The cause of this failure phenomenon is that generated by the result of unwanted photocurrent generated on the silicon material due to ionizing effect. In these studies, we have performed the following work. In the first part of the work, we have designed the circuit for the SPICE simulations of transient radiation effects on the NAND gate applied with parasitic latch-up circuit. And we investigated error phenomenon by transient radiation pulse on NAND gate device using the SPICE simulation. In the second part of the work, we carried out actual experiment tests using the high-energy pulsed gamma-ray on the electronic devices. Also, we has been carried out experiment test in the irradiation conditions used in the test dose rate of 4.0×10^{6}rad(si)/sec to 2.0×10^{8}rad(si)/sec. As in previous studies, all of the transient radiation effects experiments conducted during the course of this works were carried out using a pulsed 60 MeV, 15ns Gaussian pulse duration and 15mm spot diameter, LINAC(Linear Accelerator) facility in the Pohang Accelerator Laboratory. In this experiment by actual measurement, 13 electronic devices were selected and used. They consist of CMOS devices and linear devices which are actually commercialized and used.

2. SIMULATION

3.1 Design of NAND gate with latch-up model

The NAND gate of a CMOS structure was designed with parasitic p-n-p-n structure to simulate the latch-up phenomena of the CMOS devices according to transient radiation. And the designs of NAND circuit are divided into conventional NAND.

3.2 SPICE Simulation

We designed that latch-up modeling of the NAND gate using a TCAD simulation tool as shown in fig 1 for the analysis of latch-up phenomena caused by ionizing radiation pulse. As for the input parameters of gamma-ray used in the simulation, the absorption coefficient is 1.06×10-6μm, the wave length was setup by 0.0629/cm^2 and the energy was done by 1.17MeV[4].

The TCAD simulation results as shown fig 3, we check the generated photocurrent on P substrate is about 170uA. Thus, using these results, we applied the amount of photocurrent caused by amount of dose rate on the SPICE simulation based on TCAD results.

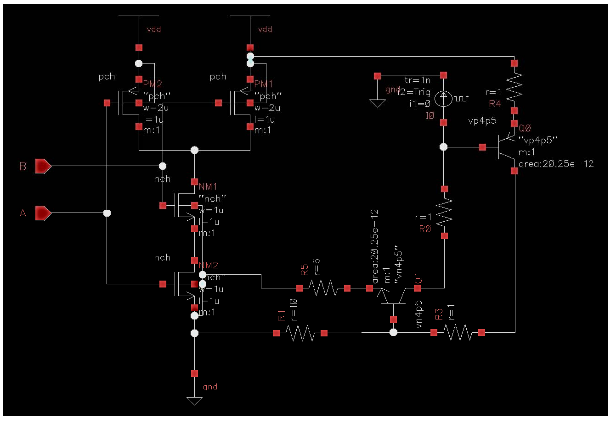
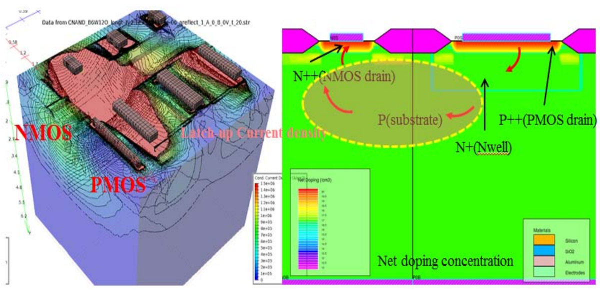


Fig. 1 The cadence modeling of NAND gate applied with parasitic p-n-p-n structure



(a) (b)

Fig. 2 (a) Latch-up status on the NAND gate cell (b) Latch-up current pass (cross-section)

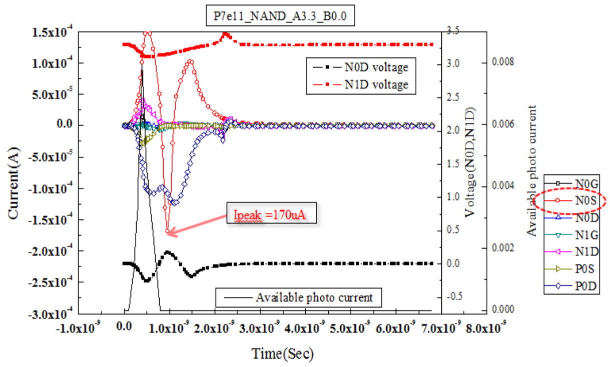


Fig. 3 TCAD simulation result (NAND gate, Beam condition = 7.0×10^{11} W/cm^2)

3. EXPERIMENTS

3.1 Tungsten converter for pulsed gamma-ray

As show in fig 6, we designed a tungsten converter for generation of pulsed gamma-ray from the electron beam by the Bremsstrahlung energy to apply the characteristic of prompt pulsed gamma-ray which generated in the initial step of nuclear explosion in this actual experiment test. In order to design this tungsten converter, we performed MCNP simulation about the tungsten's thickness change on fixed beam condition. The result that we simulated input conditions of beam energy of 60MeV with 100mA current in the tungsten's thickness change from 3.5mm to 7.5mm using MCNP-5c code has found that the thicker the tungsten' thickness is, the higher gamma dose rate we could get, but the characteristics that it is reduced from more than 6mm due to the screen effect as you see in the figures 4(a), (b). Therefore, in this test, the tungsten converter with 6 mm thickness which has the maximum Conversion Efficiency was applied. Also, based on a MCNP simulation, it was confirmed that the neutron generated from the 6mm tungsten was a negligibly small compare to gamma-ray.

3.2 Experiment Setup

Based on the a test method microcircuits, MIL-STD-883G 1020.1[2] and 1020.2[3] that specified the test methods of the dose rate about electron devices of the Department of defence (DOD), we carried out the experiment by actual measurement preparing the experimental procedure of upset and latch-up phenomenon. This experiment by actual measurement of transient radiation effects were arranged focusing on checking the overall effects on transient effects of Operational Amplifier and CMOS ICs. Therefore, it tried to examine the transient response characteristics according to transient radiation effects using 13 kinds of electronic devices that are generally commercialized. Each experimental device is built in the Device under Test (DUT) board manufactured according to bias conditions by device, input bias conditions can be set up by PC and DAQ(Data acquisition) modules and the real time measurement of output voltage and current consumption used by DSO(Wavepro 715Zi, Lecroy) and current probe(CP031, Lecroy) as I show it in fig 4,5.

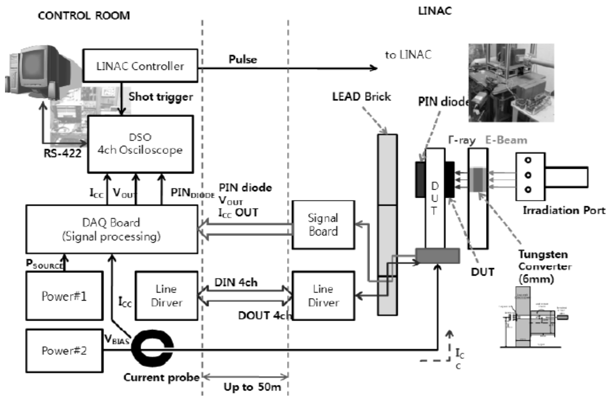


Fig. 4 Test setup for the transient radiation test

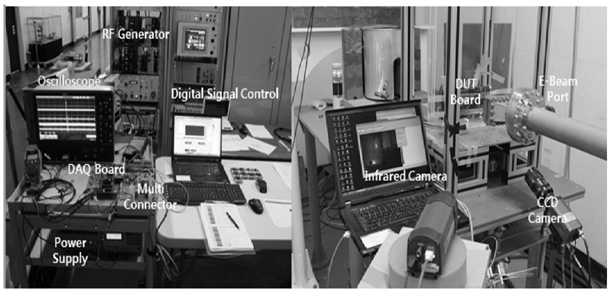


Fig. 5 Configuration of the actual measurement system for the transient radiation test

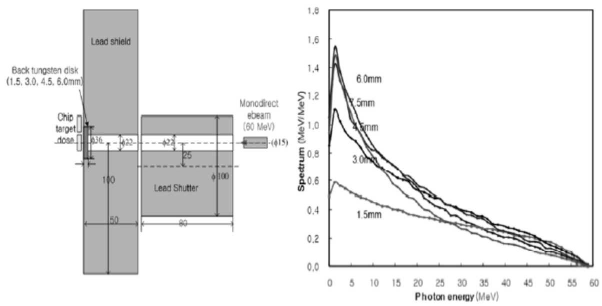


Fig. 6 (a) Configuration of tungsten converter, (b) Energy spectrum of gamma-ray on tungsten thickness

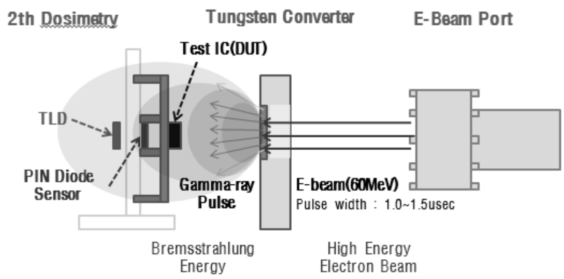


Fig. 7 Configuration of irradiation system for pulsed high energy gamma-ray

4. TEST RESULTS

4.1 Simulation Result

The simulation test results, we have identified latch-up phenomena on each node caused by the ionizing photocurrent occurs dominantly in body and N-Well junction on the irradiation conditions from 7.0×10^{10}W/cm^2 to 2.1×10^{12}W/cm^2.

The result that we simulated the voltage by each node of NAND gate by irradiation condition of 2.1×10^{12}W/cm^2 in 7.0×10^{10}W/cm^2 has found that, as for 7.0×10^{10}W/cm^2, photocurrent dominantly occurs in body and N-Well junction that photocurrent according ionizing has the largest junction area in NAND circuit. You can see the amplifying phenomena of current occur in the drain area of the NWELL and PSUB as we show them in fig 8, 9 after 7×10^{11}W/cm^2.

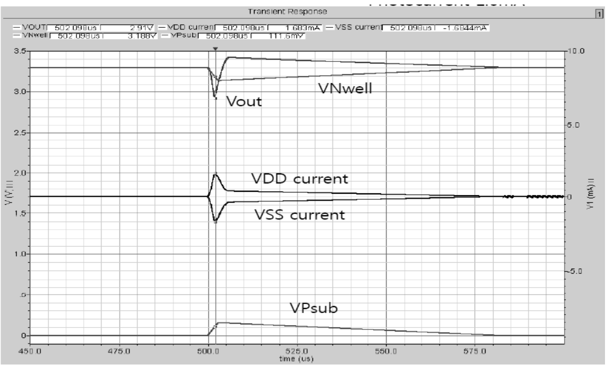


Fig. 8 The simulation result of NAND circuit (7.0×10^{10} W/cm^2)

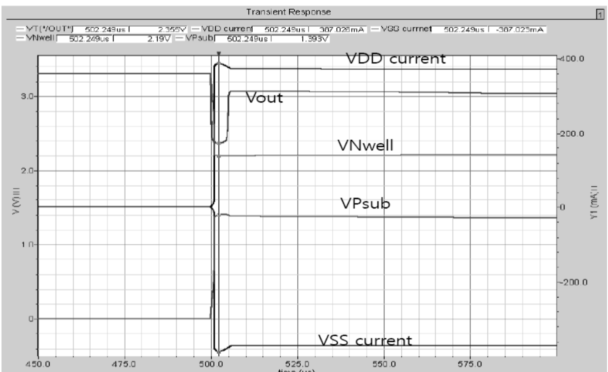


Fig. 9 The simulation result of NAND circuit (7.0×10^{11} W/cm^2)

4.2 Experiment Results

The experimental results as shown in the table 1, shows you the transient response characteristics on each electronic devices caused by gamma-ray pulse. The upset and latch-up phenomena were checked in all the DUT devices except for AD8354 device. In other words, the phenomena that current has temporarily and abnormally increased and the upset phenomena in output voltage can be checked in other devices. It could be also check that the function of the devices are abnormally operated under the state that latch-up is maintained, the phenomena that current abnormally increases due to the latch-up phenomena is removed when you clear the bias voltage supplied to DUT board by switching it on again after doing it off and after that, the devices are normally operated. As the result to measure the transient response of 74HC00 (NAND) of fig 12 is shown, the temporary error phenomena shown in the most devices could not reach the latch-up threshold level. However, it shows you the failure phenomena of internal circuit of devices in the temporally extinct section as photocurrent generated due to the ionizing radiation effects goes through the process of recombination in the substrate.

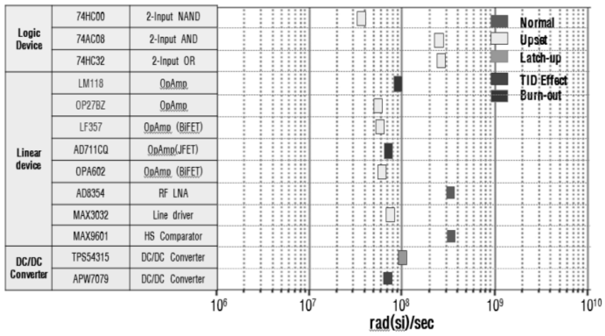


Fig. 10 Transient radiation test results for electronic devices

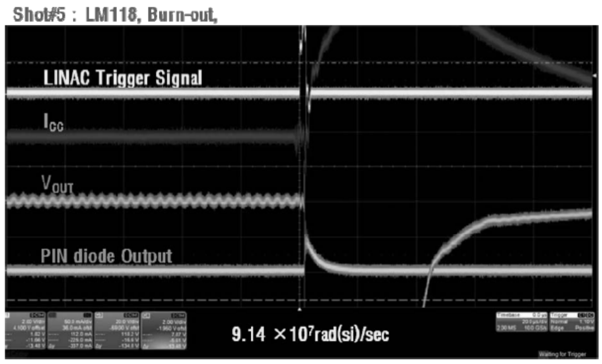


Fig. 11 Transient response of LM118 device by gamma-ray pulse (metal burnout)

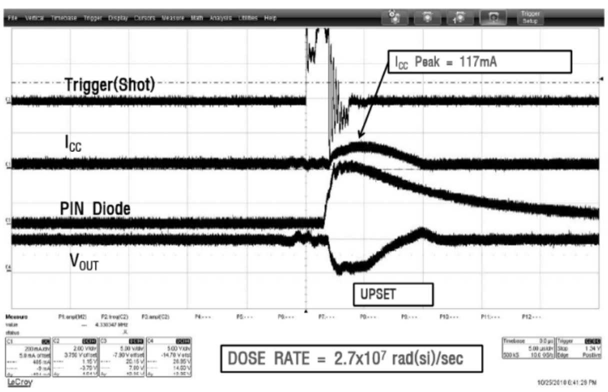


Fig. 12 Transient response of 74HC00(NAND) device by gamma-ray pulse

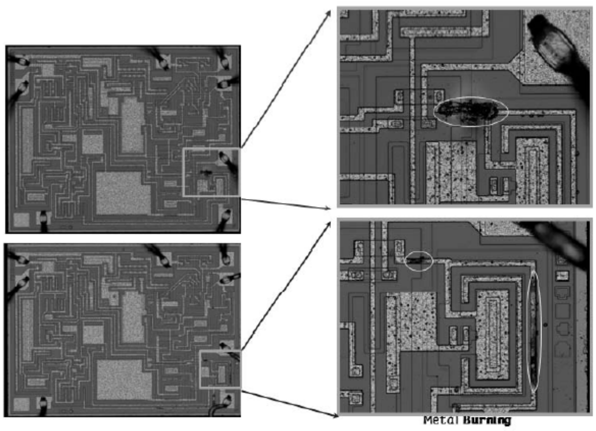


Fig. 13 The result of burnout phenomena by a transient gamma-ray pulse (LM118)

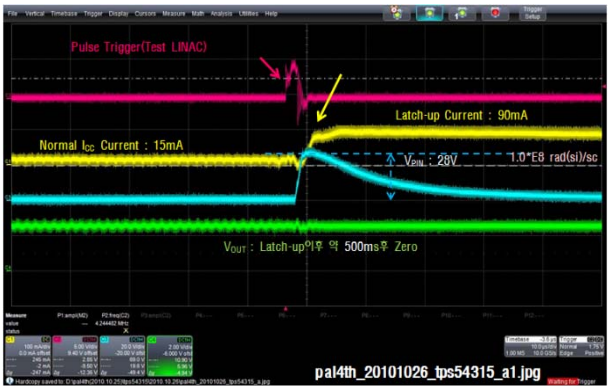


Fig. 14 The result of latch-up phenomena by a transient gamma-ray pulse (TPS54315)

Table 1 Experiment results

Shot #	Test Device	Threshold Level [rad(si)sec]	Test Result
1	LM118	9.1×10^{7}	Burn-out
2	OP27BZ	4.5×10^{7}	Upset
3	LF357	4.6×10^{7}	Upset
4	AD711CQ	6.1×10^{7}	Burn-out
5	OPA602	5.1×10^{7}	Upset/TID
6	MAX3032	6.4×10^{7}	Upset
7	AD8354	No Error	Normal
8	MAX9601	No Error	Normal
9	TPS54315	1.0×10^{8}	Latch up
10	APW7079	5.9×10^{7}	TID effect
11	74HC00	2.7×10^{7}	Upset
12	74HC32	1.6×10^{8}	Upset
13	74AC08	1.5×10^{8}	Upset

5. CONCLUSION

As show in simulation results, where the maximum power of the irradiated gamma radiation was 7.0×10^{10}W/cm^2, the output voltage change was recovered by the power-connected node NAND circuit. Therefore, the change in the output voltage was not a major concern. When the maximum power of the irradiated gamma radiation to the NAND exceeded 7.0×10^{11}W/cm^2, the NAND fell into a latch-up state. In that state, if internal current density continuously increasing by the latch-up phenomena, it will be enough to destroy NAND device itself.

The experimental test results of electronic devices as shown in fig. 10, transient upset and latch-up phenomena were arise from all DUT devices except the AD8354(Low noise amplifier) device. the latch-up phenomenon in the experiment by actual measurement could be checked in TPS54315(DC/DC Converter) devices as shown in fig 14. Finally, as you see the result of LM118 device as shown in fig 11, 13, it was checked that a result of metal burnout phenomenon was confirmed.

ACKNOWLEDGMENTS

The authors would like to acknowledge the sponsors of this effort: Agency for Defence Development (ADD)under UC090023GD.

REFERENCES

[1] Lewis Cohn and Al Wolicki and Mayrant Simons and Clay Rogers and Alfred Costantine, “Transient Radiation Effects on Electronics (TREE) Handbook ”, Defense Nuclear Agency 6801 Telegraph Road Alexandria, VA 2231-3398, December 1995

[2] MIL-STD-883G 1020.1, "Dose rate induced latchup test procedure", (28 February 2006)

[3] MIL-STD-883G 1021.2, "Dose rate upset testing of digital microcircuits", (28 February 2006)

[4] C. M. Davisson and R. D. Evans., Rev. Mod. Phys., 24 Pages 79-107 (1952)

[5] George C. Messenger and Milton S. Ash, “The Effects of Radiation On Electronic Systems”, VAN NOSTRAND REINHOLD COMPANY, New York, May 14, 1992

[6] H.S Andrew and Len Adams, “Handbook of Radiation Effects”, Oxford New York Tokyo, OXFORD UNIVERSITY PRESS, 1993

[7] L. W. RICKETTS, “Fundamentals of Nuclear Hardening of Electronic Equipment”, ROBERT E. KRIEGER PUBLISHING COMPANY, MALAABAR, FLORIDA, 1986

[8] A. H. Johnston, G. M. Swift, "Latchup in Integrated Circuits from Energetic Protons" IEEE Transactions on Nucl. Sci 44 (6), p. 2367, (1997)

[9] L.J. van Roozendaal , "The Modelling of the Latch-up effect in CMOS Integrated Circuits."(1985)R. C. Baker and B. Charlie, “Nonlinear unstable systems,” *International Journal of Control*, Automation, and Systems, Vol. 23, No. 4, pp. 123-145, 1989.