

PAPER • OPEN ACCESS

Total dose measurements by p-channel transistors of ICs

To cite this article: V I Butin *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **498** 012007

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices
to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of
every title for free.

Total dose measurements by p-channel transistors of ICs

V I Butin^{1,2,*}, I V Butin³ and A V Butina¹

¹ Dukhov Research Institute of Automatics (VNIIA), Moscow, Russia

² National Research Nuclear University MEPhI, Moscow, Russia

³ Bauman Moscow Technical University (BMSTU), Moscow, Russia

*Corresponding author's e-mail address: butin.valentin@gmail.com

Abstract. In this paper, a new approach of p-channel MOS-transistors used for total dose monitoring at semiconductor components under radiation is presented. The calibration results enable to determine the numerical parameters for the MOSFETs electro-physical model of dose effects. We propose to calculate the total dose of ionization flux using the results of MOS-transistors drain current measurements, under a fixed gate and drain voltage.

1. Introduction

The irradiation of large-size objects (such as spacecraft) that consist of heavy solid elements is connected to some difficulties, namely, the accurate estimation of total dose for radiation-sensitive elements. The actual value of total dose accumulated in radiation-sensitive regions of a semiconductor component usually differs from values for regular dosimeters that are placed at the surface of research objects. The reason for such a difference is the transformation of the radiation spectrum during its transmission through construction materials of complex objects and systems.

MOS integrated circuits are nowadays in general use in electronics. However, such devices are rather sensitive to total dose so it is possible to use semiconductor devices as total dose monitors. They respond to total ionizing dose (TID) and their design is similar to that of critical units of electronics.

The purpose of this paper is to introduce the technique of application of p-channel MOSFETs within the digital IC as detectors for quick and low-cost measurements of TID accumulated in the semiconductor components in the volume of large-size research objects. We first provide the basic principles and a new scheme for on-line TID measurements, and also discuss the main advantages of such scheme. Then, we propose and describe the research algorithm. Finally, we consider the results of the irradiation tests with on-line TID measurements for 1594TL2T under static gamma-irradiation. The calculated values of TID determined for the experimental detector are in good accordance with the values of regular dosimeters of the simulation facility.

2. Theoretical basis

Recent reports [1-6] have shown that radiation impact of MOS-structures produces the positive charge accumulation at the gate insulator and increases the surface state density at the semiconductor-dielectric interface. In our previous papers [7], experimental data was reported and the electro-physical model was proposed, which described dose effects kinetics for n-channel MOSFETs sensitive to irradiation conditions (environment temperature, radiation intensity and electrical mode). The practical realization of the proposed electro-physical model allows us to describe mathematically the behavior



of MOS-transistors under irradiation and predetermines the use of MOS-devices for TID detectors [8-10]. We propose to use p-channel MOS-transistors within the digital IC for TID monitoring.

It is necessary to ensure the compliance with accumulated dose in the sensitive volumes of the detector and MOS-devices in research electronics. Thus, the p-channel MOS-transistors within the simple digital IC (i.e. inverters, NAND circuits, NOR circuits, Schmitt triggers et al.) can be effectively used as sensitive elements, as they are in the same design as dose-sensitive electronics components.

We measured on-line the TID using the test setup, shown in Fig. 1. During the experiments, the application of p-channel MOS-transistors within the CMOS integrated circuit 1594TL2T (device under test, DUT) was researched for on-line TID measurement. The DUT was placed under a Co⁶⁰ gamma ray source. The desktop PC for accessing the measurement equipment was positioned near the irradiation room. It was assembled from "PXI" standard test devices and was managed with the special LabVIEW program for remote control of the generator and multimeter.

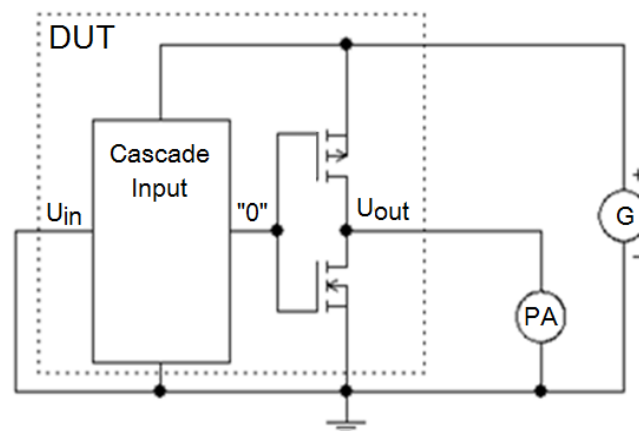


Figure 1. Schematic diagram of the test setup. G – generator, PA – multimeter

The main advantage of the proposed scheme is that the researcher is supposed to measure only drain current of the proper MOS-transistor in over-threshold mode during multichannel registration. Besides, one needs N+1 cables for N detectors. It is especially important for typical automated measurement systems, when there is difficulty in the registration of the total transfer characteristics. However, it is possible to take point-by-point measurements for a fixed power supply value.

At the stage of pre-calibration before and after irradiation, it is propose to register transfer characteristics in the over-threshold mode of p-channel MOSFETs within the IC.

The irradiation of the p-channel MOS-transistor with dose $D(t) = P \cdot t$ changes its transfer characteristics $I_{DS}(D)$ [11,12]:

$$I_{DS(D)} = \frac{W}{2L} \frac{\mu_0 \cdot C_{ox}}{(1 + K_{\mu} \cdot \mu_0 \cdot D)} (U_{GS} - U_{T0} - K_{\Delta V_T} \cdot D)^2 \quad (1)$$

where W is channel width, L is channel length (these parameters are typical and dependent from technology of MOS-devices);

μ_0 is the initial value of carriers mobility in the channel;

C_{ox} is specific capacity of the gate insulator;

K_{μ} is dose sensitivity coefficient of electrons mobility in the channel; U_{GS} is gate-source voltage (in our case $U_{GS} = U_{CC}$, U_{T0} is threshold voltage);

$K_{\Delta V_T}$ is dose sensitivity coefficient.

Using the notations $a = K_{\mu} \cdot \mu_0$ and $b = \frac{K_{\Delta V_T}}{U_{GS} - U_{T0}}$, the simplified expression for p-channel MOS-transistor current by fixed power supply value may be expressed as follows:

$$I_{DS(D)} = I_{DS(0)} \frac{1}{(1 + a \cdot D)} (1 - b \cdot D)^2 \quad (2)$$

where $I_{DS(0)}$ is the initial current value (before irradiation).

The values of coefficients a and b can be calculated through calibration data of the radiation facility with determined spectrum and intensity – for instance, a Co^{60} source.

3. Details of the model

We propose that p-channel MOS-transistors within the digital IC should be used as detectors for measurements of TID as following:

1) Calibration.

The drain current I_{DS} change of p-channel MOS-transistors within the digital IC is experimentally measured under radiation by a facility with determined spectrum and dose rate. During this experiment, the power supply value is fixed. The irradiation dose is about 20-50 krad (Si).

2) Extraction of model numerical parameters.

The numerical values of a and b are calculated for equation (2) through the calibration data.

3) Use of TID detectors

The drain current I_{DS} change of p-channel transistors is measured under conditions with unknown spectrum and composition of irradiation. The fixed power supply value provides the over-threshold mode. Using the parameters a and b that were determined at the stage of calibration, one can calculate the corresponding value of TID for a given irradiation time.

The time diagram of source power of the relative change and the initial measurements data are used to determine the real value of TID for over-irradiated detectors in experimental research under static and quasi-static irradiation.

4. Results

Let us discuss the experimental research of ICs 1594TL2T for radiation hardness under static gamma-irradiation by a facility with determined radiation spectrum and dose rate. The digital IC consists of six inverted Schmitt triggers that were used as TID monitors.

The automated measuring system was developed on the basis of modular equipment National Instruments (chassis NI PXI-1042, DC Power Supply PXI-4110, Digital Multimeter PXI-4072) and software LabVIEW2014. This system provided the power supply U_{DS} with proper accuracy (up to several mV) and it enabled to take the current I_{DS} measurement under condition of changing voltage U_{DS} within determined time intervals.

1) Calibration

The detectors were irradiated at the voltage $U_{DS} = 1$ V. The certain voltage value at the inputs of the transistors was 0 V. The value of TID at the end of irradiation was equal to 30 krad (Si). Fig.2 represents the experimental curve $I_{DS}(D)$. The numerical values of coefficients of equation (2) were determined using this curve:

$$a = 0.0132; b = -0.0086; I_{DS(0)} = 3.305 \text{ mA}.$$

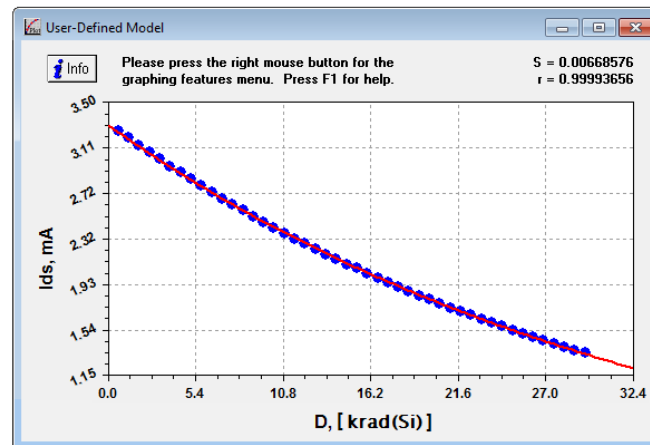


Figure 2. The equation for experimental correlation between the current I_{ds} and total dose D and its coefficient values:

$$y = 3.305 \left(\frac{1}{1 + a x} \right) \left(1 + b x \right)^c$$

2) Application of detectors for research of electronics radiation hardness

The detectors were mounted at the experimental board closely to research objects during the experiments. The irradiation was carried out at the facility with determined spectrum and dose rate. The current I_{ds} was measured during the experiment at intervals of 10 minutes.

The detectors functioned in the proper electrical mode of the facility before, during, and after the irradiation and the control parameter annealing was observed.

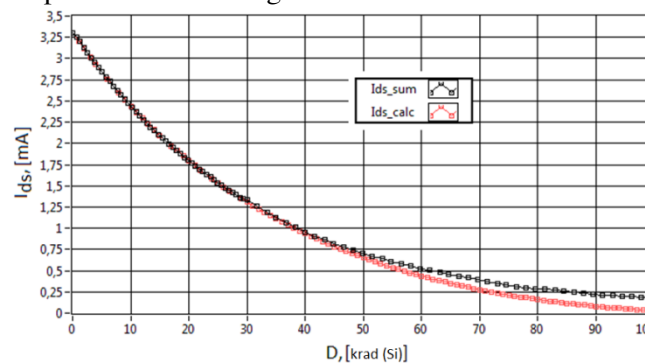


Figure 3. The comparison of $I_{ds}(D)$ functions: experimental (black) and calculated after parallel translation (red)

Finally, Fig.3 illustrates the difference between values of TID determined for the experimental detector and values of regular dosimeters for the simulation facility (imprecision is less than 10%).

Thus, the irradiation experiments revealed the detector tolerance within TID ranging from 0 to 35 krad (Si) (without the TID value that was accumulated during calibration) is less than 10%.

3) Stability of calibration results

It is important to point out that the application of p-channel transistors within CMOS integrated circuit as TID detectors is possible only for stable values of parameters that were determined during the calibration. The experimental research revealed that the degradation of function $I_{ds}(D)$ remained quasi-stable after 1000 hours post irradiation.

5. Conclusion

In this article, there was considered the application features of p-channel MOS-transistors within the CMOS integrated circuit as a TID detector for total ionizing dose monitoring in DUT under irradiation.

This work presented one of the applications of electro-physical modeling for the forecasting of the degradation of the MOS-transistors TID characteristics.

In the proposed method, the TID value of the detector is in good accordance with that of ICs for a wide spectrum of radiation energy.

References

- [1] Oldham T R and McLean F B. 1987 *Basic mechanisms of radiation effects in electronic materials and devices (Harry Diamond Laboratory Technical Report)* HDL-TR-2129
- [2] McWhorter P J 1986, *Simple technique for separating the effects of interface traps and trapped-oxide charge in metal-oxide-semiconductor transistors* ed. P. J. McWhorter, P.S. Winokur (*Applied Physics Letters*.) **48** 2 pp 133-134
- [3] Oldham T R *Basic Mechanisms of TID and DDD Response in MOS and Bipolar Microelectronics* (DSFG, Inc. NASA Goddard, Radiation Effects and Analysis Group)
- [4] Oldham T R, 1999 *Ionizing Radiation Effects in MOS Oxides*, Advances in Solid State Electronics and Technology (ASSET) Series, World Scientific Publishing, Singapore
- [5] Oldham T R and McLean F B 2003, *IEEE transactions on nuclear science* **50** 3
- [6] Mazur J 2002 *Radiation Effects — From Particles to Payloads* (IEEE NSREC Short Course) pp II-1 – II-69
- [7] Barmakov Yu N, Butin V I and Butina A V 2013 *Questions of atomic science and technics. Series: Physics of radiation effects on radio-electronic equipment* **3** pp 5-9
- [8] Winokur P S, Schwank J R, McWhorter P J, Turpin D C and Dressendorfer P V 1984 *IEEE Transactions on Nuclear Science* **31** (6) pp 1453-1460 DOI: 10.1109/TNS.1984.4333529
- [9] Ma T P, Dressendorfer P V, 1989, *Ionizing Radiation Effects in MOS Devices and Circuits* 1st edition (Wiley New York)
- [10] Schwank J 2002, *Total Dose Effects in MOS Devices (Radiation Effects – From Particles to Payloads)* IEEE NSREC Short Course
- [11] Muller R S and Kamins T I 1989 *Device Electronics for Integrated Circuits* 2nd Edition, (Russian Translation published in Moscow, USSR 1989)
- [12] Schwank J R, Shaneyfelt M R and Dodd P E *Radiation Hardness Assurance Testing of Microelectronic Devices and Integrated Circuits: Radiation Environments, Physical Mechanisms, and Foundations for Hardness Assurance* (Sandia National Laboratories Document Sand) 2008-6851P