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Investigation of CMOS Multiplexor SEL Sensitivity at Low Temperature

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Abstract — **The paper presents the data obtained during the study of CMOS multiplexors single-event effects sensitivity at ion accelerator and at laser SEE-simulation facility. A comparison of SEL rate at normal and low temperature is made.**

Keywords — **Single Event Effects, CMOS Multiplexor, laser SEE simulation technique, temperature dependence.**

I. Introduction

The development relevance of infrared (IR) photodetector arrays of various formats, which are the basis of television / heat-vision systems, continues to grow. The bulky optomechanical (vacuum) photosensitive-systems are replaced by compact integrated circuits. Modern IR active-pixel sensors (APS) provide high spatial and temperature resolution and are widely used in various branches of science and technology [1].

Modern APS systems consist of two main parts: a multi-element photosensitive structure and a silicon readout circuit (multiplexer). A multiplexer (MUX) is an integrated circuit that reads obtained electrical signals which are a result of photoelectric conversion of incident infrared light in photosensitive elements of a focal plane array (FPA).

Multiplexers used to switch signals are based on CCD and MOS transistor. MOS switches have the following advantages over the CCD: higher fill factor, smaller values of control voltage, greater dynamic range, lower power consumption and heat dissipation. Silicon multiplexers usually operate at temperatures in the range 65-300K. CMOS technology is widely used in embedded systems, such as readout ICs of infrared image sensors [2, 3].

Spacecraft tracking and guidance systems are used to determine the launch orientation of a carrier or satellite during a space mission. The reliability of these systems is crucial, and the requirements for radiation hardness are unavoidable [4].

During space operation, even if electronic devices are exposed to temperatures up to 200K, IR systems operate at cryogenic temperatures (up to 50K). Such conditions are necessary to increase their performance. The effectiveness of these systems can be affected by factors of space environment such as absorbed dose (gamma-rays, electrons), structural damage (protons, neutrons) and single event effects from heavy charged particles (heavy ions, protons) [5]. This paper is dedicated to the study of SEE and associated effects on CMOS Multiplexor of IR image sensor.

For the space industry, the risk of SEE can be evaluated with radiation tests on simulation facilities [6, 7] capable of providing exposure to a beam of heavy ions or protons with characteristics similar to the space environment. The exposure to heavy particles can also be simulated by using a laser-based method, which can assess devices sensitivity to upsets and failures.

II. Device Under Test

The aim of the work is to study the sensitivity of the multiplexer of a two-spectral matrix unit, which is part of an infrared photodetector, to the effects and failures caused by heavy ions and high-energy protons typical to outer space.

One of the key components of an image sensor system - multiplexer is an integrated circuit that reads electrical signals generated by photosensitive elements when exposed to incident light [2]. A general structure of the readout CMOS multiplexer circuit is presented in Figure 1 [8].

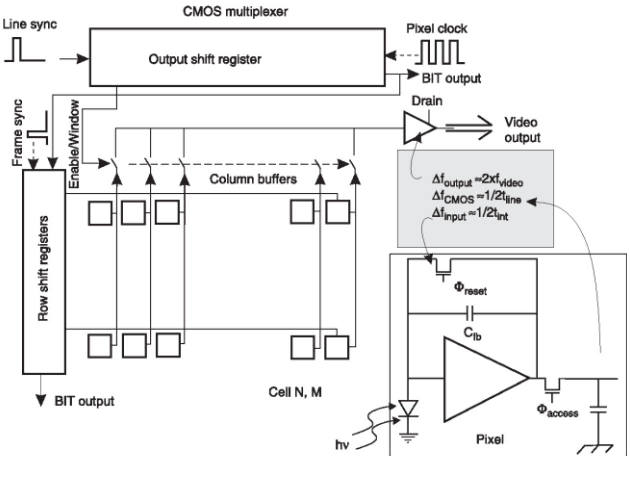

Fig. 1. CMOS multiplexing readout circuit scheme

The multiplexer consists of the following parts: a matrix of M × N read cells, horizontal and vertical registers, M read channels, an output amplifier. In each cell, a bias voltage VCM is set on the photodiode using an input transistor and to read the photocurrent. Photocurrent integrates on the storage capacity. When the addressing key (switch) is opened the accumulated charge is read by the source-follower amplifier. The subsequent charging of the capacitance is carried out with the help of a reset transistor. The received signals are multiplexed to the output using a horizontal register.

The considered matrix block consists of silicon CMOS ASIC, manufactured by “Micron” (Russia) for two-spectral APS blocks.

III. DUT CONNECTION CIRCUIT

In order to estimate devices suitability for space operations, it is necessary to evaluate its radiation hardness level. The connection diagram of DUT during irradiation is shown in Figure 2. During the radiation experiment, the following parameters of the product were monitored:

- Voltage at information outputs;

- Current consumption of the power circuit;

- Current consumption of secondary circuits.

The absence of upsets and failures was the criterion of devices normal operation. The threshold for recording of SEL was 45 mA, and the current consumption limit was 50 mA.

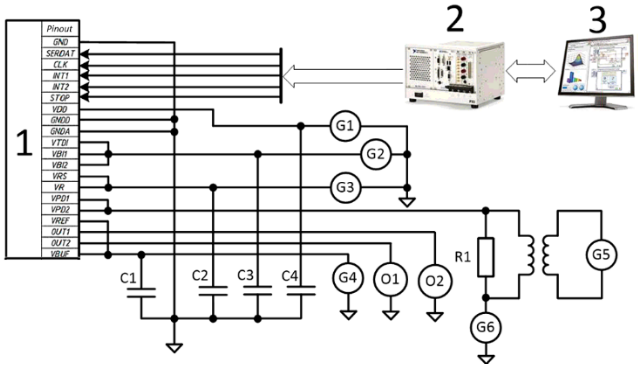

Fig. 2. MUX connection diagram during radiation tests

The multiplexer (labelled as 1 in Figure 2) parameters were monitored using the National Instruments hardware-software complex (labelled as 2 in Figure 2) with programmable power supply module (G1-G6), a digital-analog input-output module (FPGA), a signal generator module, and an oscilloscope module (O1, O2) to control transient effects, C1-C4 are isolation tanks.

IV. EXPERIMENTAL SETUP

The experimental data of device’s irradiation at heavy ions cyclotron and at pulsed laser modulating facility in two temperature conditions is presented [9]. The results are described in the respective sections.

A. Heavy Ions Irradiation

The irradiation was carried out at heavy-ion cyclotron U-400M (JINR Dubna, Russia) with the following ions: argon (Ar), krypton (Kr), and xenon (Xe). The DUT was placed inside the vacuum chamber in a rotating frame. The ambient temperature during ion irradiation was +25°C. The parameters of test ions are given in Table 1. During irradiation, the samples were operated in dynamic mode: transmitting signal (200 Hz ,3.3 V) to a transformer with an offset. Every second the internal configuration registers we reflashed. The interval between registration of the thyristor effect (SEL) and its parry [9-11] was 50 ms, time during which power supply was switched off after SEL registration was 100 ms.

Table 1

Single event latch-up recording results after Xe, Kr, Ar ion irradiation

Ion LET, MeV·cm²/mg	Sample number	SEL amount	Fluence, cm^{-2}	SEL XS, cm^2
67 (Xe)	1	112	$2\cdot10^6$	5E-05
	2	110	$4\cdot10^6$	2E-05
41 (Kr)	1	14	$2\cdot10^7$	6E-07
	2	1	$2\cdot10^7$	7E-08
18 (Ar)	2	0	$3\cdot10^7$	≤ 5E-08
	3	0	$2\cdot10^7$	
	4	0	$2\cdot10^7$	

The current consumption level for the recording of SEL for each of the 4 channels was 45 mA. When the product was irradiated with Xe and Kr ions, SEL were observed only through the VDD channel. Any destructive events or devices failures were not recorded during irradiation. The timing diagram reflecting the dynamics of the current and the parrying of the thyristor effect to the VDD channel of sample No. 1 is shown in Figure 3.

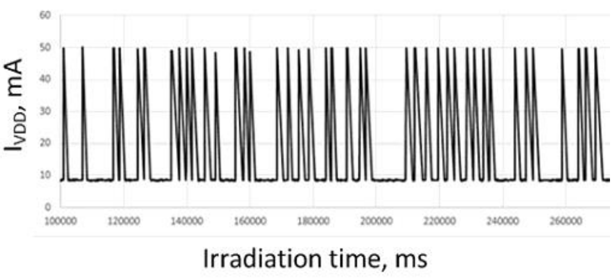

Fig. 3. Sample №1 current consumption monitoring results of the of VDD channel when exposed to Xe ion beam

The most adequate technique to estimate SEE sensitivity is based on heavy-ion accelerator tests, but it is rather expensive and time-consuming. In order to get complementary information, there is an alternative SEE simulation technique utilizing focused picosecond laser radiation [12-14] to trigger SEE events.

Subsequent identifying tests were carried out with a picosecond laser radiation simulator «PICO-4». More details on the testing features of this facility can be found in references [15-18].

B. *Laser SEE Simulation Facility*

There is an alternative way of SEE sensitivity estimation – the use of laser irradiation technique, which does not require a vacuum environment and provides more time and spatial information than traditional methods [12-14, 19].

The laser source of this facility has the following characteristics for wavelengths of 1.064 µm / 0.532 µm, respectively:

- Pulse energy: 9,1±0,5 / 2,7±0,2 µJ;
- Relative output laser energy level setting deviation of built-in attenuator: 4,0% / 7,4%;
- Pulse duration: 70 ps / 70 ps;
- Focused spot diameter: 2,4 µm / 1,8 µm;

SEE tests of microelectronic parts are usually carried out at normal and high temperatures. Common practice shows that the rate of single event effects at elevated temperature is significantly higher than at normal climatic conditions [9, 18]. In this case, since the product as part of its hardware unit which operates at low temperature, the tests were carried out at low temperature, which is much closer to its actual operating conditions.

The first step of laser tests was to scan the laser beam across the part, in order to localize SEL sensitive areas at a temperature of + 25°C. From the many sensitive areas, the most critical ones are determined as the ones with the lowest threshold energy for SEL occurrence [15].

The second step was to scan the part, similar to step 1, but at a temperature of -20°C.

The exposure to laser radiation of a wavelength of 1.064 µm and duration of 70 ps was carried out from the upper layer. The scanning step was 10 µm, the spot diameter was 20 µm, and the scanning area was 0.079 cm^2. As with exposure to ions, the threshold for recording of SEL was 45 mA, and the current consumption limit was 50 mA.

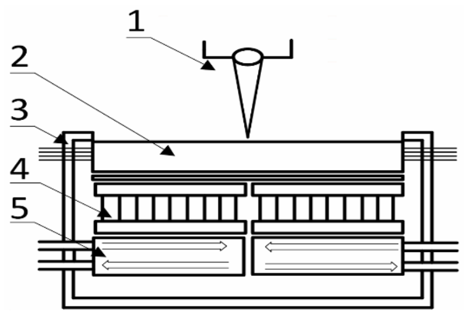

Fig. 4. General scheme of the applied multiplexer sample cooling system

There are various ways to set the product to a low temperature. The most common option is a liquid nitrogen evaporation control system. The difficulty of conducting tests at a low temperature on a laser facility is associated with such difficulties as the scattering of laser light on nitrogen vapor and the impossibility to place vapor nozzle in the immediate vicinity of a decapsulated sample. For these purposes, a compact cooling system was developed, and its block diagram is shown in Figure 4.

The laser source (1) is above the active area of the sample (2) located in the casing of the cooling system (3). A cascade of thermoelectric coolers (4) is used as cooling elements. Heat removal was carried out by placing the TEC “hot” side on copper heat sinks (5), with water heat removal tubes connected to them. This design made it possible to stably maintain a temperature of -20°C for several hours – long enough to conduct the laser scanning.

V. Results

The results of the laser scanning, presented in Table 2, show that maintaining the device in a temperature regime close to its natural operation mode (i. e. low temperature) during exposure to a laser pulse, prevents SEL occurrence. Therefore, this mode of operation provides the device a significant resistance to the manifestation of SEL.

Table 2

The results of the MUX IC surface scanning in two temperature regimes

Ambient (sample case) temperature	Laser Pulse Energy, nJ	Amount of registered SEL
+25°C	150	1
	170	15
	200	156
	270	250
	380	308
-20°C	< 300	**0**
	310	**0**

Tests of a similar CMOS multiplexer at an ion accelerator were carried out by a team of authors and described in [5]. According to their results, it was determined that when the product is irradiated in the mode that is closest to the natural (i. e. low temperature), the cross section of effects is significantly lower than in the normal climatic conditions. These results are consistent with the data obtained here and confirm the need for testing microelectronic products not only in general critical temperature conditions but also in the modes closest to the equipment operating modes.

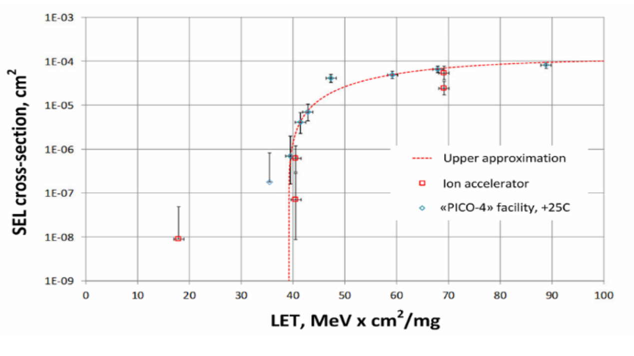

Fig. 5. Multiplexer test results (confidence probability P = 0.95)

Figure 5 presents the comparative results (SEL cross-section) of testing a multiplexer at a heavy-ion accelerator and at a laser facility at the same temperature conditions. From the consistency of the results, it can be assumed that, given the technical feasibility of conducting tests at lower temperatures at the cyclotron, we would get results that correlate with the data obtained at the laser facility.

VI. CONCLUSION

Studies of a 0.35 μm CMOS multiplexer sensitivity to SEE on the U-400M ion accelerator (JINR, Dubna, Russia) and the PICO-4 laser facility were conducted.

The product in the hardware unit operates at low temperatures. For this reason, tests of sensitivity to single event effects induced failures were not carried out at elevated temperatures, typical for microelectronic products, but at low temperatures, closer to the operating conditions for this device. A special chiller was developed to meet the testing needs of such a device at the laser facility at low temperature.

It is noted that when the tested products operate in temperature conditions closer to their application (i. e. low temperature) during irradiation, the cross-section of effects is much lower than under normal climatic conditions. In this condition, it is important to use an individual approach to setting a product regime during tests, taking into account the specificity of its operating conditions.

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УДК 004

Исследование чувствительности КМОП-мультиплексора к тиристорному эффекту при пониженной температуре

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***Аннотация* — В работе представлены данные, полученные при исследовании чувствительности КМОП-мультиплексоров к одиночным ядерным эффектам на ускорителе ионов и на моделирующей лазерной установке. Проведено сравнение числа зарегистрированных тиристорных эффектов при нормальной и пониженной температуре.**

Ключевые слова — одиночные эффекты, тиристорный эффект, КМОП-мультиплексор, лазерная установка ПИКО-4, ускоритель ионов.

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