“PICO-4” Single Event Effects Evaluation and Testing Facility Based on Wavelength Tunable Picosecond Laser

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***Abstract*—Technical characteristics of “PICO-4” SEE simulation facility utilizing a tunable picosecond laser source are presented. Its capabilities aimed on simulation of single event effects under space environment in Si, GaAs, SiGe etc. microelectronic devices are discussed.**

I. Introduction

Currently there is a great progress in the development of experimental techniques aimed on single event effects (SEE) evaluation and testing of electronic devices in space environment [1,2]. The most adequate technique of SEE sensitivity parameters estimation is based on heavy-ion accelerator tests, but it is rather expensive and time consuming. There is the alternative SEE simulation technique utilizing focused picosecond laser radiation [3-5]. To simulate ionization tracks produced by single ions with various penetration depths in various semiconductors, laser pulses with different wavelengths can be used [6]. For Si and GaAs devices the most appropriate wavelength values are between 0.7 and 1 µm. On the other hand, with sub-bandgap picosecond laser pulses (having wavelengths greater than 1.1 µm for silicon devices), it is possible to minimize linear absorption in the substrate and utilize two-photon mechanisms of non-equilibrium charge generation, thus providing additional opportunities for laser SEE simulation, such as backside device irradiation [7]. In many cases pulsed laser technique can replace common testing based on ion accelerators and can provide valuable complementary information and additional capabilities specific to SEE studies [8].

In this article we describe “PICO-4” experimental SEE simulation facility, which is based on wavelength tunable picosecond laser source. “PICO-4” provides additional possibilities compared to laser simulators “RADON-9F” and “PICO-3” [8]. It can be used for radiation hardness evaluation of wide class of modern Si, GaAs and SiGe semiconductor devices with various technology and architecture. We also discuss its main features and characteristics, as well as present some illustrative results of its capabilities.

II. General Description

“PICO-4” is designed according to general block scheme presented in Fig. 1a and consists of the following major parts: laser source, variable attenuator, focusing unit (microscope) with illuminator, CCD camera, XYZ translation stage with device under test (DUT), and control PC with all necessary interfaces. The general view of “PICO-4” facility is shown in Fig. 2. It has compact design mounted on the 1.2 m × 1 m vibro-isolated optical table, carrying all parts except the laser source power supply and PC.

The laser source is based on EKSPLA PL2210A-SH diode-pumped solid state picosecond laser, which generates 25 ps pulses with 532 nm wavelength to pump the custom designed optical parametric generator (OPG) EKSPLA PG503. This combination of pump laser and OPG allows tuning output wavelength in the 0.7…1 or 1.15…2.1 µm range, depending on the specific SEE simulation technique used. Output wavelength control is performed by the OPG internal microprocessor, which provides precision automatic positioning of the relevant components (such as non-linear crystals and diffraction grating). Precise temperature stabilization of the nonlinear crystals assures a long-term stability of the OPG output parameters. Special attention was paid by the OPG manufacturer to optimize the diameter and profile of the output laser beam for further focusing into a micron-sized spot. The output laser pulses frequency can be changed from single shot to 1000 Hz by the use of PL2210A-SH internal pulse picker.

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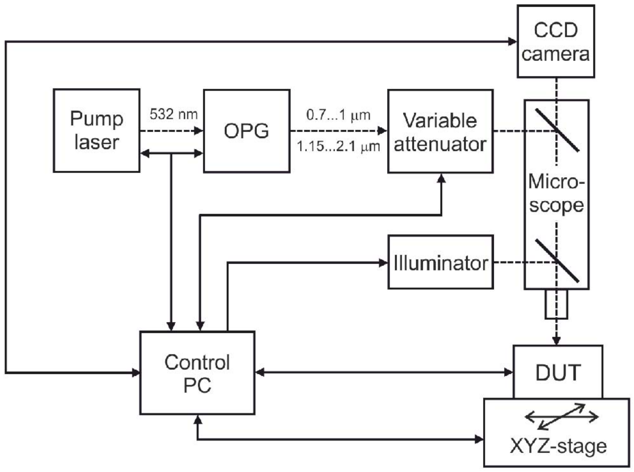

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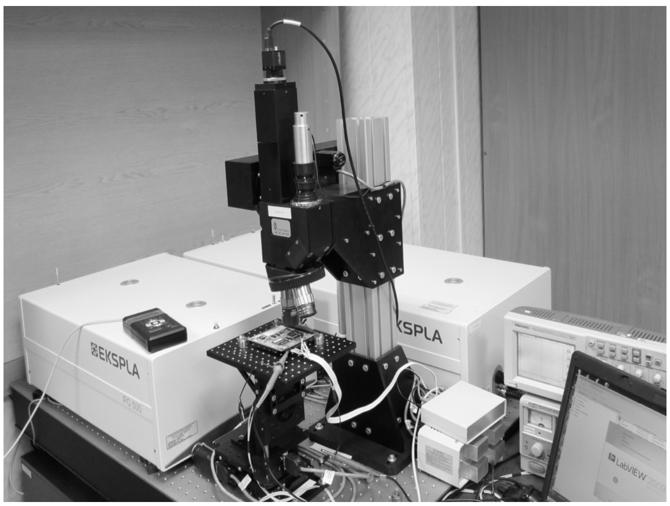

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Fig. 1. Block scheme (a) and general view (b) of "PICO-4" laser SEE simulation facility.

Laser pulses from the OPG output travel through the variable attenuator to focusing unit. The attenuator is based on a combination of polarizing prisms, one of which can be rotated to the arbitrary angle. The maximum attenuation coefficient is as much as 10^5, allowing to precisely adjust laser pulse energy on DUT from tens of pJ to several μJ. Output laser energy is calibrated for every used wavelength. Due to high stability of laser source and attenuator parameters, there is no need of frequent recalibration, however, calibration can be easily done with external etalon energy meter, which can be placed instead of DUT.

The focusing unit is a high-resolution optical microscope equipped with an input laser port, shadowless telecentric illuminator (based on high-power XLamp LED) and a set of large working distance Mitutoyo infinity corrected NIR objectives. The color CCD camera, attached to the microscope, produces the images of the DUT surface and helps to target the focused laser beam. The typical scale of obtained images is about 60 nm/pixel with $20^{\times}$ objective, though the optical resolution of the microscope in the visible range is diffraction limited to 0.5 μm. The minimum laser spot diameter on DUT surface depends on laser beam quality factor of OPG ($M^2 \approx 2$) and estimated to be not greater than 2 μm for 0.7…1 μm wavelength range. This estimation was obtained by measurements of laser burn marks on a special slide with thin metal layer.

In order to perform backside device visual inspection, the color CCD camera can be changed to SWIR camera with long-pass optical filter, having cut-on wavelength of 1.1 μm, which is optimal for looking through silicon substrate (to minimize losses due to interband light absorption). For other semiconductor devices (e.g. GaAs) filters with other cut-on wavelengths can be attached. When using SWIR camera, special SWIR-capable illuminator is used instead of the XLamp LED. It should be noted, that backside device irradiation and SWIR visualization require good optical quality of front surface of the substrate (sometimes, additional polishing is needed).

The three-dimensional translation stage is used to precisely move the DUT relative to the focused laser beam. Its maximum travel range in both horizontal (X and Y) directions is 100 mm, while in vertical (Z) direction travel range is 25 mm, with positioning accuracy of less than 0.2 μm. Motion control is performed by step-motor controller connected to PC via USB interface. The same PC is also used to control laser source, variable attenuator, microscope illuminator, CCD camera, as well as to perform functional tests, SEE registration and parameters measurements. Specialized PC software code is designed to:

– auto-focus the laser beam on the DUT surface and compensate its tilt during horizontal movement;

– vary the laser beam diameter on the DUT surface from microns to hundreds of microns;

– full laser source control (pulse energy, wavelength and frequency);

– perform scanning of the selected area synchronously to laser irradiation and SEE response recording;

– take DUT surface high resolution or panoramic images, etc.

III. Some Results

To illustrate the capabilities of "PICO-4", Fig. 2 presents the fragment of single event latchup (SEL) map obtained by scanning of Analog Devices ADuC841 chip with laser 30 μm beam. This procedure is typical for primary localization of most sensitive to SEL area and cross-section measurements. In Fig 2 these areas are marked as light circles.

After the sensitive area is localized, the dependence of SEL threshold energy vs. laser beam diameter is measured. As an example, Fig. 3 presents this dependence for some sensitive point of Xilinx XCV50 FPGA chip at 900 nm wavelength. Such data is further used to calculate equivalent LET values and to estimate configuration and dimensions of the selected sensitive area. It this experiment, the 900 nm wavelength was used because the irradiation of the same point of the chip at 1,064 μm does not produce SEL up to the energy of 500 nJ, corresponding to thermal breakdown of FPGA's structure.

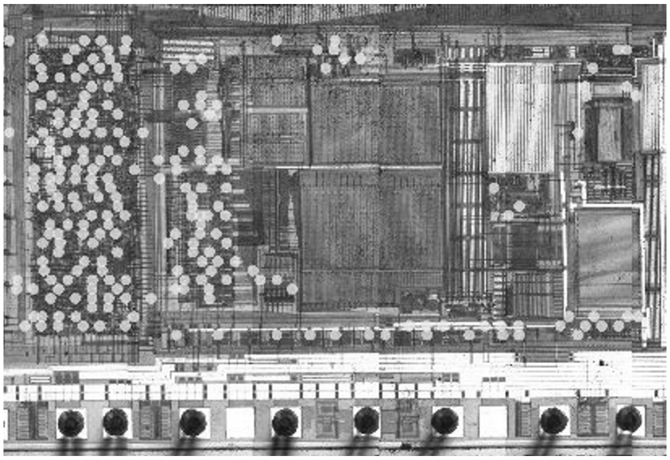


Fig. 2. Map fragment of SELs in Analog Devices ADuC841 chip. Laser pulse energy is 30 nJ, beam diameter is 30 μm.

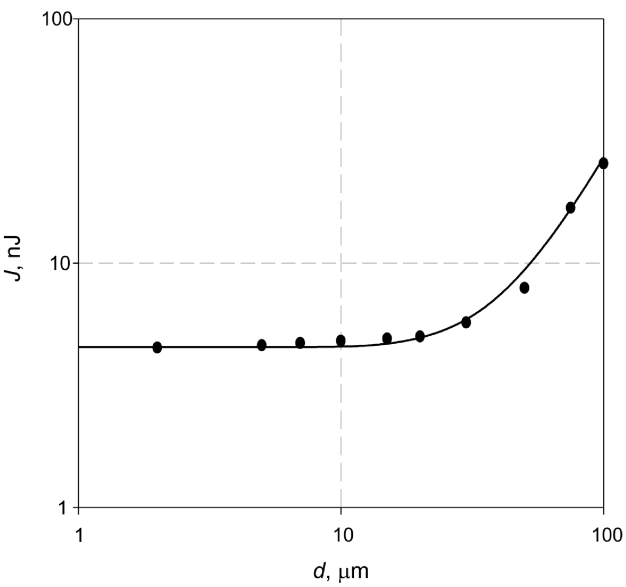
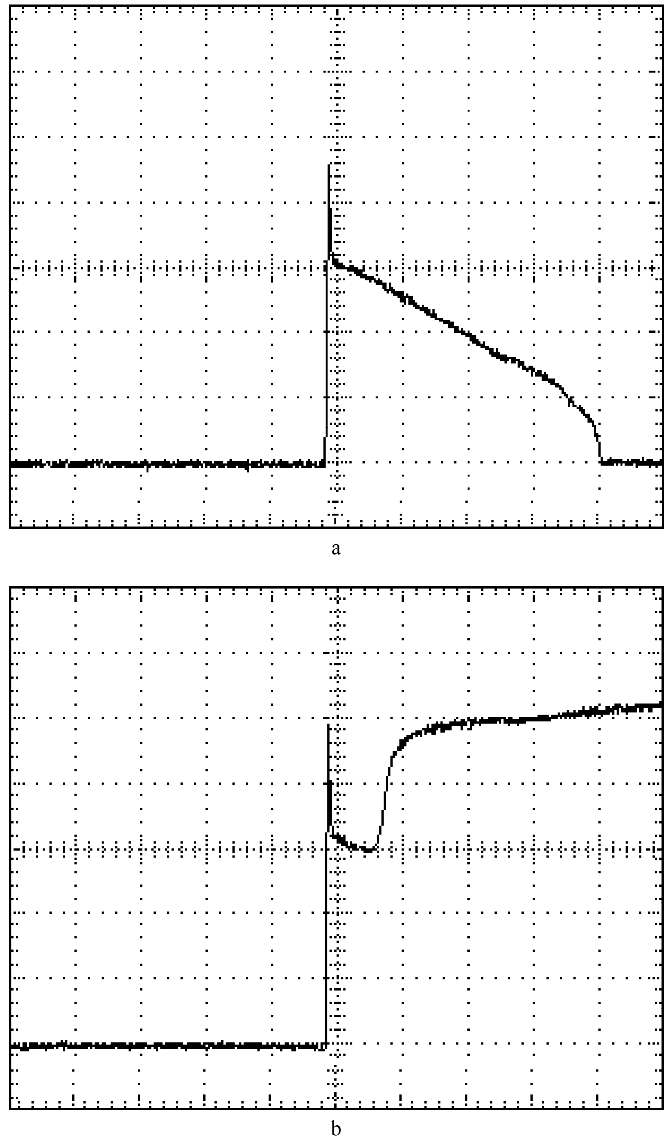


Fig. 3. The dependence of SEL threshold energy vs. the laser beam diameter at 900 nm wavelength for FPGA XCV50.



Fig, 4. Transient current records in power supply circuit of CMOS test structure in pre-latchup (a) and latchup (b) states.

The results of chip scanning can be further used for topology redesign to exclude SEL in microelectronic devices for space applications.

One more example (see Fig. 4) shows the results of SEL transient parameters measurements under focused picosecond laser irradiation. In Fig. 4a one can see pre-latchup current record in the power supply circuit of a typical CMOS structure, when the energy of laser pulse is smaller than the latchup threshold. If the laser energy is increased above the threshold, the current transient grows into a stationary latchup state (Fig. 4b). These measurements are very helpful to develop special means for IC protection from the negative effects of a single event latchup (burnout and/or catastrophic failure etc.), such as limiting of SEL current, protection of inputs or outputs that can be damaged during an SEL, providing automatic shutdown and further "re-application" of the IC power supply.

One of the main problems of laser SEE simulation technique is the optical losses due to the reflection from the metallization layers. To estimate these losses, measurement of electrical response to laser irradiation for various regions of the semiconductor device is usually performed. This technique is similar to one, when single-event transients (SET) are measured. As an example, the results of GaAs pHEMT transistor scanning with focused laser beam while registering the current pulse amplitude in the power supply circuit are presented in Fig 5. It can be seen that the maximums of SET signal correlate with the gaps between metal strips, which are the part of the transistor structure. After finding the most sensitive point of transistor, the dependence of SET amplitude vs. laser wavelength was measured.

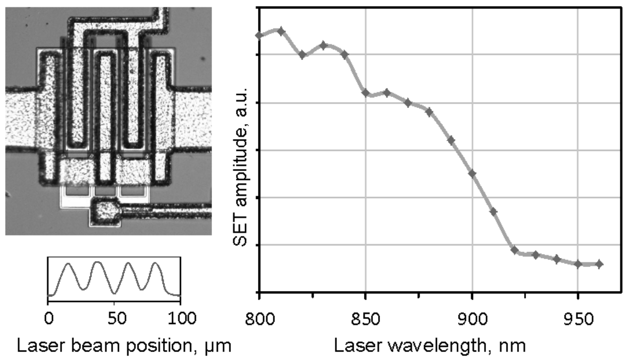
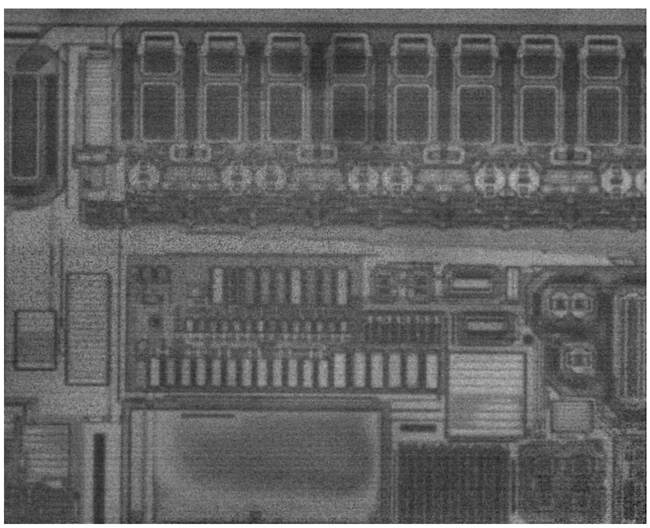


Fig 5. The results of GaAs pHEMT transistor testing with picosecond laser pulses in wavelength range.



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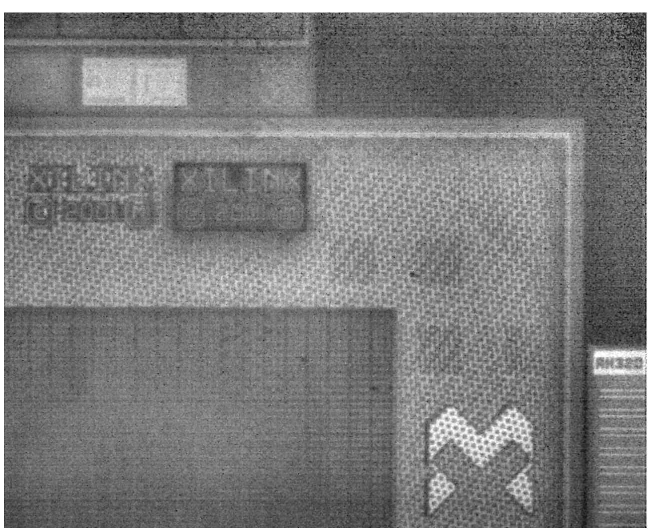

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Fig. 6. Backside SWIR image of ASC713ELCTR (a) and XC2V4000-5BF957I (b) chips.

Another very important application of the "PICO-4" facility is backside device irradiation and visualization. In Fig. 6 one can see the results of backside visualization obtained from SWIR camera. The images were taken using $20^{\times}$ objective and have 400 μm × 300 μm field of view. First one (see Fig. 6a) corresponds to ASC713 chip, which is BiCMOS linear Hall effect current sensor, manufactured on 300 μm substrate. The front side laser irradiation of this chip is impossible due to the presence of primary copper conduction path, which is used for current sampling. The second one (see Fig. 6b) presents the area with crystal mark of Xilinx XC2V4000 FPGA. It can be seen that a substrate of 600 μm (twice as thick as the ASC713) does not seriously reduce the overall quality of the image. The resolution of both images is high enough to identify various topology elements while scanning the chip and locating the most sensitive to SEE areas.

IV. Conclusions

Here we present the description of "PICO-4" SEE simulation facility, developed by NRNU MEPhI in collaboration with SPELS. The main advantage of "PICO-4" is that it utilizes focused picosecond laser pulses with tunable wavelengths in order to simulate charge tracks of ions with different LET. The charge tracks of variable length generated by tunable laser can be a very convenient and informative instrument to investigate charge collection mechanisms and characteristics of semiconductor devices.

"PICO-4" facility can be used for SEE testing and space radiation hardness evaluation of various (Si, GaAs, SiGe, etc.) devices in a fully automated manner.

V. References

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