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

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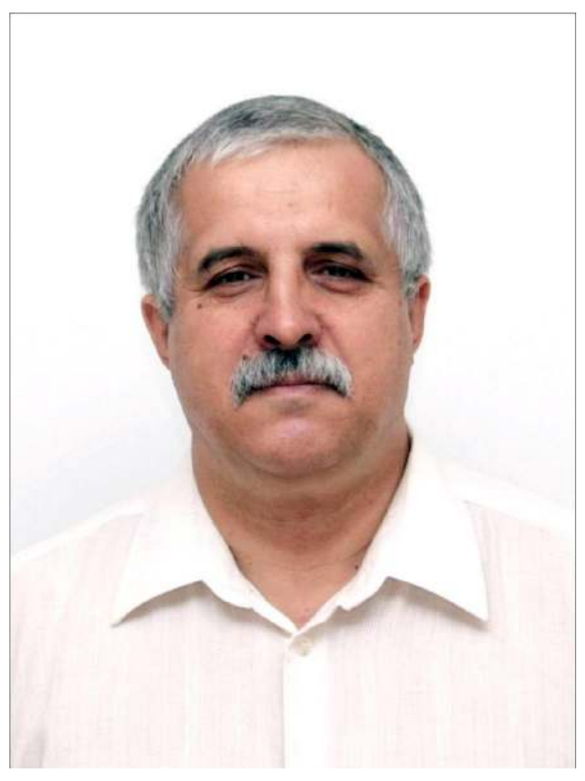

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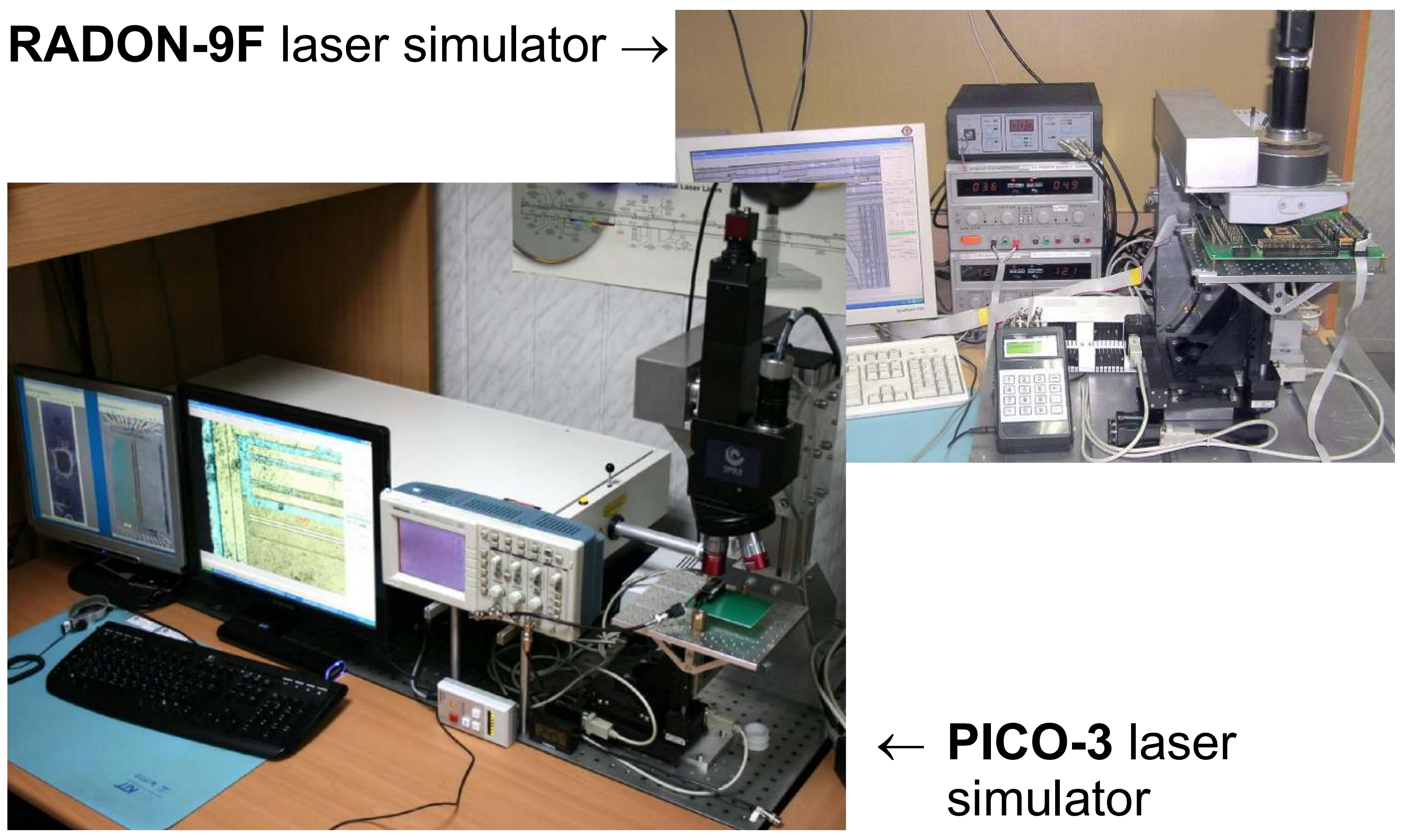
Abstract — Technical characteristics of “PICO-4” SEE simulation facility utilizing tunable picosecond laser source are presented. Its capabilities aimed on simulation of single event effects under space environment in Si, GaAs, SiGe etc. microelectronic devices are discussed.

Introduction

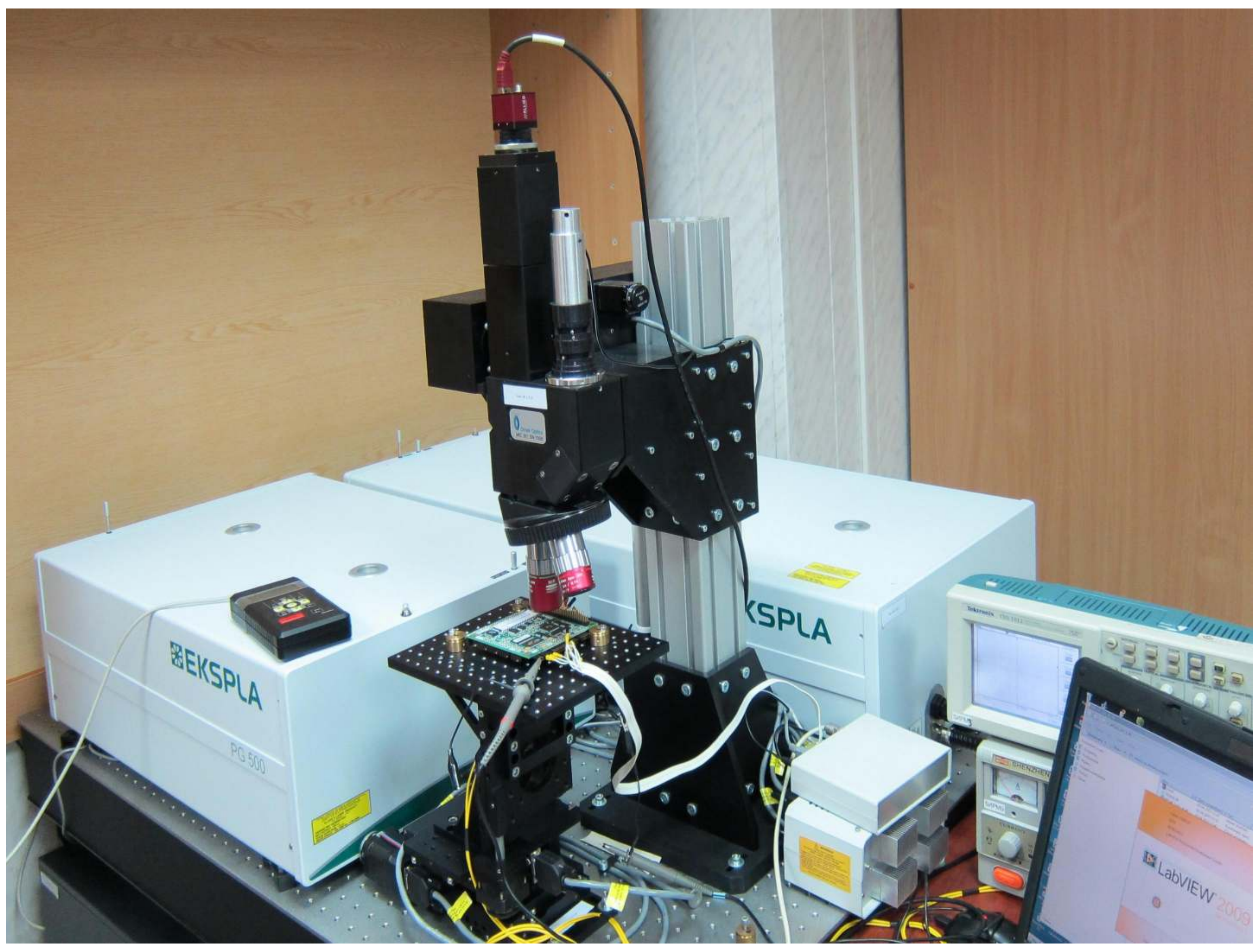


RADON-9F laser simulator →

← **PICO-3** laser simulator

Possible applications of **laser simulation facilities, developed by NRNU MEPhI and SPELS**:

- ★ Investigation of chip topology
- ★ Location of most sensitive to SEE chip areas
- ★ SEL threshold and cross-section measurements
- ★ SEU/SET effects simulation and measurements
- ★ Validating of radiation-hardening techniques
- ★ Testing of radiation hardened designs
- ★ Investigation of destructive failures in ICs due to SEL
- ★ Micromachining
- ★ More…



PICO-4 is a next step in “PICO” series laser simulators with advanced features:

- ★ Simulation of ionization tracks produced by single ions with various penetration depth by changing the wavelength of laser pulse
- ★ Simulation of SEE in various semiconductor devices (Si, GaAs etc.)
- ★ Possibility to use two-photon absorption mechanism of charge generation (by using wavelength > 1.1 μm)
- ★ Backside device irradiation and visualisation

PICO-4 General Description

Picosecond wavelength tunable laser source

Laser source consists of pump picosecond laser and optical parametric generator (OPG).

Pump laser is mode-locked Nd:YAG laser with built-in second harmonic generator, producing picosecond pulses at a kilohertz pulse repetition rate. A pulse picker option allows control of the laser pulse repetition rate and operation in single-shot mode.

Features:

★ diode pumped solid state design
★ air cooled
★ PC control via USB

Main parameters:

★ Wavelength:	0.53 µm
★ Output energy:	~ 600 µJ
★ Pulse width:	25 ps
★ Pulse frequency:	1000 Hz to single shot

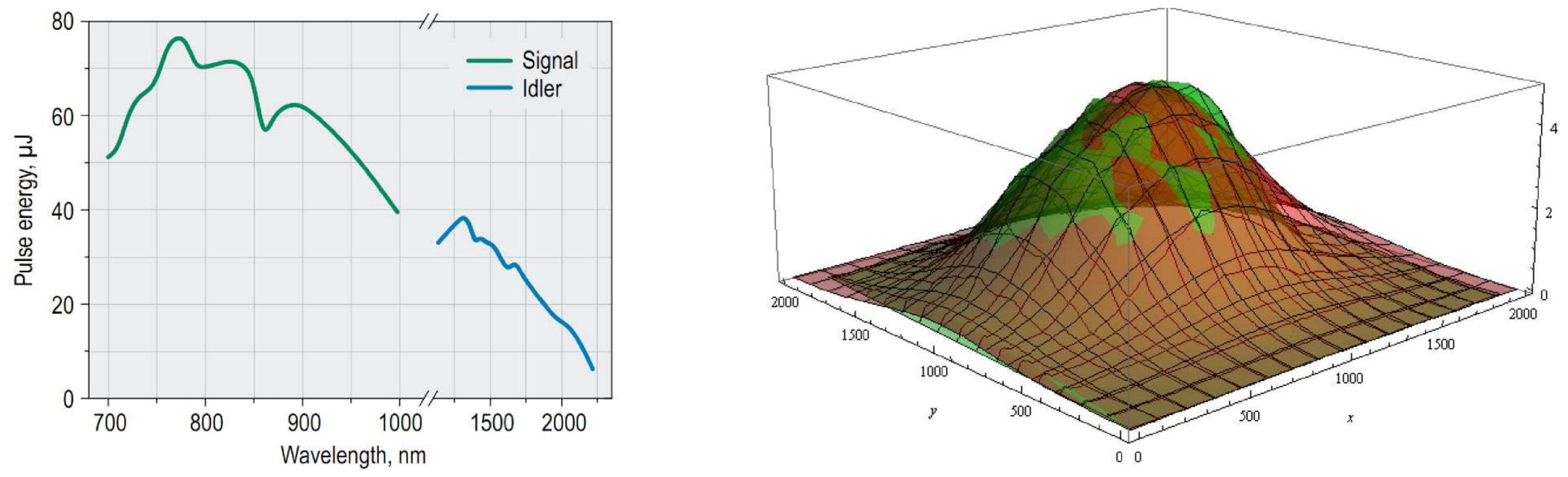
The OPG optical design is optimized to produce low divergence beams with moderate linewidth (typically 12 cm^{-1}). It is a cost-effective alternative to the narrow-band mode-locked Ti:Sapphire lasers. Nonlinear crystals, diffraction grating and filters are rotated by ultra-precise stepper motors in the microstepping mode, with excellent reproducibility.

Features:

★ compact design
★ full microprocessor control
★ optimized output beam diameter and profile
★ temperature stabilization of all parameters

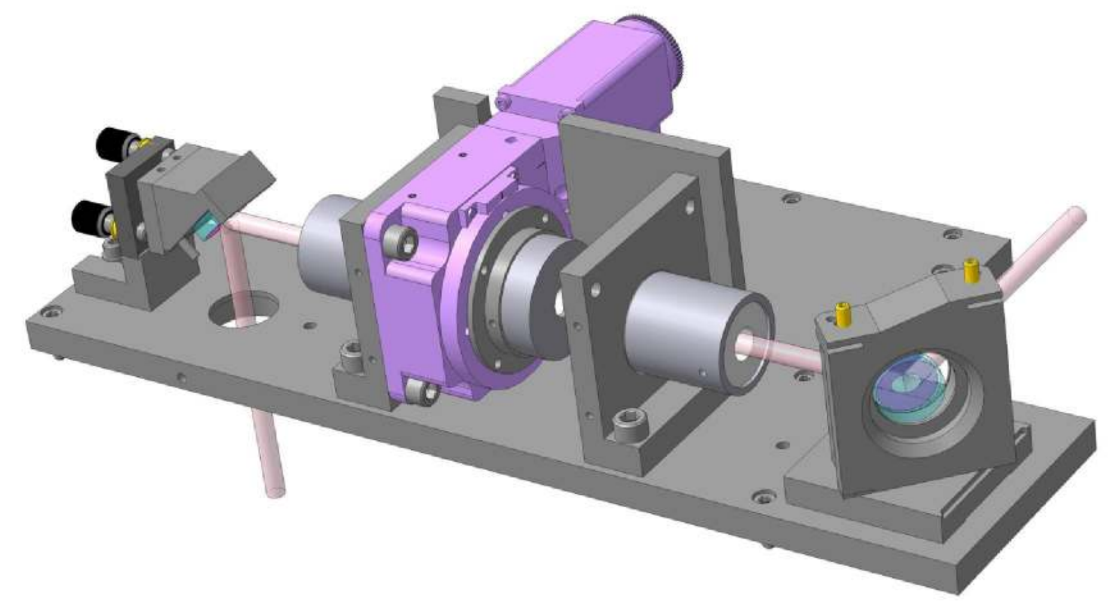
Main parameters:

★ Wavelength	0.7...1; 1.15…2.1 µm
★ Output energy	10...100 µJ
★ Pulse width	20 ps



Typical PICO-4 tuning curve (left) and output beam profile (right)

Variable attenuator



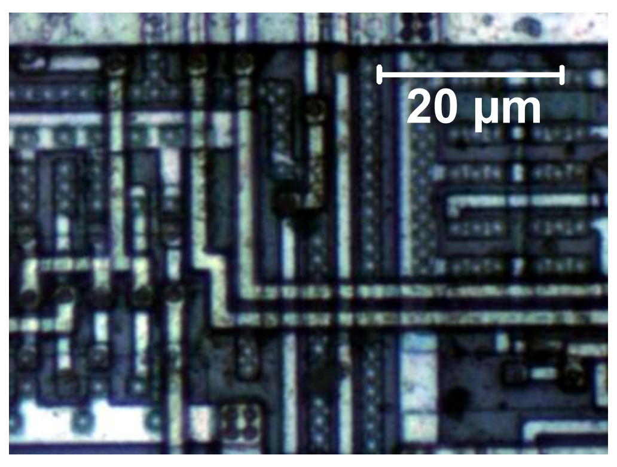
Variable attenuator is based on three polarizing prisms, one of which (middle) is mounted in the rotation stage.

Features and parameters:

★ Maximum attenuation coefficient is more than 10^5.
★ Laser pulse energy on DUT can be adjusted from tens of pJ to several µJ.
★ Attenuation coefficient is independent on wavelength used.

CCD camera

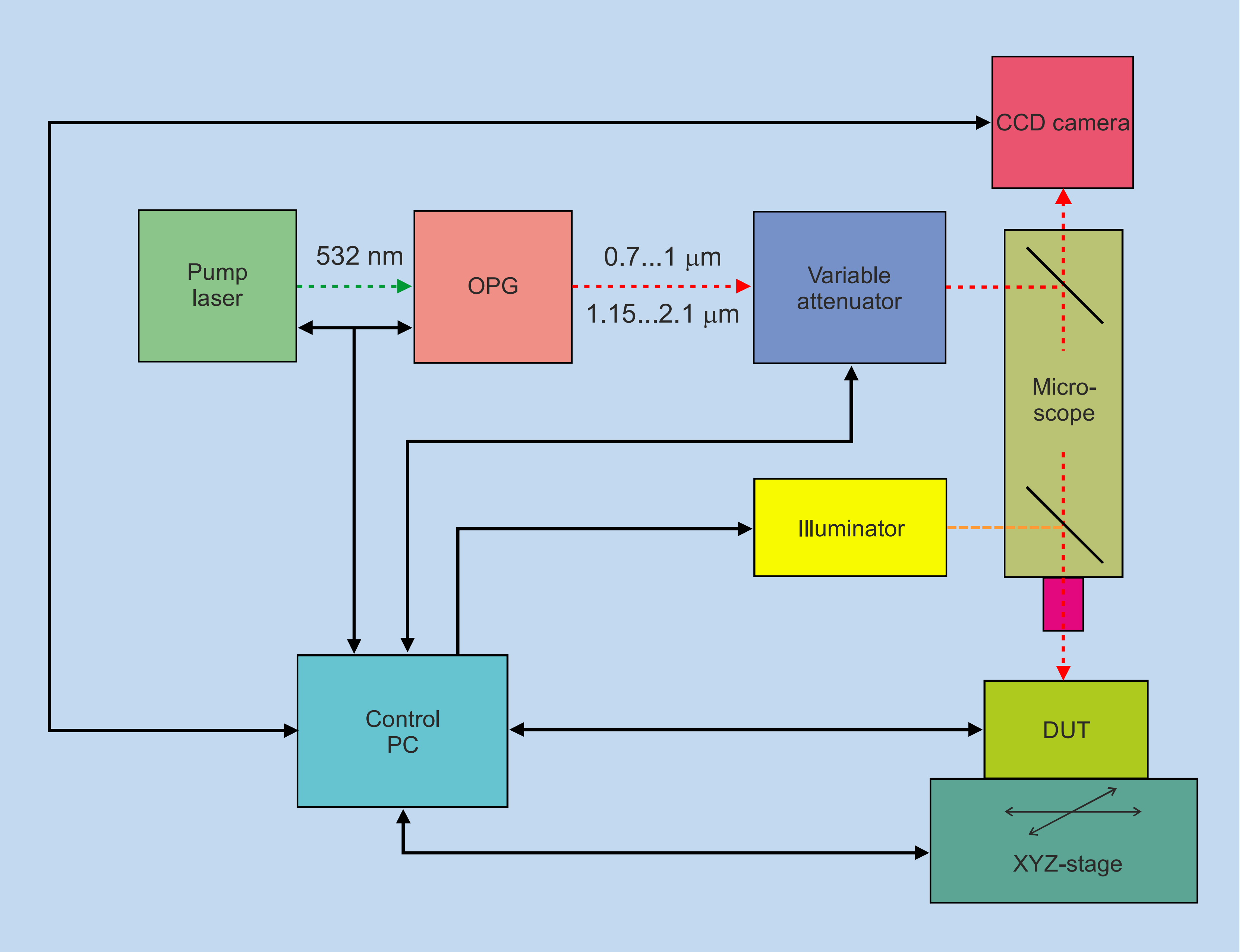
Two changeable high-resolution CCD cameras (color and SWIR) produce the images of DUT surface and helps to target focused laser beam.



100^x objective

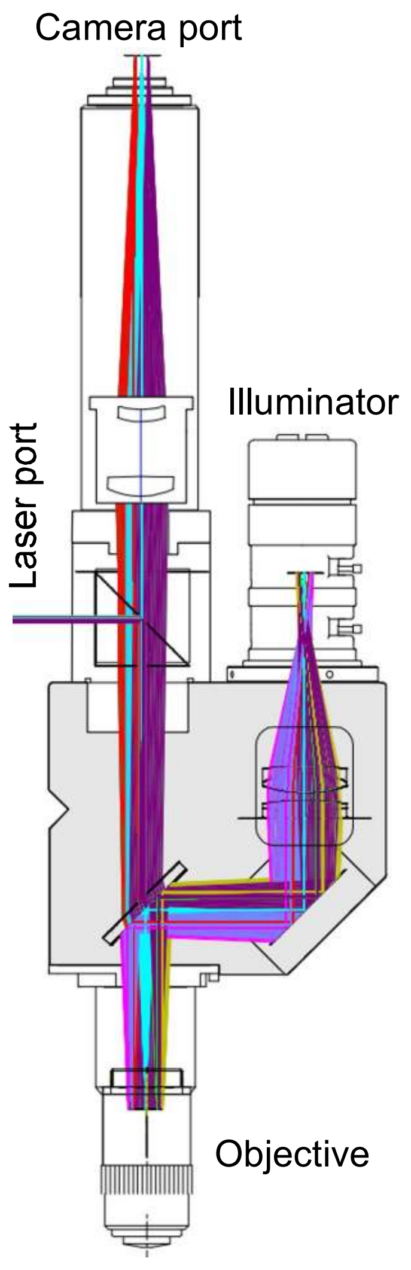
Features and parameters:

★ visible (color) spectral range for front-side visualization
★ SWIR spectral range for back-side visualization
★ FireWire IEEE1394a interface
★ 1.3 Mpixel high-resolution CCD sensor
★ up to 17 frames per second (for color CCD camera)
★ Special cut-off filters to protect CCD camera from burnout by reflected laser beam



General block scheme of “PICO-4” SEE laser simulator

Microscope and Illumination system



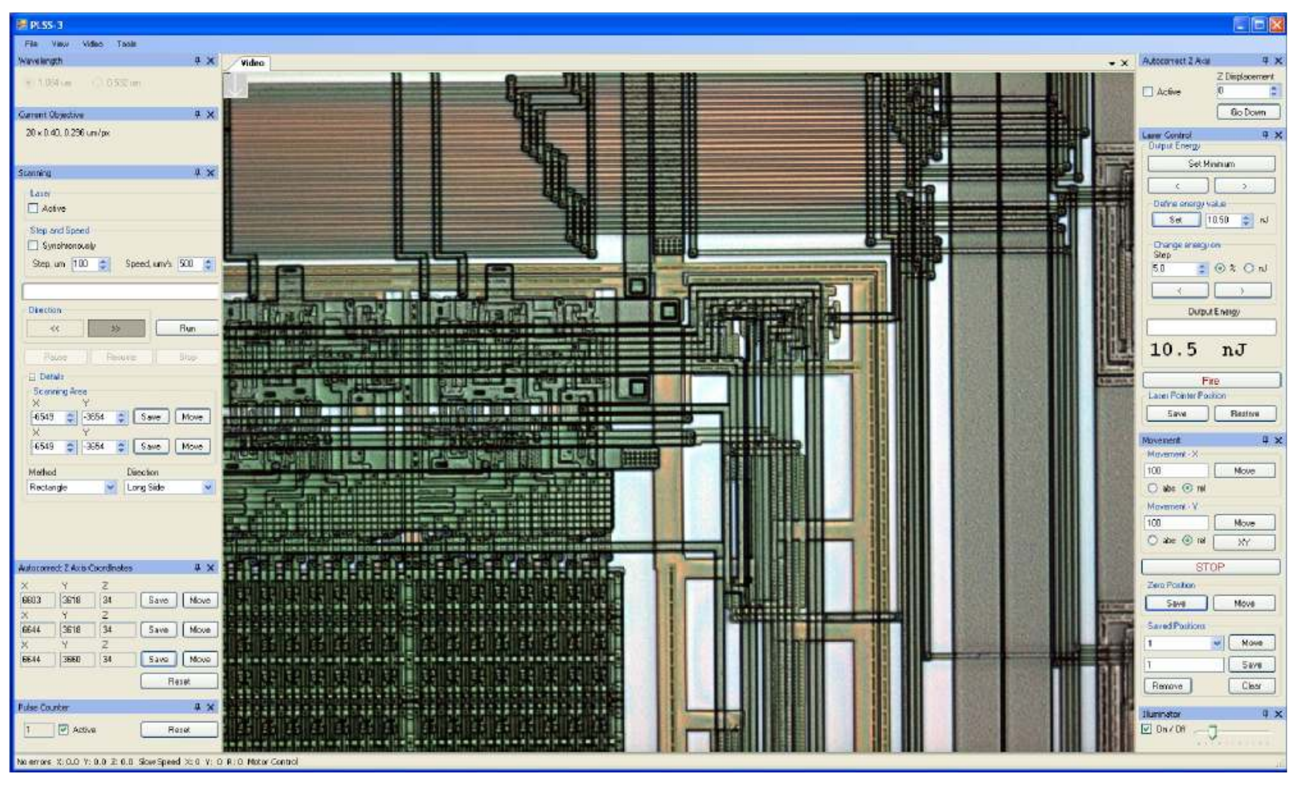
High-resolution optical microscope is equipped with input laser port, shadowless telecentric illuminator and a set of large working distance Mitutoyo infinity corrected NIR objectives.

The typical scale of obtained images is about 60 nm/pixel with 20× objective, though the optical resolution of the microscope in 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 mark on special slide with thin metal layer.

In order to perform backside device visual inspection, 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.

Control PC with spesialized software



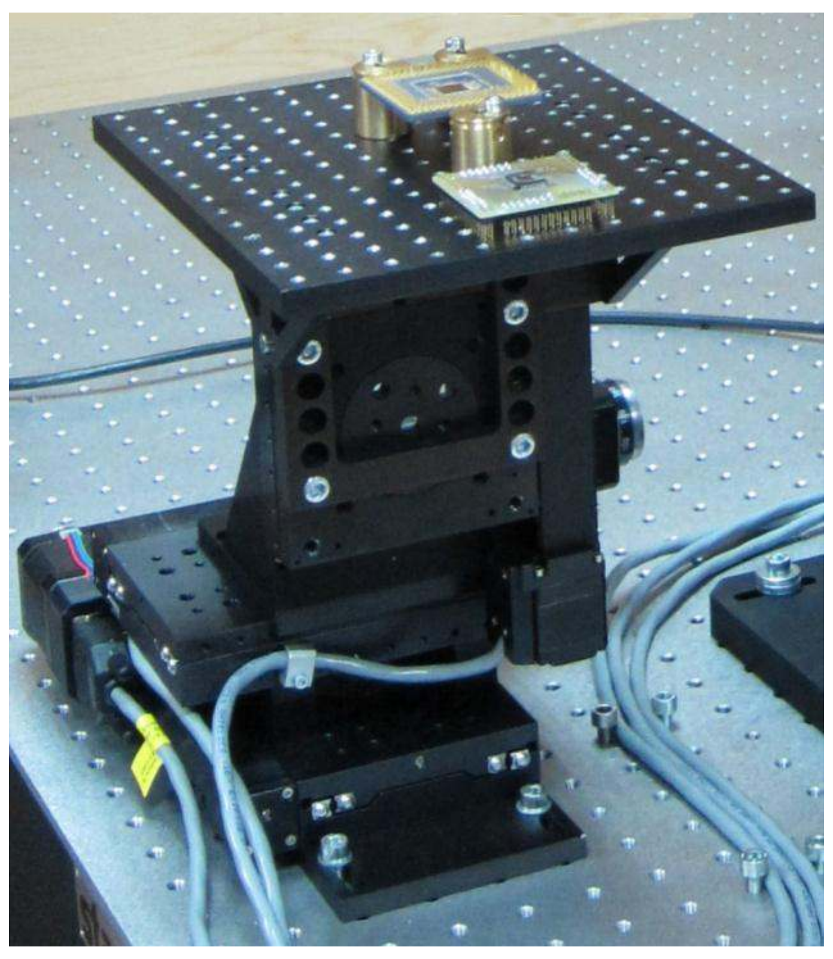
Control application main window

The PC is used to control laser source, variable attenuator, XYZ translation stage, microscope illuminator, CCD camera, as well as to perform functional tests and SEE registration and parameters measurements.

Specialized PC software code is designed to:

★ autofocus laser beam on DUT surface and compensate tilt during horizontal movement;
★ vary laser beam diameter on DUT surface from microns to hundreds of microns;
★ full laser source control (pulse energy, wavelength and frequency);
★ perform scanning of selected area synchronously to laser irradiation and SEE response recording;
★ take DUT surface high resolution or panoramic images, etc.

XYZ translation stage



Three-dimensional XYZ translation stage is used to precisely move DUT relatively to 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.

Experimental results

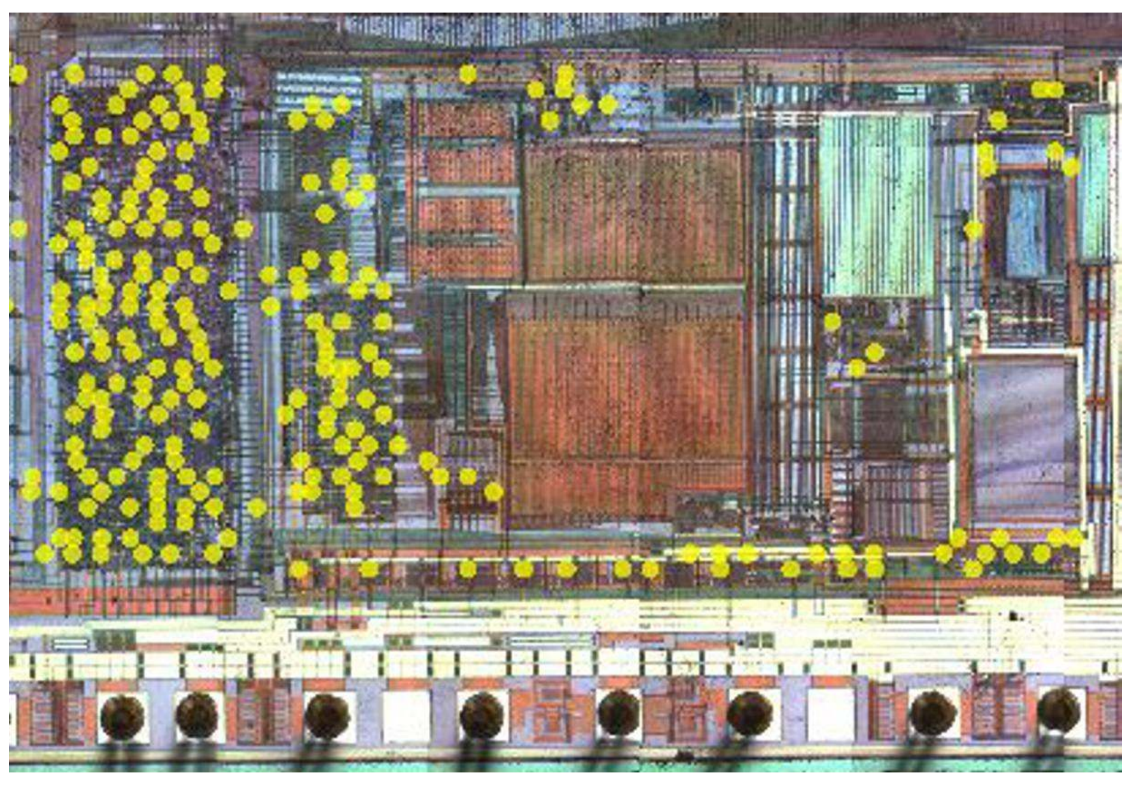
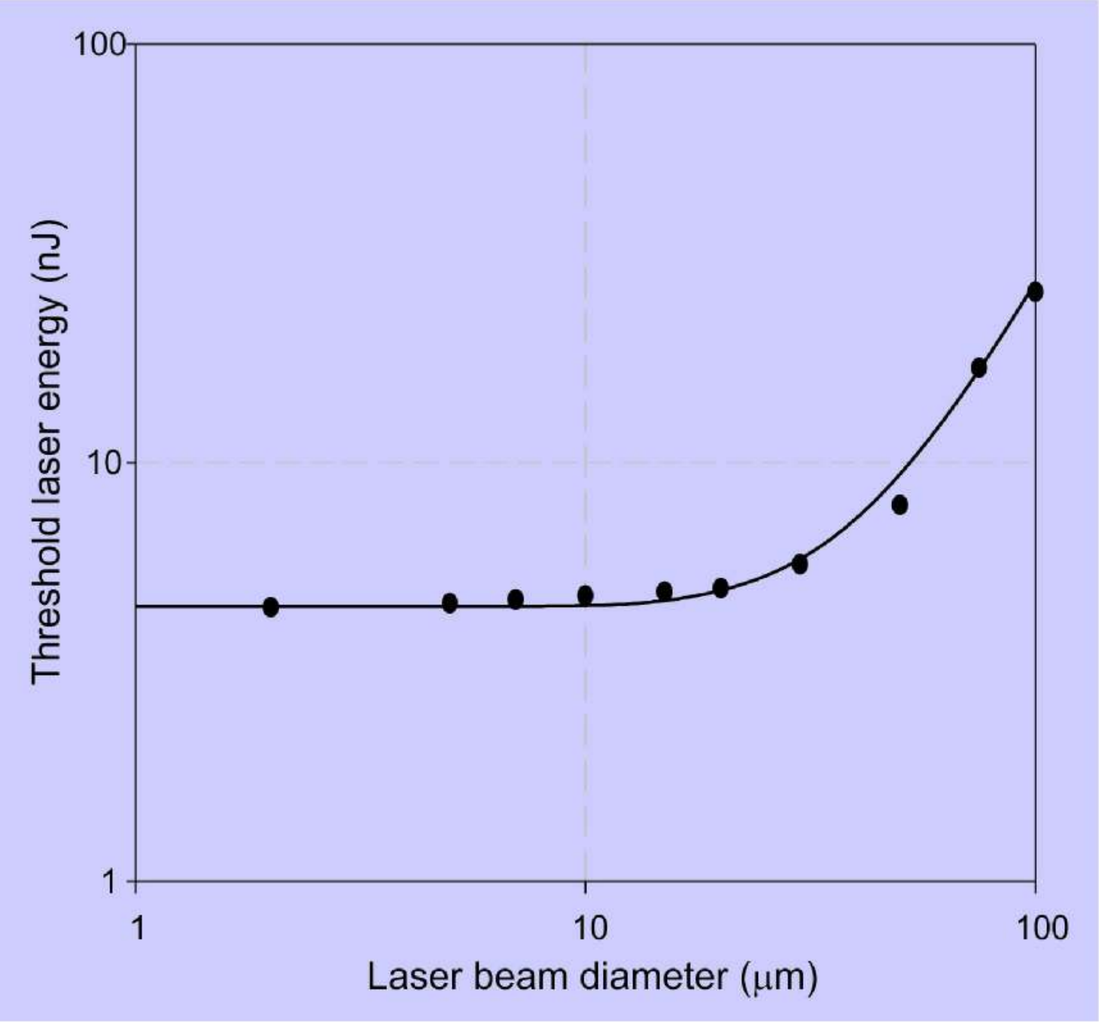
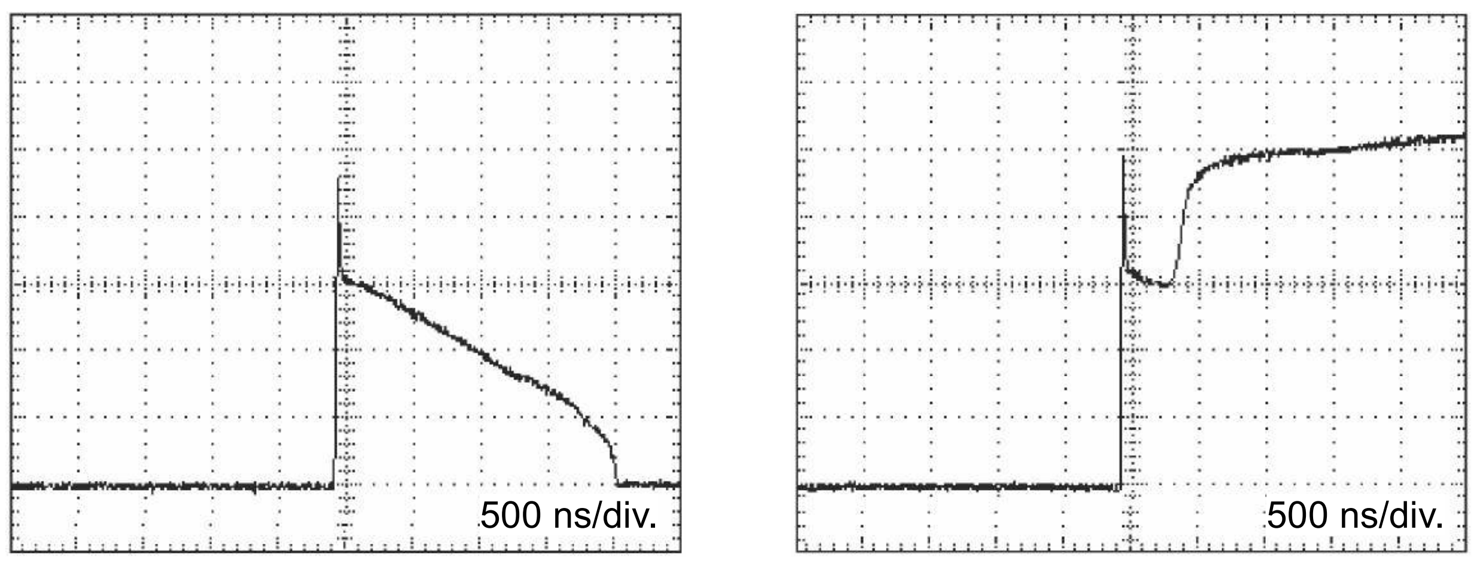


Figure presents the fragment of **single event latchup (SEL) map** obtained by scanning of Analog Devices ADuC841 chip with 30 µm laser beam. This procedure is typical for primary most sensitive to SEL area localization and cross-section measurements. In the Figure these areas are marked as yellow circles.

After the sensitive area is localized, **the dependence of SEL threshold energy vs. laser beam diameter** is measured. As an example, Figure to the right presents this dependence for some sensitive point of Xilinx XCV50 FPGA chip at 0.9 µm wavelength. Such data is further used to calculate equivalent LET values and to estimate dimensions of selected sensitive area. It this experiment, the 0.9 µm 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, that is close to thermal breakdown of FPGA's structure.

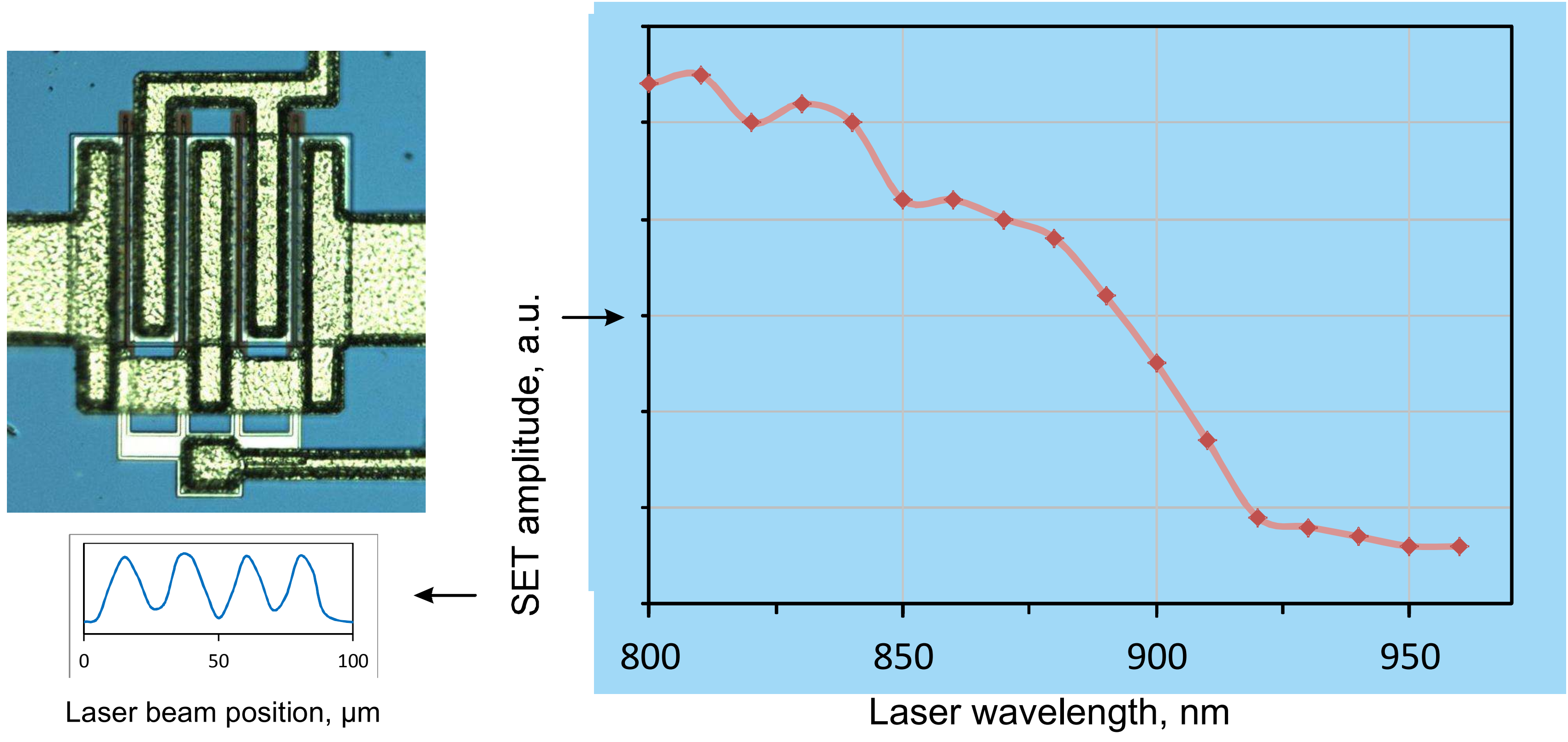
The results of chip scanning can be further used for topology redesign to exclude SEL in microelectronic devices for space applications.



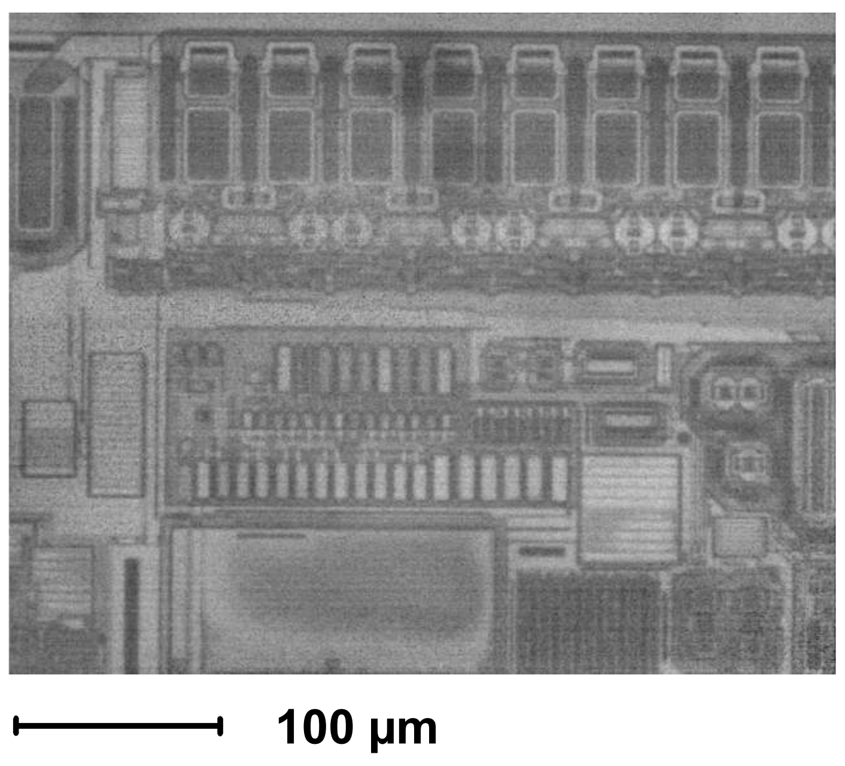


One more example (see Figure above) shows the results of **SEL transient parameters measurements** under focused picosecond laser irradiation. First oscillogram presents the pre-latchup current record in power supply circuit of in typical CMOS structure, when the energy of laser pulse is smaller than latchup threshold. If the laser energy is increased above the threshold, current transient grows into stationary latchup state (see the second oscillogram). These measurements are very helpful to develop special means for IC protection from the negative effects of a SEL (burnout and/or catastrophic failure etc.).

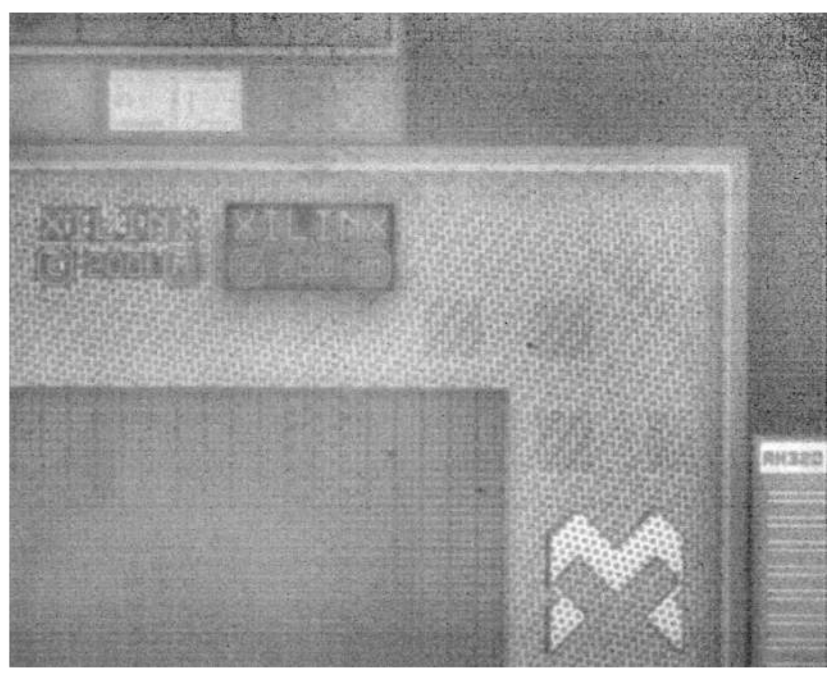
The results of scanning of GaAs pHEMT transistor with focused laser beam while registering the current pulse amplitude in the power supply circuit are presented below. This technique is similar to one, when **single-event transients (SET)** are measured. After finding the most sensitive point of transistor, the dependence of SET amplitude vs. laser wavelength was measured.



ASC713 chip, 300 µm substrate



XC2V4000 chip, 600 µm substrate



Another very important application of "PICO-4" facility is **backside device irradiation and visualization**. In the Figure one can see the results of backside visualization obtained from SWIR camera. The images were taken using 20× objective and have 400 µm × 300 µm field of view. First one 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 presents the area with crystal mark of Xilinx XC2V4000 FPGA. It can be seen, that twice thicker substrate of this chip (600 µm), as compared to 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.

Conclusion

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 wavelength in order to simulate charge tracks of ions with various penetration depth. The charge tracks of variable length generated by tunable laser can be very convenient and informative instrument to investigate charge collection mechanisms and characteristics in wide range 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 fully automated manner.

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