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Laser Technique for the Investigation of Single Event Effects in Integrated Circuits

National Research Nuclear University MEPhI
Specialized electronic systems
Moscow, Russia

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Presentation outline

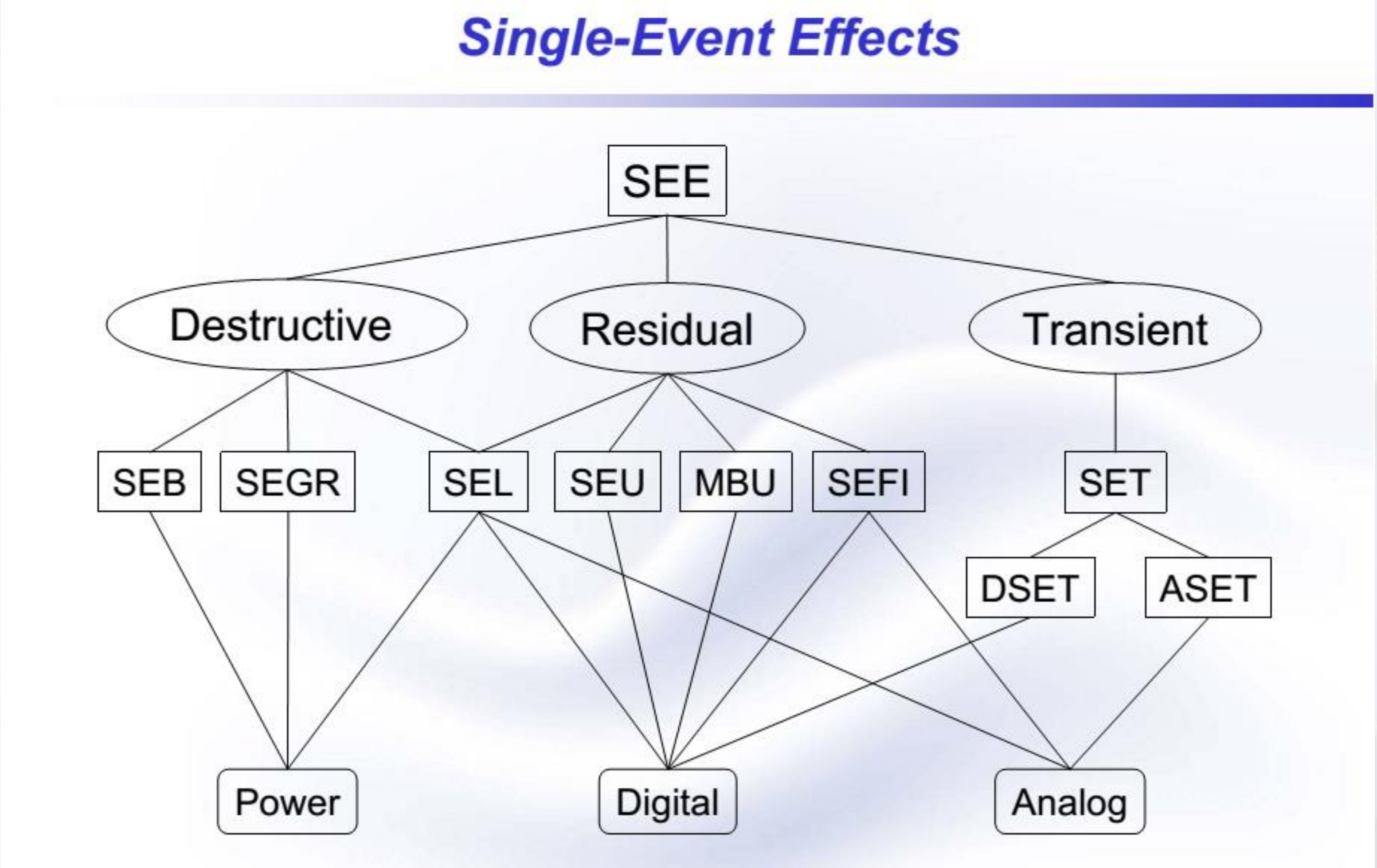
- Single event effects (SEE) in integrated circuits (IC)
- SEE test techniques
- Laser single event effects (SEE) tests
- Laser SEE investigations
- Laser SEE tests in NRNU MEPhI / SPELS
- Future trends
- Conclusion

Introduction

- A large part of malfunctions in spacecraft electronics is caused by upsets in the memory chips, control registers and cache-memory of microprocessors, FPGA configuration memory, etc.

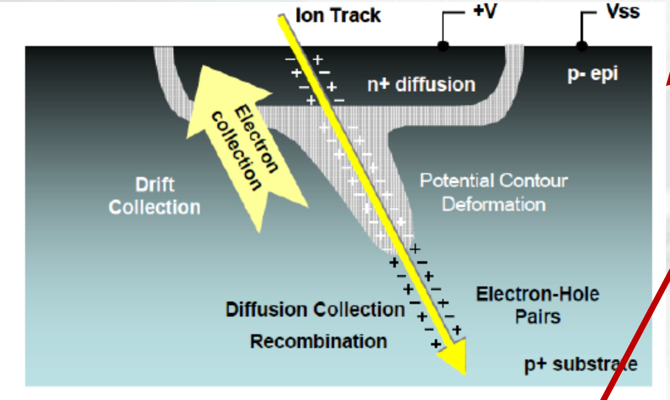
- A noticeable part of loss operability of spacecraft electronics is caused by Latch-up effect in CMOS ICs, as well as failures of power MOSFETs

Classification of SEE

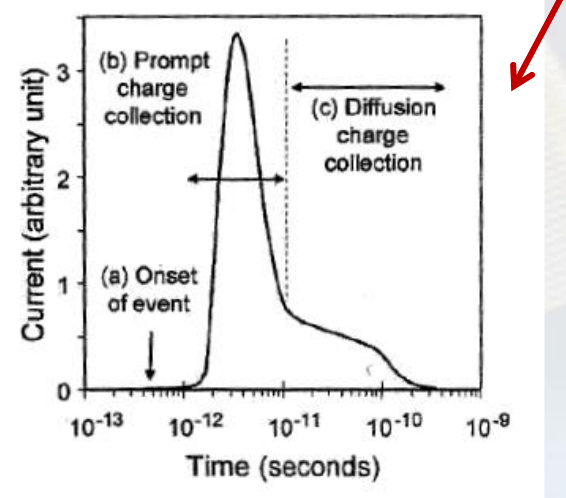


V. Pouget. Fundamentals and recent developments for SEE laser testing at the IMS laboratory. RALDFAY'07

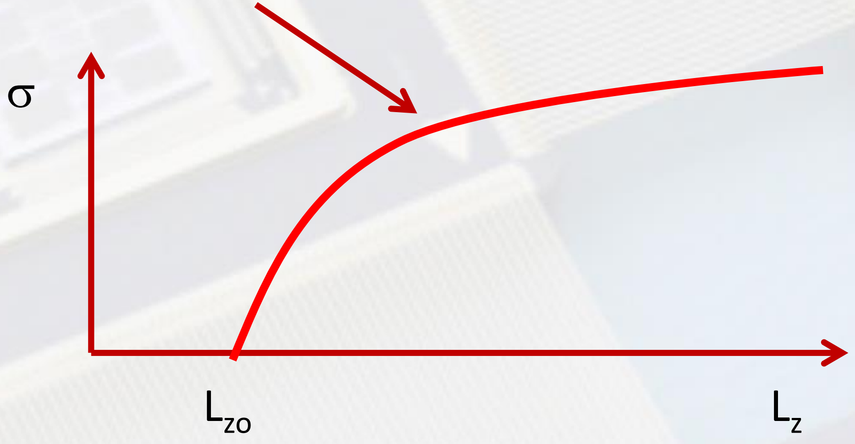
Single Event Effects in IC



From R. Baumann, 2005 IEEE NSREC Short Course, section II



- Generation of electron-hole pairs by ion
- Charge collection by drift and diffusion processes
- Current pulse on IC`s elements nodes
- Single Event Effect



Dependence of SEE cross section on Linear Transfer Energy (LET)

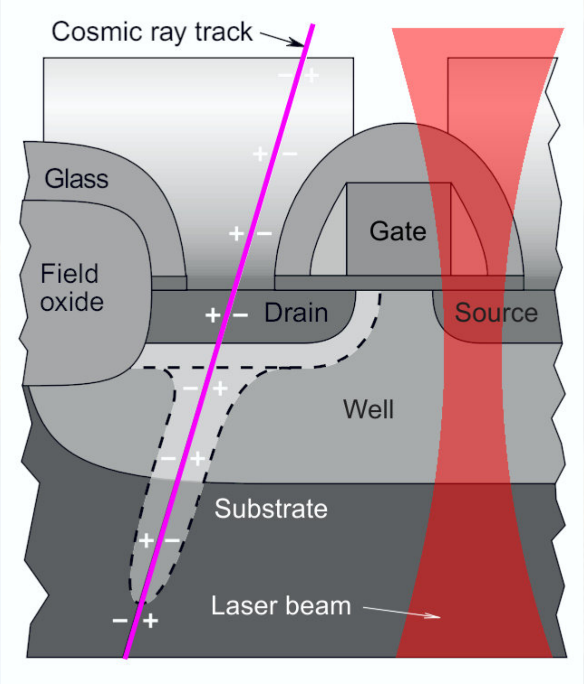
$\sigma = N_{SEE}/\Phi_z$, σ - number of SEE, Φ_z– ion fluence.

Standard Test Methods

- Heavy ions accelerators
- Proton accelerators
- Isotope sources
- Focused laser facilities

In Russia laser techniques are officially allowed to be used for ICs radiation tests

SEE Induced by Laser Beam



SEEs can be simulated by focused ultra-short pulsed laser beam

Advantages:

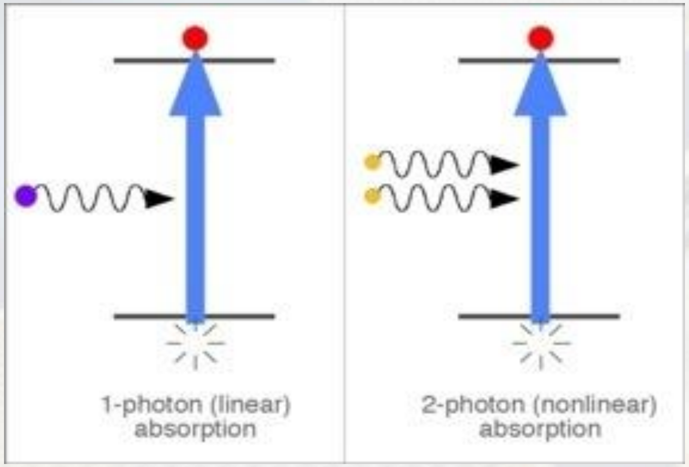
- Lower price
- Easy to implement
- Testing of separate IC elements

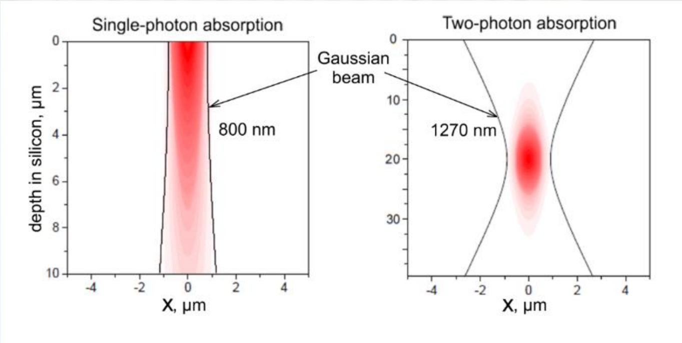
Disadvantages:

- Can’t pass through metal layers
- Does not ionize dielectric layers
- Can’t be focused to nano-sized spot

A. Egorov, A. Chumakov et al. Laser Technique for the Investigation of Single Event Effects in Integrated Circuits. ©NRNU MEPhI – SPELS 2016

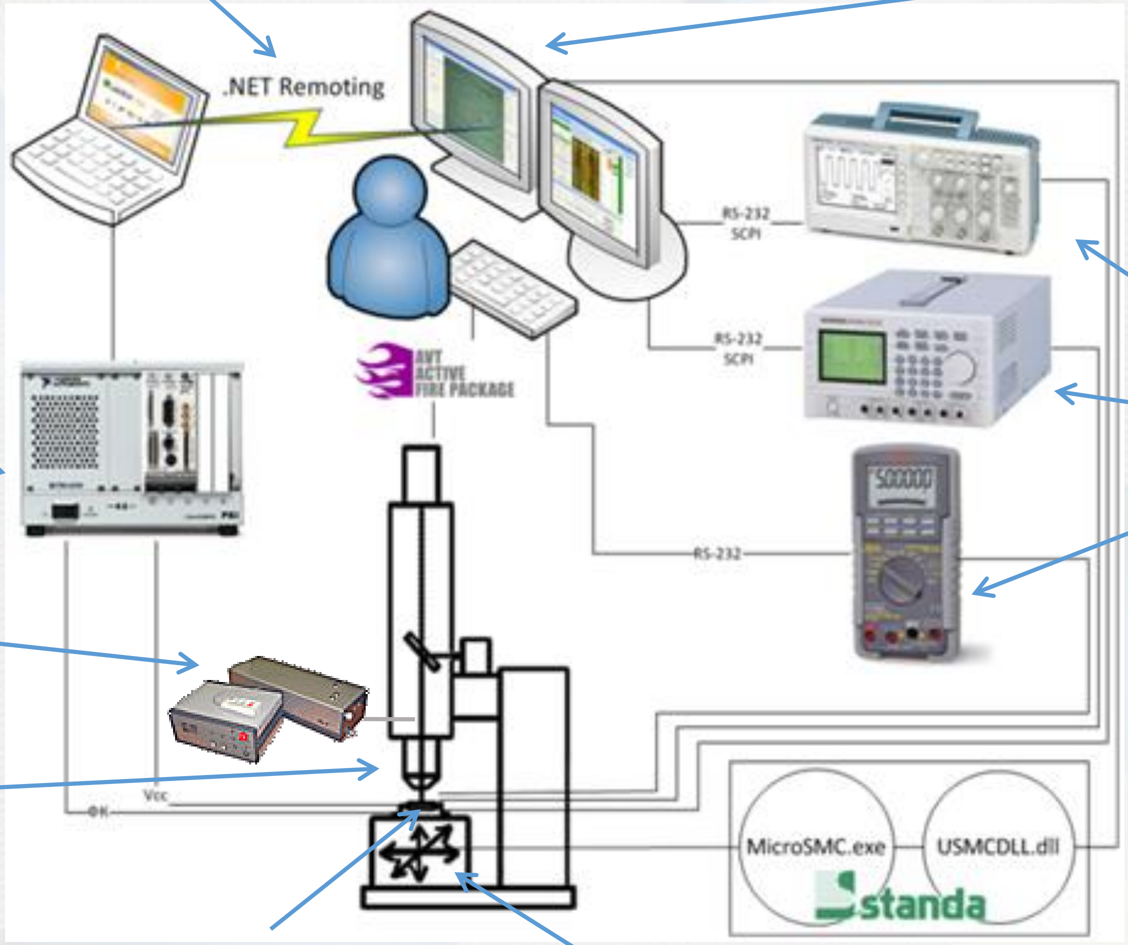
SEE Laser Tests Principles





1. Laser can produce almost all types of SEEs.
2. Two main mechanisms of charge generation:
   – **single photon absorption**;
   – *two photon absorption*.
3. Spatial distributions of generated charge by laser and ions differ, but the electrical effects are practically the same.

Typical Focused Laser Facility



LAN connection

PC with control and automation software

Functional test equipment and software

Power Supply and parameter test equipment

Laser source

Focusing unit

Device under test (DUT)

Positioning unit

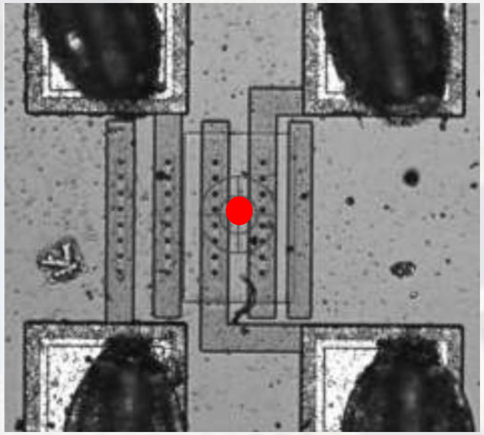
O.V. Mavritskii, A.I. Chumakov, A.N. Egorov, A.A. Pechenkin, A.Yu. Nikiforov, Pribory i Tekhnika Eksperimenta, 2016, No. 5, pp. 5–29.

The Role and Place of Laser Technique in SEE Research and Testing

- Debugging of testing procedures and equipment;
- Ion and laser SEE cross section curves correlation;
- Testing of flip chip ICs;
- SEE sensitive nodes mapping;
- Volt-Ampere characterization of parasitic p-n-p-n structures;
- SEL "Survival" test of ICs;
- Performance check of SEE protection systems;
- SEE test at different temperatures, electric modes, etc.

A. Egorov. A. Chumakov, O. Mavritskii, A. Pechenkin, D. Savchenkov, A. Novikov The Current State and Perspectives of Laser Radiation Hardness Investigation and Testing Techniques in Russia/Radiation Tests Workhop, Sevilia, 2016

Simple Devices



Micron-sized technology
One or two metal layers

Focused laser
approach can be used

Relation between equivalent LET and laser pulse energy J_l

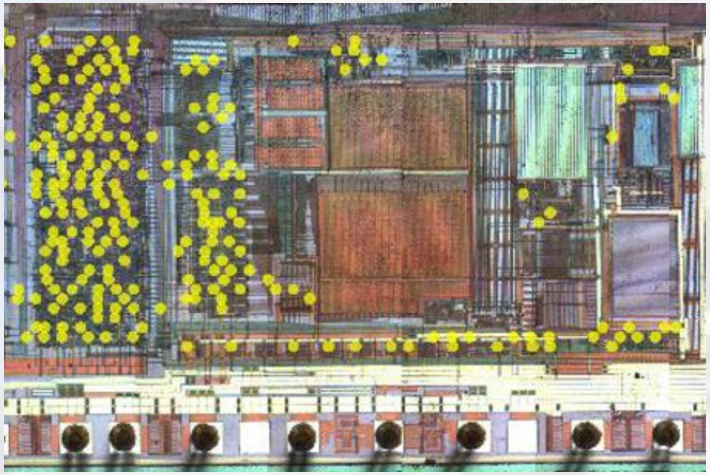
$$LET \sim 1.8 \cdot 10^4 \cdot \alpha_0 \cdot J_l \cdot \lambda \cdot (1 - R_\lambda)/\rho$$

Assumptions:

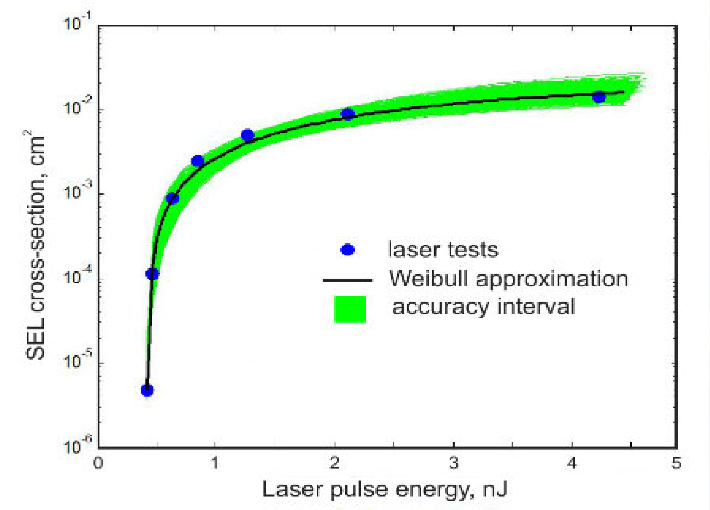
- Laser intensity does not change along the charge collection length
- Very short laser pulse duration

Chumakov A.I. Interrelation of equivalent values for linear energy transfer of heavy charged particles and the energy of focused laser radiation / Russian Microelectronics, 2011, 40 (3), pp. 149-155

Complex ICs



SEL map



Nano-sized technology
Multiple metal layers

↓

Large and non-uniform
optical losses

↓

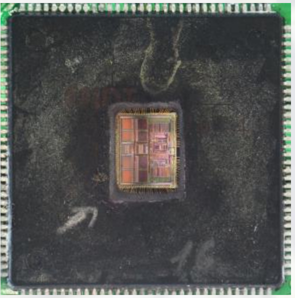
Scanning the whole chip with
laser beam (Weibull curve)

Joint use of laser and heavy ion tests is required to determine laser pulse energy vs. LET correlation

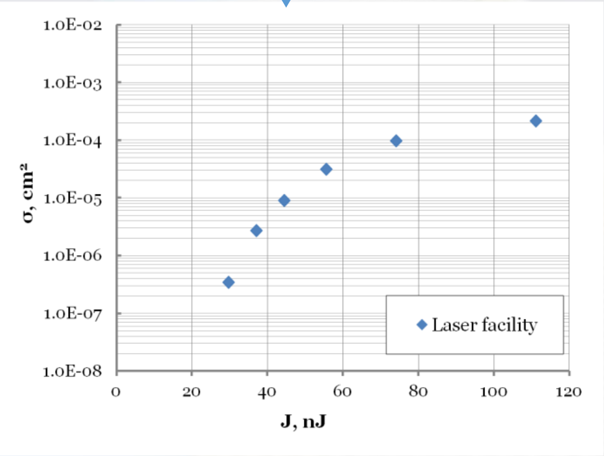
Chumakov A.I., Pechenkin A.A., Savchenkov D.V., et al/ Compendium of SEE comparative results under ion and laser irradiation. Proceedings of RADECS-2013

Joint Use of Heavy Ion and Laser Facilities

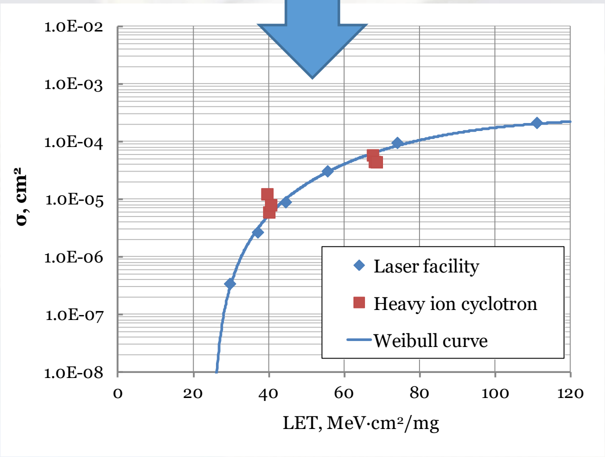
Focused laser irradiation

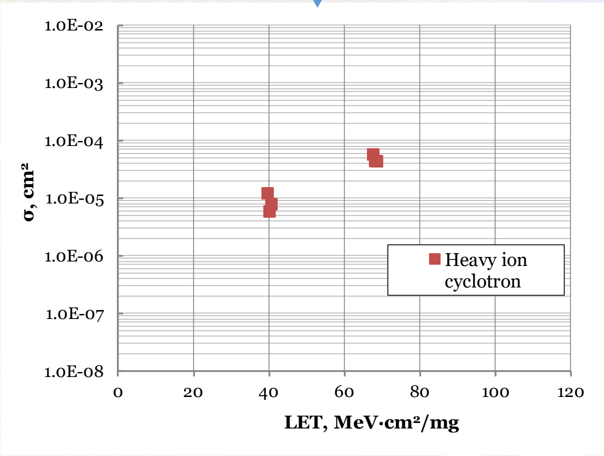


Heavy ions irradiation



$$LET_{ie} = K_j \cdot J$$

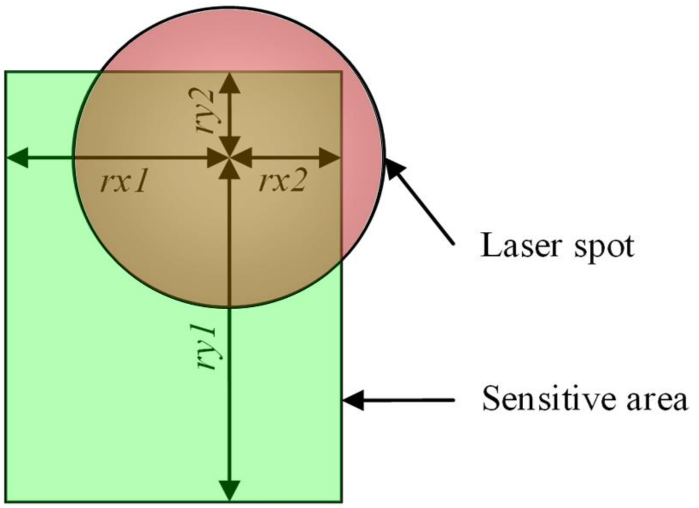


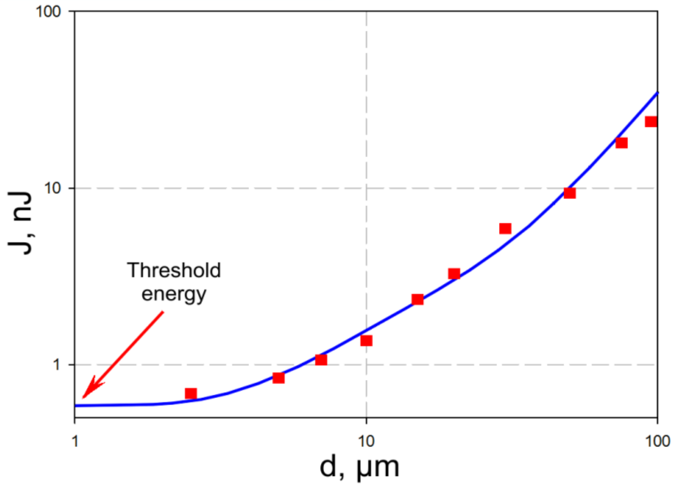


$$\sigma_{ie} = K_{\sigma} \cdot \sigma_l(J)$$

Joint use of heavy ions and laser facilities for single event effects testing. A. Chumakov et al. The Second International Conference on Radiation and Dosimetry in Various Fields of Research. 2014. Nis. Serbia.

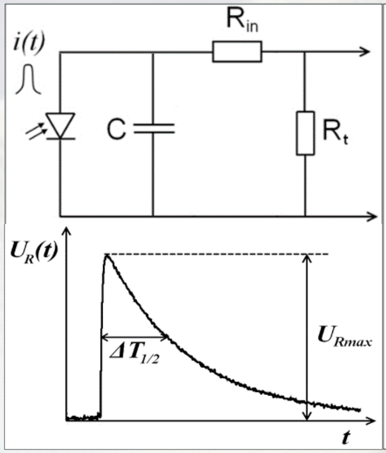
Local Laser Technique





1. SEE sensitive region localization by scanning of all chip surface
2. Determination of the asymptotic value of the focused laser energy
3. The estimation of the optical losses coefficient

Chumakov A.I. et. al. Local Laser Irradiation Technique for SEE Testing of ICs / Proc. Of RADECS, 2011, pp. 449 – 453.



$$L_{z0} = \alpha_0 (1 - R_\lambda) \frac{J_0}{K_m} \frac{\varepsilon_i}{h\nu} \frac{1}{\rho} = K_l \cdot J_0$$

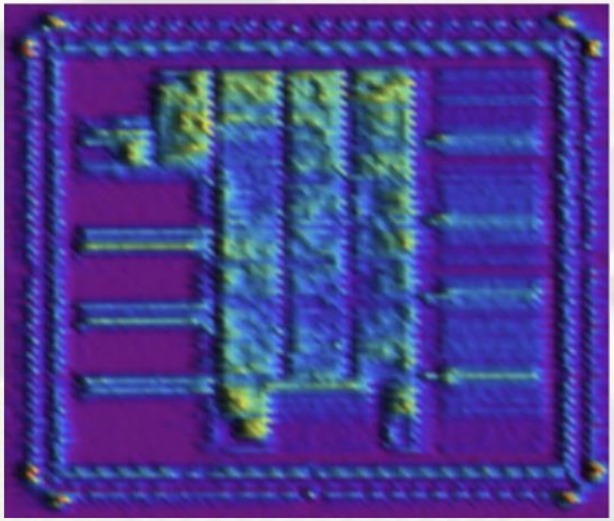
+

$$U_{R\_max} = q \cdot \alpha_0 \cdot g_0 (1 - R_\lambda) \frac{\varepsilon_i}{h\nu} \cdot \frac{1}{\rho} \cdot \frac{1}{C} \frac{J_u}{K_m} L_{e\_max}$$

↓

$$L_{z0} = \frac{1}{q \cdot g_0} \frac{J_0}{J_u} \frac{C \cdot U_{R\_max}}{L_{e\_max}}$$

Local Laser Technique (cont.)



$$L_{z0} = \alpha_0(1 - R_\lambda)\frac{J_0}{K_m}\frac{\varepsilon_i}{h\nu}\frac{1}{\rho} = K_l \cdot J_0$$

$$+$$

$$U_{R\_max} = q \cdot \alpha_0 \cdot g_0(1 - R_\lambda)\frac{\varepsilon_i}{h\nu} \cdot \frac{1}{\rho} \cdot \frac{1}{C}\frac{J_u}{K_m}L_{e\_max}$$

$$\downarrow$$

$$L_{z0} = \frac{1}{q \cdot g_0}\frac{J_0}{J_u}\frac{C \cdot U_{R\_max}}{L_{e\_max}}$$

Main problems:

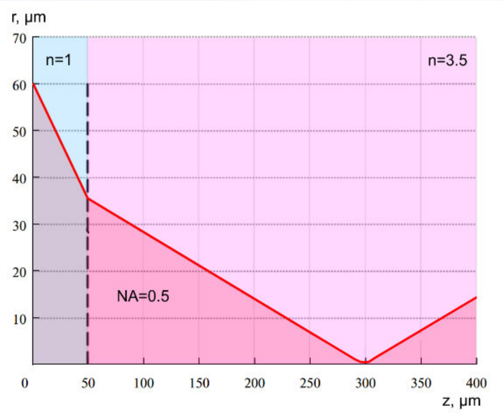
- uncertainty of some IC technology parameters;
- significant optical losses when irradiating from the active layers;
- too much difference in optical losses for various parts of IC.

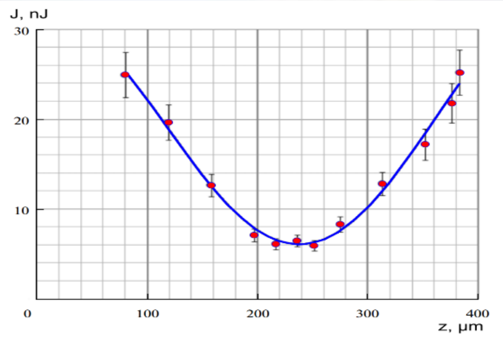
Possible solutions:

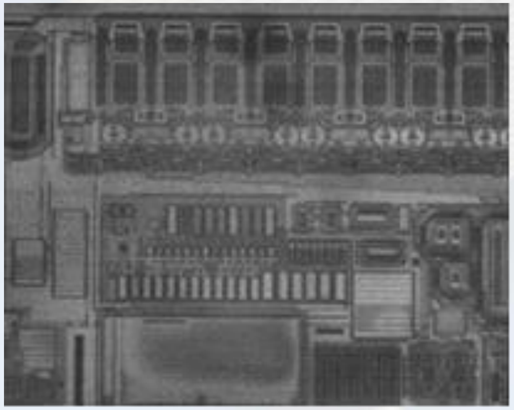
- joint use of laser and pulsed X-ray facilities;
- creating the electrical response map over the whole IC crystal for further results correction;
- using backside irradiation (see next slide).

Chumakov A. I., Vasil'ev A. L., Pechenkin A. A., Savchenkov D. V., Tararaksin A. S., Yanenko A. V. Single-event-effect sensitivity characterization of LSI circuits with a laser-based and a pulsed gamma-ray testing facilities used in combination / Russian Microelectronics, vol. 41, no. 4, 2012, pp. 221-225.

Backside Irradiation







Used when multiple metal layers cover the active layers:

- 1064 nm laser radiation is used for silicon devices;
- both focused and local laser techniques are applicable;
- the change of incident laser beam divergence needs to be taken into account.

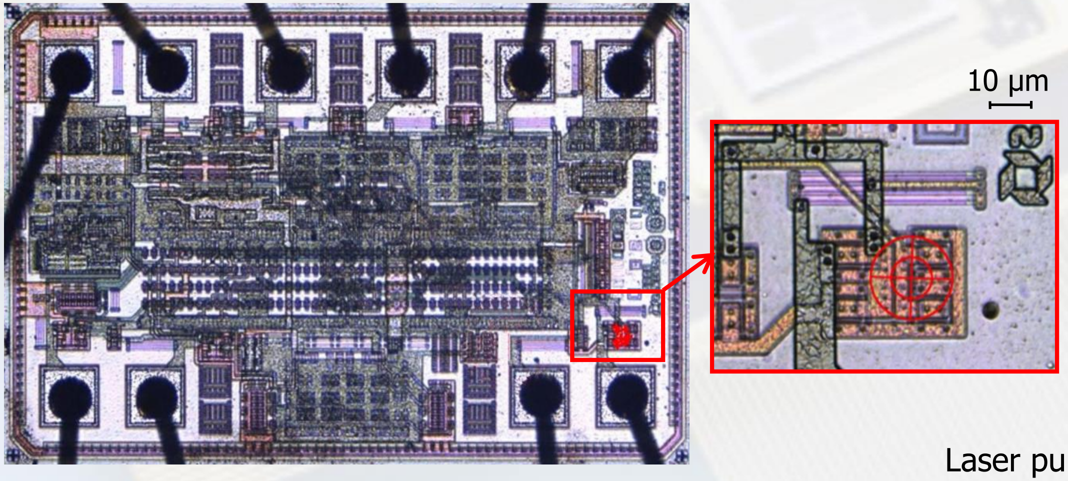
Methods of active layers depth determination:

- SEE threshold energy measurements;
- measurements of electrical response timing and delay;
- back-side visualization with IR-camera (most convenient).

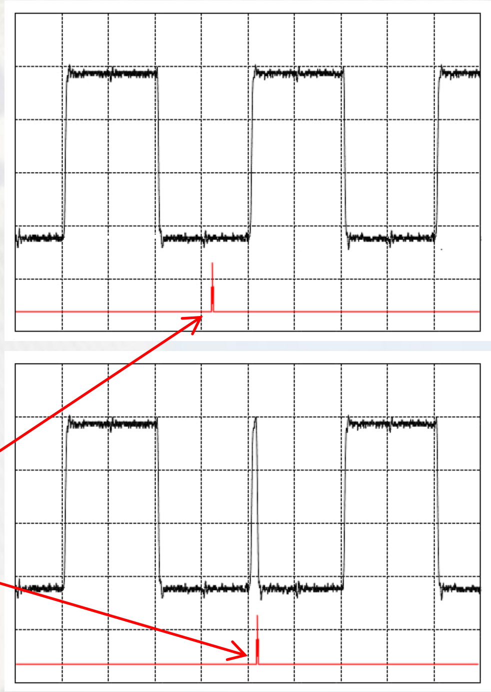
Pechenkin A.A., Savchenkov D.V., et al. Evaluation of sensitivity parameters for single event latchup effect in CMOS LSI ICs by pulsed laser backside irradiation tests/ Russian Microelectronics, 44 (1), pp. 33-39

Localization of SEEs

1. Scanning the whole chip by moderately focused laser beam with varying energy;
2. Testing the occurrence of SEE synchronously with laser excitation;
3. Testing at particular moment of timing diagram.

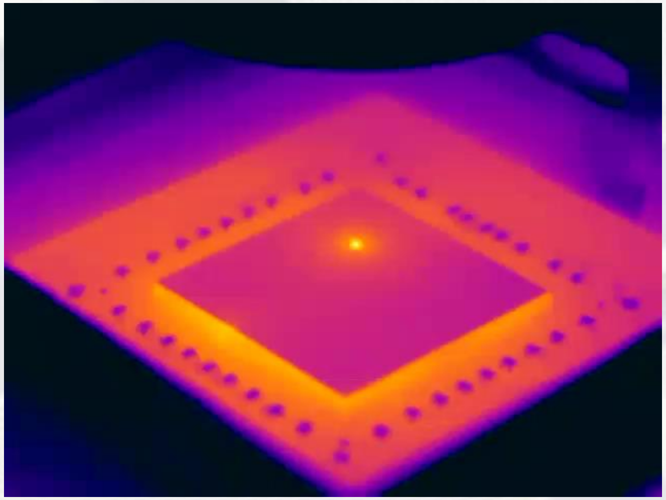


Localization of SEU sensitive area in SY55852U

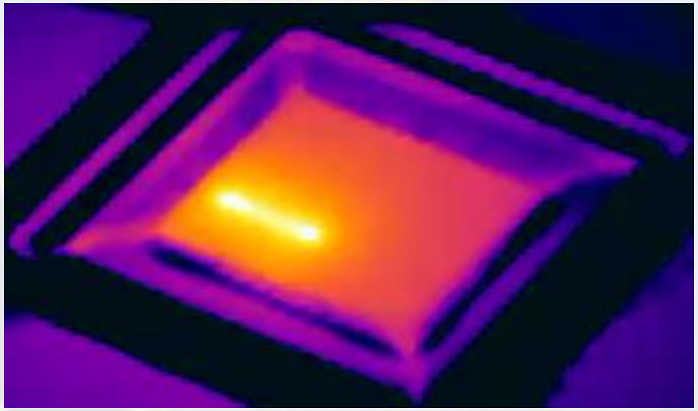


Localization of SEL

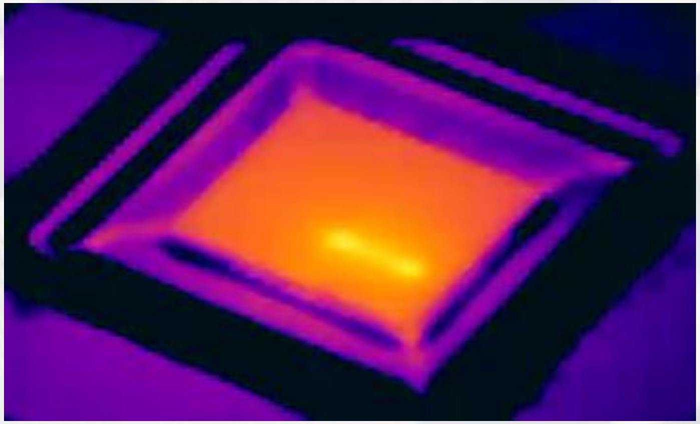
Microprocessor test chip 90nm



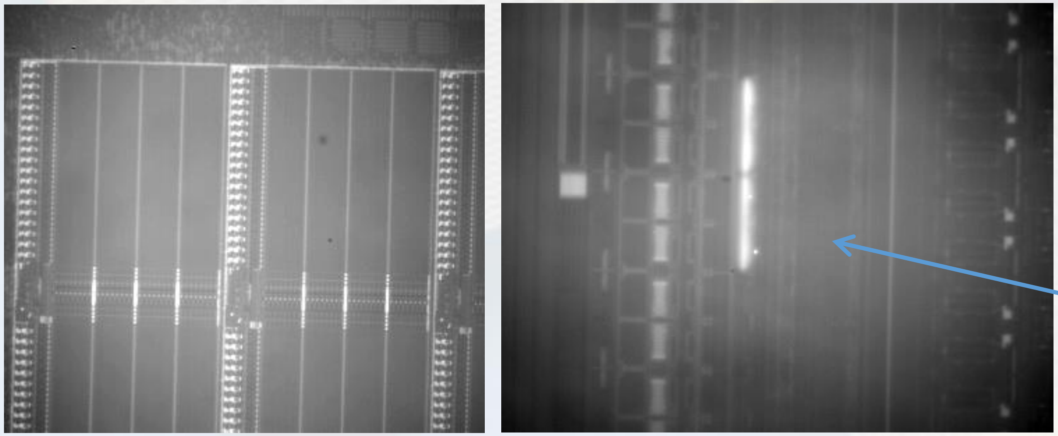
Thermal Images (backside) (frontside)



Xilinx QPRO XQ4000E FPGA



Infrared images (backside)



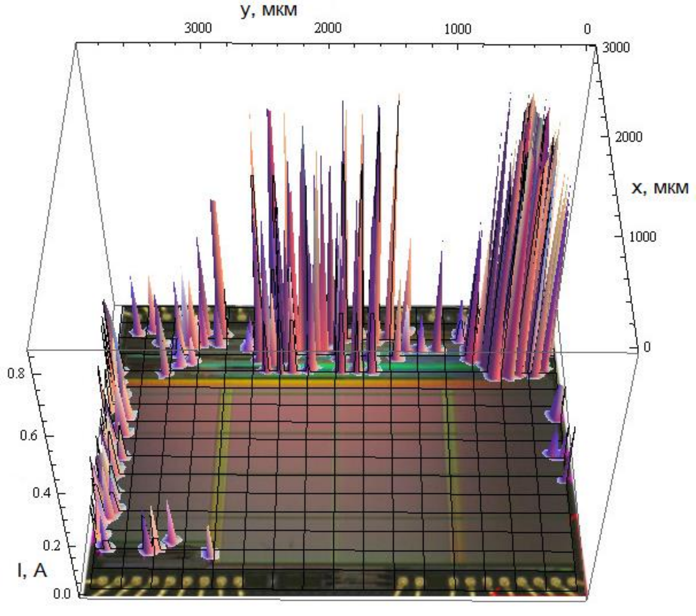
SEL light emission Microscopy (backside) in Xilinx Virtex 6 FPGA

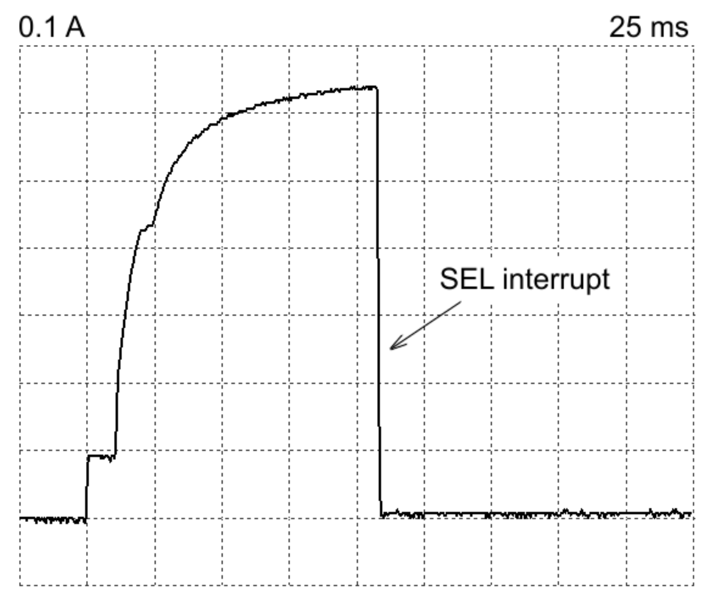
Parry of SEE in Electronic Board

Possible techniques: automatic SEL interrupt, RAM data reservation and coding, etc.

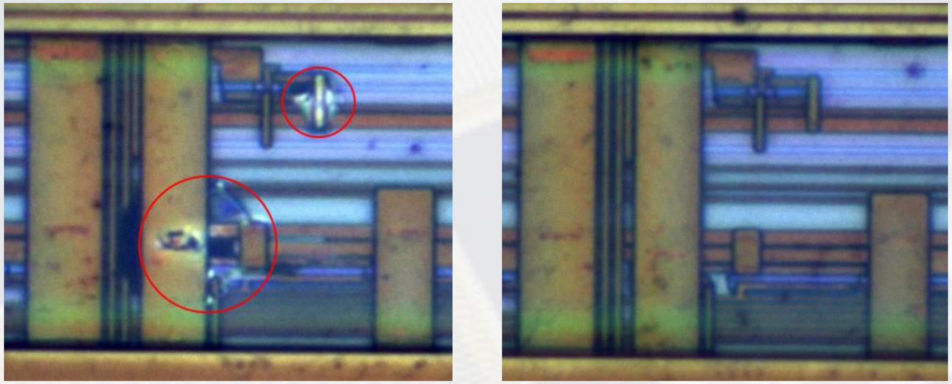
Role of laser:

- reproduce the effect;
- find out critical parts of IC and modes of operation;
- helps to develop the technique for particular part of IC.

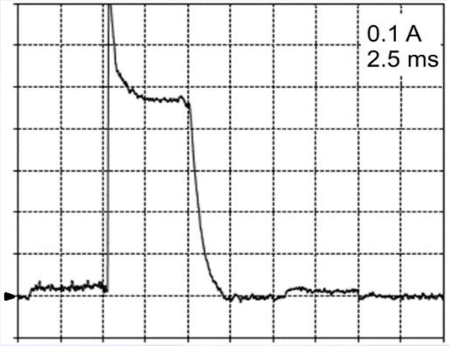


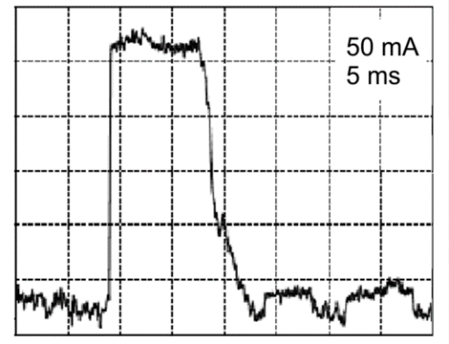


SEL Survivability Tests



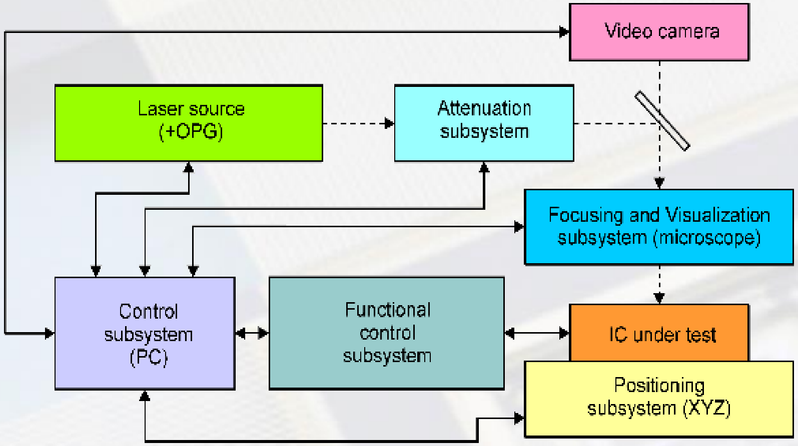
Laser beam initiates the latchup selectively in particular part of IC



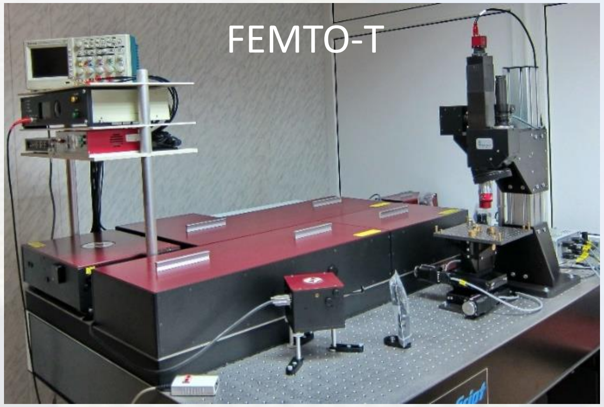


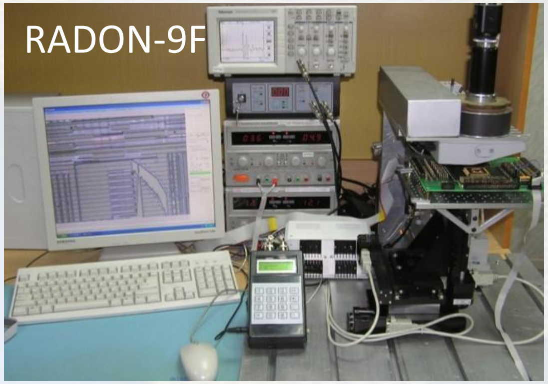
Adding the current limiting resistor in power supply circuit enhances survivability (prevents structure damage)

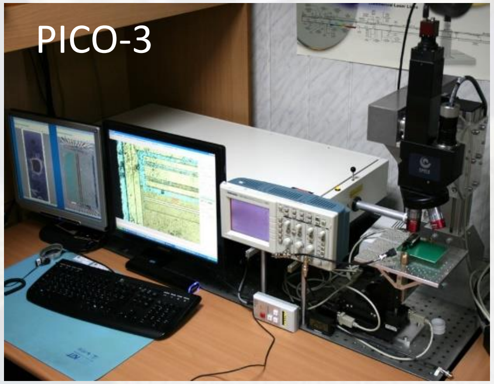
Laser Test Facilities in MEPhI

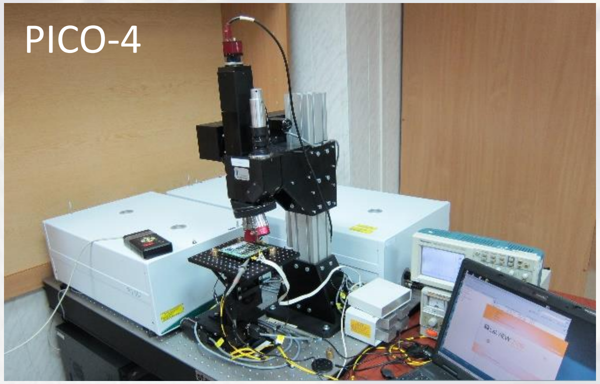


Focused laser system schematic diagram





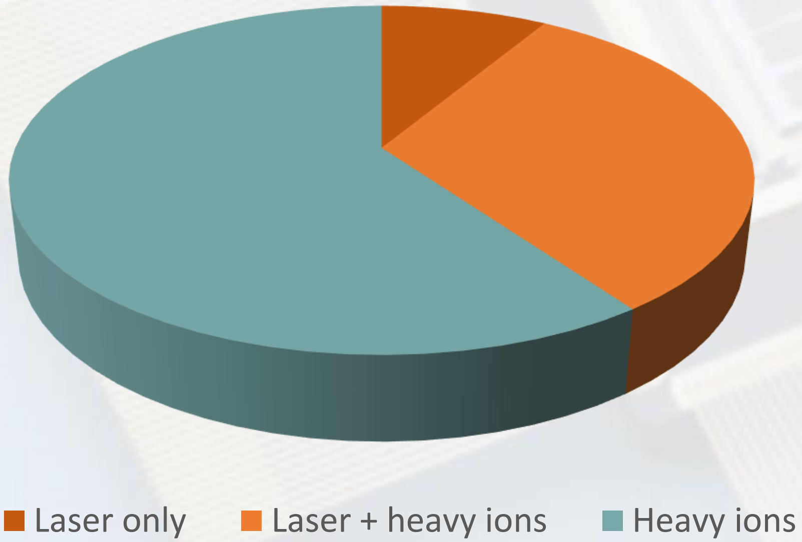




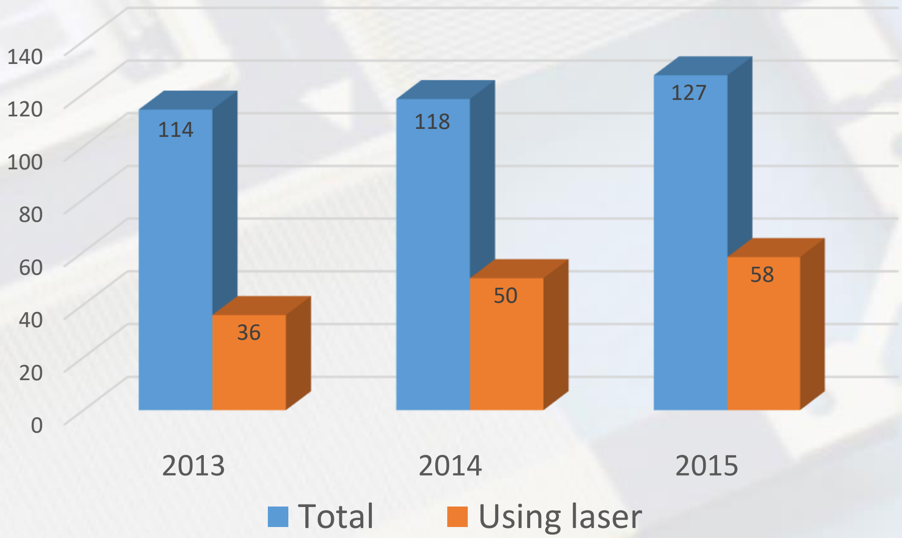
A.N. Egorov et. al. "PICO-4" Single Event Effects Evaluation and Testing Facility Based on Wavelength Tunable Picosecond Laser / Radiation Effects Data Workshop (REDW), 2012 IEEE, PP. 69-72.
A.N. Egorov et. al. Femtosecond Laser Simulation Facility for SEE IC Testing / Radiation Effects Data Workshop (REDW), 2014 IEEE, PP. 247-250.

Laser SEE Tests in NRNU MEPhI / SPELS

Common structure of SEE tests in 2013-2015



Laser tests fraction by year



A. Egorov, A. Chumakov et al. Laser Technique for the Investigation of Single Event Effects in Integrated Circuits. ©NRNU MEPhI – SPELS 2016

Future Trends

The roadmap of further laser techniques development includes:

- utilization of higher harmonics of laser radiation to simulate SEEs in wide bandgap semiconductor devices;
- decreasing the focused laser beam spot size to facilitate laser tests of deep sub-micron technology devices;
- development of two-photon absorption technique using femtosecond lasers;
- laser generation of ultra-short hard x-ray pulses with photon energies sufficient to penetrate through metal layers.

Conclusion

1. Laser techniques are developed and widely used in NRNU MEPhI / SPELS for radiation effects simulation in semiconductor devices for space applications.
2. In Russia laser techniques are officially allowed to be used for ICs radiation tests.
3. Noticeable part of radiation hardness tests performed during last years were made by using laser facilities.
4. Laser facilities proved to be a good tool for such operations as SEE localization, sensitivity parameters confirmation, survival tests, sample preparation etc.

THANK YOU FOR YOUR ATTENTION!

Further reading

1. O.V. Mavritskii, A.I. Chumakov, A.N. Egorov, A.A. Pechenkin, A.Yu. Nikiforov. Pribory i Tekhnika Eksperimenta, 2016, No. 5, pp. 5–29.
2. Radiation Hardness of Electronic PARTS/Ed. by Chumakov A.I. M: MEPhI, 2015. 520 p. (in Russian).
3. A. Pechenkin, A. Egorov. SEE radiation hardness confirmation procedure of electronic components and systems in Russia/Radecs 2015, Moscow, Short Course.
4. R. Velazco, P. Fouillat, and R. Reis. Radiation Effects on Embedded Systems. Dordrecht, The Netherlands: Springer, 2007.
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6. M.S. Gorbunov, B.V. Vasilegin, A.A. Antonov, P. N. Osipenko, G.I. Zebrev, V.S. Anashin, V.V. Emeliyanov, A.I. Ozerov, R.G. Useinov, A. I. Chumakov, A. A. Pechenkin, A.V. Yanenko. Analysis of SOI CMOS Microprocessor's SEE Sensitivity: Correlation of the Results Obtained by Different Test Methods / IEEE Trans. on Nucl. Sci., 2012, V. NS-59, No 4, P. 1130-1135.
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8. A. A. Novikov, A. A. Pechenkin, A. I. Chumakov, A. O. Akhmetov, O. B. Mavritskii. SEE Laser Testing at Different Temperatures/ Proc. of RADECS, 2015, pp. 147-150