RADIATIONTEST WORKSHOP 2016
SEVILLE – SPAIN 31st MARCH – 1st APRIL

National Research Nuclear University MEPhI
Specialized electronic systems
Moscow, Russia

The Current State and Perspectives of Laser Radiation Hardness Investigation and Testing Techniques in Russia

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in collaboration with:
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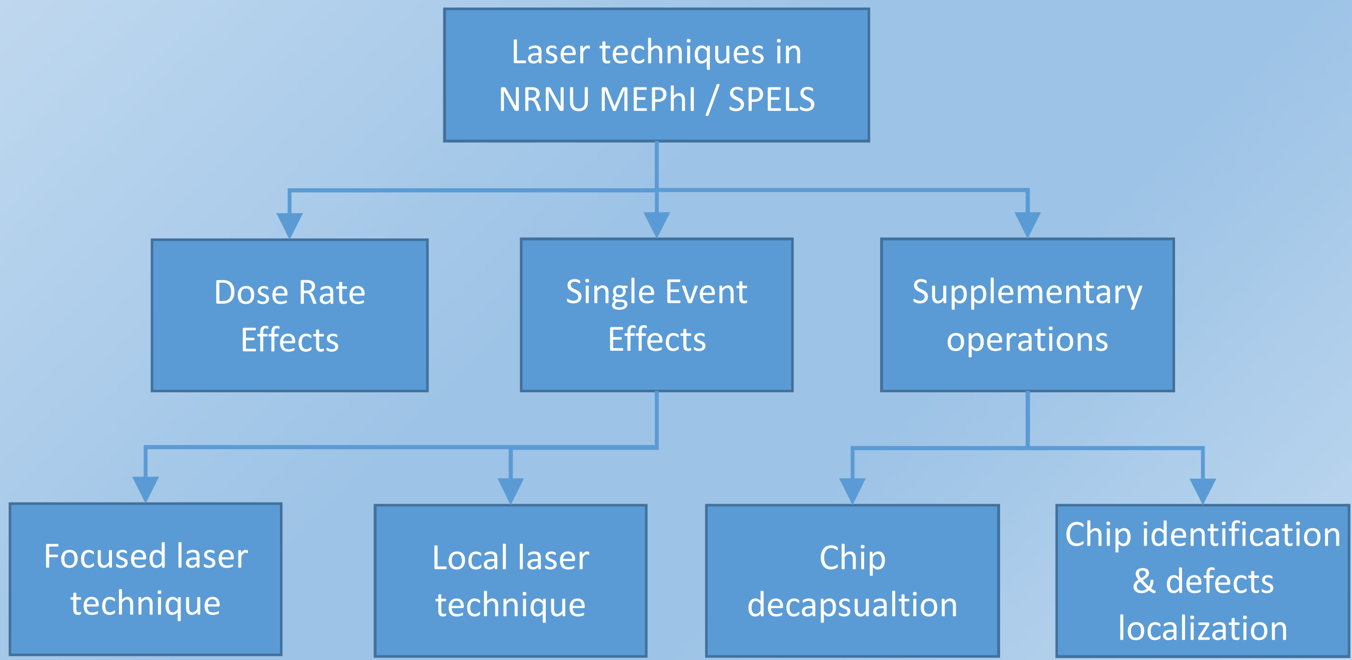
Presentation outline

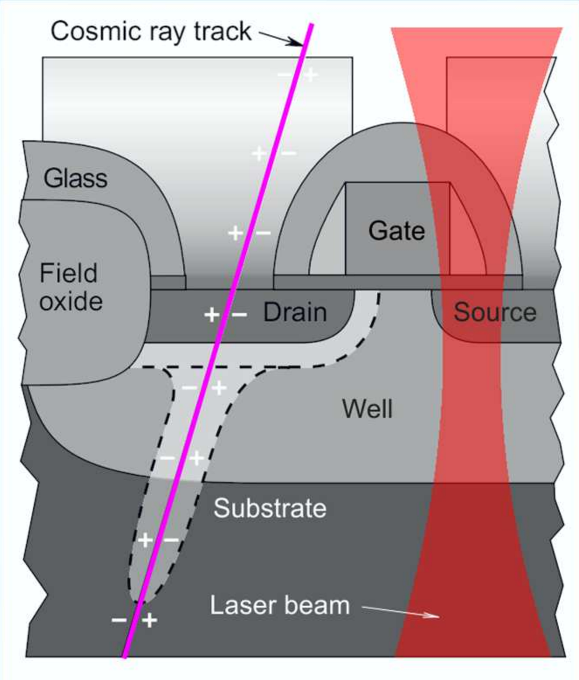
- Classification of laser tests and techniques
- Laser single event effects (SEE) tests
- Laser SEE investigations
- Compendium of laser SEE tests in NRNU MEPhI / SPELS
- Future trends
- Conclusion

Laser techniques for radiation hardness evaluation and testing



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

Single event effects



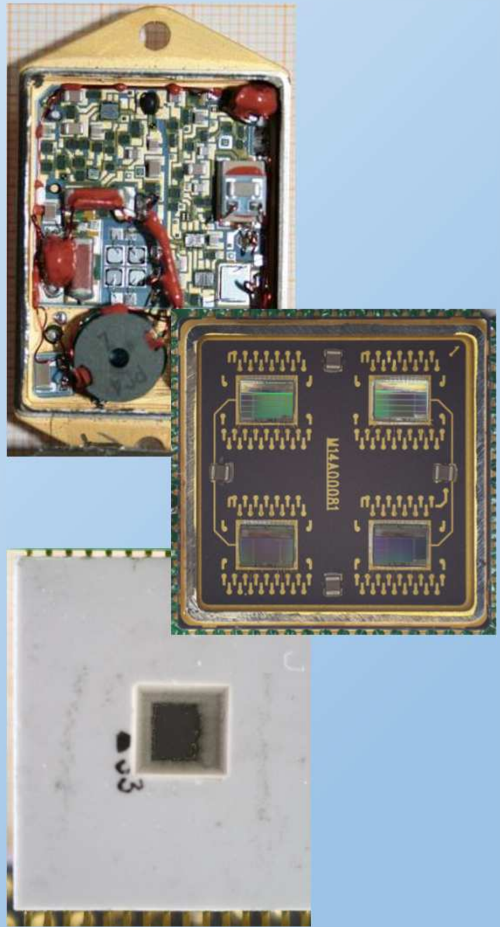
SEE is a serious limitation for the reliability of electronic components, circuits, and systems for space applications

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 nanosize spot

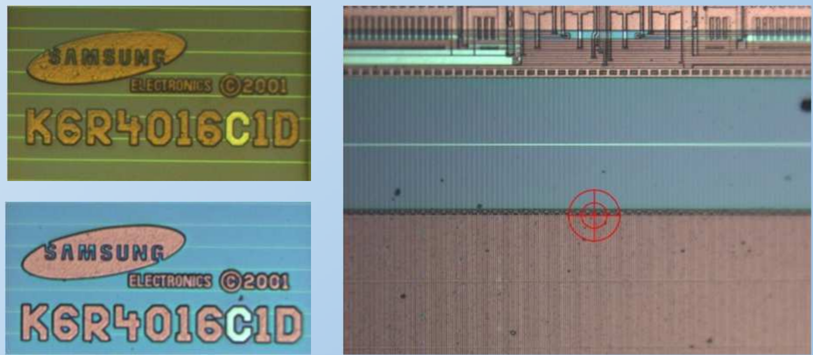
Sample preparation

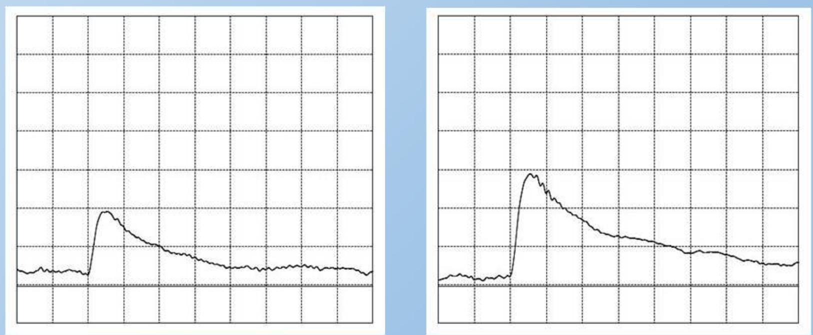


It is possible to use laser for IC chip decapsulation and preparation:

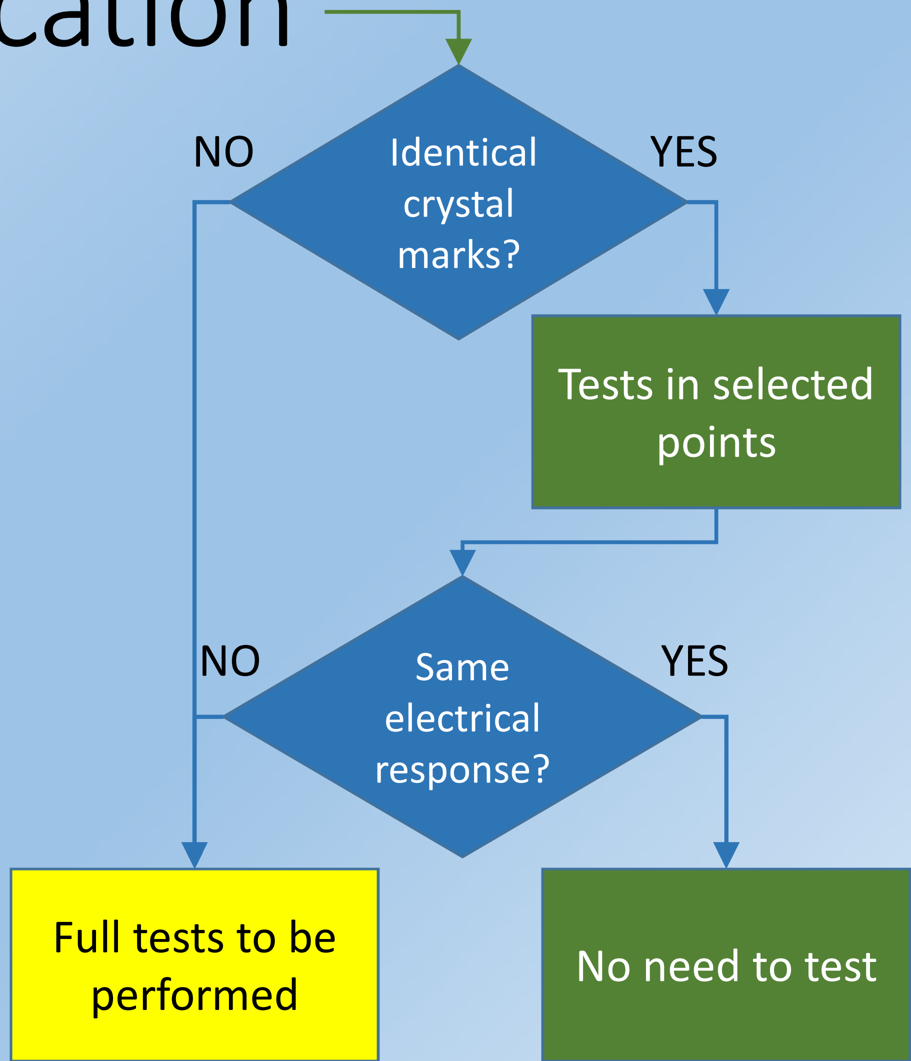
- metal cover removal
- ceramic or plastic package removal
- substrate thinning (for back-side irradiation)

Chip identification

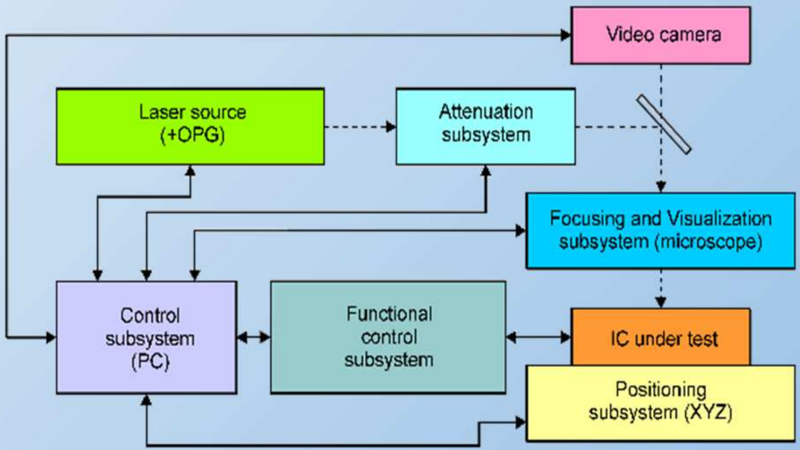




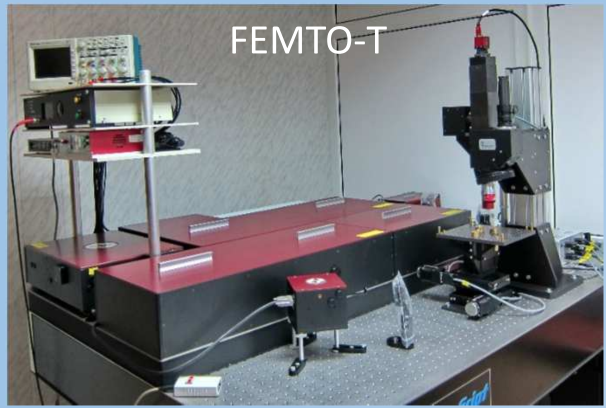
The example of different electrical response to laser irradiation for two chips with identical technological marks.

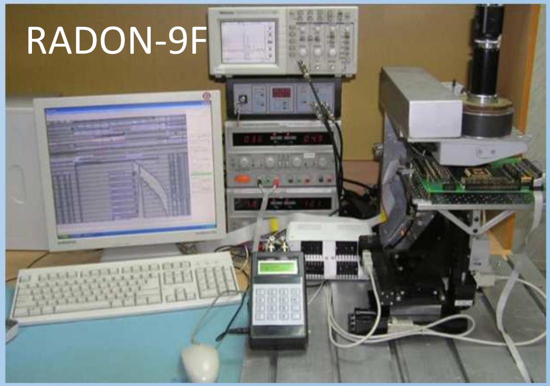


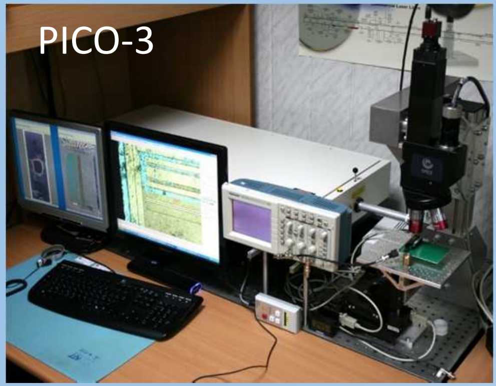
Laser test facilities

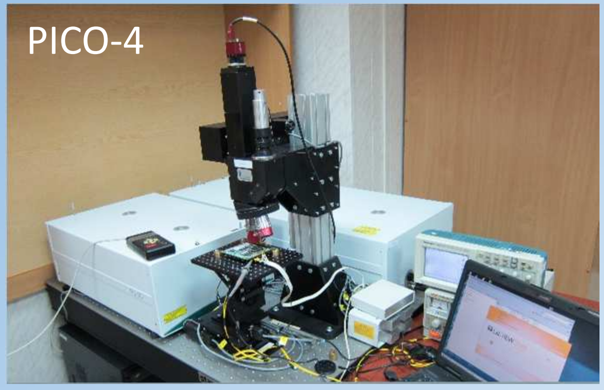


Focused laser system schematic diagram







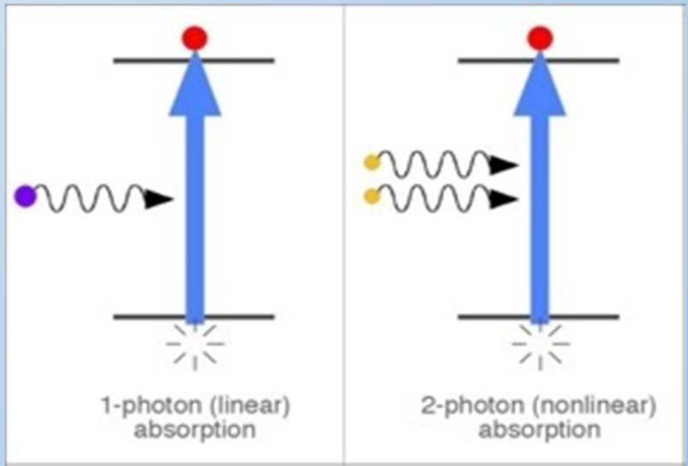


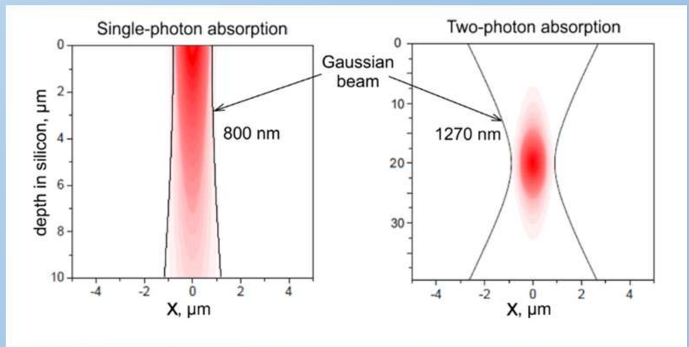
A.N. Egorov et. al. “PICO-4” Single Event Effects Evaluation and Testing Facility Based on Wavelength Tunable Picosecond Laser / Radiation Effects Data Workshop (REDW), 2012 IEEE, PP. 69-72.
A.N. Egorov et. al. Femtosecond Laser Simulation Facility for SEE IC Testing / Radiation Effects Data Workshop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

Focused laser facilities: the role and place 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.

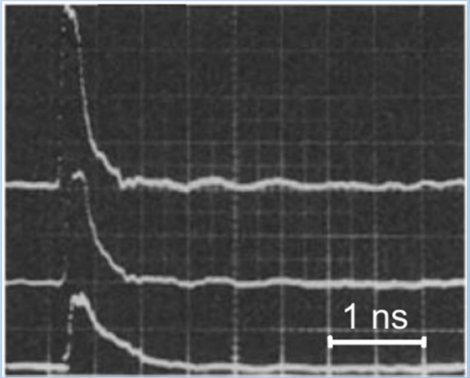
SEE laser tests principles



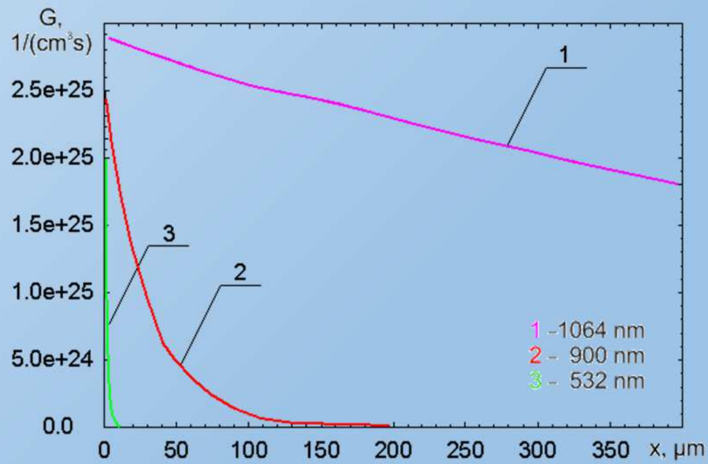


1. Laser can produce almost all types of SEEs.
2. Two main mechanisms of charge generation:
   − single photon absorption;
   − two photon absorption.
3. Spatial distributions of generated charge by laser and ions differ, but the electrical effects are practically the same.

Pulse duration and wavelength



Electrical response in fast opto-switch



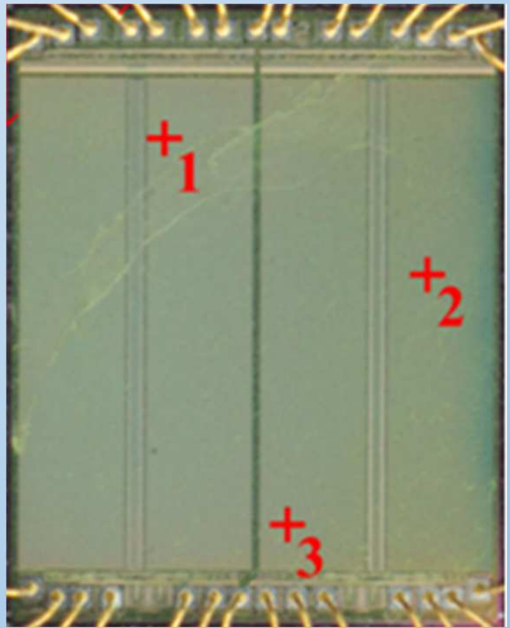
Charge generation rate in Si for different wavelengths

Typical internal response times for modern advanced electronics (shorter than 1 ns) require usage of pico- or femtosecond laser sources.

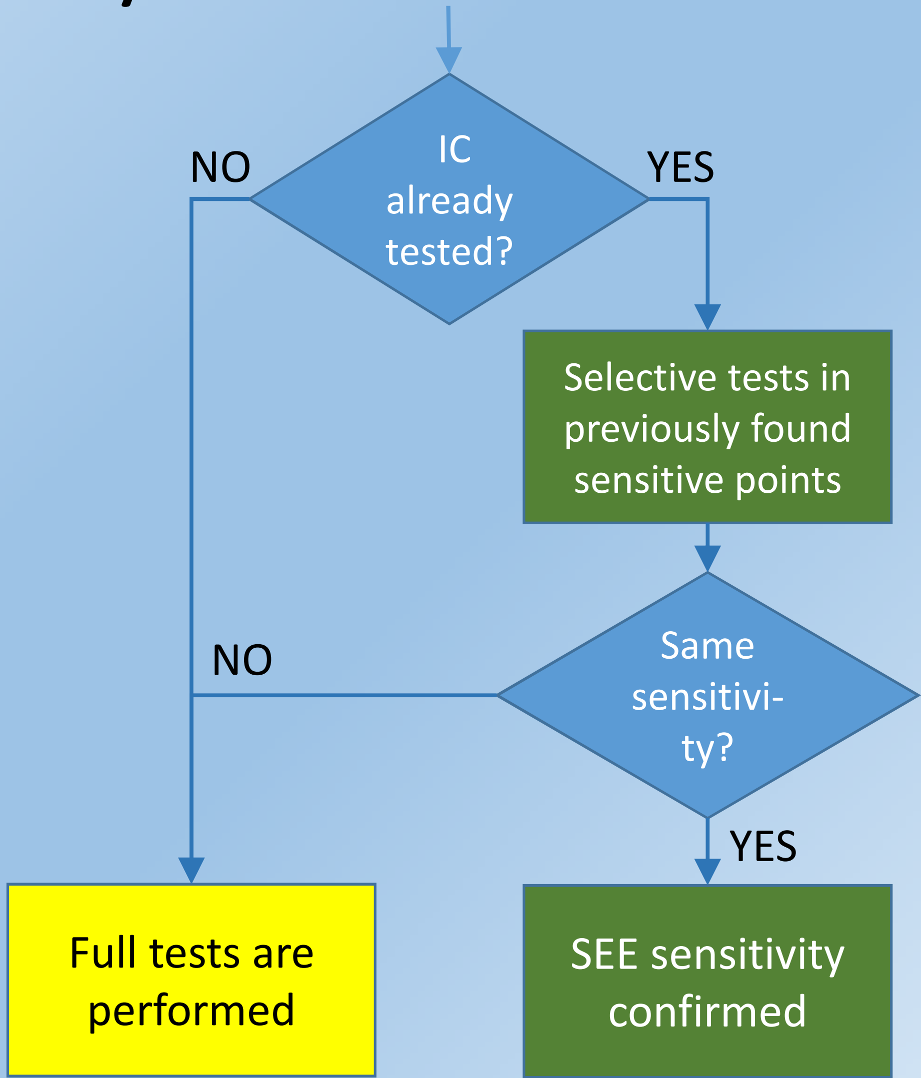
Commonly used wavelengths for silicon devices:

- ~ 900 nm (front-side irradiation);
- 1064 nm (back-side irradiation);
- 532 nm for SOI technology.

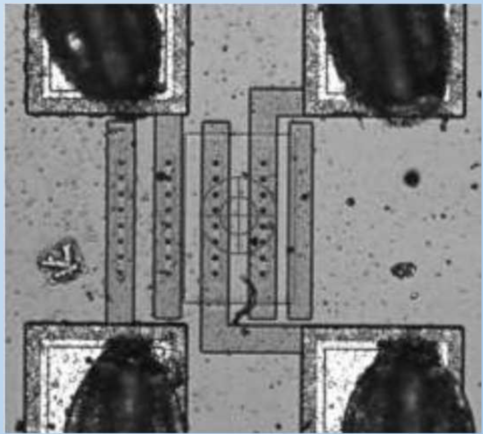
SEE sensitivity confirmation



Example of chip sensitive point location



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

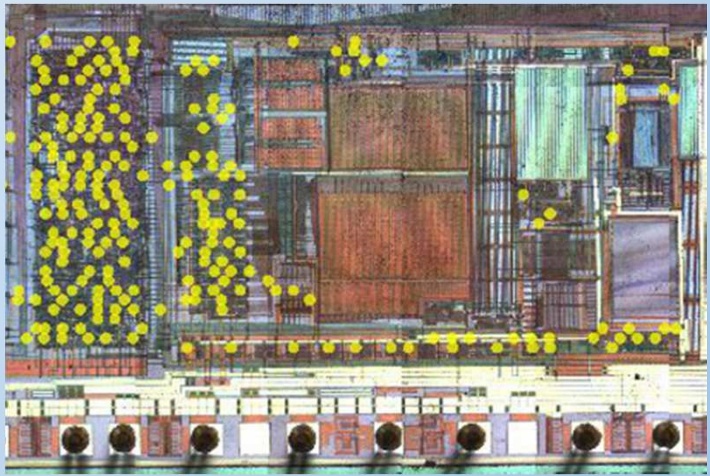
$$LET \sim 1.8 \cdot 10^4 \cdot \alpha_0 \cdot J_l \cdot \lambda \cdot (1 - R_\lambda)/\rho$$

Assumptions:

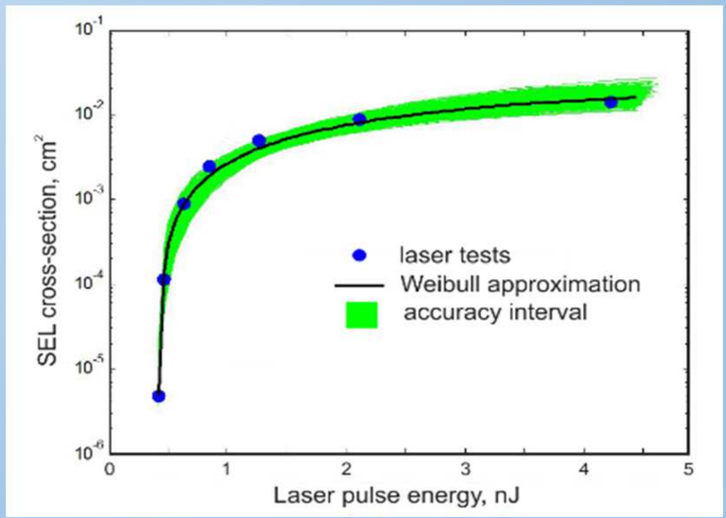
- Laser intensity does not change along the charge collection length
- Very short laser pulse duration

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

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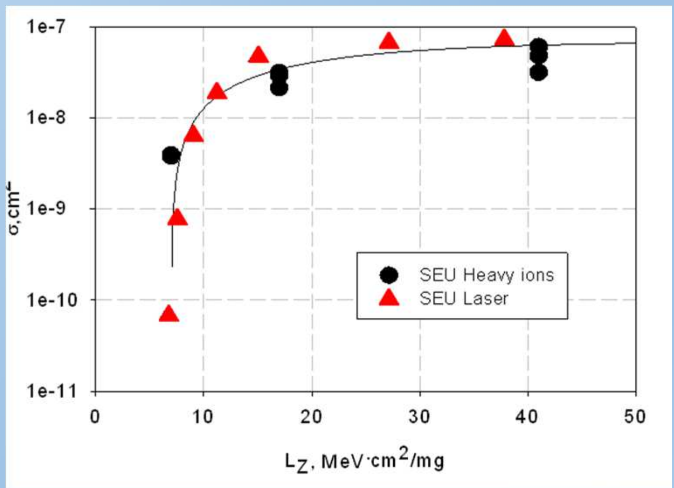
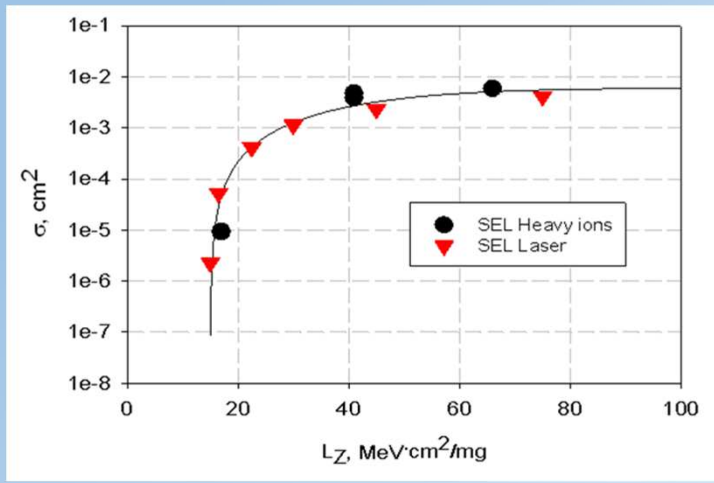
Heavy ion calibration

Roscosmos U-400M isochronous cyclotron (JINR, Russia, Moscow region, Dubna).

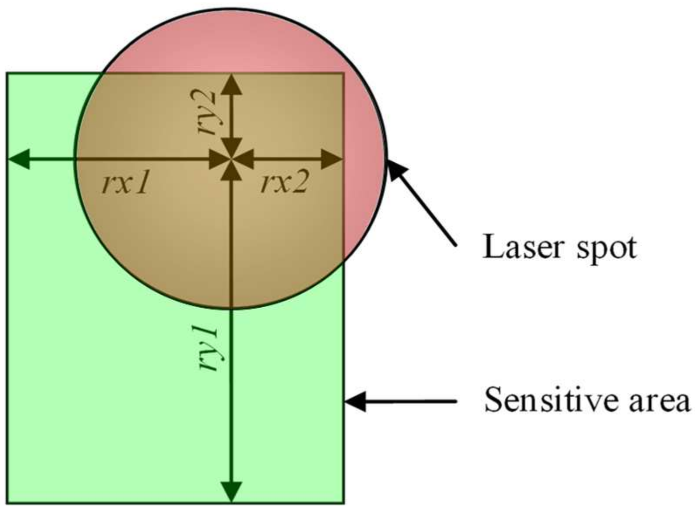
Laser-obtained Weibull curve and heavy ion experimental points are combined to determine LET threshold and cross-section of SEE.

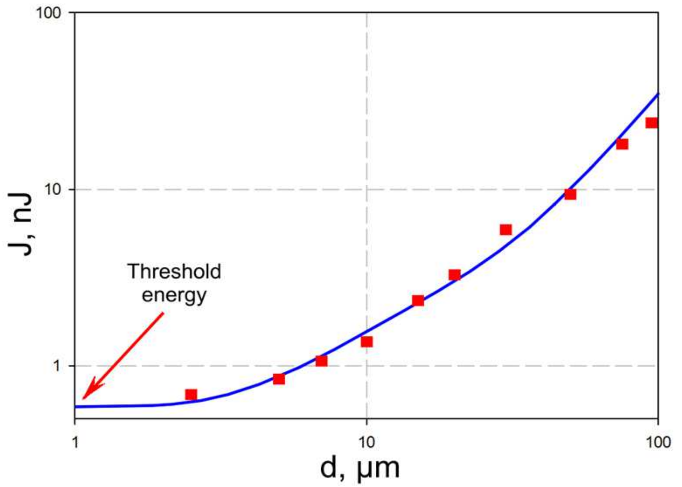
Note: different correlation coefficient between laser energy and LET for different effects in the same IC





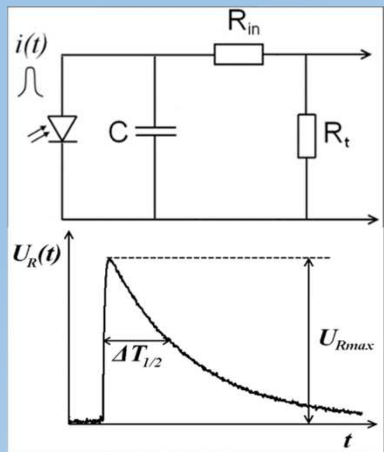
Local laser technique





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.



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

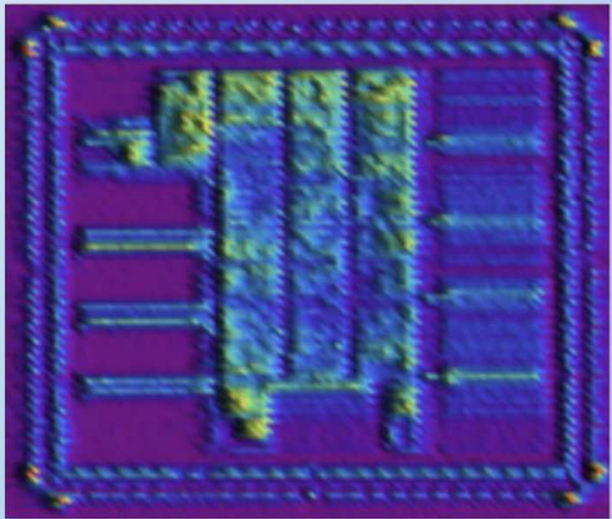
+

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

↓

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

Local laser technique (cont.)



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

+

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

↓

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

Main problems:

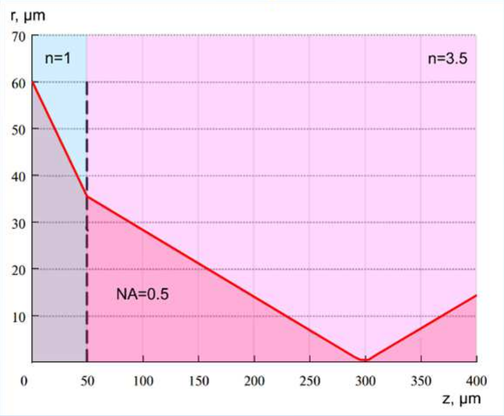
- uncertainty of some IC technology parameters;
- significant optical losses when irradiating from the active layers;
- too much difference in optical losses for various parts of IC.

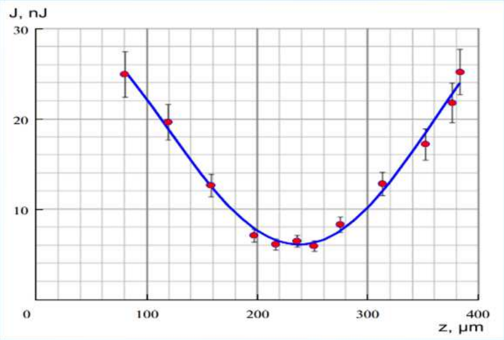
Possible solutions:

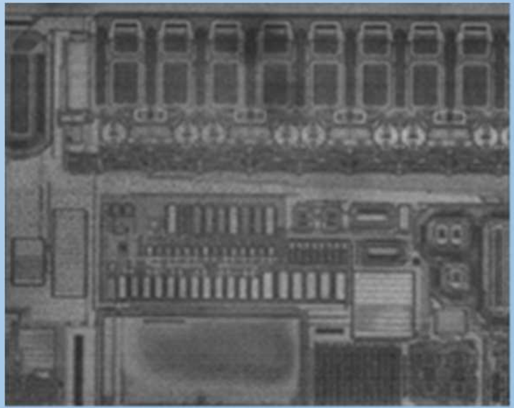
- joint use of laser and pulsed X-ray facilities;
- creating the electrical response map over the whole IC crystal for further results correction;
- using backside irradiation (see next slide).

A. I. Chumakov et. al. 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:

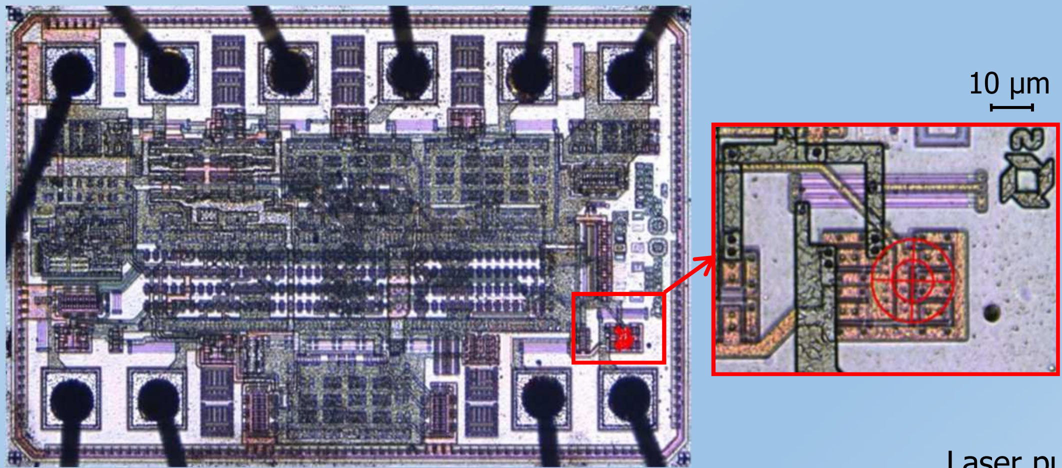
- 1064 nm laser radiation is used for silicon devices;
- both focused and local laser techniques are applicable;
- the change of incident laser beam divergence needs to be taken into account.

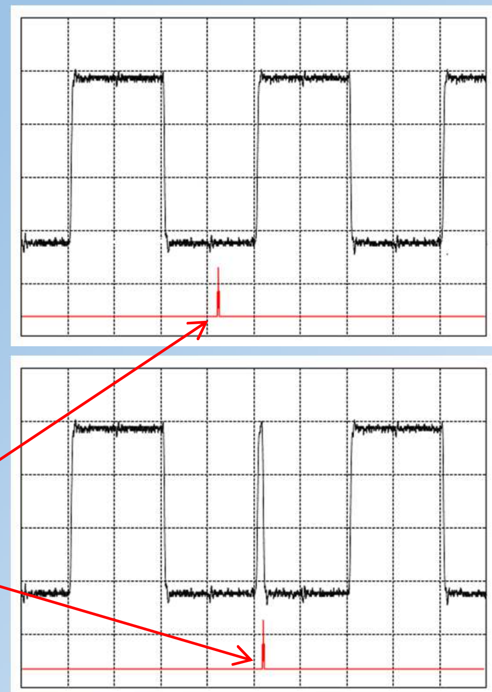
Methods of active layers depth determination:

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

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.





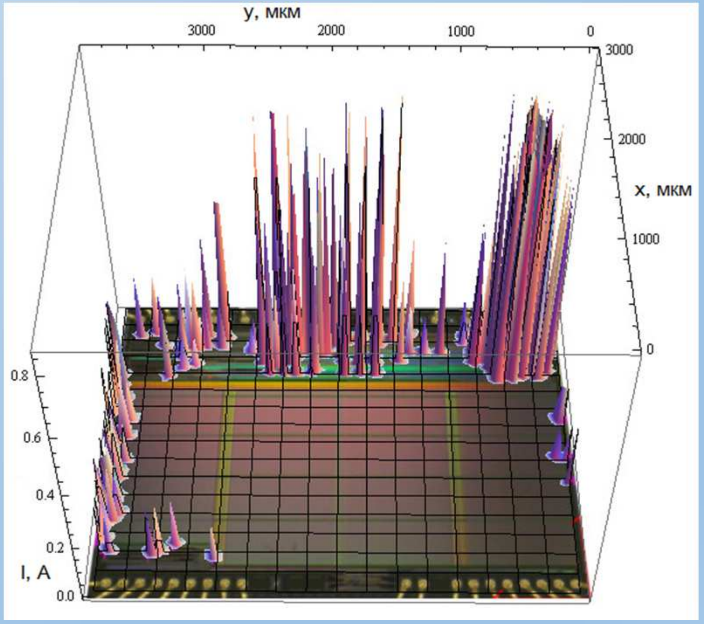
Localization of SEU sensitive area in SY55852U

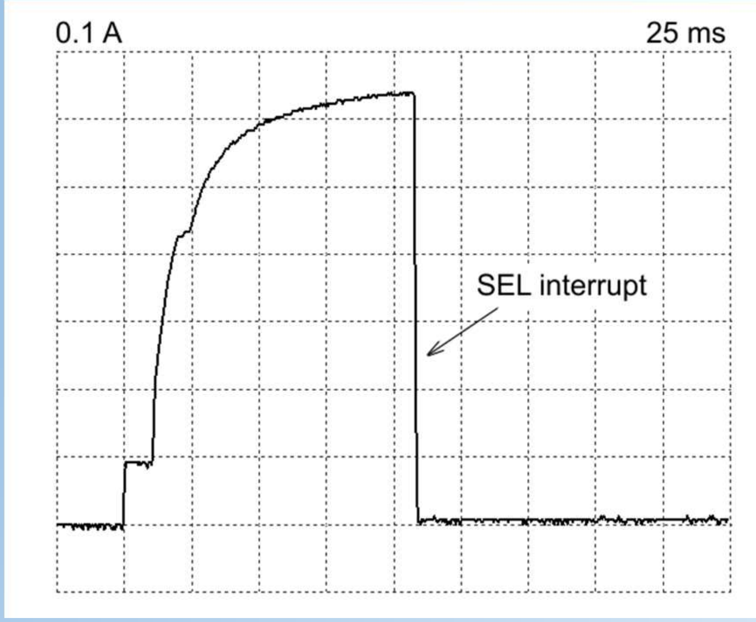
Parry of SEE in electronic board

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

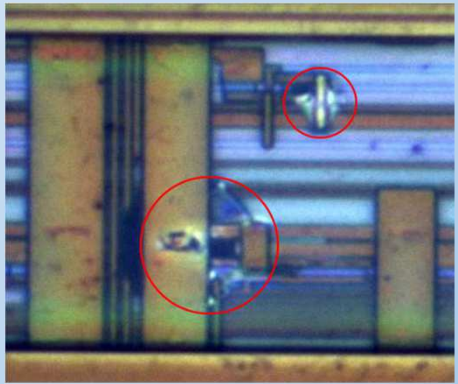
Role of laser:

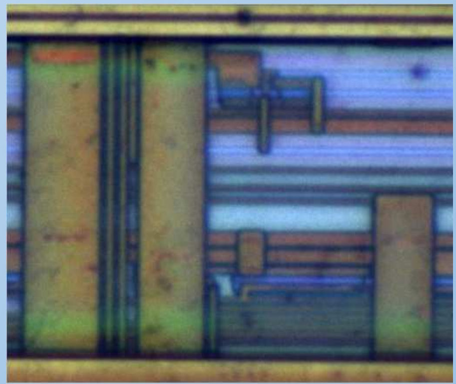
- reproduce the effect;
- find out critical parts of IC and modes of operation;
- helps to develop the technique for particular part of IC.

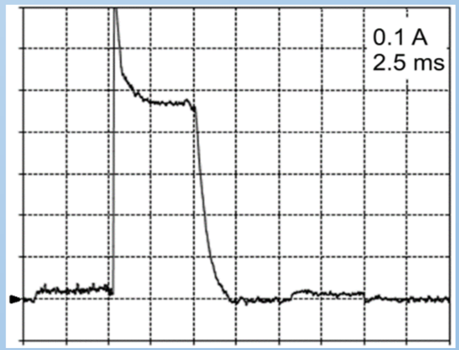


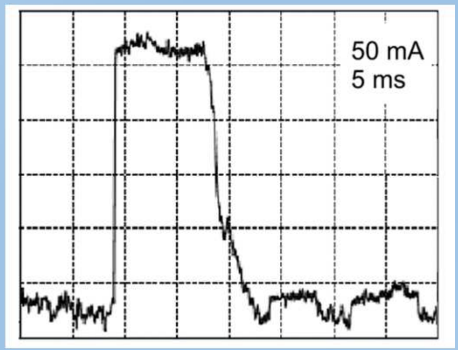


SEL survivability tests





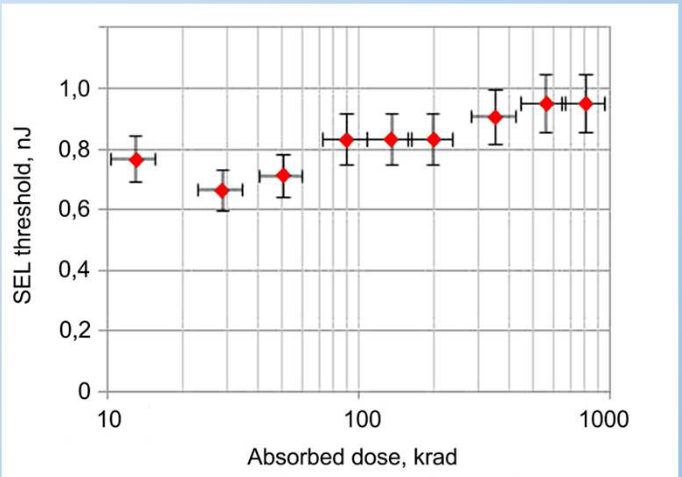




Laser beam initiates the latchup selectively in particular part of IC

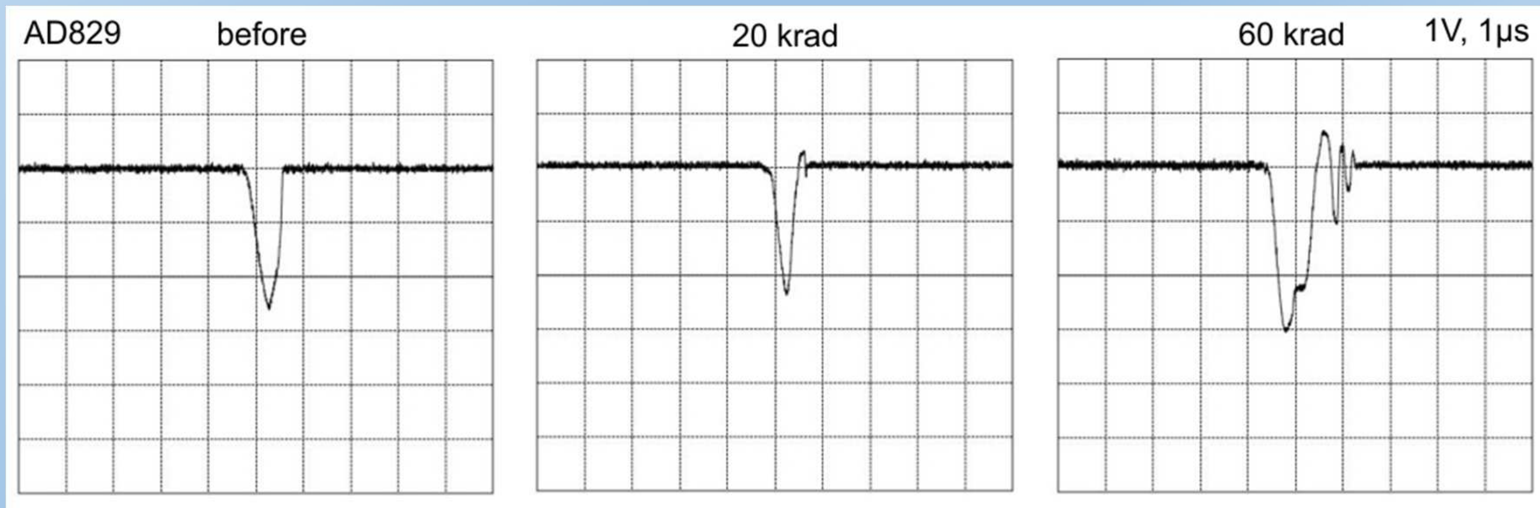
Adding the current limiting resistor in power supply circuit enhances survivability (prevents structure damage)

Influence of TID



SEL threshold in test static RAM vs. absorbed dose

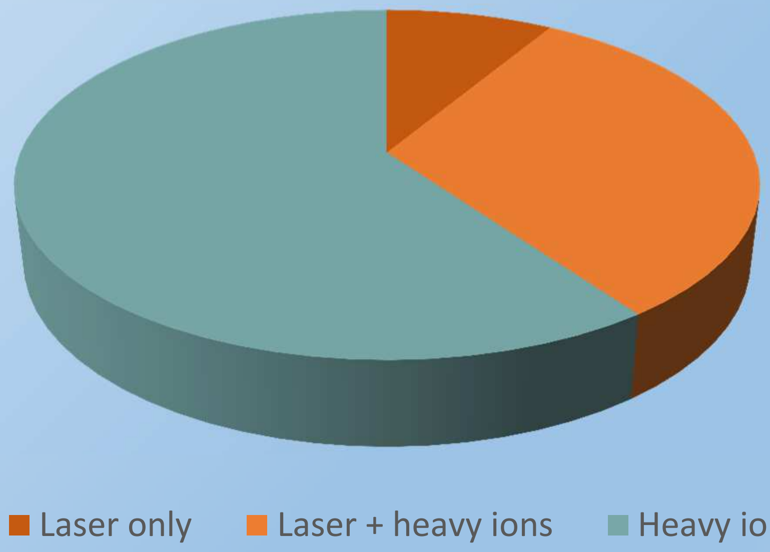
A.A. Novikov, A.A. Pechenkin, A.I. Chumakov. The Behavior of SEE Sensitivity at Various TID Levels / 2014 IEEE Radiation Effects Data Workshop, 2014, pp. 151-154.



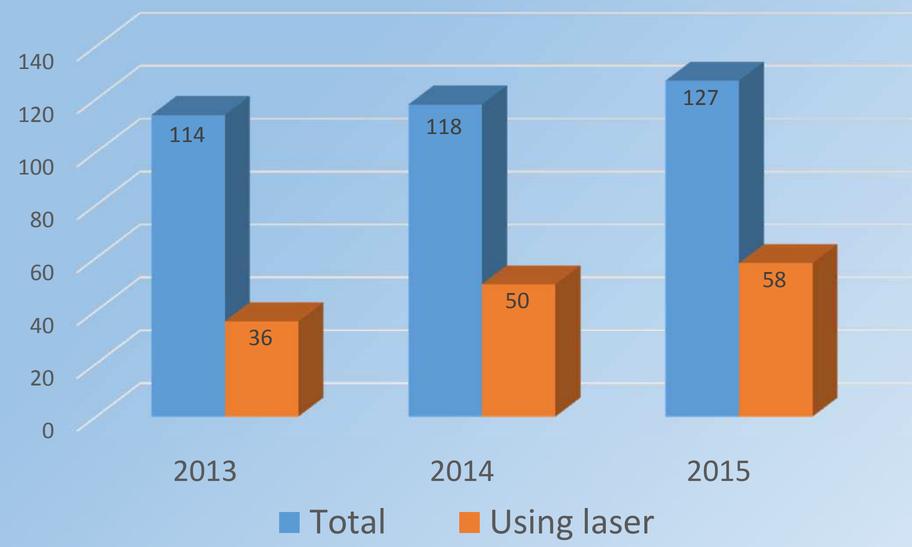
SET waveform in AD829 is changing while the TID increases

Laser SEE tests in NRNU MEPhI / SPELS

Common structure of SEE tests



Laser tests fraction during last three years



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. R. Velazco, P. Fouillat, and R. Reis, Radiation Effects on Embedded Systems. Dordrecht, The Netherlands: Springer, 2007.
2. D. V. Savchenkov, A. I. Chumakov, O.. Merkushin, G. G. Davydov, V. A. Marfin, Nonuniform Optical Losses in Laser SEE Tests / Proc. of RADECS, 2015, pp. 147-150.
3. 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.
4. Pechenkin, A.A., Savchenkov, D.V., Mavritskii, O.B., Chumakov, A.I., Bobrovskii, D.V. Evaluation of sensitivity parameters for single event latchup effect in CMOS LSI ICs by pulsed laser backside irradiation tests / Russian Microelectronics, 44 (1), 2015, pp. 33-39
5. Chumakov, A.I., Pechenkin, A.A., Savchenkov, D.V., Yanenko, A.V., Kessarinskiy, L.N., Nekrasov, P.V., Sogoyan, A.V., Tararaksin, A.I., Vasil'Ev, A.L., Anashin, V.S., Chubunov, P.A. Compendium of SEE comparative results under ion and laser irradiation / Proc. of RADECS, 2013, art. no. 6937390.
6. Savchenkov, D.V., Chumakov, A.I., Petrov, A.G., Pechenkin, A.A., Egorov, A.N., Mavritskiy, O.B., Yanenko, A.V. Study of SEL and SEU in SRAM using different laser techniques / Proc. of RADECS, 2013, art. no. 6937411.