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Laser-plasma accelerator for radiation hardness assessment of microelectronic devices

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IXVI Zababakhin Scientific Talks / Snezhinsk, May 31, 2023

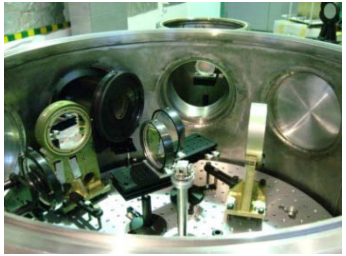
Testing of microelectronics on susceptibility to single charged particles

Charged particles cause single event upsets in microelectronics of space apparatuses:

1. Heavy ions (1-10 MeV/nucleon)
2. High energy protons (>30 MeV)
3. Low energy protons (~1 MeV)
4. High energy Electrons (>10 MeV)

Advantages of laser-plasma accelerators:

1. Different particle types at a single facility
2. Small footprint
3. Exponential spectrum resembles that of cosmic rays



B. Hidding et al., NIM A 636, 31 (2011)
B. Hidding et al., Sci Rep. 7:42354 (2017)

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Irradiation of a micro controller with laser accelerated proton bunches

Experimental Setup

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Laser:

- Pulse energy 0.1 ... 2 J;
- Pulse duration ~25 fs;
- F-number f/2;
- On target intensity up-to $5 \cdot 10^{20}$ W/cm^2

Targets:

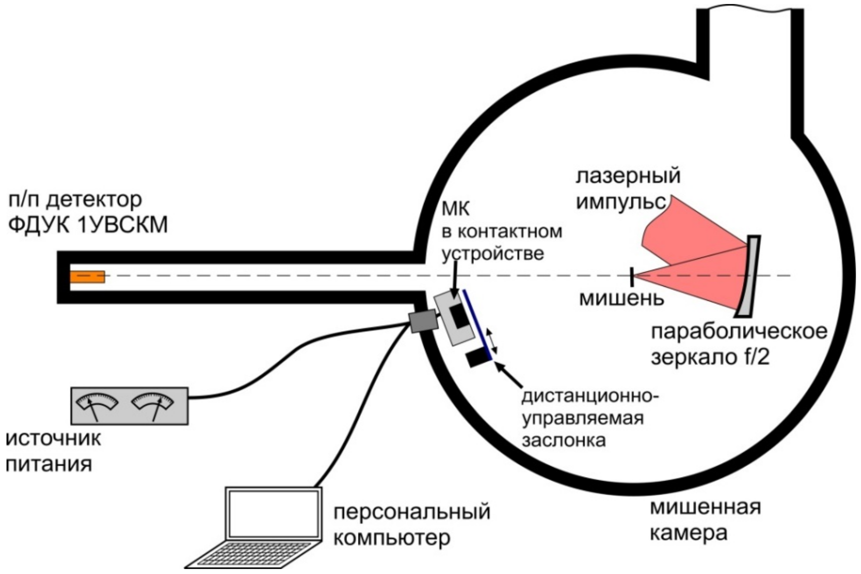
- 6 um Al foils

Time-of-flight spectrometer:

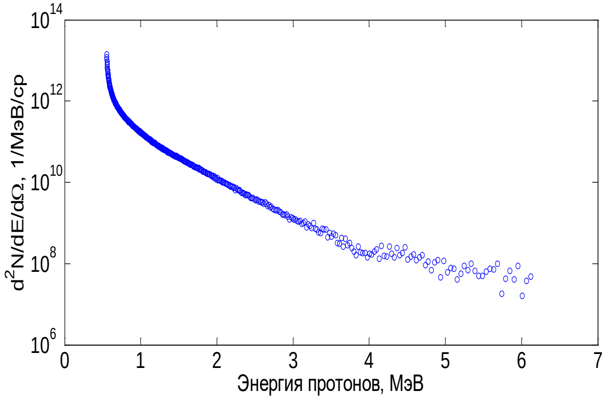
- target-detector distance 1.45 m;
- Detector - Si pin-diode FDUK-1UVSKM;
- Filter Al 6 um;
- Viewing angle 0°, либо 11°.

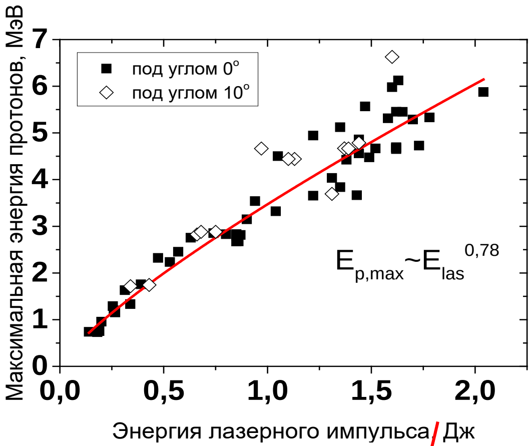
Device under test:

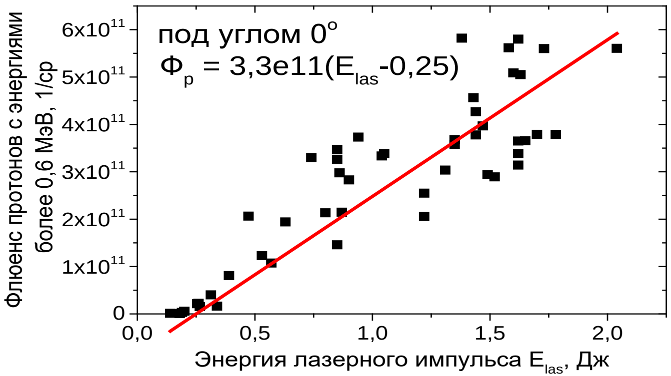
- ARM Micro-controller from «Milandr» ;
- Topology 180 nm;
- Internal RAM 32 kB;
- Chip was decapped before irradiation

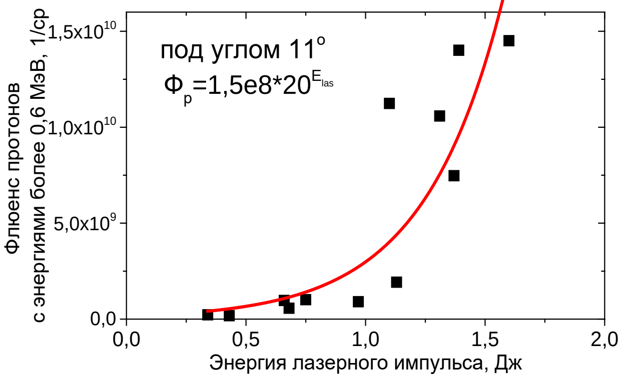


Proton beam parameters

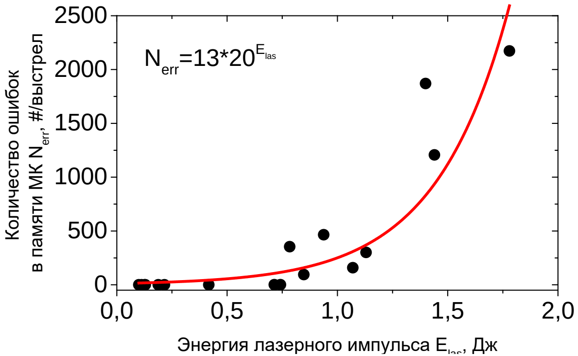




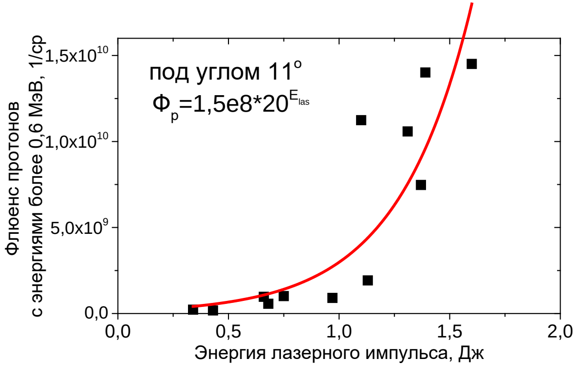




Device reaction on irradiation with laser accelerated protons



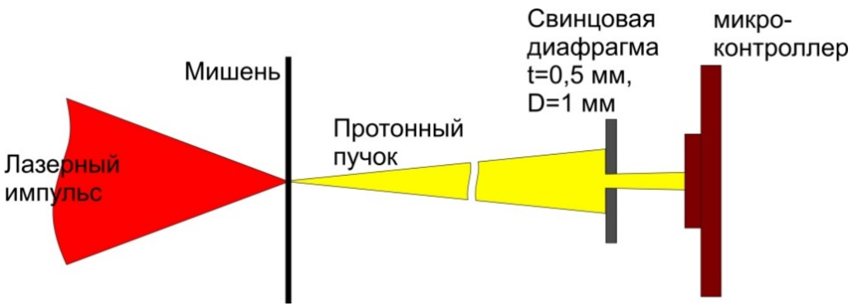
Number of errors in RAM versus laser pulse energy



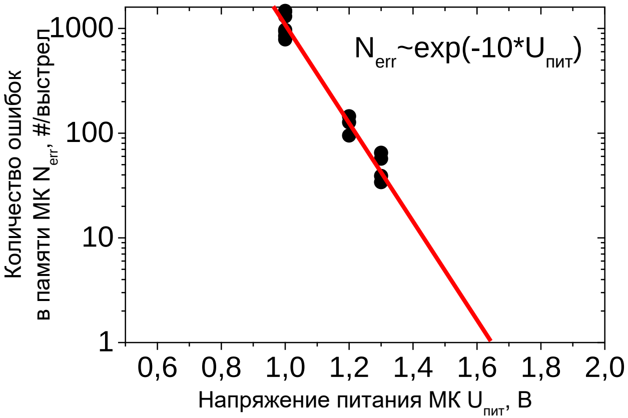
Fluence of protons versus laser pulse energy

$$\sigma_p^{err} = \frac{N_{err}}{\Phi_p}\frac{R^2}{N_{bit}} = (5 \pm 1) \cdot 10^{-10}\ cm^2/\mathrm{bit}$$

Dependence of chip's radiation hardness on bias voltage



Laser pulse energy (1.3 ... 1.7) J;



Number of errors after irradiation exhibits exponential dependence on bias voltage which is an evidence of single event upset (SEU) mechanism

K.P. Rodbell et al., IEEE Trans. Nucl. Sci. 54, 2474 (2007)
B.D. Sierawski et al., IEEE Trans. Nucl. Sci. 57, 3273 (2010)
M.P. King et al., IEEE Trans. Nucl. Sci. 60, 4122 (2013)

2

Irradiation of SRAM chip by laser accelerated electron bunches

Experimental Setup

Laser

- Pulse energy up-to 2.5 J
- Pulse duration 25 fs
- Peak power up-to 100 TW
- Focusing *f/(20...16)*

Target

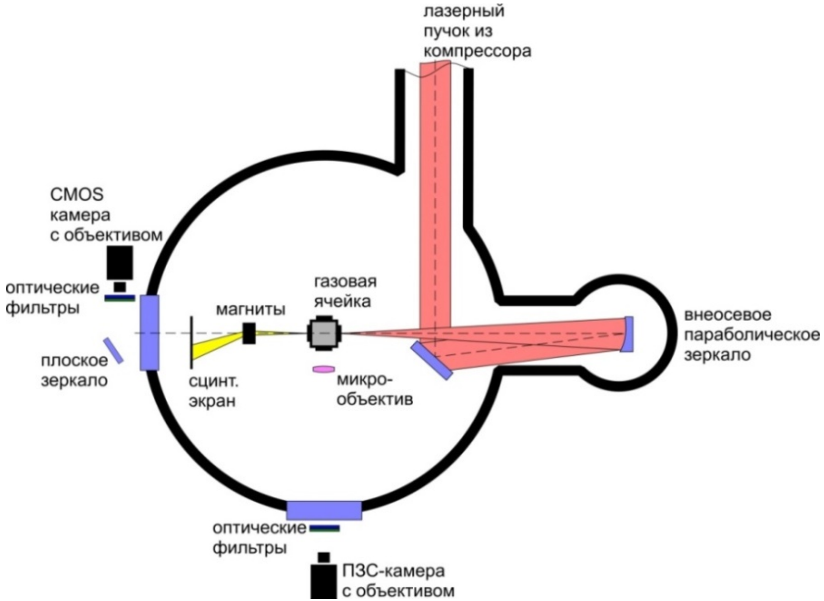
- Helium gas cell
- Length 0.6 ... 0.8 mm
- Medium helium + ~5% of air
- Gas density (1.5÷2)·10^{18} cm^{-3}

Diagnostics

- Magnetic spectrometer with lanex screen
- Stack of absolutely calibrated TLD (Al_2O_3) of 1 mm

Объект воздействия

- SRAM chip from Samsung
- Topology 130 nm
- Capacity 1 Mbit



Electron bunch parameter

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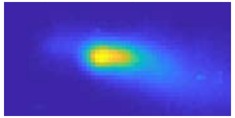
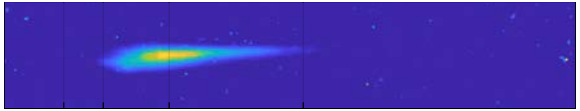


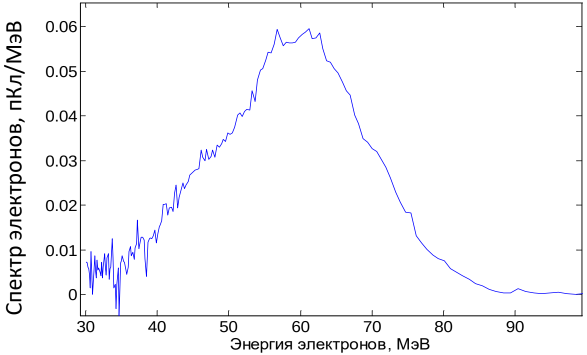
2 mrad

4 mrad

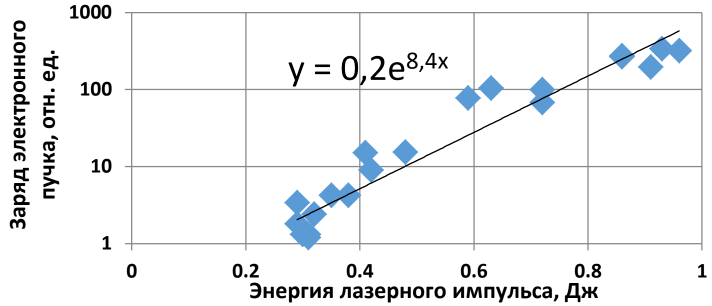


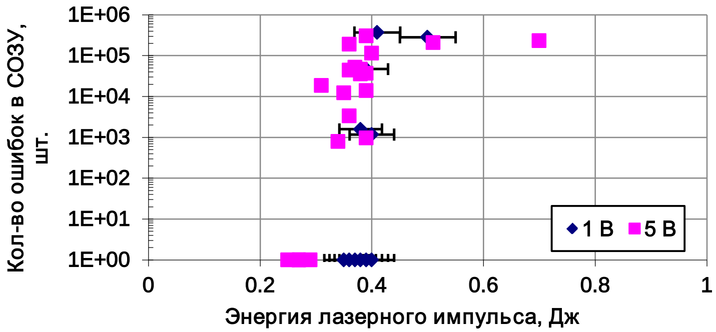
- Laser pulse power (20÷40) TW
- Mean squared deviation from mean emission angle in horizontal plane 6 mrad
- in vertical plane 4 mrad
- Bunch charge 5÷30 pC

- Mean energy 60 MeV
- ΔE/Emean ~ 50%



Chip's reaction on irradiation with laser accelerated electron bunch





100 consequential shots onto stack of TLDs @ E_{las}= (0.63±0.02) J

Threshold of mass failure from laser accelerated electrons (0.1÷1) R

Earlier measurements at pulse X-ray tube have shown that threshold is at (9±5) R

Conclusion

1. Laser-plasma accelerators can generate bright charged particle bunches with parameters suitable for radiation hardness assessment of microelectronic devices

2. For the first time, laser-plasma accelerators were applied to investigate microelectronic devices susceptibility to low energy protons (LEP) and relativistic electrons

3. Laser accelerated protons induce single event upsets (SEU) in the tested device, relativistic electrons induce mass failure of the tested SRAM due to dose-rate effect

4. High proton flux density can model heavy ion irradiation

5. Electron bunch duration (~1 ps) is 2 orders of magnitude lower than switch time of memory cell. So laser electron accelerators can be used to measure impulse response of microelectronic devices

Работа выполнена при поддержке АО «Наука и инновации», проект ЕОТП-ЛТ-48

Thank you for your attention

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05 / 31 / 2023