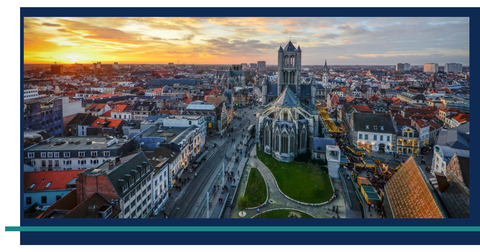

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Radiation induced improvement of Timing Performance in 3D Si Devices

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BACKGROUND AND MOTIVATION

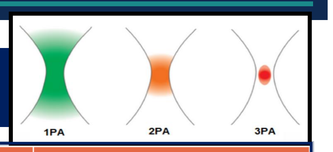
This work investigates the impact of irradiation on the timing performance of the 3D silicon devices. The investigated device is multi-arrays of 3D cylindrical detectors. Each 3D cylindrical device has diameter or 20 µm, active width of 20 µm and central (junction) electrode of 0.5 µm diameter. Device is produced by utilizing 8-INCH CMOS process at the Institute of Microelectronics at the Chinese Academy of Science (IME-CAS) in Beijing. Central n+ electrode is etched up to 25 µm in epitaxial 30 um layer while circular p+ electrode is etched up to 35 µm (entering the holding substrate of 595 µm). Advanced Two-Photon Absorption – Transient Current Technique (TPA-TCT), developed at the ELI ERIC, ELI Beamlines, was used as characterization technique.

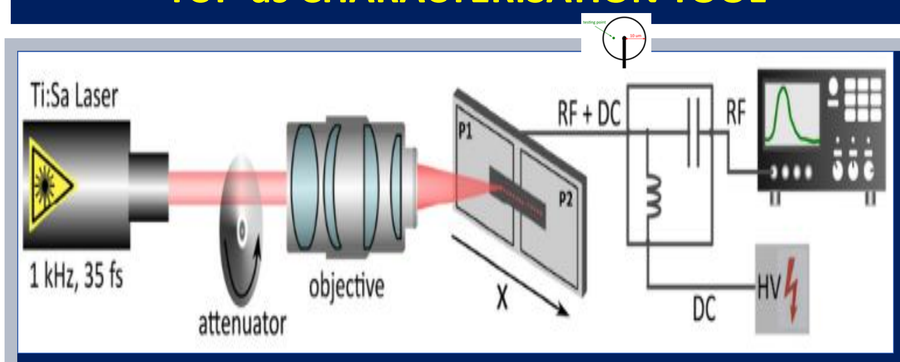
The results highlight several effects.

- First, irradiation reduces the influence of geometrically induced low-field regions (in non-overlapping electrode region), thereby suppressing the slow component of charge collection and significantly shortening the long tails observed in the signal waveforms. This leads to an improvement in timing response.
- Second, although irradiation decreases the signal amplitude, this loss can be compensated by the higher electric field developed in the device, which enhances charge multiplication in 3D IMECAS devices with gain. This effect is an intrinsic feature of 3D geometries with very small electrode radii, where strong local electric fields can be established.
- Despite the high electric field near the electrode tip, in the 3D IME-CAS device, the device remains stable due to a self-quenching mechanism that limits the multiplication process. These results indicate that, irradiation can mitigate detrimental waveform components while preserving stable operation and improving timing performance
- Charge Efficiency after irradiation is almost 100%. It seems that electric field is sufficiently high to prevent thecharge trapping in this device. Several pixels (only 2 are shown here) are tested, and all of them show compatible (almost identical) results confirming high precision of device fabrication.
- Contribution from SPA to 2PA is negligible (as seen in Z-scans).

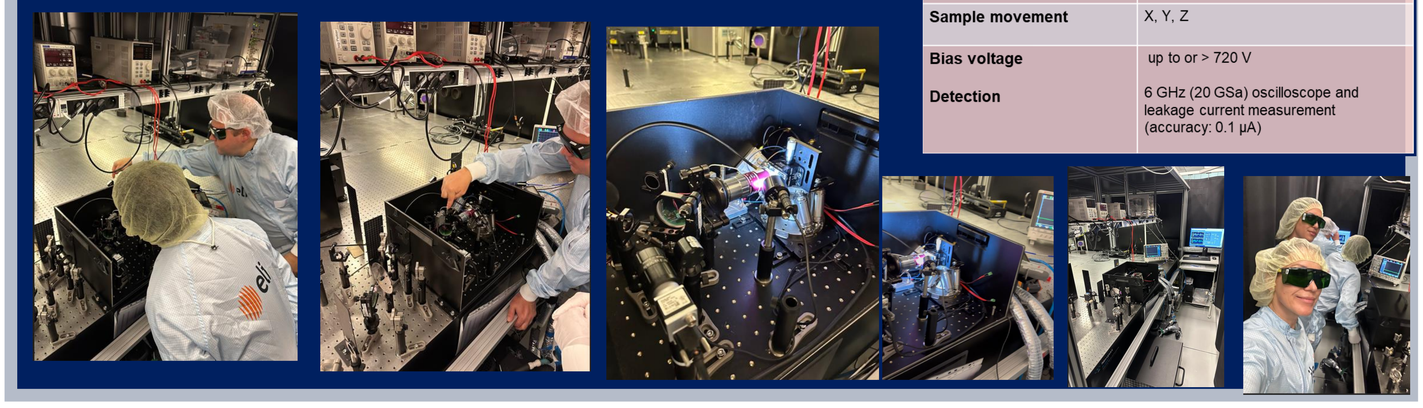
Keywords: 3D Si detector, multi-arrays of 3D cylindrical detectors, gain self -suppression, multi-arrays of 3D cylindrical detectors ion, device stability near breakdown

TCT as CHARACTERISATION TOOL

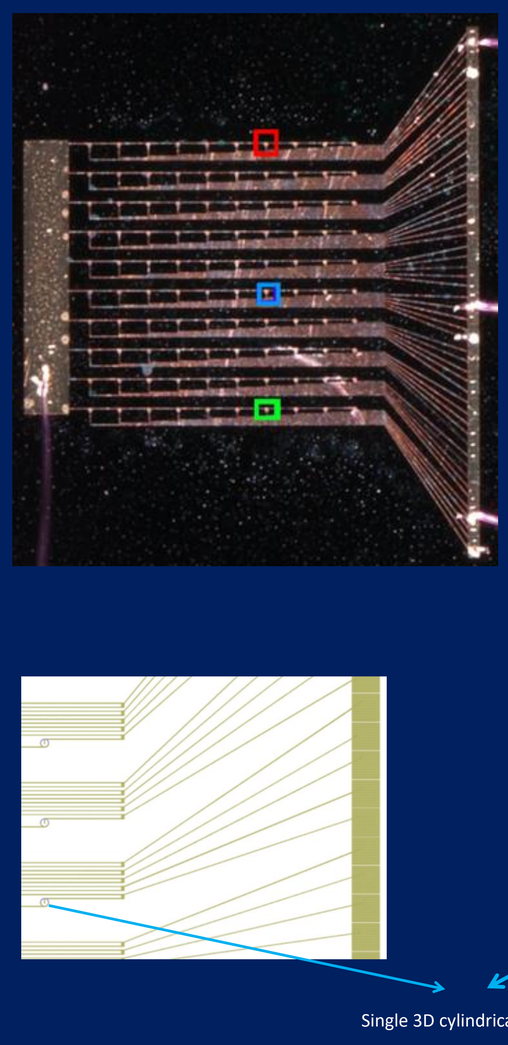




Place	ELI Beamlines
Operational modes	Single and two photon absorption (SPA and TPA)
Pulse energy on sample	Variable by ND filters (accuracy: 0.2 pJ) 800 nm (SPA), 1550 nm (TPA)
Wavelength	1550 nm, ~ 150 fs 800 nm, ~ 50 fs
Pulse width in sensor	
Focus waist radius	0.85 µm (SPA), 1.5 µm (TPA)
Rayleigh length	3.31 µm (SPA), 7.74 µm (TPA)
Sample cooling	Down to -25 deg. C
Sample movement	X, Y, Z
Bias voltage	up to or > 720 V
Detection	6 GHz (20 GSa) oscilloscope and leakage current measurement (accuracy: 0.1 µA)

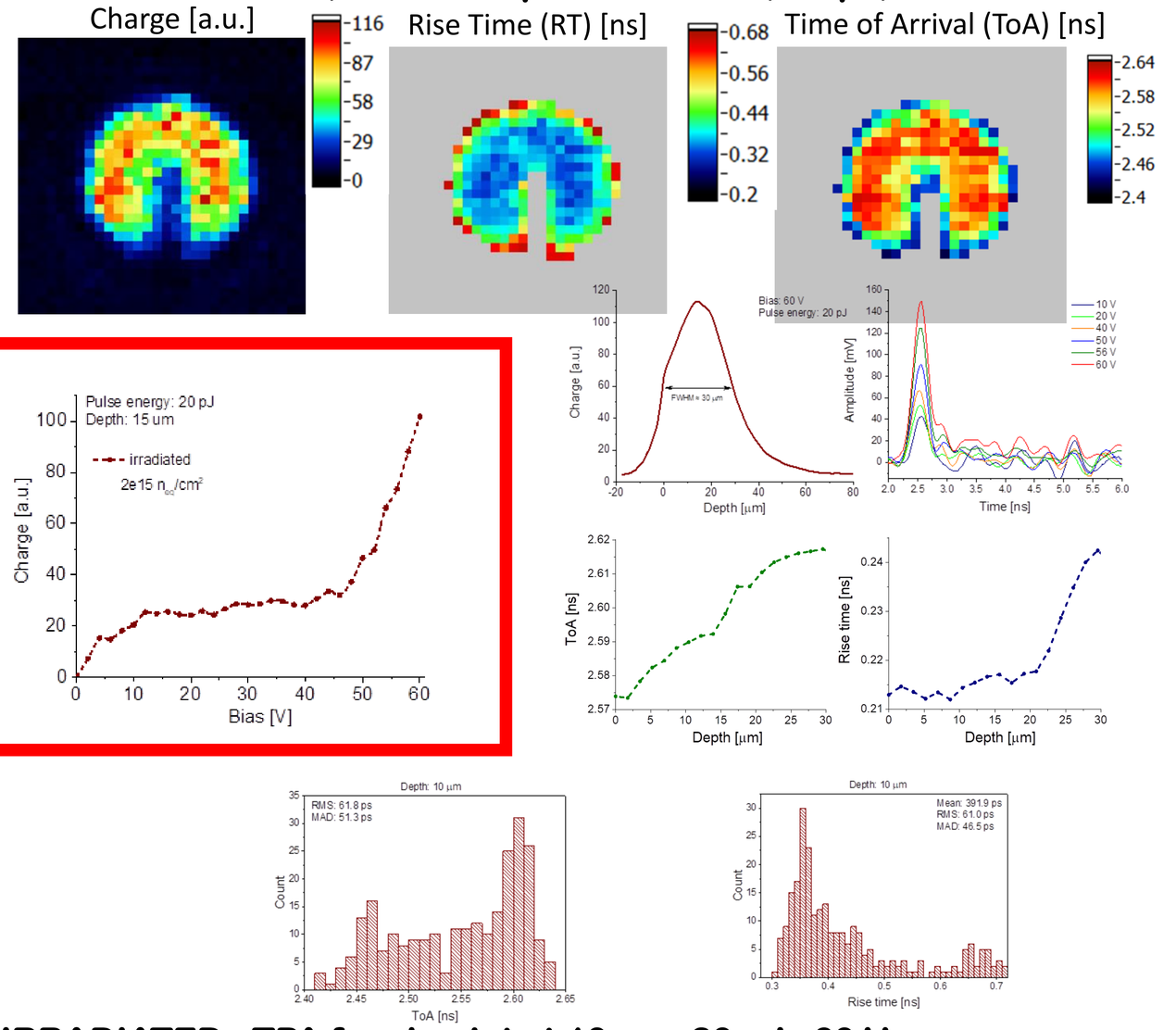


INVESTIGATED SAMPLE

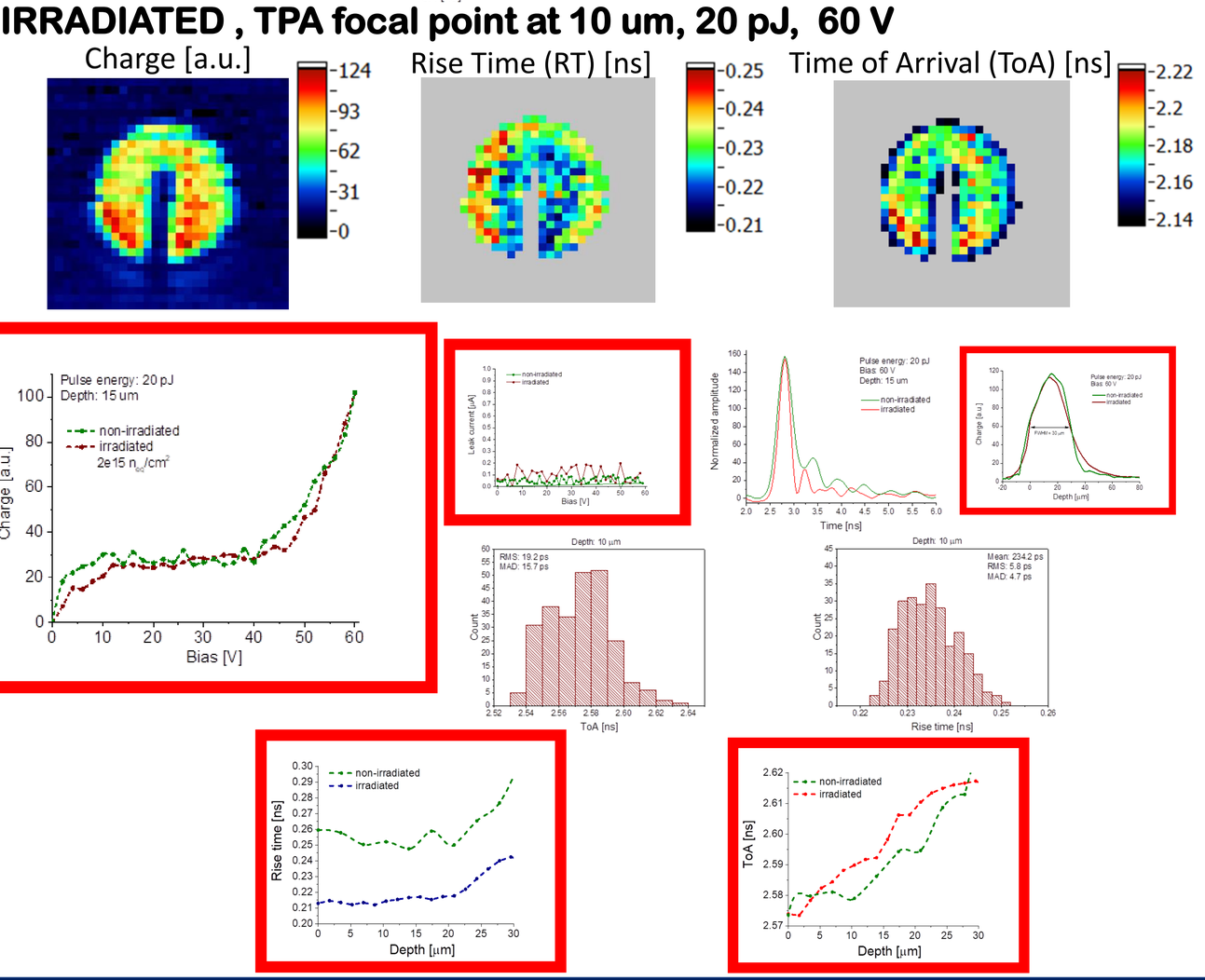


EXPERIMENTAL RESULTS

NON-IRRADIATED , TPA focal point at 10 um, 20 pJ, 60 V



IRRADIATED , TPA focal point at 10 um, 20 pJ, 60 V



CONCLUSION

- ✓ The investigated device is multi-array of 3D cylindrical detectors. Each 3D cylindrical device has diameter or 20 µm, active width of 20 µm and central (junction) electrode of 0.5 µm diameter. Device is produced by utilizing 8-INCH CMOS process at IME-CAS.
- ✓ Although produced as proof of technology and not tuned for optimal timing, devices show great timing resolution (several tens of ps).
- ✓ Opposite to low Gain Avalanche diodes (planar detector), where Gain in charge is achieved via impact ionisation in highly doped gain layer, in 3D Si IMECAS gain is achieved geometrically.
- ✓ Opposite to expectation, no break at the tip of the column electrode (focused el field), at bias close to breakdown (60V) was seen. We assume gain is self-stabilized (due to self-suppression).
- ✓ Negligible impact (almost no effect) on trapping is seen after device was exposed to neutron irradiation at fluency of 2.5e15 n_{eq}/cm^2 in TRIGA reactor at JSI in Ljubljana. This is in agreement with simulation.
- ✓ Timing was improved including the rise time depth dependence.
- ✓ Several 3D pixel from multi-array device is tested and all show the same leakage current, and the same gain at 60 V.
- ✓ Knowledge gain in this research contributes to the next IME-CAS batch product aiming for state of-the art timing device
- ✓ Data collected in this study presents very valuable data for the future ionisation impact study at high fluencies. We will continue study on this device towards the impact ionization coefficient study.

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