

THE impact of single and multiple trenches on interpad resistance and charge multiplication in interpad region:

The Transient Signal Waveforms and X- Profile Analyses

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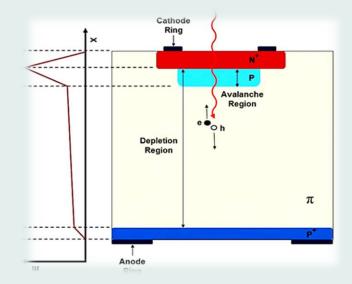
OUTLOOK

- Reminder: UFSD Type 10 from TI-LGAD batch
- 2p-stops and bias ring in interpad region
- TI-LGAD with 2 Trench (non-irradiated)
- TI-LGAD with 2 Trenches (irradiated)
- Ti-LGAD with 1 Trench
- Conclusions



Problem definition

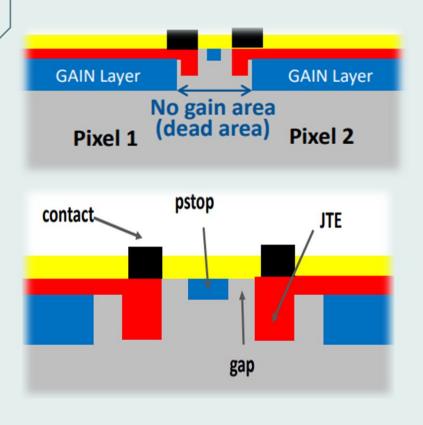
- ➤ 4D tracking a new paradigm in HEP and medical applications (pCT)
- ➤ LGAD mature technology for timing detectors; has excellent timing resolution (30 ps), but spatial resolution is not yet enough good
 - ✓ segmentation problem
 - ✓ Solution: different inter-pad solation and termination structures designed for periphery and inter-pad region
- ➤ Radian hardness sufficiently good for fluencies up to 2.5x10¹⁵ n_{eq}/cm², but above the gain is lost; LGASD behaves as pin
 - ✓ Gain lost
 - ✓ Solution: Different gain design is offered (some of them did not yet pass the Proof of concept and proof of principles)



RESEARCH QUESTION:

> To establish the dependence of the interpad region properties on deposited energy and charge density.

LGAD Segmentation problem



- Detectors with internal gain are typically affected by Fill Factor reduction.
- > Two regions are present:
 - ➤ i) GAIN region (pixel core)
 - ii) NO-GAIN region (pixel border)
- ➤ The pixel border is a dead-region.
- ➤ The carriers generated in this area are not multiplied.
- ➤ This region hosts all the structures to control the E field (JTE, p-stop, etc..)
- ➤ Its dimensions are due to design and technology constraints.
- ➤ Fill Factor = total area /gain area

New strategies to improve Fill Factor

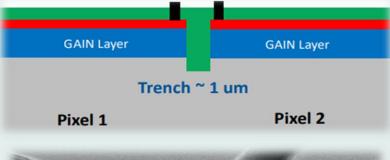
Standard JTE + p-stop isolation

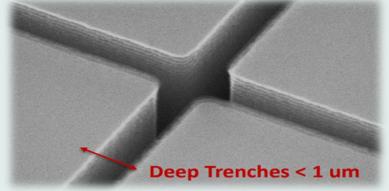




- Trench isolation could drastically reduce the inter-pixel border region down to few microns
- Typical trench width < 1 um</p>

Trench Isolation LGAD

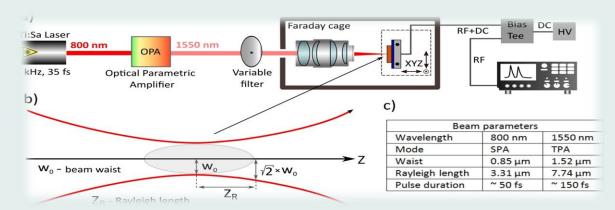




Research Methodology

TCT technique
Designed and developed
at the laser facility ELI
Beamlines, ELI ERIC in
Prague

- ➤SPA & TPA
- ➤Fs-laser, 1KHz
- ➤OPA system (for TPA)
- >XYZ tables
- ➤IR laser (800 nm basic wavelength) with beam focusing
- ➤HV on backplane Operating conditions
- **Cooling @ -25°C** → Cooling @ -25°C
- ➤Insulation cap
- ➤Closed environment



Gordana Laštovička-Medin, et al., "Femtosecond laser studies of the Single Event Effects in Low Gain Avalanche Detectors and PINs at ELI Beamlines.", NIM A: Accelerators, Spectrometers, Detectors and Associated Equipment, Vol. 1041 (2022): pp:167321; https://doi.org/10.1016/j.nima.2022.167321

laser



Extracting the effective IP distance

Fit Erf(x) on charge collection profiles for both pads

- Fit Ert(x) on charge collection profiles for both pads

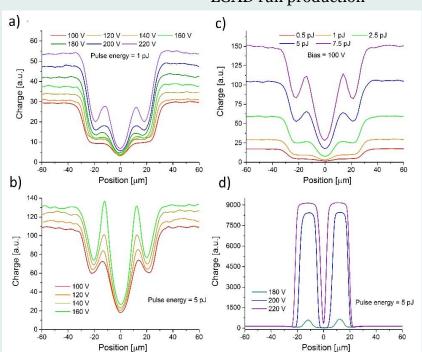
 Take the distance between half maxima as effective IPD
- Maximum collected charge changes with irradiation and voltage, also depends on laser power

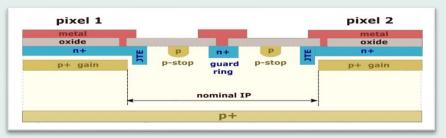
Reminder:

Non typical "UFSD" with 2 p-stops + bias; IP = 49 μ m

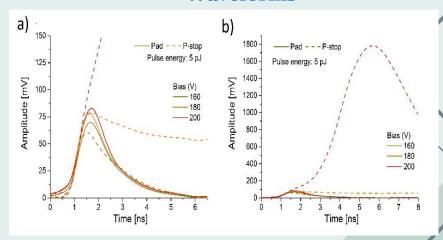
X-profile

Reference UFSD type 10 from TI-LGAD run production





Waveforms

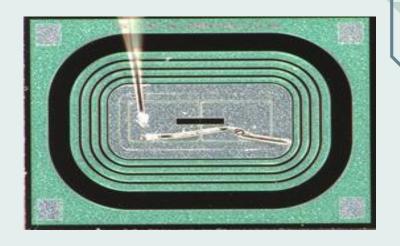


Trenched LGAD W112 Tr C1 V2* * x

Array of sensors (3x2).

Standard SPA experiment at 800 nm. Jumpy signal at RT but cooling to -20C improves stability.

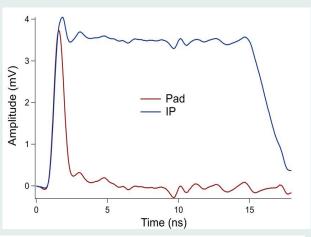
A double trench sensor exhibits increase of the signal in entire IP region. More precisely, the waveforms are significantly broadened in IP region (see next slide). The width of this region is about 10 um.



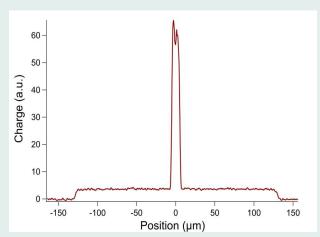
If we look closer in X-profile of IP we can see something like 2-peaks structure but it's hard to say if this is real double trench structure resolved.

Even at low temperature, the signal in IP region is still quite jumpy.

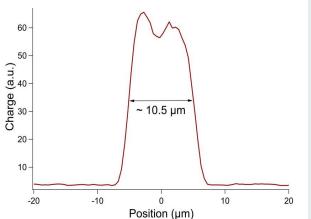
X-profiles & Waveforms at 0.2 pJ and 100 V



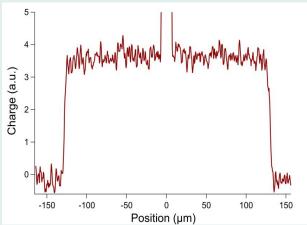
Waveforms in the center of pad and in the center of IP region



When we integrate the waveforms to get the charge X-profile this broadening results in strong increase in IP region.

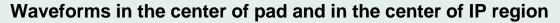


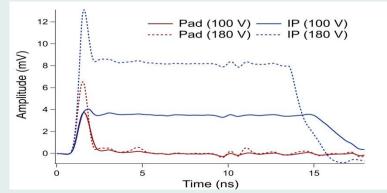
X-profile: t's hard to say if this is double trench resolved structure because the signal is quite jumpy in IP.



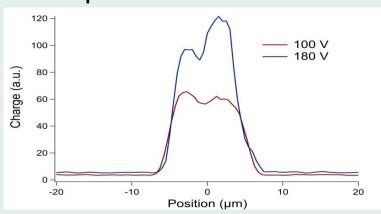
X-profile – vertical zoom

Comparison for two different biases: 100 \lor and 180 \lor

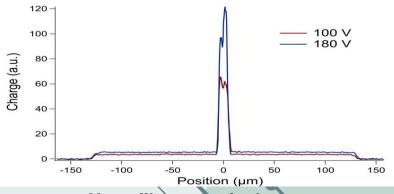




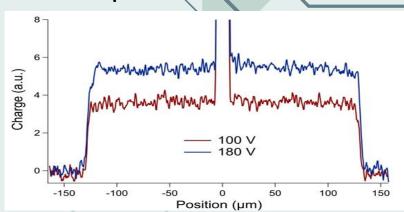
X-profiles - horizontal zoom



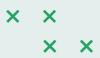


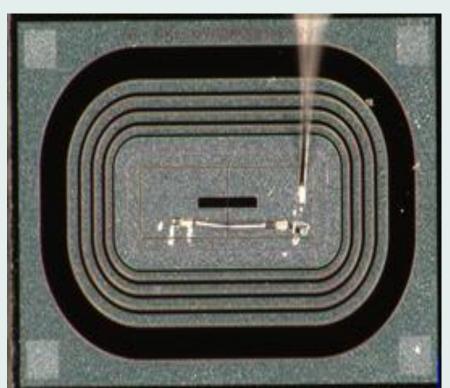


X-profiles - vertical zoom



W11 C2-V2-2TR IRRADIATED

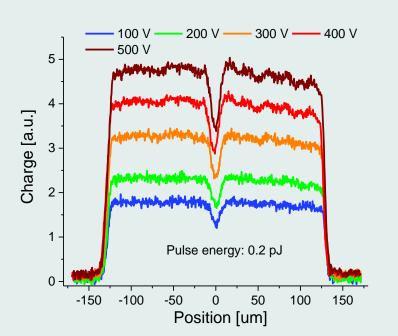


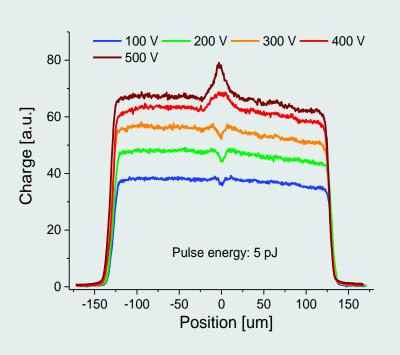


Standard SPA experiment at 800 nm Temperature: -20 C, No amplifier

Bias range: 100-500 V

X-profiles at 0.2 pJ and 5 pJ vs bias

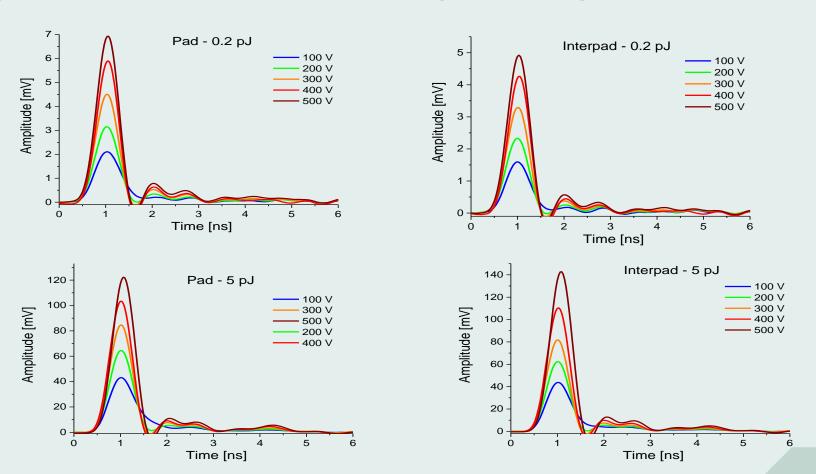


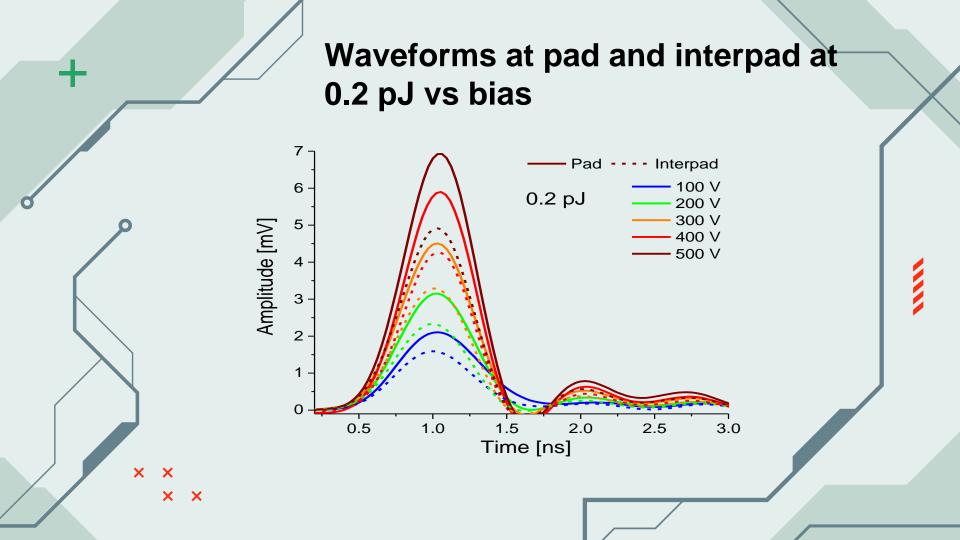


X

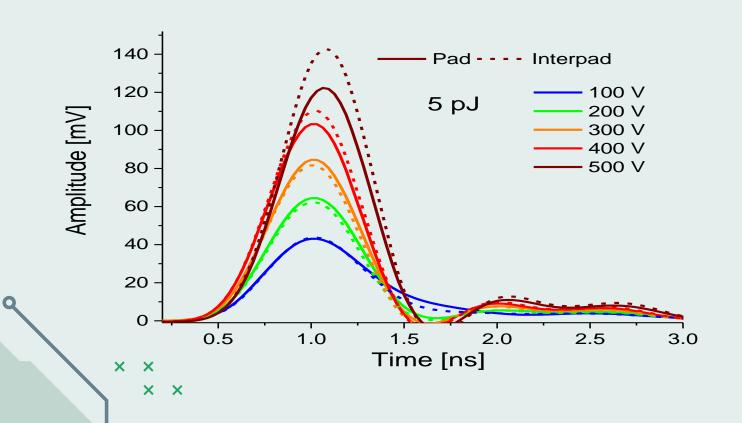
in contrast to non-irradiated one here the enhancement of the signal is much smaller and it's present only for high power (5 pJ) and high bias (500 V). Since 500 V is very close to burnout limit we didn't go higher to avoid SEB.

Waveforms at 0.2 pJ and 5 pJ vs bias





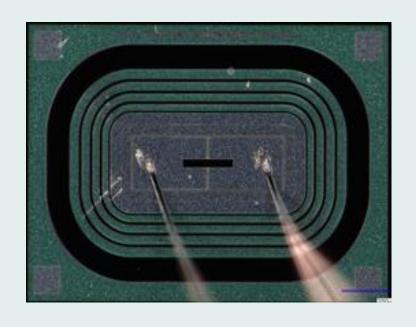
Waveforms at pad and interpad at 5 pJ vs bias

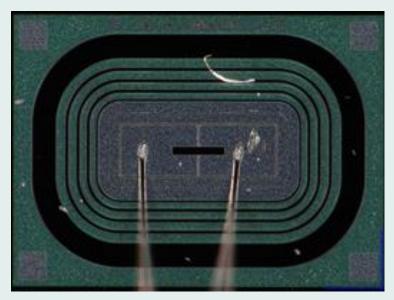


Single trenched LGAD

1TR W11 A C1V3

1TR W11 A1 C1V4

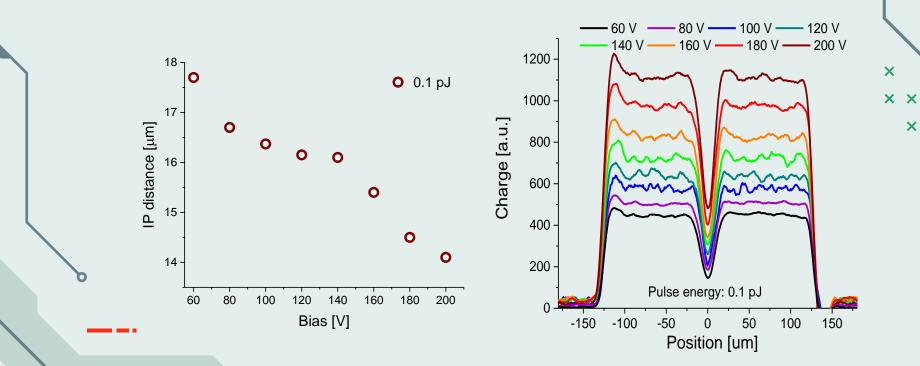




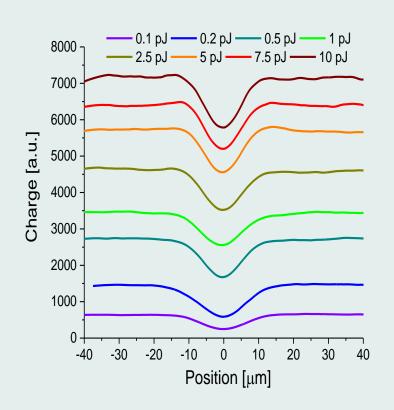
1TR W11 A1 54 C1V3

Full X-profiles vs bias at 0.1 pJ

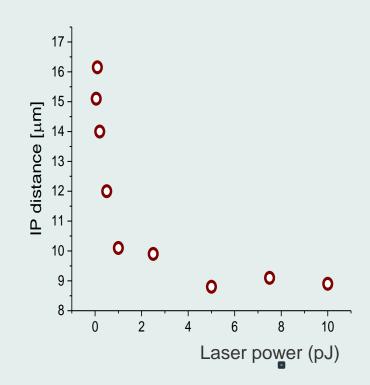
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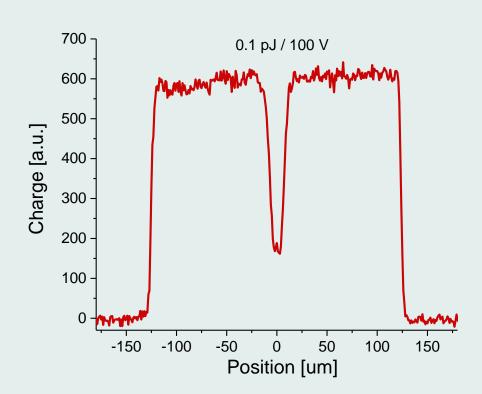
X profiles vs power at 100 V



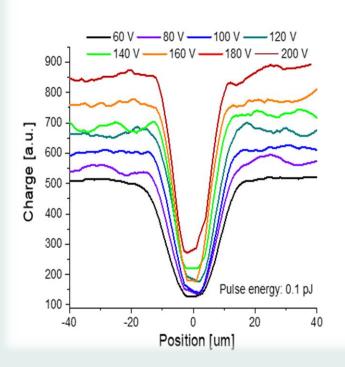
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1TR W11 A1 54 C1V4 Full X-profile at 0.1 pJ and 100 V



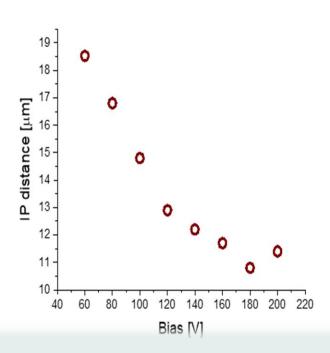
X-profiles vs bias at 0.1 pJ



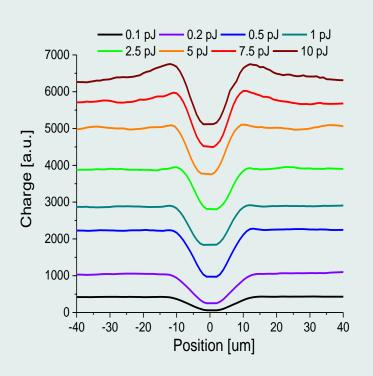
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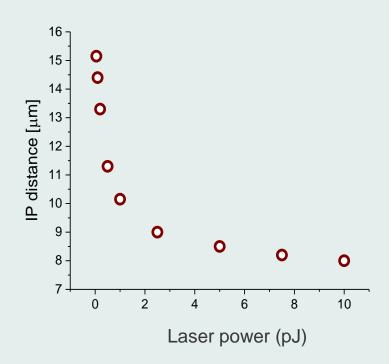
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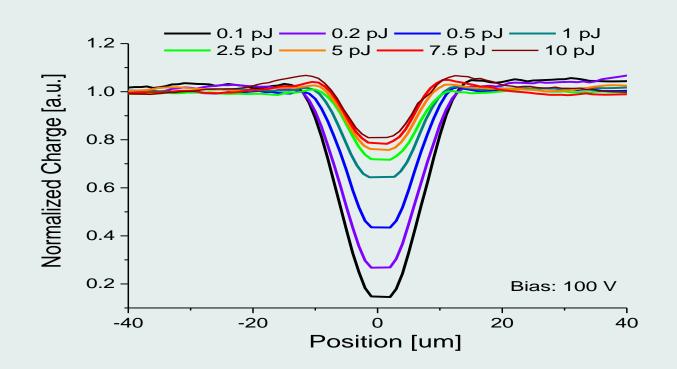
× × X profiles vs power at 100 V



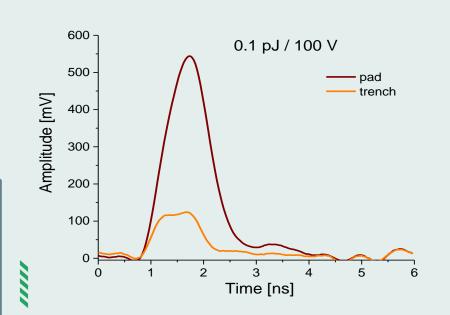


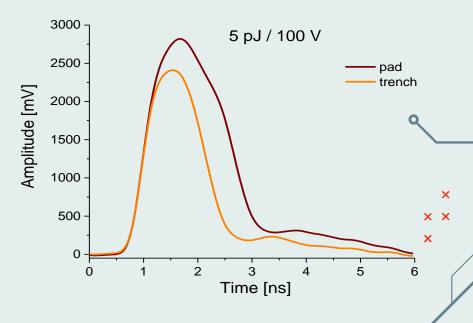
× ×

NORMALIZED



Waveforms vs power at 100 V





CONCLUSIONS

- Previously observed strong excess of charge in IP region near p-stops in UFSD with 2p-stops and bias ring as isolation structure (from TI=LGAD batch) has been studied in trenched LGADs.
- > This enhancement is bias and laser intensity dependent

 \times \times

X

- Strong Charge Multiplication is also observed in proximity of Trenches in TI-LGADs with 2 trenches
- ➤ Much stronger excess and very broaden waveform is observed in this case; the two peaks are also observed in IP region but they are less resolved (Trenches are also closer to each other than p-stops are in UFSD Type 10 (with 2p-swtops and bias ring)
- Asymmetry in 2 peaks (although not well resolved) in IP region is also observed; it increases with bias; it could be related to difference in trench etching
- Radiation significantly reduces the CM in IP region (Vanja will say more in her talk)
- No spikes (no CM) are observed in single Trenched LGAD

