Performance Evaluation of Ultra-Thin Low-Gain Avalanche Diodes (LGADs) for Fast Timing and 4D Tracking

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Introduction

Goals

- Detectors for **Electron Ion Collider (EIC) ~ 20ps** timing resolution
- Designs that suit the specific requirements of various sub-detector systems to accomplish the physics goals of the Electron-Ion Collider (EIC)

Fast Timing Detectors

- Low Gain Avalanche Detector (LGAD) based technology.
- Thin detectors (for fast signal processing)
- Suitable candidate for **timing applications**
- Applications in Particle Physics (particle identification), as well as in medical and space facilities

Pellegrini, Giulio, et al. *NIM A* 765 (2014): 12-16.

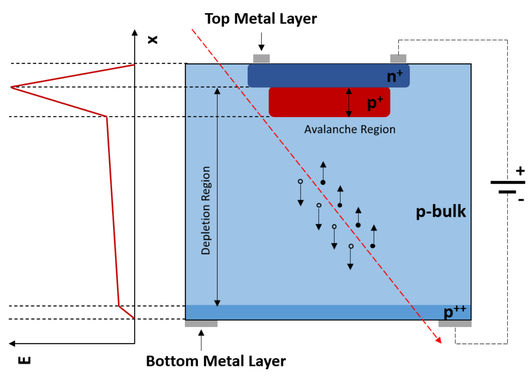

Figure 1: Schematics of a standard-LGAD structure.

Pictures are not to scale!

Giacomini, Gabriele, et al. NIM A 934 (2019): 52-57.

Devices Under Test (DUT)

- LGADs and diodes used in this work are from wafer 3082 and 3108, manufactured by **BNL, USA.**
- The difference in LGAD as compared to diode is the additional **p⁺-implant (gain layer).**
- Device parameters are given in Table 1.

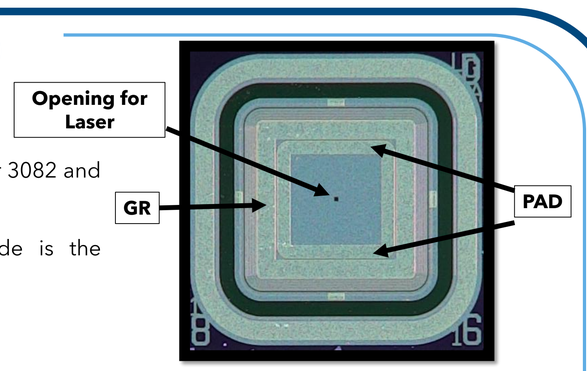

Figure 2: Image of an LGAD with 50 µm opening.

Table 1: Details of the devices used in this work

Wafer	Thickness (µm)	V_{GL}	V_{FD}	End Capacitance	Pixel Size (mm)
3082	20	21 V	22 V	10pF	1.3x1.3
3108	30	21 V	23 V	7pF	1.3x1.3

Electrical Characterizations: I-V & CV

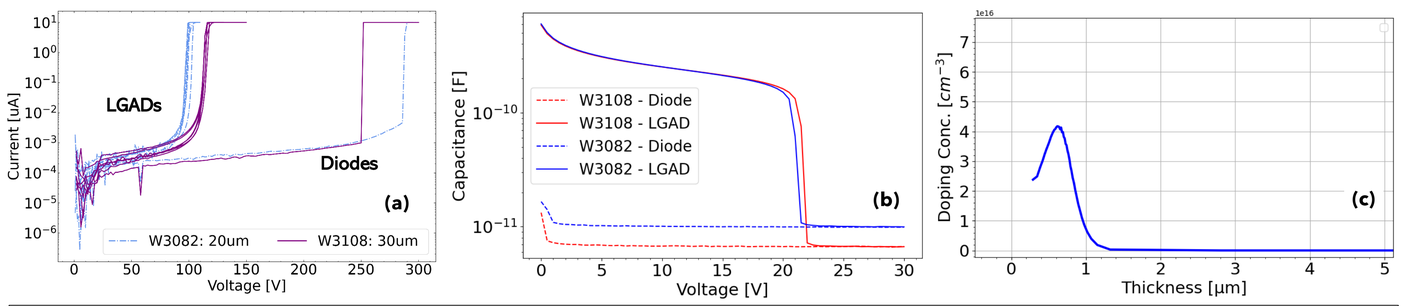

Figure 3: (a) Current-Voltage characteristics of LGADs and diodes from wafer 3082 and 3108. (b) Capacitance-Voltage characteristics of LGADs and diodes from wafer 3082 and 3108. (c) Doping concentration of the LGAD from the wafer 3082, calculated from CV curves.

- Figure 3(a): Leakage current is **nanoamperes (nA)** before breakdown. Breakdown due to avalanche is observed at **90 V** for wafer 3082, and **110 V** for wafer 3108. Breakdown voltage for diodes is in the range of 250 – 300 V.
- Figure 3(b): Higher capacitance is observed from w3082 (20µm), as thinner devices have higher capacitance. The gain layer starts to deplete at V_{GL}=**21V** for both thicknesses, but full depletion occurs at V_{FD} = **22V** for w3082 and V_{FD} = **23V** for w3108. End capacitance for w3082 is C_{END} = **10pF**, and for w3108 is C_{END} = **7pF**.
- Figure 3(c): Doping concentration shows that the gain layer implant is shallow, i.e., ~ peak at **0.7 µm**.

TCT Setup

- Infrared Laser **(1064 nm)** used for charge creation.
- **10 µm** beam waist
- xy-stage with sub-micron precision
- Tuneable laser intensity

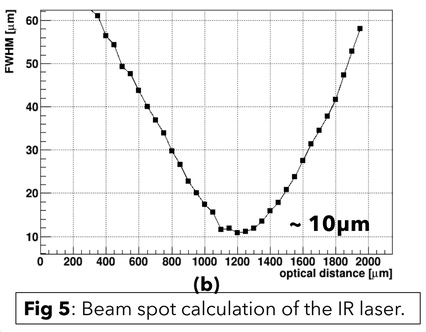

Fig 5: Beam spot calculation of the IR laser.

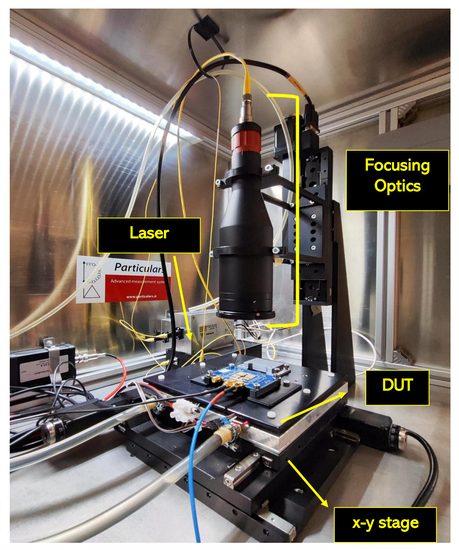

Figure 4: TCT setup at AGH University of Krakow.

LASER Characterizations

GAIN

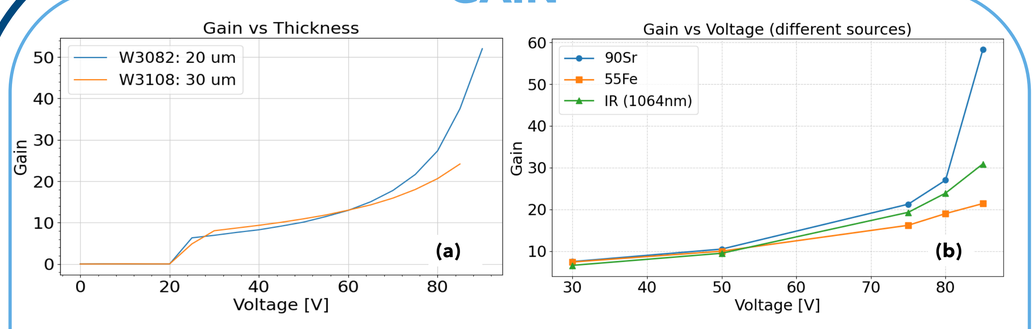

Figure 6: (a) Comparison of the gain with different active thicknesses. (b) Comparison of the gain from w3082 with different sources for charge creation.

- Gain of **~ 15** is observed around **70 V**.
- Gain does not vary with active thickness before approaching avalanche, as shown in Fig. 6(a).
- Different sources i.e. **90Sr**, **55Fe**, and **IR laser** were used to create e/h pairs in silicon to observe variation in gain.
- The gain calculated with the IR laser is similar to 90Sr as seen in Fig. 6 (b)

GAIN SUPPRESSION

- Gain suppression is a well-known phenomenon where the **reduction of gain** is observed when laser intensity is increased.
- The gain reduction is observed due to the **screening effect** of the charge carriers below the gain layer, which prevents further charge carriers from undergoing multiplication.
- Laser intensity is depicted here as a DAC value percentage, where a **higher percentage** refers to a **lower laser intensity**.
- Correlation between DAC percentage and collected charge is shown in Fig. 7 (a)
- Gain suppression is shown in Fig. 7 (b, c) and is observed in LGADs from both wafers.

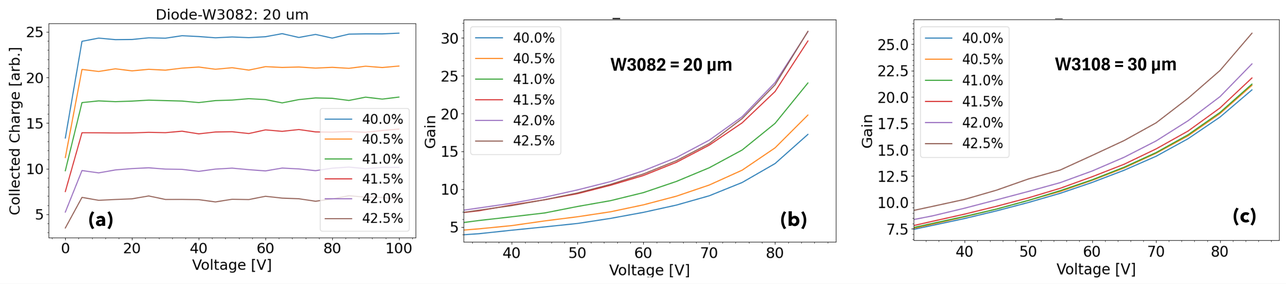

Figure 7: (a) Collected charge versus voltage in a diode with increasing laser intensity. (b) and (c) shows gain suppression for higher laser intensities in w3082 and w3108, respectively.

Time Resolution

- Time-resolution measurement setup is installed in AGH University of Krakow, which is an extension of the conventional Laser TCT system.
- Gives a good estimation of time-resolution with controlled laser system.

Currás, Esteban, et al. *NIM A* 958 (2020): 162545.

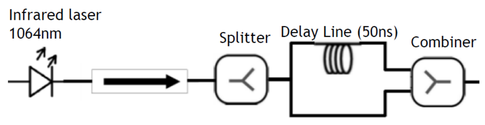

Figure 10: Schematics of time-resolution measurement setup using Laser TCT system.

$$\Delta t = t_2 - t_1 \quad \text{(time of arrival)}$$

$$\sigma_{LGAD} = \frac{\sigma_{\Delta t}}{\sqrt{2}} \quad \text{(time resolution)}$$

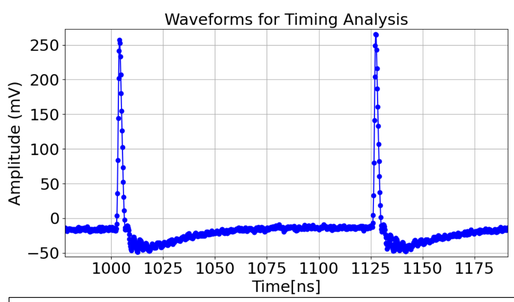

Figure 10: Waveform obtained from the experimental setup explained in Fig. 9.

- Splitting the laser with a delay line of ~ **120 ns** gives two laser pulses as shown in Fig. 10.
- A sample of **1000** waveforms is taken without averaging, to analyze timing performance of the detector.
- Requires further analysis (future work)

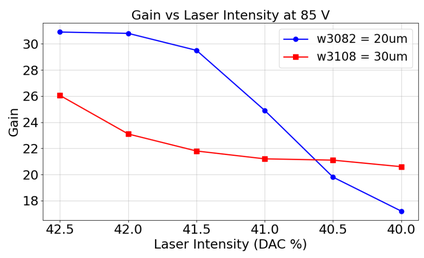

Figure 8: Estimation of gain suppression with increasing laser intensity for w3082 and w3108.

- Higher laser intensity results in lower gain.
- Reduction of gain is not consistent across the wafers and devices
- For devices under study, estimated gain suppression for **w3082 is ~ 45%,** and for **w3108 is ~ 21%,** as shown in Fig. 8.
- Collection time for both wafers is around **2 ns**, which enables these detectors timing applications.
- No effect of laser is observed in the collection time with increasing laser intensity, as shown in Fig. 9.

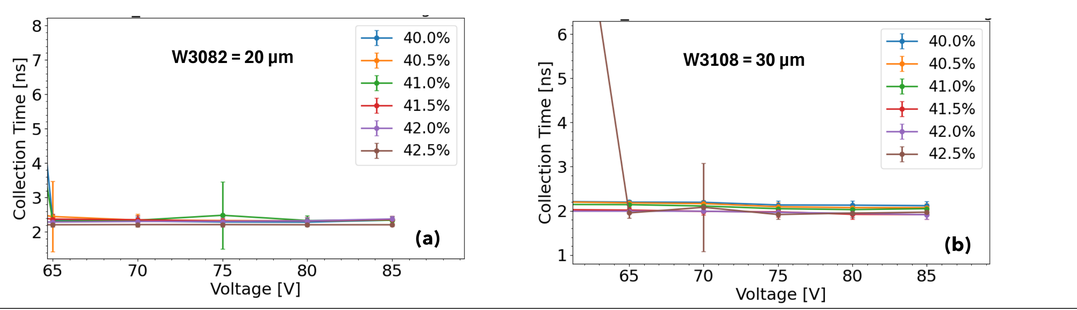

Figure 9: Collection time of the charge carriers as a function of increasing laser intensity for (a) w3082, and (b) w3108.

Currás et. al. *Nucl. Instrum. Methods Phys. Res., A* 1031. arXiv: 2107.10022 (2021): 166530.

Summary

Conclusions

- Response of these LGADs are significantly fast (2 ns collection time), enable them for 4D tracking
- Higher laser intensity leads to gain suppression.
- Gain is consistent across wafers
- No early breakdown is observed -> Breakdown due to avalanche

Future Work

- Irradiation studies with protons on these devices is planned in future.
- Time-resolution measurements before and after irradiations will be carried out.

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