50 µm Thick LGAD: Electrical Characterisation & Gain Measurement

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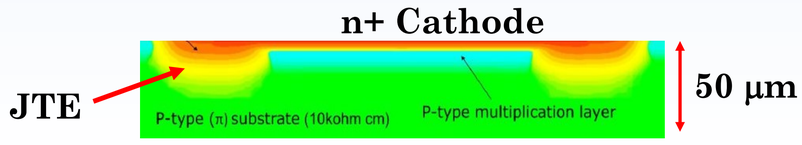
Introduction

- The Low-Gain Avalanche Detectors (LGADs) operate with an internal charge multiplication [1].
- Higher signal output compared to standard diode for MIP – excellent timing resolution.
- Identified as one of the candidates for the High-Granularity Timing Detector for ATLAS Phase-II upgrade [2].
- Typical structure: n+/p/p-/p+ on p-type high resistivity substrate [3].
- Reports the electrical characteristics & gain of 50 µm thick LGADs with various gain implant doses.

Materials and Methods

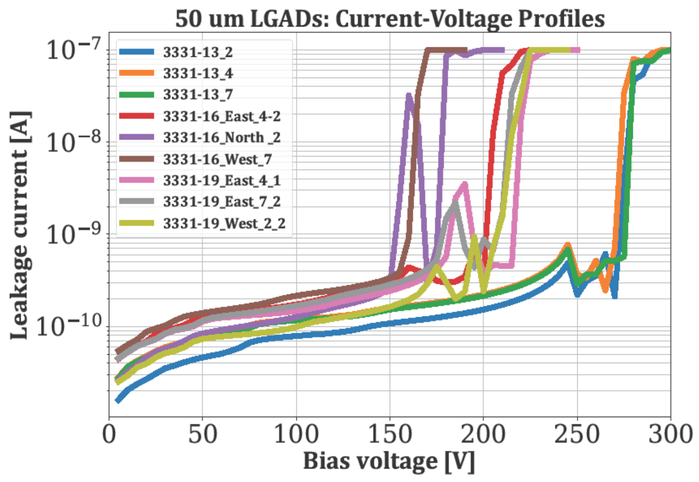
The LGADs



Wafer ID	Device ID	Pixel Size (mm²) + JTE (µm)	Electrical Characterisation	Gain Measurement
3331-19	West_2-2	(0.22 x 0.22) + 10	Current-Voltage	Single Photon Absorption (SPA) TCT
	West_7-2	(0.50 x 0.50) + 10	Capacitance-Voltage	Source: IR Laser
3331-16	North_2	(0.22 x 0.22) + 10	Temp (°C). = 24 ± 2	
	North_4	(0.50 x 0.50) + 20		Beam size: FWHM 10µm
	North_7-1	(0.50 x 0.50) + 10	RH (%) = 44 ± 3	Temp.(°C): 30, 10, 0, -10, -20, -24
	East_38	(1.0 x 1.0) + 20		
3331-13	2	(0.22 x 0.22) + 10		
	4	0.50 x 0.50) + 20		
	7	(0.50 x 0.50) + 10		
3331-19	East_29	(1.0 x 1.0) + 10	LGADs used for the gain measurement	
3331-19	West_7-2	(0.50 x 0.50) + 10		
3331-19	West_2-1	(0.22 x 0.22) + 10		

Gain Implant Dose: Wafer 3331-19 > Wafer 3331-16 > Wafer 3331-13

Electrical Characteristics

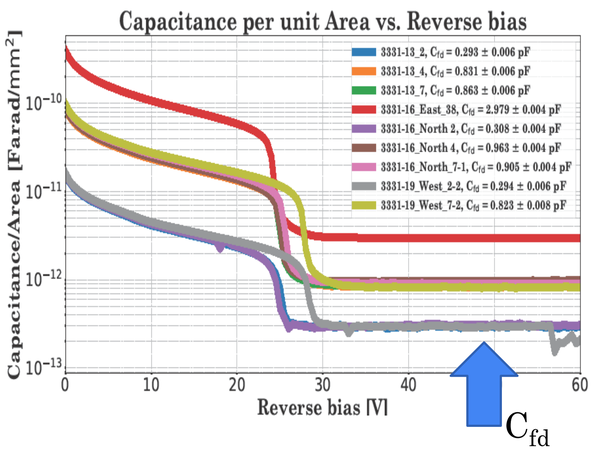


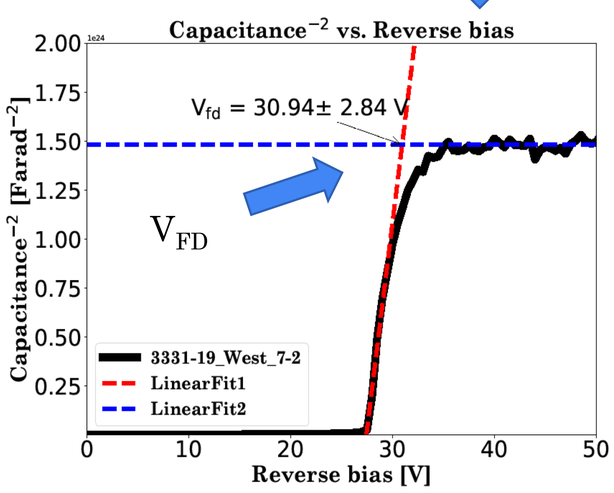
Current-Voltage (IV)

Device ID	V_{bk} (V)
3331-19	200-210
3331-16	150-180
3331-13	260 – 280

LGADs breakdown at voltages at least 5 x V_{fd}

Capacitance – Voltage (C-V)

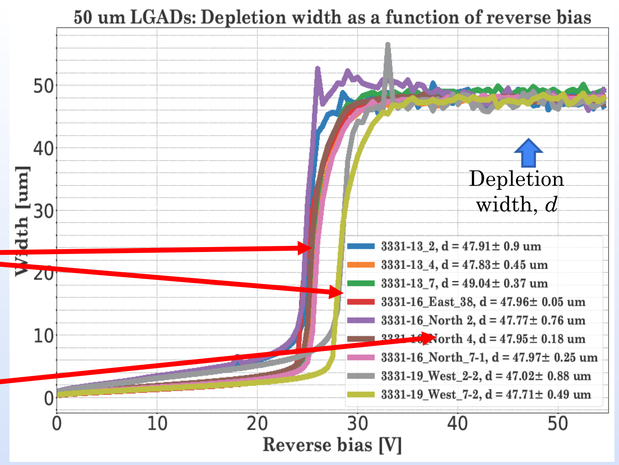




- Total Capacitance /Area at full depletion, C_{fd}/Area = C_{pixel} + C_{edges}
- Depletion extended close to the 1st Guard ring

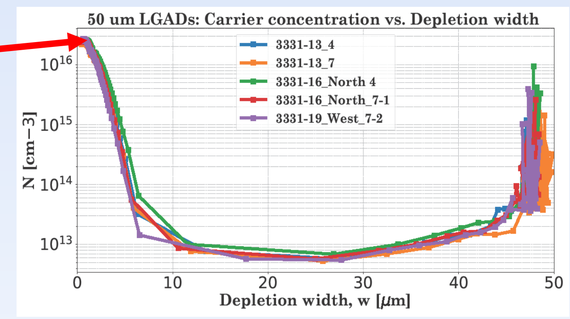
LGADs with a higher gain implant dose (3331-19) depleted at a higher voltage

Full depletion width, d ≈ Physical Thickness (48.75 ± 0.50 µm)



Gain Doping concentration, $N_{Eff.}$

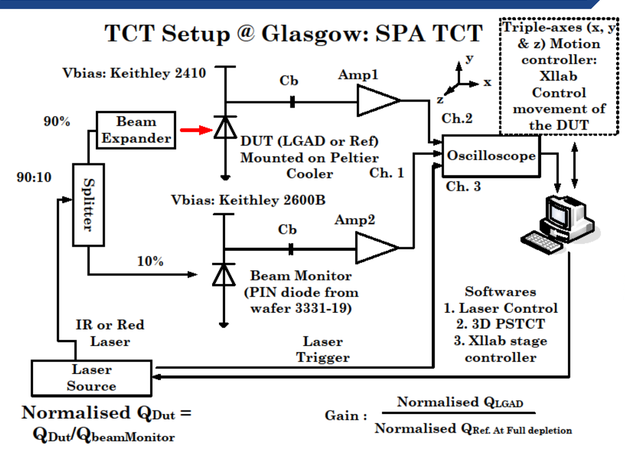
Device	Peak ($10^{16}cm^{-3}$)
3331-19_West_7-2	2.72
3331-16_North_7-1	2.61
3331-16_North-4	2.46
3331-13_7	2.37
3331-13-4	2.44

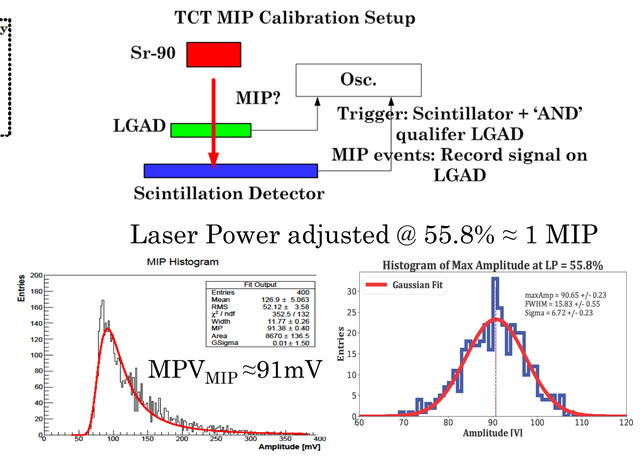


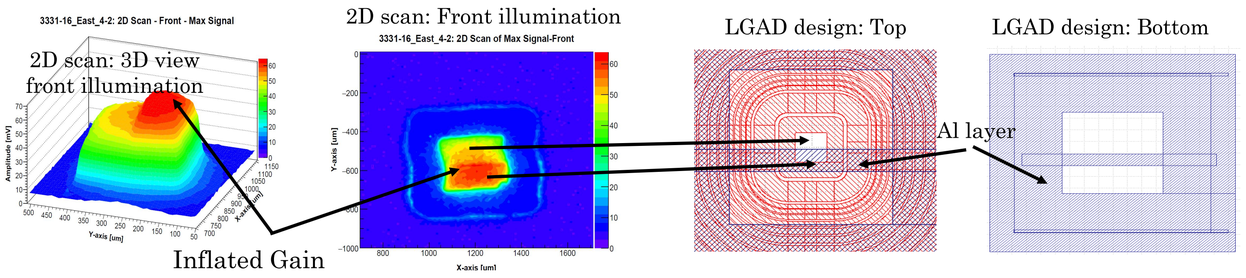
C-V Measurement Summary

LGADs	Pixel Size (mm²) + JTE(µm)	V_{fd}(V)	C_{fd}(pF/mm²)	Depletion Width, d (µm)
3331-19_West_2-2	(0.22 x 0.22) + 10	30.31	0.29	47.02 ± 0.88
3331-19_West_7-2	(0.5 x 0.5) + 10	30.95	0.82	47.71 ± 0.49
3331-16_North_2	(0.22 x 0.22) + 10	26.24	0.31	47.77 ± 0.76
3331-16_North_4	(0.5 x 0.5) + 20	27.62	0.96	47.95 ± 0.18
3331-16_North_7-1	(0.5 x 0.5) + 10	28.68	0.91	47.97 ± 0.25
3331-16_East_38	(1.0 x 1.0) + 10	28.35	2.98	47.96 ± 0.37
3331-13_2	(0.22 x 0.22) + 10	26.64	0.29	47.91 ± 0.90
3331-13_4	(0.5 x 0.5) + 20	28.36	0.83	47.83 ± 0.37
3331-13-7	(0.5 x 0.5) + 10	28.30	0.86	49.04 ± 0.37

Gain Measurement

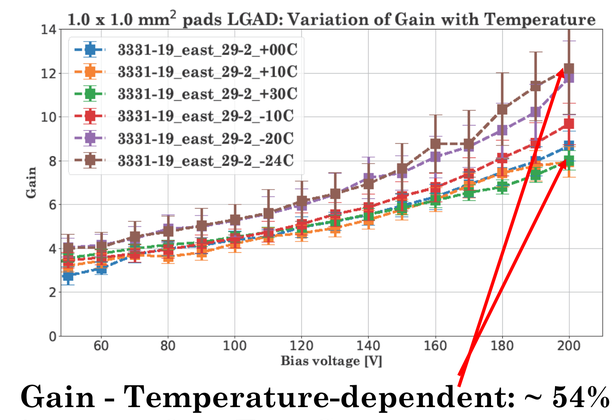


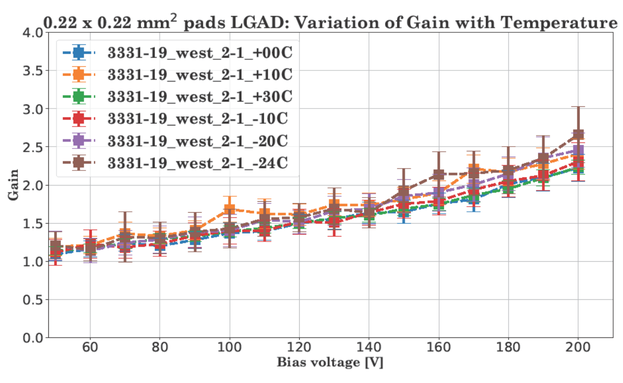




- **Inflated gain** due to **reflection**: More primary e⁻/h pairs -> Gain increased.
- Avoid this region for measuring the gain

Gain at various Temperature





Gain - Temperature-dependent: ~ 54% increase for ΔT 50°C

Gain is a function of pixel size:
- Small pixel effect reduced fill-factor in LGAD with JTE design [4].
- Unable to position the laser in the middle to avoid reflection.

Device	Pixel Size (mm²)	Gain @ 30°C	Gain @ -24°C	% increase
3331-19_East_29_7-1	1.0 x 1.0	8.0	12.3	54
3331-19_West_7-2	0.5 x 0.5	3.4	4.8	41
3331-19_West_2-1	0.22 x 0.22	2.2	2.7	23

Conclusion

- A Fully depleted 50 µm thick LGAD attains a **gain of 12 at 200V at -24 °C**.
- LGAD with a **higher gain implant dose** is fully depleted at a **higher voltage**.
- The breakdown voltages are **5-9 times higher** than the **full depletion voltages**.
- The **gain is temperature-dependent**, with a **54 % increase for a 50°C** change in temperature.
- **Gain variation** as a function of **pixel size** is understood; it was due to the **reduction of fill-factor (*small pixel effect*)** in LGAD with JTE structure.

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References

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