Design and Fabrication of IHEP-IME ultra-fast timing sensors (ATLAS)

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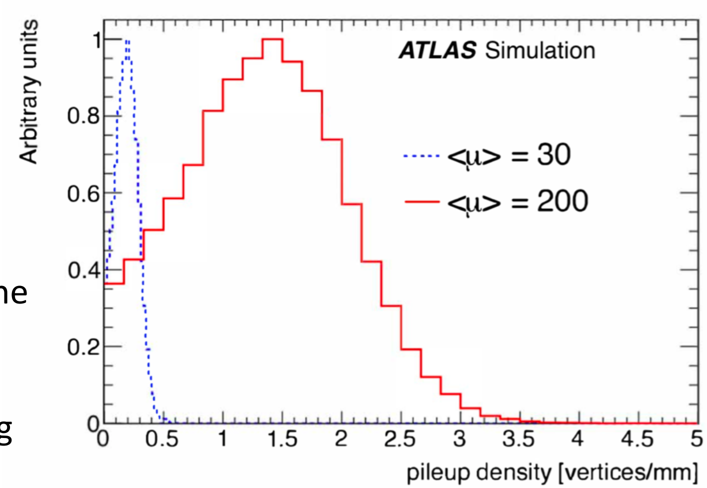
2020/11/08

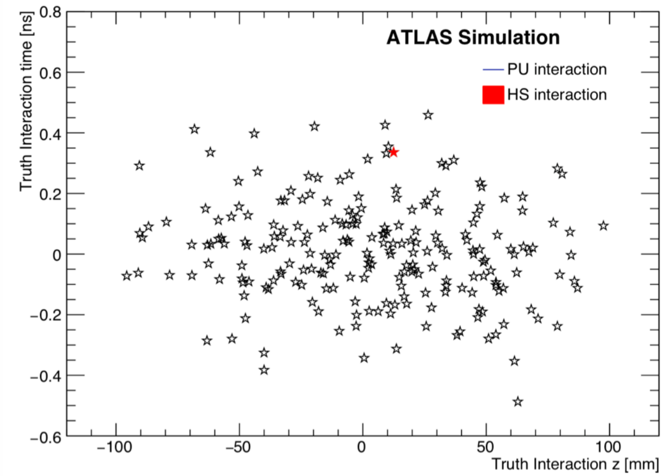
HL-LHC & ATLAS HGTD

The high-luminosity (HL) phase of the Large Hadron Collider (LHC) at CERN aims to deliver to deliver an integrated luminosity of up to 4000fb^{-1}.

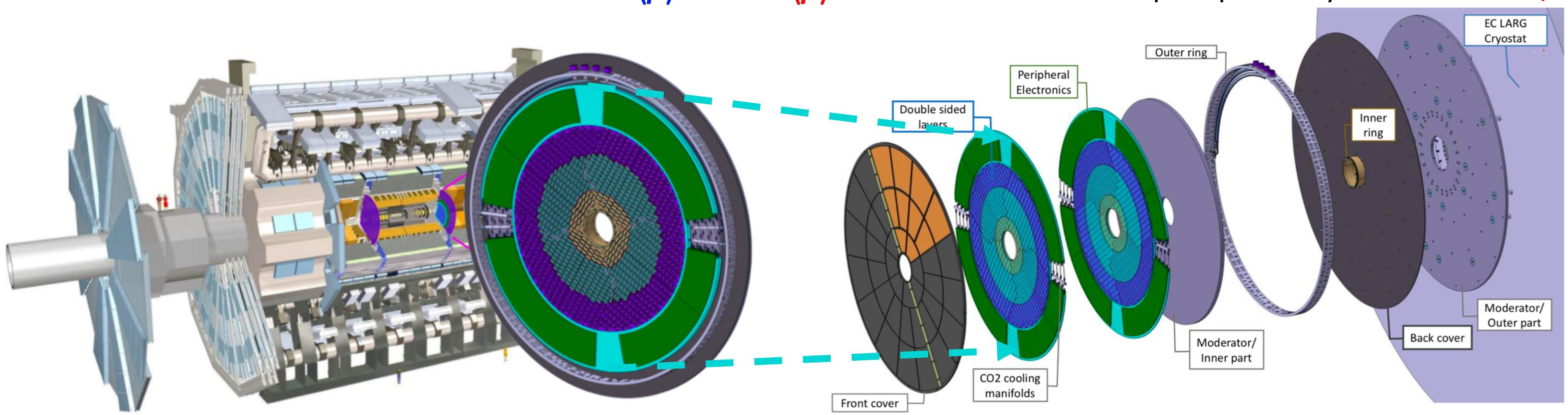
The instantaneous luminosity of the HL-LHC will reach up to 7.5×10^{34} cm^{-2} s^{-1}, a large increase from the 2.1×10^{34} cm^{-2} s^{-1} obtained during Run 2 of the LHC



$\langle\mu\rangle = 30 \rightarrow \langle\mu\rangle = 200$

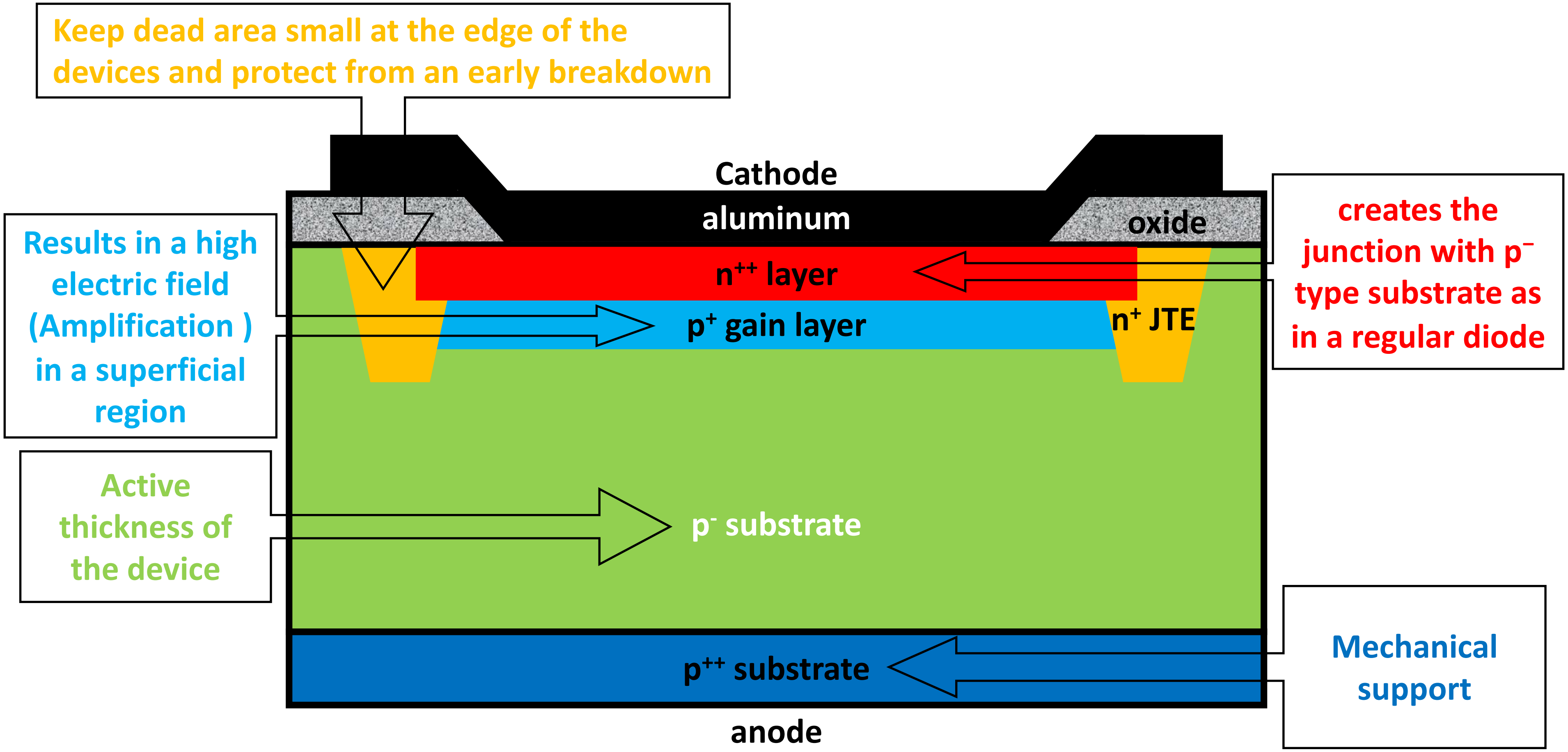


local pileup density is 1.44 vertices/mm

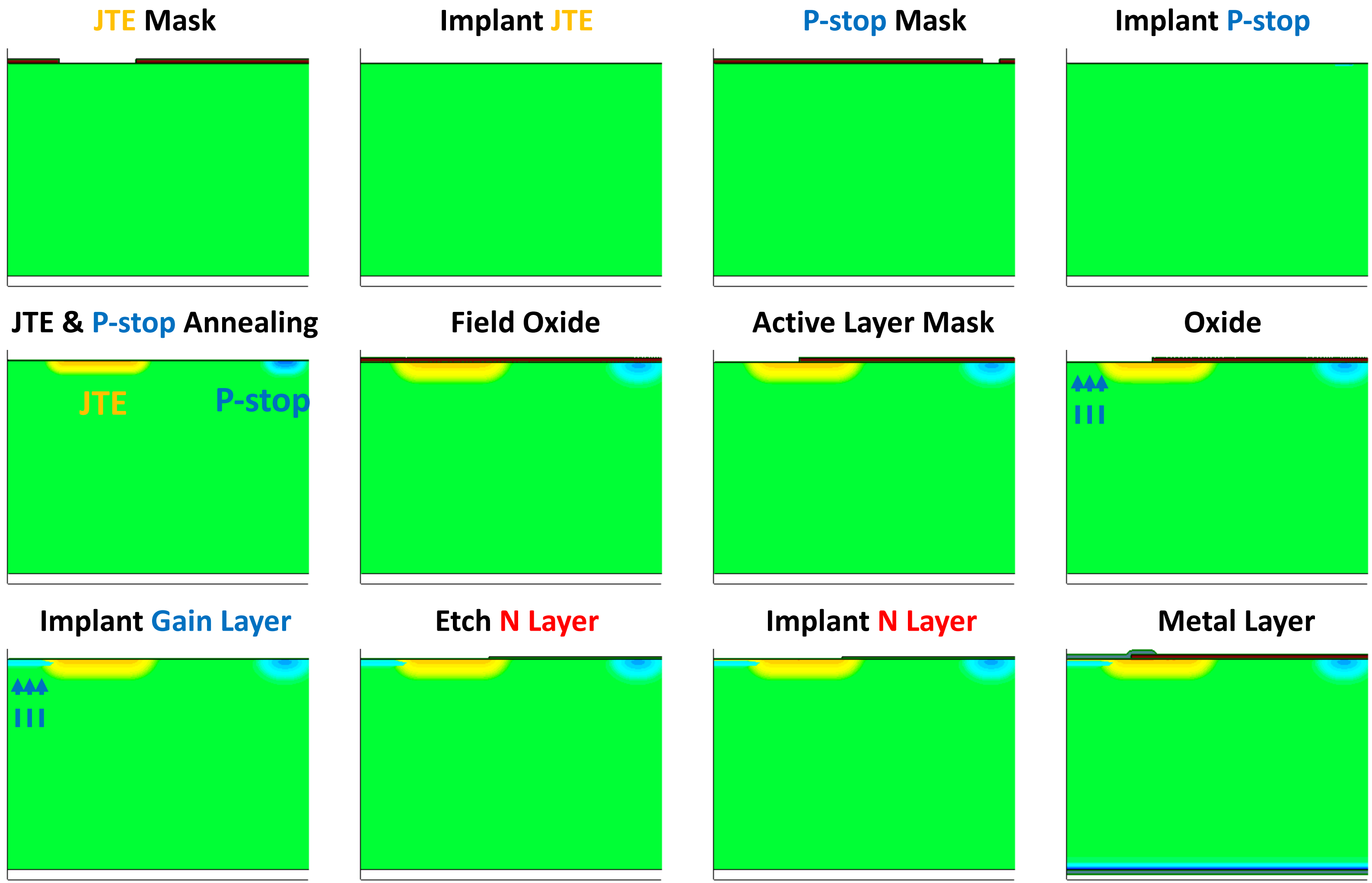


The ATLAS Collaboration, *Technical Design Report: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade*, **CERN-LHCC-2020-007 ATLAS-TDR-031**

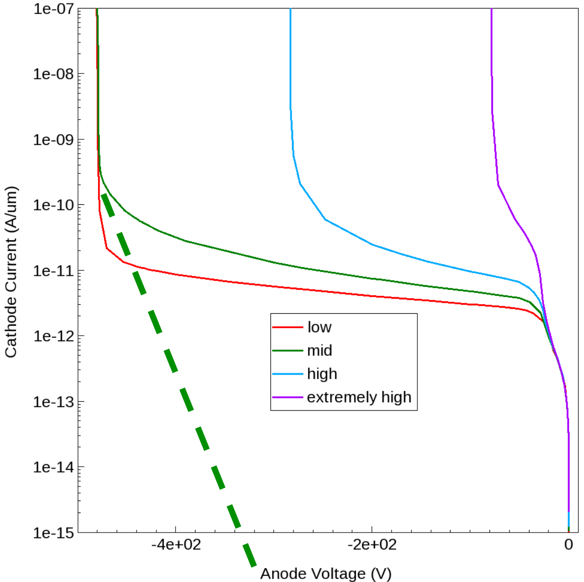
LGAD Sensor Structure



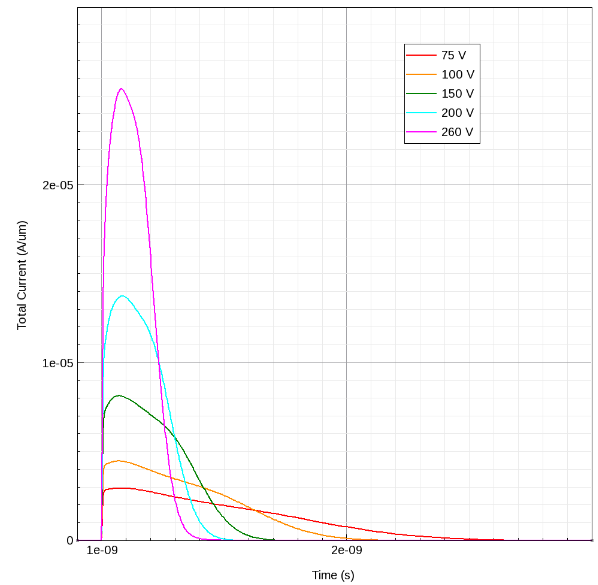
Fabrication Process Simulation



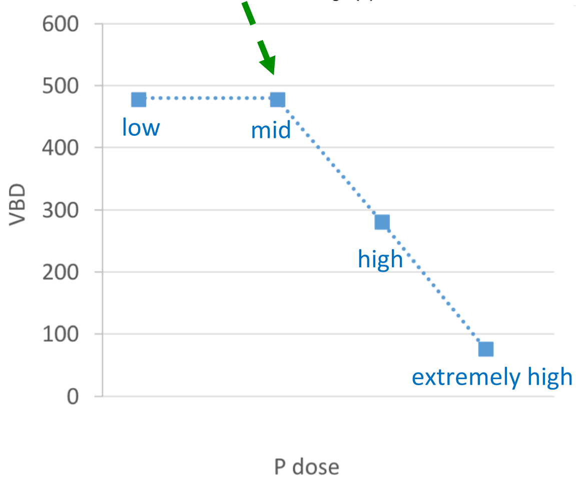
IV and Gain Simulation



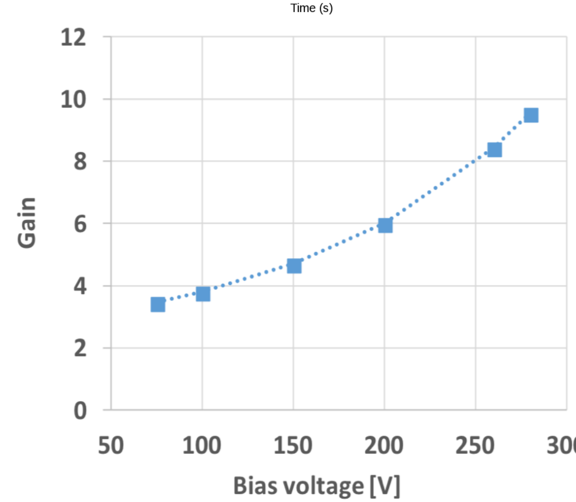
IV simulation curves for different gain layer implantation dose: higher dose leading to lower breakdown voltage



Charge collection curve with different bias voltage: higher bias voltage leading to more collected charge

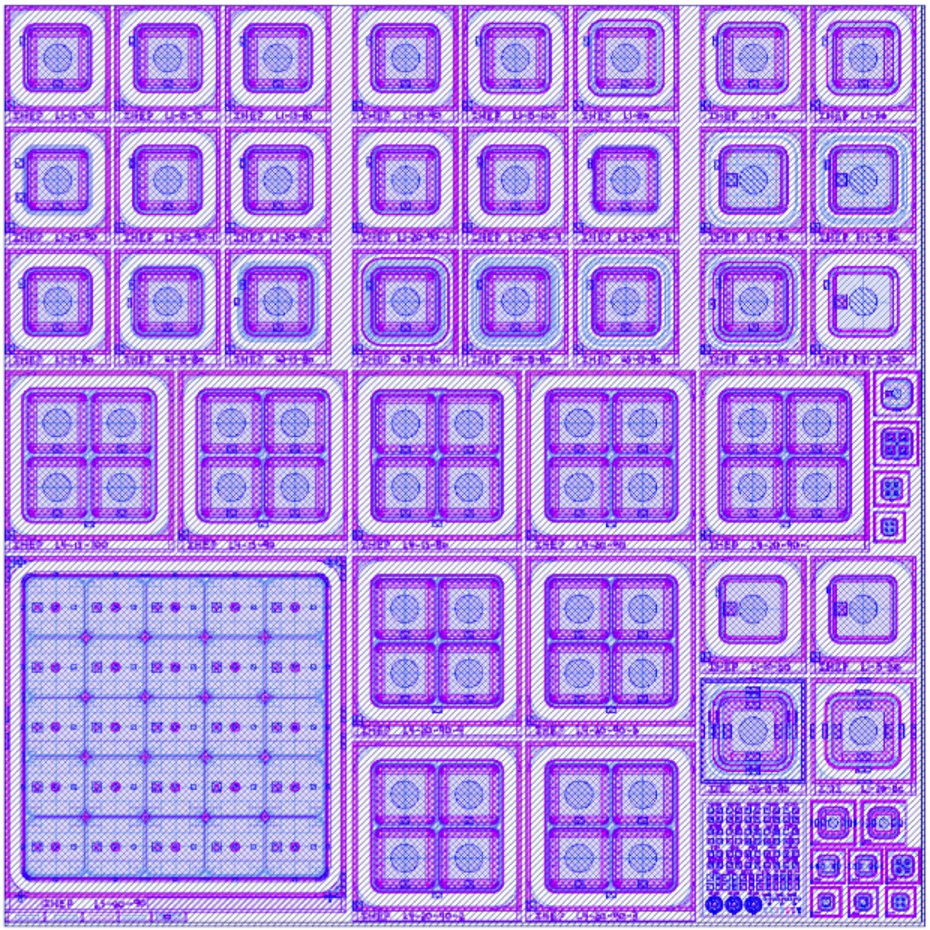


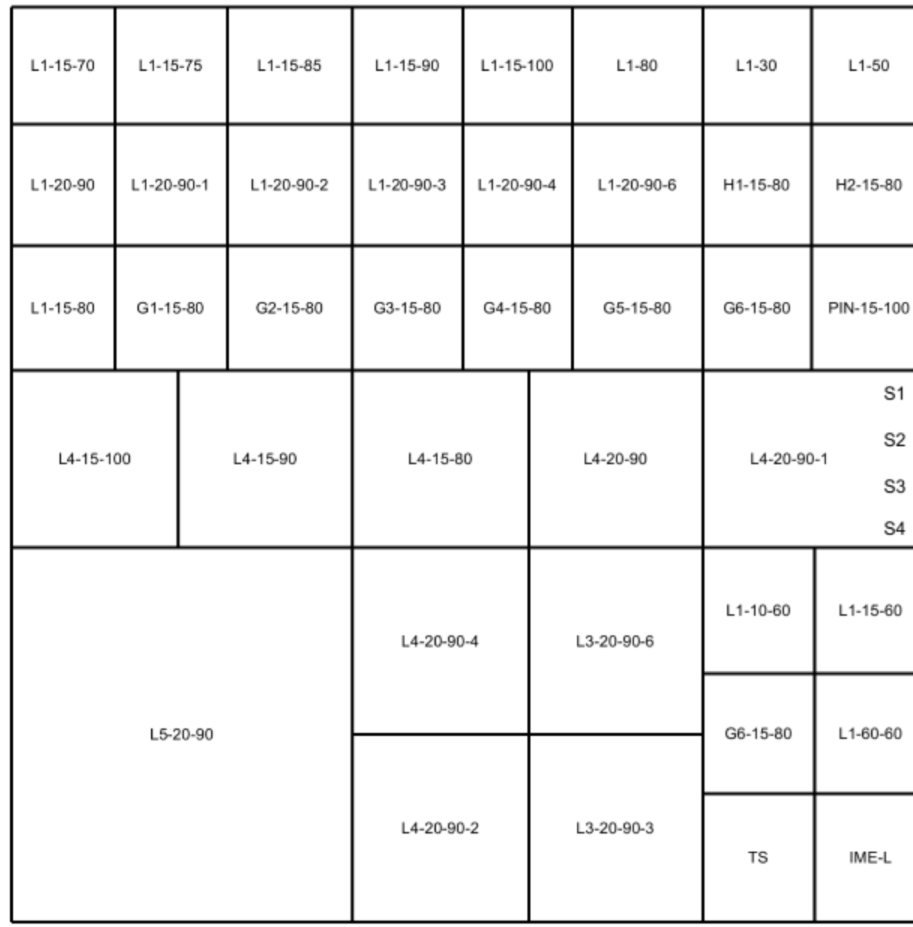
BV for different implantation dose: tuning point at mid dose, breakdown voltage in simulation lower than 479V



Gain versus bias voltage curve for high dose LGAD sensors

Mask and Cutting





Publications

J inst Published by IOP Publishing for Sissa Medialab

Received: *October 31, 2019*
Revised: *December 25, 2019*
Accepted: *January 28, 2020*
Published: *March 5, 2020*

International Summer School on
Intelligent signal processing for FrontIEr Research and Industry
Huazhong University of Science and Technology, HUST, at Wuhan, China
12–26 May 2019

Design and fabrication of Low Gain Avalanche Detectors (LGAD): a TCAD simulation study

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on behalf of IHEP HGTD collaboration

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2020 JINST 15 C03008

Abstract: Low Gain Avalanche Detectors (LGAD) are silicon sensors with a time resolution better than 20 ps. The ATLAS and CMS experiments are designing LGAD detectors to address the pile-up challenge at the High Luminosity-Large Hadron Collider (HL-LHC). The Institute of High Energy Physics (IHEP) High-Granularity Timing Detector group has recently developed its first version of LGAD sensors. The LGAD structure was designed using Technology Computer-Aided Design (TCAD) simulations and optimized to obtain a high breakdown voltage and ideal gain. The n-type Junction Termination Extension (N-JTE) zone is a critical structure to guarantee a high breakdown voltage. The gain layer is optimized for an ideal gain factor and hence good time resolution. The optimized LGAD sensor has a gain higher than six and a breakdown voltage higher than 400 V.

Keywords: Solid state detectors; Timing detectors; Charge transport and multiplication in solid media; Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs, CMOS imagers, etc)

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https://doi.org/10.1088/1748-0221/15/03/C03008

Nuclear Inst. and Methods in Physics Research, A 984 (2020) 164558

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

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Design of Low Gain Avalanche Detectors (LGAD) with 400 keV ion implantation energy for multiplication layer fabrication

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ARTICLE INFO

Keywords:
LGAD
Silicon sensors
TCAD simulation
High breakdown voltage
Gain factor
Implantation energy

ABSTRACT

Low Gain Avalanche Detectors (LGAD) are silicon sensors that can achieve a time resolution of better than 20 ps. The ATLAS and CMS experiments are designing LGAD detectors to address the pile-up challenge at the High Luminosity Large Hadron Collider (HL-LHC). The Institute of High Energy Physics (IHEP) has recently developed two versions of LGAD sensors. The LGAD sensors were designed using Technology Computer-Aided Design (TCAD) simulations and optimized to obtain high breakdown voltage and a suitable gain. The n-type Junction Termination Extension (N-JTE) and p-type gain layer are two critical structures for LGAD sensors that were investigated. IHEP has tuned the fabrication process of two foundries to obtain the most promising design. The first version of the IHEP LGAD sensor, with a gain higher than six and breakdown voltage higher than 400 V, was submitted to Tianjin Zhonghuan Semiconductor Company for fabrication. The second version of the LGAD sensor benefits from the higher implantation energy available at the Institute of Microelectronics (IME) to reach a gain higher than ten and breakdown voltage higher than 420 V.

1. Introduction

CERN will start the High Luminosity (HL) Phase-II of the Large Hadron Collider (LHC) in 2027 [1]. The HL-LHC will deliver an integrated luminosity of up to 4000 fb^{-1} over the subsequent decade. The instantaneous luminosity of the HL-LHC will reach up to 7.5×10^{34} $cm^{-2}s^{-1}$, a substantial increase from the 2.1×10^{34} $cm^{-2}s^{-1}$ obtained during LHC Run 2 [2,3]. The increase of instantaneous luminosity will increase the number of collisions in each bunch crossing. Improvement of the spatial and timing resolution is needed for particle tracks to be distinguished and primary vertices to be properly identified. One possible approach to satisfy these requirements is to use a tracking detector in conjunction with independent precise timing measurements. LGAD are silicon sensors that can achieve a time resolution of better than 20 ps. They have so far been developed by several silicon foundries [4–9]. The Institute of High Energy Physics (IHEP) High-Granularity Timing Detector group has recently developed its first two versions of LGAD sensors. In this paper, we report on the design, Technology Computer-Aided Design (TCAD) simulation and proposed fabrication technology for these LGAD sensors.

2. Structure

The LGAD structure drawn in Fig. 1 is based on the standard PIN diode architecture with an n^{++} layer as the cathode and a p^{++} layer as the anode. High voltage is applied on the anode and charge is collected from the n^{++} cathode at ground potential.

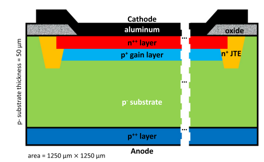

Fig. 1. Sketch of the LGAD structure with the active area shown. Height and width are not at the same scale. The sensor total area is 1250 μm × 1250 μm. The thickness of the p^- substrate is 50 μm.

The p^- substrate is the active volume for charge drifting. A thinner sensor contributes to better time resolution due to fewer Landau fluctuation. The proper gain factor can reduce jitter from electronic noise and time walk from amplitude variations allowing for high time

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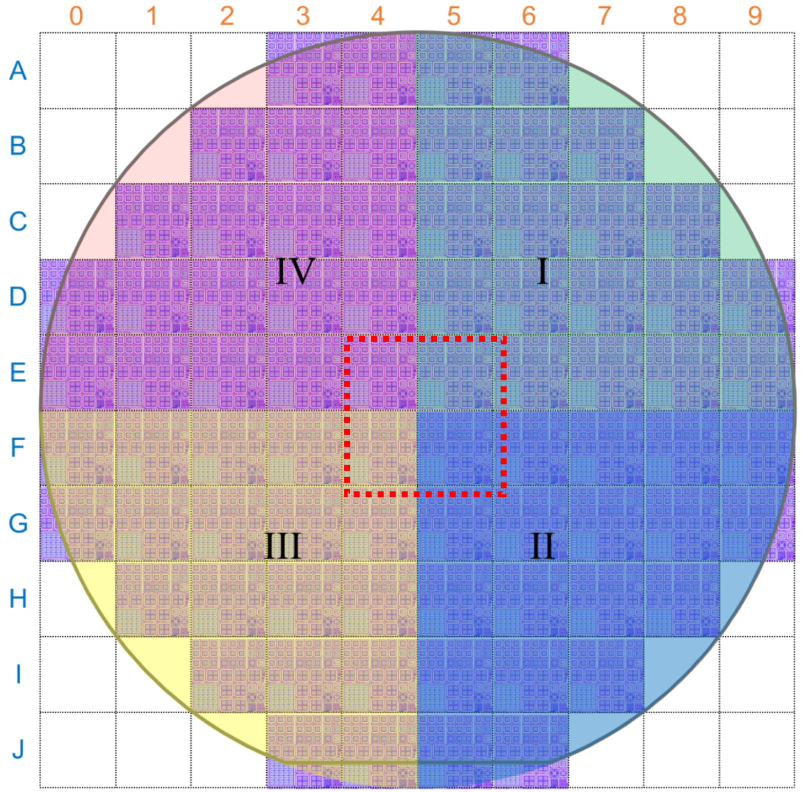
https://doi.org/10.1016/j.nima.2020.164558
Received 16 March 2020; Received in revised form 15 July 2020; Accepted 11 August 2020
Available online 20 August 2020

https://iopscience.iop.org/article/10.1088/1748-0221/15/03/C03008 https://linkinghub.elsevier.com/retrieve/pii/S0168900220309554

IME Production Summary

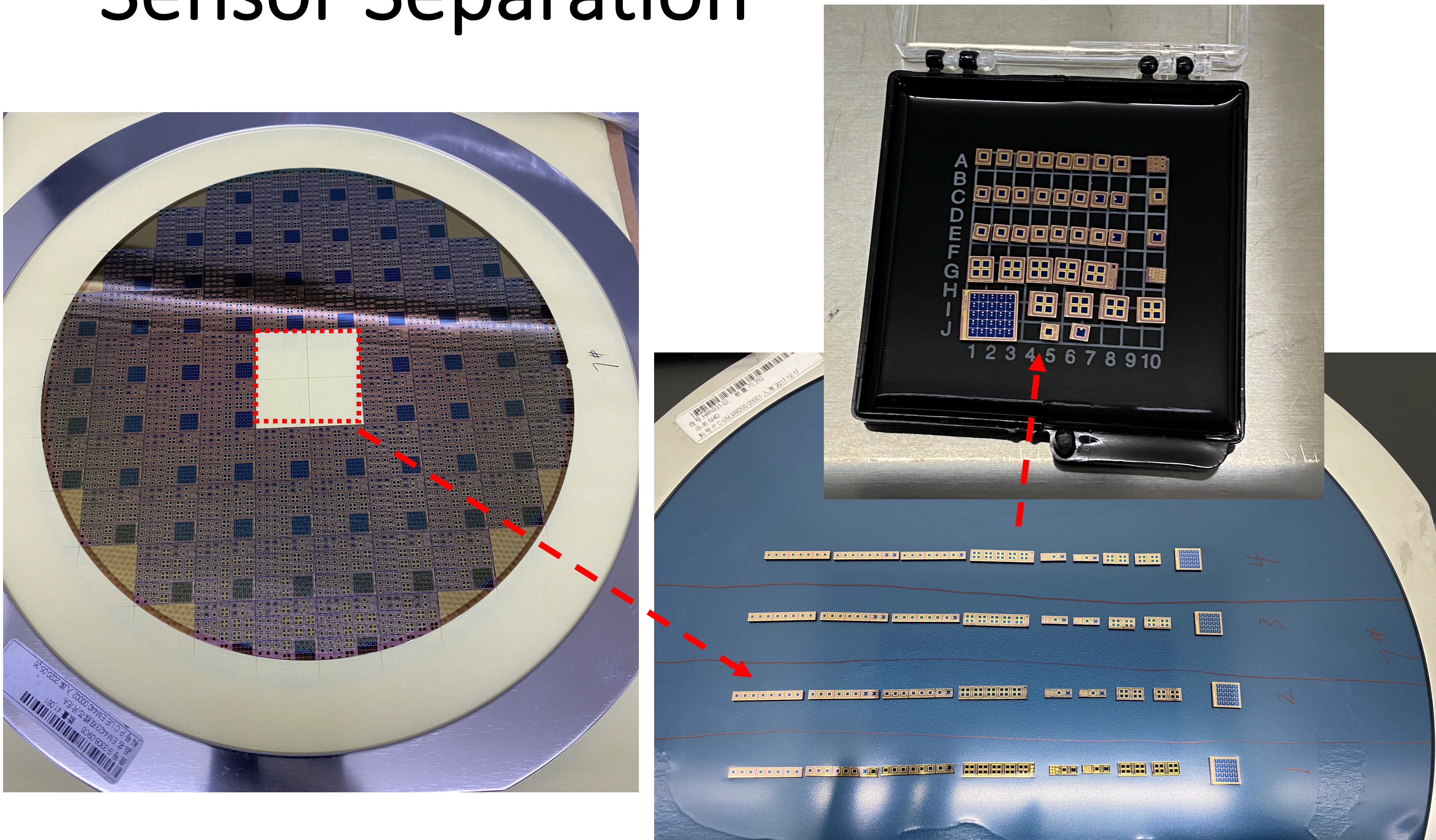
- ➢Four wafers: #1, #3, #7, #8.
- ➢Four quadrants: I, II, III, IV.



Wafer	*N Energy*	*Carbon*
#1	*mid*	*+*
#3	*mid*	*-*
#7	*mid*	*-*
#8	*high*	*-*

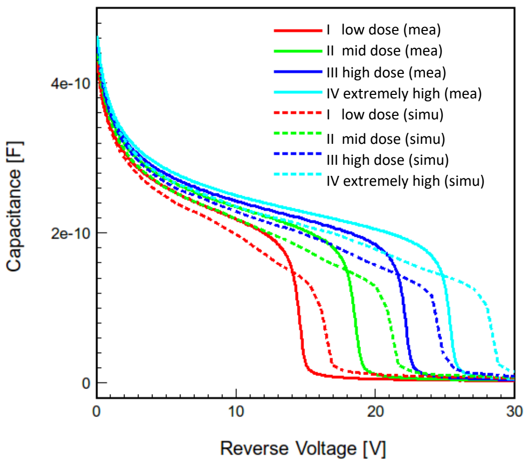
Quadrant	*P dose*
I	*low*
II	*mid*
III	*high*
IV	*extremely high*

Sensor Separation

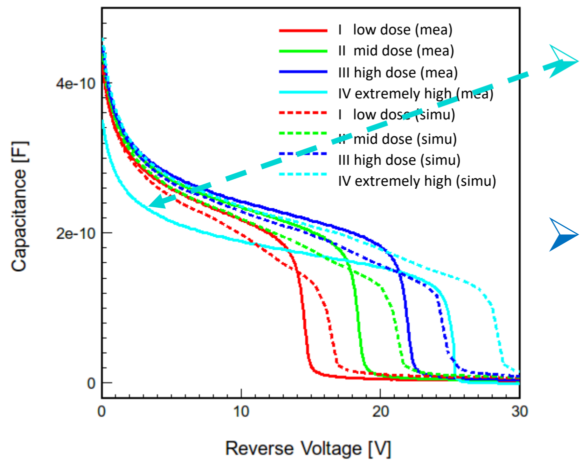


CV Test and Simulation

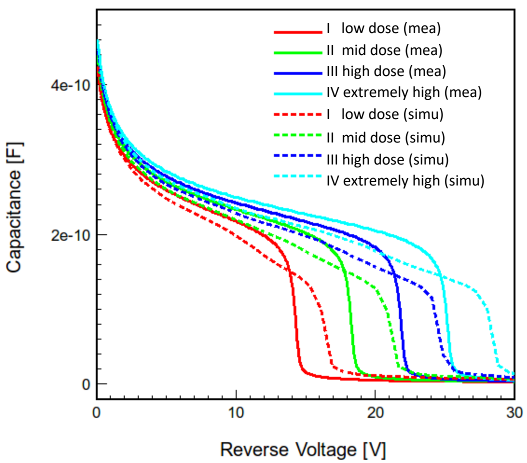
Wafer1



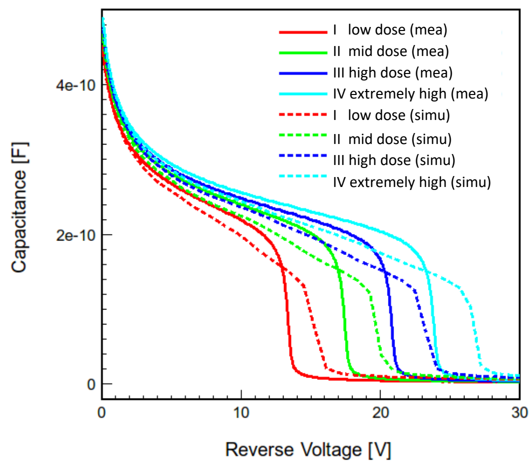
Wafer3



Wafer7

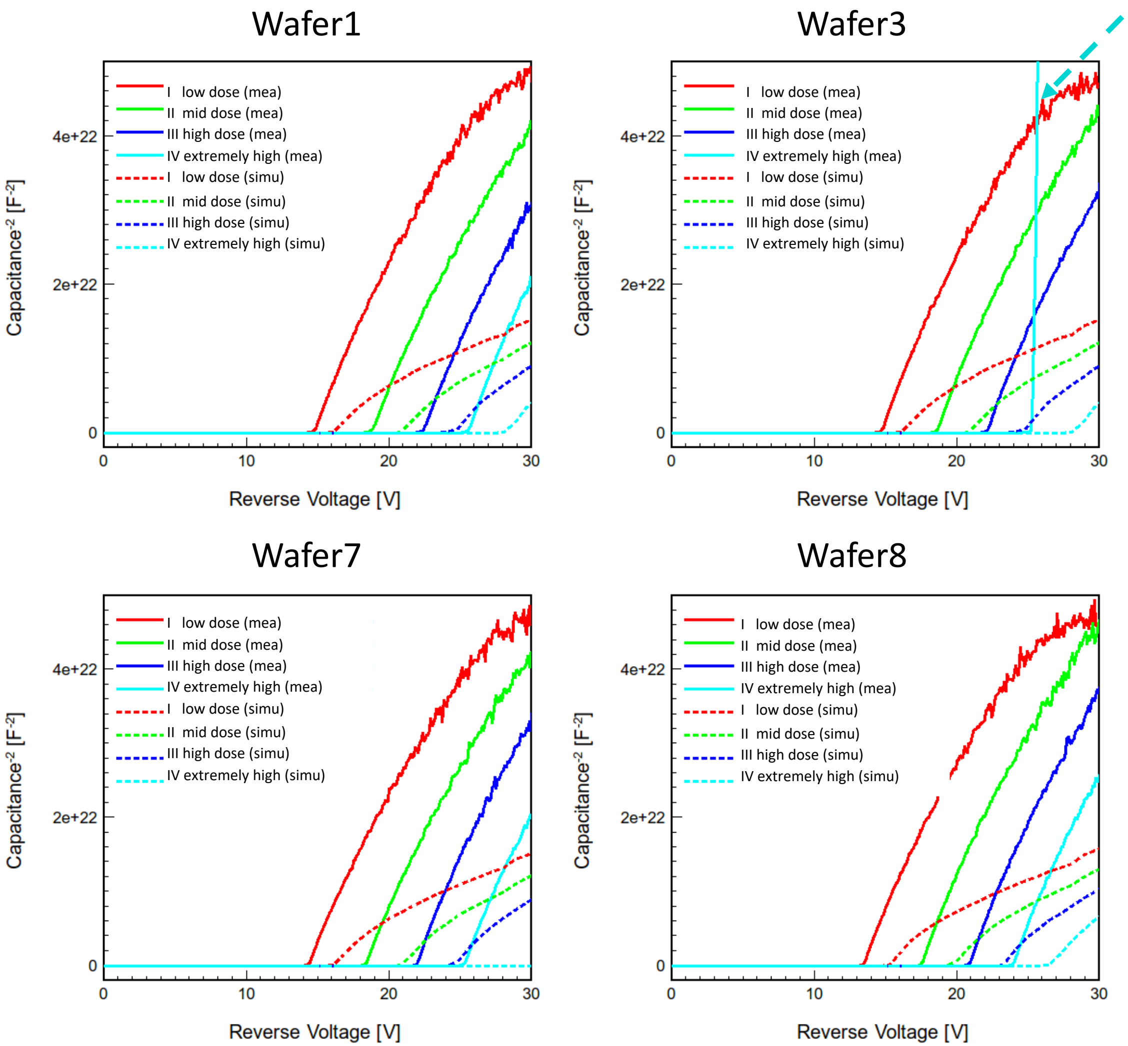


Wafer8



- **Wafer3 Quadrant IV problem**
- **In simulation (dash line), higher gain layer depletion voltages show up from low dose to extremely high dose. Because the gain layer doping concentration is increasing.**
- **In measurement (solid line), higher gain layer depletion voltages show up from Quadrant I to Quadrant IV.**
- **The change of CV measurement fit with CV simulation.**

$C^{-2}V$ and Simulation

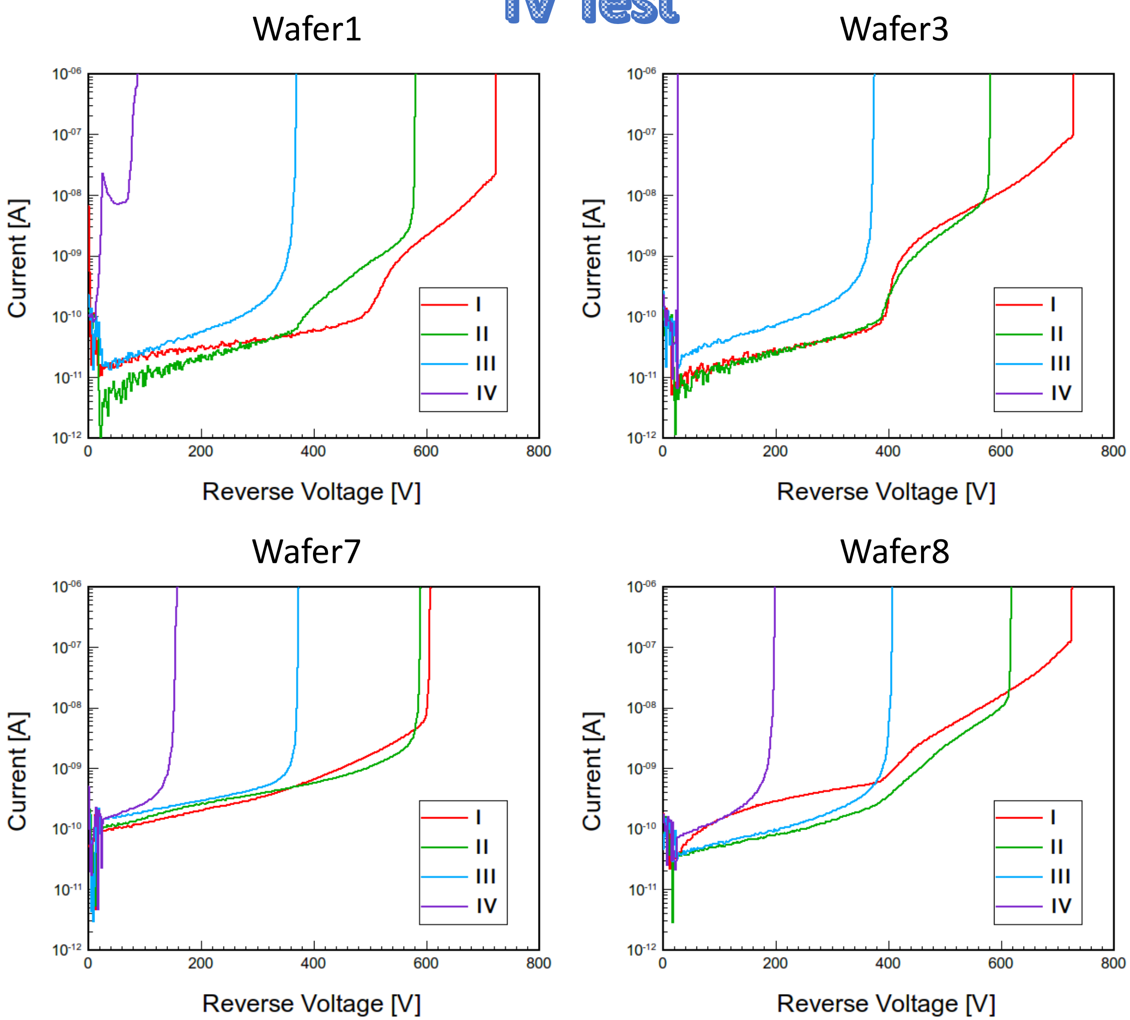


Wafer3 Quadrant IV problem

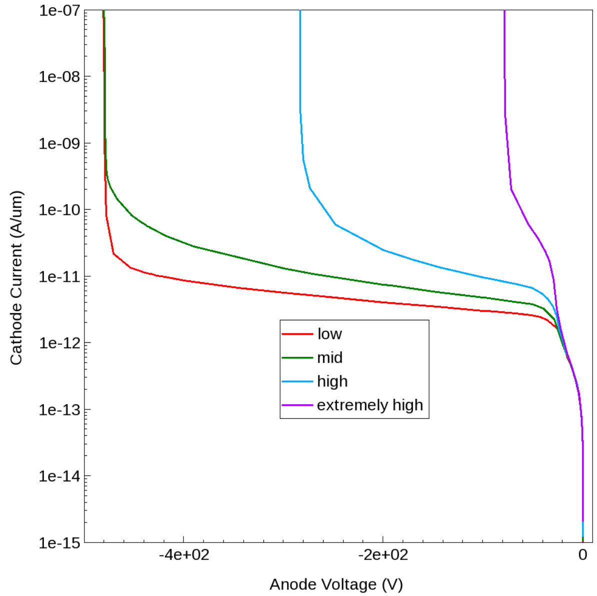
Wafer	Quadrant	$V_{gain\ layer}$ difference
1	I	16 V →14.5 V (-9.4%)
	II	21 V →18.5 V (- 11.9%)
	III	24.5 V →22.5 V (-8.2%)
	IV	28 V →25.5 V (-8.9%)
3	I	16V → 14.5V (-9.4%)
	II	20.5V → 18.5V (-9.8%)
	III	23.5V → 21.5V (-4.3%)
	IV	28V → 25V (-10.7%)
7	I	16V → 14V (-12.5%)
	II	20.5V → 18.5V (-9.8%)
	III	24V → 21.5V (-10.4%)
	IV	31V → 25V (-19.4%)
8	I	15V → 13V (-13.3%)
	II	19.5V → 17.5V(-10.3%)
	III	23V → 20.5V (-10.9%)
	IV	26.5V → 24V (-9.4%)

IV Test and Simulation

IV Test



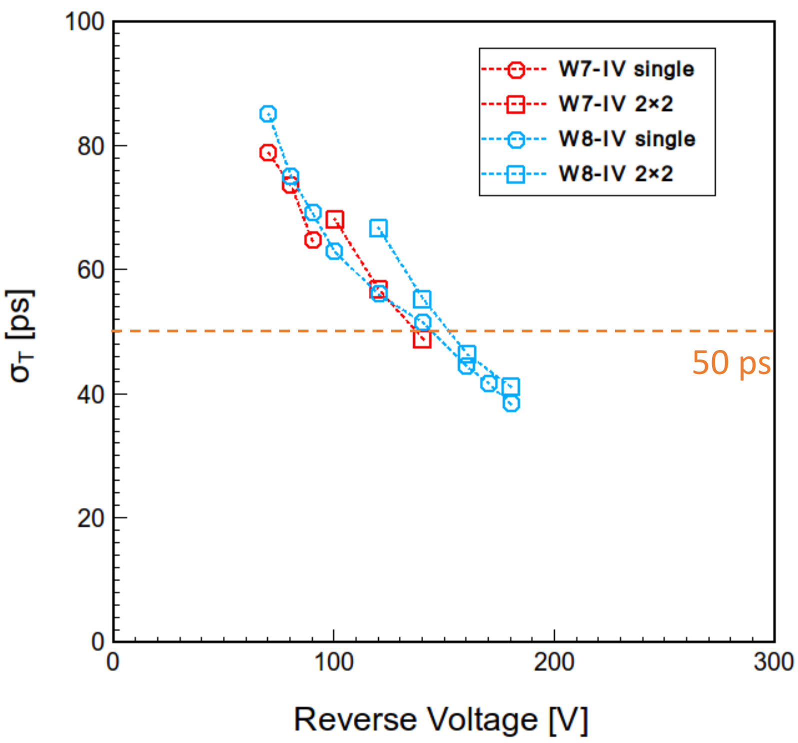
W7 IV Simulation

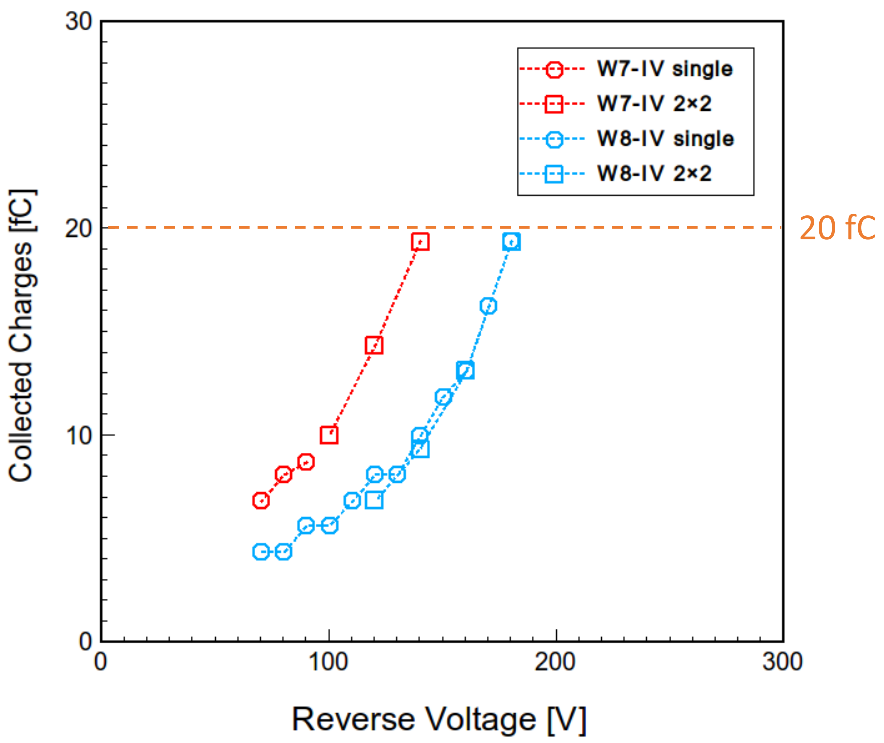


Quadrant	Simu BV	Test BV	Difference
I	*76 V*	*148 V*	*+94.7%*
II	*283 V*	*370 V*	*+30.7%*
III	***479 V***	***584 V***	***+21.9%***
IV	*479 V*	*602 V*	*+25.7%*

- **BV in measurement fit with simulation.**
- **Baseline design BV has the least difference.**

Time Resolution & Collected Charges W7-IV & W8-IV

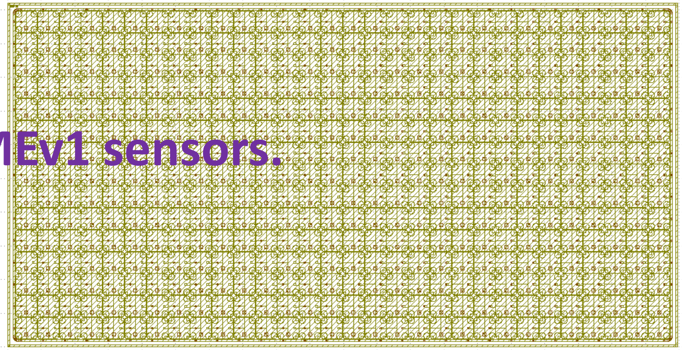




- **50ps and 20 fC in room temperature achieved, better results expected in low temperature.**

Summary & Plan

- ✓ CV and IV measurements show high uniformity for first production IHEP-IME LGAD. Low $I_{leakage}$ (<100pA) for medium and high boron dose implantation.
- ✓ Carbon implantation achieved low leakage current (<100pA, U<200V).
- ✓ Pretty charge collection and time resolution before irradiation (<50ps, >20fC).
- ✓ TCAD process simulated results are close with measurements but process calibration is necessary in next run.



- ➢ Proton (CIAE) and neutron (JSI) radiation for IMEv1 sensors.
- ➢ Large size production in IMEv2 production.

Thanks for your listening!

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