Progress of AC-LGAD TOF

MEI ZHAO

2025-4-21

Content

1、Submission

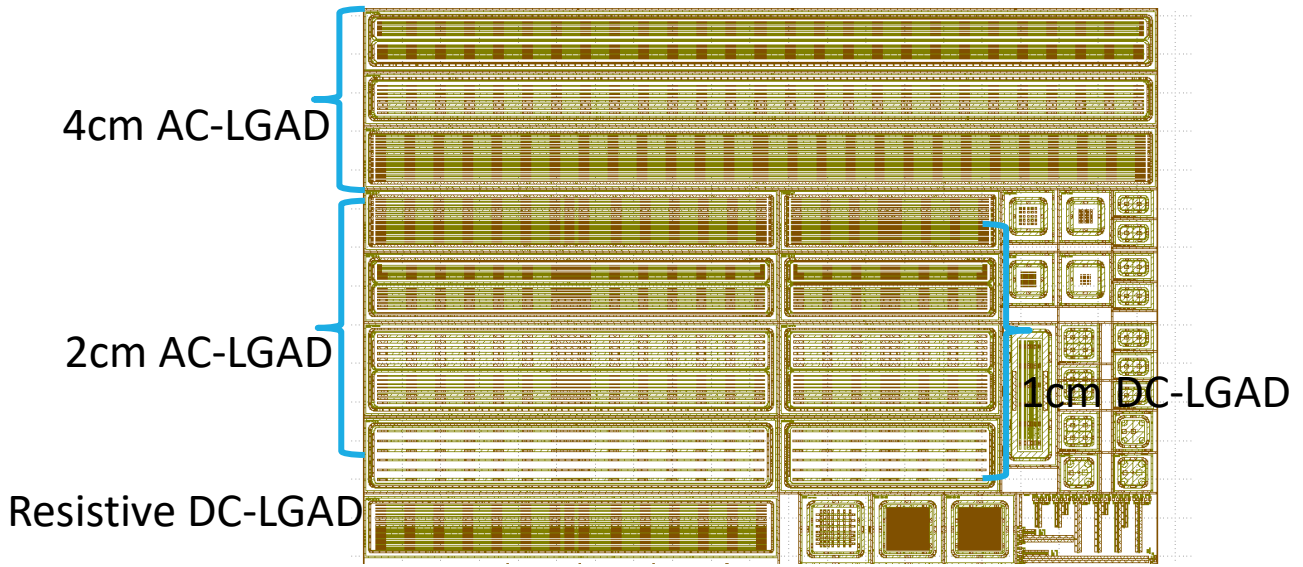
2、Testing of IHEP strip AC-LGAD sensors(TID)

3、Simulation of optimized sensors

4、Testing of FBK sensors

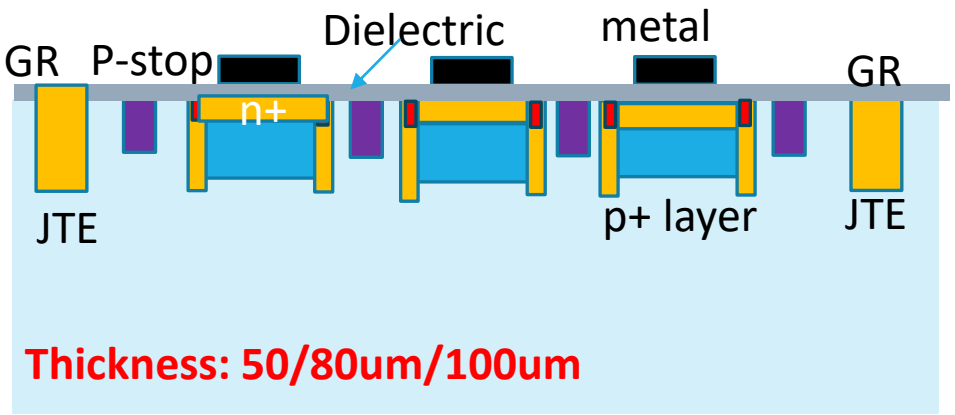
Submission

- Summitted for tap-out in March 2025.
- Masks under fabrication.
- IME is preparing the contract.



➢**Structure:** strip AC-LGAD, Resistive DC-LGAD, PIN, testing structure to check process.

- ➢P-stop structure be added as the isolation structure for this submission.



➢**Wafer and process:**

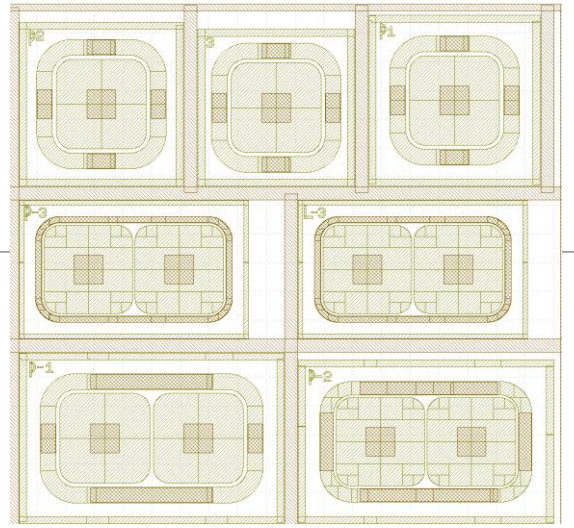
25 wafers, with different EPI thickness, n+ dose, n++ dose and coupling dielectric.

Submission

赵梅：总体设计
李梦朝(东莞): 小尺寸结构

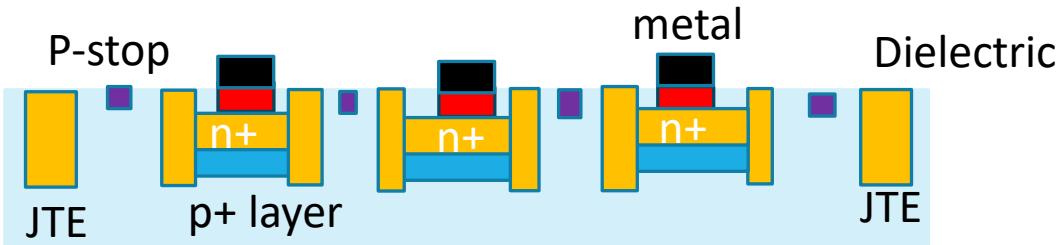
➢ **AC-LGAD and PIN:**

Small sensors with different non-active edge(300um to 200um, 150um), to check if the dead area of sensor can be reduced. [From simulation, it is fine to do such change]

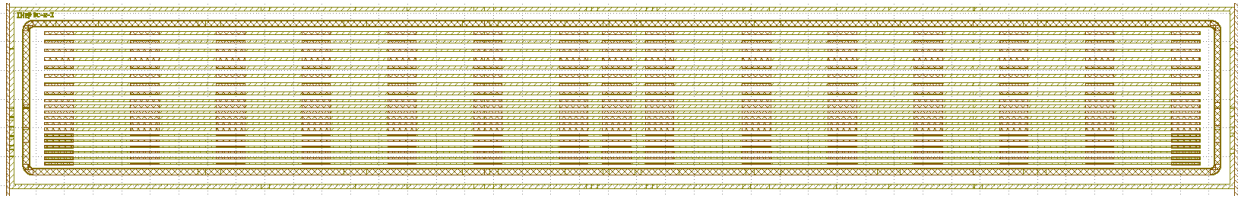


➢ Resistive **DC-LGAD: (DC-RSD)**

If AC-LGAD still has problem for capacitance and so on, we can use this type of DC-LGAD. (INFN,FBK design), this be added according to Gregor's suggestion.[DRD3 project meeting]



Thickness: 50/80um



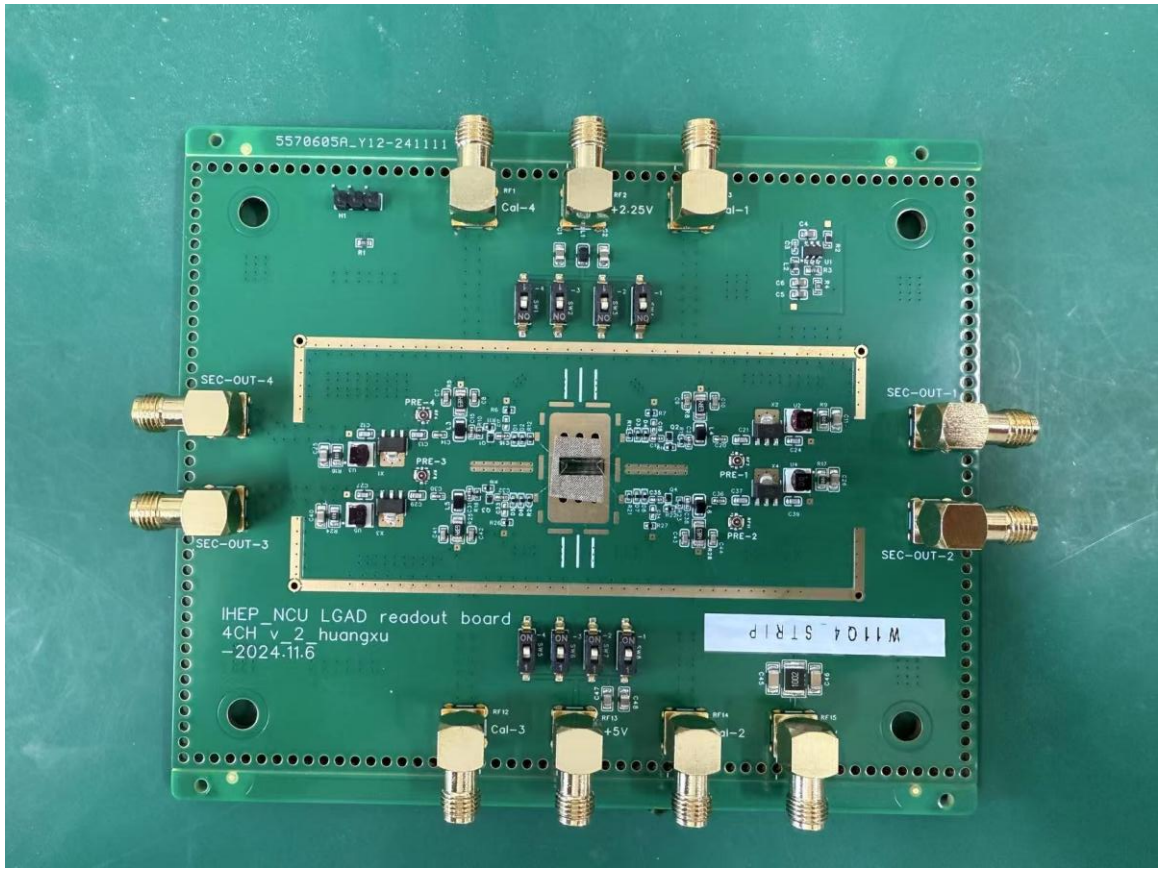
Strip length: 2cm long
pad-pitch: 25-100um, 50-100um, 50um-150um

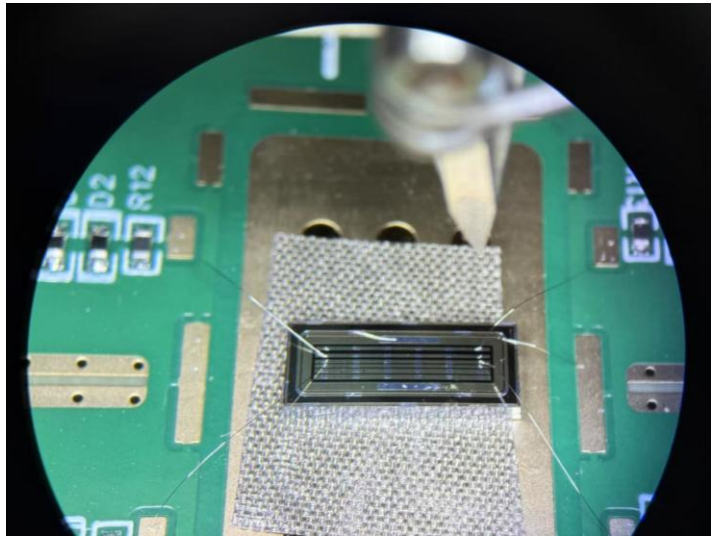
	wafer	EPI thickness	P dose	N++ dose	N+ parameter	Coupling dielectric	masks
DC-LGAD 8 wafer	1-3	50um, 80um, 300um	2P	None	1N	Oxide 1	Same as LGAD
	4-6	50um, 80um, 300um	1P	None	1N	Oxide 1	Same as LGAD
	7-8	50um, 50um	2P	None	1N	Oxide 1	Same as LGAD
AC-LGAD 17 wafer	9-11	50um, 65um, 80um	1P	1N	As last version	Oxide 2	Add n++ layer
	12-14	50um, 65um, 80um	1P	1N	As last version	Other dielectric material 2	Add n++ layer
	15-17	50um, 65um, 80um	1P	1N	Less than last version	Oxide 2	Add n++ layer
	18-21	**50um, 65um, 80um, 100um**	**1P**	**1N**	**Less than last version**	**Other dielectric material 2**	**Add n++ layer**
	22-23	50um, 80um	1P	1N	Deep implantation	Oxide 2	Add n++ layer
	24-25	50um, 80um	1P	1N	Deep implantation	Other dielectric material 2	Add n++ layer

4-channel test board

赵梅
李梦朝(东莞)
吴天涯（南昌大学）
黄旭（南昌大学学生）

- 25 test boards have been designed and fabricated.
  - 4-channel readout board with 2 stage amplifiers (Gain~70)
  - Has been used for TID test





Testing of IHEP sensor

TID test: [IDRC reviewers' comment of radiation hardness]

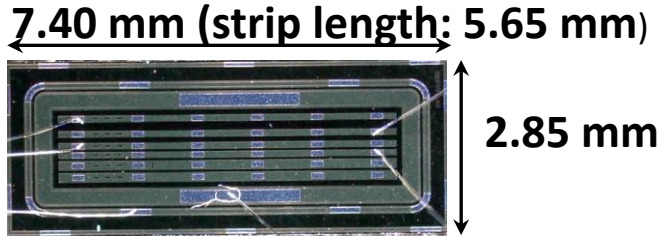
赵梅，孙维益，梁志均

Sample： IHEP AC-LGAD, strip length: 5.65mm, pad-pitch: 100-150um, 100-200um, 100-250um

X-ray machine: MultiRad 160

TID dose: 0, 500Gy, 1kGy, 10KGy, 100KGy, 1MGy

【For OTK， TID<0.1kGy】



Conclusion： (Dose from 0 to 1kGy)

1、Breakdown voltage(V_{bd}), Gain layer depleted voltage(V_{gl}) almost did not change

means: Sensor bias voltage and Gain almost not change.

2、Leakage current increases a little(10nA to 20nA), due to surface damage

3、Beta source test: Timing resolution still less than 50ps [testing board testing results]

4、Laser testing: Position resolution keep similar as before irradiation (~9-12um)

[Results add to Ref-tdr?]

Neutron radiation: 7 sensors be sent to JSI for neutron radiation. 【For OTK， NIEL<10^{10} n_{eq}/cm^2】

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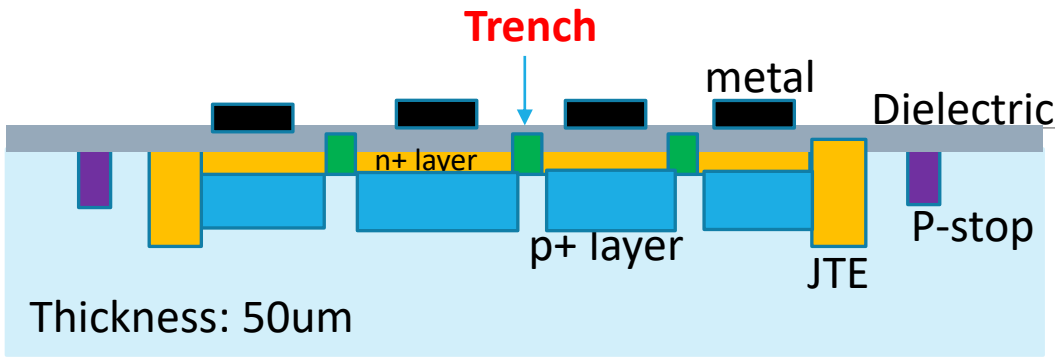
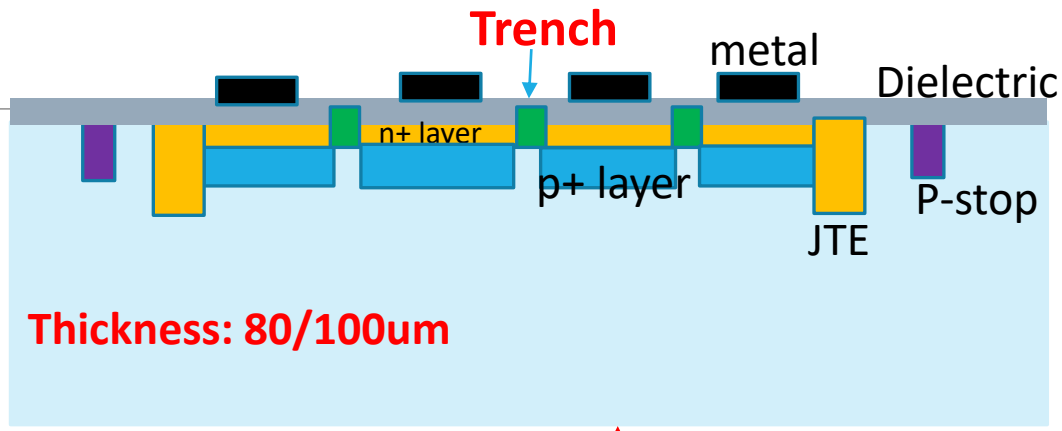
Capacitance for AC-LGAD

赵梅



$C = \varepsilon_0 * \varepsilon_r * A / d$



$C = \varepsilon_0 * \varepsilon_r * A / \mathbf{d}$

Isolated AC-LGAD: one strip

length	pitch	EPI thickness (50um)	EPI Thickness（80um）	EPI thickness (100um)
4cm	100um	4/1.69 x 4.2=~10pF	6.25pF	~5pF
	200um	20pF	12.5pF	10pF
2cm	100um	5pF	3pF	2.5pF
	200um	10pF	6.25pF	5pF

HGTD LGAD results:

Bulk capacitance: C_2

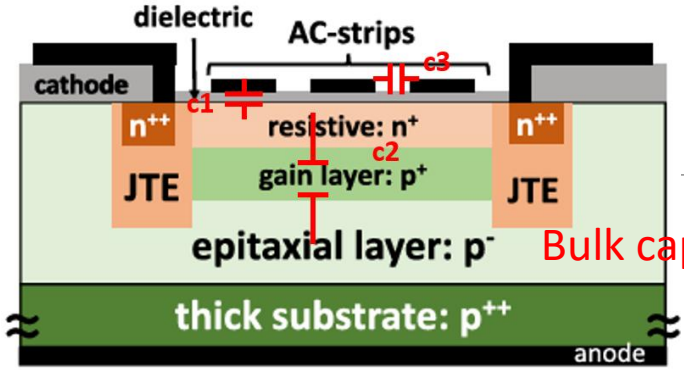
50um thick, 1.3mm x 1.3mm

Capacitance: 4.2pF

Simulation

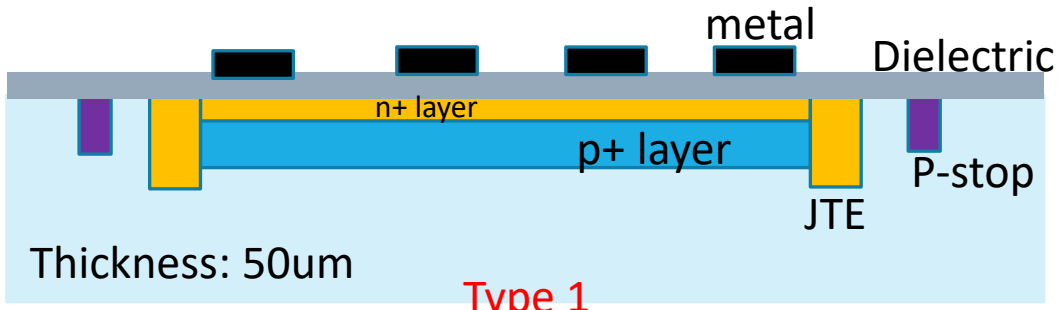
赵梅

- Bulk capacitance, coupling capacitance, capacitance between strips
  - Simulation ongoing (2D and 3D)： Solution for reducing bulk and capacitance between strips (Review mentioned this also)
  - Also check the signal shape(rise time), charges variation as position changing



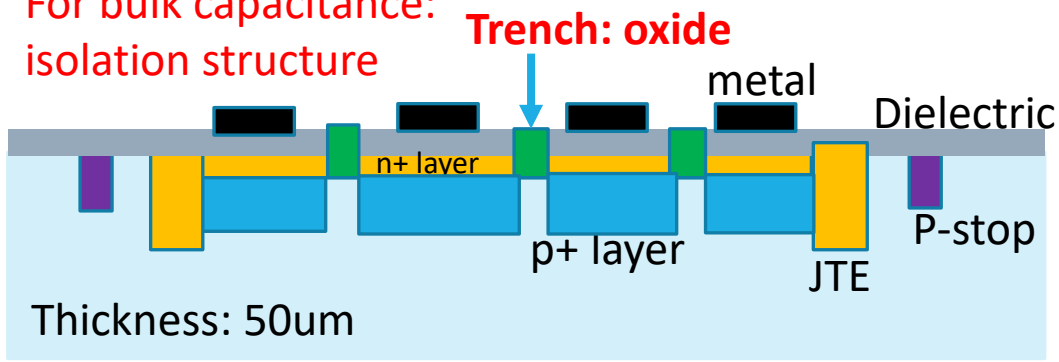
Bulk capacitance C_2

- Simulation be done on these 3 types of sensors firstly.
  - Size: 100um pitch(2D). 100um pitch and 400um long strip(3D)

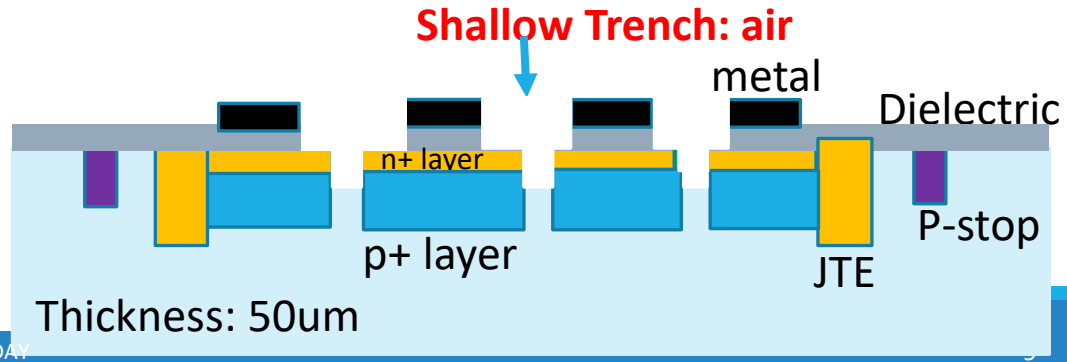


Type 1

For bulk capacitance:
isolation structure



Type 2



Type 3

For capacitance between strips:
Change the distance between strips metal
Remove the oxide and n+ layer between strips

Simulation

赵梅
黄文豪，叶竞波
黄旭，吴天涯（南昌大学）
张晓旭，张雷（南京大学）

➢Strip sensor TCAD model（2D and 3D）

2D TCAD model

2D： Pitch 100um

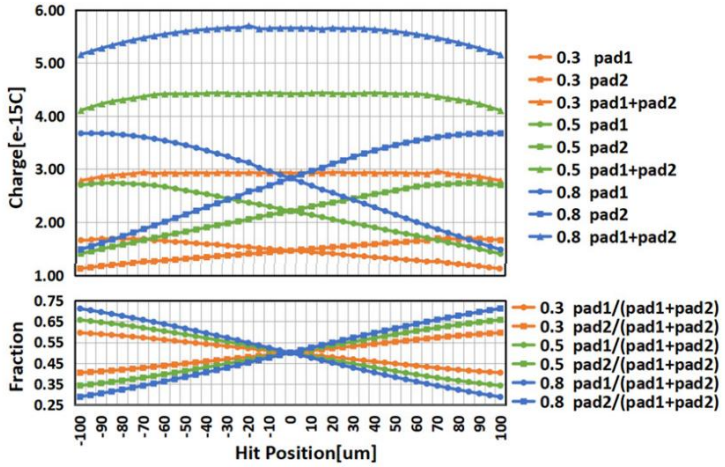
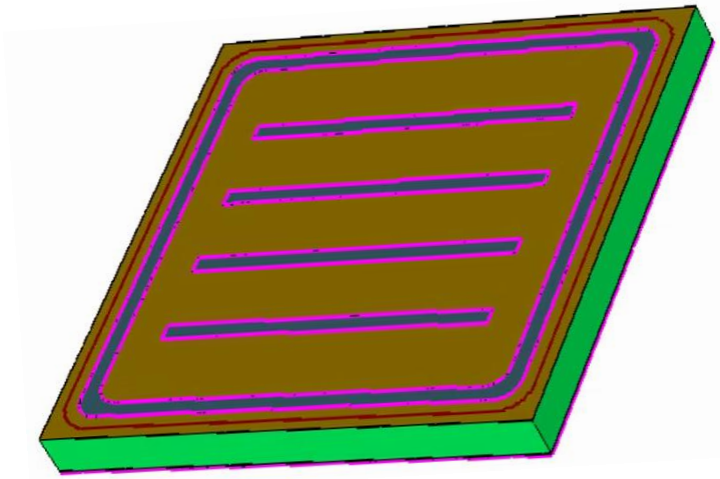
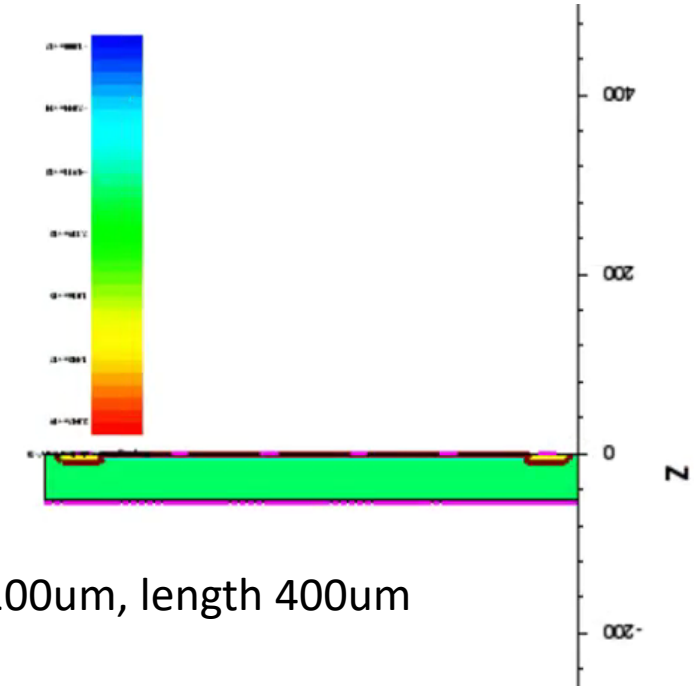


Figure 8. Charge collection of two pads for 5 different values of pad/pitch ratio: 0.3, 0.5 and 0.8.

3D TCAD model





3D: Pitch 100um, length 400um

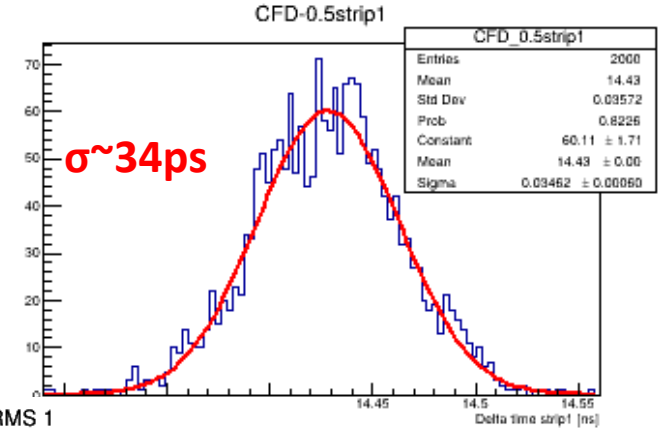
Simulation of sensor with new structure:

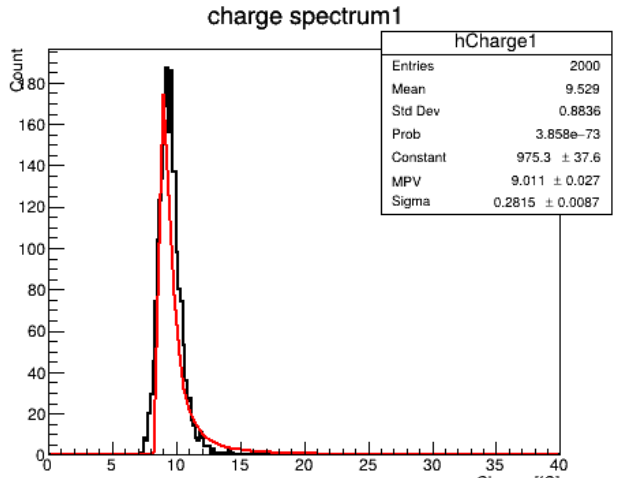
- ◆Bulk capacitance, coupling capacitance, capacitance between strips
- ◆check the signal shape, charges as position changing(as we did before)
- ◆Simulate the surface damage(TID) affect

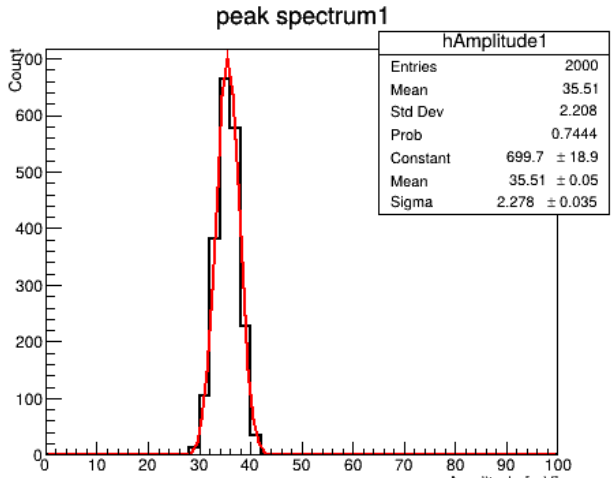
→ The capacitance
Timing performance
Position resolution ability

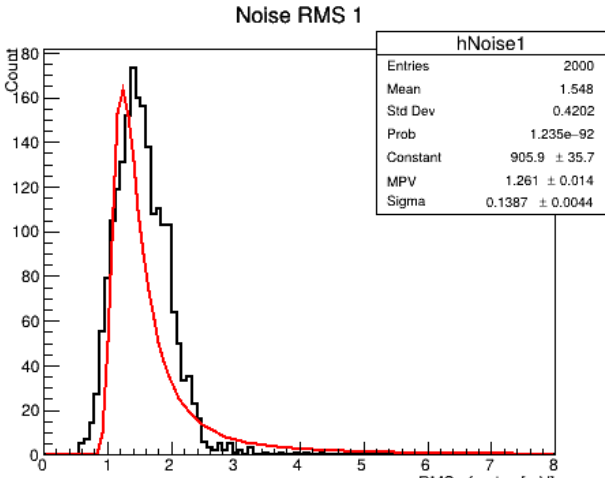
Testing of FBK sensors

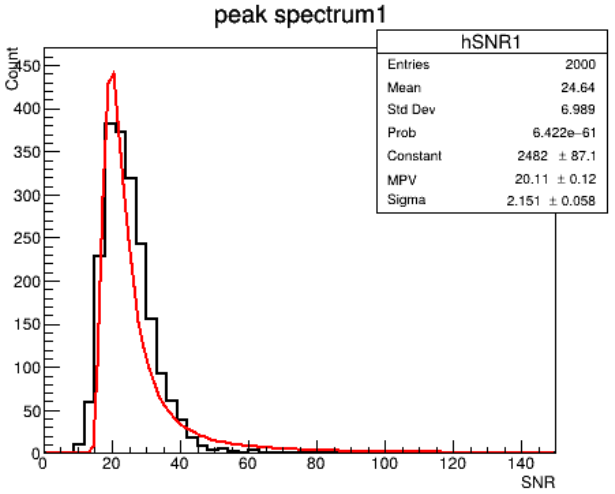
W6-50/150μm-180V-4MIP

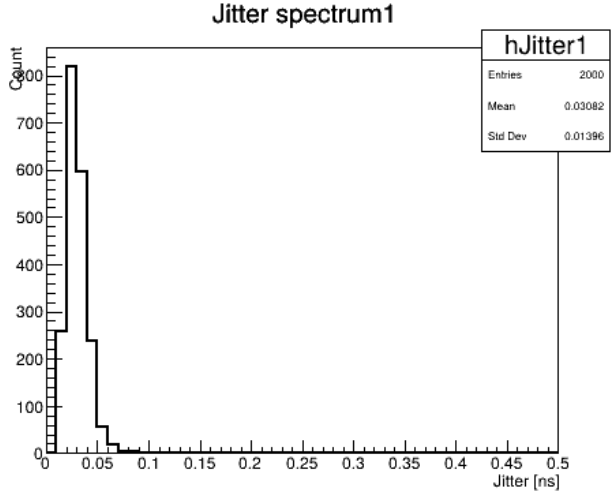


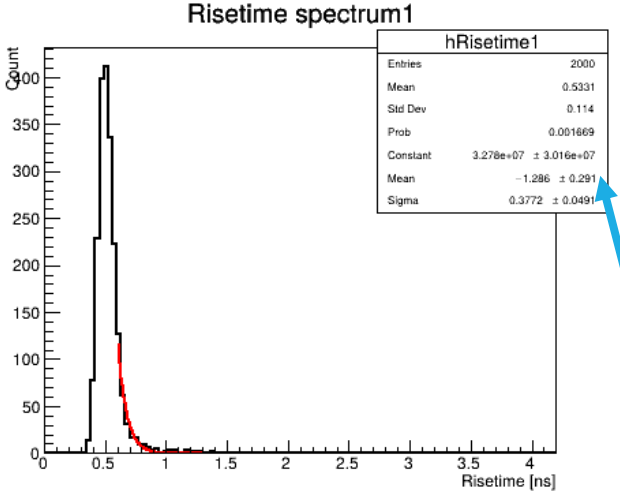












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Comments from Mei:

1、Only test one strip?

2、Where is the laser hit position?

3、Mean value of rise time here is not right?

Testing of FBK sensors

Capacitance for 2 cm AC-LGAD

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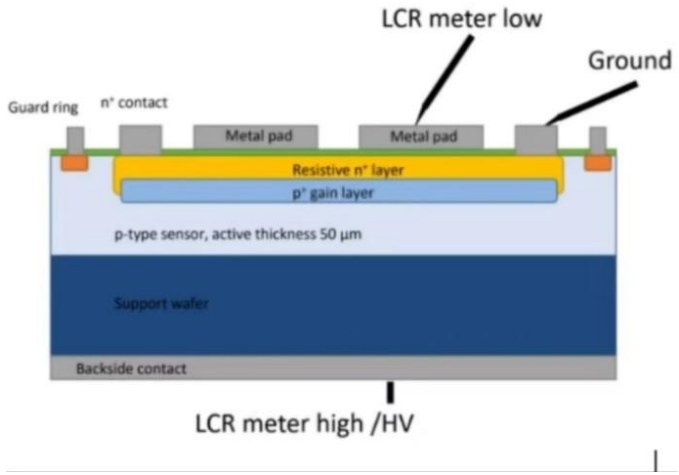
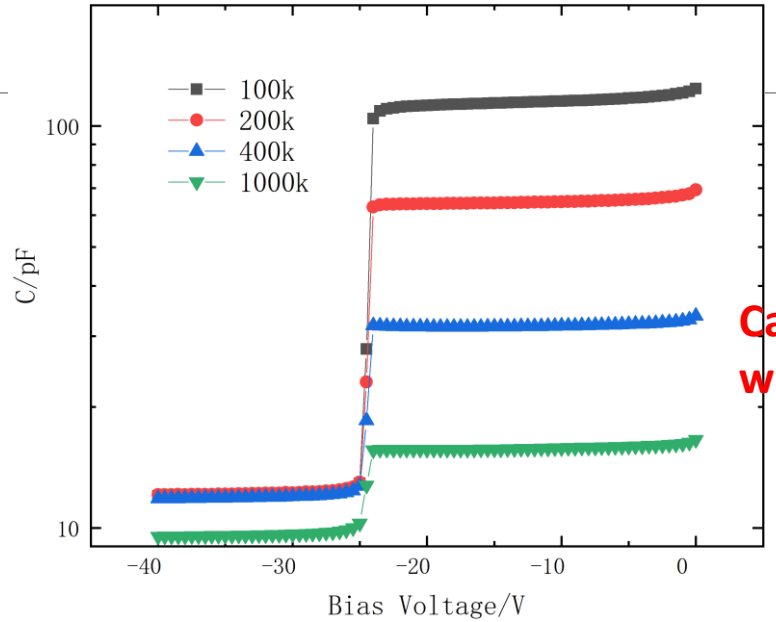
Samples with 11 strips: p1- p11





Capacitance varied with the frequency

✓ Strip p2: 100kHz-1MHz , **~11pf - ~9.8 pf**

Strip-P2: Capacitance Vs Bias Voltage

Metal/Pitch： 50/150um

Comments from Mei:

Please check the structure of FBK sensors, [not AC-LGAD, but DC-RSD].

We only care about the capacitance after depletion(working condition).

What is the capacitance between strips?

Summary and Plan

1、**Submission** done. **Fabrication** is expected to be finished in August.

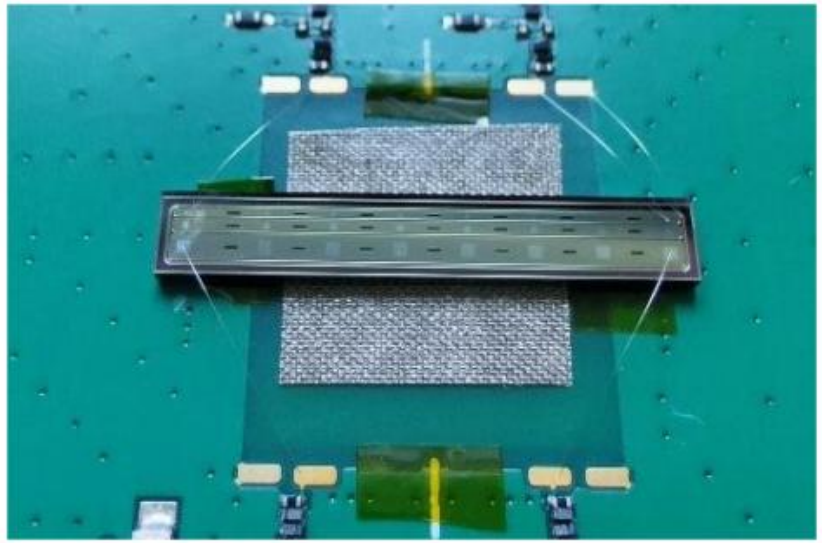
2、**TCAD simulation** about the sensors with new structures(but short strip), get some conclusion before end of June.

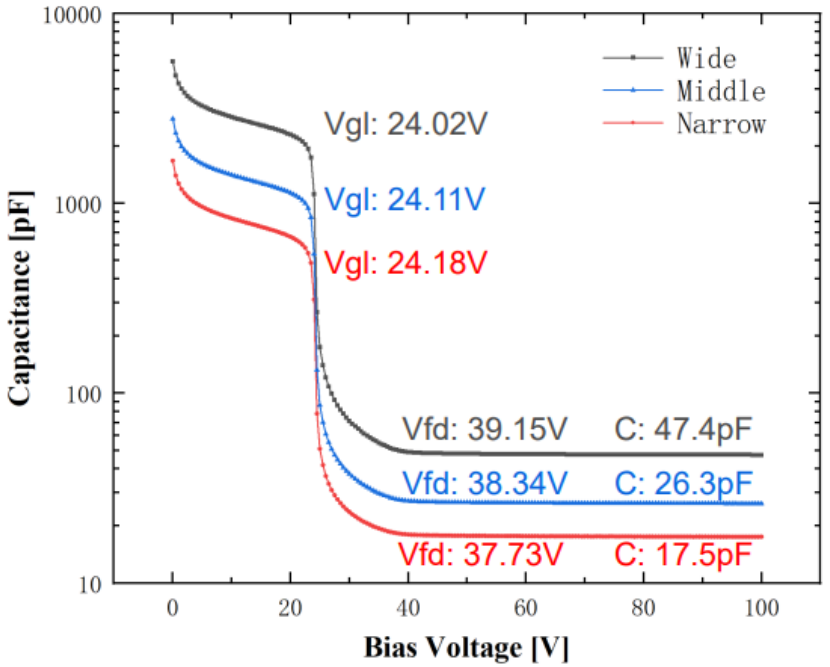
Information: Capacitance, signal shape(rise time) and position resolution for the optimized devices

3、**Testing** of irradiated sensors (TID done, neutron next)

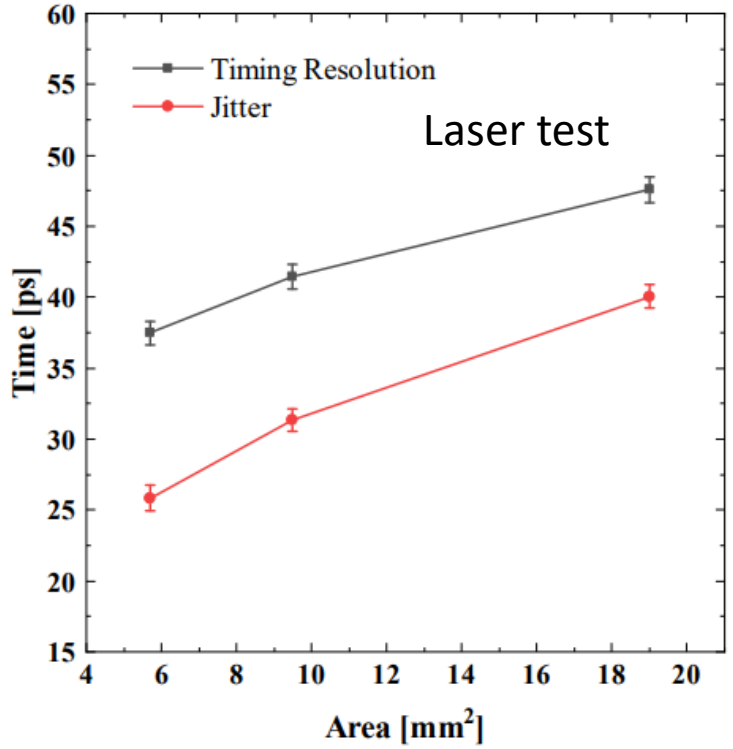
4、DRD3 project meeting [JSI, USP, University of Montenegro, SDU, ZZU, SJTU, NKU]

Backup: 2cm DC-LGAD results（IHEP）





Length: ~1.9cm
Pitch: 1000um, 500um, 300um
47.4pF, 26.3pF, 17.5pF



Length: 1.9cm
Pitch Width: 100um→capacitance: 6pF
Position resolution: readout method

Bulk capacitance, Calculation: 4.2pFx[0.3x19/1.69]=14.2pF

Testing of FBK sensors

Capacitance for 2 cm AC-LGAD

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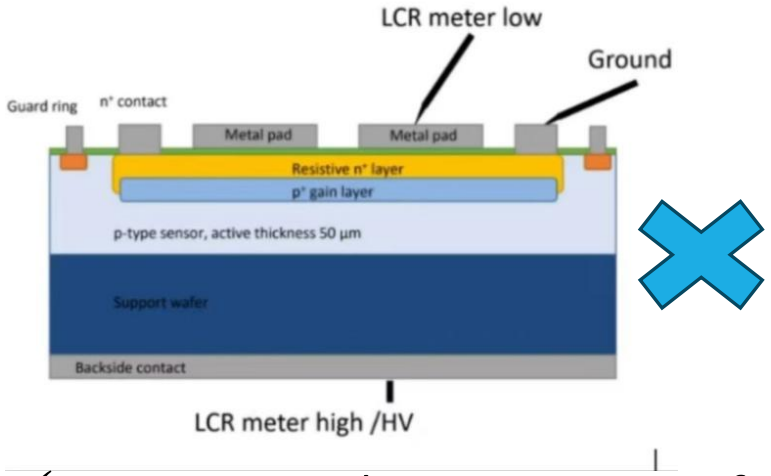
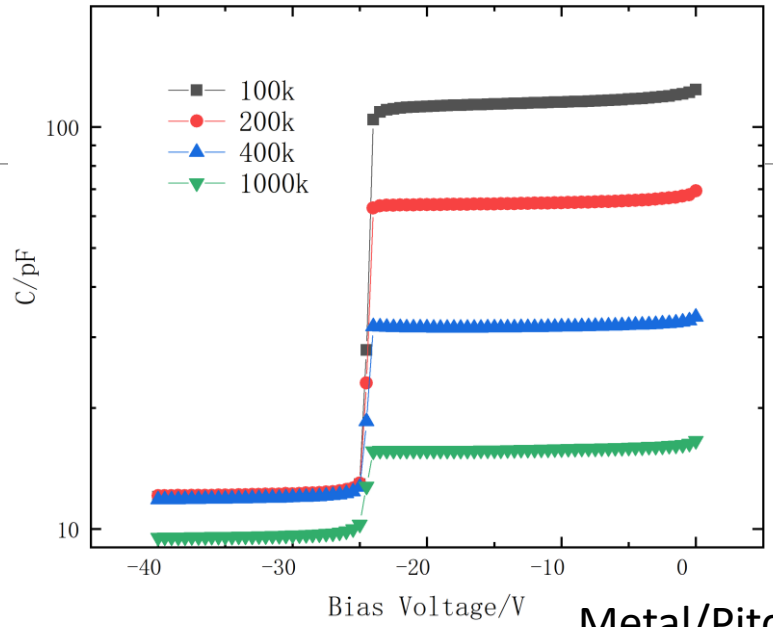
Samples with 11 strips: p1- p11



Capacitance varied with the frequency

DC-RSD!



Metal/Pitch： 50/150

Strip-P2: Capacitance Vs Bias Voltage

✓ Strip p2: 100kHz-1MHz , **~11pf - ~9.8 pf**

2cm long, 150um pitch,
Assume thickness 50um,
One strip: Capacitance is 7.5pF. [calculation]

Comments from Mei:

Please check the structure of FBK sensors, may be not AC-LGAD, but DC-RSD

The capacitance result is similar as IHEP 2cm DC-LGAD results.

If more strips(as shown in the picture), then the capacitance cannot be 10pF

RSD sensors show some non-ideal features:

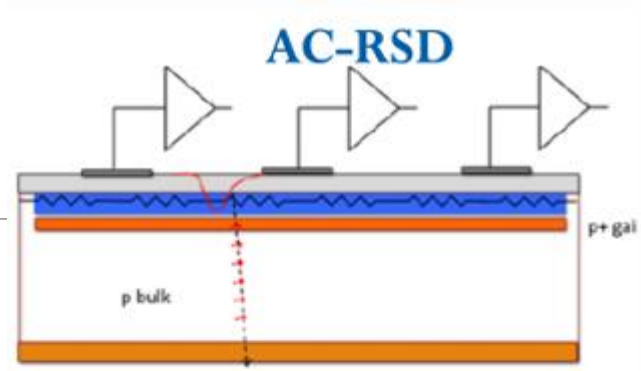
- Signal spread may involve a large (>4) and variable number of electrodes, leading to slight deterioration and a spatial resolution which is position-dependent
- Baseline fluctuations (leakage current collection only at the edge)
- The bipolar nature of the signals, with rather long tails during the discharge

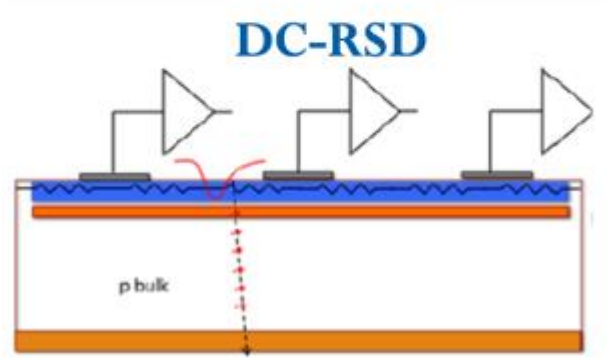
DC collection of signals, with low resistivity paths to readout pads + charge "containment" ⟹ DC-RSD design

- Signal is confined: charge sharing in a predetermined number of pad
- the leakage currents is removed locally at each electrodes
- No bipolar signal → 1-2 ns-long pulses

→ expected uniform performance and scalable to large devices

Extensive simulation studies performed to optimize design: resistive path, charge sharing, electrodes geometry, confinement method…





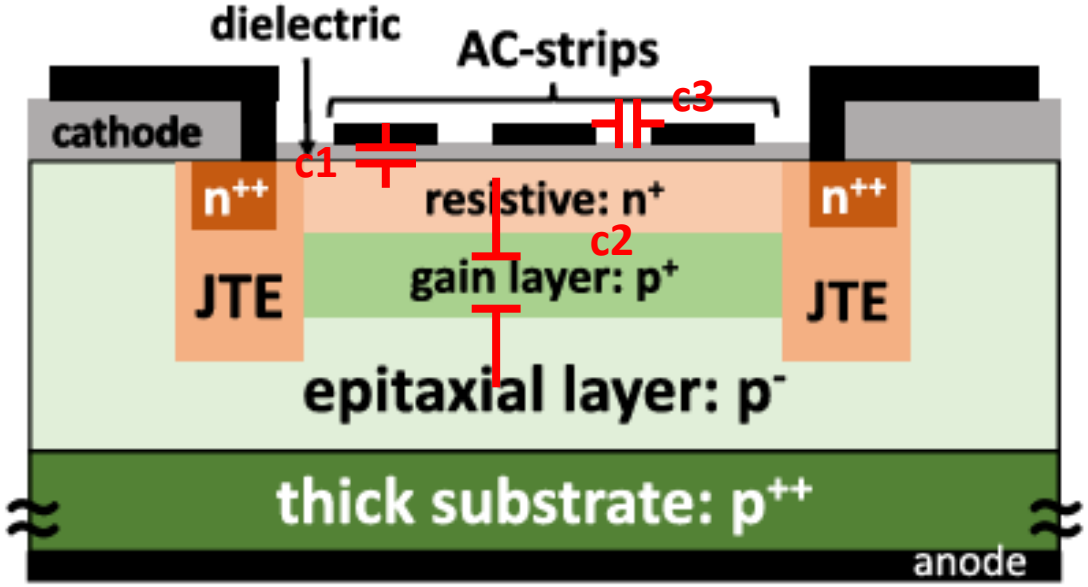
https://indico.cern.ch/event/1439336/contributions/6242237/attachments/2978078/5243054/Status4DShare.pdf

The first, **proof-of-concept**, production was completed @FBK in November: **DC-RSD1**

- The solution selected to achieve **charge containment**: use of Isolating Trenches (like TI-LGADs or SiPM)

Capacitance for AC-LGAD

- AC-LGAD capacitance component



C1: capacitance between AC metal and n+ layer (MIS)

metal length and width, dielectric thickness and material

HPK: 1cm long, 50um wide, 600pF/mm^2 ,
capacitance: 300pF

IHEP: 5.65mm long, 100um wide, 300pF/mm^2 ,
oxide thickness:150nm
capacitance: 170pF

100pF Magnitude

C2: capacitance PN junction (PN)

Strip length and pitch, strip group(isolated), EPI layer thickness

IHEP: EPI 50um thick, 1.3mm x 1.3mm
capacitance: 4.2pF

10pF Magnitude

C3: capacitance between strips (MIM)

Strip length and pitch, oxide thickness

Capacitance along the signal path: C1 and C2, Series Connect

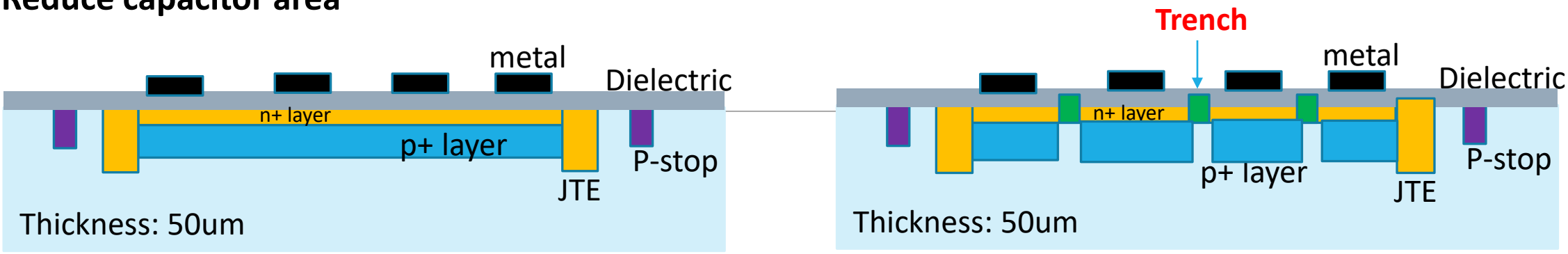
$$\frac{1}{C}=\frac{1}{C_1}+\frac{1}{C_2}$$

$$C=\frac{C_1C_2}{C_1+C_2}$$

C2 smaller, decide the capacitance

Capacitance for AC-LGAD

1、Reduce capacitor area



$$C = \varepsilon_0 * \varepsilon_r * A / d$$

C_2 area: Strip length, pitch, number of strip

HGTD LGAD results:

Bulk capacitance:

50um thick, 1.3mm x 1.3mm=1.69mm^2

Capacitance: 4.2pF

Isolation structure: reduce this number of strips to one

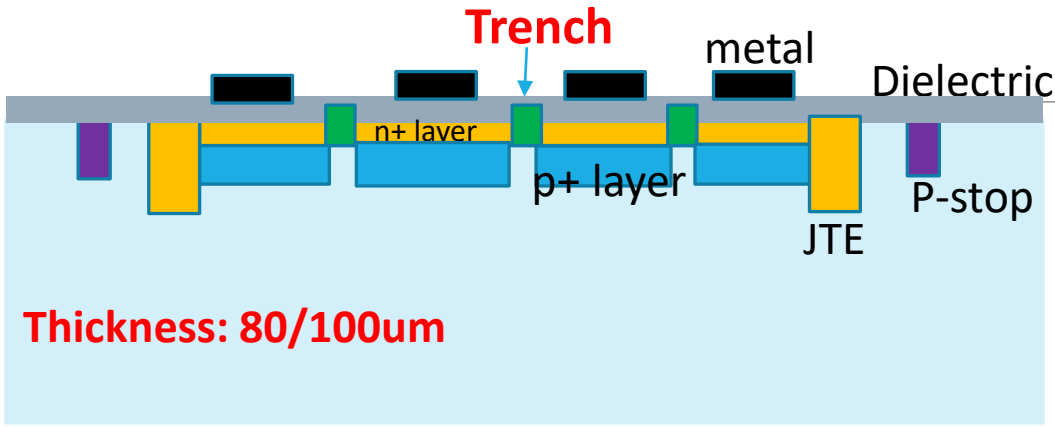
Isolated AC-LGAD: one strip

The capacitance is proportional to [strip length X pitch]

length	pitch	Two strip EPI thickness(50um)	One strip EPI thickness(50um)
4cm	100um	~20pF	4/1.69 x 4.2=~10pF
	200um	40pF	20pF
2cm	100um	10pF	5pF
	200um	20pF	10pF

Capacitance for AC-LGAD

2、Increase EPI thickness



$C = \varepsilon_0 * \varepsilon_r * A / d$ ↑

HGTD LGAD results:
Bulk capacitance: C_2
50um thick, 1.3mm x 1.3mm
Capacitance: 4.2pF

Isolated AC-LGAD: one strip

length	pitch	EPI thickness (50um)	EPI Thickness（80um）	EPI thickness (100um)
4cm	100um	4/1.69 x 4.2=~10pF	6.25pF	~5pF
	200um	20pF	12.5pF	10pF
2cm	100um	5pF	3pF	2.5pF
	200um	10pF	6.25pF	5pF

Before

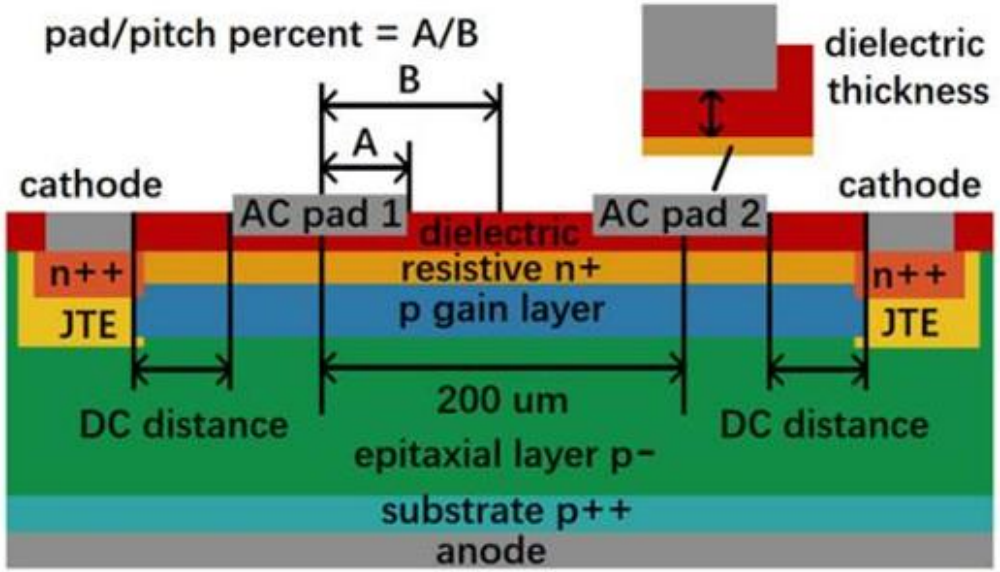
7cm	100um	10pF

Simulation (2D)

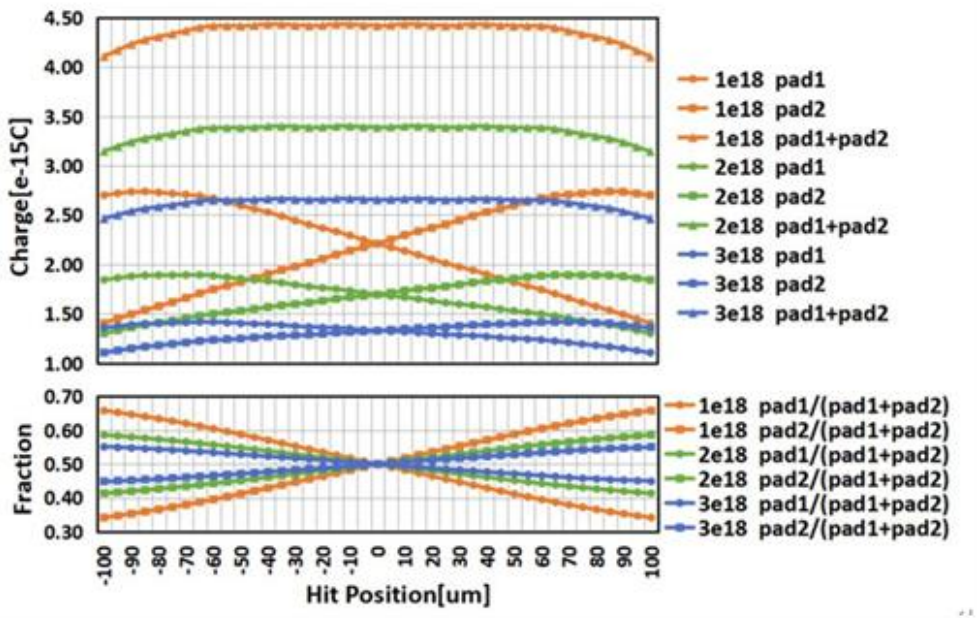
AC-LGAD sensor simulation: Optimization of process and structure parameters

Process parameter: n+ layer dose, AC dielectric material and thickness

Structure parameter: pad shape, pad-pitch size



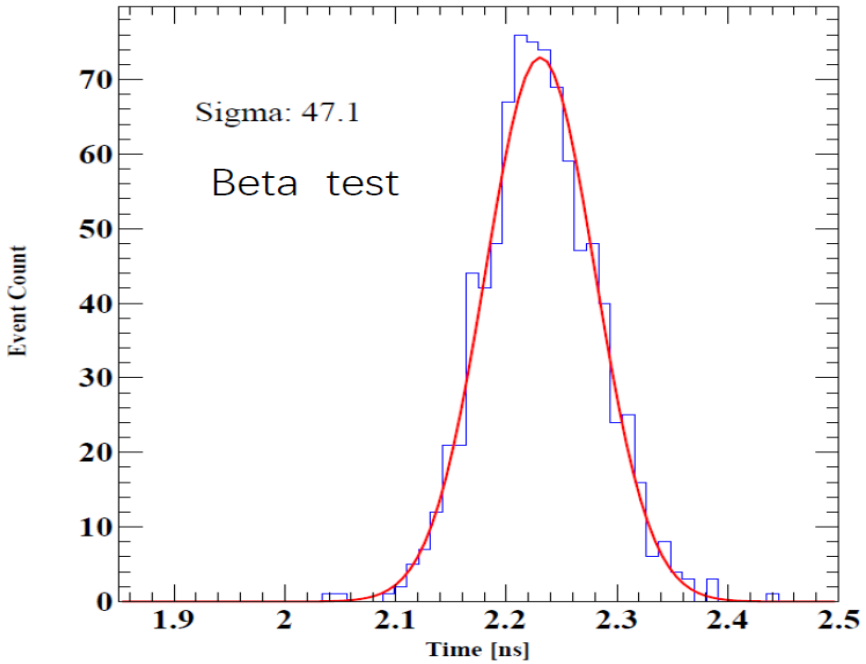
TCAD model of AC-LGAD for simulation



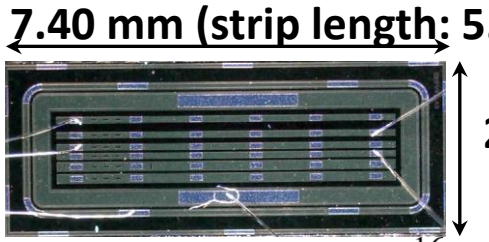
Lower n+ dose→ Large resistivity →good spatial resolution

Design of AC-coupled low gain avalanche diodes (AC-LGADs): a 2D TCAD simulation study, JINST, 2022.9, DOI:10.1088/1748-0221/17/09/C09014

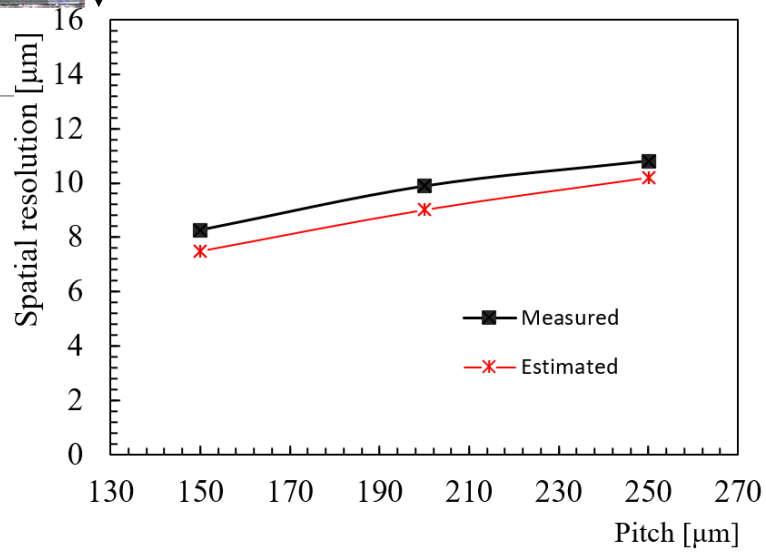
^{90}Sr Beta source test



Time resolution: 38 ps



Laser test



Spatial resolution:
8 μm for 150 μm strip pitch

Transmission line affect:

Check the transmission line affect to signal quality, by simulation (ADS)