LGAD sensor design status and further plan

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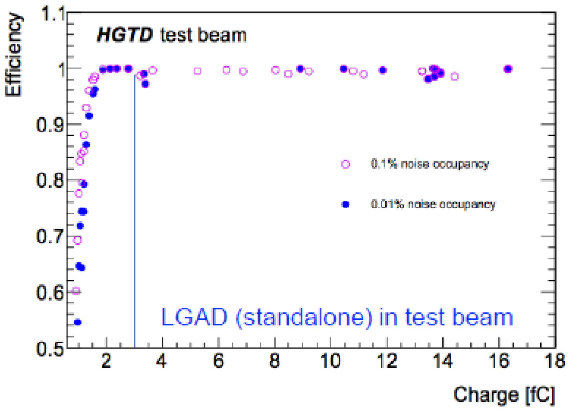
Sensor requirement

- LGAD: low gain avalanche diode

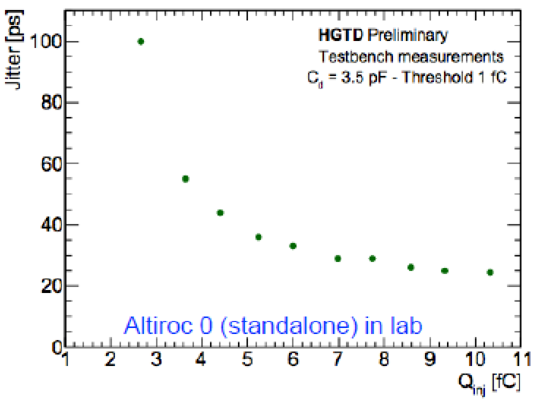
  Gain>10 or charge>2.5fC better 4fC

  Breakdown voltage>200V

  Irradiation hardness>6*10^{15} neq/cm^2



Q >~2.5 fC → ε_{hit} ~ 100%



Q =2.5fC (5fC) → Δt_{jitter} ~100 (40) ps

- Status of other Institutions

HPK\FBK\CNM

Gain-- ok

Breakdown –ok

Irradiation hardness is not ok only 3*10^{15} neq/cm^2

?Other things

Status

Sensor fabrication: first and second versions:

Company: maximum injection energy is 130keV, and diffusion temperature is 1150℃, 6 inch line.

- Buy wafers---done

Wafer type: 4 inch and 6 inch, 50μm 15kΩ.cm/low resistivity wafer, 15kΩ.cm FZ wafer

- Sensor design---done

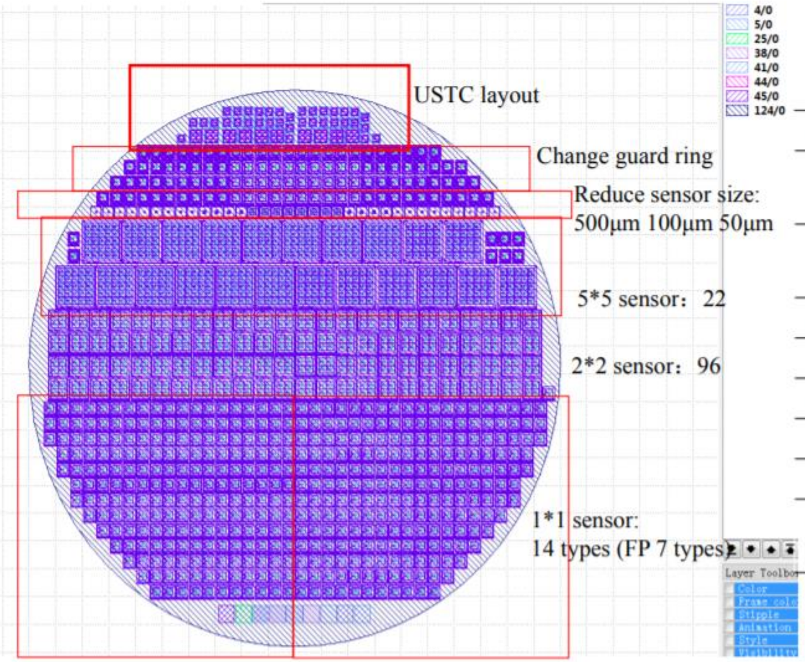
about spaces between each structure and process for each structure

- Layout design---done

the space and field plate, including single sensors and 2*2\5*5 arrays

- Company to fabrication ---ok

- Mask---doing
- Process--- this week begins
- Sensor got---1.5 months then we can test them



Label	Structure
4/0	JTE and WN-ring
5/0	P-stop and DC-stop
25/0	Open zone
38/0	P layer
41/0	N^{++} layer
44/0	Contact
45/0	Metal
124/0	Mark not mask

Status

Other institutions(that may also involved in this part)

- Beijing Normal University(BNU or NDL):
- 2x2 sensors (tested before irradiation , to be irradiated)
  - Based on Epi layer (33um, medium resistance 100Ω~300Ω)
  - Two type without guard ring (BV60, BV170), EPI layer resistance is difference.
  - Three type with guard ring has been fabricated.
  - will do proton irradiation in China and Japan, and X ray irradiation in IHEP
- 5x5 sensors (MPW submitted, to be tested with ASIC)
- Full size sensor (to be submit after testing 5x5 sensor)
- Beijing Institution of Microelectronics(IME):
- 8 inch line
- Injection energy is about 600keV
- Diffusion temperature is 1300C

Towards HGTD TDR

- Sensor characteristic

Our sensor and results

Irradiation hardness

Guard ring optimisation

- Test

New HGTD TDR schedule

All results finalized by Nov-Dec 2019

- Sept 2019: restart TDR writing/editing (mini WS w/ all editors on 18-20 Sept)
- Early January 2020: HGTD/Lar internal circulation
- Early Feb: First ATLAS circulation
- Early March: Second ATLAS circulation
- End March: ATLAS approval and submission to LHCC

Main concerns during TDR March ATLAS circulation

"Sensors irradiated to $5.1 \times 10^{15} n_{eq}/cm^2$ do not fulfil requirement of Q > 2.5 fC"

Sensor failure/reliability studies (T, humidity, rate…) and guard ring optimisation: more results by fall

Issues

- Time is urgent!

  The first sensors should be finished asap and improve them

- Irradiation hardness is important!

  How?

（surface damage and bulk damage）

By deeper B implantation？

Or C spray？

Further plan

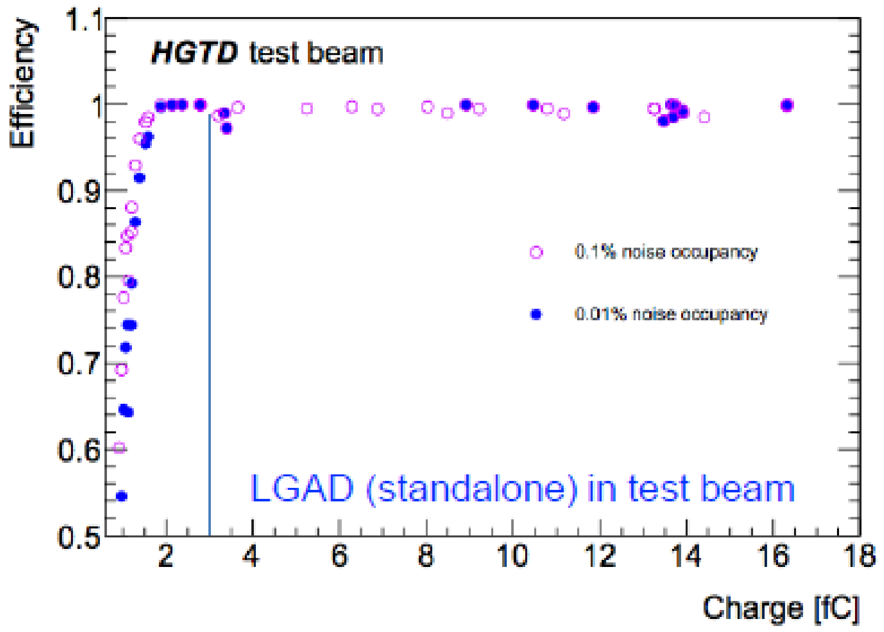
- Finish the first and second versions and test
- Test the BNU sensors and more?
- Test about the failure or reliability? of HPK /CNM sensors

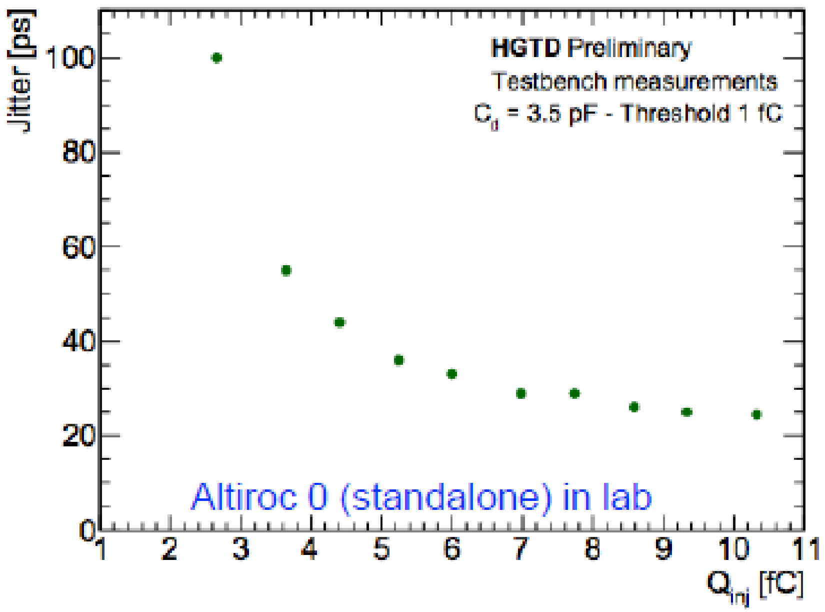
- Sensors fabricated by using higher injection energy(IME)
- Guard ring modify(simulation and fabrication)

- Thanks!

BACKUPS

2x2 ch sensor (LGAD)+Asic (Altiroc0) performance (n_{irr})





Q >~2.5 fC → ε_{hit} ~ 100%

Q =2.5fC (5fC) → Δt_{jitter} ~100 (40) ps

Minimum required charge for Altiroc = 2.5fC , but > 4 fC for adequate jitter time resol.

BACKUPS

Additional tests/results to be included in the TDR

approved on the ATLAS EB 10th May 2019

https://indico.cern.ch/event/740402/contributions/3419073/attachments/1840869/3018169/go

(on SLIDES 9 -14)

In Green : tests/results for the TDR
In Orange: Potential additional tests/results for TDR

Sensors

Irradiation program

Neutron (JSI): continue irradiation of HPK-3.2 and FBK-C up to largest expected fluence 6x10^{15} n_{eq}/cm^2

→ Measurement of sensors (Q vs V) on-going and available by summer

TID (Xray, CYRIC): Xray at IHEP started : results by summer at ~3 MGy

Done also with proton at CYRIC (already accumulated 4 MGy)

Proton: starting soon at IHEP ; CYRIC in July 19→result by end of year (results from CERN-PS already available)

New campaign at Los Alamos at fall

Investigating others facilities (PSI, Fermilab) tbc, possibly later this year

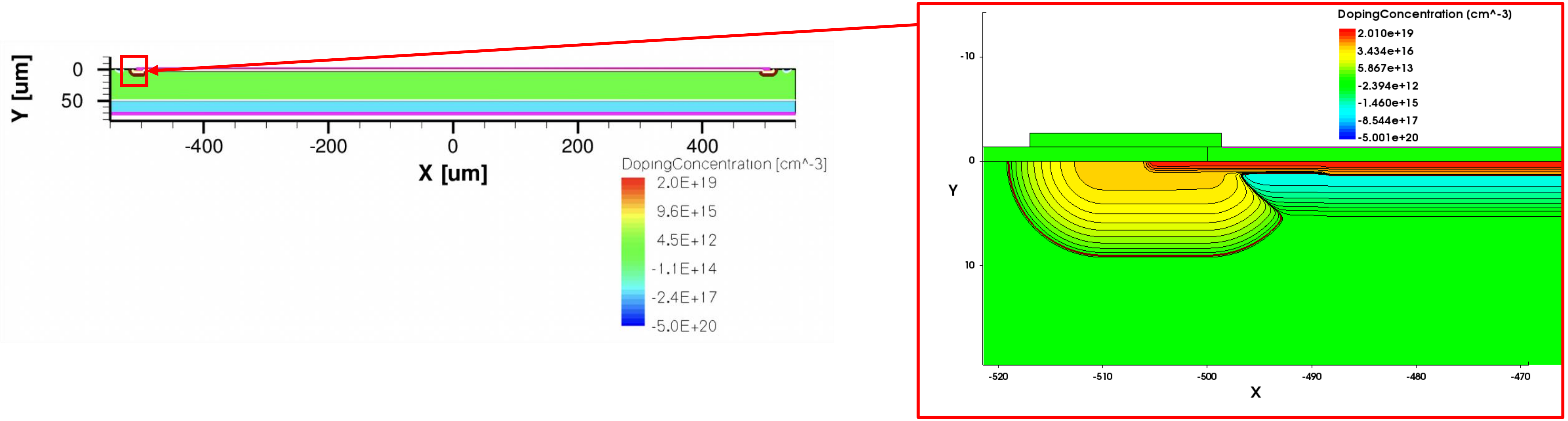
Sensor power optimisation and thermal runaway analysis : Ongoing , results by Sept/Oct

Sensor failure/reliability studies (T, humidity, rate…) and guard ring optimisation: more results by fall

BCAKUPS

LGAD (Low Gain Avalanche Detector) Structure Simulation, Design, Fabrication

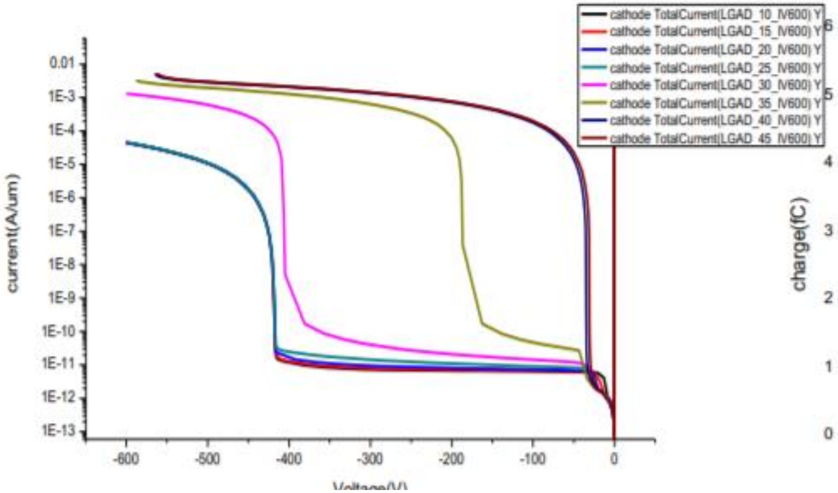
- TCAD model building, performance simulation, process simulation
- Fabrication: draw layout mask, purchase high resistance wafer, modify process parameters, tape out IHEP 1st LGAD

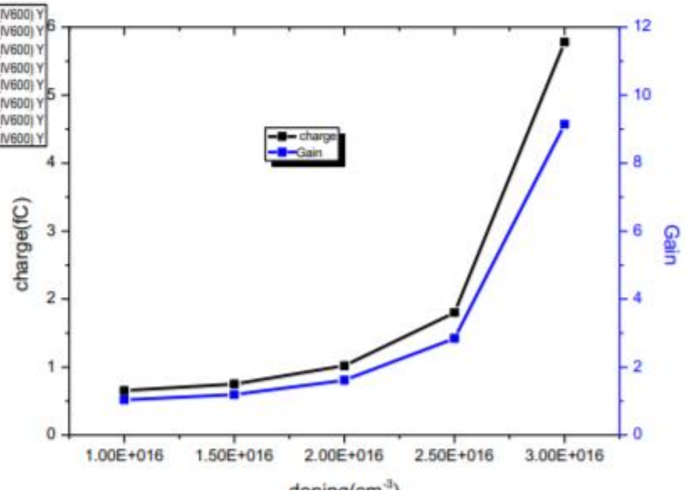


BACKUPS

Chip design and process design:

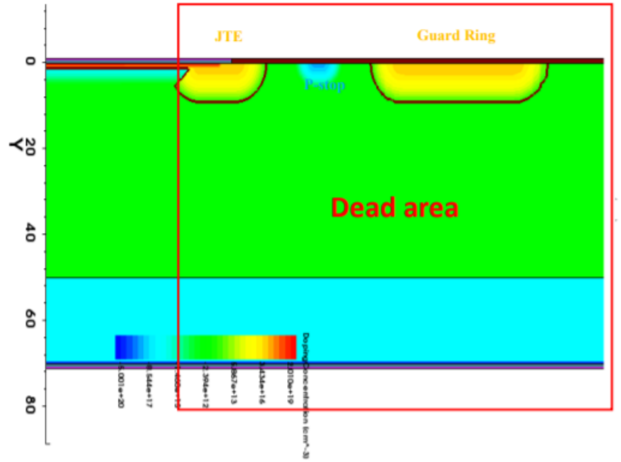
1 Process simulation 2 Structure simulation

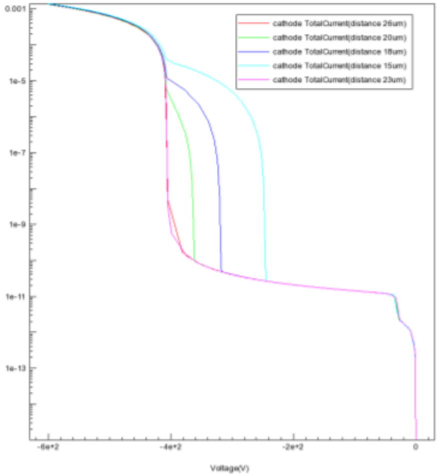




Gian layer doping concentration vs breakdown voltage and Gain

$3e16cm^{-3}$, Vbd>400V, Gain>10

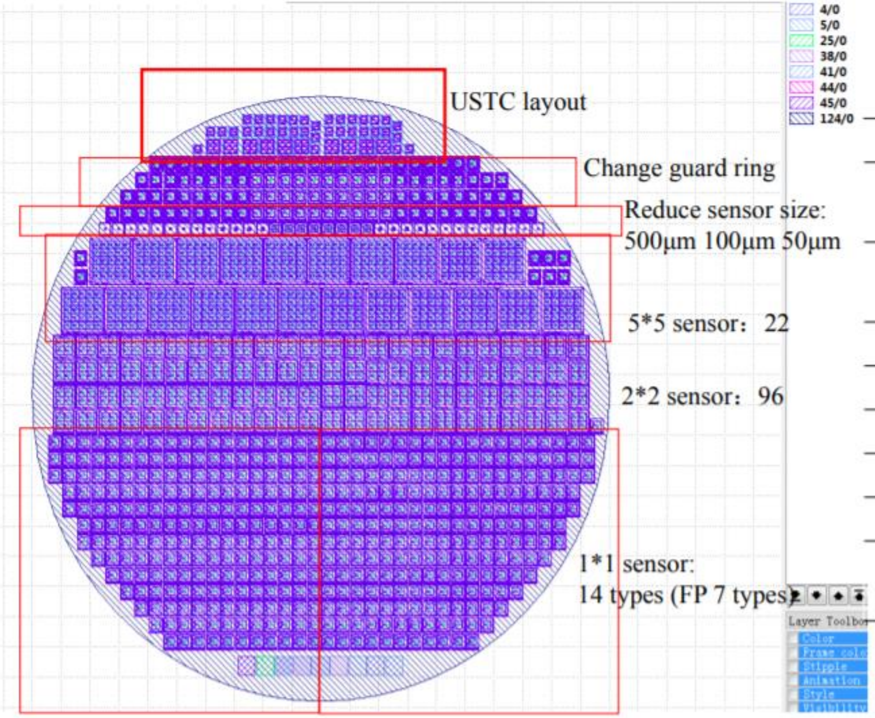




Gap size between JTE and guard ring vs breakdown voltage

BACKUPS

- Layout， real process and parameters



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→wafer clean

→JTE Implantation

Deposit oxide layer, photolithographically etching the oxide layer, (mask 4/0)
Phosphorus ion injection, remove oxide layer, and thermally diffuse

→P-stop Implantation

Deposit an oxide layer, photolithographically etching the oxide layer, (mask 5/0)
Boron ion injection, remove oxide layer, and thermally diffuse

→P layer Implantation

Deposit oxide layer, photolithographically etching the oxide layer, (mask 38/0)
Boron ion implantation, thermal diffusion, and remove oxide layer

→n++ Implantation

Deposit oxide layer, photolithographically etching the oxide layer (mask 41/0)
Phosphorus ion implantation, remove oxide layer, and thermally diffuse

→Deposit oxide layer

1.3 μm thickness, photolithographic etch oxide layer (mask 44/0)

→Deposit metal layer

Photolithography etching metal layer (mask 45/0)

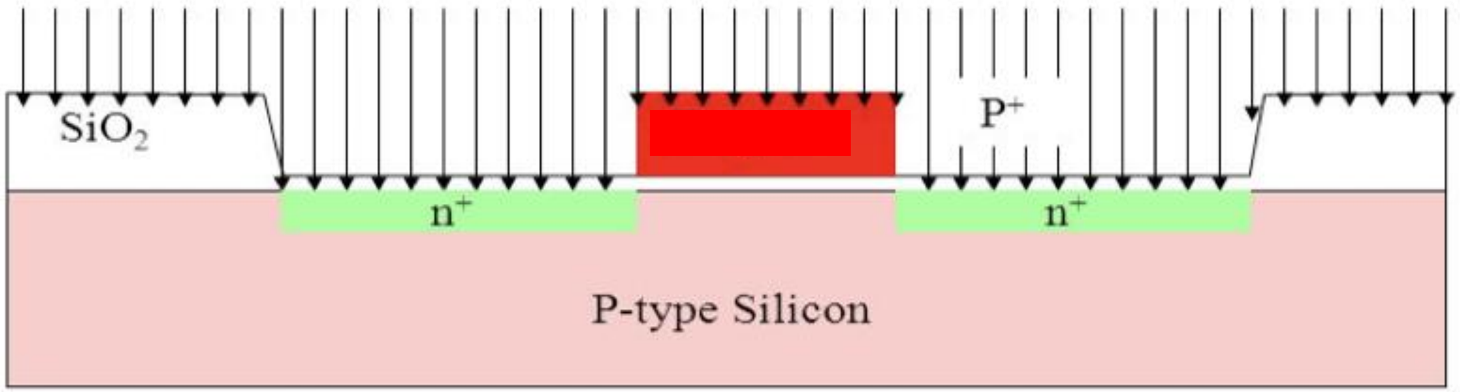
→lithography etches out the window area (mask 25/0)

→p++ Implantation

Boron ion implantation from backside

Process

1. Implant Phosphorus with N-JTE and WN-ring mask (dose=4e13<cm-2> energy=100<keV> diffuse temperature=1200<C> time=10.0<min>)
2. Implant Boron with P-stop and DC-stop mask (dose=2e14<cm-2> energy=40<keV> diffuse temperature=1200<C> time=10.0<min>)
3. Implant Boron with P+ layer mask (dose= ? ? ? <cm-2> energy=100→130<keV> diffuse temperature=1200→1150<C> time=60.0<min>)
4. Implant Phosphorus N++ layer with mask (dose=1e15<cm-2> energy=40<keV> no diffusion)
5. Implant Boron from back without mask (dose=1e15<cm-2> energy=40<keV> diffuse temperature=1050<C> time=10.0<s>)



BACKUPS:NDL sensor

– LGAD sensor with Epitaxial layer
  - NDL is foundry for SipM. They can provide LGAD as well.
  - First batch LGAD sensor fabricated. (~100 2x2 sensors)
    - Thickness of epitaxial layer: 33um
    - epitaxial layer Resistivity: 10kOhm.cm

http://www.ndl-sipm.net/contacteng.html

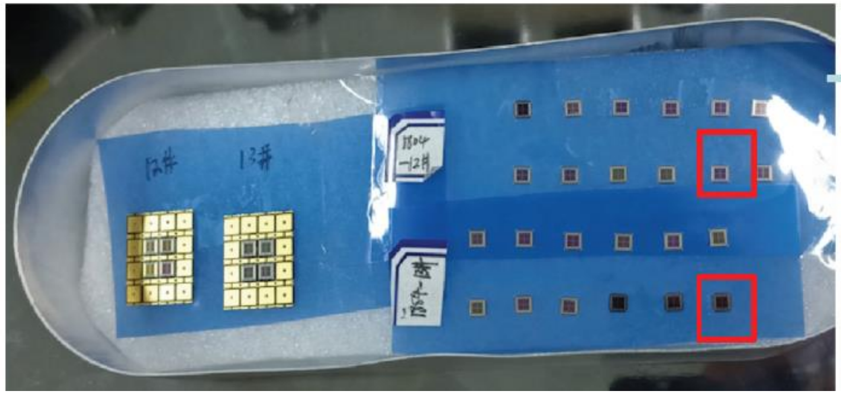

NDL 新 器 件 实 验 室
Novel Device Laboratory
Home Devices Modules Order information News 中文版

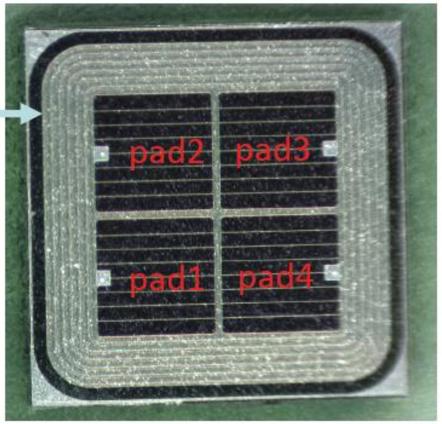
NDL can provide reliable and cost effective SiPMs with typical delivery time from 1 week to 3 months.

Novel Device Laboratory（NDL）
Address: XueYuan Nan Lu No.12
Hai Dian District, Beijing, China,100875
Tel: +86-10-62207419, Fax：+86-10-62207419
Email：info@ndl-sipm.net

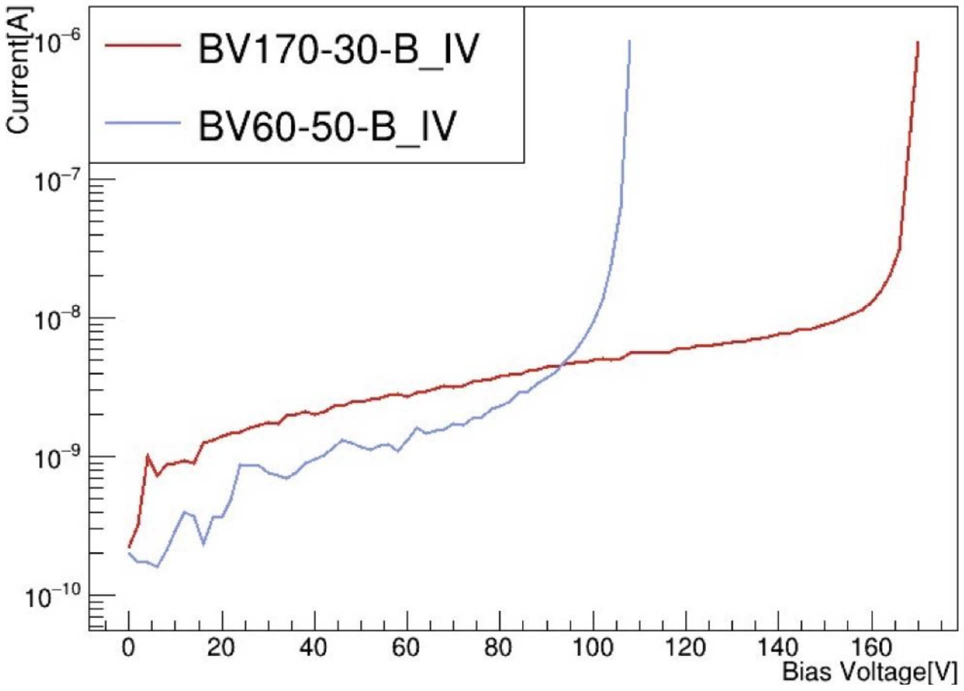
Photoelectric Instrument Factory of Beijing Normal University
Address: 1st floor in block B of Dormitory 4 Xin Wai Da Jie No.19, Hai Dian District, Beijing, China
Tel: 010-58807630
Email: 58807630@163.com
Web: http://www.peifbnu.com/plus/view.php-aid=72.html

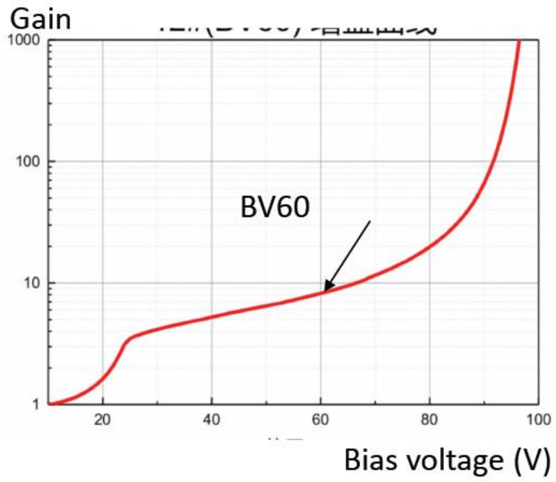
Two type of sensors BV170-30-B, BV60-50-B

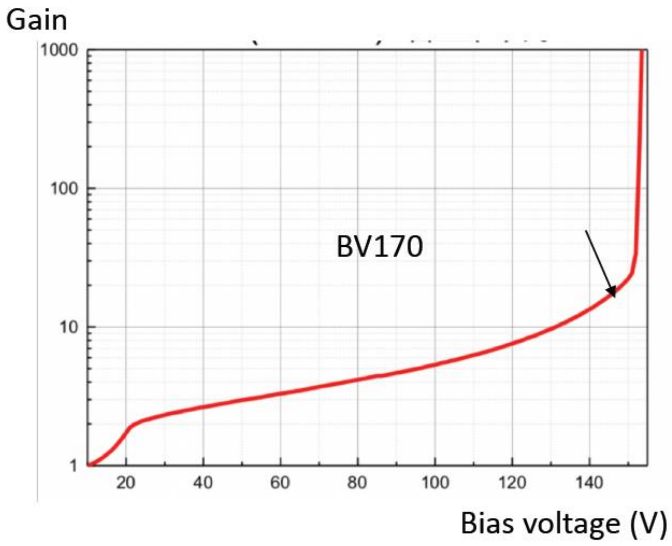




Next version of NDL LGAD



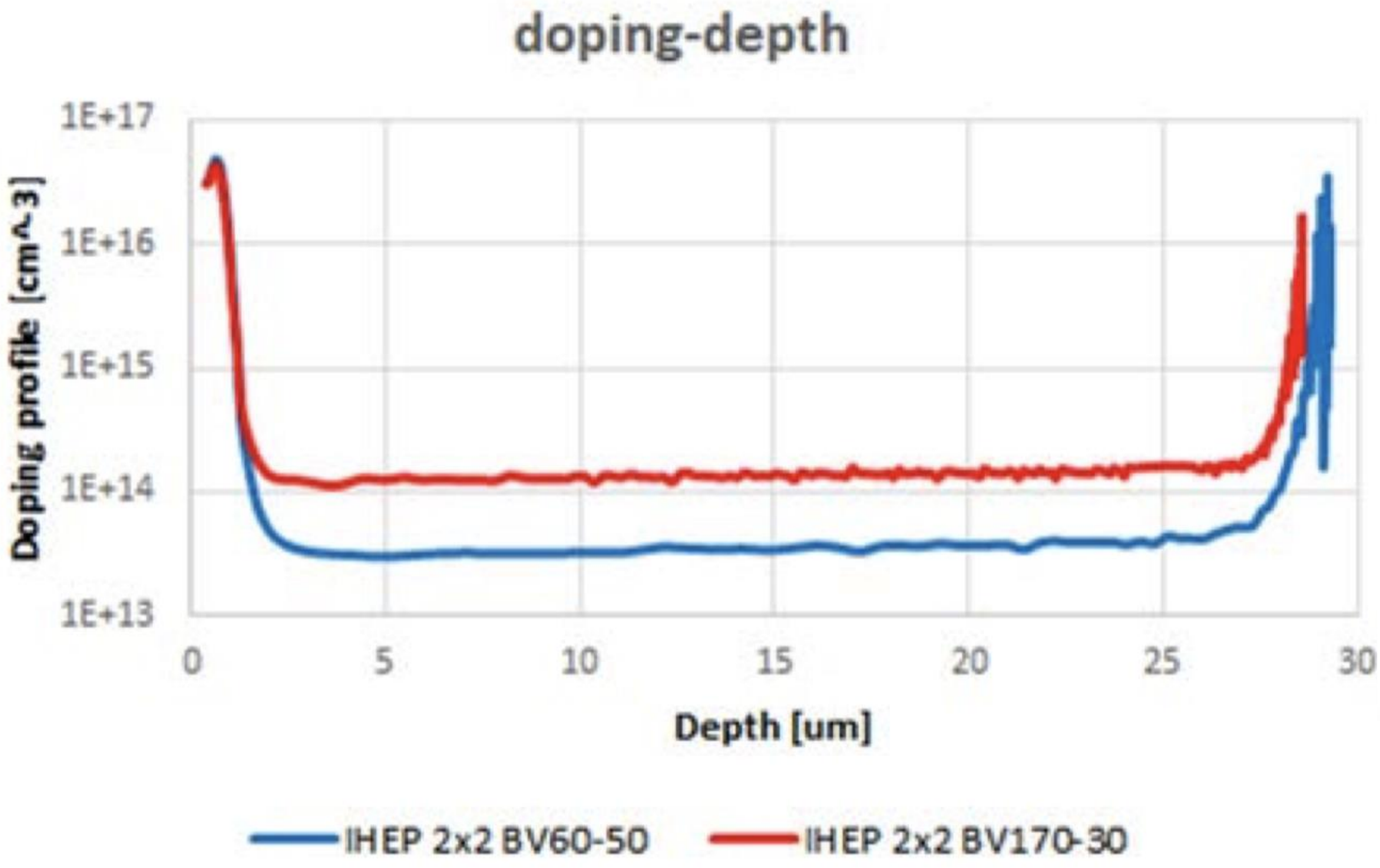




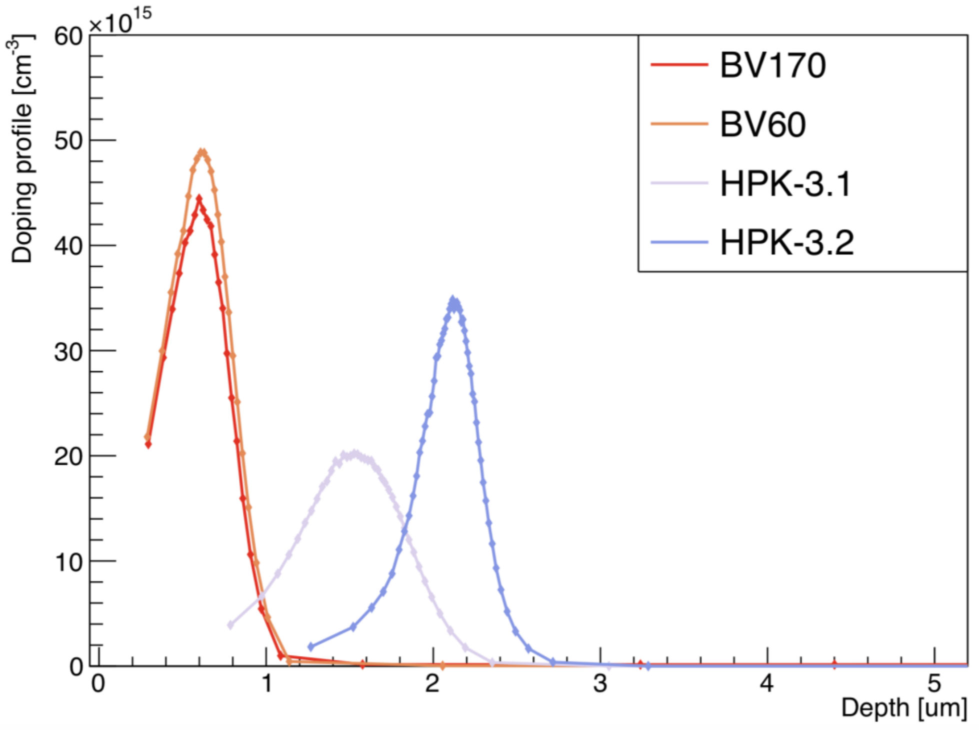
- 2nd version of NDL LGAD will use 5x5 HPK layout
  - MPW, will submit in May 2019
- Two doping profile (BV60, and doping like HPK 3.2)
- Area : 6.5 mm ×6.5 mm
- Epi layer thickness : 33μm,300Ohm.cm
- layout : 5×5 LGAD
- gain : 10-30
- capacitance : <4 pF
- Time resolution <50 ps
- Leakage current : <1nA
- Diameter for bump bonding pad: 90 μm,pitch:1.3mm
- Two different doping
  - One with BV60-50-B design ;
  - Another with deep P+ implantation (~2um)

Doping profile for NDL sensor

(UCSC measurement)



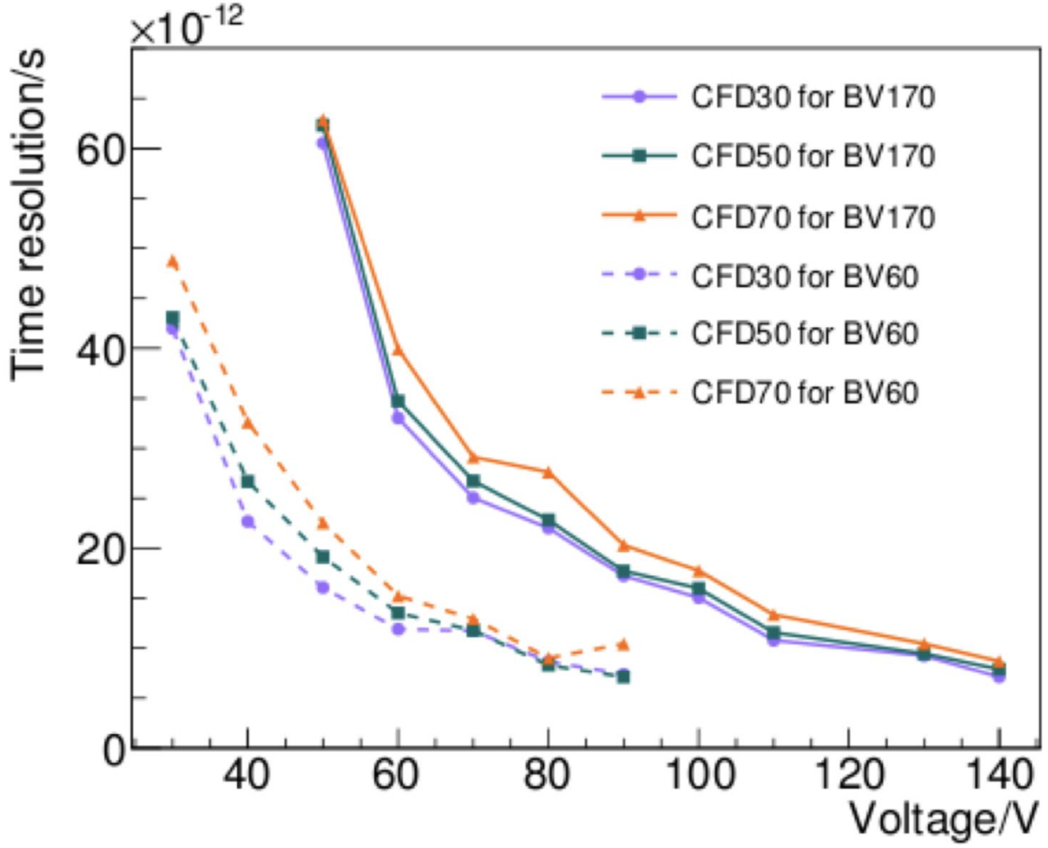
IHEP measurement



Timing performance

Laser test

Sigma analysis (offline)



Beta test
(UCSC measurement)