# Research and development of 3D detector and LGAD based on 8-inch CMOS Process

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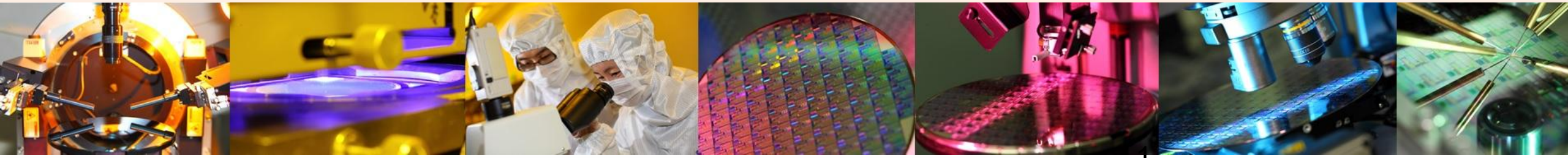
**Institute of Microelectronics, Chinese Academy of Sciences (IMECAS)**



# 1. Institute of Microelectronics, Chinese Academy of Sciences (IMECAS)

中国科学院微电子研究所
INSTITUTE OF MICROELECTRONICS OF THE CHINESE ACADEMY OF SCIENCES

**Founded in 1958 as the first semiconductor fab in China**


**Leading organization in Microelectronic R&D in China**

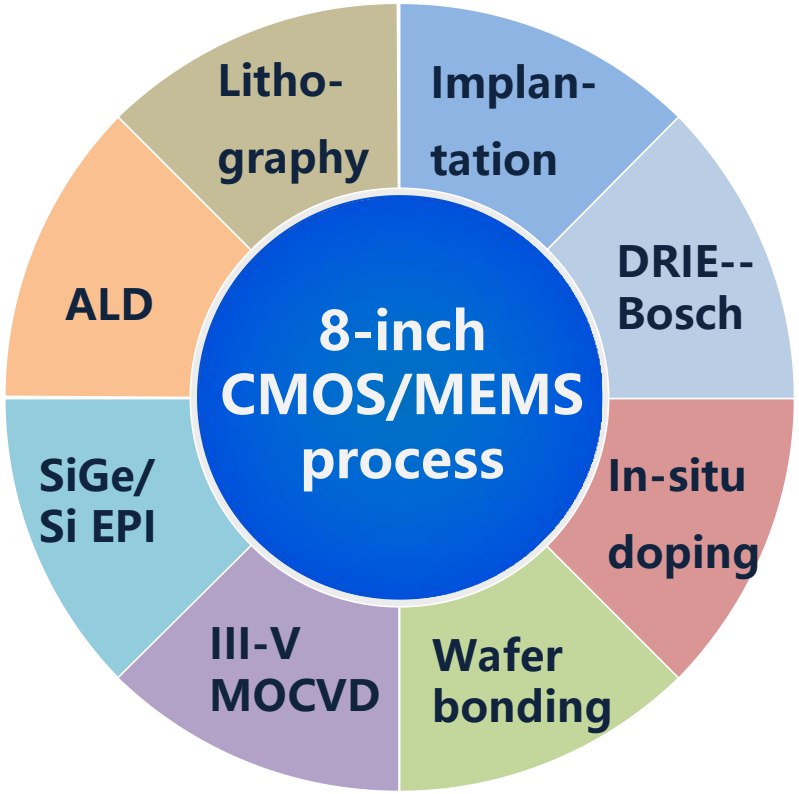
**~1100 Employee (~100 Professors), ~1000 Graduate students**

# 1. Institute of Microelectronics, Chinese Academy of Sciences (IMECAS)


It is located in Chaoyang district, Beijing.

# 2. Integrated Circuit Advanced Process R&D Center (ICAC) of IMECAS


- Currently, ~130 research staff, ~15 Professors, ~200 graduate students of ICAC-IMECAS.
- There are currently over 100 sets of large and medium-sized process research and testing equipment with a clean room of 2500 square meters.
- 22-5 nm Key Process Research and Development; 130/180 nm CD mass production technology; CMOS full process; MEMS full process.



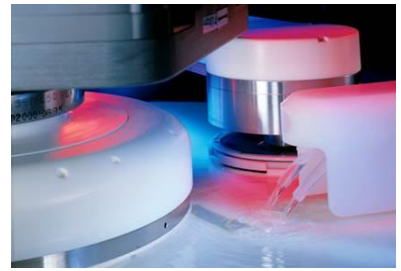
# 2. Integrated Circuit Advanced Process R&D Center (ICAC) of IMECAS

Deep silicon etching equipment

Ion implantation equipment

0.13/0.18/0.5 μm lithography equipment

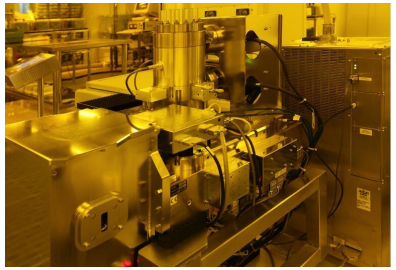
Dielectric CVD deposition equipment



Chemical mechanical planarization CMP equipment

**Based on the 8-inch CMOS process platform of the ICAC-IMECAS, a complete set of silicon device process modules has been developed.**

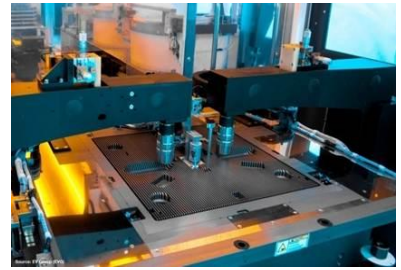
Oxygen/polycrystalline/annealing horizontal furnace tube/low stress silicon nitride LPCVD equipment



Double-sided exposure equipment

CD-SEM

Dielectric/metal etching equipment



Wafer level bonding equipment

**The research of silicon radiation detectors has been developed rapidely in recent years .**

Slot type automatic cleaning equipment

RTP rapid annealing equipment/silicide annealing equipment

Scanning electron microscope SEM/Atomic force microscope AFM/Optical profilometer/Stepping instrument

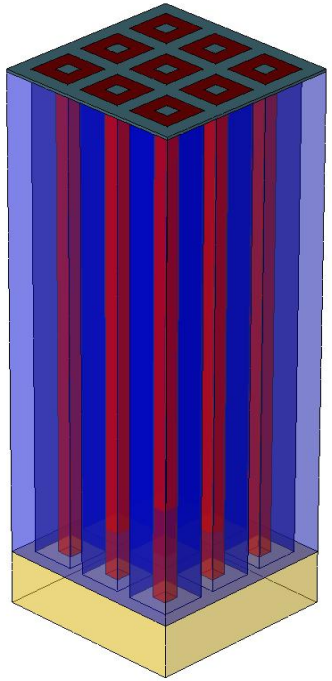

Metal PVD sputtering equipment

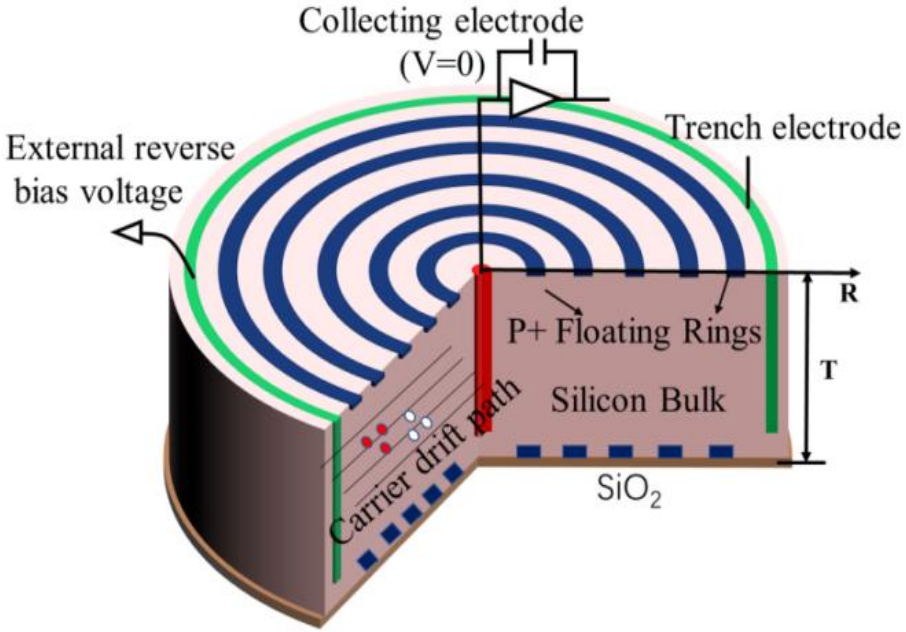
High and low temperature electrical testing probe platform

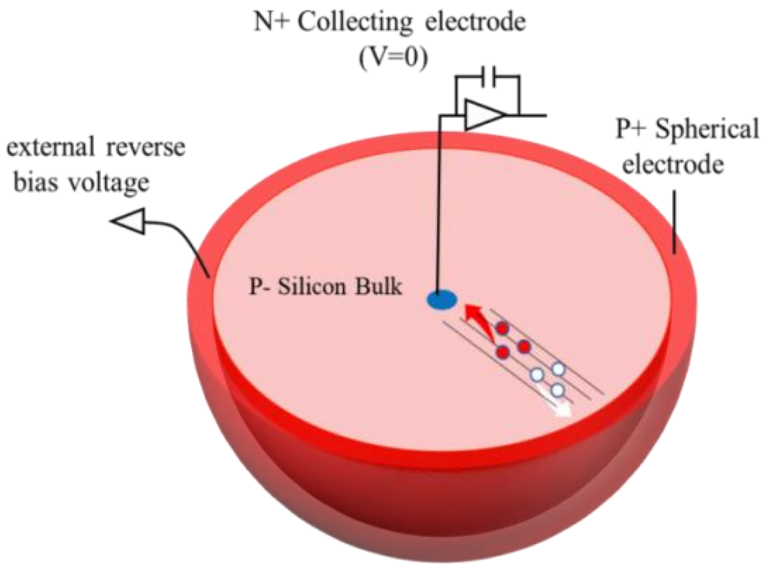
**3D detectors, LGAD, pixel detectors, and SDD.**

# 3. Research and development of silicon detectors--3D detectors

- **Propose multiple innovative 3D detector models, such as ultra-fast 3D detectors, large area 3D detectors, semi-sphere 3D electrode detectors, 3D open shell electrode detectors and so on.**

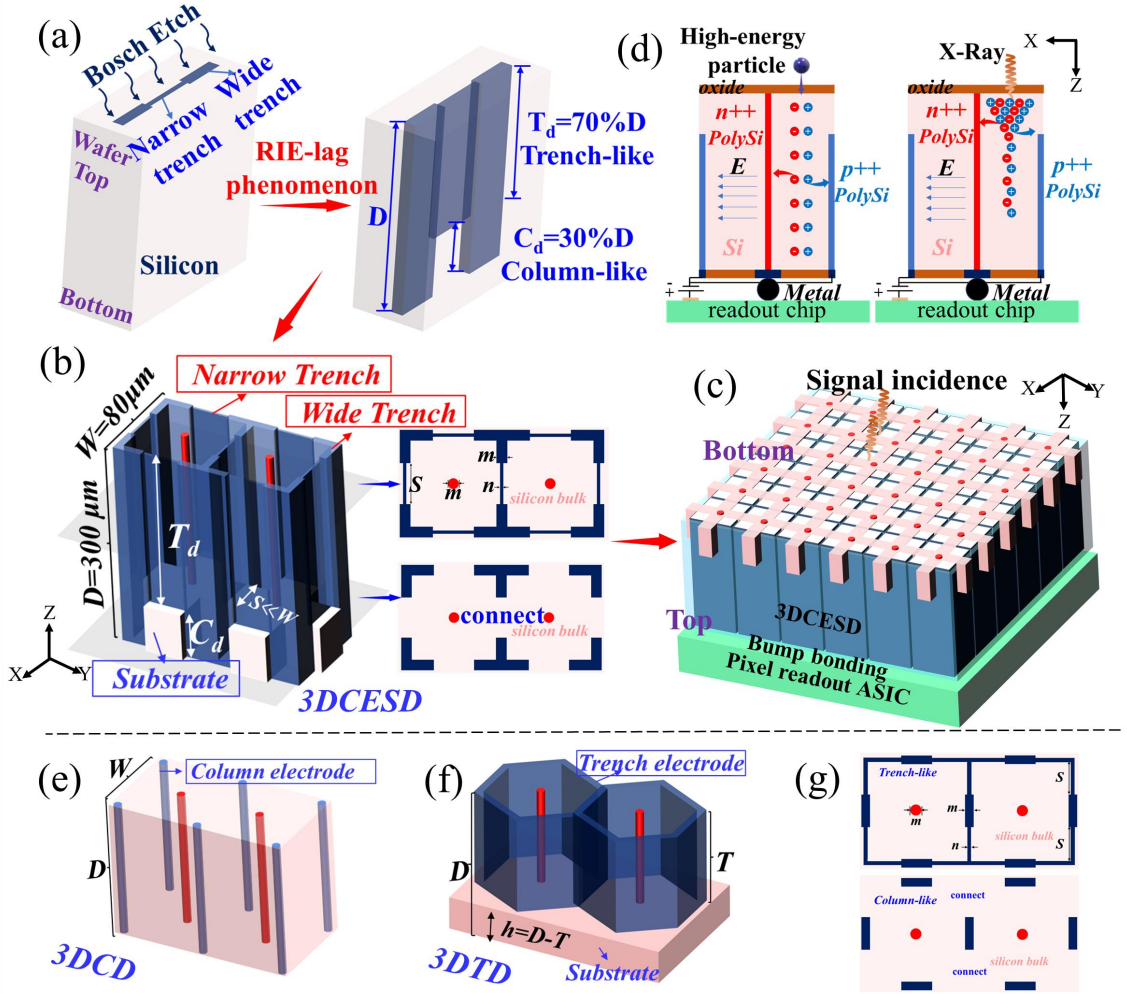




# 3. Research and development of silicon detectors--3D detectors

## ➢ Fast Response Back-Illuminated 3D Composite Electrode Silicon Detector Utilizing the RIE-Lag Phenomenon




(a) RIE-lag phenomenon of Bosch etch.

(b) 3D composite electrode silicon detector, 3DCESD.

(c) Diagram of the array.

(d) Schematic diagram of 3DCESD carrier collection of High-energy particle or X-ray incident .

(e) 3D column electrode silicon detector,3DCD.

(f) 3D trench electrode silicon detector,3DTD.

(g) Schematic diagram of 3DCESD-3, its narrow trench are located at the four corners of the pixel.

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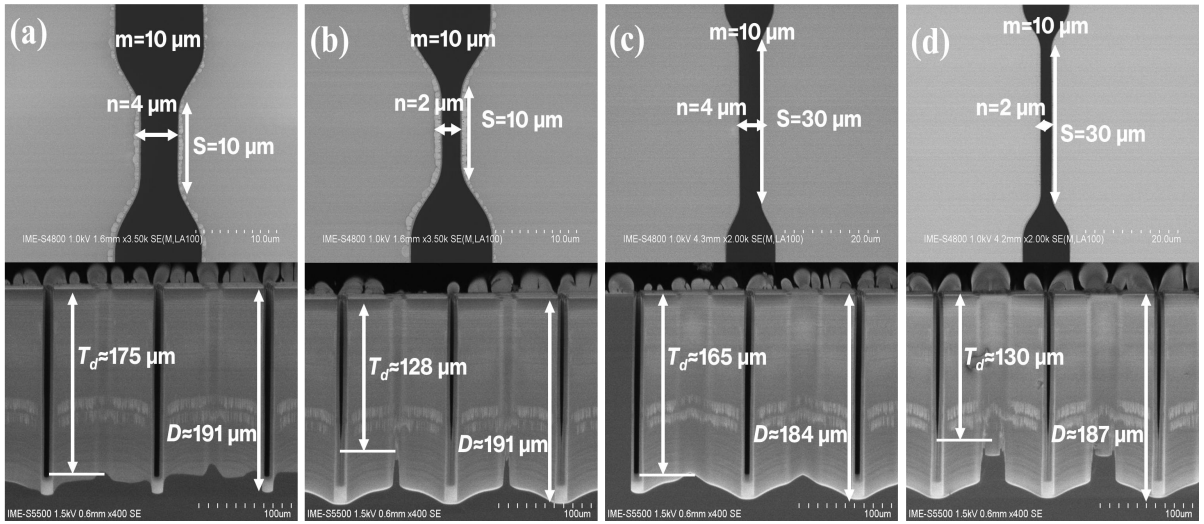


SEM image of bosch etching experiment: (a) n = 4 μm, S = 10 μm; (b) n = 2 μm, S = 10 μm; (c) n = 4 μm, S = 30 μm; (d) n = 2 μm, S = 30 μm.

Structural parameters of 3D TCAD simulation

| Structure (μm) | $S$ | $m$ | $n$ | $T$ | $T_d$ | $C_d$ |
|---|---|---|---|---|---|---|
| *3DCD* | - | 10 | - | - | - | - |
| *3DTD-210* | - | 10 | - | 210 | - | - |
| *3DTD-270* | - | 10 | - | 270 | - | - |
| *3DCESD-1* | 10 | 10 | 2 | - | 210 | 90 |
| *3DCESD-2* | 30 | 10 | 2 | - | 210 | 90 |
| *3DCESD-3* | 25 | 10 | 2 | - | 210 | 90 |

# 3. Research and development of silicon detectors--3D detectors

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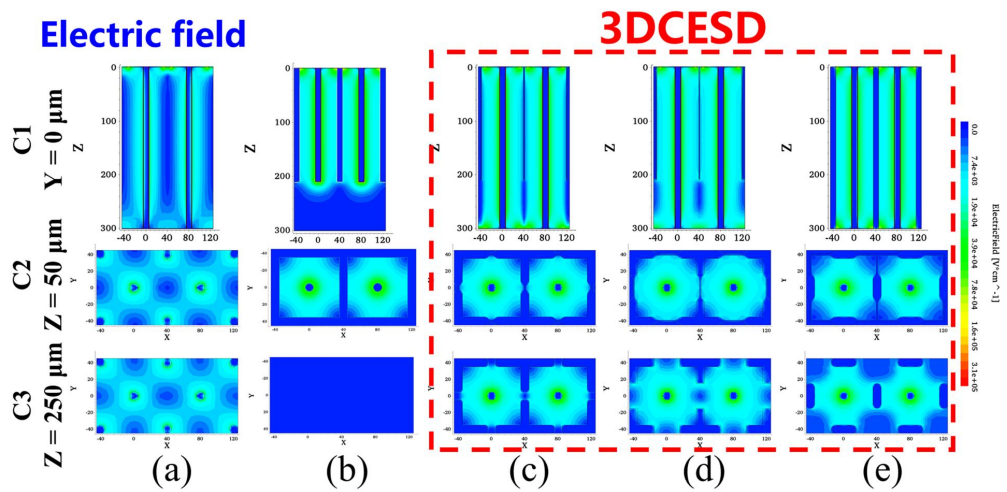
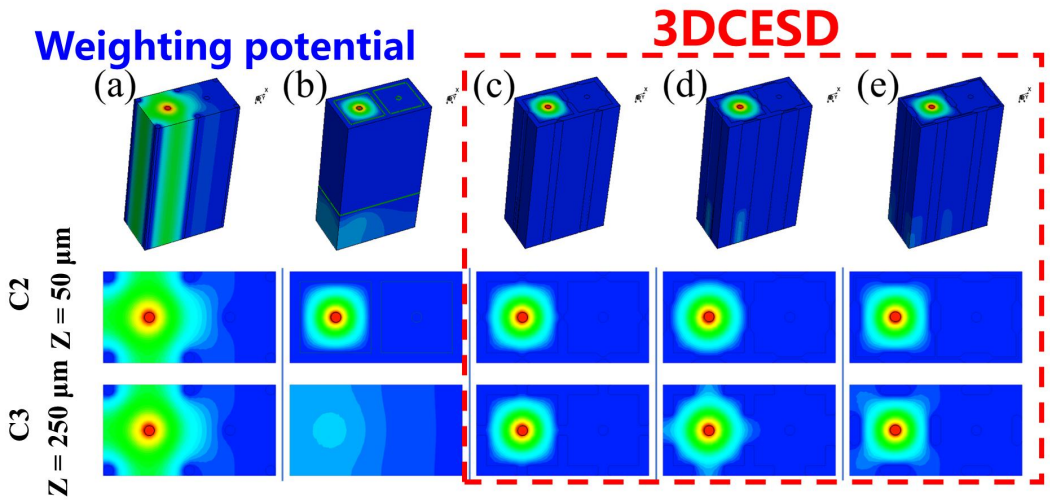


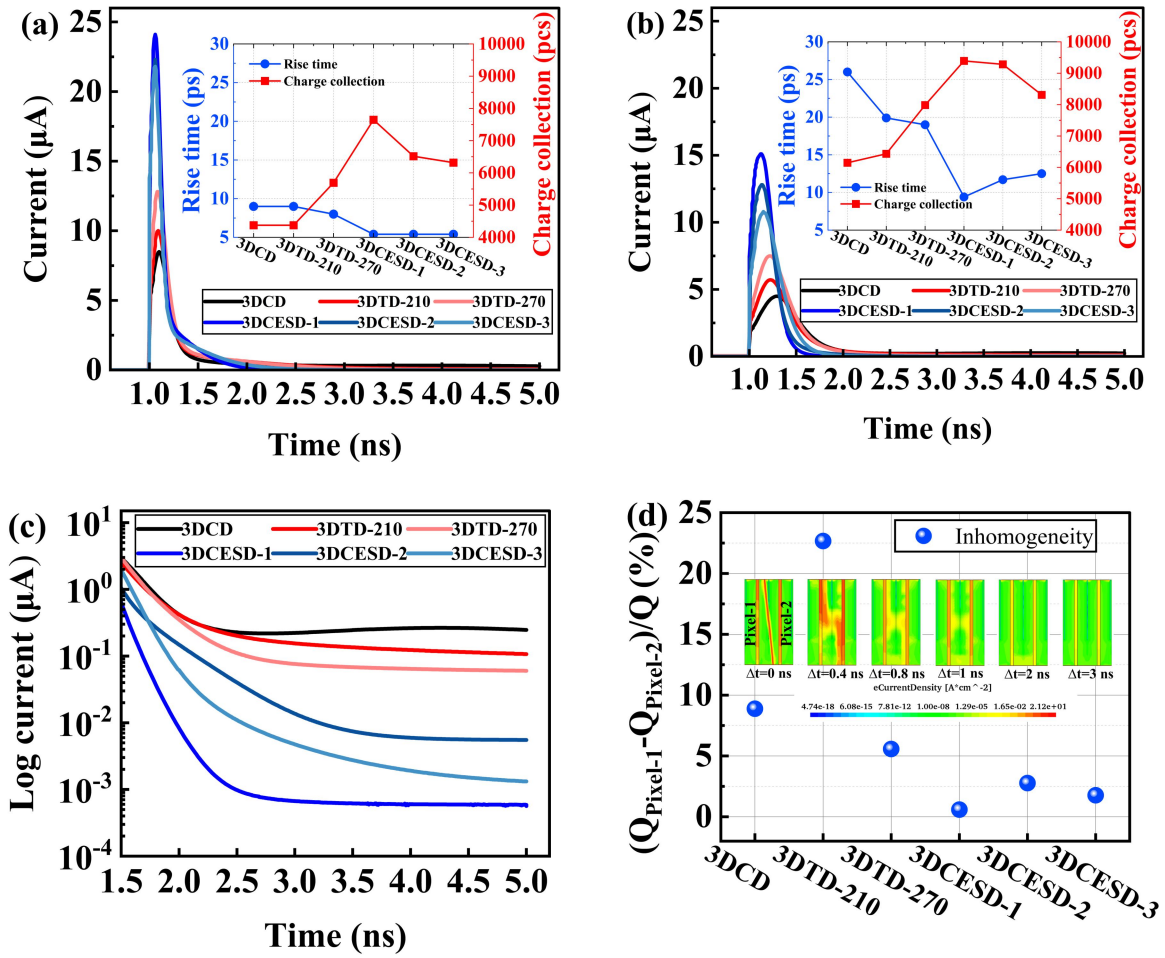

Electric field distribution with -50V reverse bias voltage applied: (a) 3DCD; (b) 3DTD; (c) 3DCESD-1; (d) 3DCESD-2; (e) 3DCESD-3.




Weighting potential distribution: (a) 2DPD; (b) 3DCD; (c) 3DTD; (d) 3DCESD-1; (e) 3DCESD-2; (f) 3DCESD-3; (g) 2D cross section of weighting potential distribution at Z=50 μm and 250 μm.

# 3. Research and development of silicon detectors--3D detectors

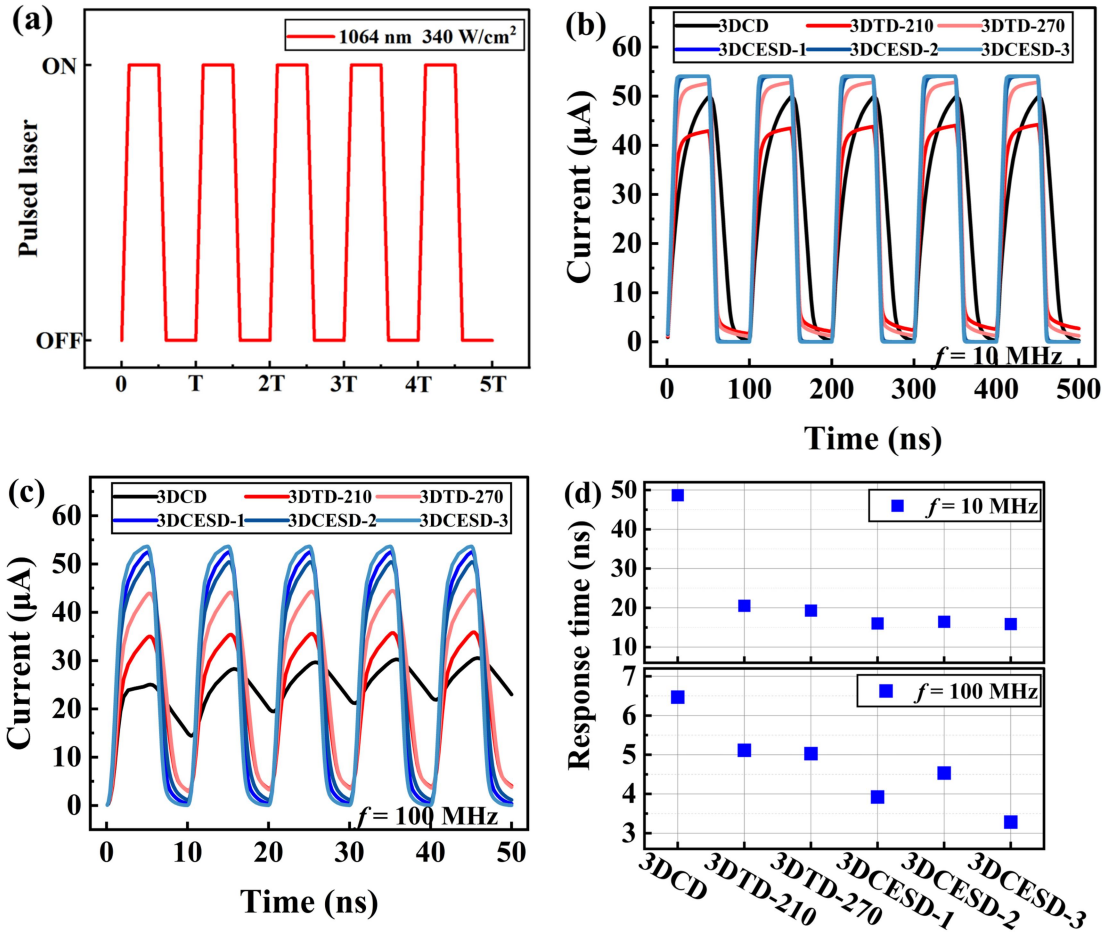
## ➢ Fast Response Back-Illuminated 3D Composite Electrode Silicon Detector Utilizing the RIE-Lag Phenomenon




The i-t curves, rise time and charge collection (a) (15,0,0); (b) (25,0,0); (c)The log current after the 1.5 ns in (c); (d)3DCESD-2 electron current density distribution from Δt=0 ns to 3 ns time range. The MIP incidence point and exit point are (25,0,0) and (55,0,300) respectively.

# 3. Research and development of silicon detectors--3D detectors

## ➢ Fast Response Back-Illuminated 3D Composite Electrode Silicon Detector Utilizing the RIE-Lag Phenomenon

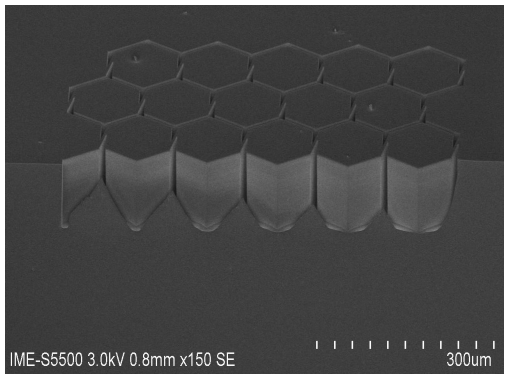


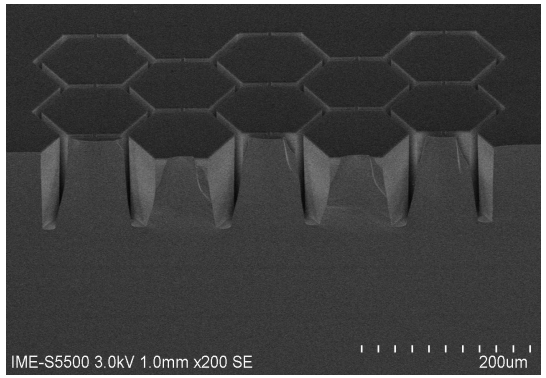

A penetrating infrared laser with a wavelength of 1064 nm and a light intensity of 340 W/cm$^2$ was utilized for simulation based on the ray tracing method.

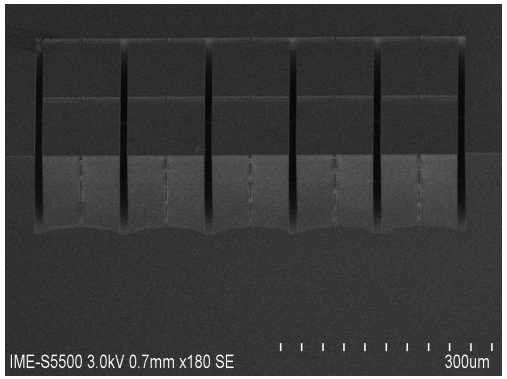
Pulsed laser. (a) Input pulse. (b) The output pulse at 10 MHz. (c) The output pulse at 100 MHz. (d) Response time at 10 MHz and 100 MHz. The sum of the rise time (10%-90%) and fall time (90%-10%).

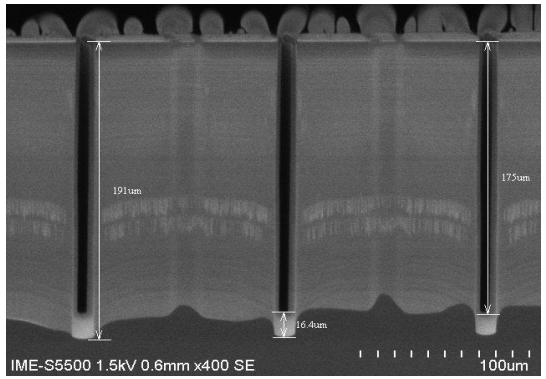
# 3. Research and development of silicon detectors--3D detectors

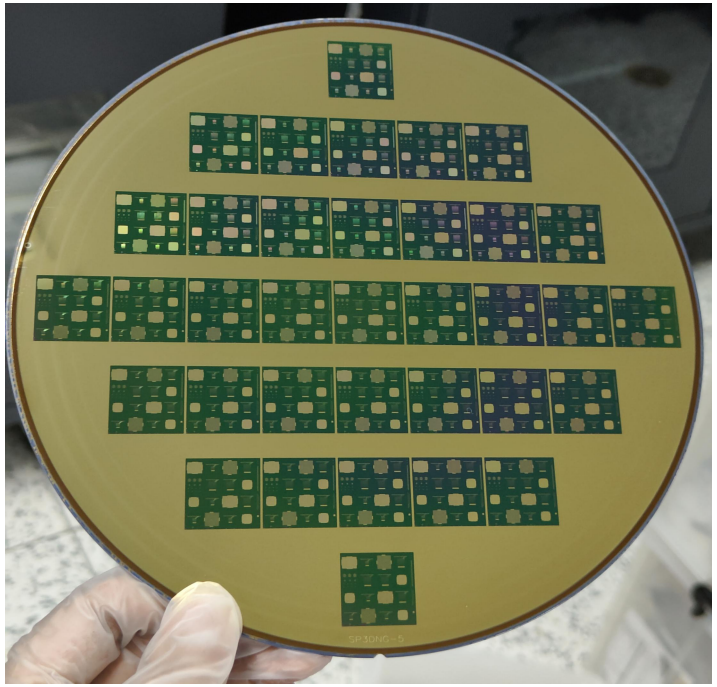
- Developed key 3D electrode processes based on an 8-inch CMOS process platform, including deep reactive ion etching DRIE--Bosch process, multi-source diffusion (in-situ) doping, and so on.
- The newly completed 8-inch 3D detector wafer is shown below.



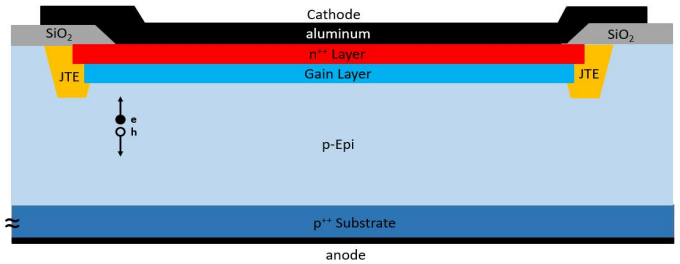



8-inch wafer

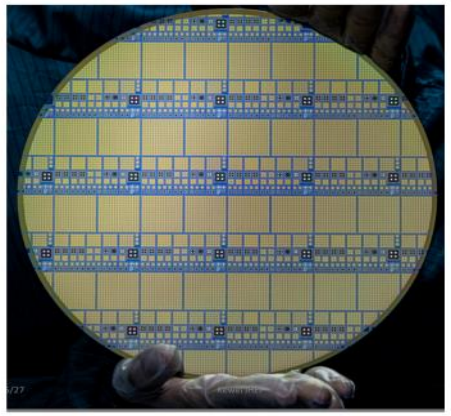
# 3. Research and development of silicon detectors--LGAD

- Low-Gain Avalanche Diodes (LGAD) with ultra-high time resolution (35 ps) and good radiation resistance using high-energy boron implantation and carbon doping technology has been developed in IMECAS.
- After irradiation with an equivalent neutron flux of $2.5\times10^{15}$, it has the lowest acceptor removal rate.

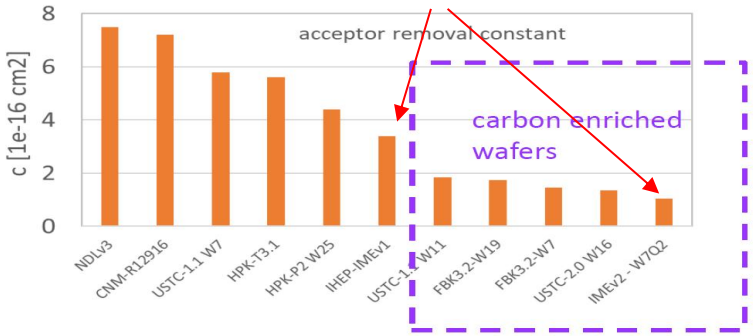
## LGAD design and manufacture



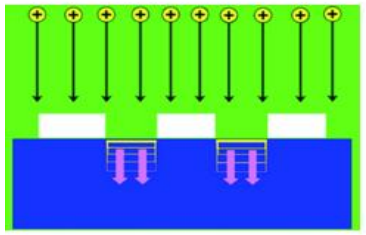

## 8 inch LGAD wafer



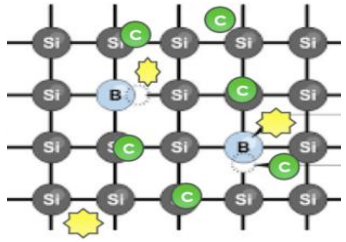
## Anti-radiation



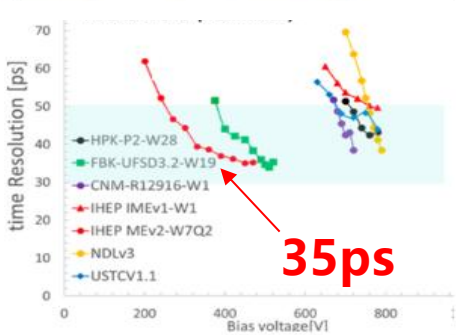

## High-energy boron implantation

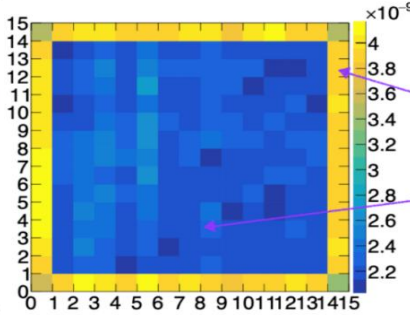


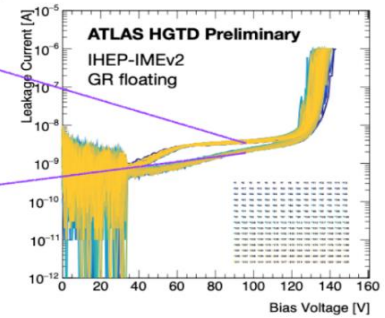
## Carbon doping




## Excellent uniformity of 15×15 full-size sensors

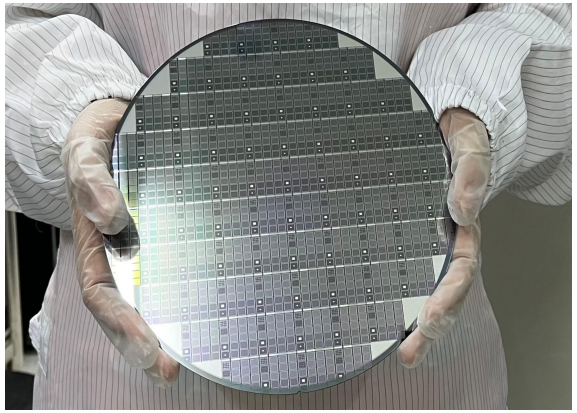


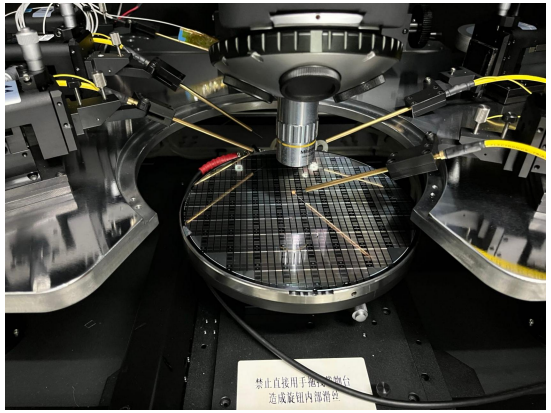



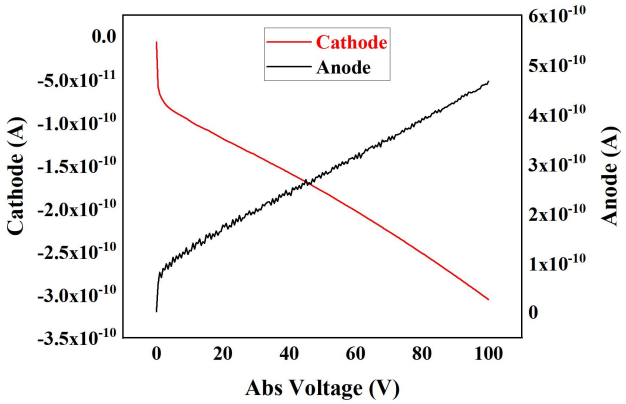



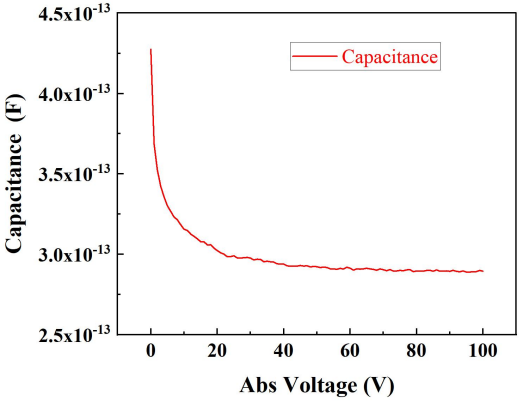
# 3. Research and development of silicon detectors--Pixel detector

- The development of high detection efficiency, high energy/position resolution, and low noise soft X-ray pixel detectors is being driven by the demand for pulsars soft X-ray detection applications.
- A production process based on CMOS technology on the 8-inch process platform is developed.
- Low dark current and capacitance at room temperature, good consistency, and integration.
- The wafer surface is clean and the pixels are clear, and the test results meet the project expectations.



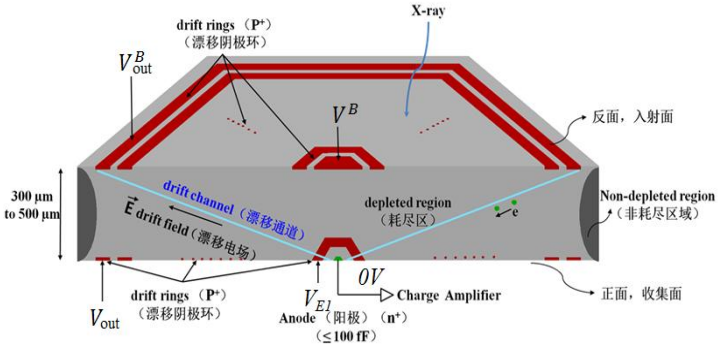




# 3. Research and development of silicon detectors--SDD

- To meet the application requirements of pulsar navigation square meter array, a large area unit of 314 mm², low noise, and high energy resolution silicon drift detector SDD chip and system are developed.
- Adopting an innovative design of spiral electrode voltage divider, with unique impurity absorption oxidation and high-precision double-sided lithography alignment process.
- Good voltage divider effect, dark current less than 5 nA, and readout capacitance less than 100 fF.
- The energy spectrum of the main amplifier with a gain of 500 times and a bias voltage of -300 V has a half width/energy resolution of 150 eV at 5.9 keV.

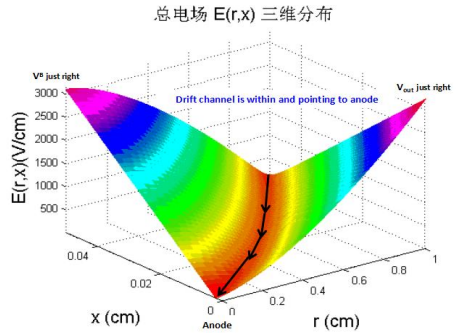


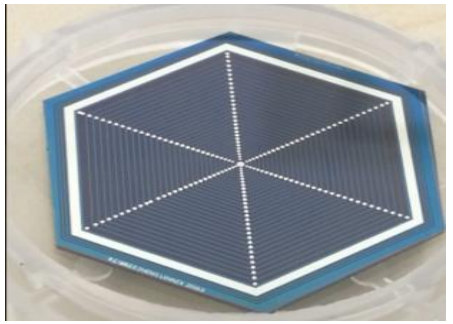

$$\Phi(r)=\frac{V_{out}-V_{E1}}{R^{\frac{3}{2}}-r_1^{\frac{3}{2}}}r^{\frac{3}{2}}+\frac{R^{\frac{3}{2}}V_{E1}-r_1^{\frac{3}{2}}V_{out}}{R^{\frac{3}{2}}-r_1^{\frac{3}{2}}}$$

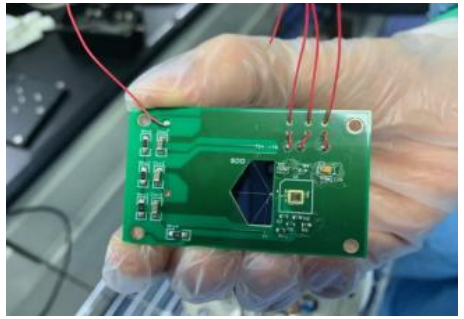
$$E_{dr}(r)=\frac{1}{2}\frac{V_{out}-V_{E1}}{R-r_1}[(1+r)+(1-r)\frac{V_B}{V_{fd}}]-\frac{1}{4}\frac{(1-r)^2}{V_{fd}(R-r_1)}(V_{out}^2-V_{E1}^2)$$

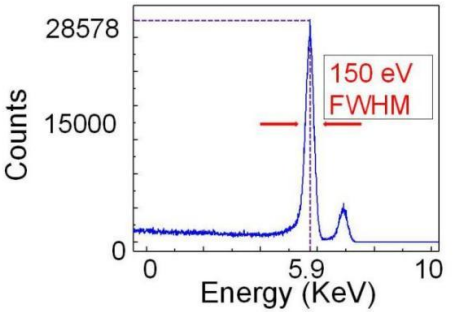
$$r=r_1[1+\frac{3}{8\pi}\frac{p_1}{r_1}(\theta-\theta_1)]^{\frac{4}{3}}$$

$$W(r)=\frac{\rho_S I\alpha\sqrt{rr_1}}{E(r)p_1}$$



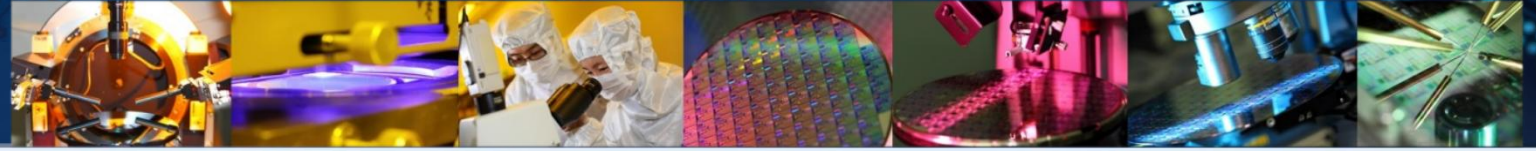




# 4. Conclusion

- **3D detectors, LGAD, Pixel detector, and SDD have been developed in IMECAS.**
- **Recently, we focus on the development of noval 3D trench electrode detectors.**
- **Seek cooperation in test beams, readout systems, raidation characterizations, and so on.**

| Number | Schedule | Deliverables | Milestones | Funding |
|---|---|---|---|---|
| IMECAS-3D-DETECTOR-#-1 | *T+12* | *1st batch of novel 3D trench detector chip (8-inch wafer)*<br>I-V, C-V, Response time, Charge collection Efficiency, Radiation harnness | Ultra-fast 3D detectors, Large area 3D detectors, Semi-sphere 3D electrode detectors, 3D open shell electrode detectors<br>Different pixel sizes | National Natural Science Foundation of China<br>National Key R&D Program of China |
| IMECAS-3D-DETECTOR-#-2 | *T+24* | *2nd batch of novel 3D trench detector chip (8-inch wafer)*<br>I-V, C-V, Response time, Charge collection Efficiency, Radiation harnness | Double-sided 3D detectors<br>Large area 3D detector array<br>Smaller pixel sizes | National Natural Science Foundation of China<br>National Key R&D Program of China |
| IMECAS-3D-DETECTOR-#-3 | *T+36* | *3rd batch of novel 3D trench detector chip (8-inch wafer)*<br>I-V, C-V, Response time, Charge collection Efficiency, Radiation harnness | Various 3D detector designs<br>Smaller pixel sizes<br>Different trench thickness<br>Customized fabrication | National Natural Science Foundation of China<br>National Key R&D Program of China |



# *Thanks!*