19th international workshop on radiation imaging detectors, 2-6, July, 2017, Krakow, Poland

Compact 3D core-shell diode array for high performance particle detector & imaging sensor applications

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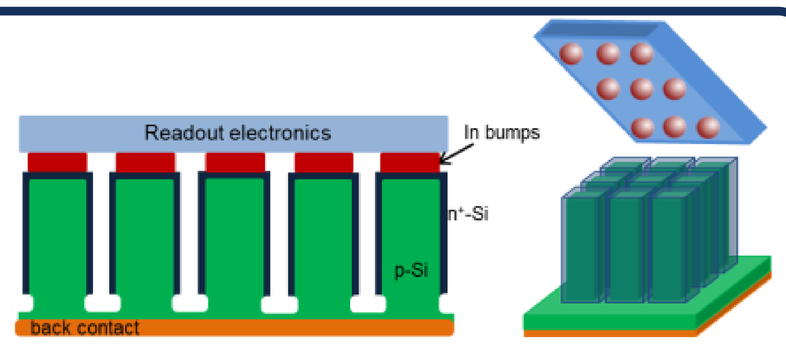
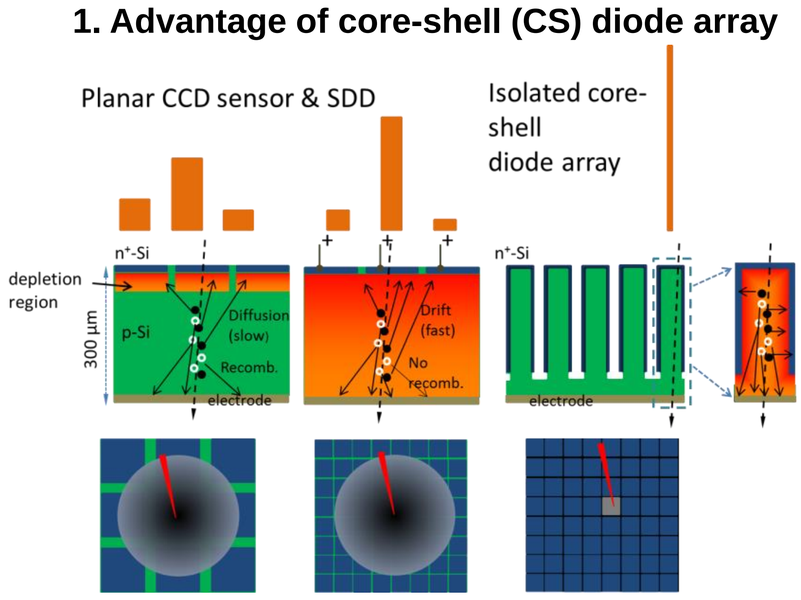
Motivation

- High performance particle detectors & imaging sensors (ultrahigh radiation hardness, high spatial resolution, low power consumption, fast signal response and high sensitivity) are needed in future for fundamental research in high energy physics (HEP), astrophysics, life science etc.
- Conventional planar detectors/imaging sensors suffer from low radiation hardness mainly due to defects generation, type inversion, and increasing doping level, resulting in a great increase of the full depletion voltage and dark current.
- Novel core-shell diode array design allows full depletion of detector even without additional reverse bias, and the generated carriers are collected by a short lateral path, and will have ultrahigh radiation hardness, low power consumption, fast signal response, and high spatial resolution simultaneously[1,2].

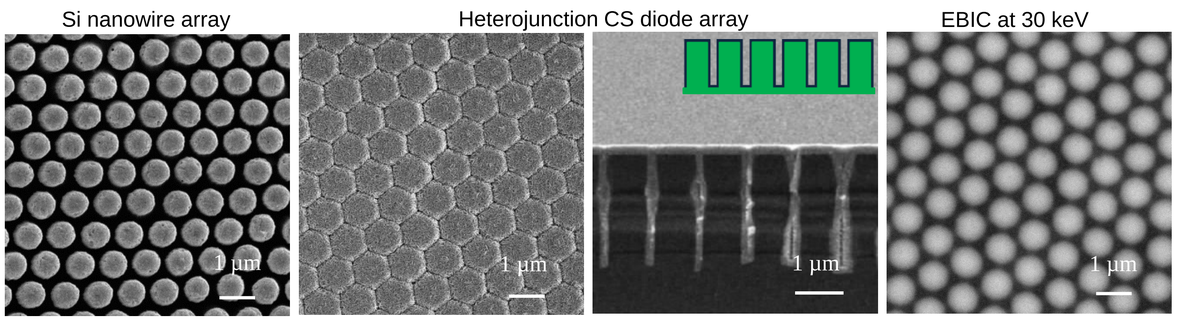


1. Advantage of core-shell (CS) diode array



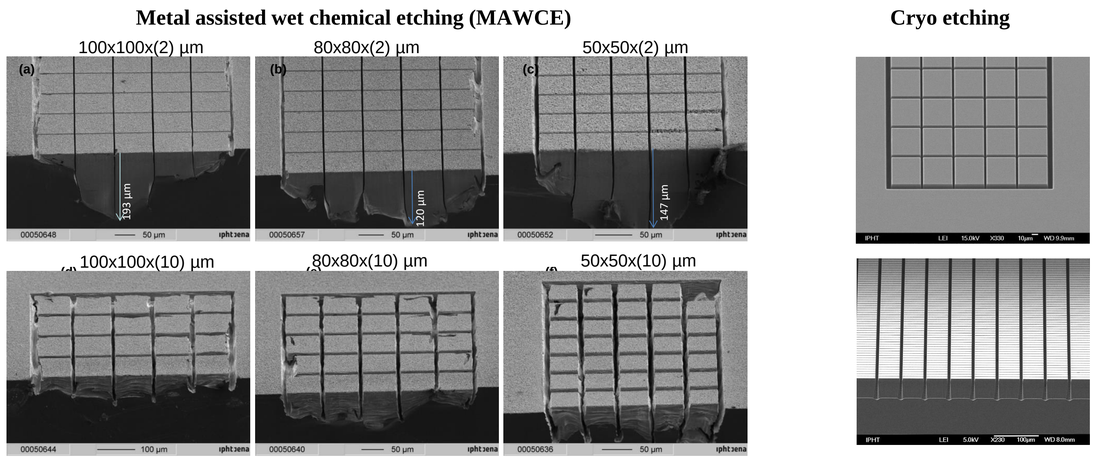
Structures / Properties	Planar	CS diode (array)
Radiation hardness	Low (sensitive to generated crystal defects)	**Ultrahigh[1,2] (not sensitive to defects).**
Spatial resolution	Poor (crosstalk between neighboring pixels), very poor resolution for particle detectors and imaging sensors working at infrared region. wrong information from neighboring pixel	**High (no crosstalk and it depends only on the pixel size), it is especially suitable for infrared sensors and particle detectors. No wrong information: Signal detected comes from where it is generated.**
Power consumption	High power consumption and leakage current (high reverse bias and cooling needed).	**Working even without reverse bias and cooling, very low power consumption.**
Signal response	Slow (long carrier collection length and slow diffusion process)	**Ultrafast due to short lateral carrier collection length by drift process), suitable for measurements at ultrahigh count rate.**
Sensitivity	Low (recombination loss of generated carriers.)	**High (no recombination loss of carriers and narrow, high peak)**

2. Proof of concept



- Very high aspect ratio structure with narrow channel can be prepared by silicon nanotechnology[3].
- High energetic electrons as particle source→work principle for particle detectors demonstrated.

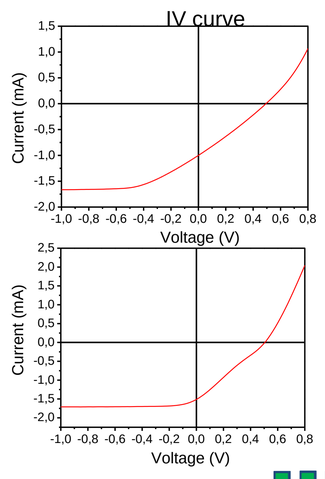
3. Development of CS diode array



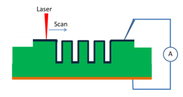
4. Electrical and optical characterization

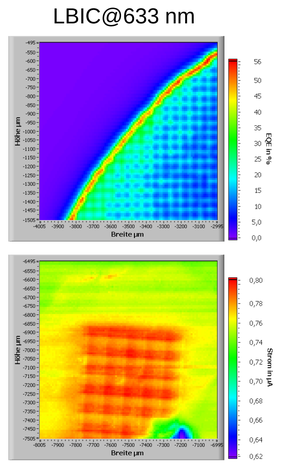
→ Pixels not separated

Homojunction by dopant drive-in



Laser beam induced current (LBIC)

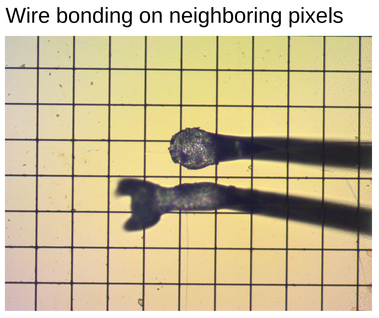




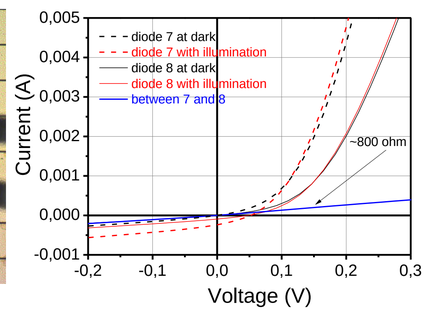
Heterojunction by PECVD: AZO/1 nm Al_2O_3/a-Si:H/c-Si

→ Pixel separation by a 2nd Cryo etching

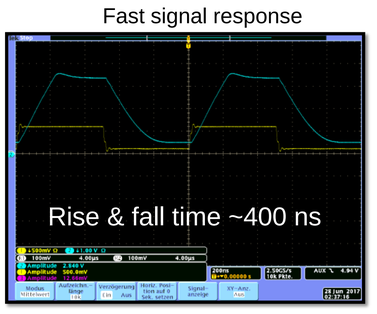
Wire bonding on neighboring pixels



IV curves



Fast signal response



- **Electrical contact by wire bonding on neighboring pixels is successful,**
- **Junction separation demonstrated,**
- **Signal response (~400 ns) is orders shorter than planar case (>tens of µs), and it can be much faster if the core is depleted (with small pixel size, or by applying reverse bias).**

Summary

- **First isolated CS diode array demonstrated,**
- **Very fast signal response of the CS diode measured,**
- **Promising for high performance (ultrahigh radiation hardness, high spatial resolution, low power consumption, fast signal response and high sensitivity) particle detectors working at extreme conditions and imaging sensors working especially within infrared region,**

Outlook

- **Optimization of the fabrication technology and process,**
- **Other junction types (for example Schottky diode for ultrahigh fast signal response) and material systems with CS configuration possess high potential to reach beyond state-of-the-art,**
- **System integration with readout chip by bump bonding, and beam test will be undertaken in the subsequent development phase.**

1. Jia et al., J. Phys. D: Appl. Phys. 49, 065106 (2016).
2. Jia et al., 18th international Workshop on radiation imaging detectors (IWORID 2016), Jinst , c02044 (2017).
3. Jia et al., Photonics and Nanostructures-Fundamentals and Applications 19, 64-70 (2016).

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