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Core-shell diode array for high performance particle detectors & imaging sensors

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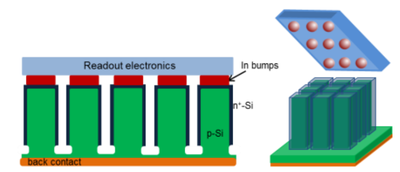
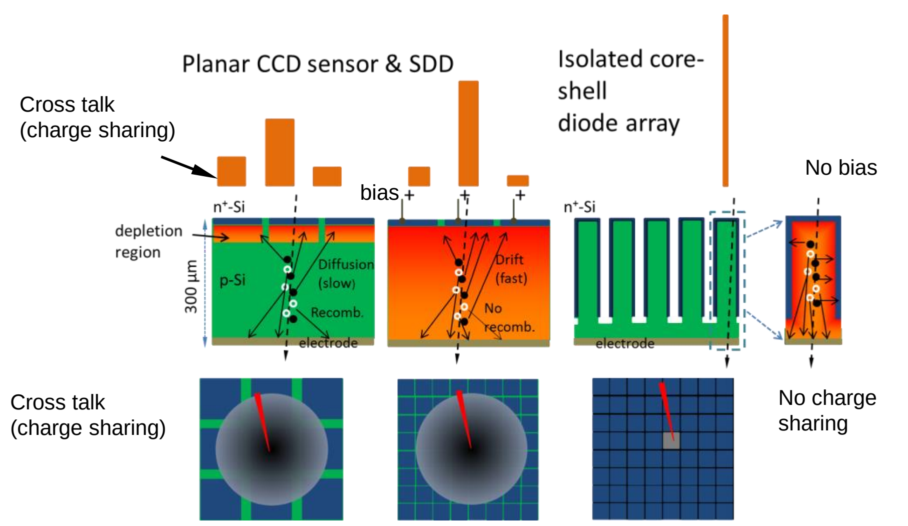
Motivation

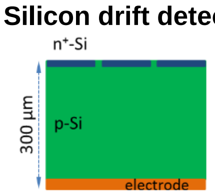
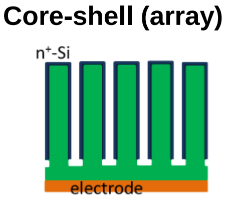
- High performance particle detectors & imaging sensors (ultrahigh radiation hardness, high spatial resolution, low power consumption, fast signal response and high sensitivity) are needed in the future for fundamental research in high energy physics (HEP), astrophysics, life science and so on.
- Conventional silicon drift detectors (SDDs) prepared on planar wafer 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 the 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.



Isolated core-shell diode array for the application as particle detectors/imaging sensors.

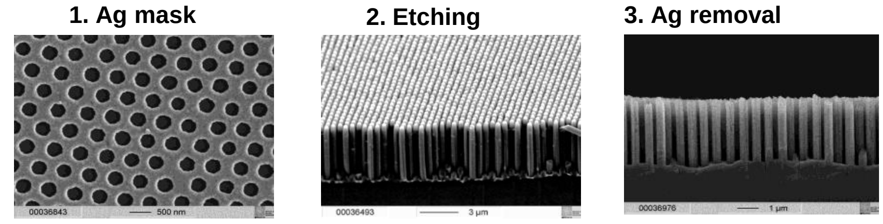
Planar vs. core-shell design



Structures / Properties	Silicon drift detectors	Core-shell (array)
		
Radiation hardness	Low (sensitive to generated crystal defects)	Ultrahigh[1] (not sensitive to defects).
Spatial resolution	Poor (crosstalk between neighboring pixels), 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)

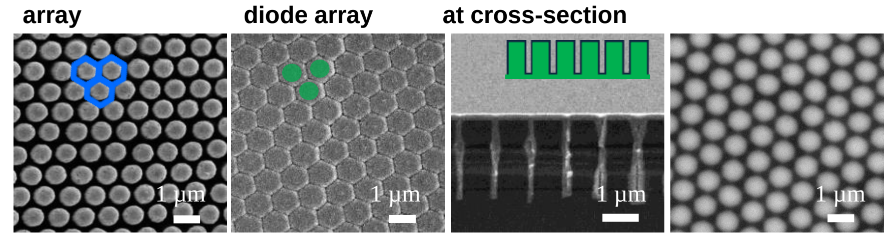
Prototype and perspective

1. High aspect ratio ordered silicon nanowire array produced by Ag induced wet chemical etching.



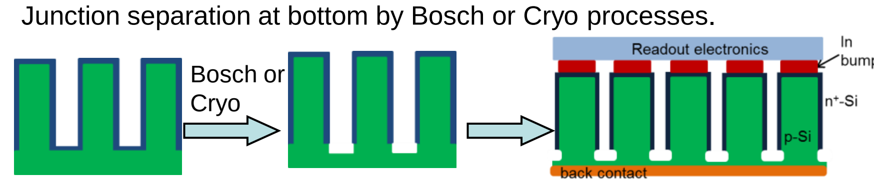
Structures defined by Ag-mask
Very high aspect ratio structures: >>100
Narrow trenches: sub-µm

2. Prototype and the functionality test by electron beam induced current (EBIC)[2].



3. Perspective

Junction separation at bottom by Bosch or Cryo processes.



Pixel number:	>1000×1000
Depth of the structure:	>200 µm
Pixel size (square):	<10×10 µm^2
Gap between neighboring pixels:	< 1 µm
Contact:	by bump bonding to readout ASIC

1. Jia et al., J. Phys. D: Appl. Phys. 49, 065106 (2016).
2. Jia et al., Photonics and Nanostructures-Fundamentals and Applications 19, 64-70 (2016).

Potential impact

- Particle detectors & imaging sensors with a novel core-shell diode array design are expected to have **ultrahigh radiation hardness**, **high spatial resolution, low power consumption**, **fast signal response** and **high sensitivity <u>simultaneously</u>** beyond state-of-the-art, and will meet all the requirements for the high energy physics (HEP) in the future.
- The high performance particle detectors & imaging sensors will open many applications in fundamental research in HEP, astrophysics and life science at powerful particle accelerators, and will revolutionize imaging sensors with the above-mentioned properties.
- A patent has been granted with the core-shell structure design under DE 10 2014 104 602.1.