ATTRACT

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PHOTONICS FOR LIFE

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

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Motivation

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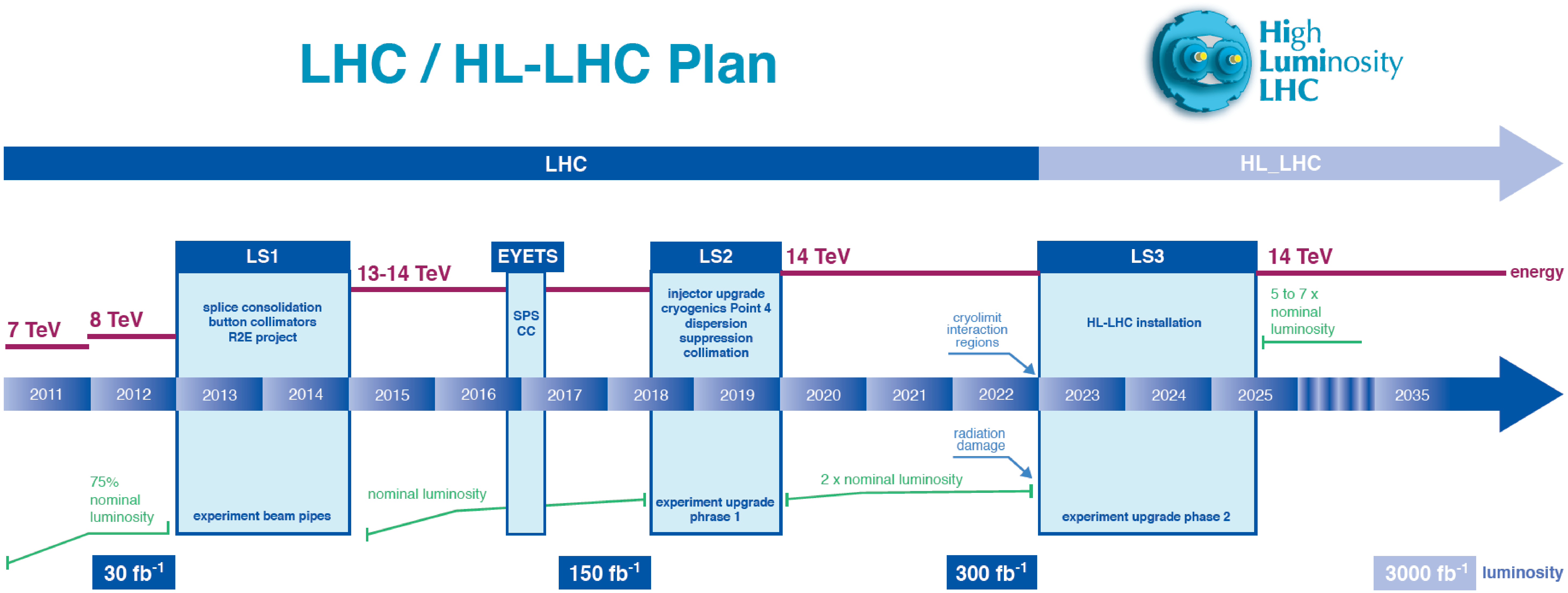
- High performance particle detectors/imaging sensors are needed in high energy physics, astrophysics, and life science, etc.
- Current planar CCD or CMOS based technologies are approaching the performance limit (radiation hardness, spatial resolution, power consumption, signal response etc.), and there is not too much room for improvements.
- Particle detectors/imaging sensors with a core-shell diode array design possess simultaneously all the desired properties regarding to **ultrahigh radiation hardness**, **high spatial resolution**, **fast signal response**, **low power consumption** etc., and are promising to realize high performance particle detectors & imaging sensors beyond state-of-the-art.

Challenging of the tracking detectors



High performance particle tracking detectors needed.

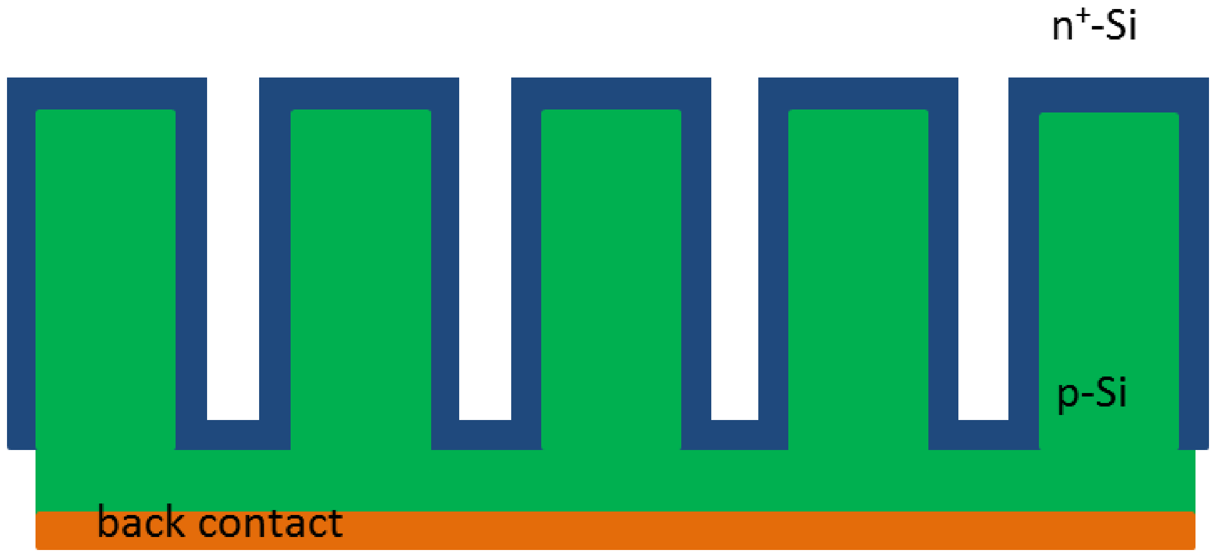
Ultrahigh radiation hardness: long lifetime, can be positioned closer to the interaction point

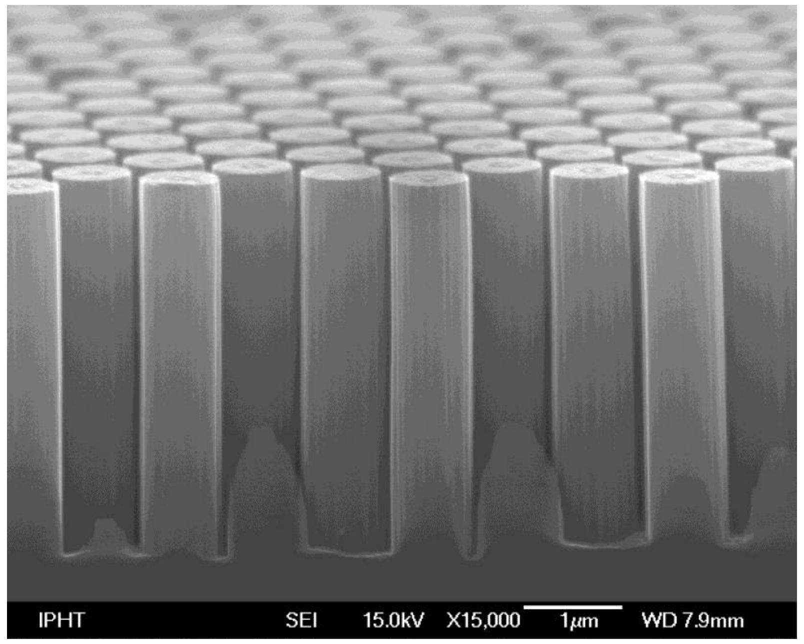
High spatial resolution: better tracking, high granularity

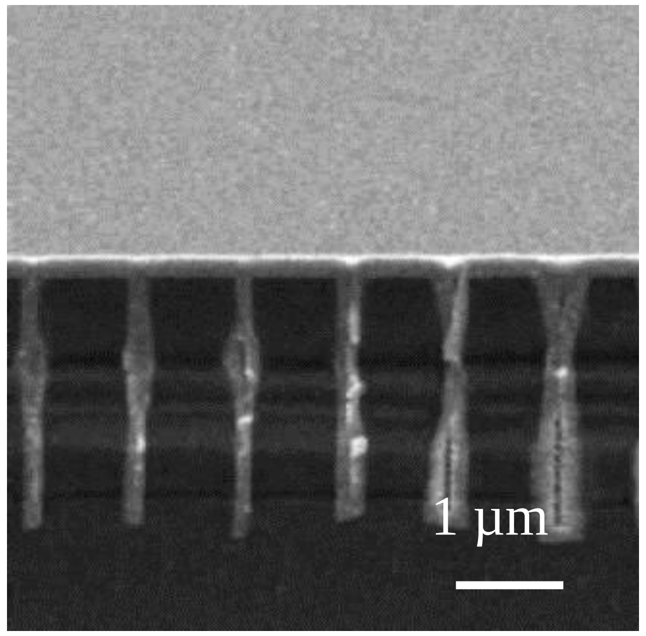
Fast signal response: measurements at high count rate, avoid pile-up

Low power consumption: low maintenance, cooling may not be needed

Core-shell diode array for particle detectors/imaging sensors



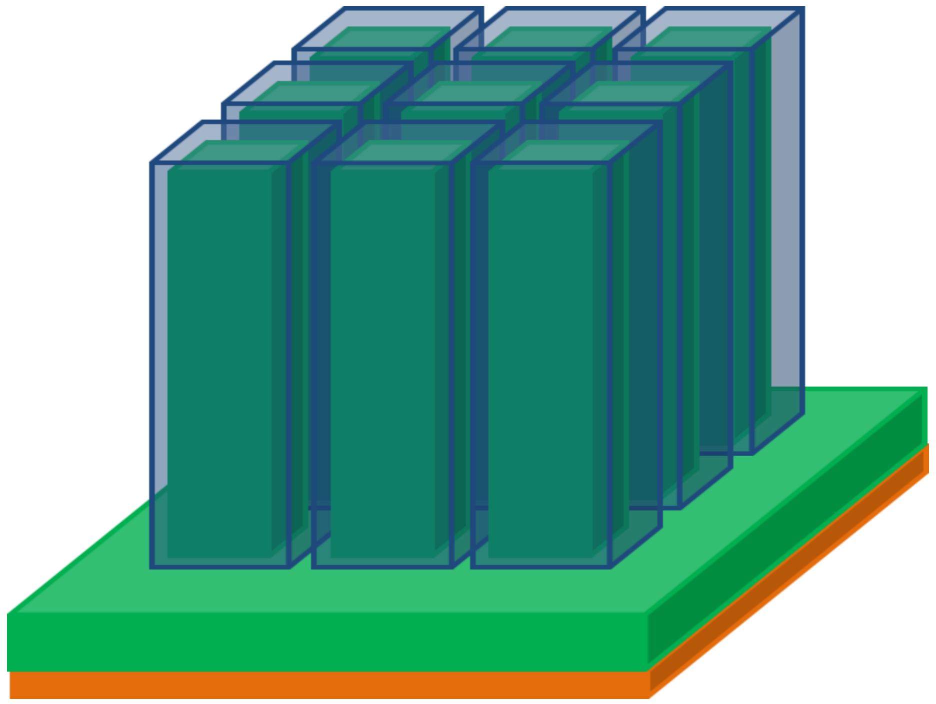




Silicon nanowire based core-shell solar cells.

Cross-section

3D view

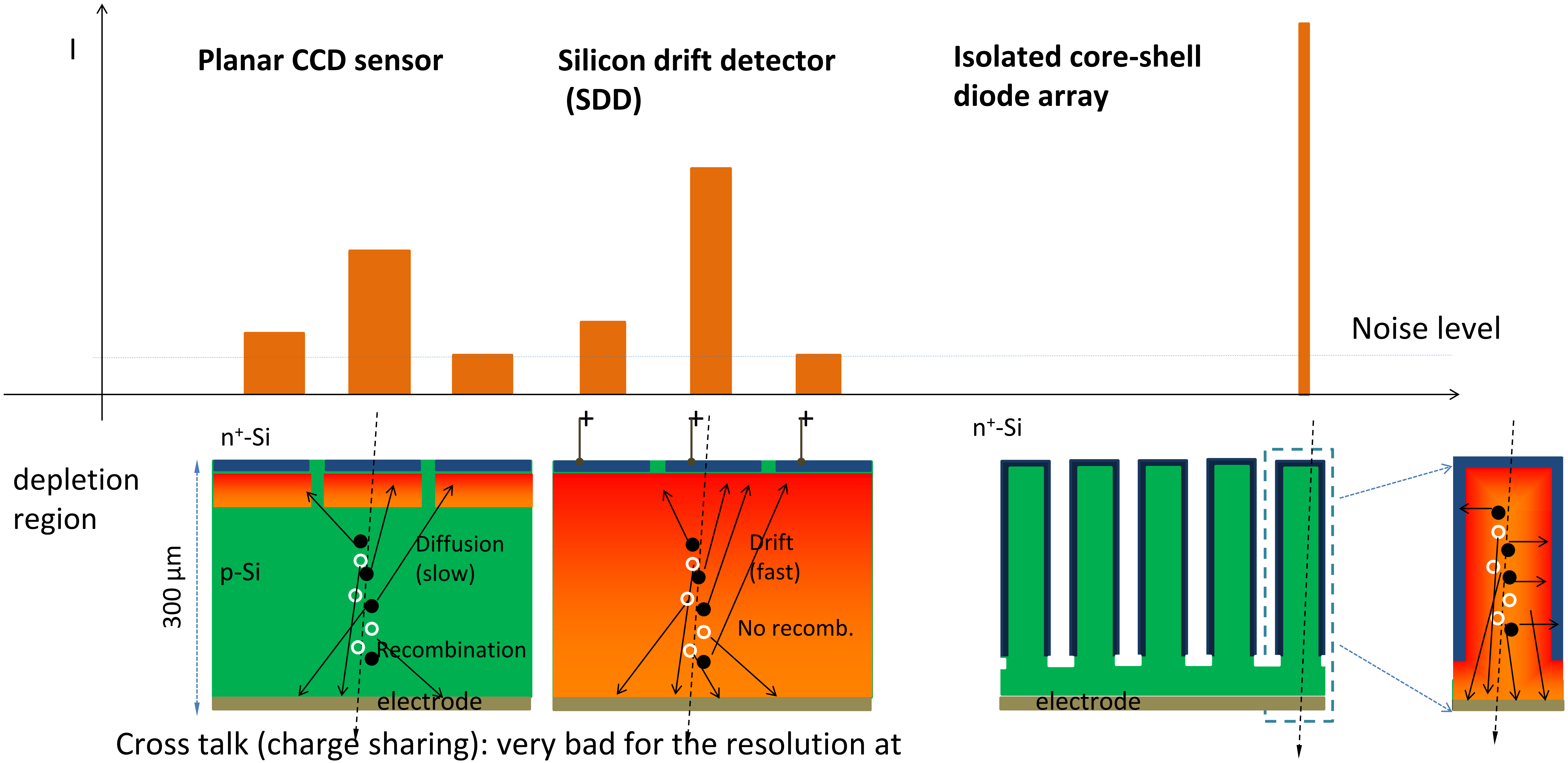


Electrically isolated core-shell diode array.

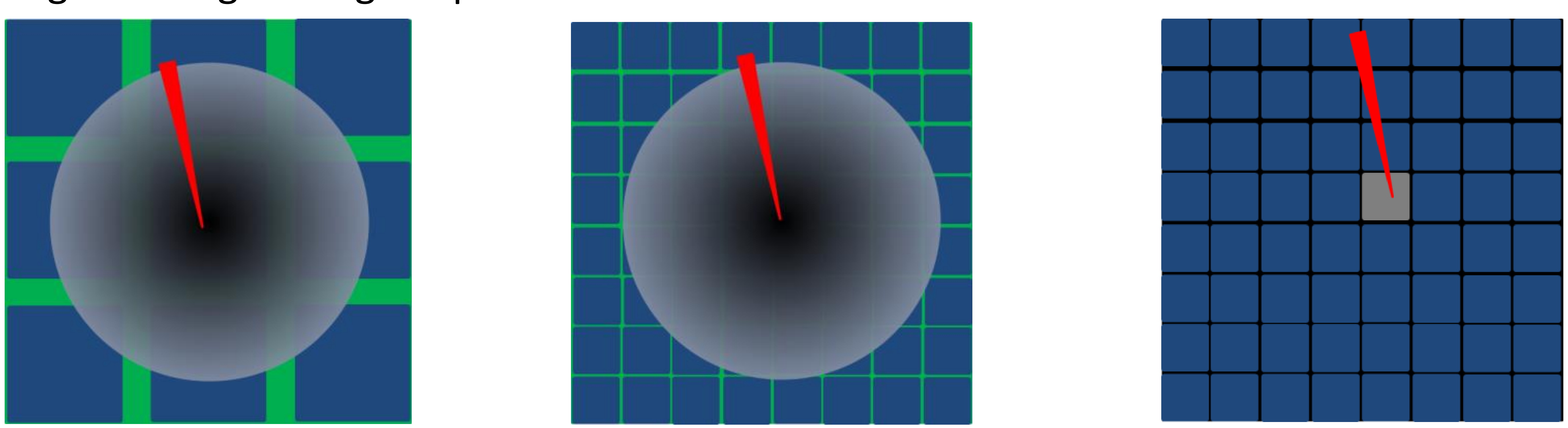
Applications:

High performance imaging sensors and high performance radiation detectors (Patent: G. Jia, Hartpartikeldetektor mit einem Kern-Schale-Aufbau).

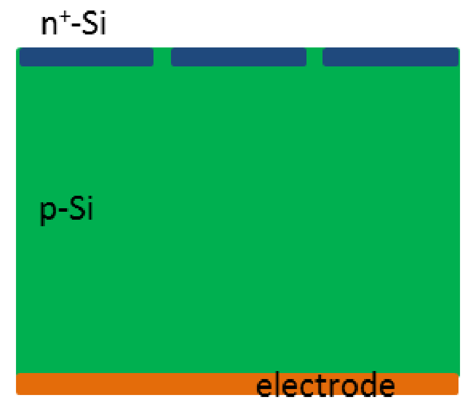
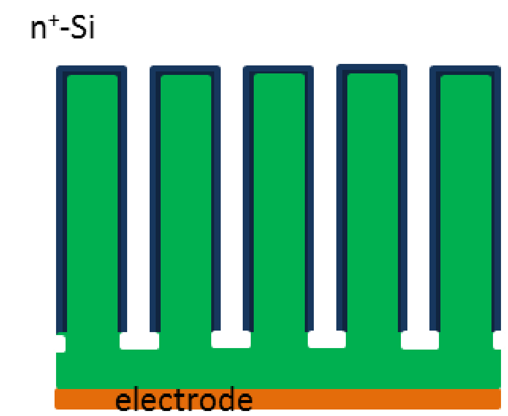
Comparison with planar CCD sensor/silicon drift detectors



Cross talk (charge sharing): very bad for the resolution at IR region or high energetic particles.



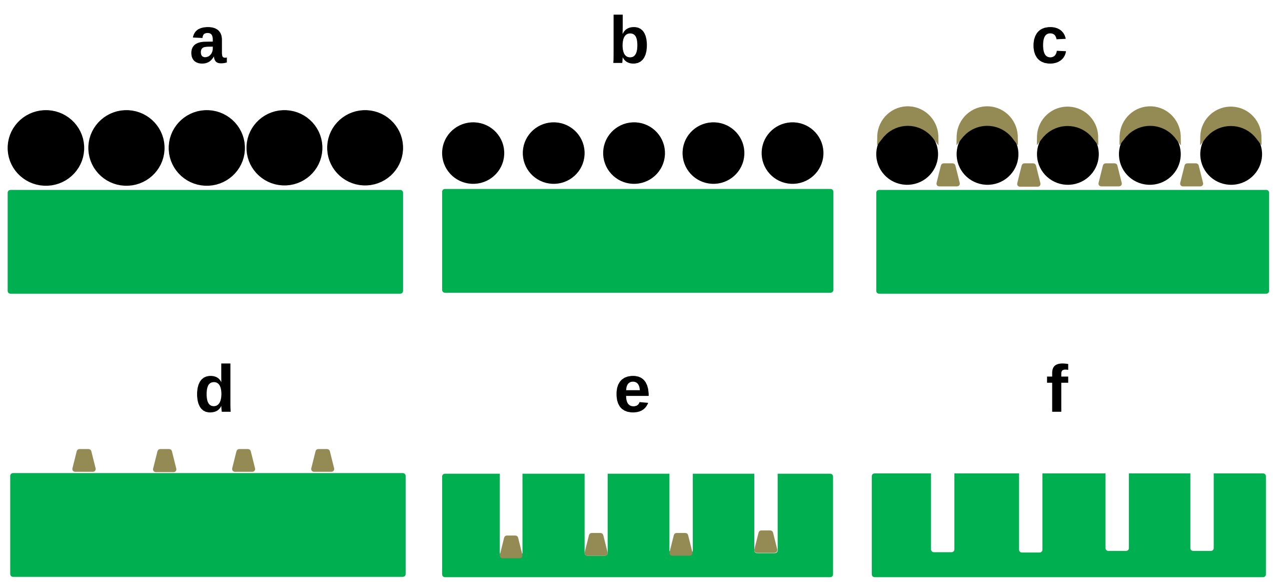
Advantages of the core-shell sensor array

Structures / Properties	Silicon drift detectors (SDDs) 	Core-shell (array) 
Radiation hardness	Low (sensitive to generated crystal defects)	**Ultrahigh[1] (not sensitive to defects). Can be <u>several orders</u> higher than planar SDDs.**
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, for 10 µm pixel, <50 ps), suitable for measurements at ultrahigh count rate.**
Sensitivity	Low (recombination loss of generated carriers.)	**High (no recombination loss of carriers and narrow, high peak)**

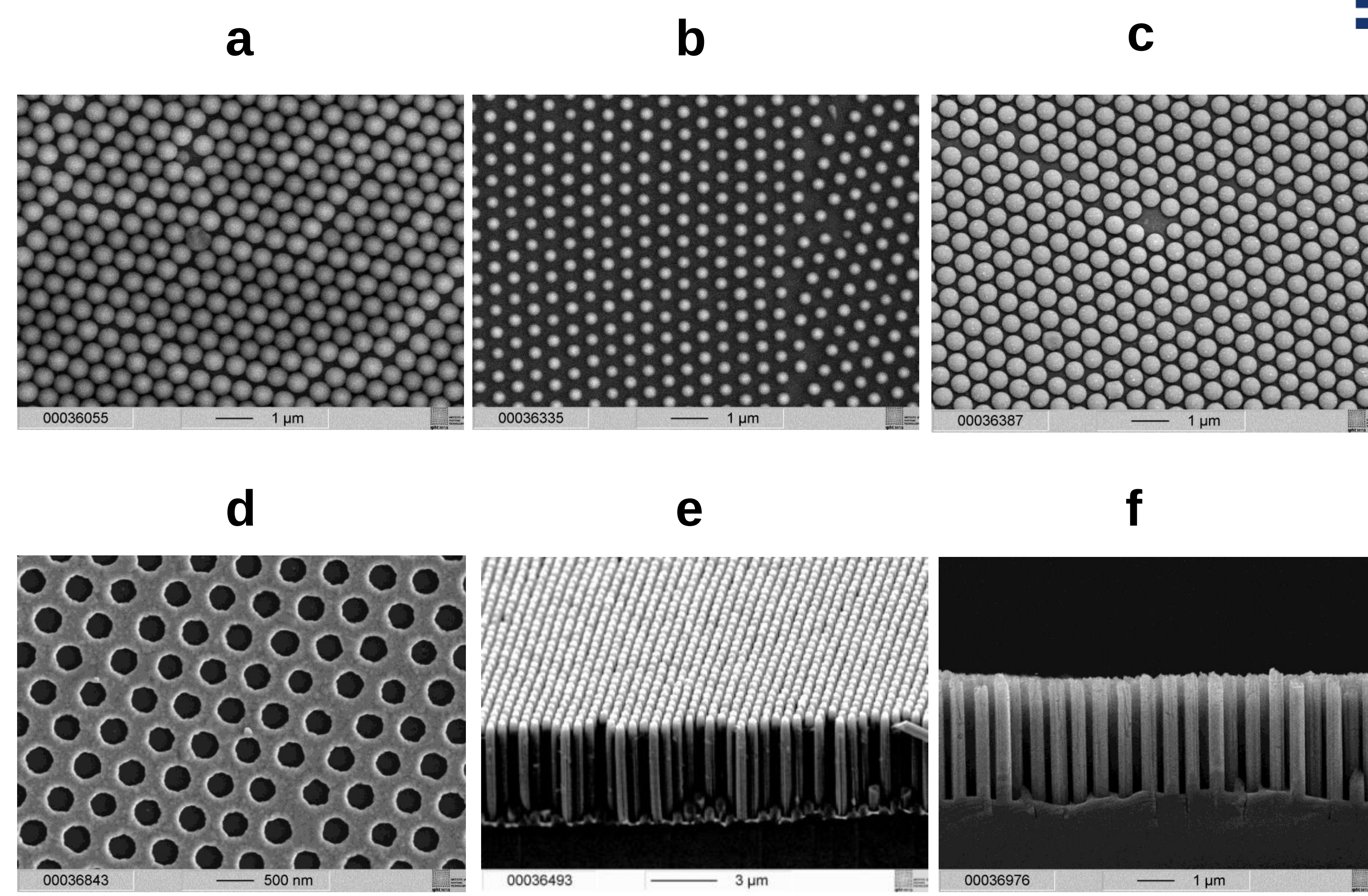
1. G. Jia, J. Plentz, I. Höger, J. Dellith, A. Dellith and F. Falk, Core-Shell Diodes for Particle Detectors, *J. Phys. D: Appl. Phys.* 49, 065106 (2016).

High aspect ratio structure: Ag-assisted wet chemical etching

Sketch of process flow



SEM images

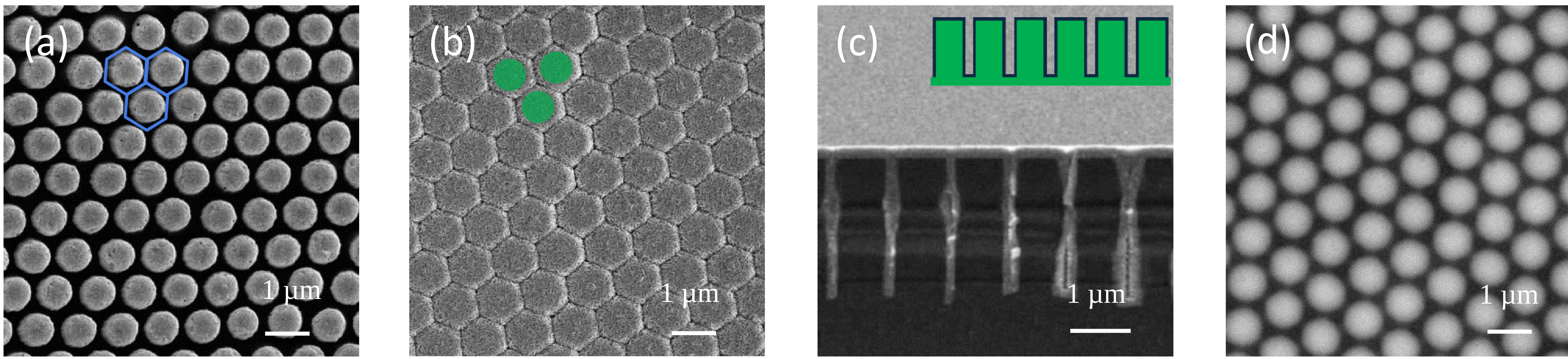


a) Monolayer of NSs
b) O_2 plasma etching
c) Ag deposition using the NS mask
d) Removal the NS
e) Etching in $HF:H_2O_2$ solution
f) Removal of Ag

G. Jia et al., *Photonics and Nanostructures-Fundamentals and Applications*, published online (2016).

Prototype and functionality tests

a) Ordered silicon nanowire array prepared by nanosphere lithography in combination with Ag-assisted wet chemical etching[1].
b) Core-shell diode array (heterojunction).
c) Cross-section (array connected to each other).
d) Functionality tested by Electron Beam Induced Current (EBIC)[2].

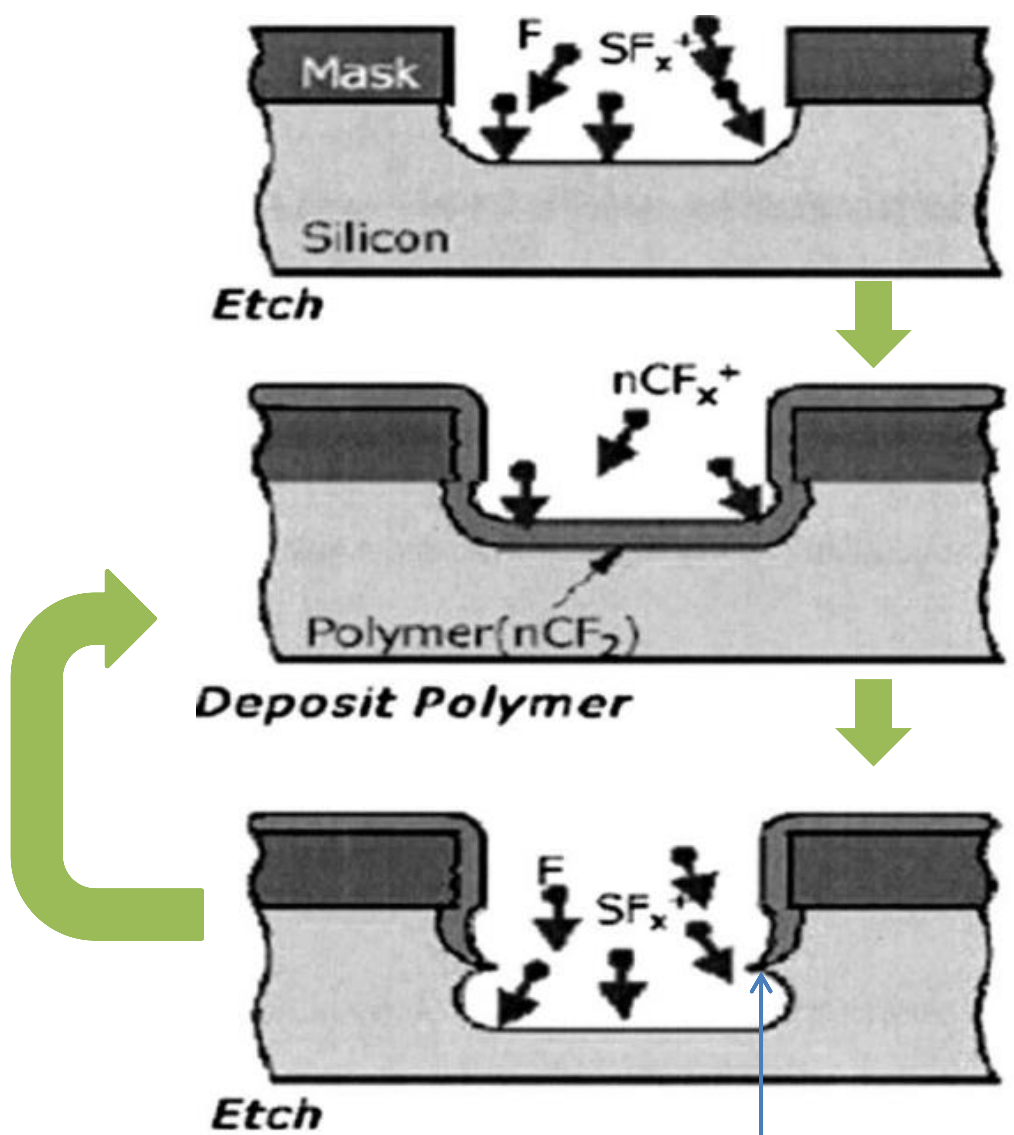


Control the penetration depth of the electron beam by accelerating energy at 10, 20 keV, the penetration depth is approximately 1 and 3 µm respectively, the generartion of carriers occurs just in the nanowires.

1. G. Jia et al., *Photonics and Nanostructures-Fundamentals and Applications*, published online (2016).
2. G. Jia, J. Plentz, I. Höger, J. Dellith, A. Dellith and F. Falk, Core-Shell Diodes for Particle Detectors, *J. Phys. D: Appl. Phys.* 49, 065106 (2016).

High aspect ratio structure: Bosch or Cryo processes

Deep reactive ion etching (DRIE)



SF_6 plasma Etch

C_4F_8 plasma passivation

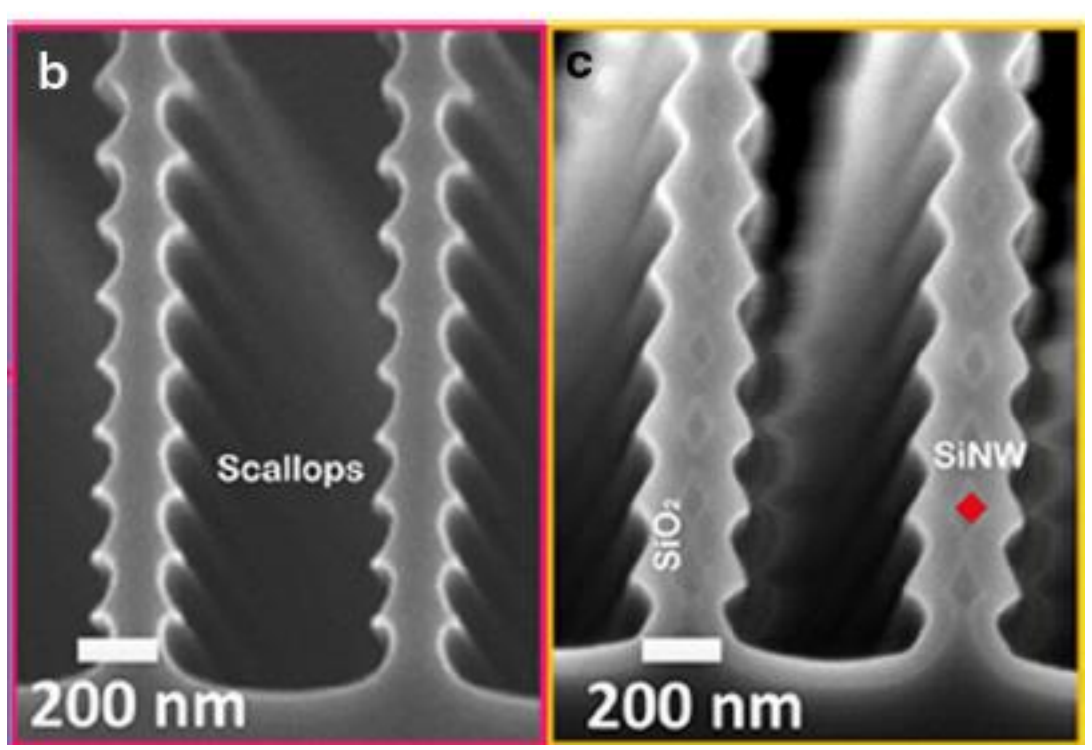
Polymer protects the sidewall from being etched.

SF_6 plasma Etch

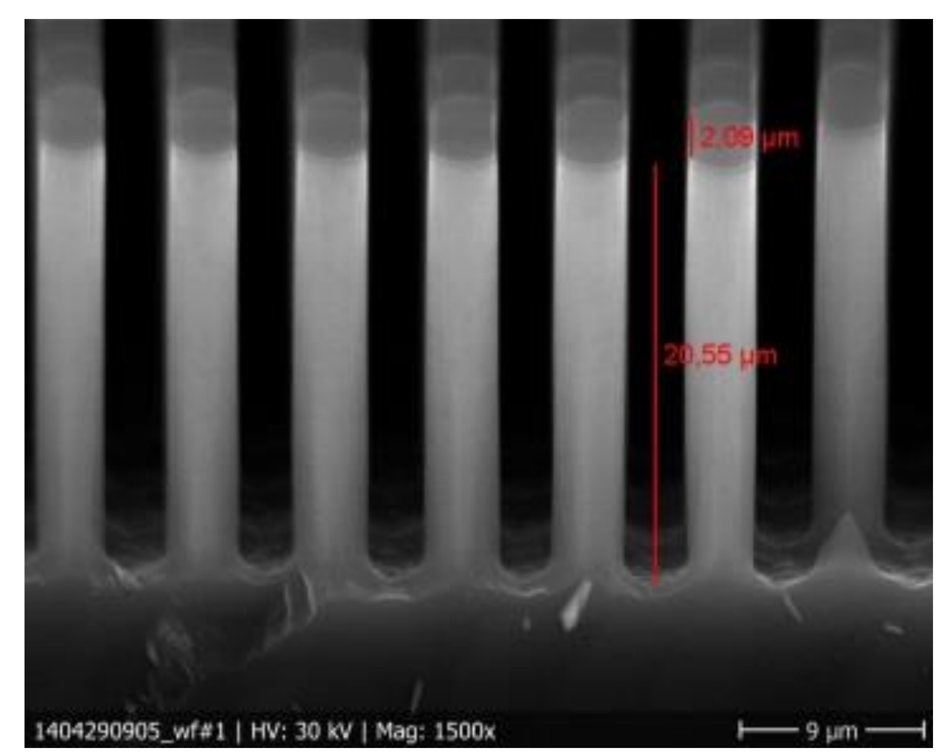
Ions etch prefered in vertical direction, sidewall is protected during the etching by a passivation polymer.

Scallop

Bosch (scalloped)



Cryo (smooth)



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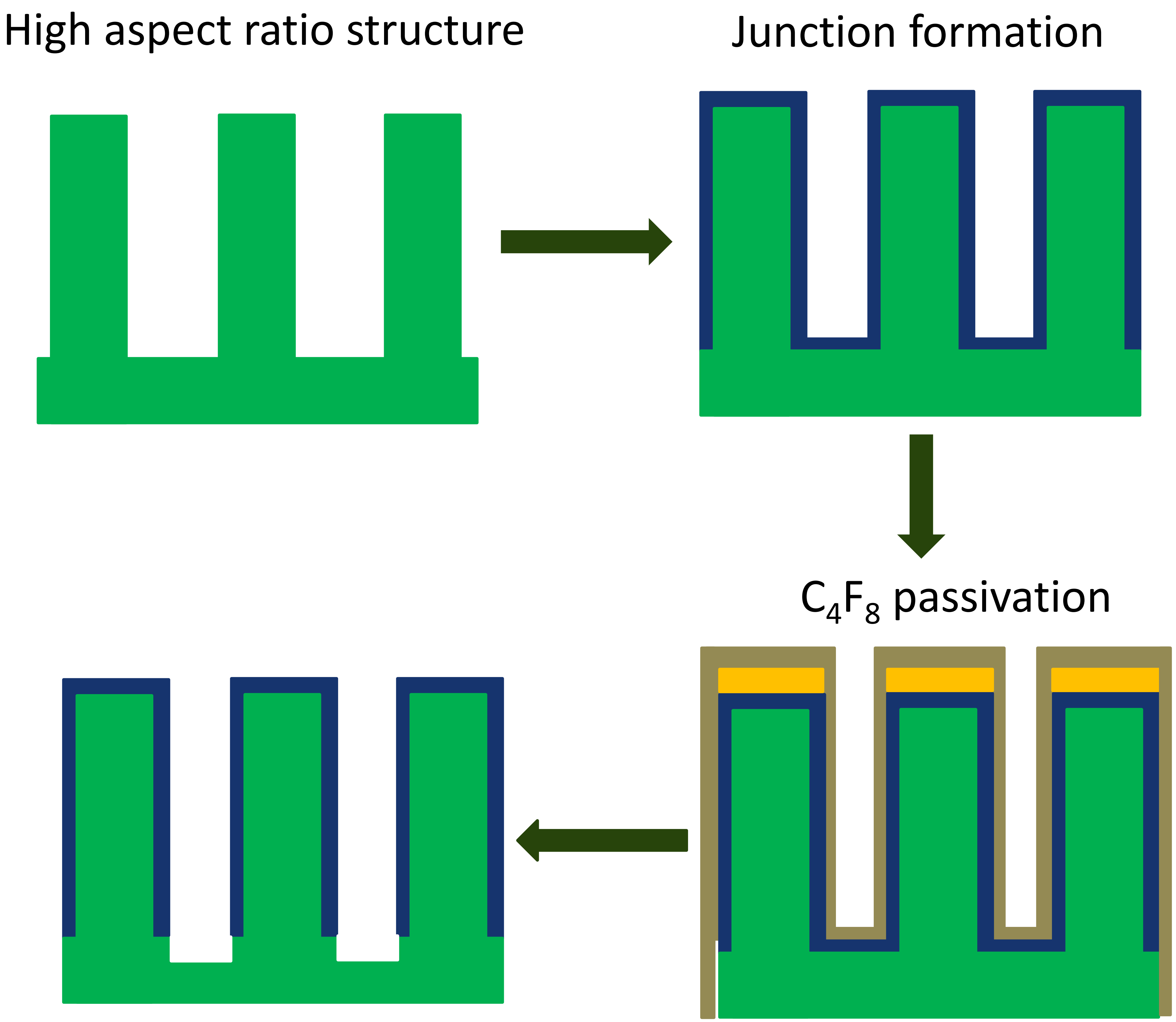
Junction formation and separation



Emitter types:

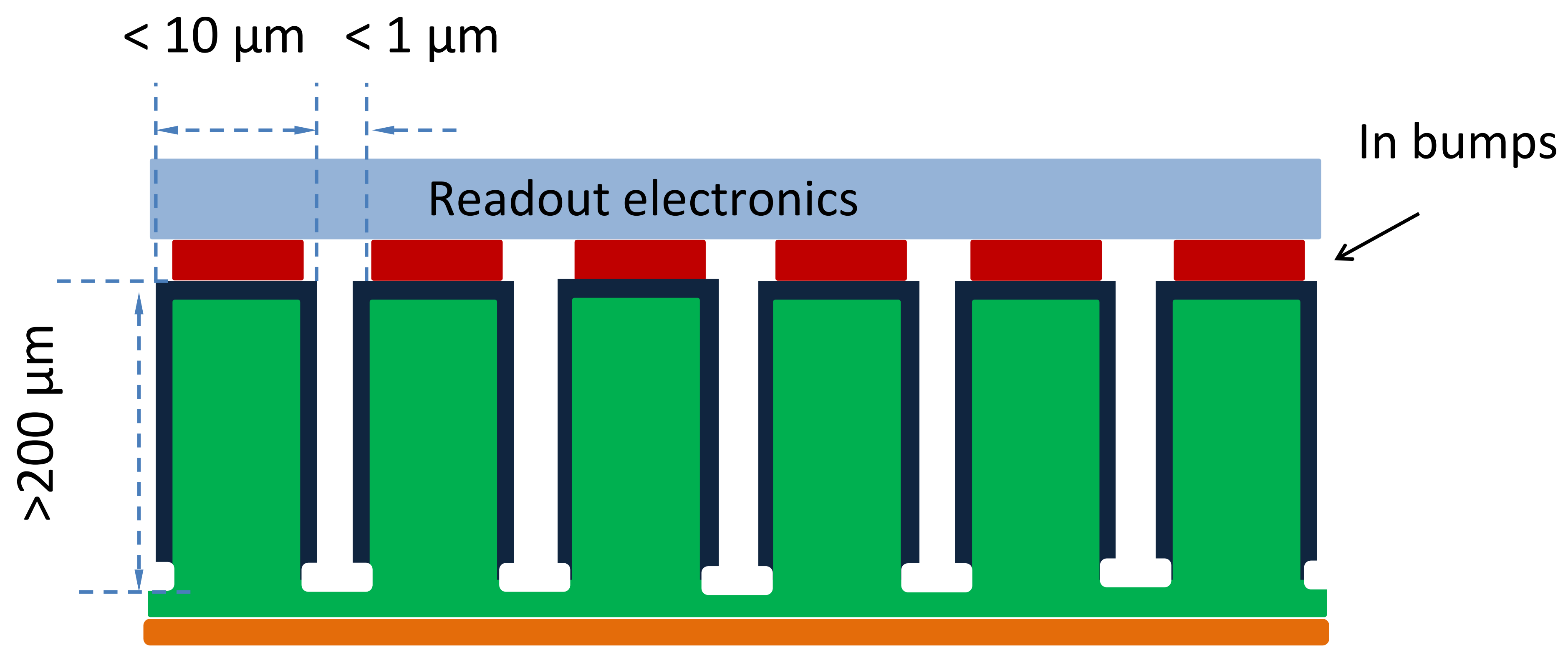
Heterojunction: a-Si:H+AZO

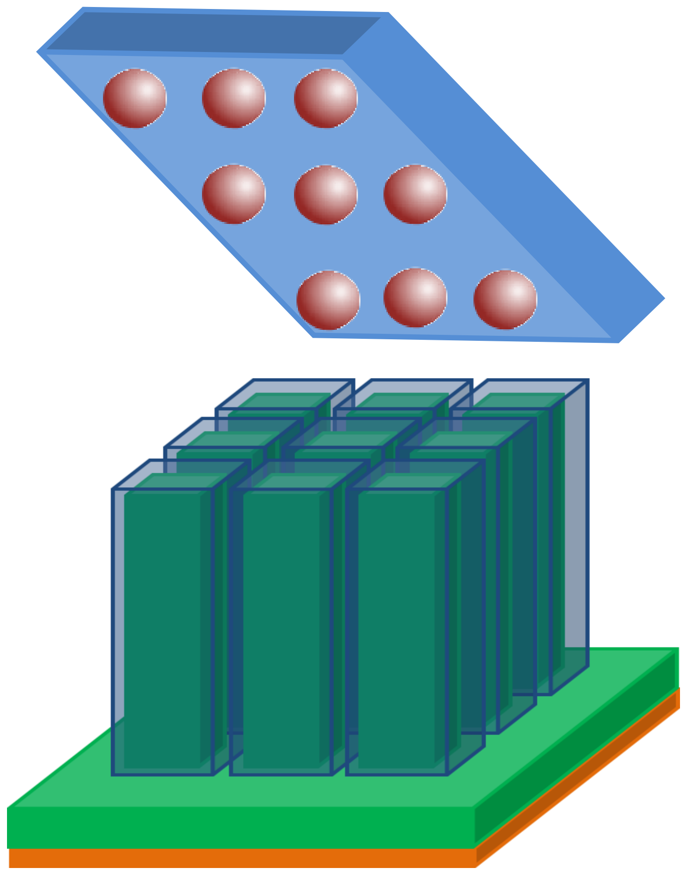
Homojunction: highly doped c-Si

SIS: ITO or AZO

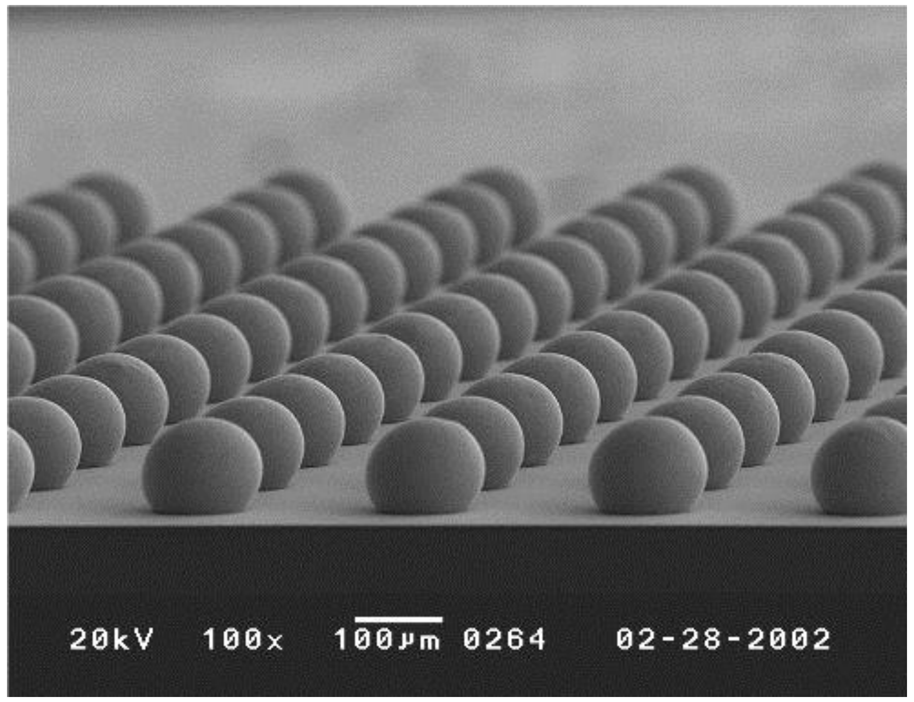
Schottky: thin metal layer

Perspective





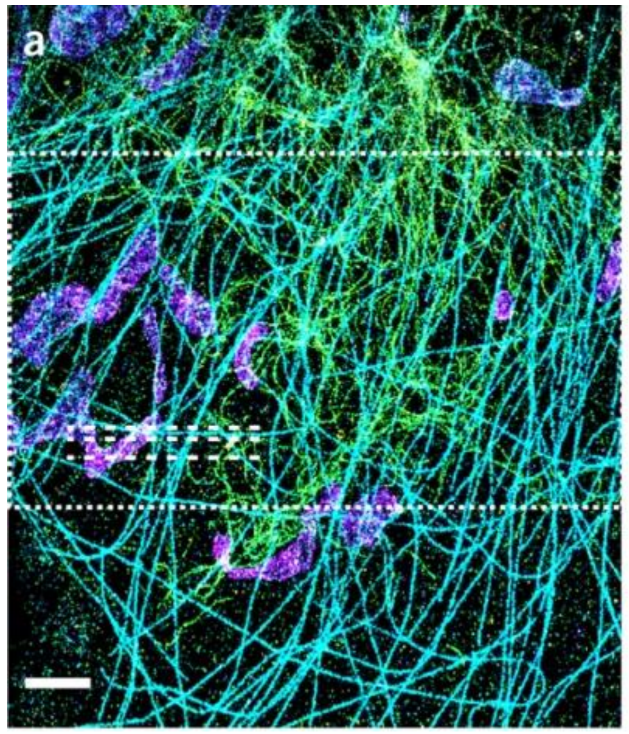
Pixel number: >1000×1000
Depth of the structure: >200 µm
Pixel size (square): <10×10 µm^2
Gap between neighboring pixels: < 1 µm
Contact: by bump bonding to readout ASIC



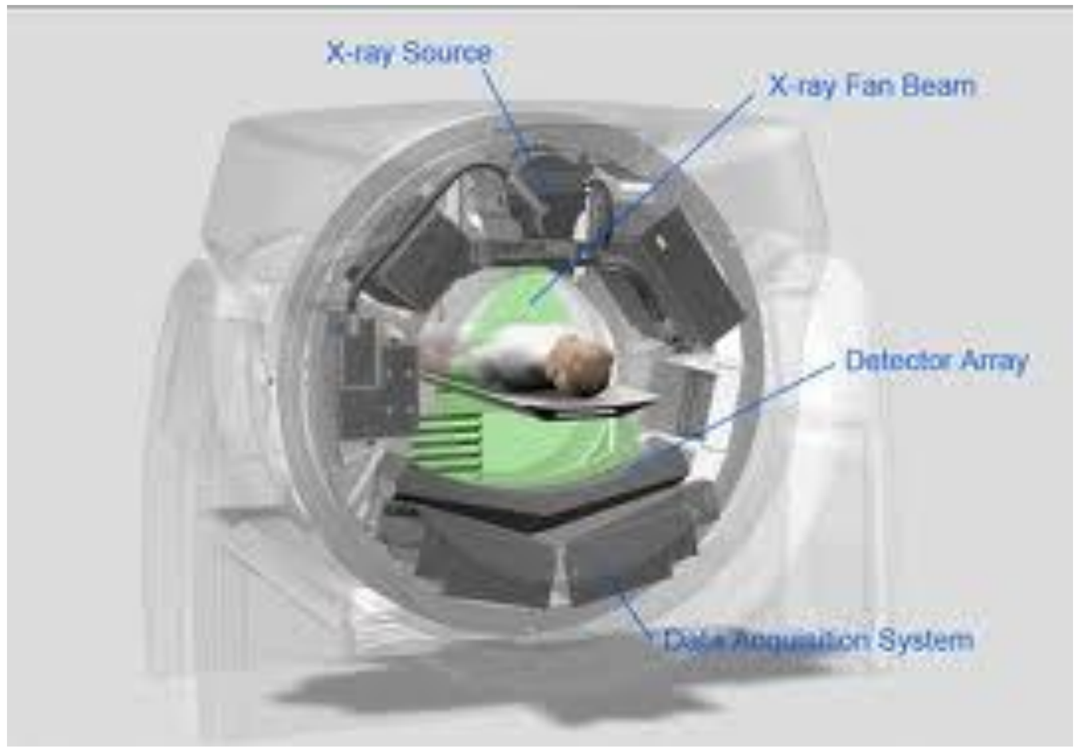
Impact and Applications

Life science, diagnostics, medicine

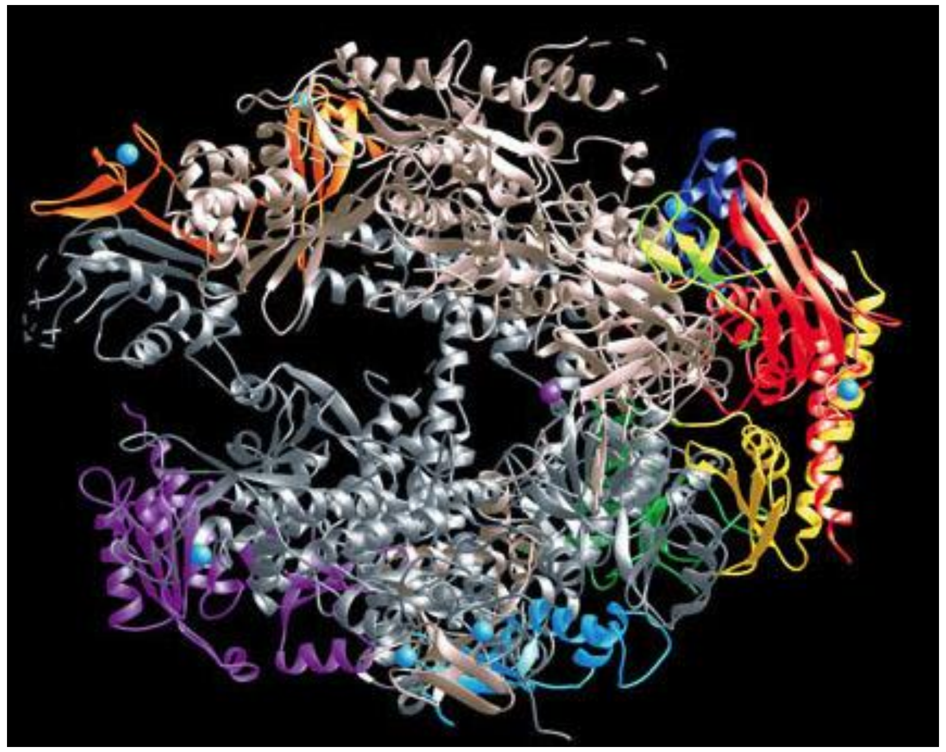
Super resolution microscopy
Single molecule detection



Computed tomography (CT)



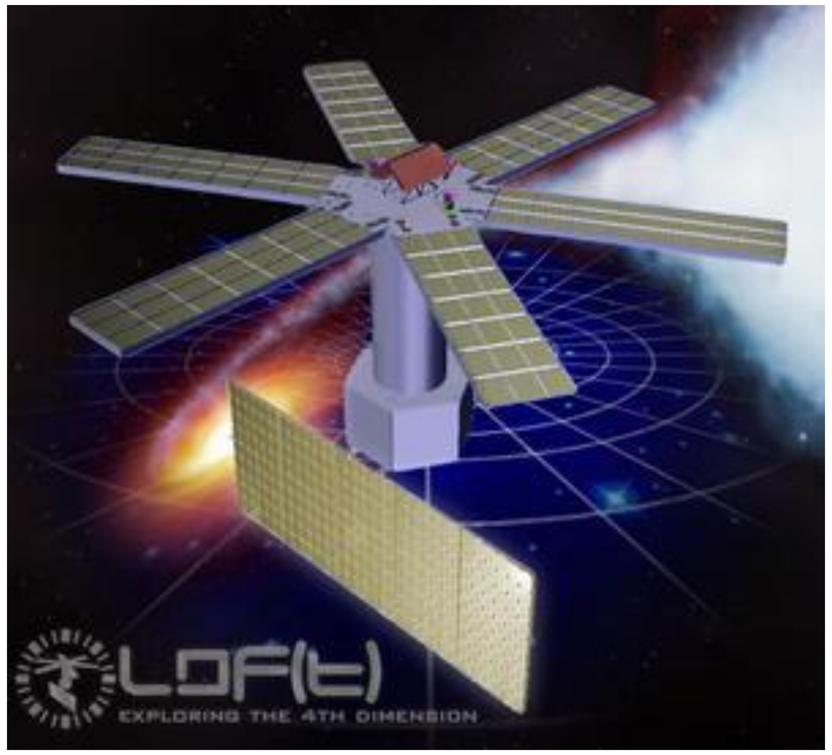
Protein crystallography



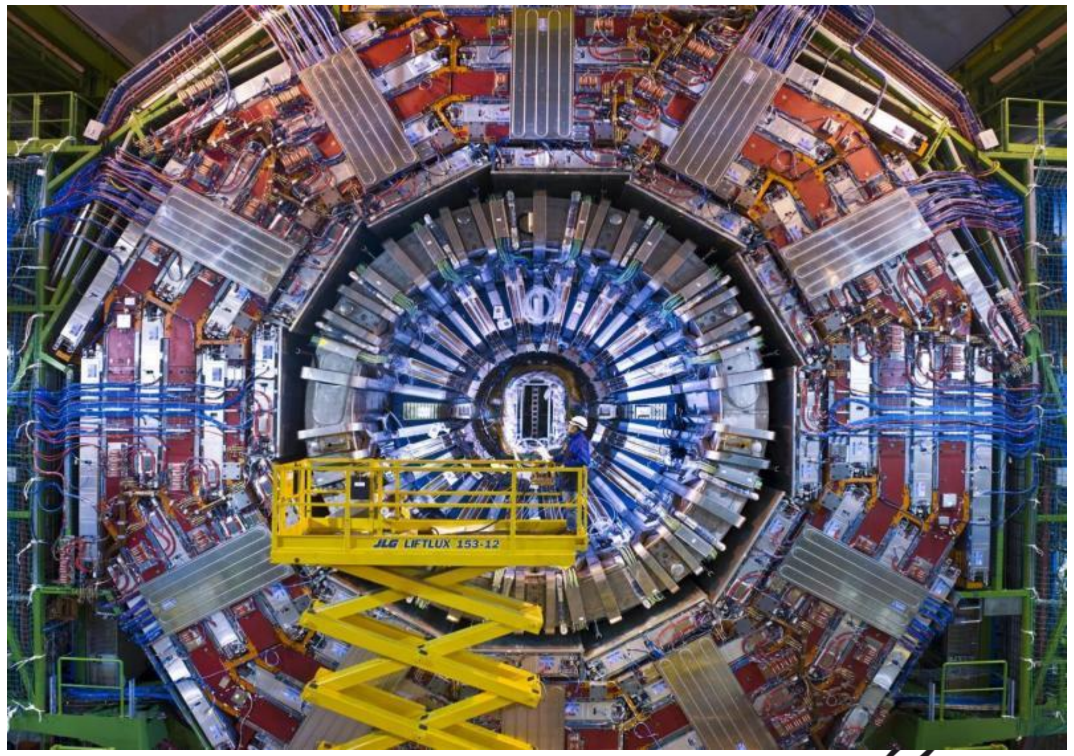
Geoscience and fundamental physics

Space borne geophysics

Astrophysics



Fundamental physics at CERN



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Acknowledgement

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FA3: Quantum Detection, AG Micro- & Nanotechnology, Uwe Hübner

FG: Magnetometry, Ronny Stolz

Central Scientific Service (ZeWiDi): Jan Dellith

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Thank you for your attention.

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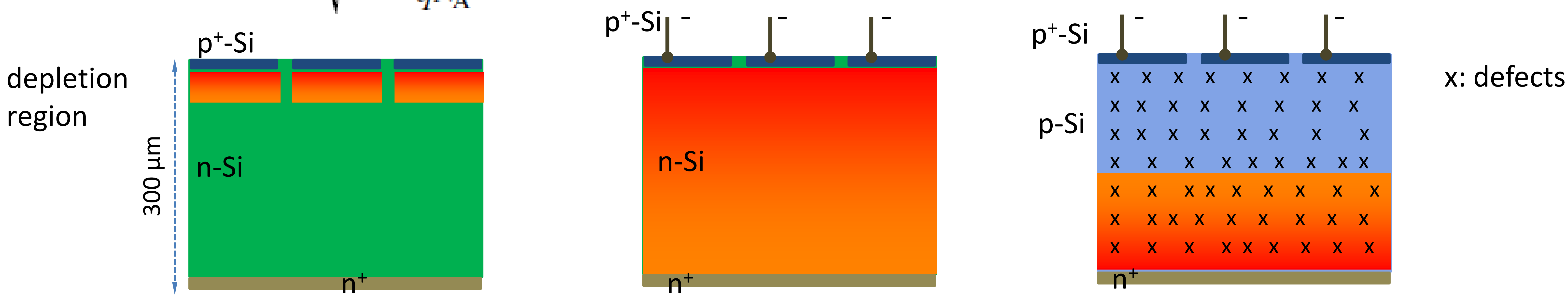
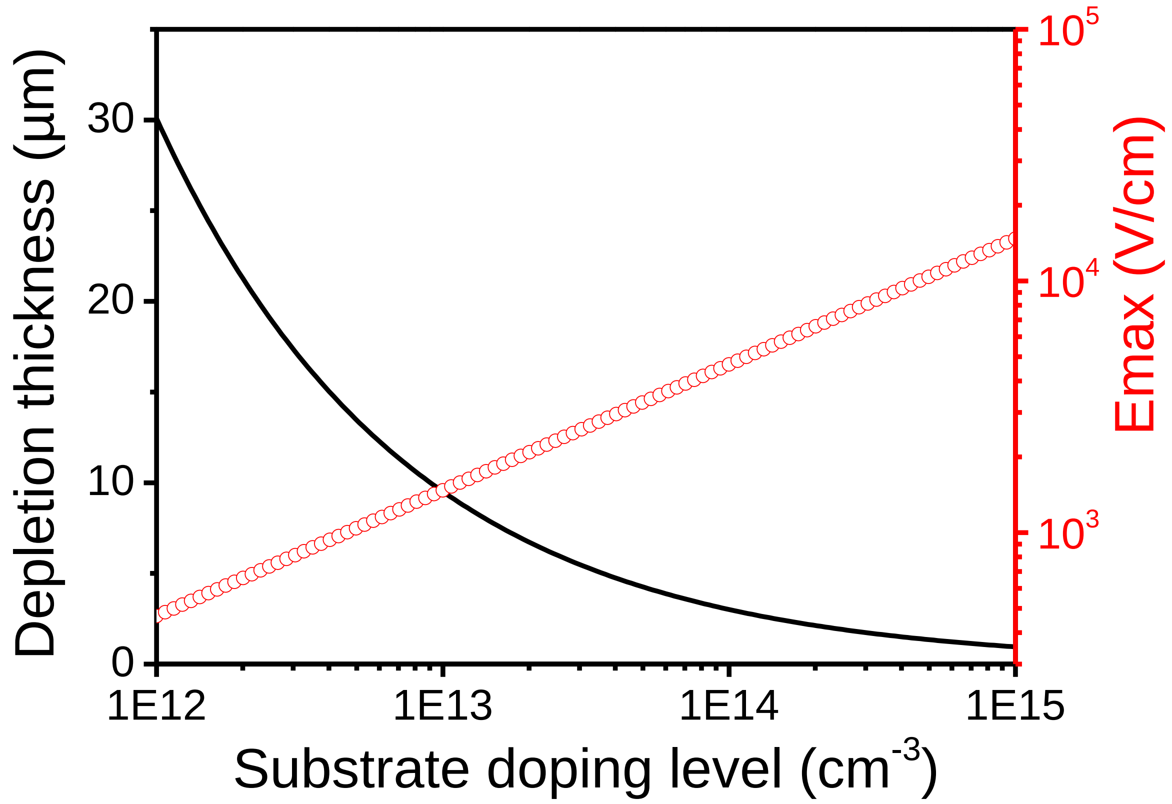
Radiation hardness of SDDs on planar wafer

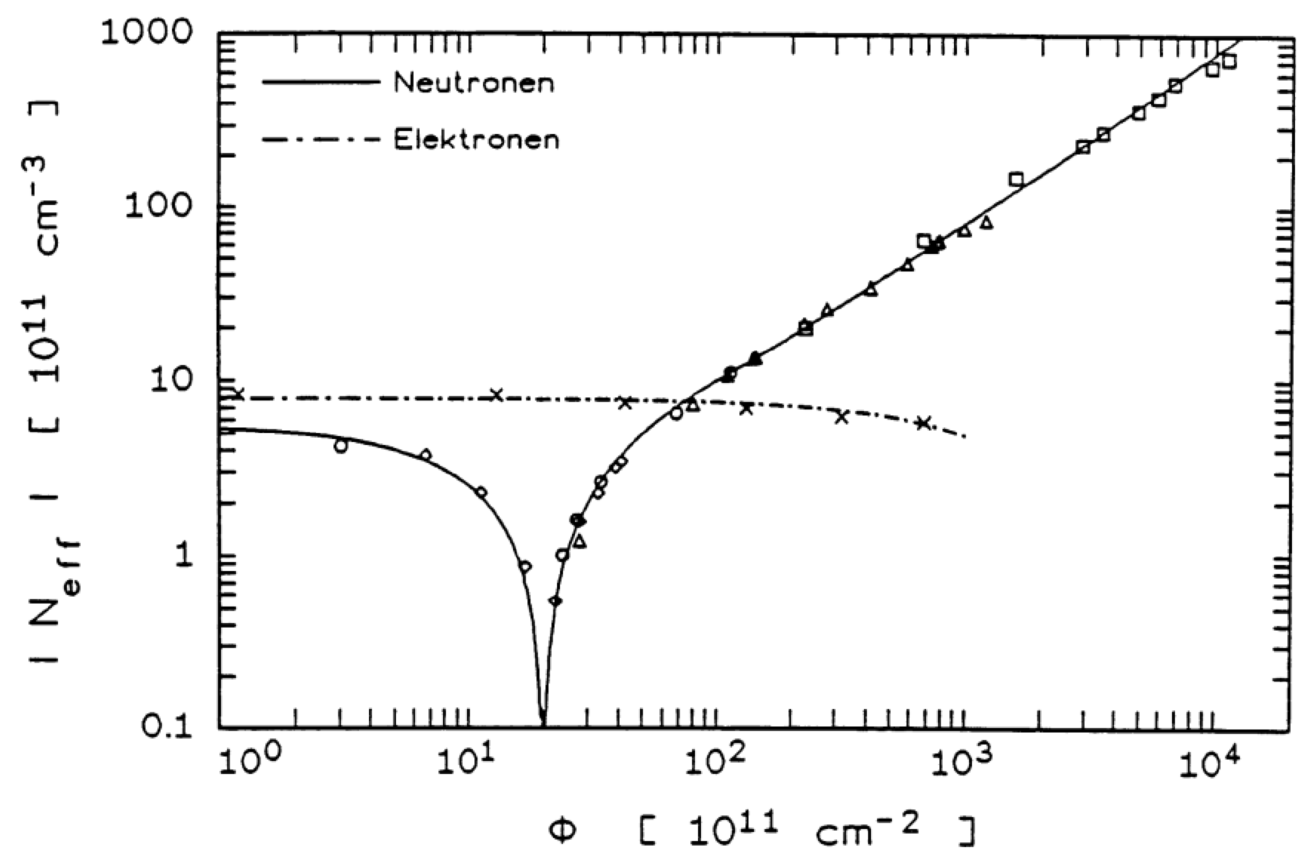
$$x_p \approx \sqrt{\frac{2\varepsilon\varepsilon_0(-V_{bias})}{qN_A}}.$$

Non-irradiated SDDs
~70V

Heavily irradiated SDDs
>1000 V







Wunstorf, Dissertation, 1992, Desy.

n-type substrates suffer from type inversion and increasing of effective doping level, resulting in a shifting of V_{fd} up to two orders of magnitude.