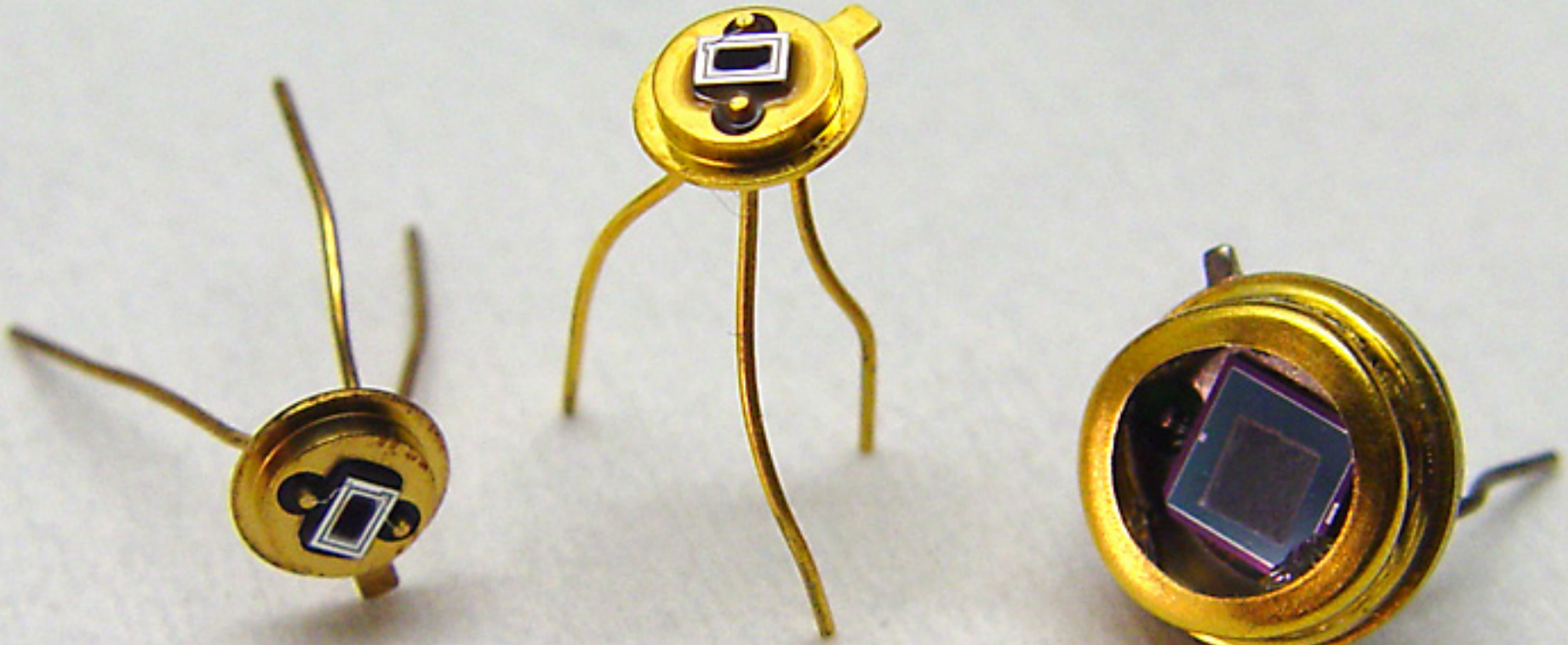
Pushing a physics discovery towards commercial impact



REU Seminar
Harvard University
Cambridge, MA, 24 July 2013

Harvard Spinoff Company Takes on $200 Billion Global Market for Silicon

David L. Shenkenberg, Features Editor, david.shenkenberg@laurin.com

Imagine if a new substance could replace silicon, a material that is used in almost every electronic device on the market today. SiOnyx Inc. plans to do just that with its new material, black silicon, which was discovered at Harvard University in Cambridge, Mass.

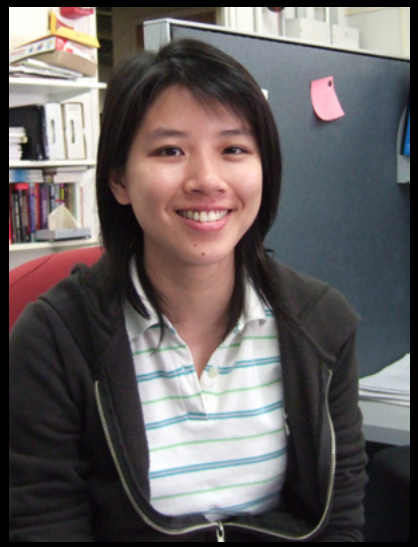
Dr. James E. Carey, SiOnyx Inc. co-founder and principal scientist, holds a black silicon wafer in the cleanroom at company headquarters in Beverly, Mass.

I recently sat down with Stephen D. Saylor, CEO of SiOnyx, and Dr. James E. Carey, its co-founder and principal scientist, at the company's headquarters in Beverly, Mass., which is about 20 miles northeast of Boston.

Carey and Saylor told me that the potential applications of black silicon are numerous because it could be employed wherever silicon is currently used: in computers, satellites, cameras, mobile phone cameras, solar panels and radiological imaging equipment.

"We believe that the technology meets its highest purpose in the commercial markets," Saylor said. The industry for silicon chips in mobile phone cameras alone is $7 billion, out of a $200 billion global market for silicon. "To get venture capital, you have to show that there is a big (market), and there is a big (market) for black silicon," Saylor said. SiOnyx has raised $11 million in venture funding from Partners and Harris & Harris.

Renee Sher



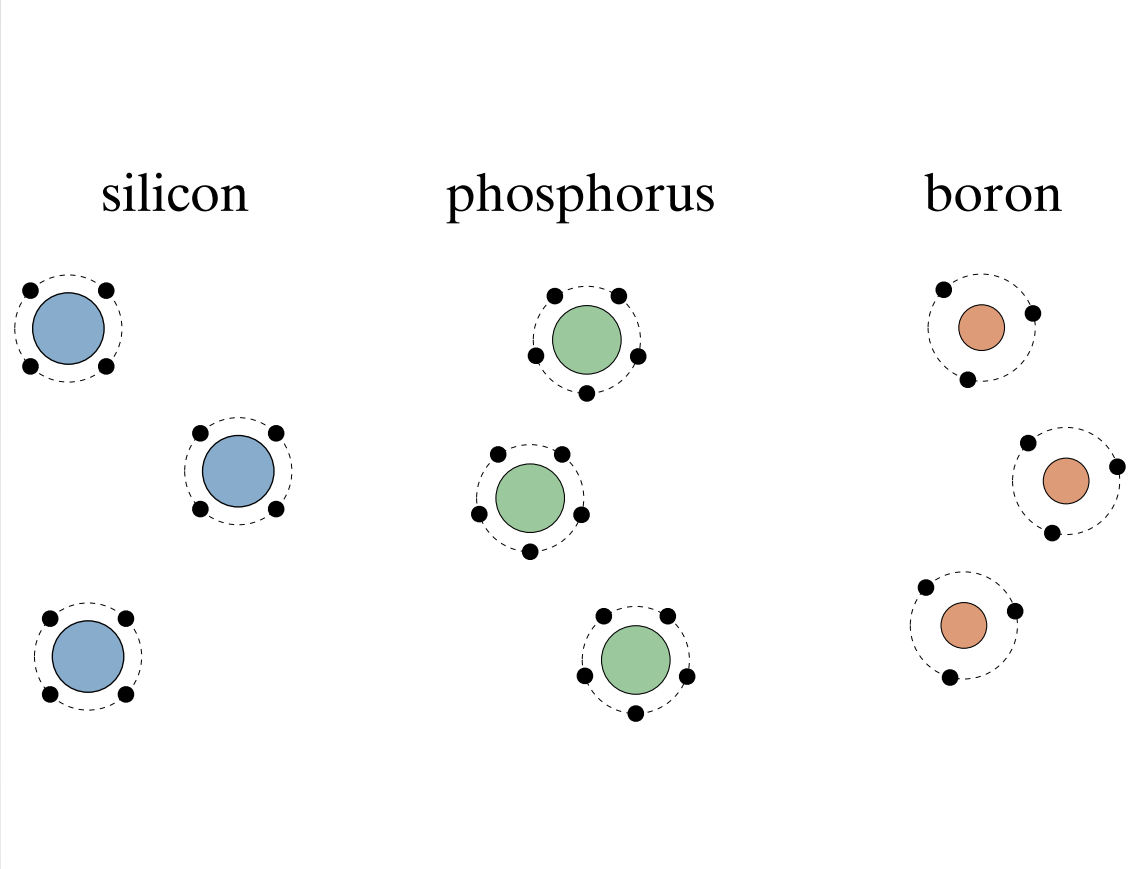
Yu-Ting Lin

Kasey Philips

Ben Franta

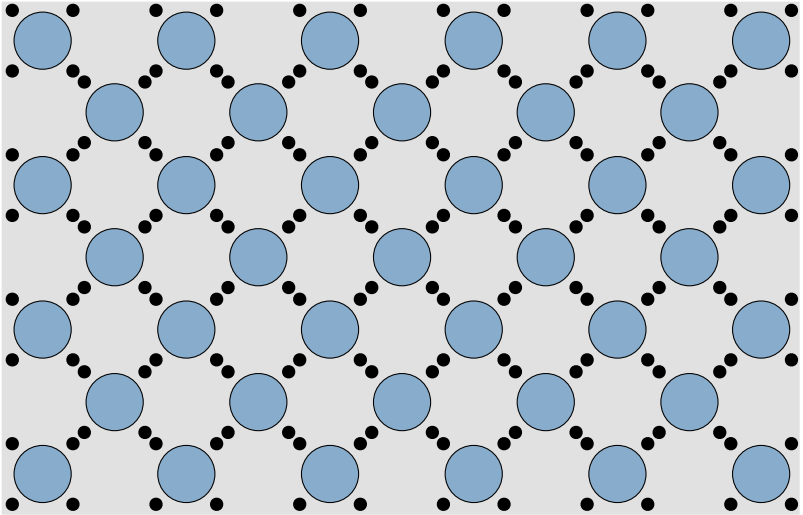
eric_mazur

Introduction



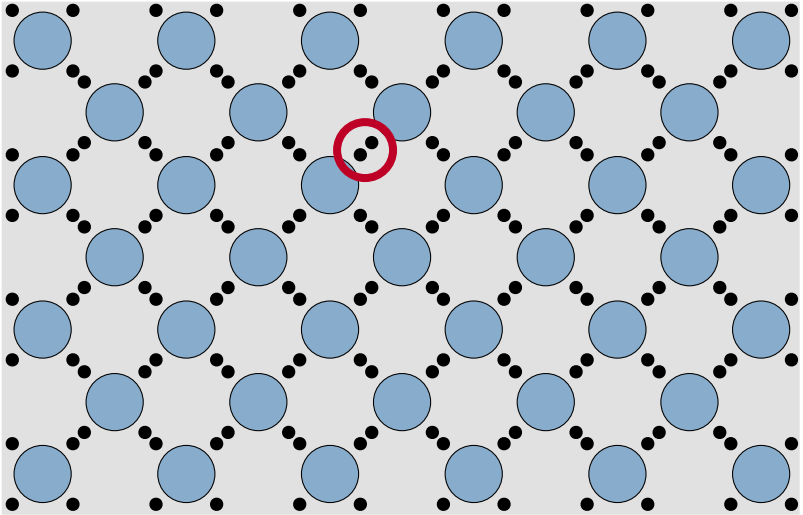
outer ("valence") electrons determine electronic properties

Introduction



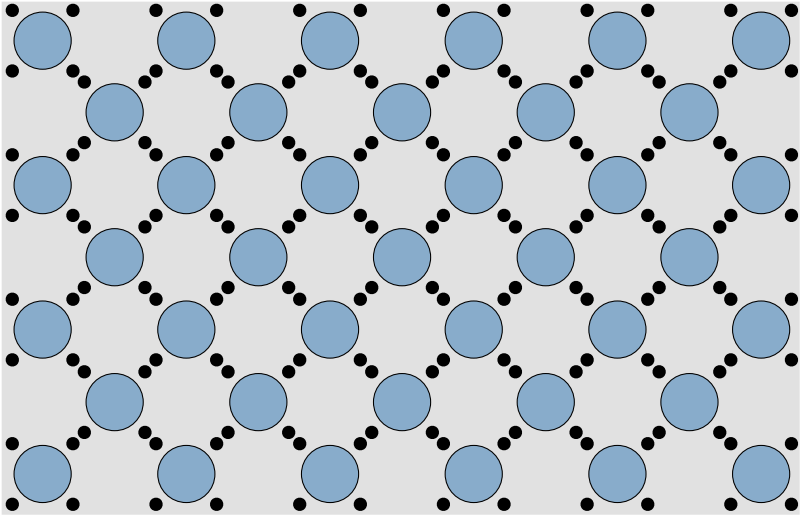
pure (“intrinsic”) silicon

Introduction



electrons in covalent bond are immobile

Introduction

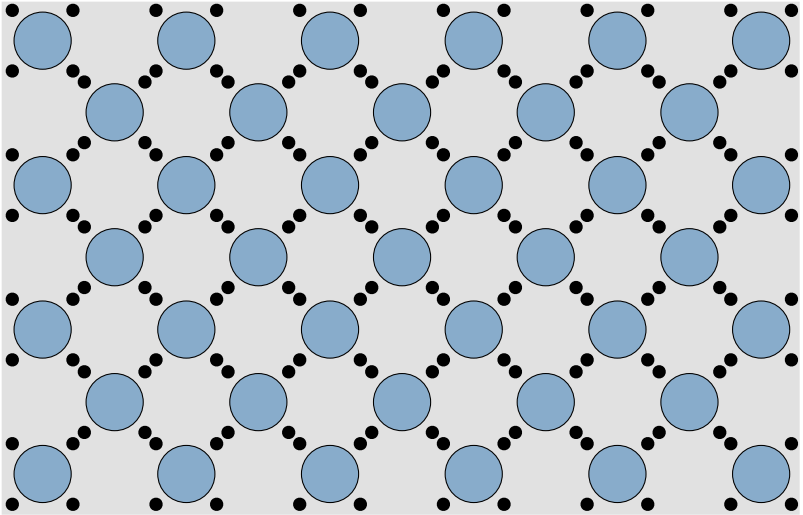


all electrons bound, so no conduction

Outline

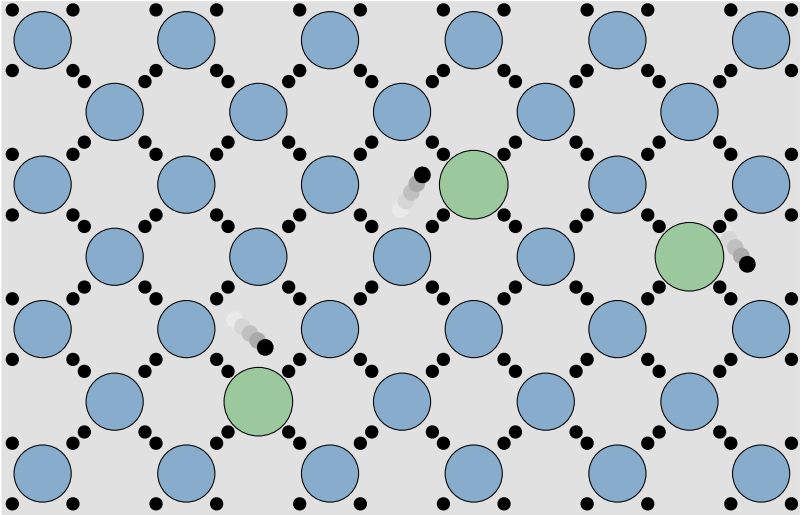
- doped semiconductors
- *pn*-junctions
- black silicon

Doped semiconductors



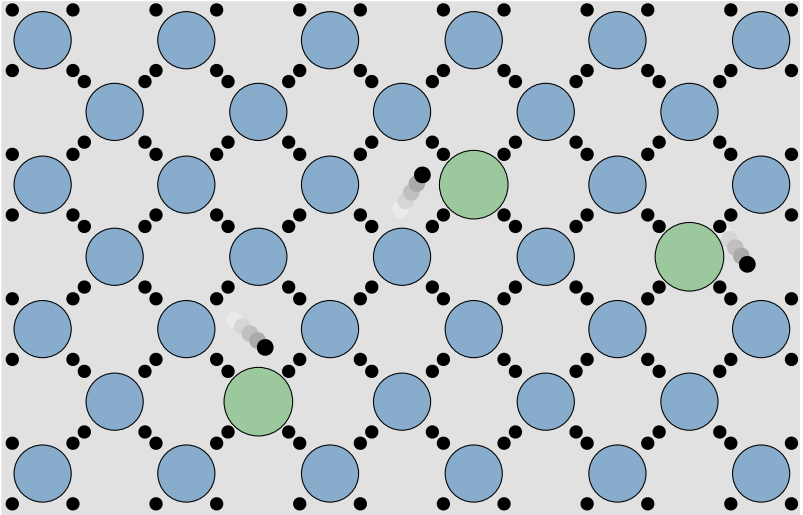
intrinsic silicon: no conduction

Doped semiconductors



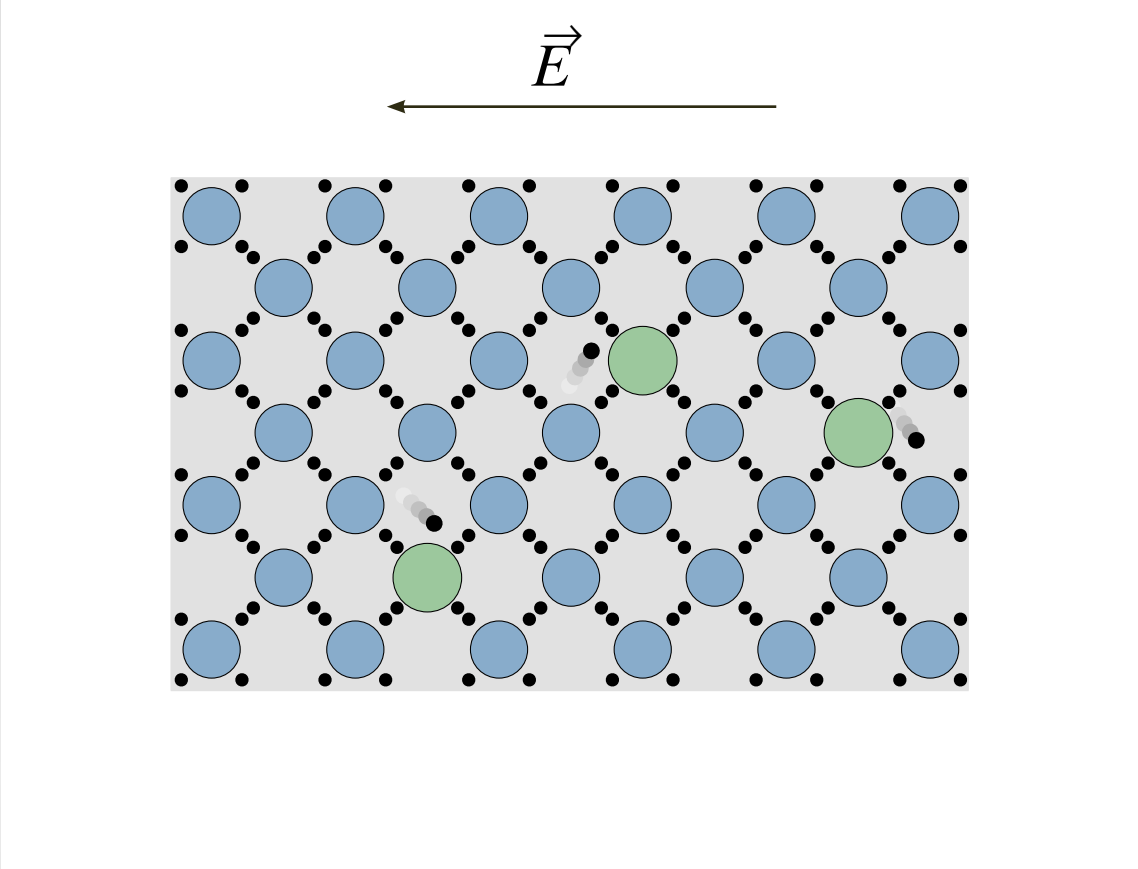
substitute phosphorous: surplus of (free) electrons

Doped semiconductors



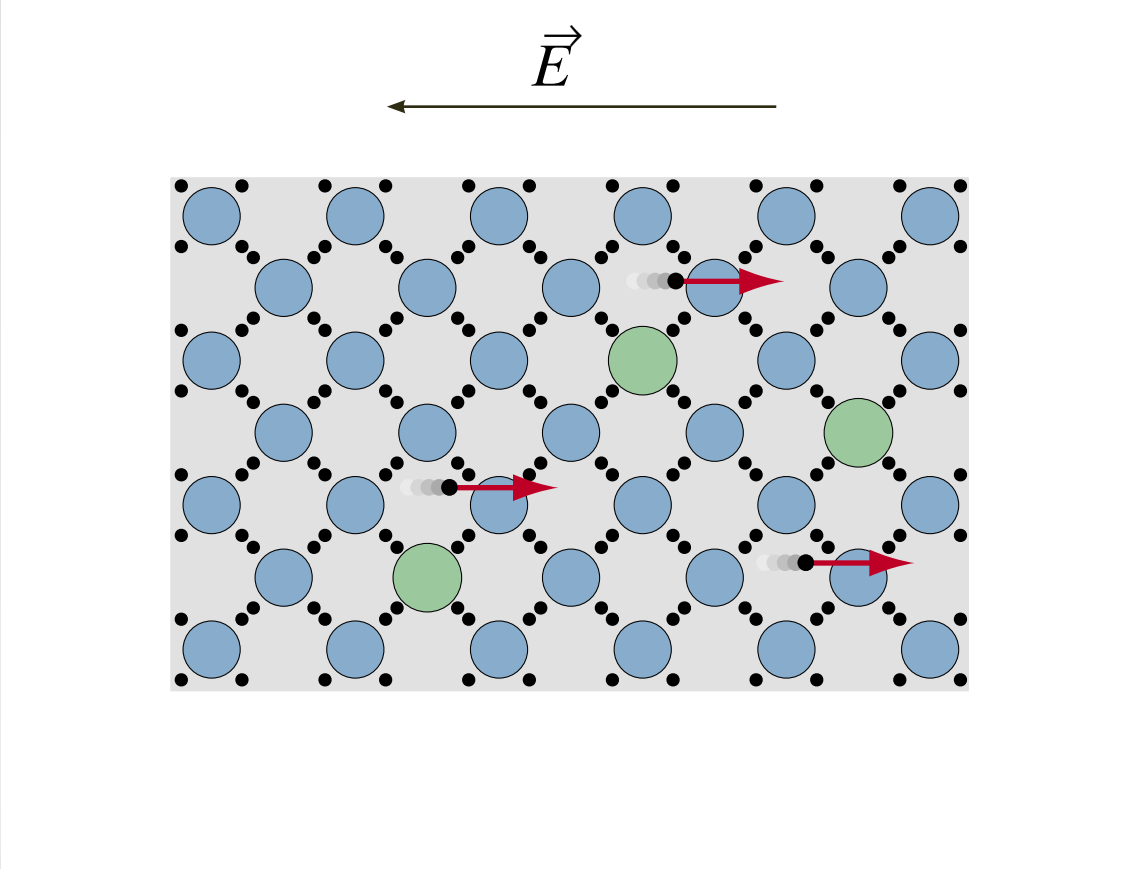
(but material as a whole still neutral!)

Doped semiconductors



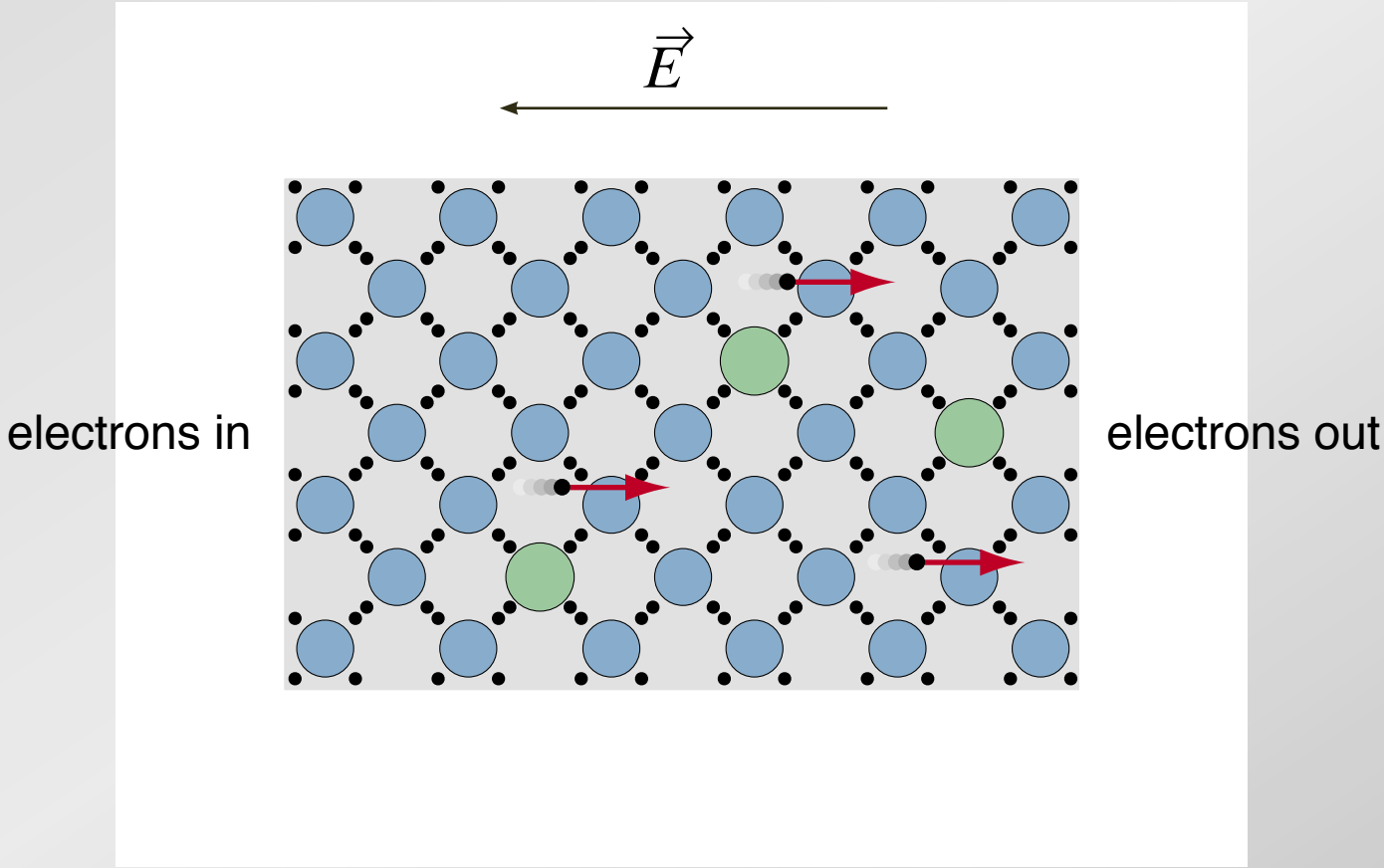
apply electric field…

Doped semiconductors



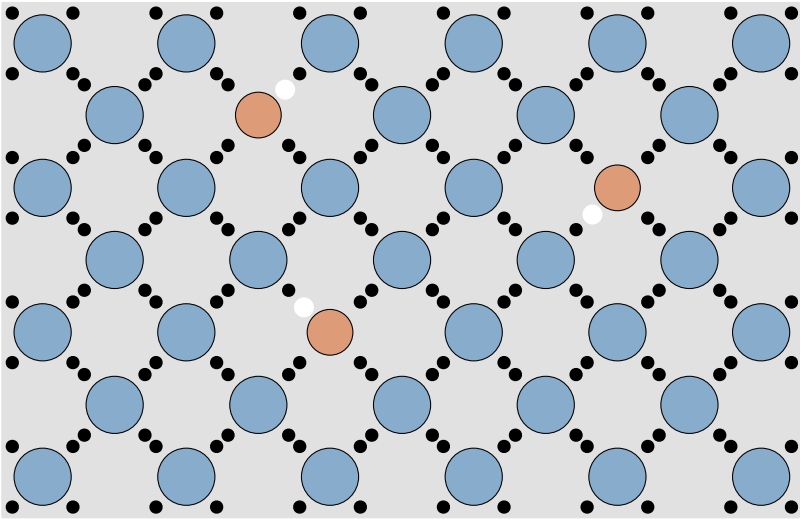
…free electrons lead to conduction

Doped semiconductors



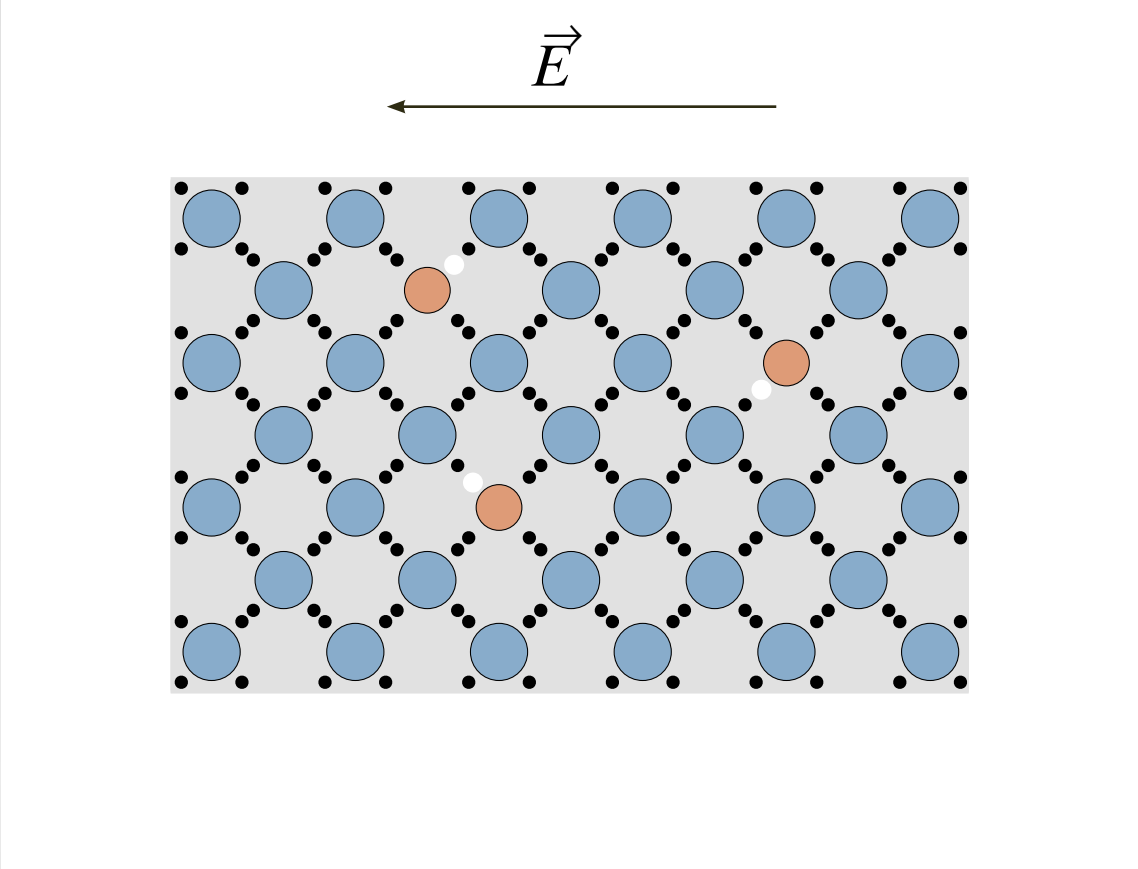
…free electrons lead to conduction

Doped semiconductors



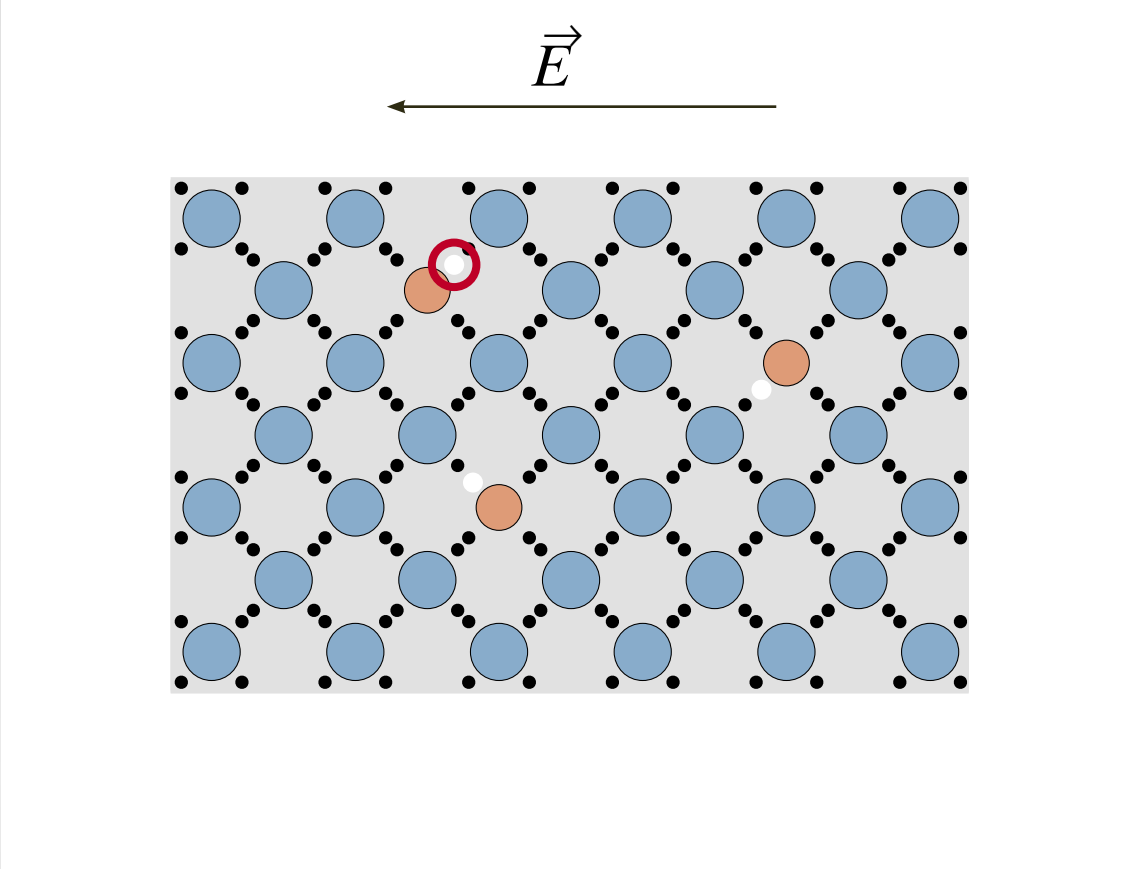
substitute boron: deficit of electrons leaves “holes”

Doped semiconductors



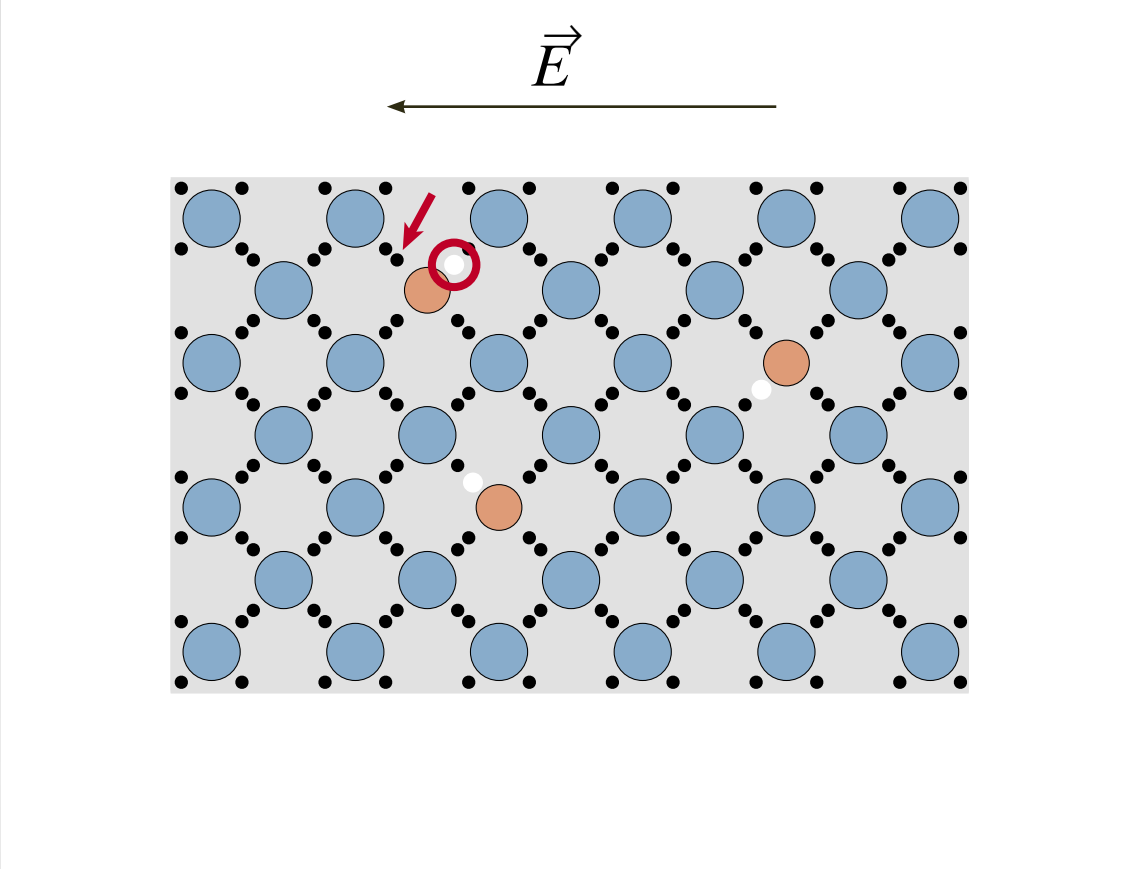
apply electric field…

Doped semiconductors



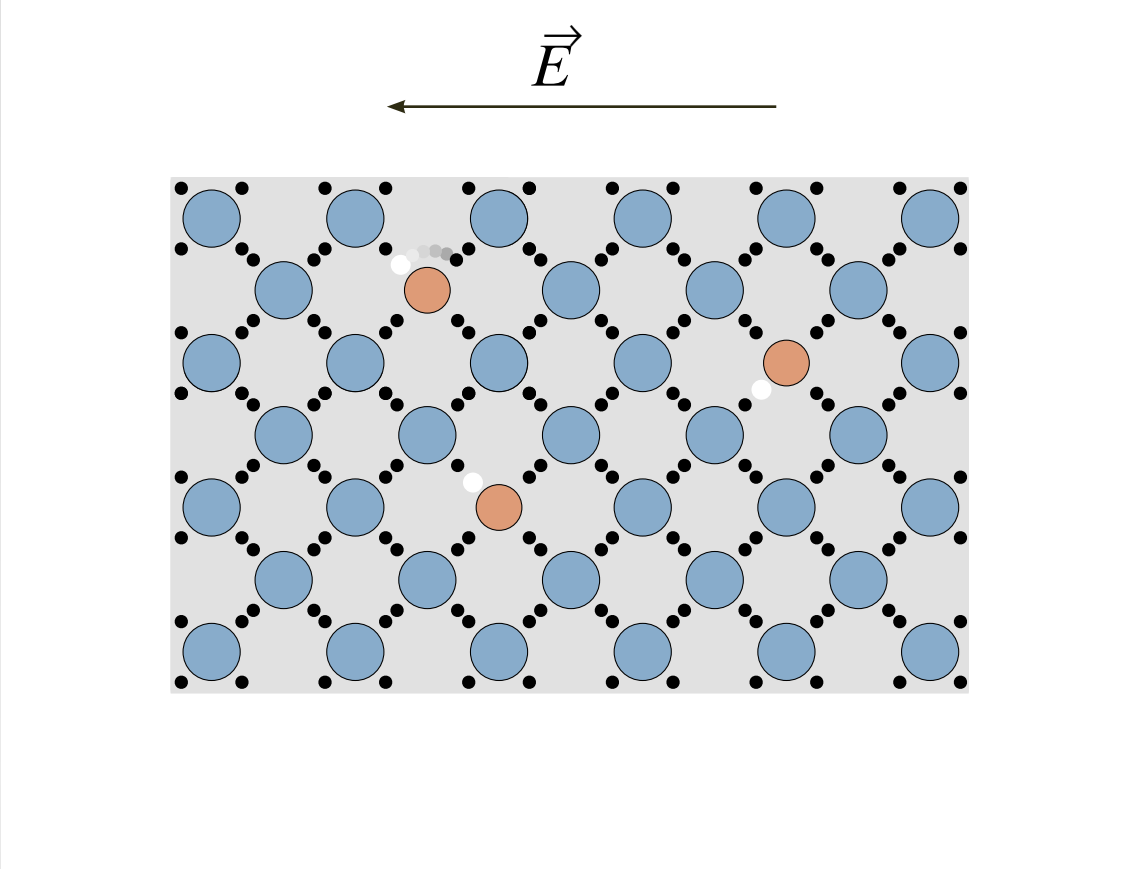
…presence of holes leads to conduction

Doped semiconductors



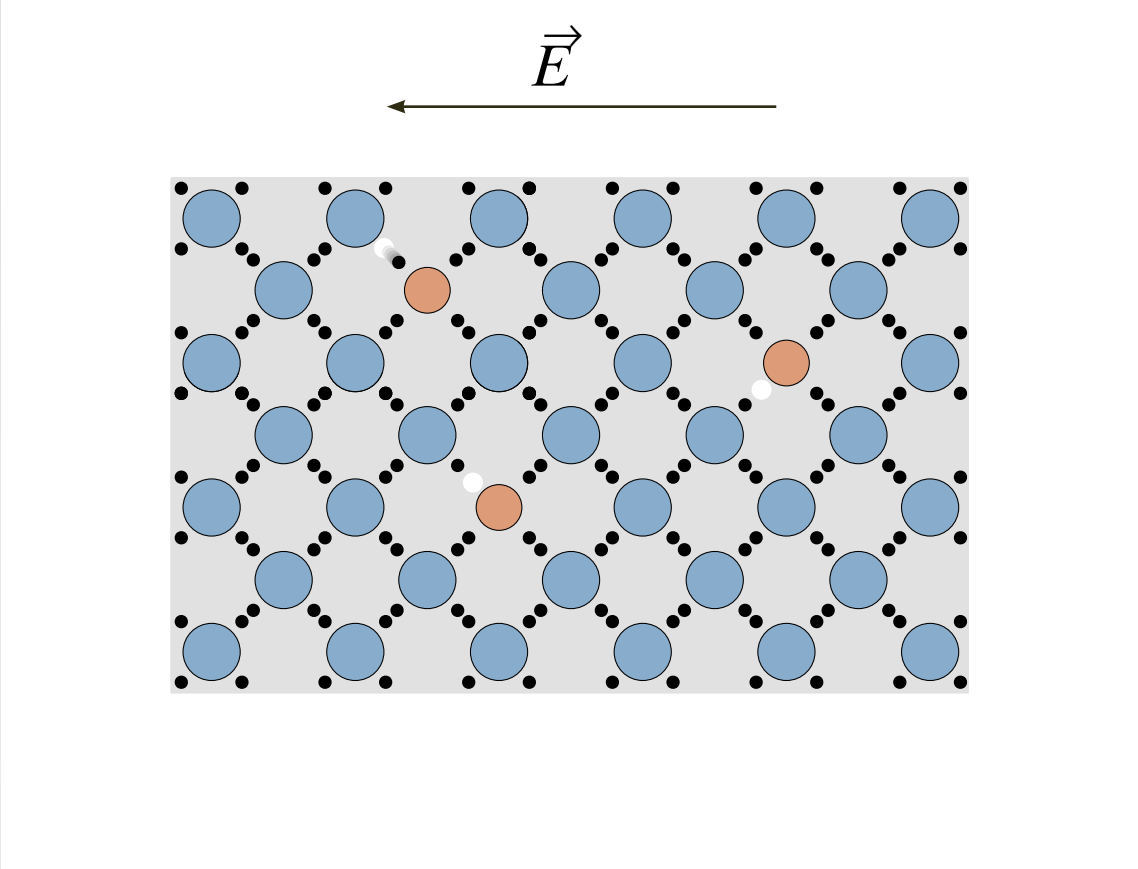
…presence of holes leads to conduction

Doped semiconductors



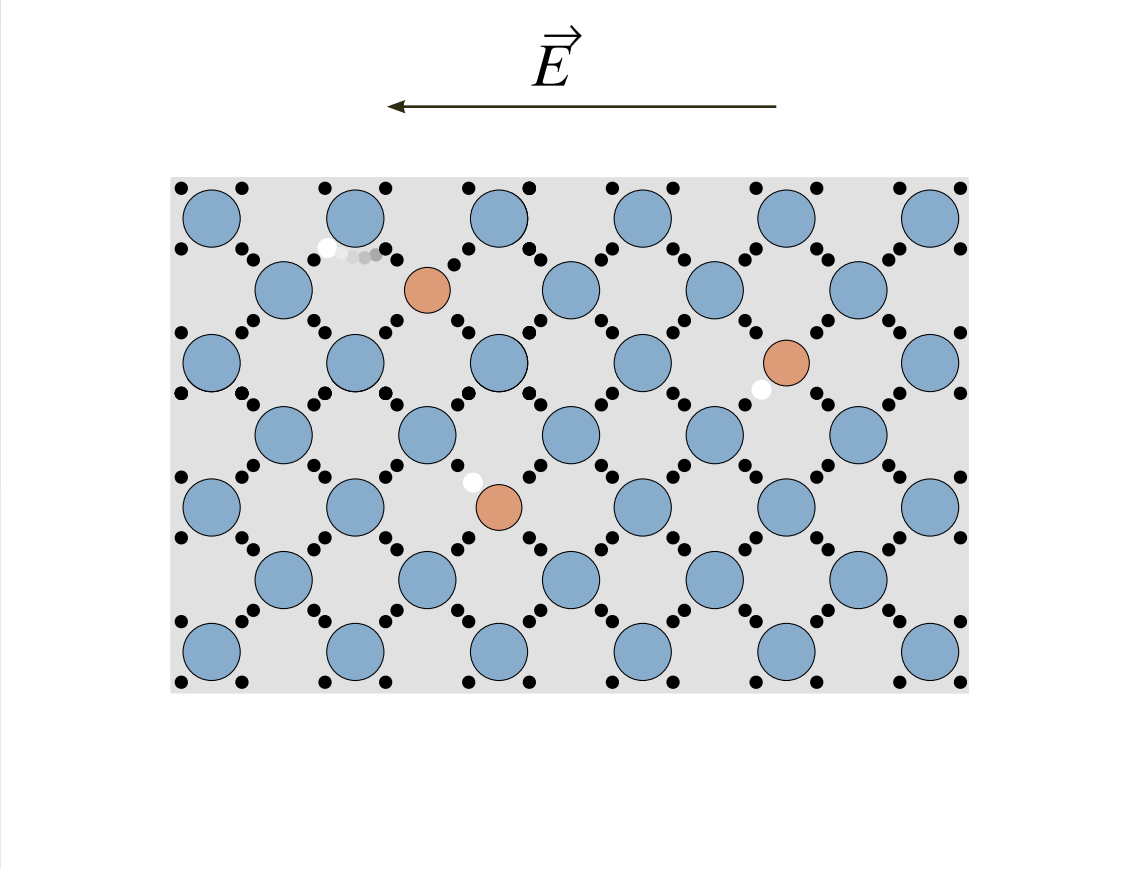
…presence of holes leads to conduction

Doped semiconductors



…presence of holes leads to conduction

Doped semiconductors



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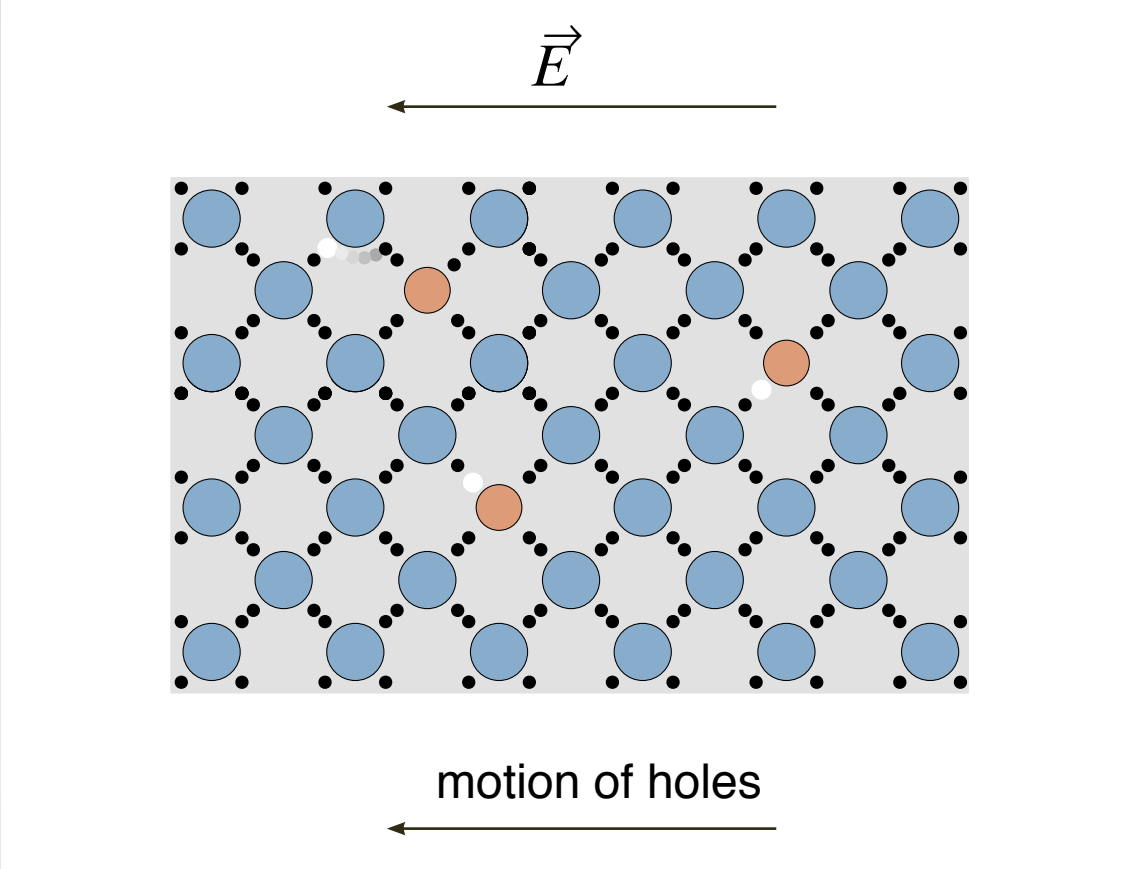
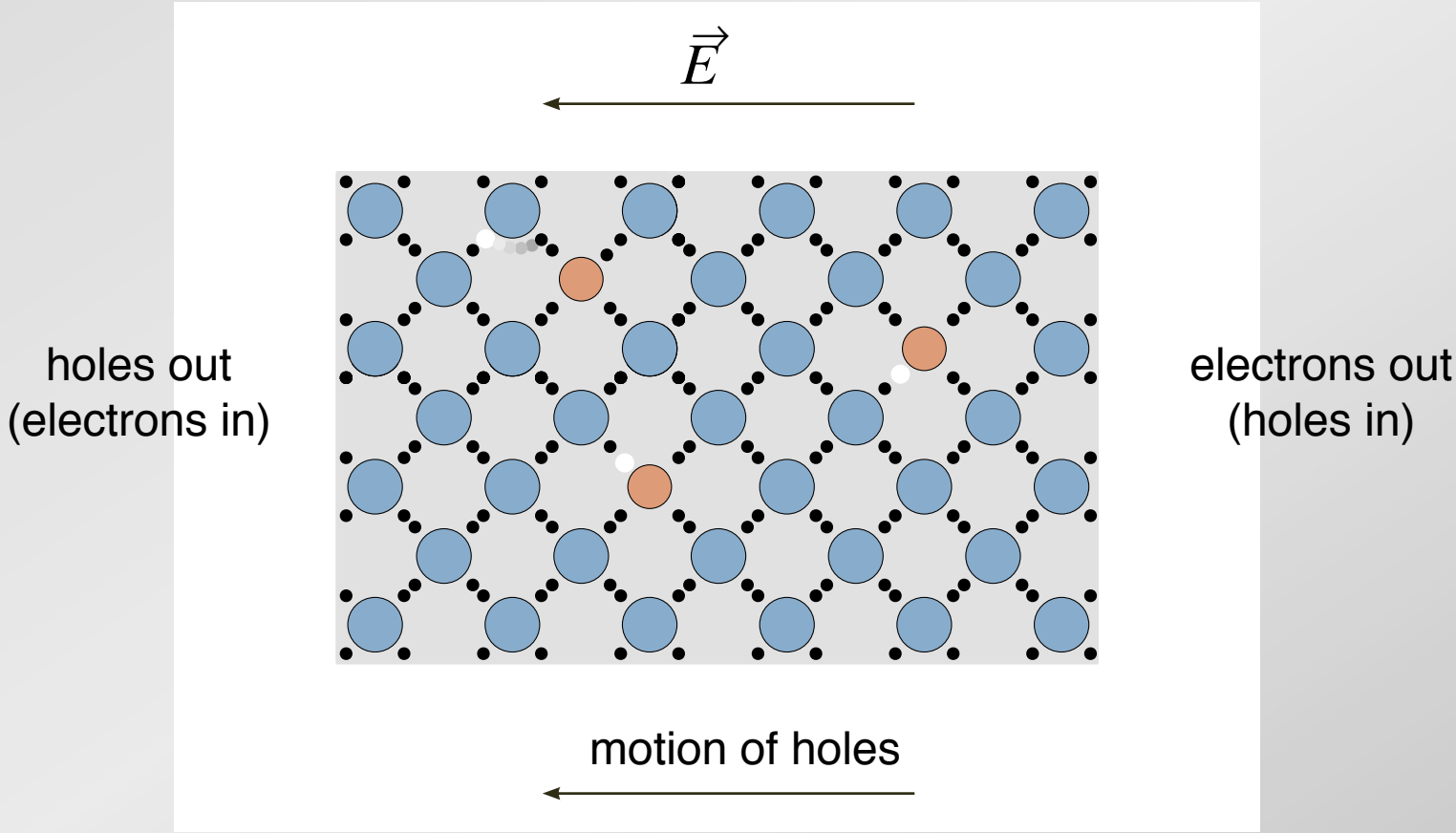
Doped semiconductors



holes are like positively charged particles

Doped semiconductors



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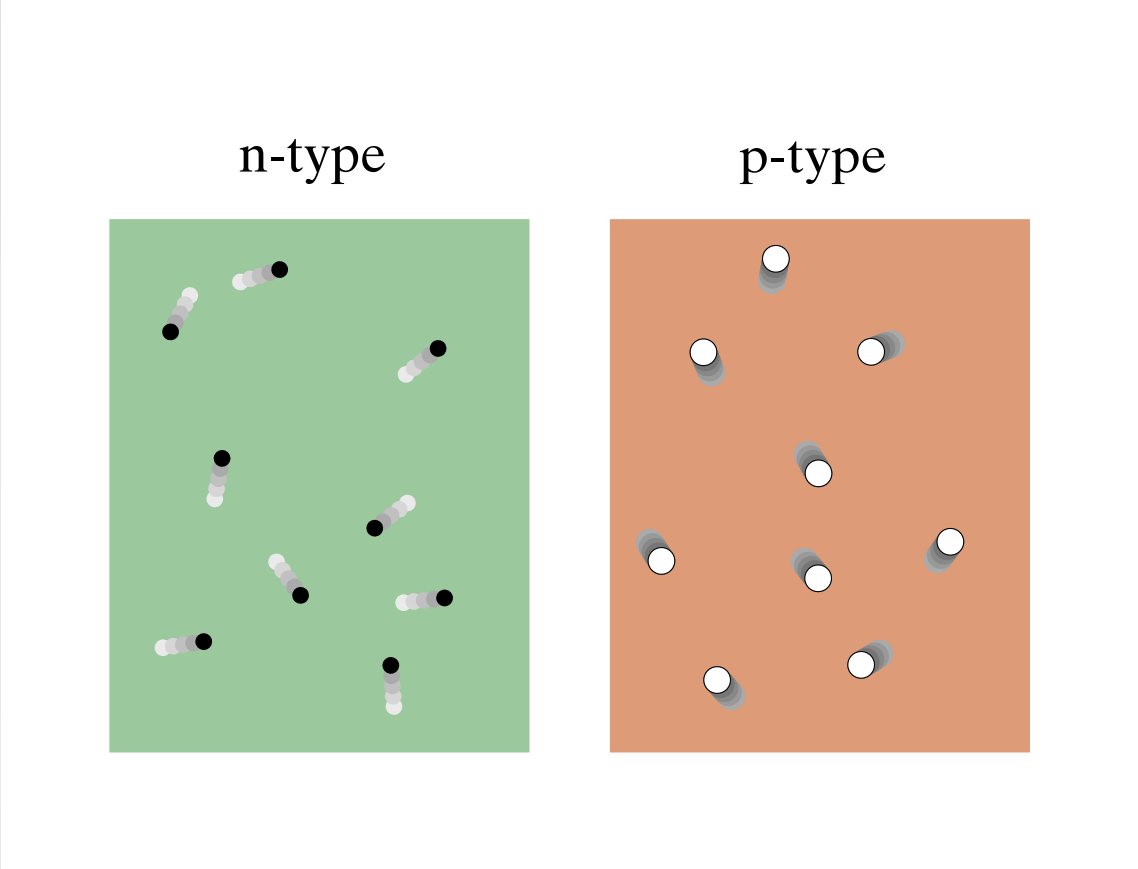
Doped semiconductors

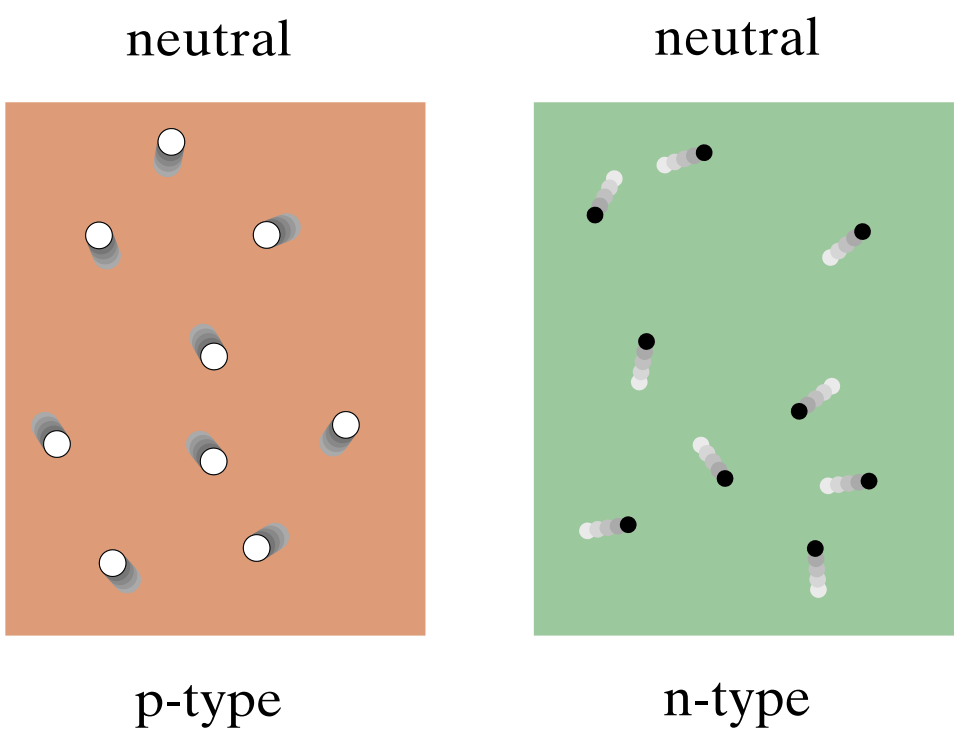


simplify representation

Outline

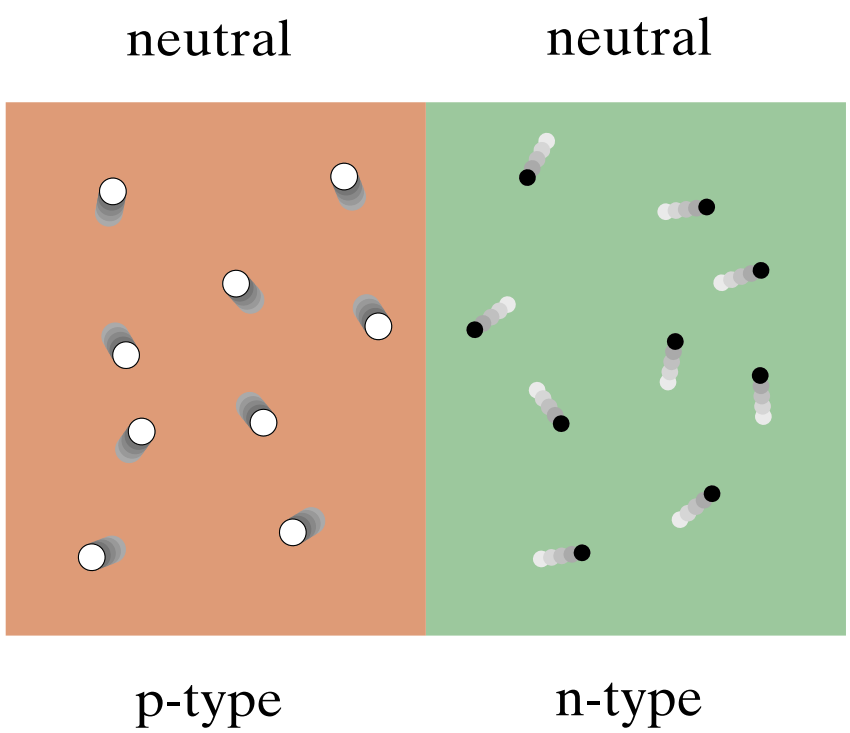
- doped semiconductors
- *pn*-junctions
- black silicon

pn-junctions



bring *p* and *n* materials together…

pn-junctions



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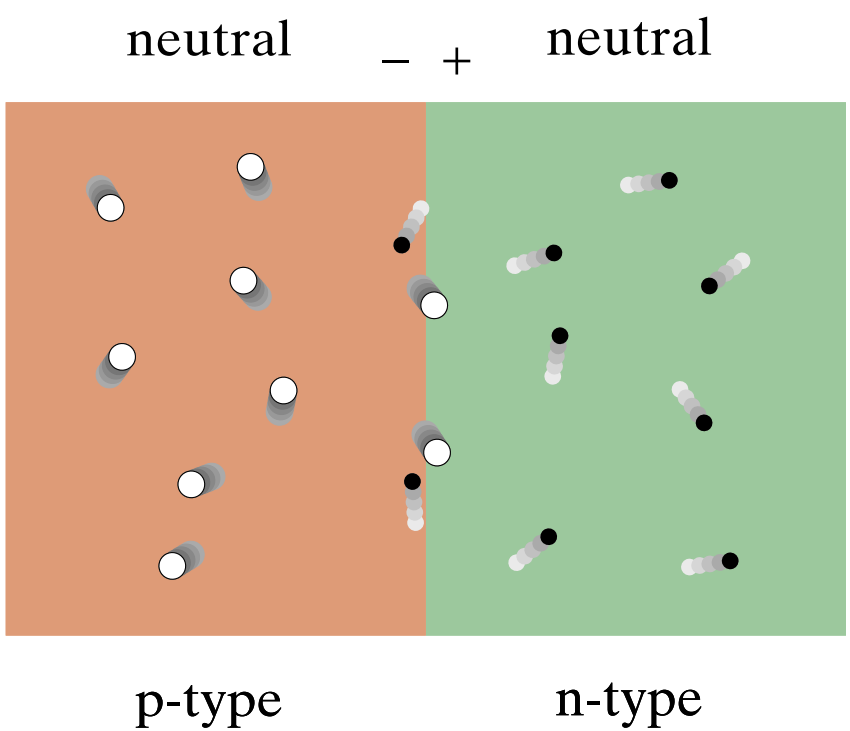
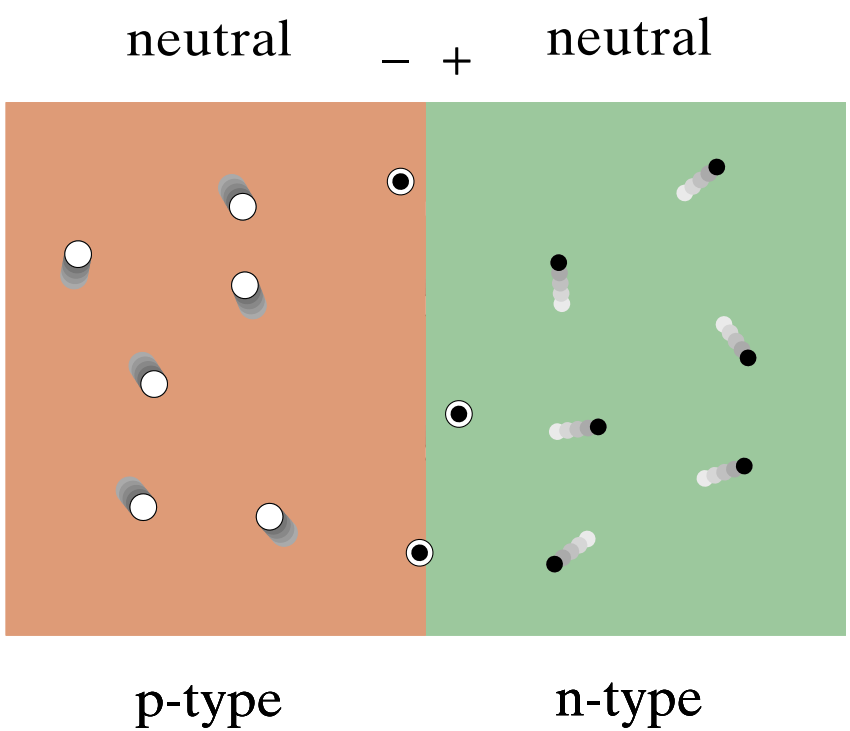
pn-junctions



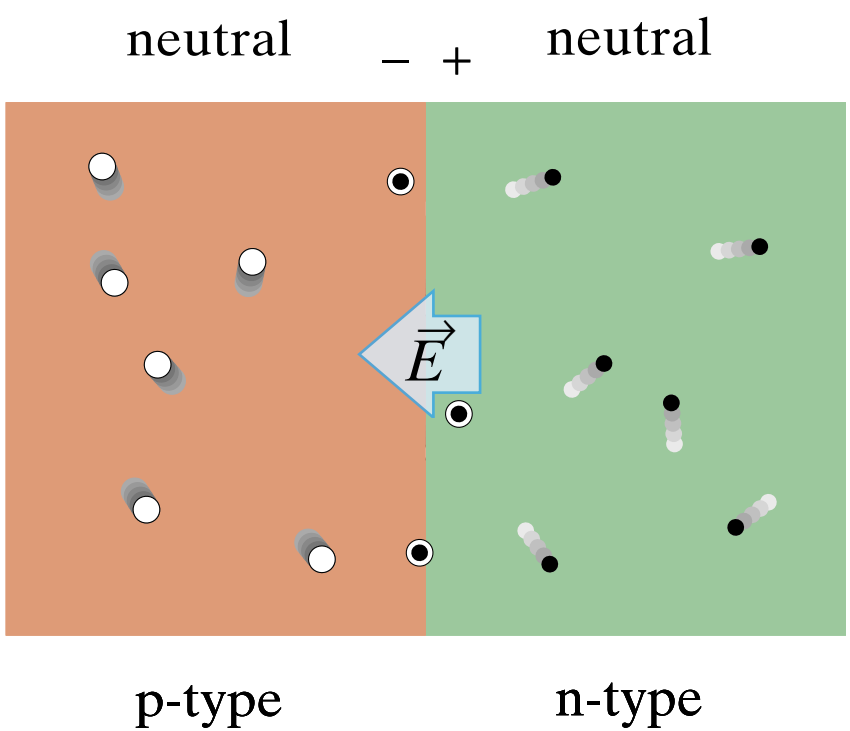
electrons and holes diffuse across junction…

pn-junctions



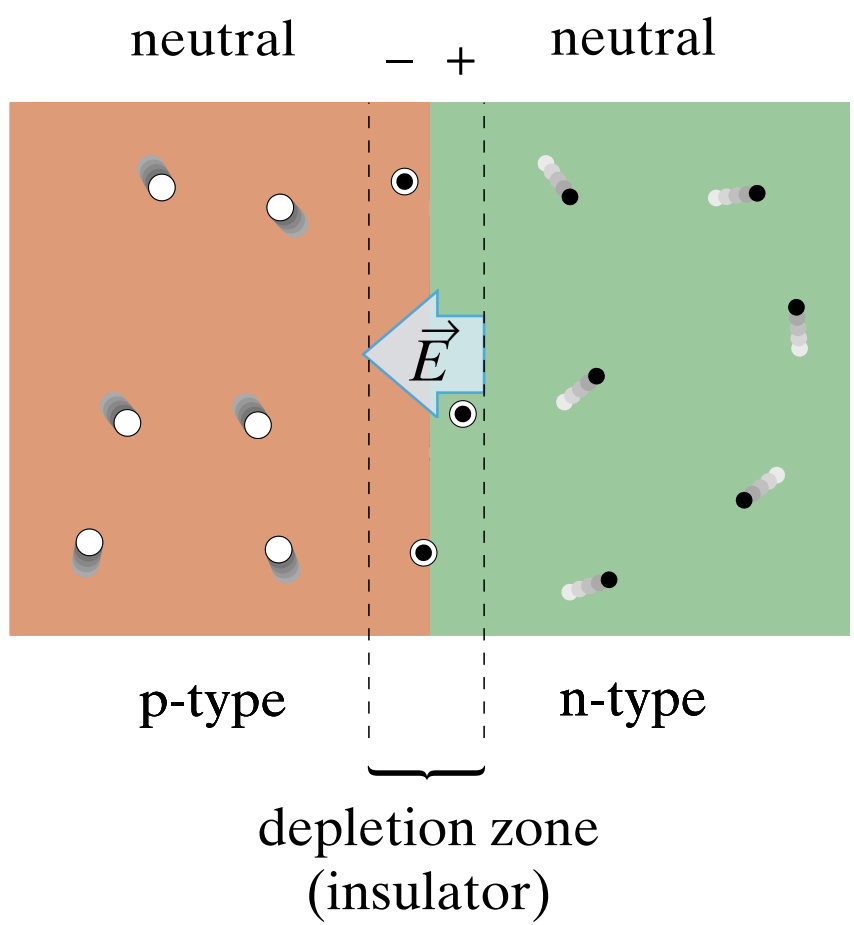
…and get ‘trapped’ after they combine

pn-junctions



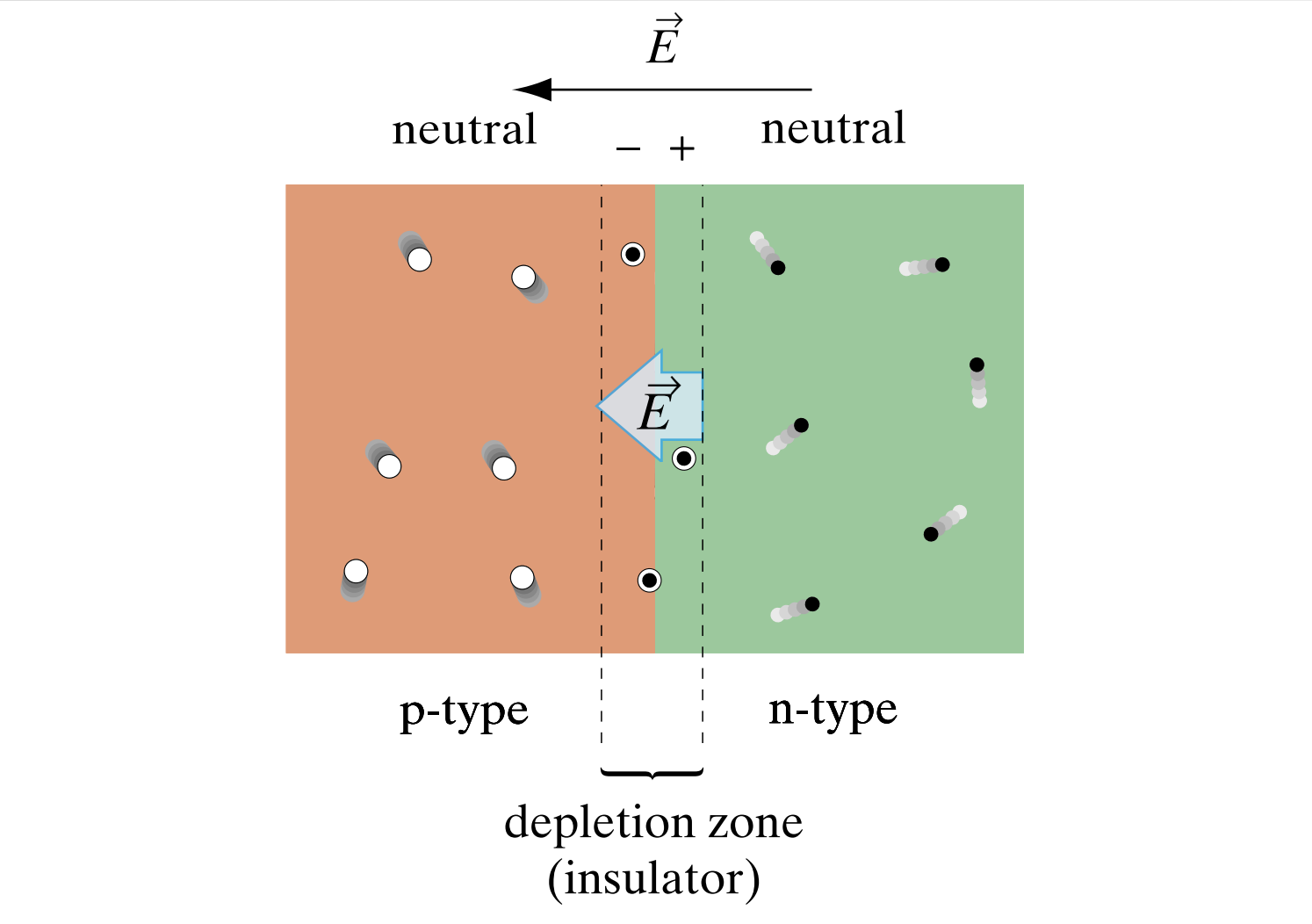
build-up of charge leads to electric field that stops diffusion

pn-junctions



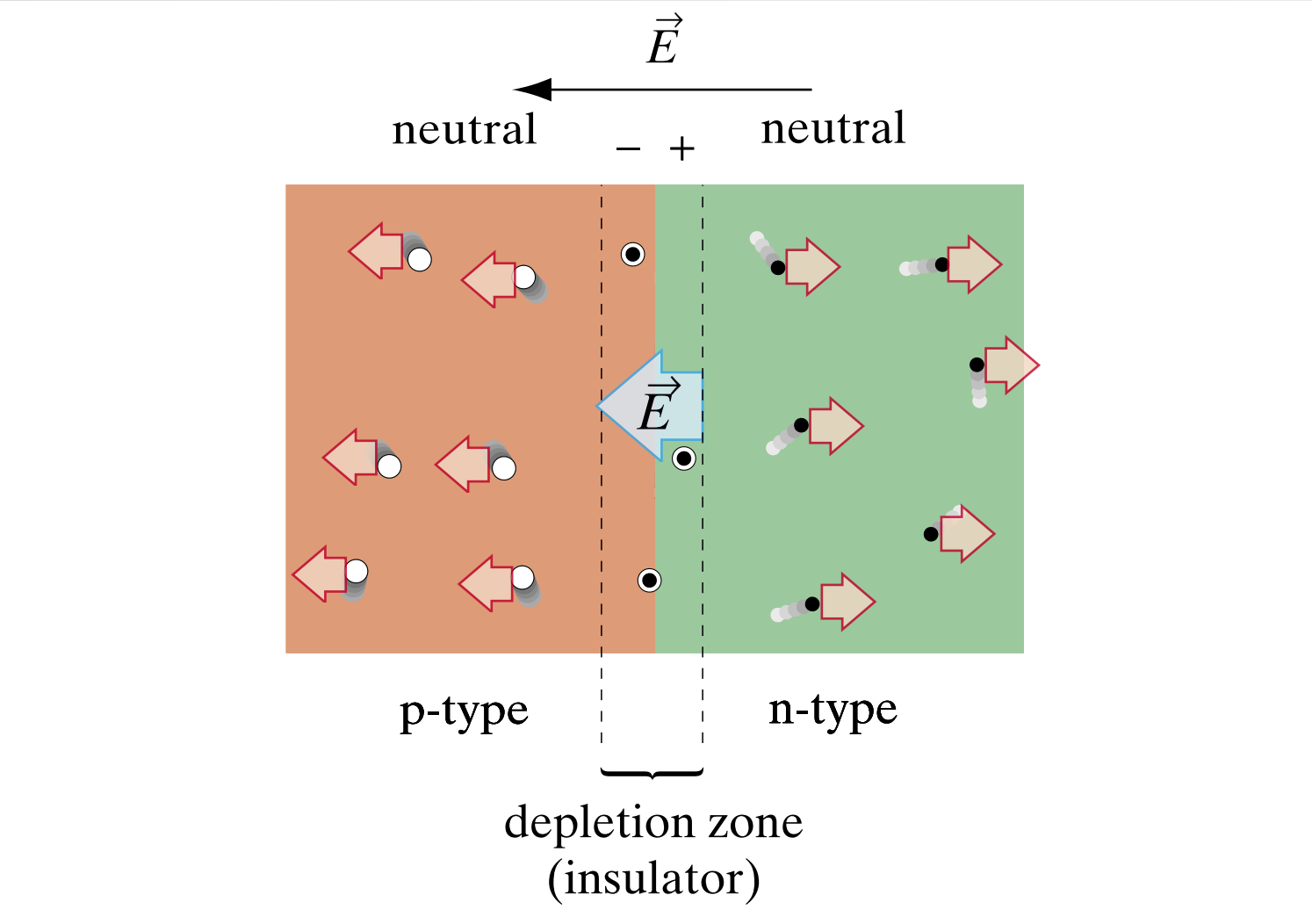
non-conducting layer at junction

pn-junctions



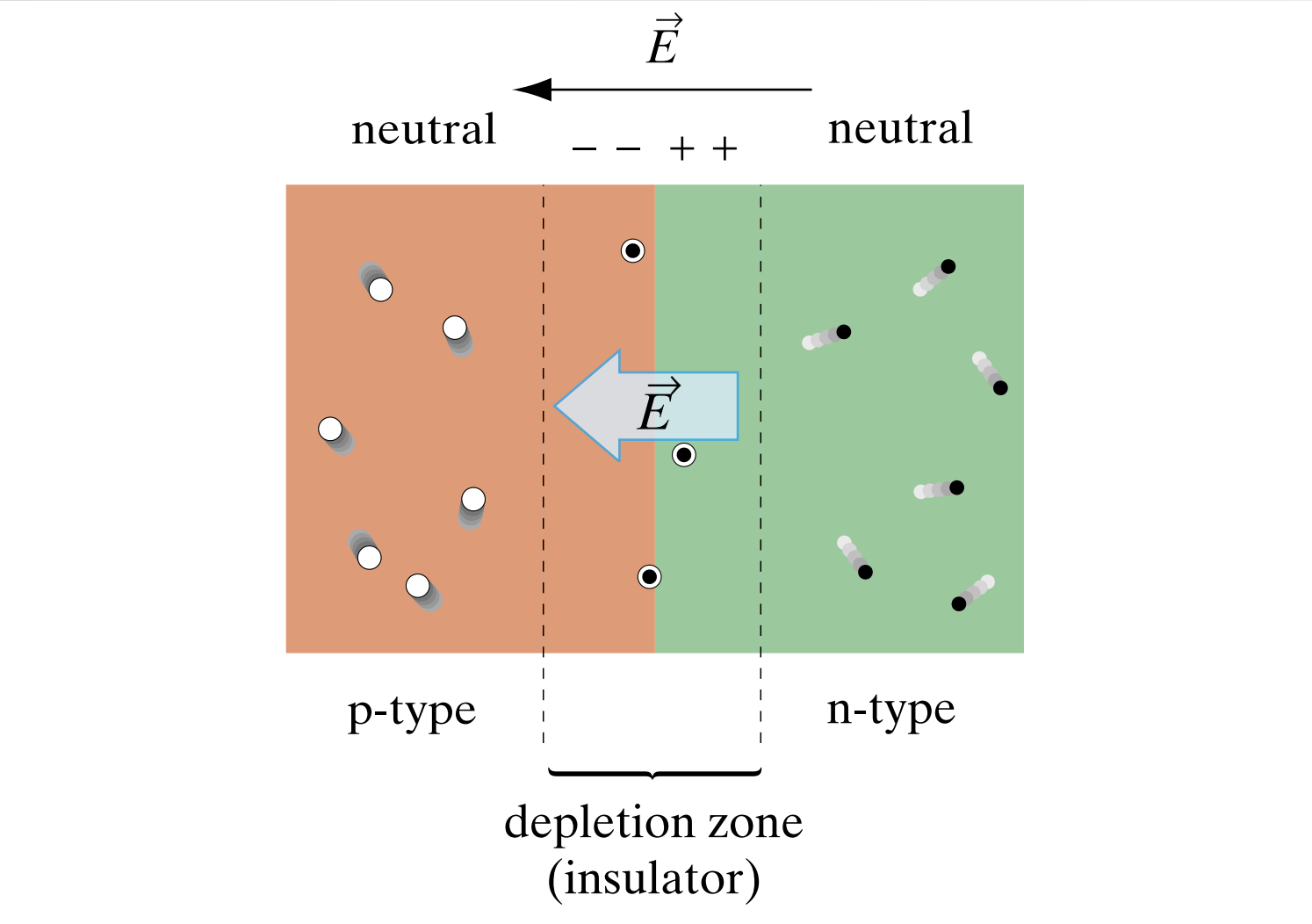
apply electric field…

pn-junctions



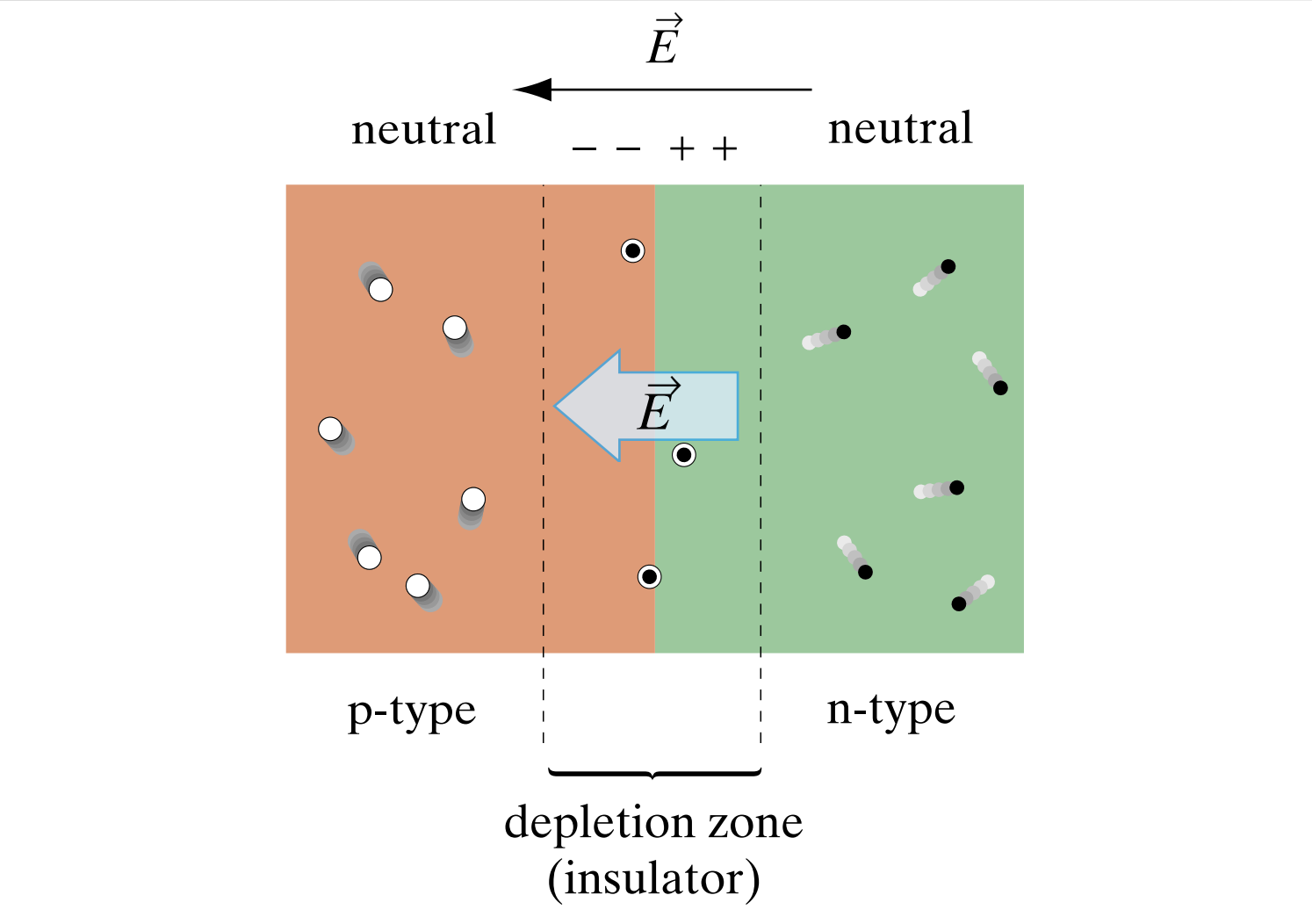
…holes pushed to left, electrons to right…

pn-junctions



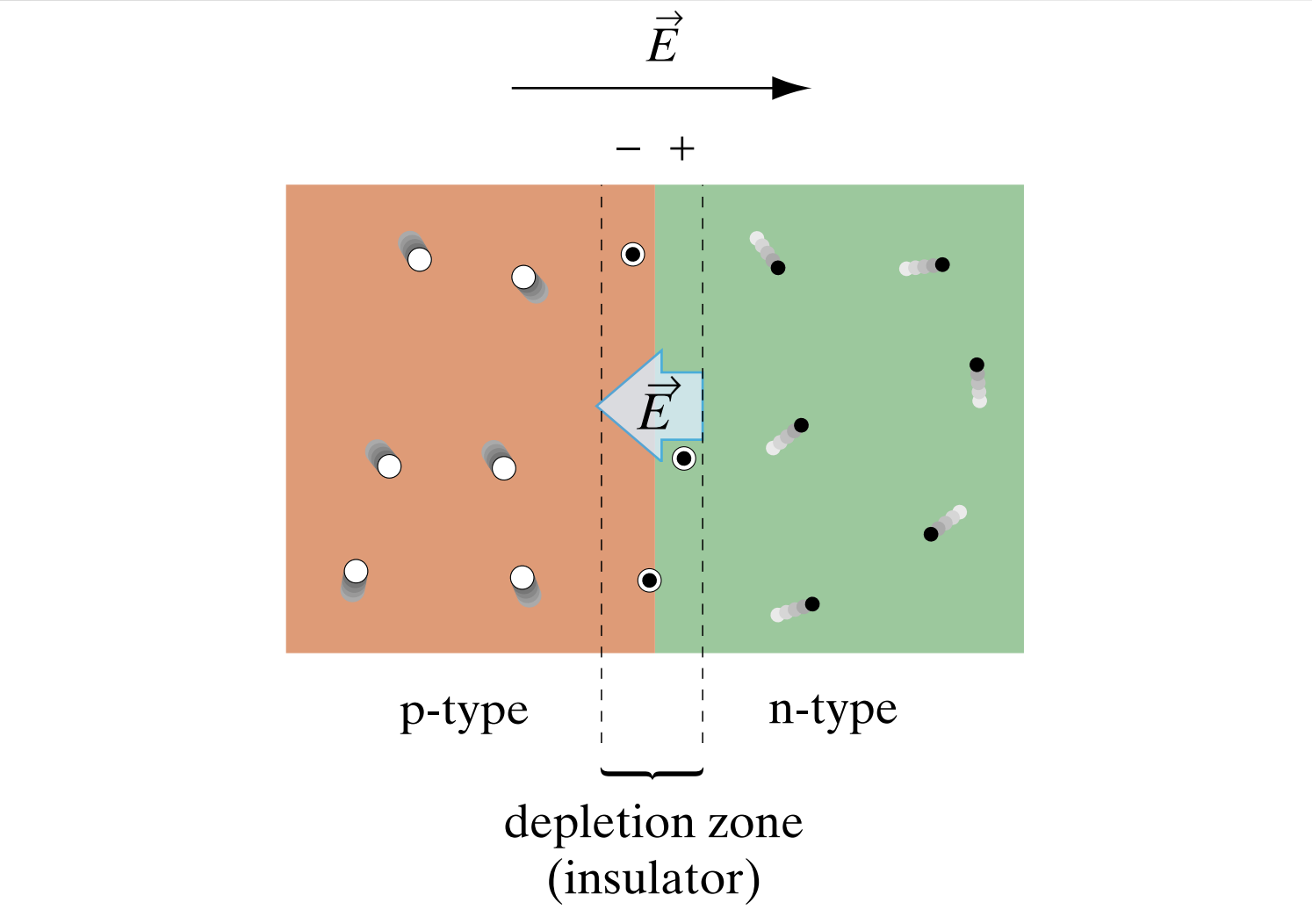
…and so depletion zone expands

pn-junctions



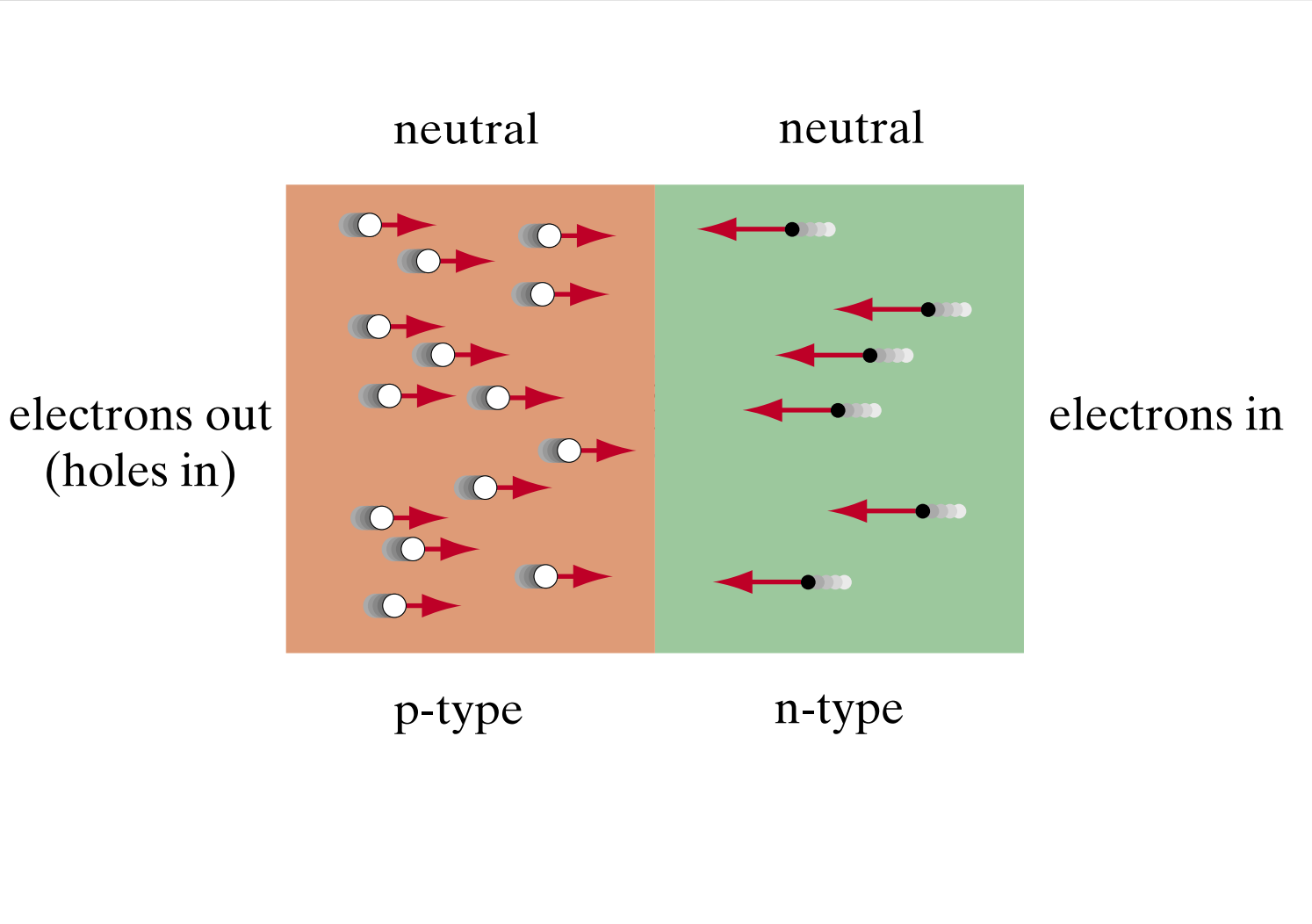
NO conduction

pn-junctions



reverse electric field…

pn-junctions



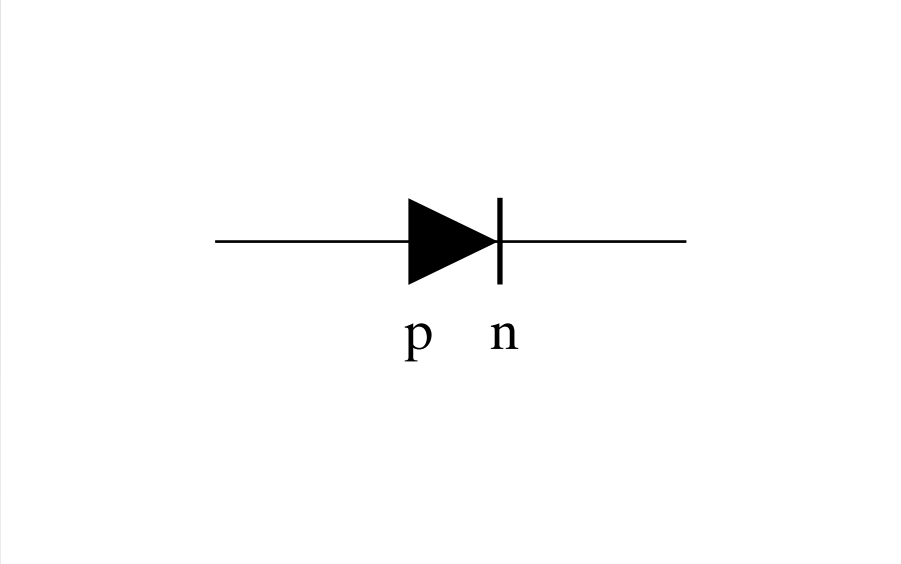
…depletion zone shrinks and current flows

pn-junctions

so *pn*-junction like one-way valve for charge flow

pn-junctions

diode

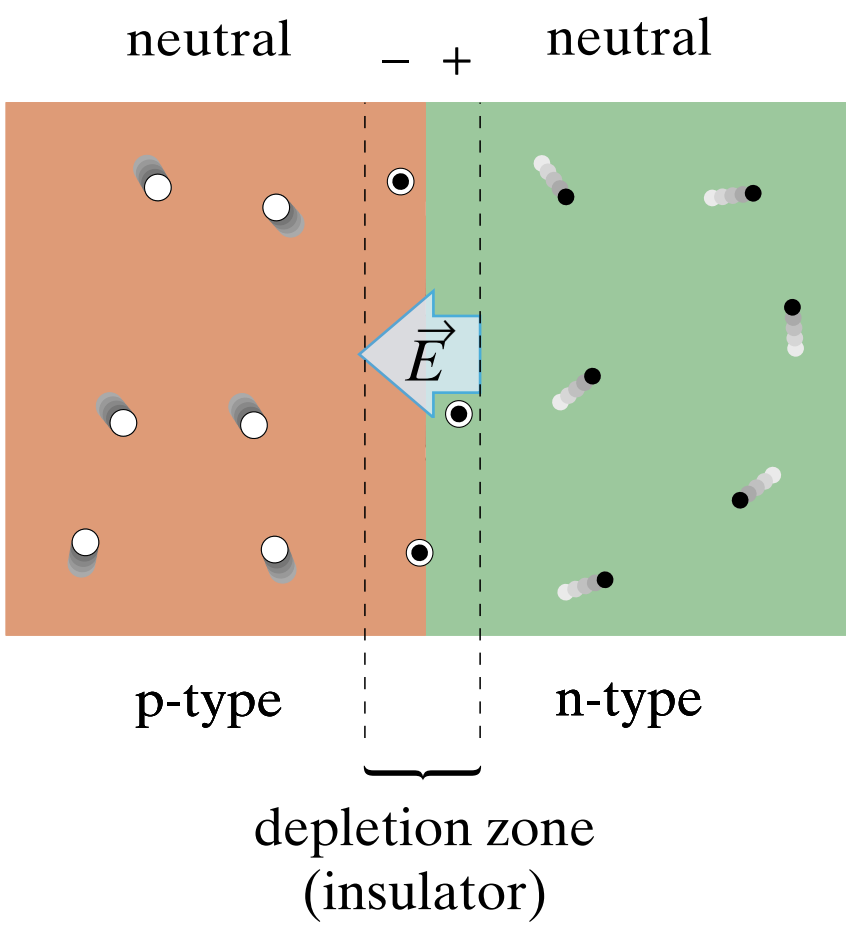


current flows along arrow only (from *p* to *n*)

pn-junctions

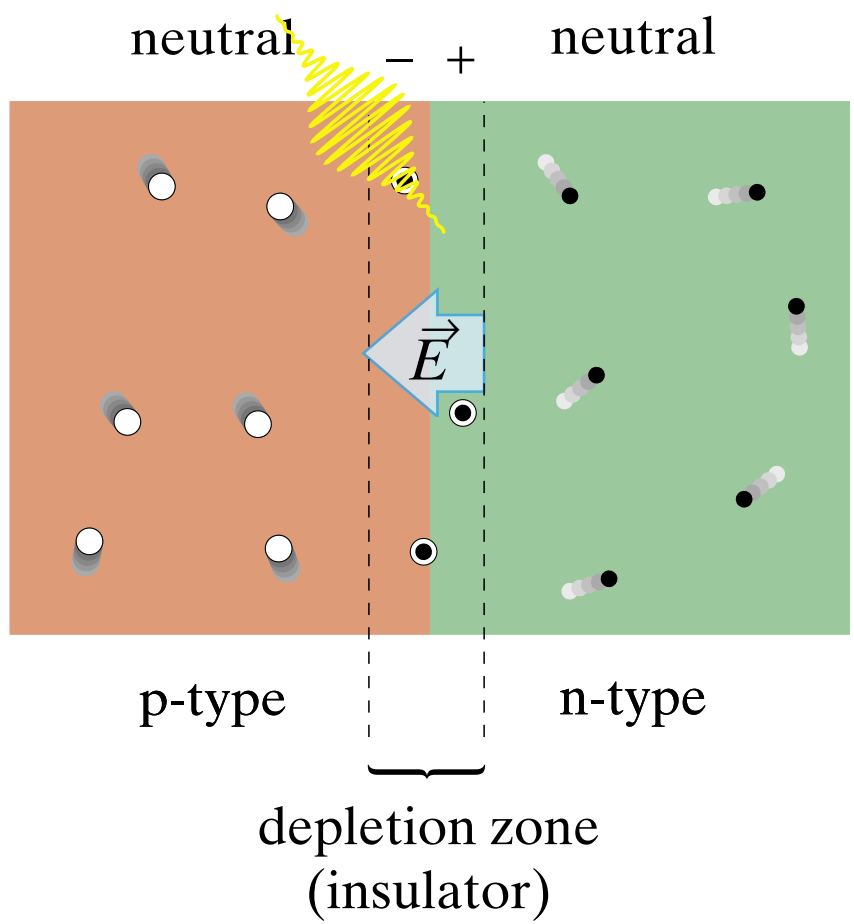
can also be used as a light detector!

pn-junctions



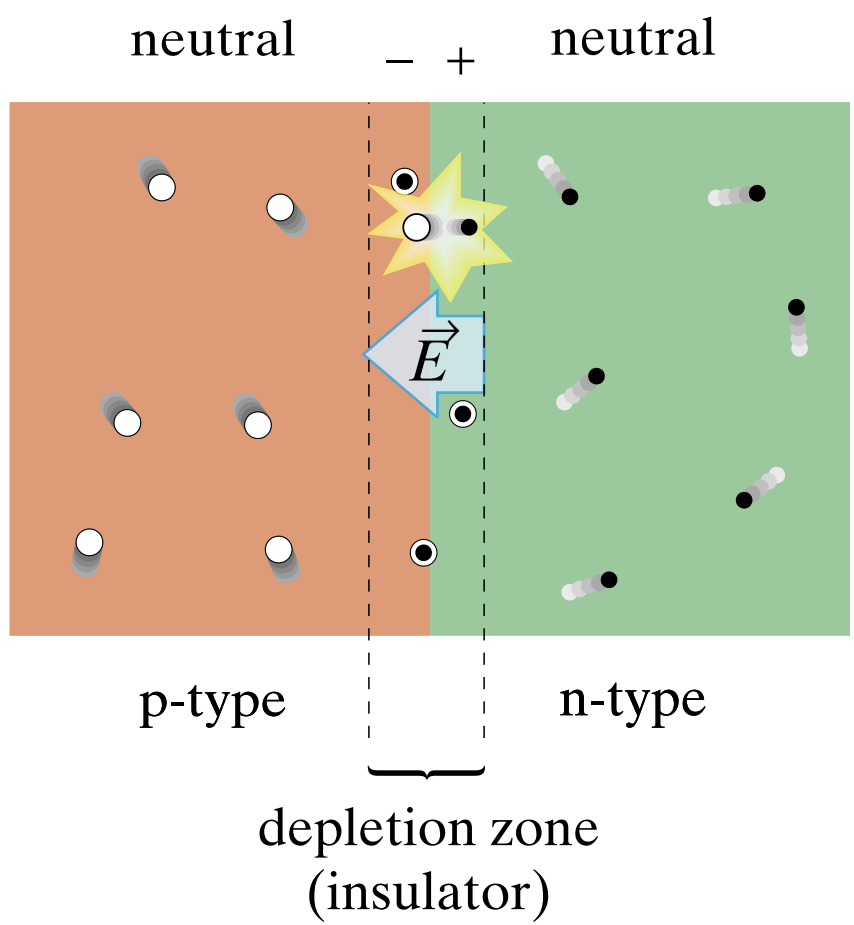
depletion layer can convert light into electric energy

pn-junctions



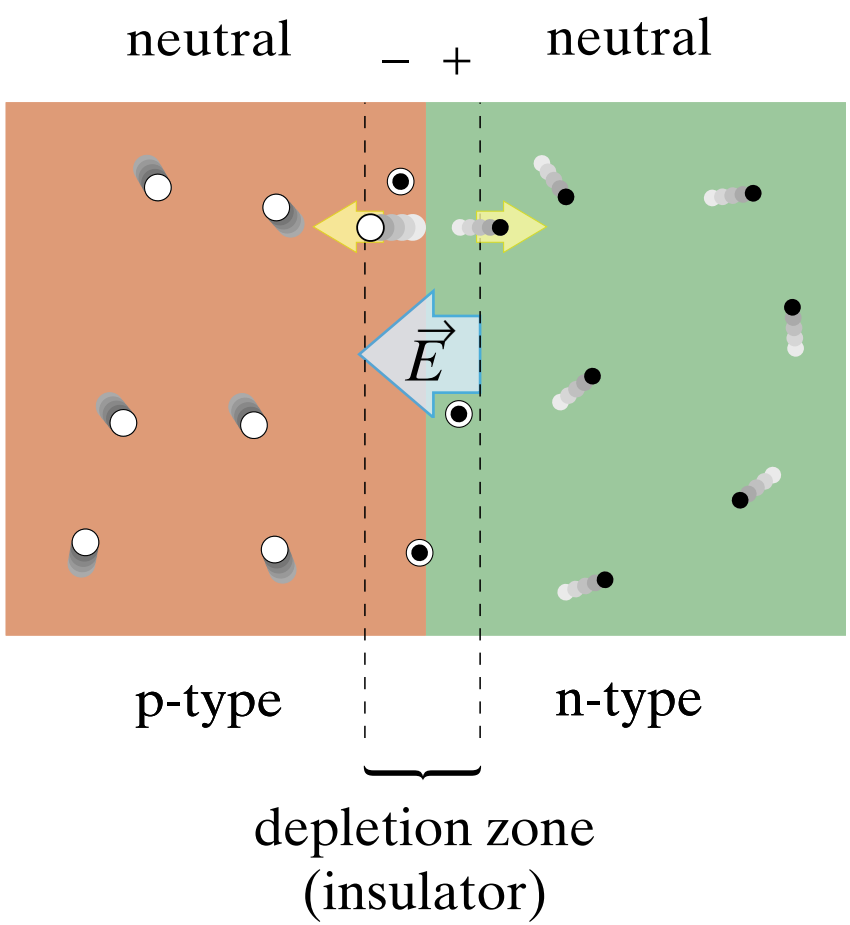
incident photon knocks out electron…

pn-junctions



…creating an electron-hole pair

pn-junctions

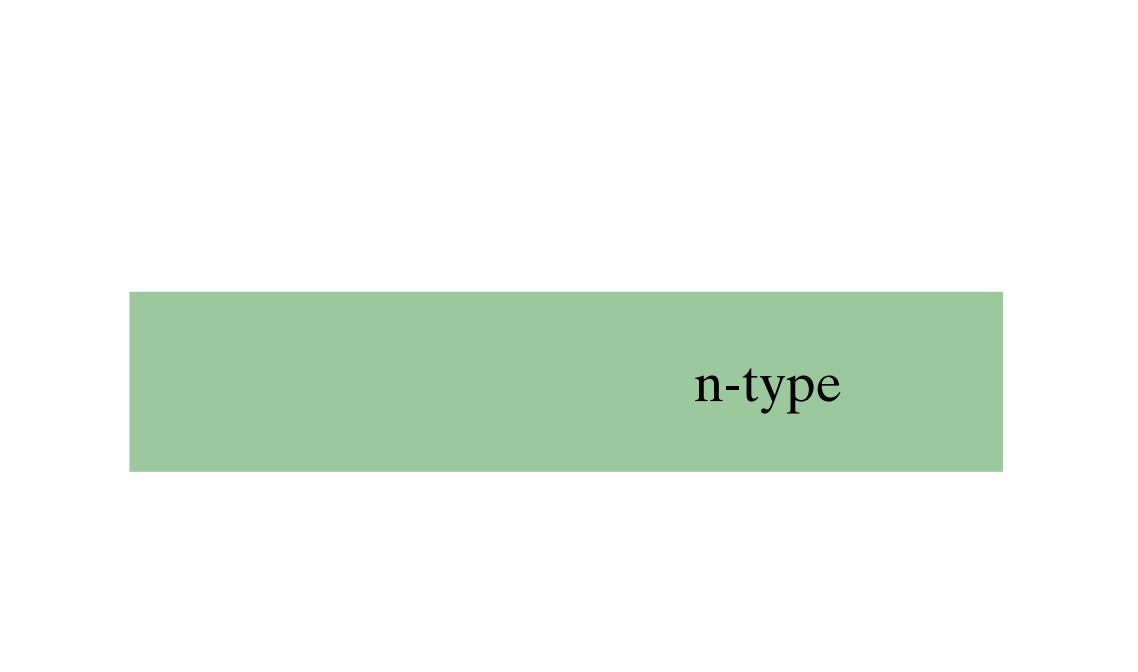


E-field separates eh-pair, causing current

pn-junctions

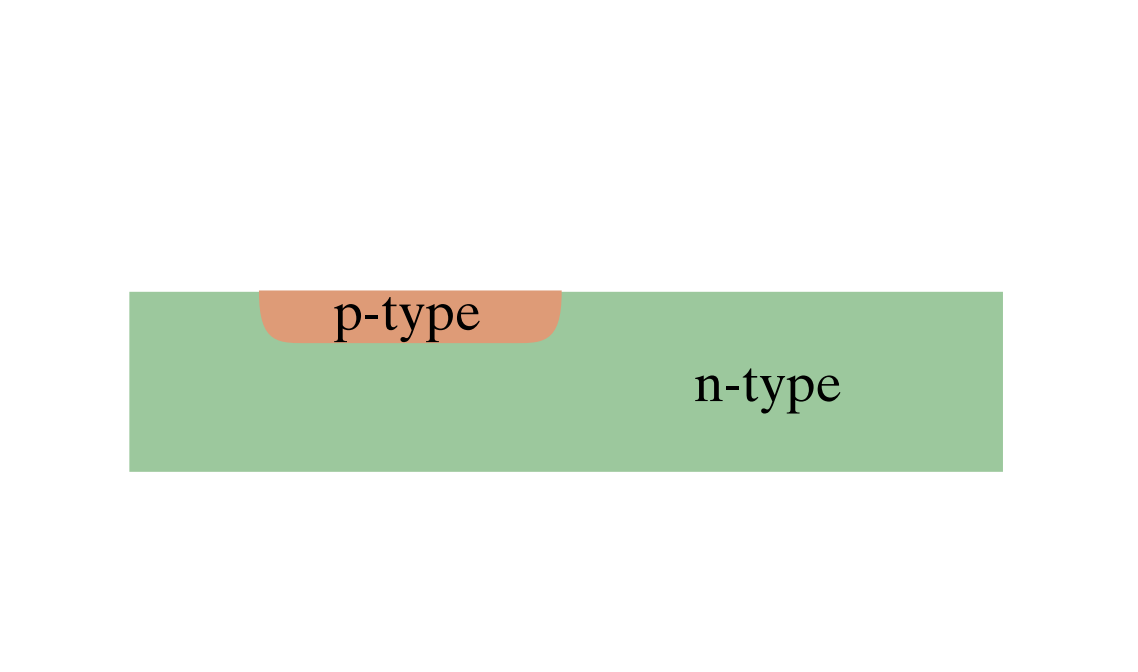
how to make a miniature diode on a chip?

pn-junctions



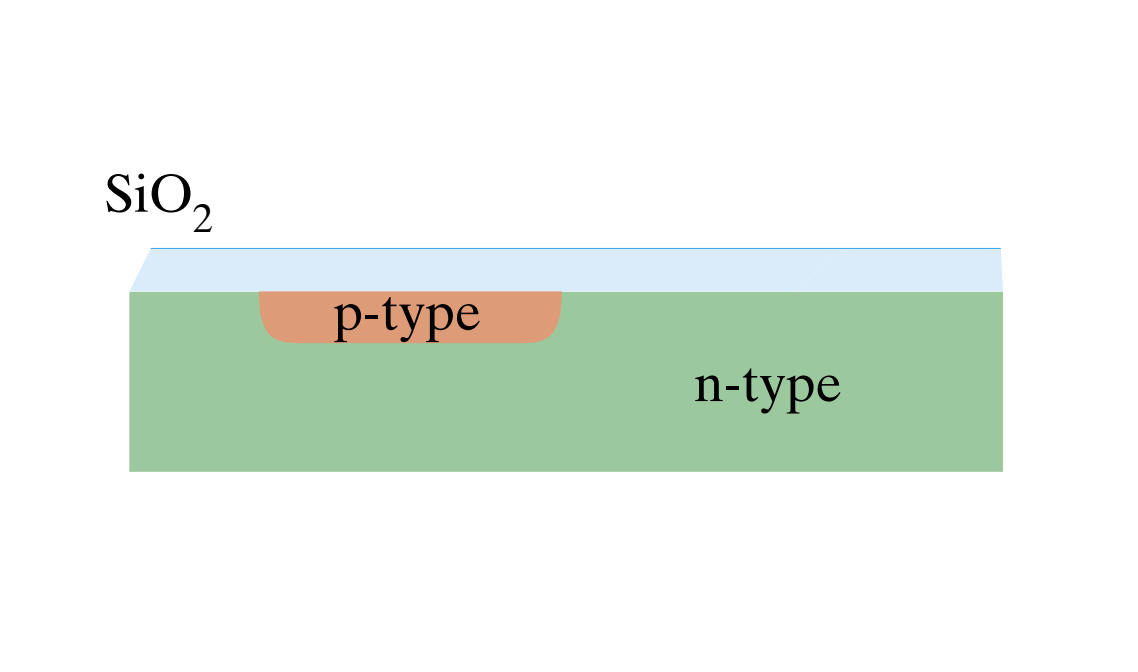
begin with an *n*-doped wafer

pn-junctions



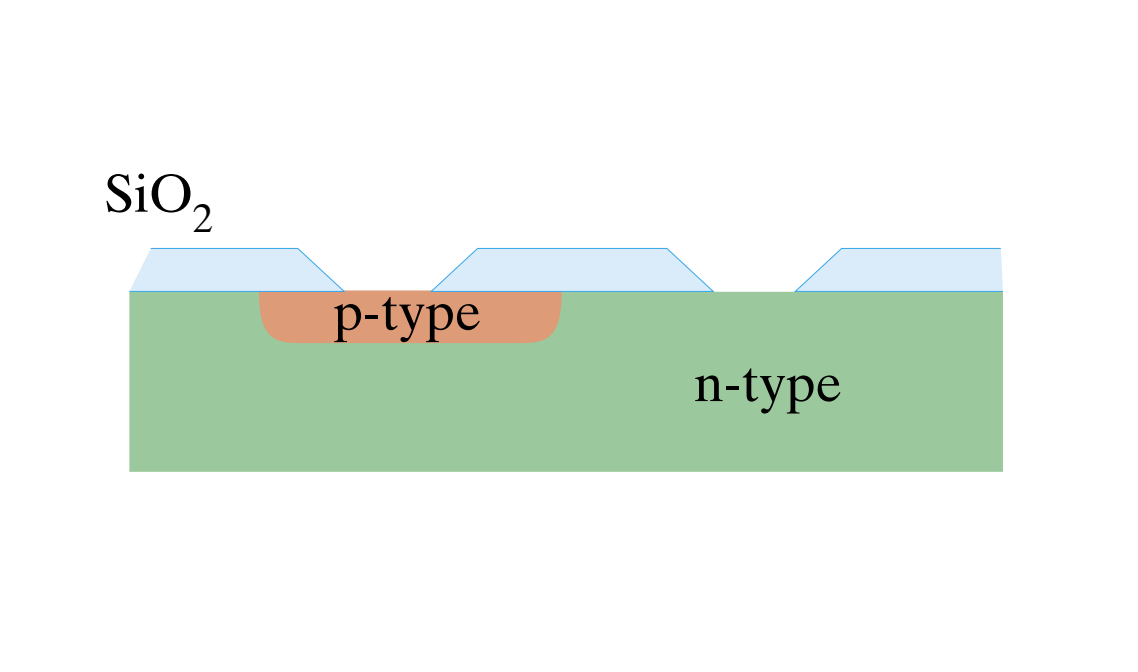
***p*-dope small region**

pn-junctions



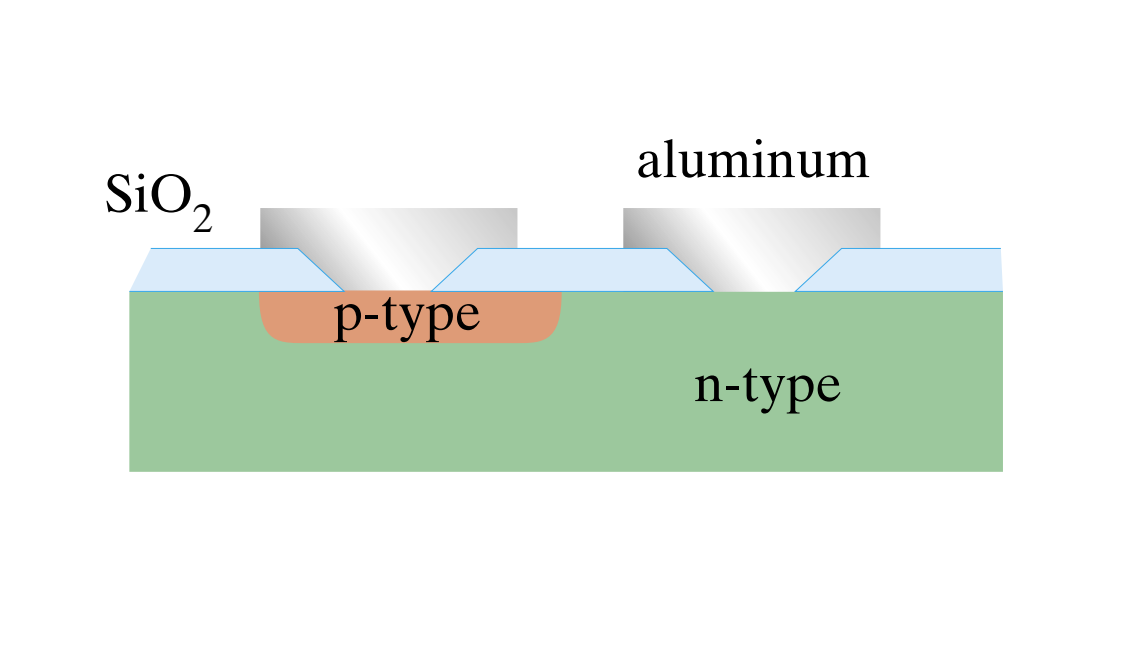
cover with insulating layer

pn-junctions



etch insulating layer

pn-junctions

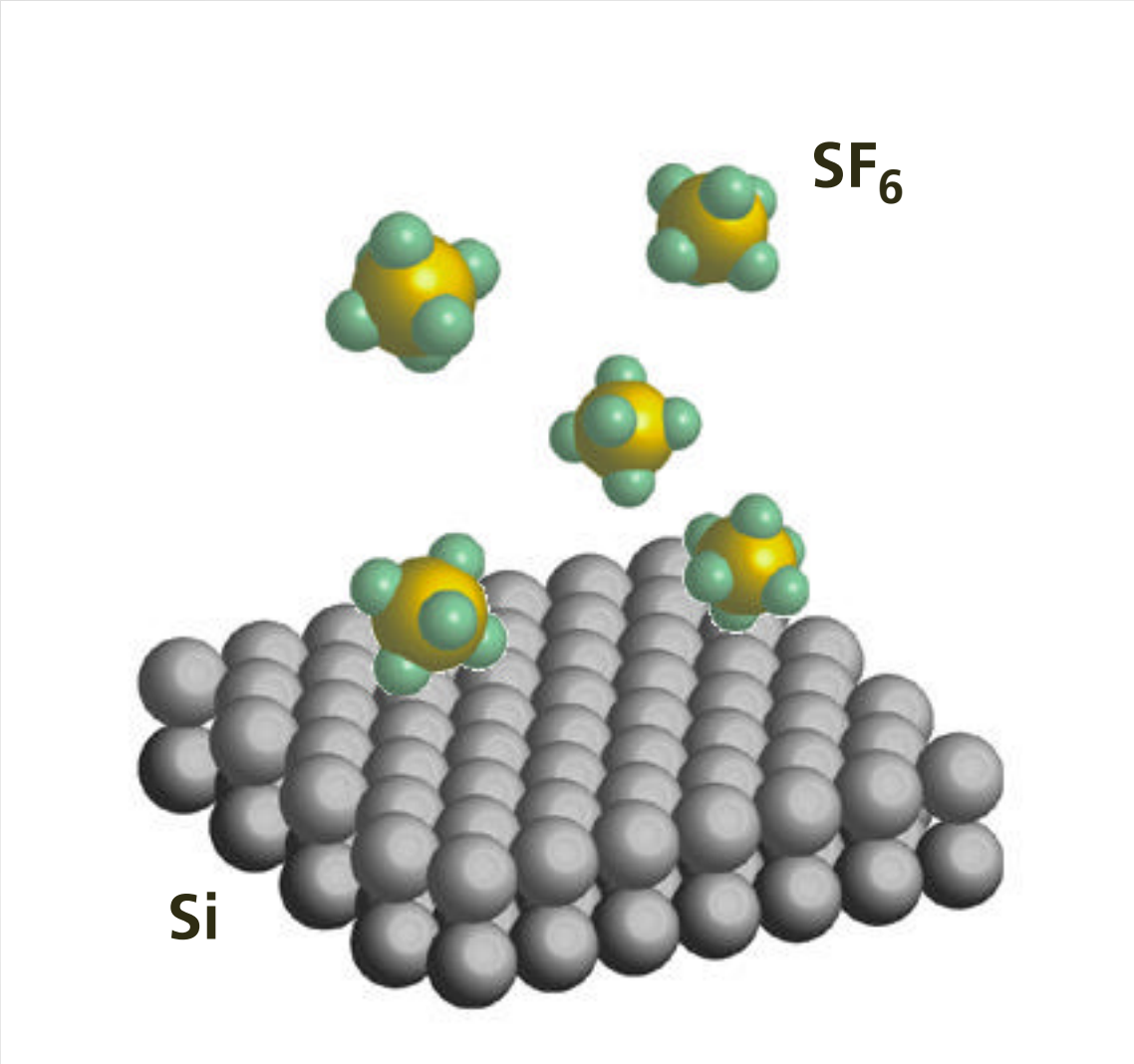


add aluminum contacts

Outline

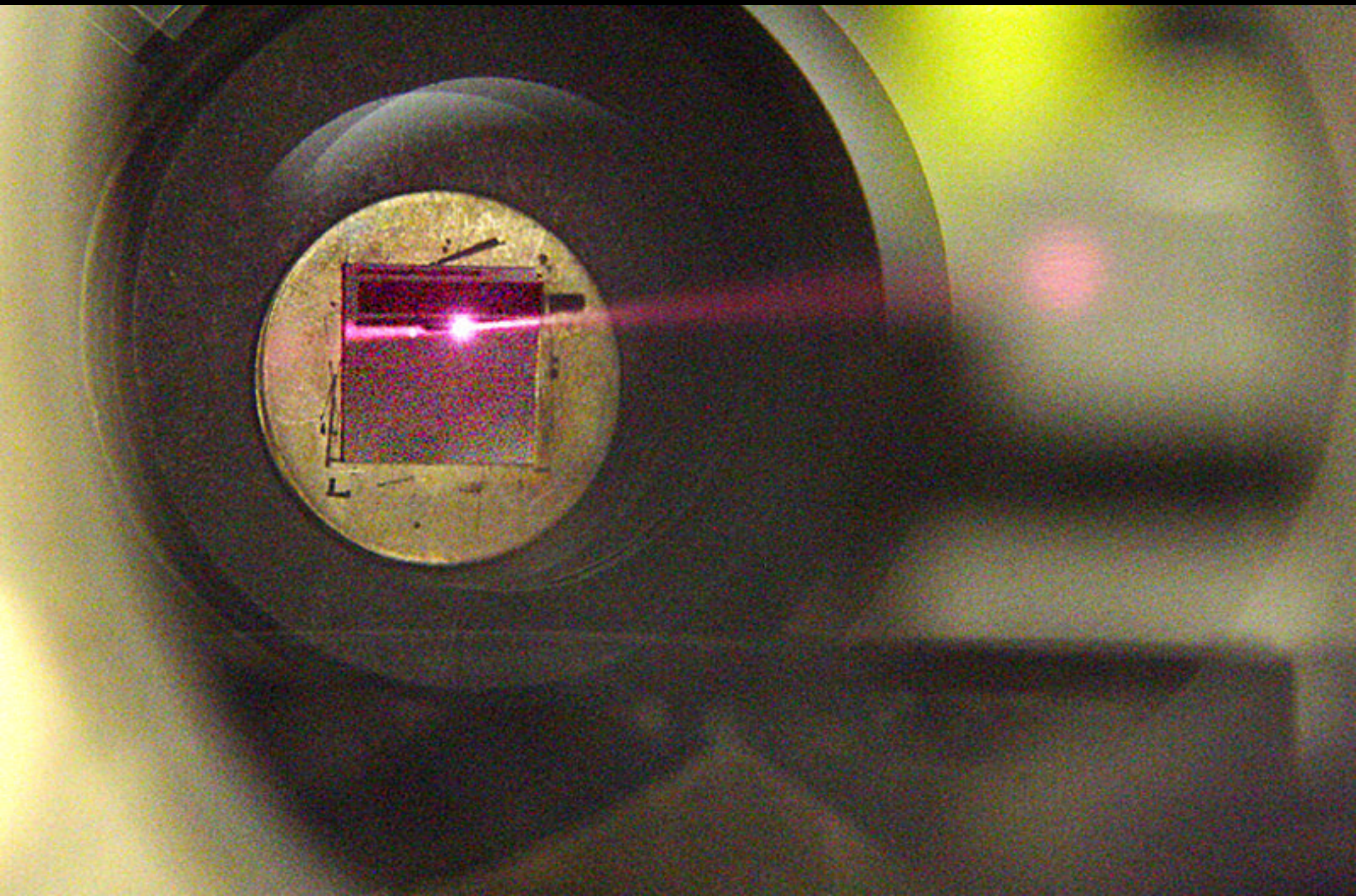
- doped semiconductors
- pn-junctions
- **black silicon**

Black silicon

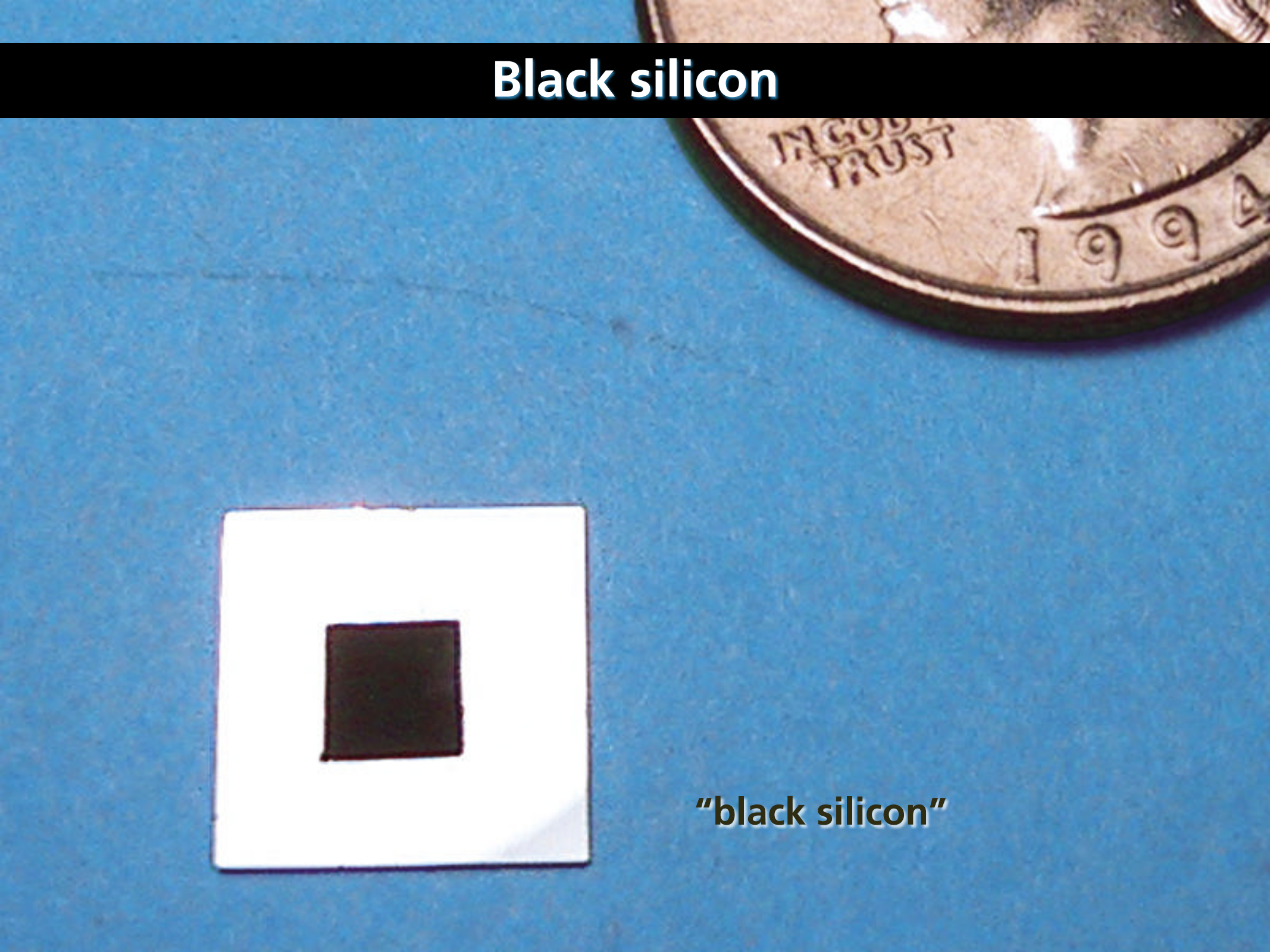


irradiate with 100-fs 10 kJ/m^2 pulses

Black silicon

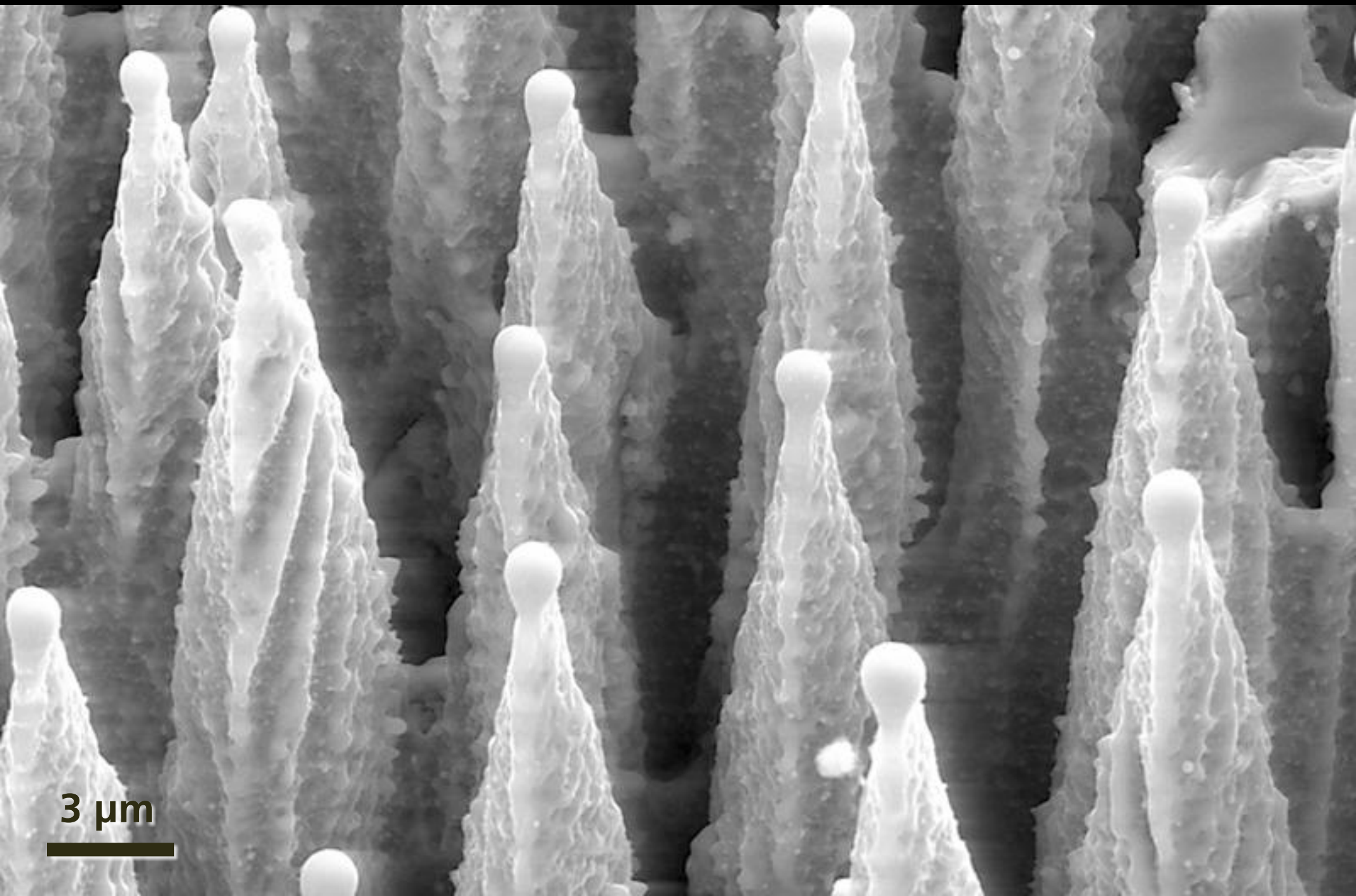


Black silicon

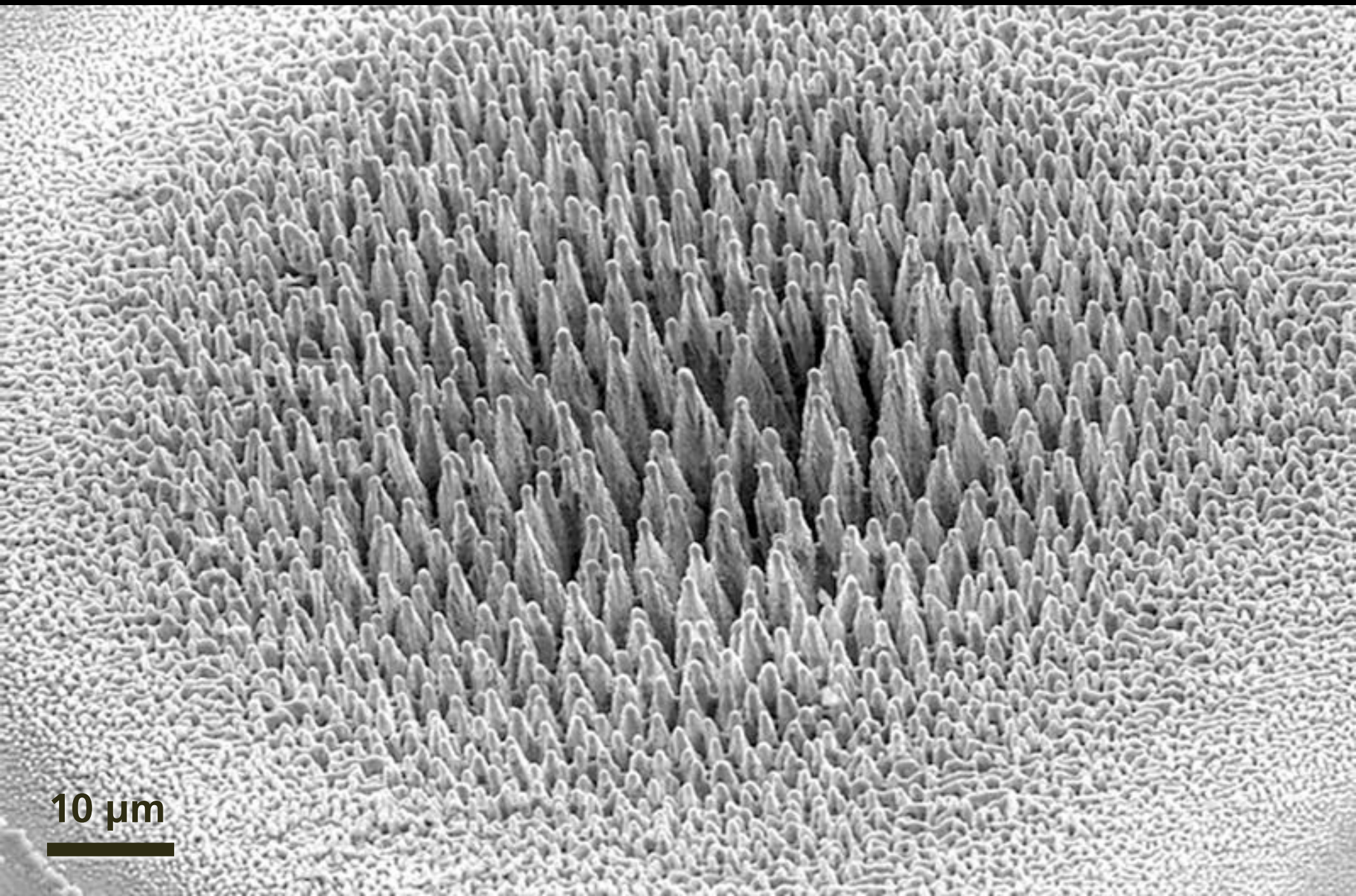


“black silicon”

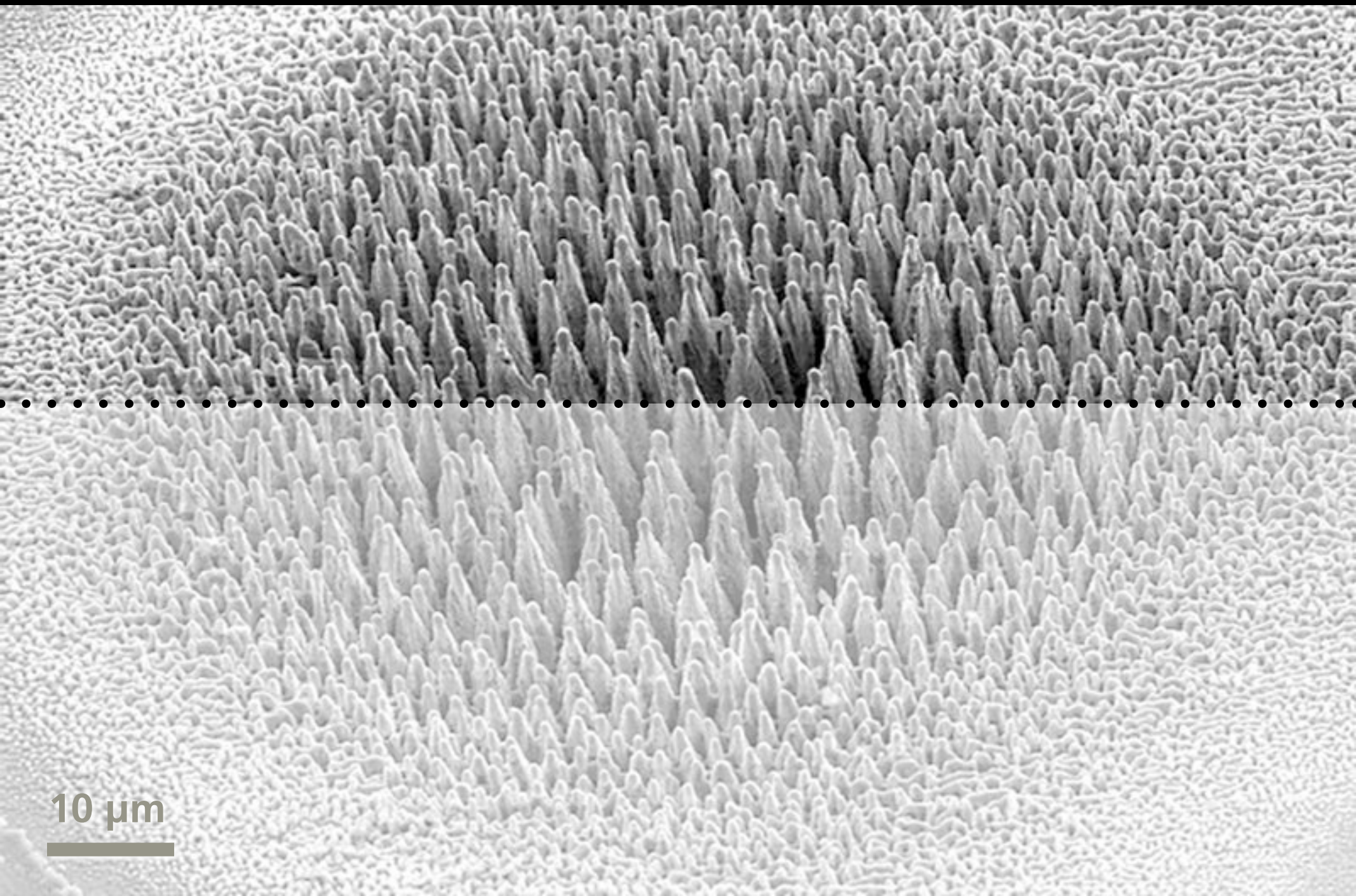
Black silicon



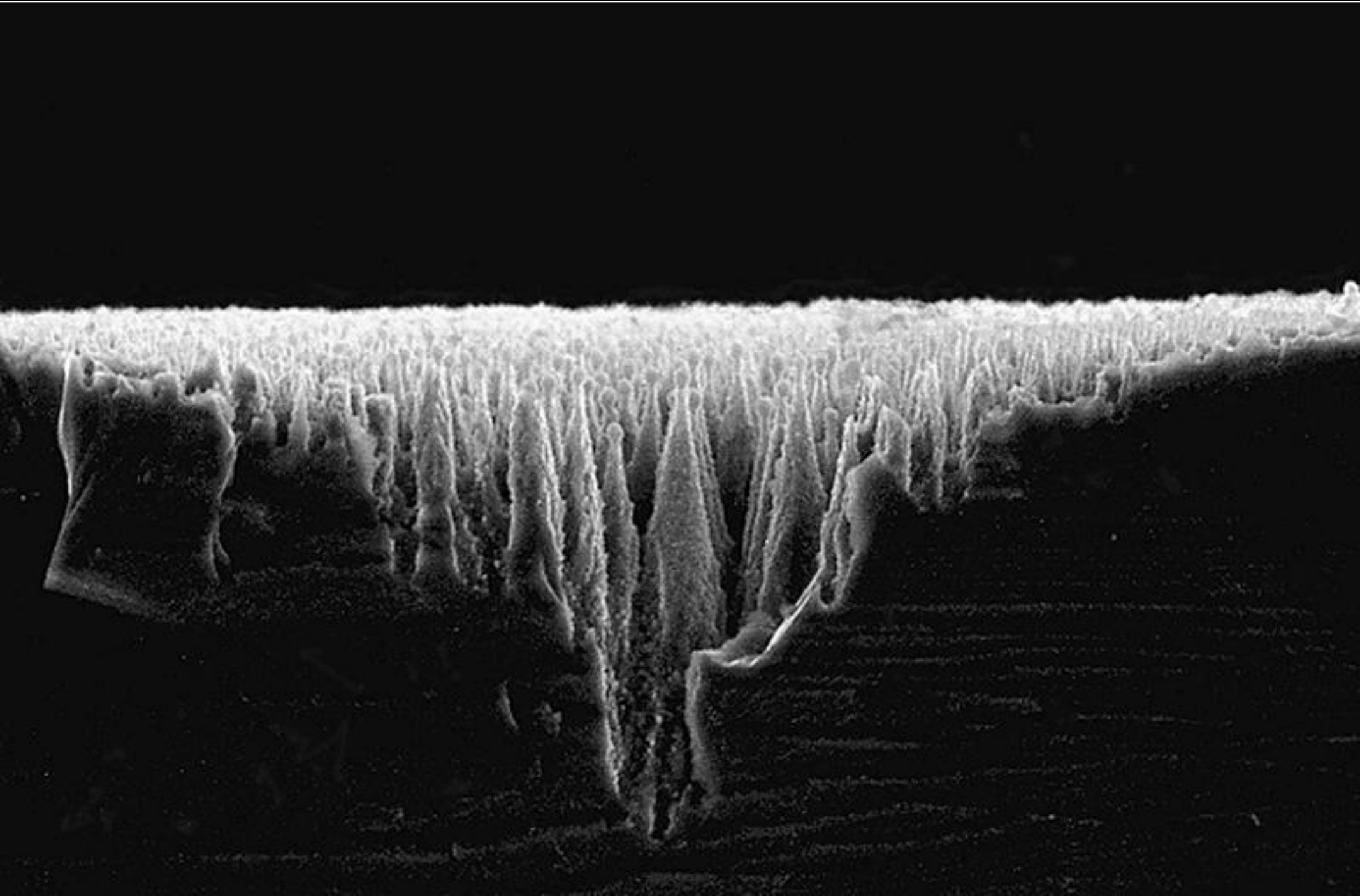
Black silicon



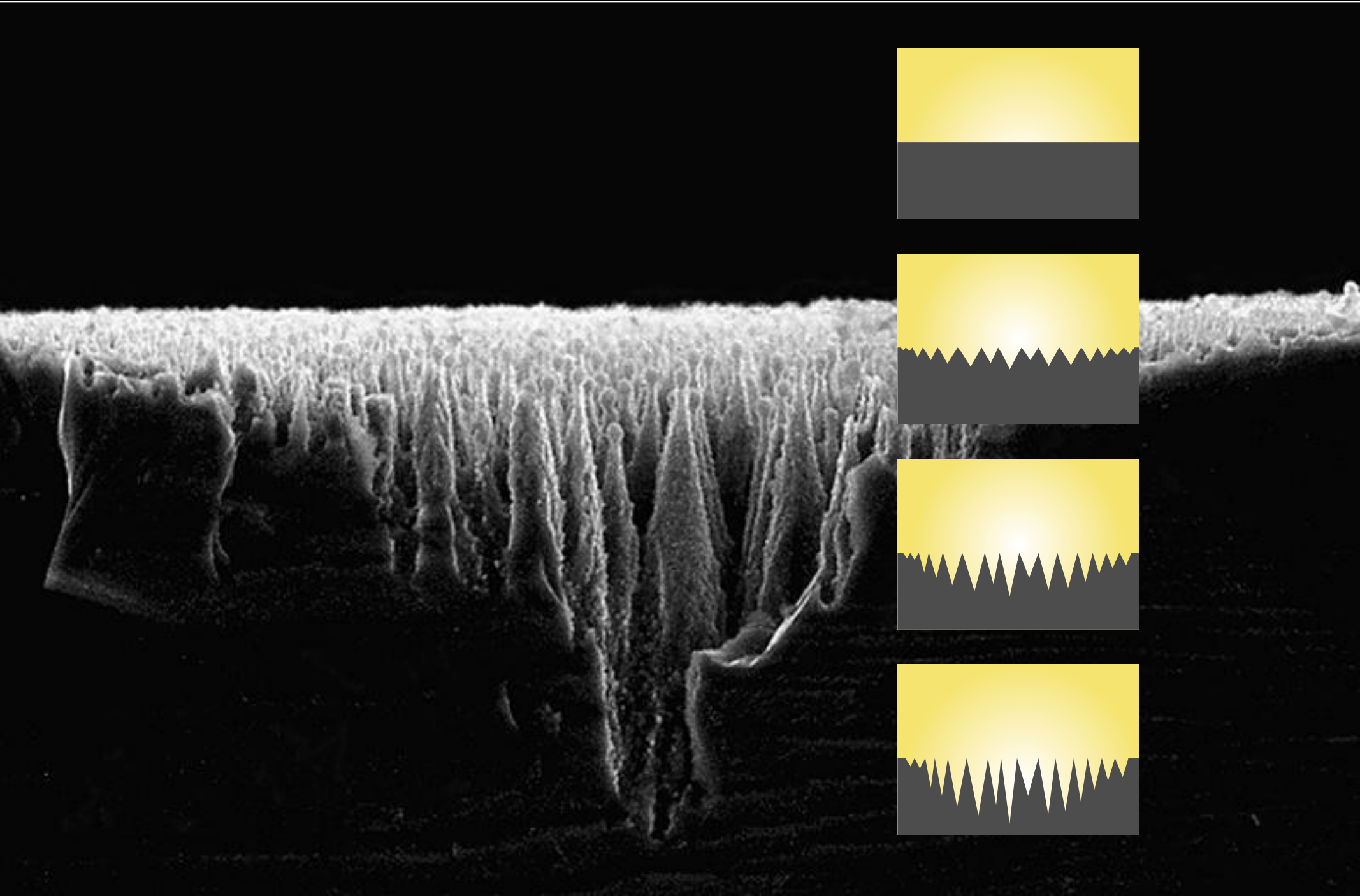
Black silicon



Black silicon

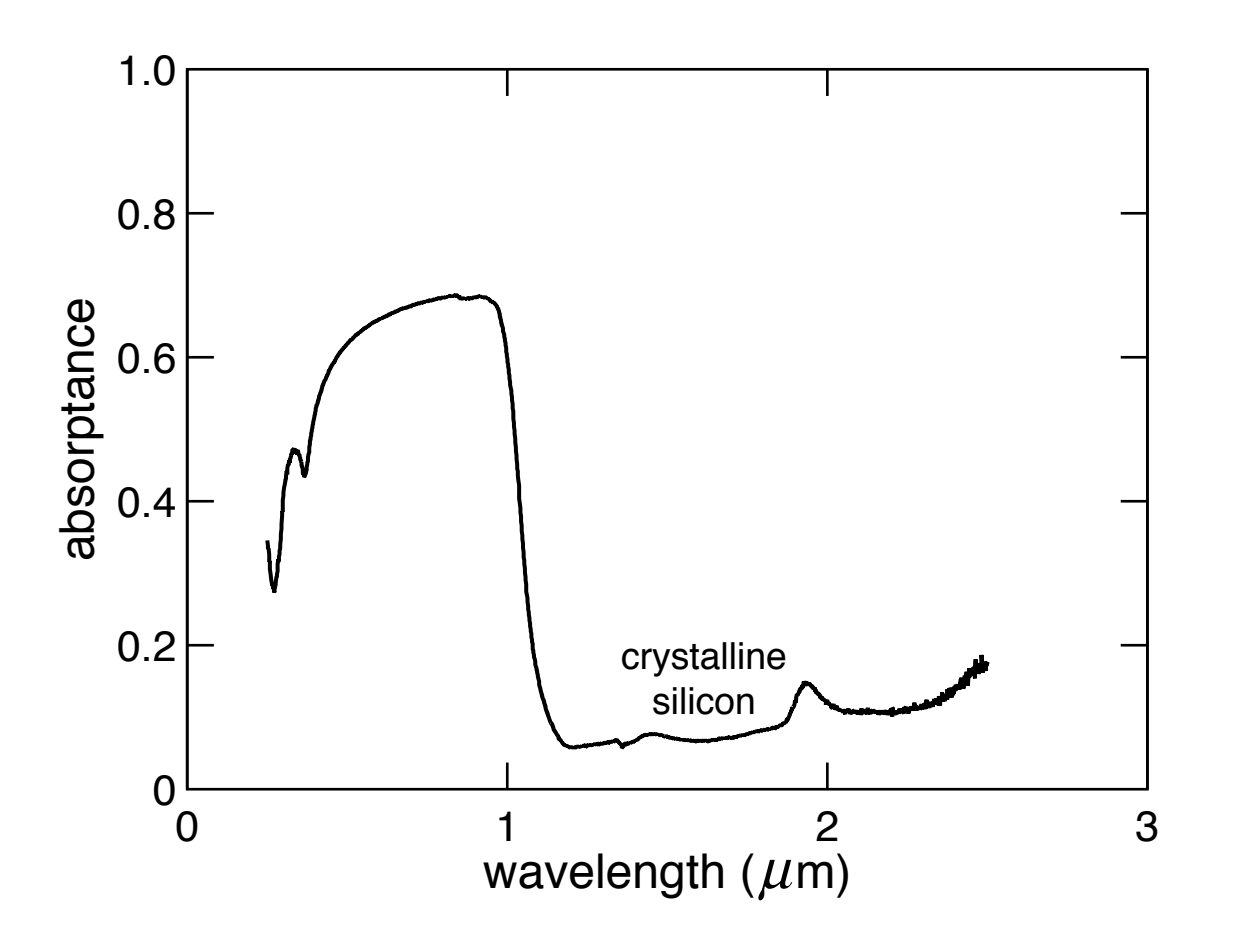


Black silicon



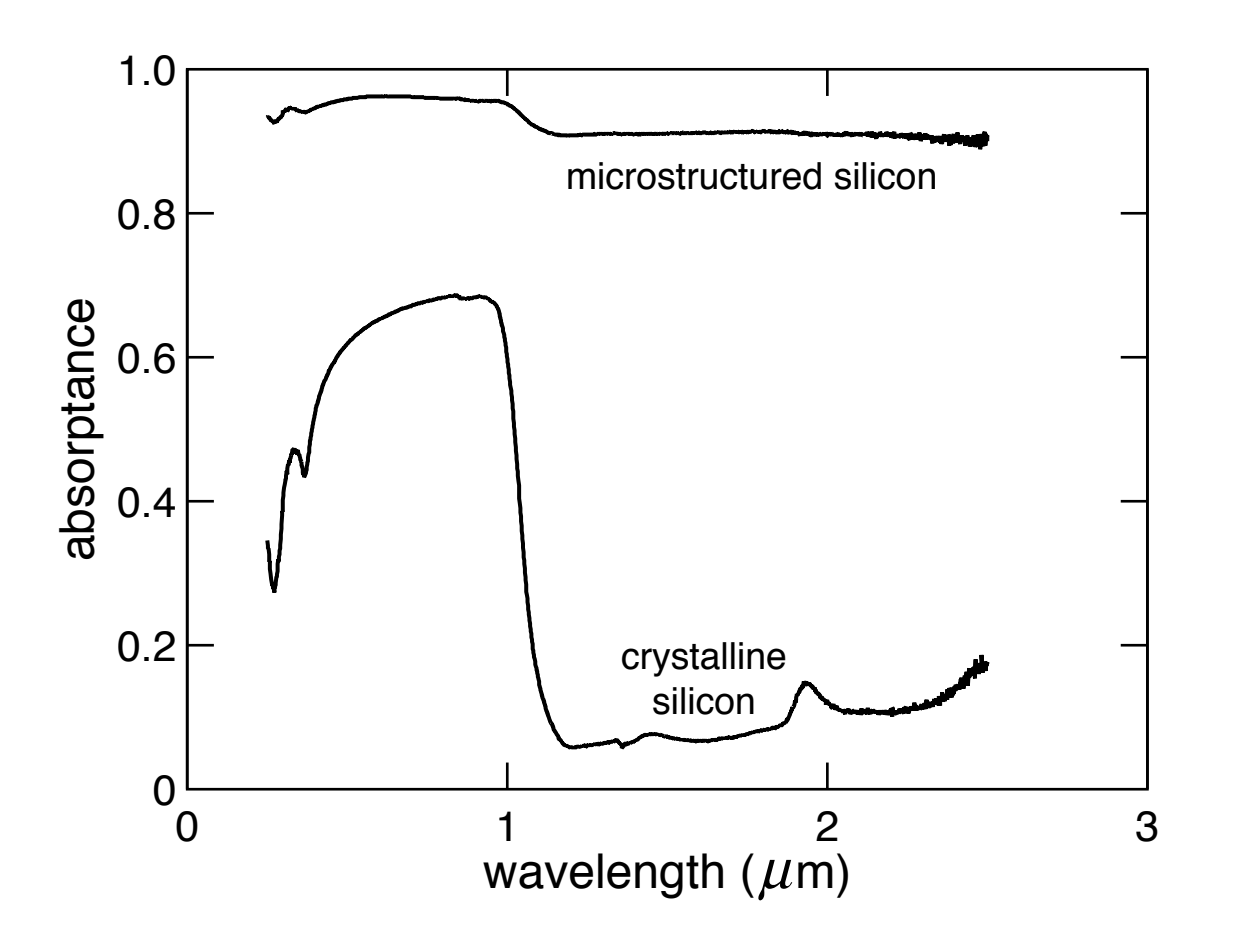
Black silicon

absorptance



Black silicon

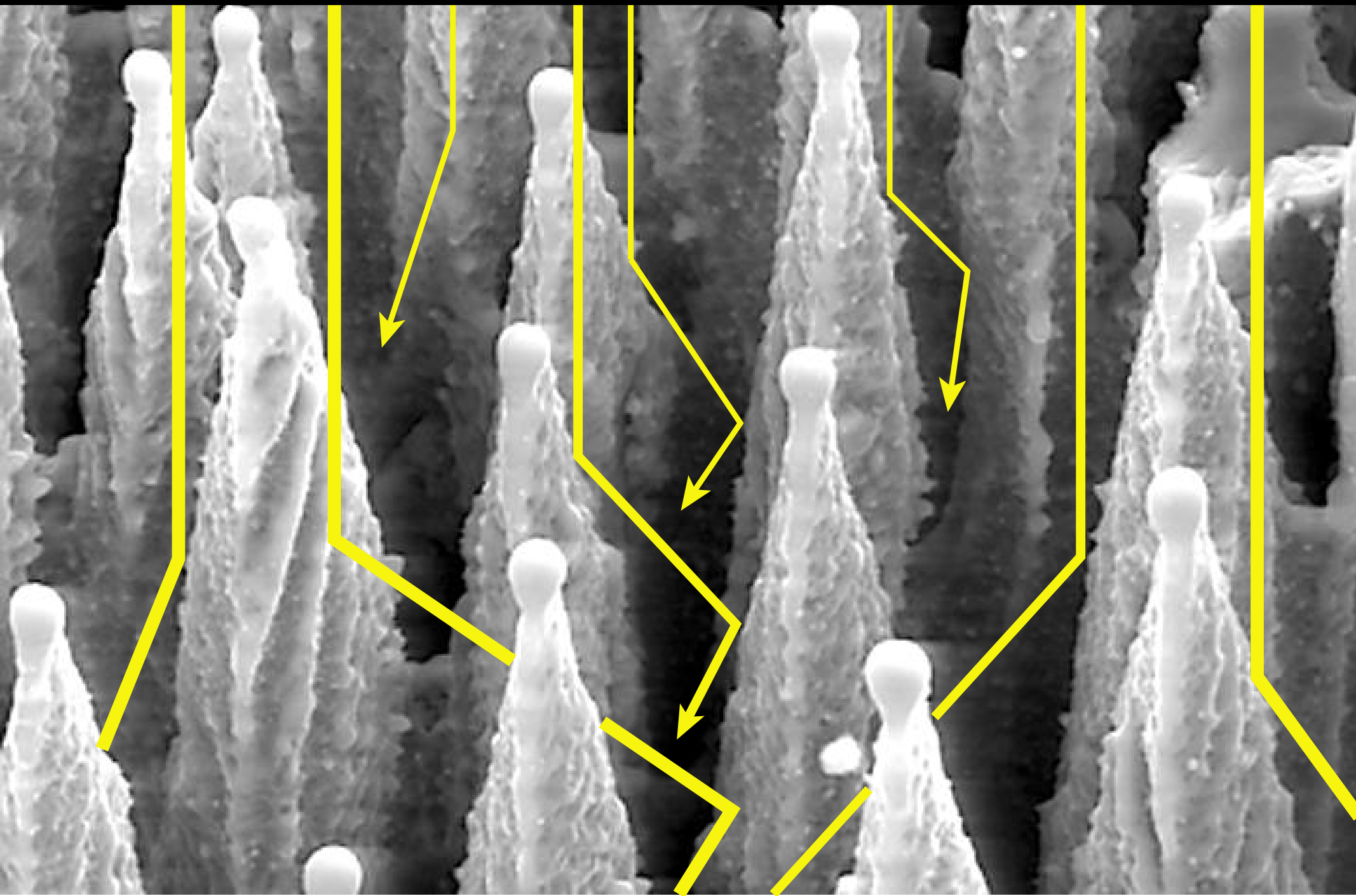
absorptance



Black silicon

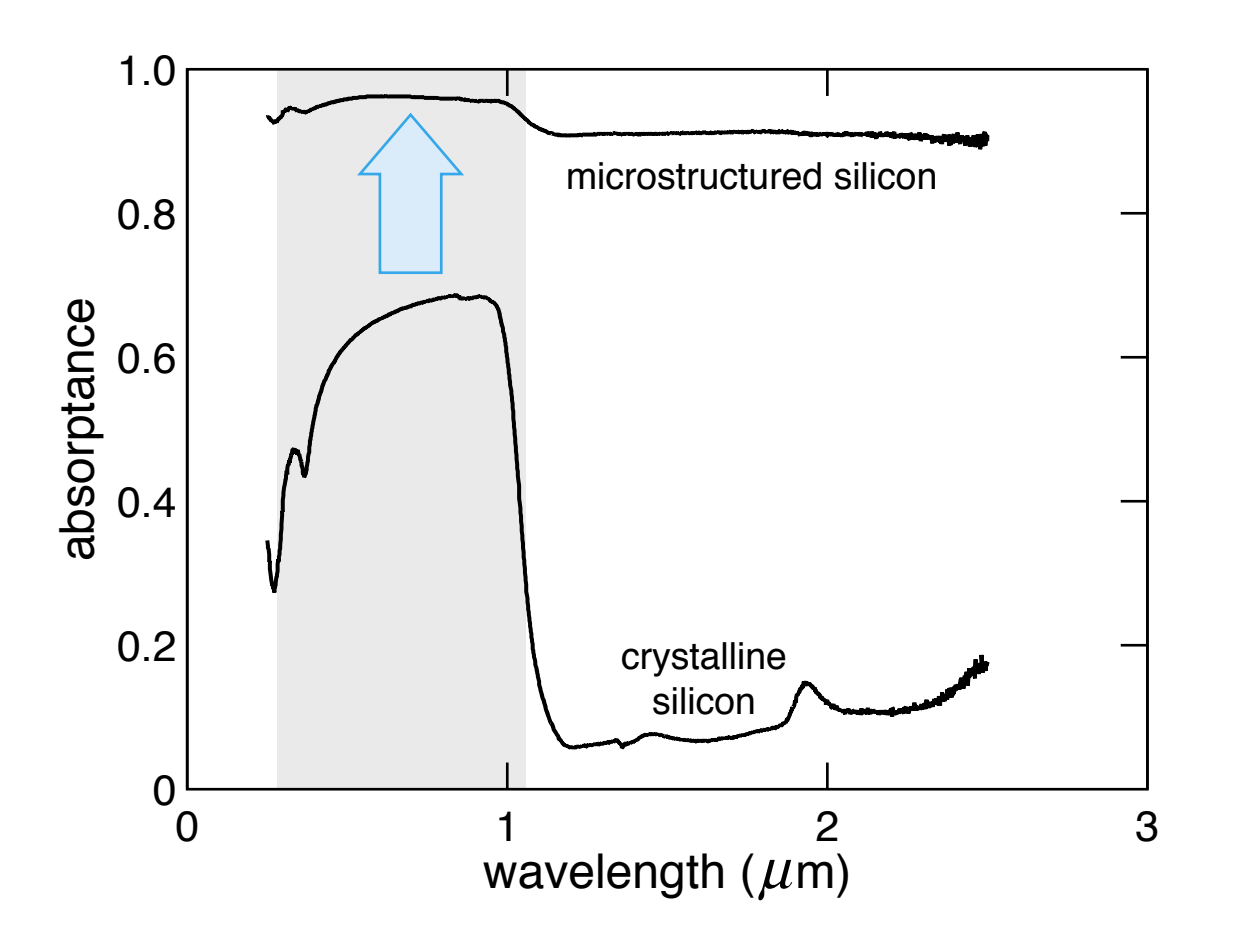
What causes the near-unity absorptance?

Black silicon



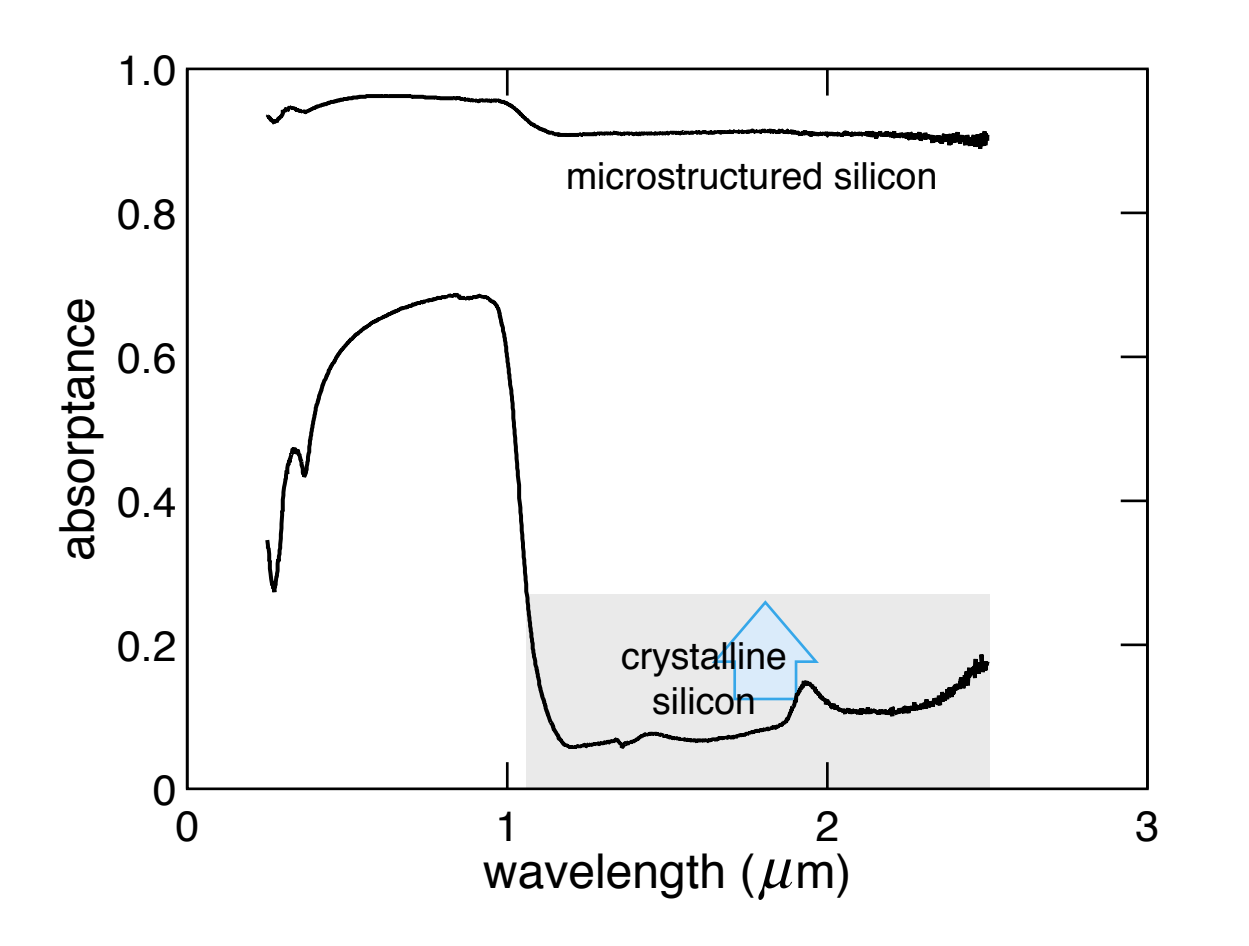
Black silicon

multiple reflections enhance absorption



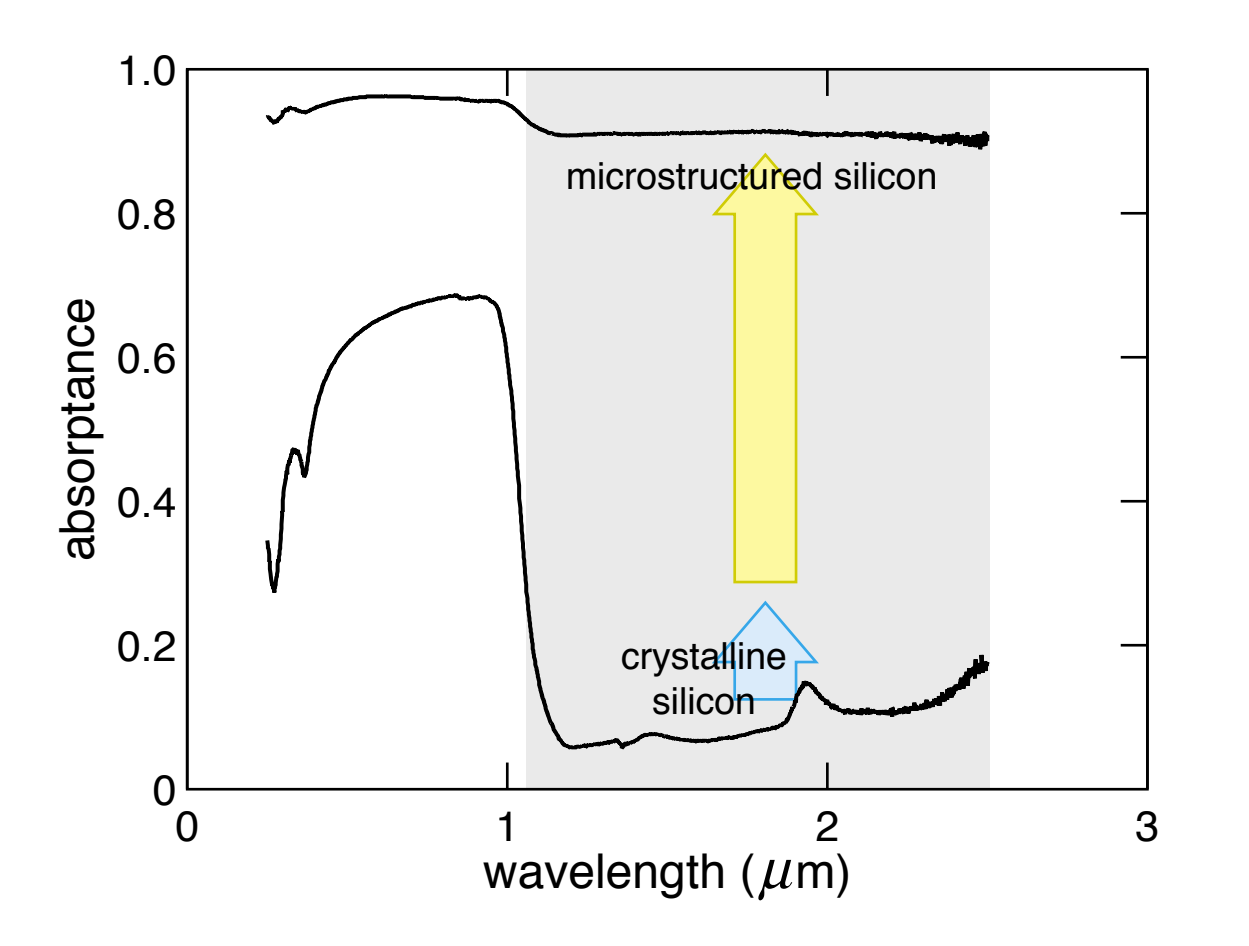
Black silicon

multiple reflections enhance absorption

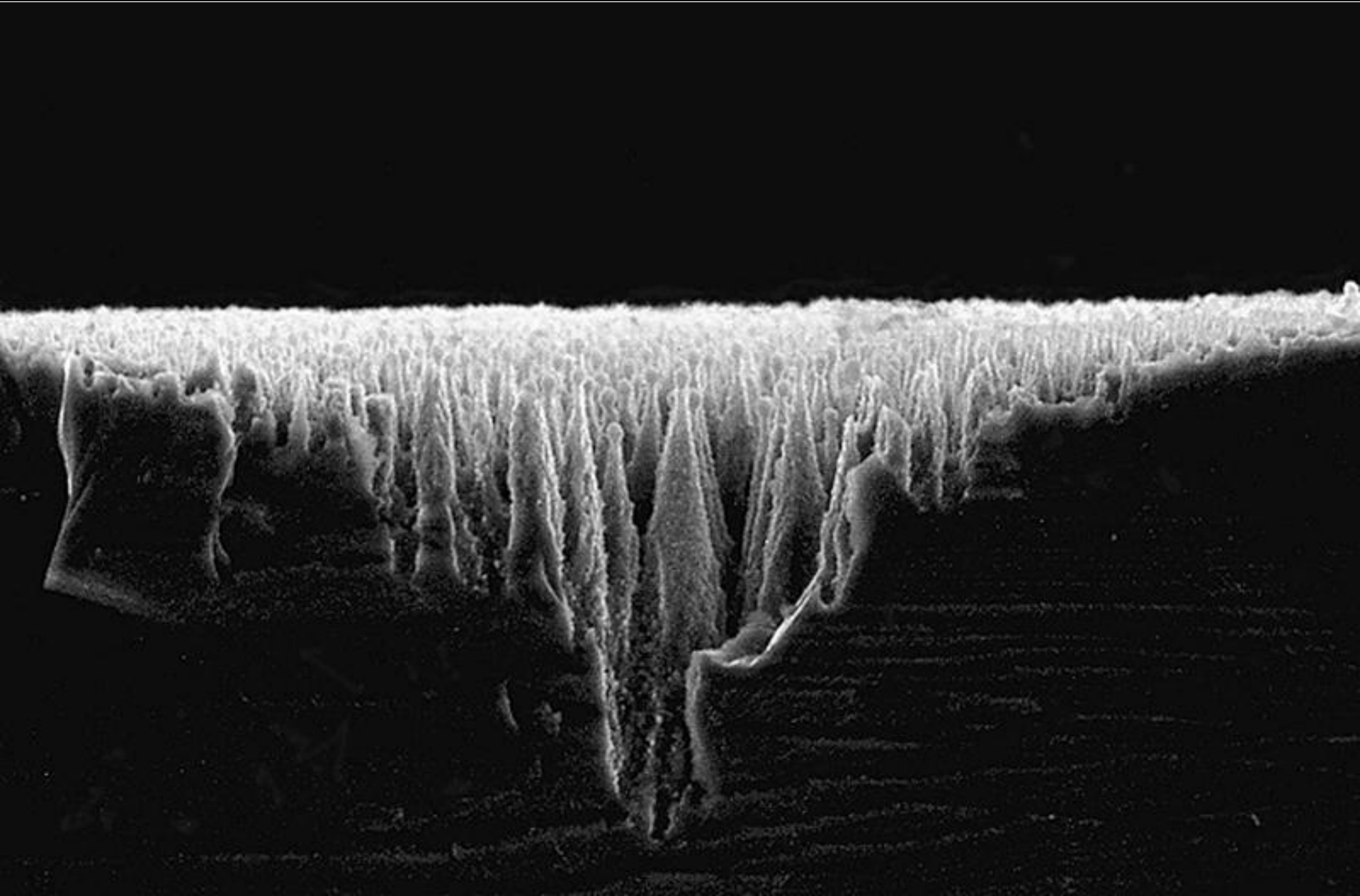


Black silicon

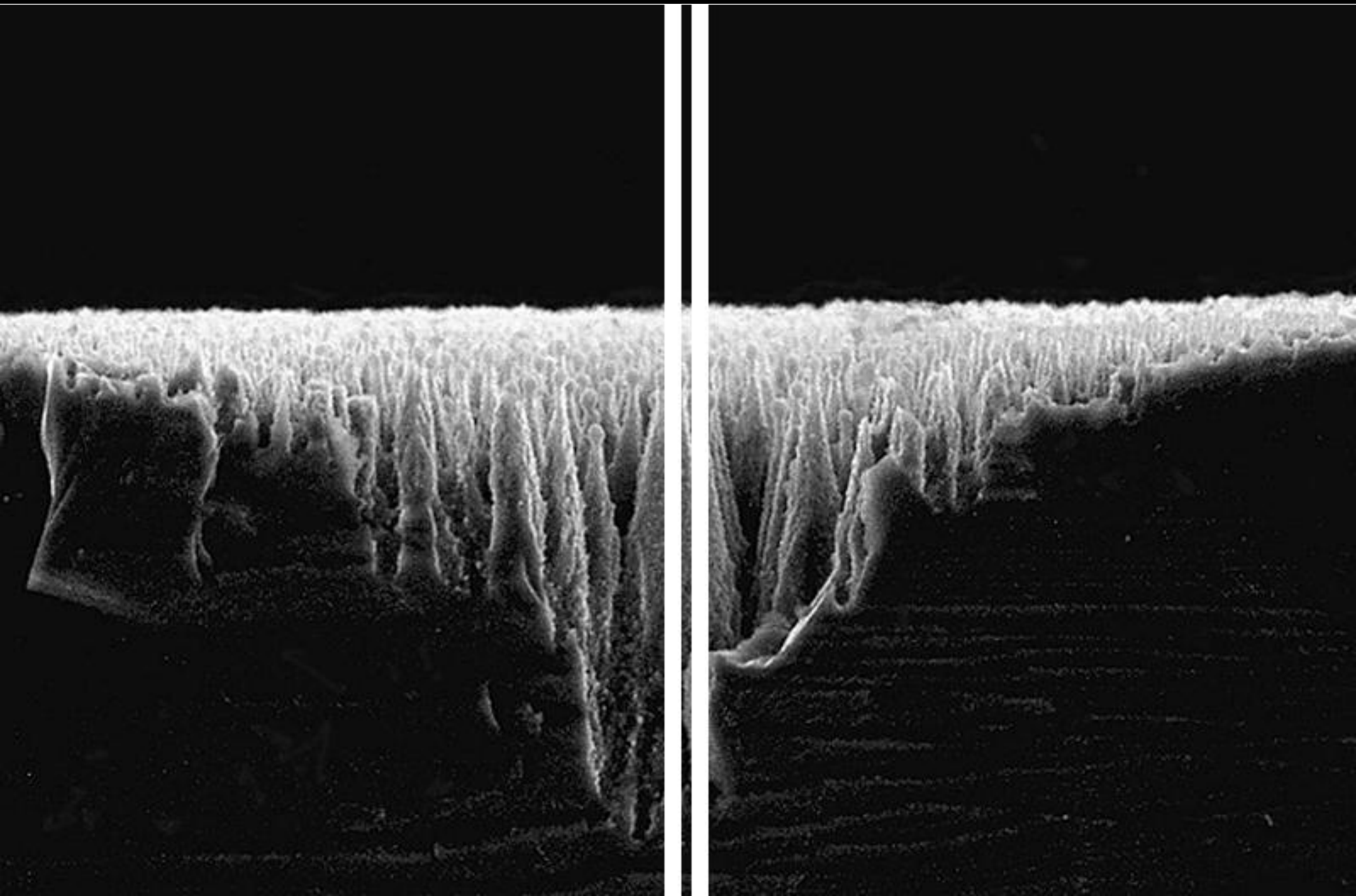
heavy sulfur doping causes infrared absorption



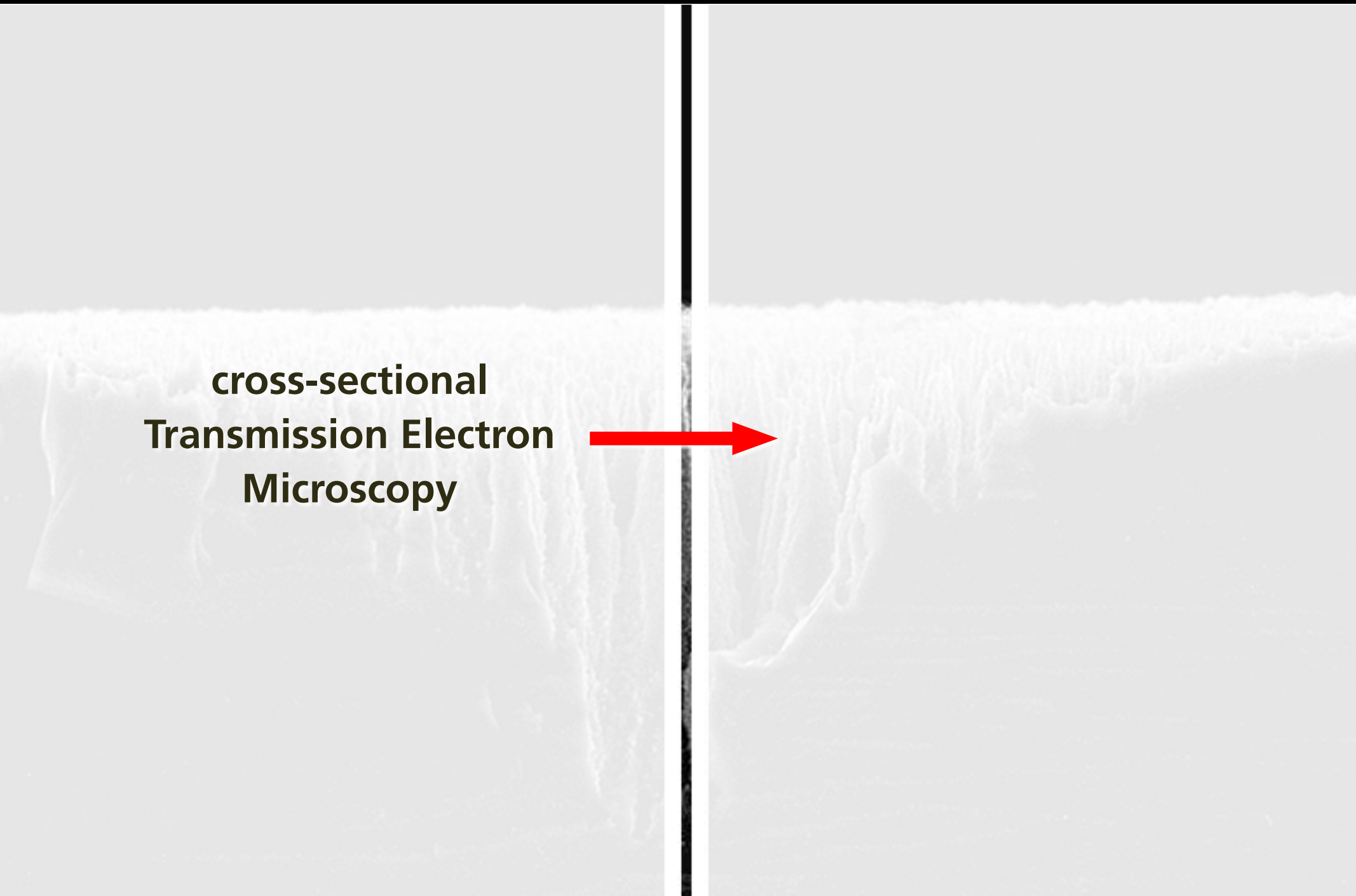
Black silicon



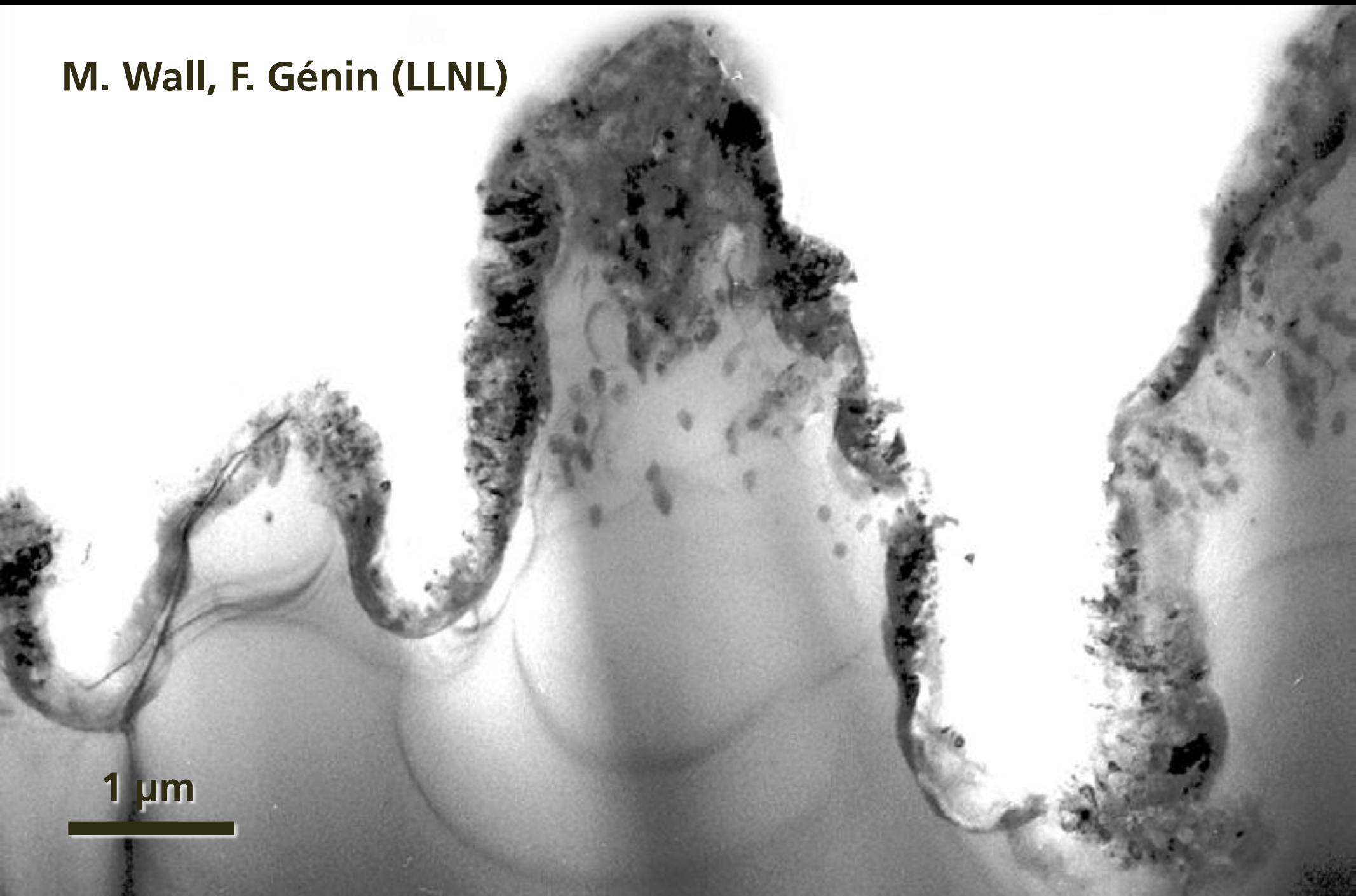
Black silicon



Black silicon



Black silicon



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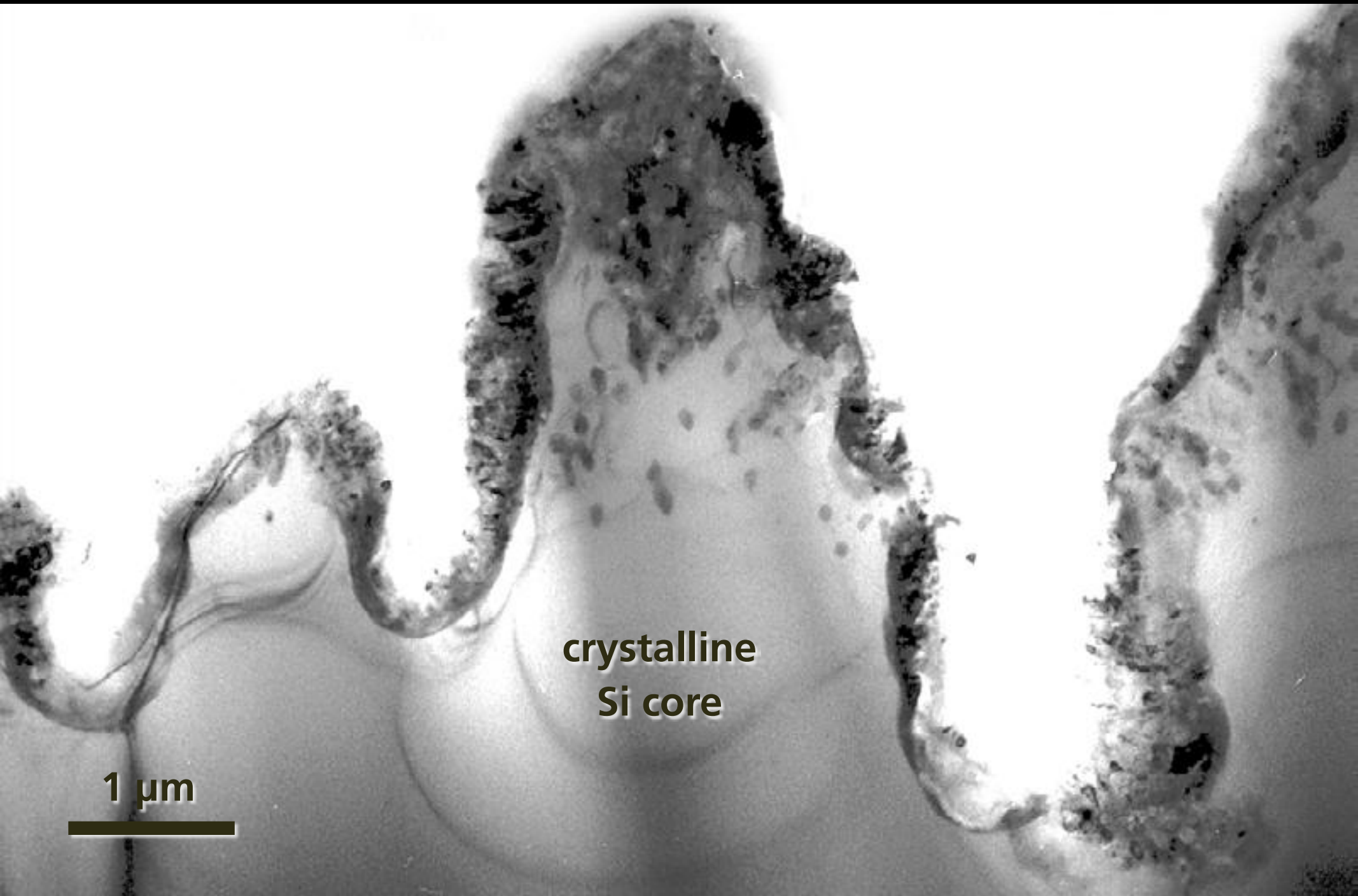
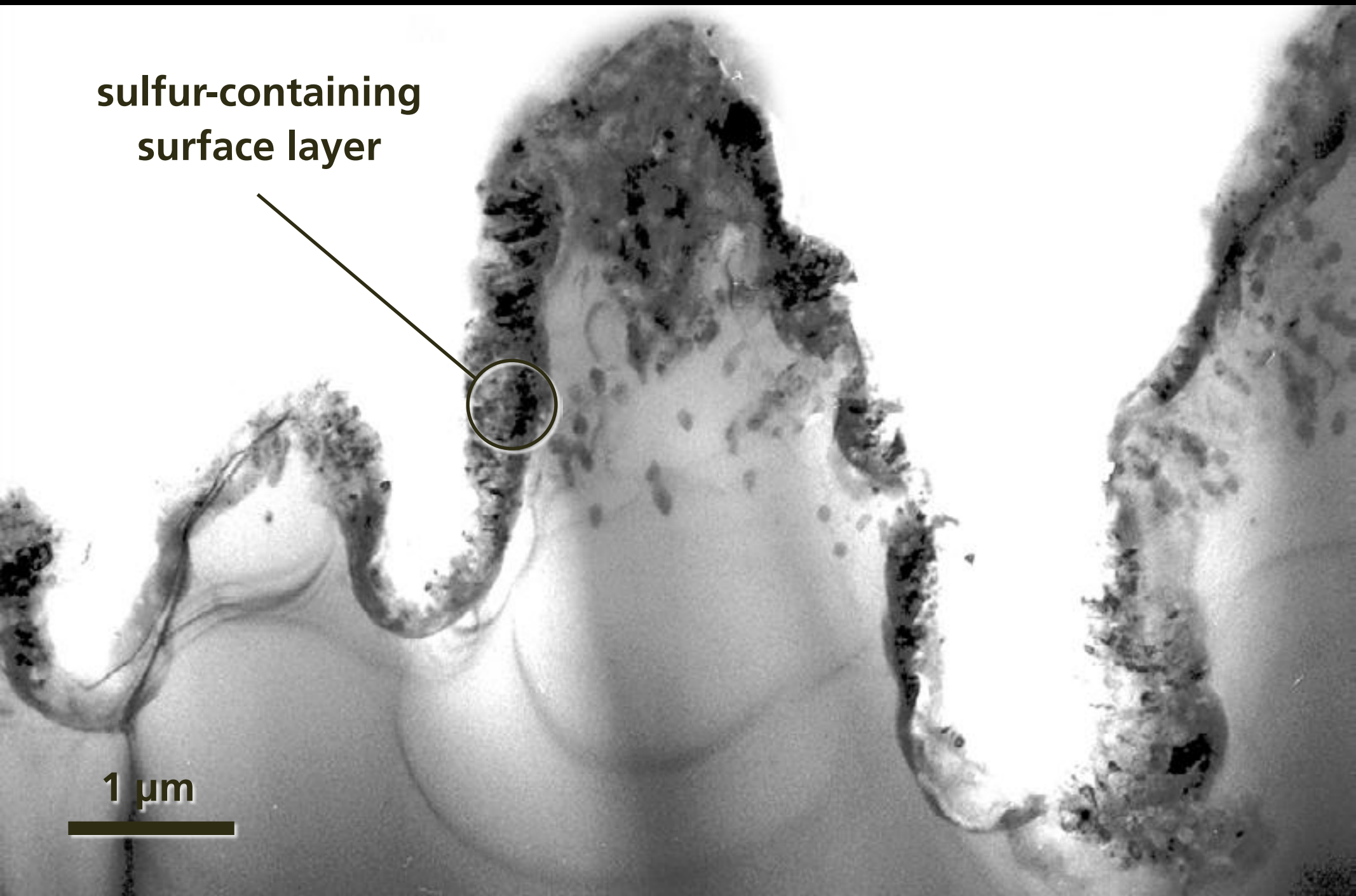
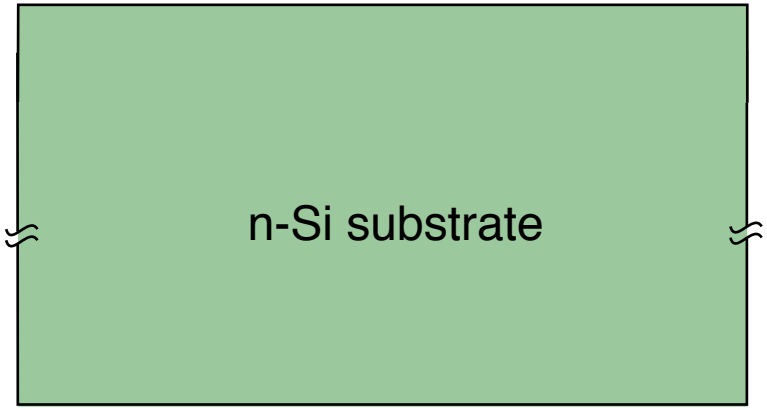


Black silicon



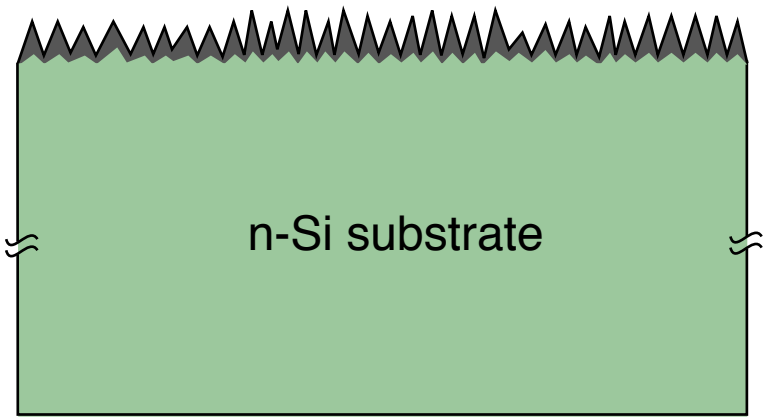
Black silicon

black silicon/n-type silicon junction



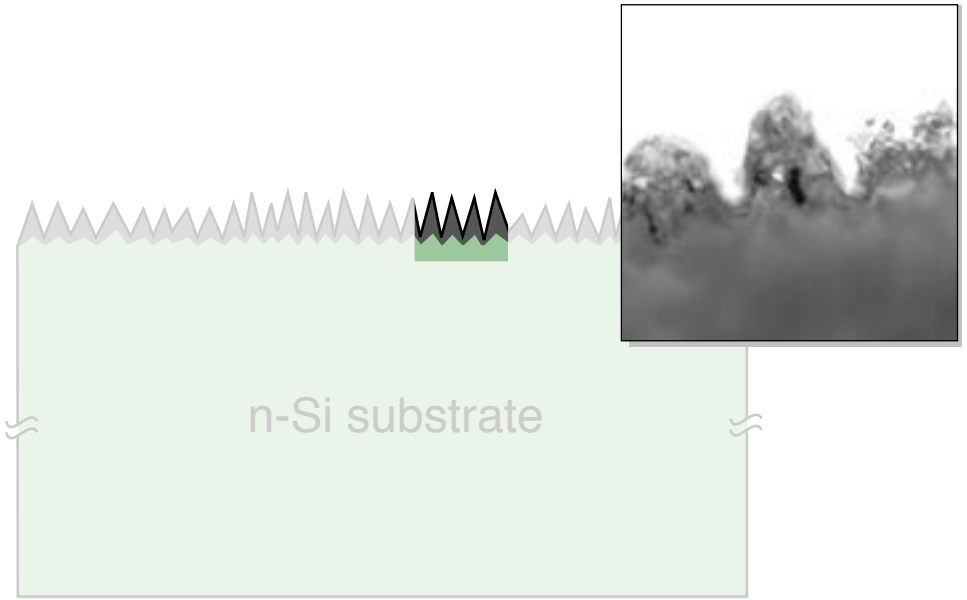
Black silicon

black silicon/n-type silicon junction



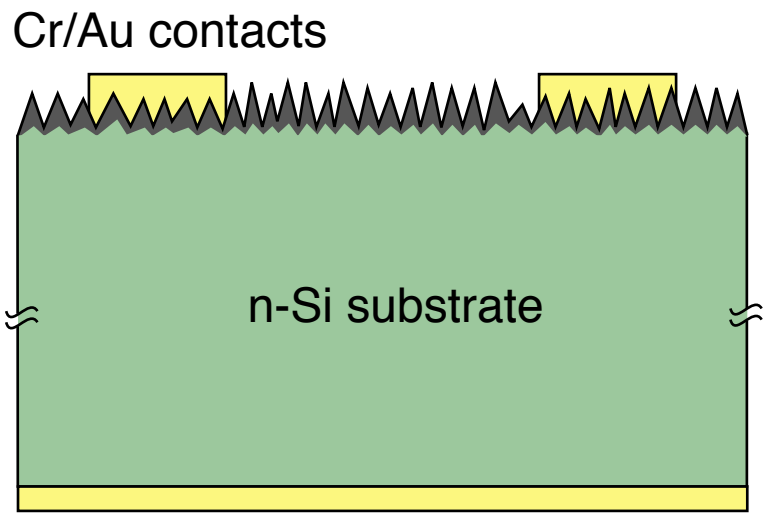
Black silicon

black silicon/n-type silicon junction



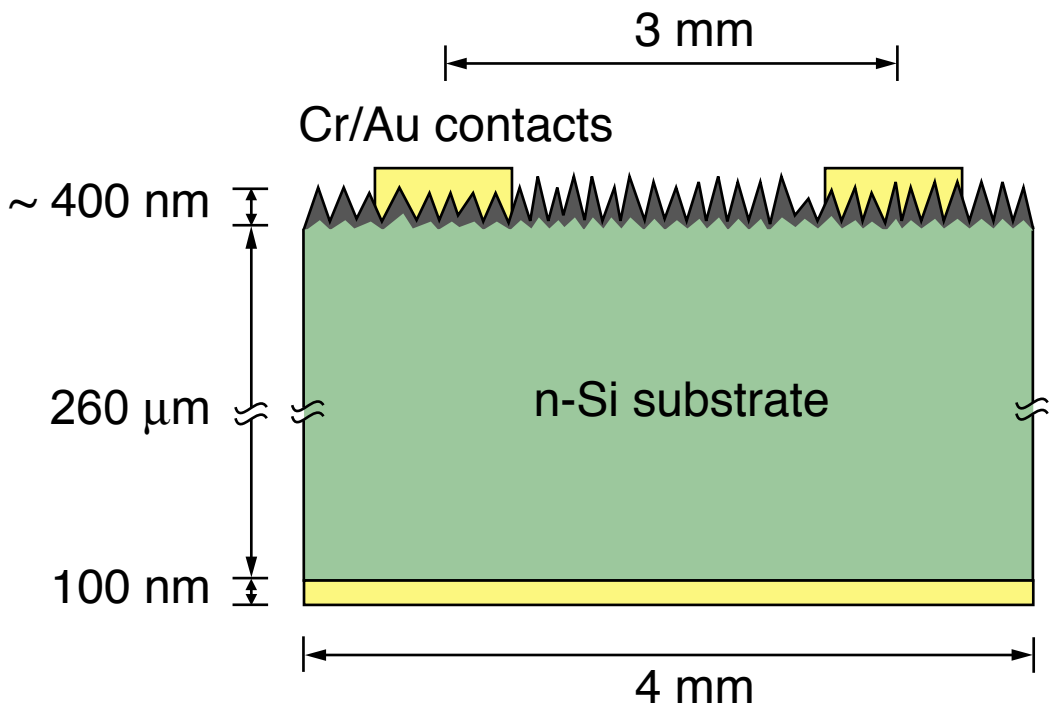
Black silicon

black silicon/n-type silicon junction



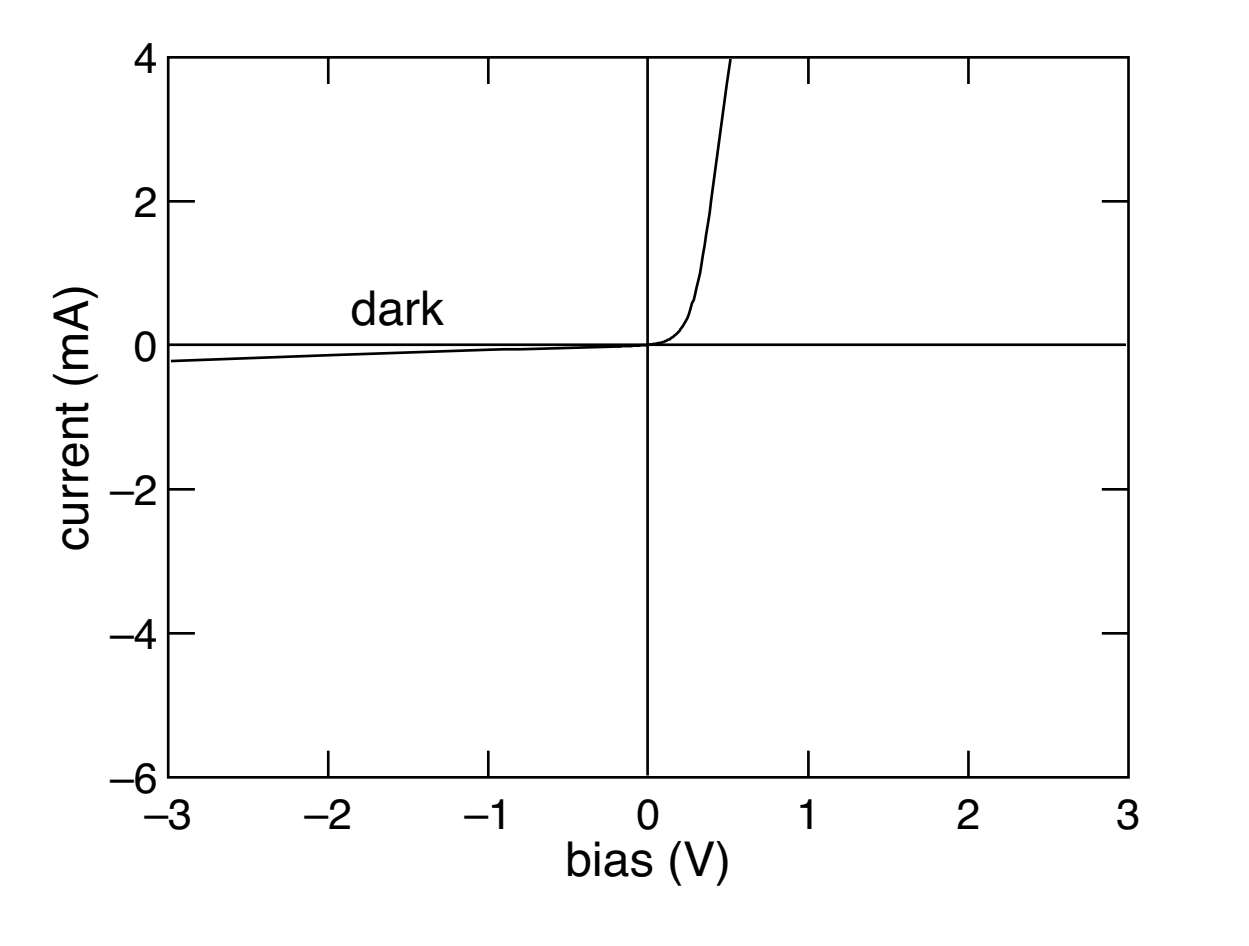
Black silicon

black silicon/n-type silicon junction



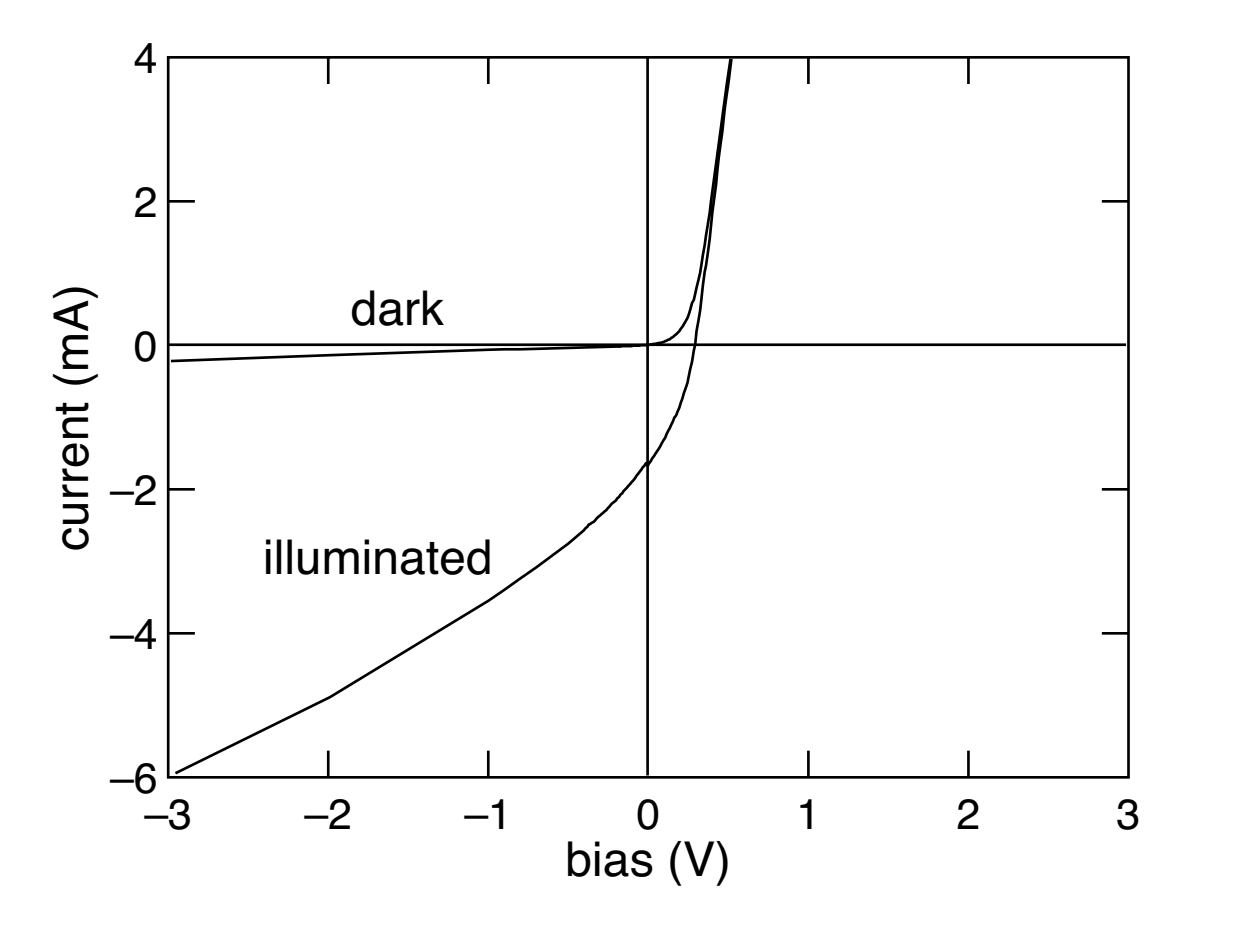
Black silicon

IV characteristics



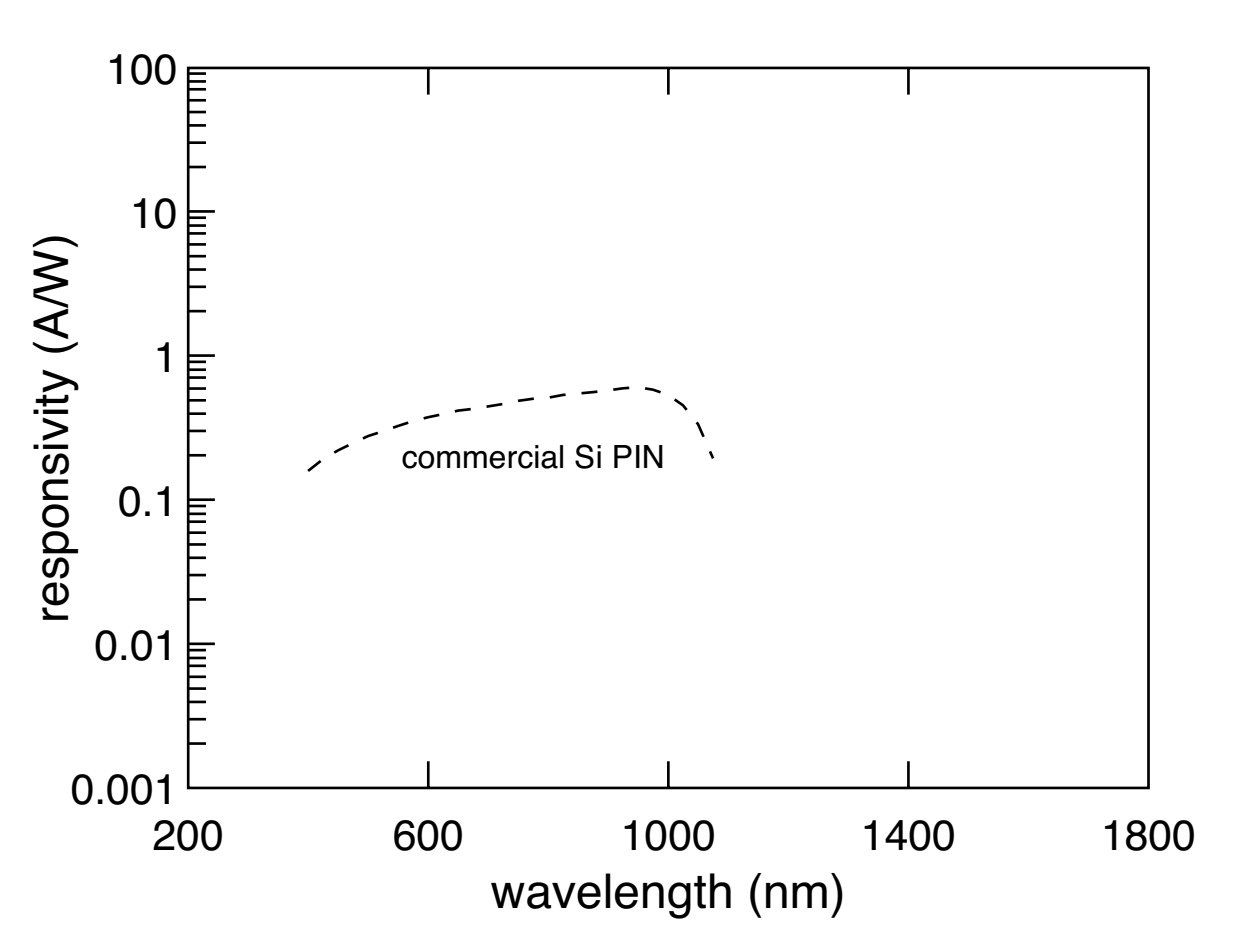
Black silicon

IV characteristics



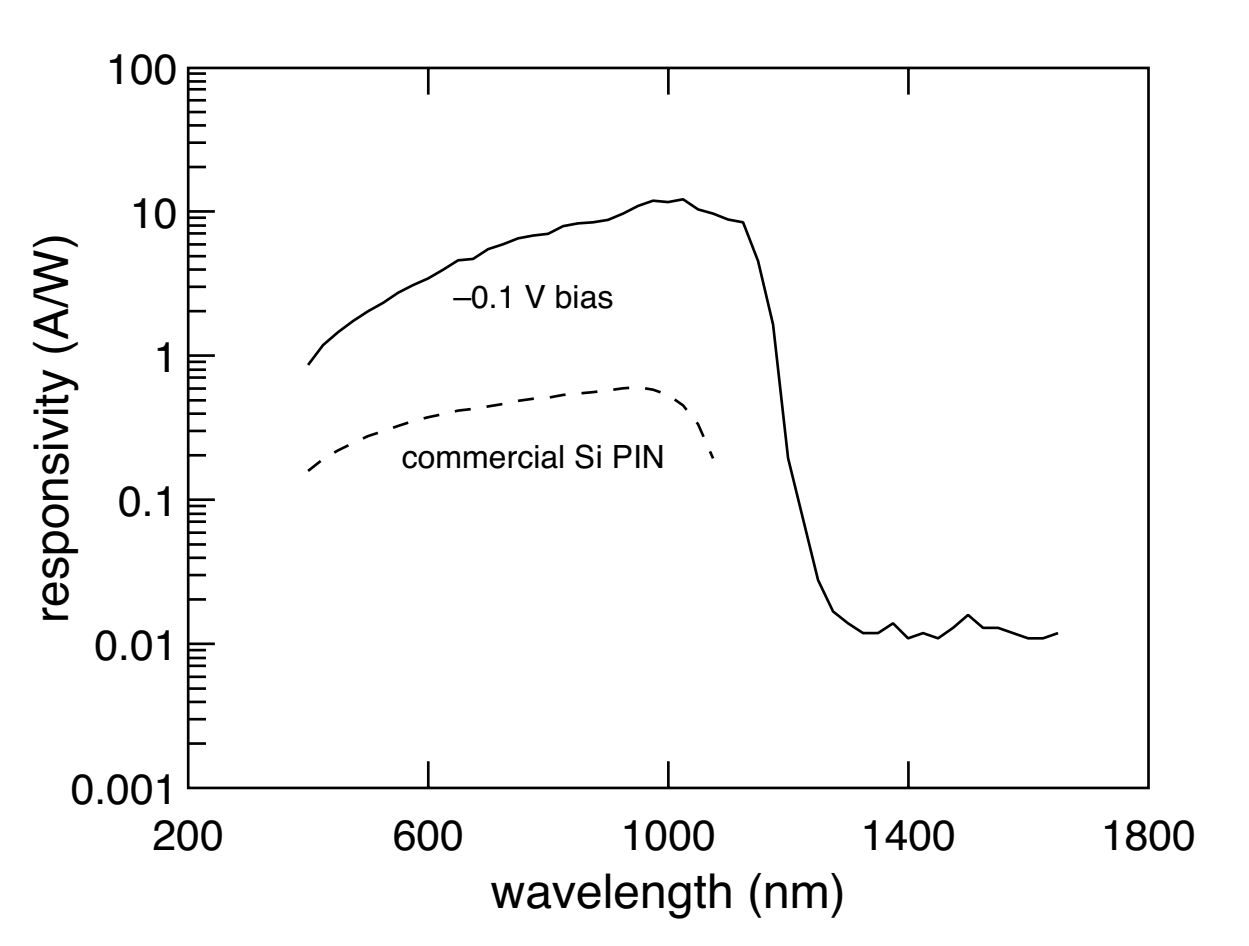
Black silicon

responsivity



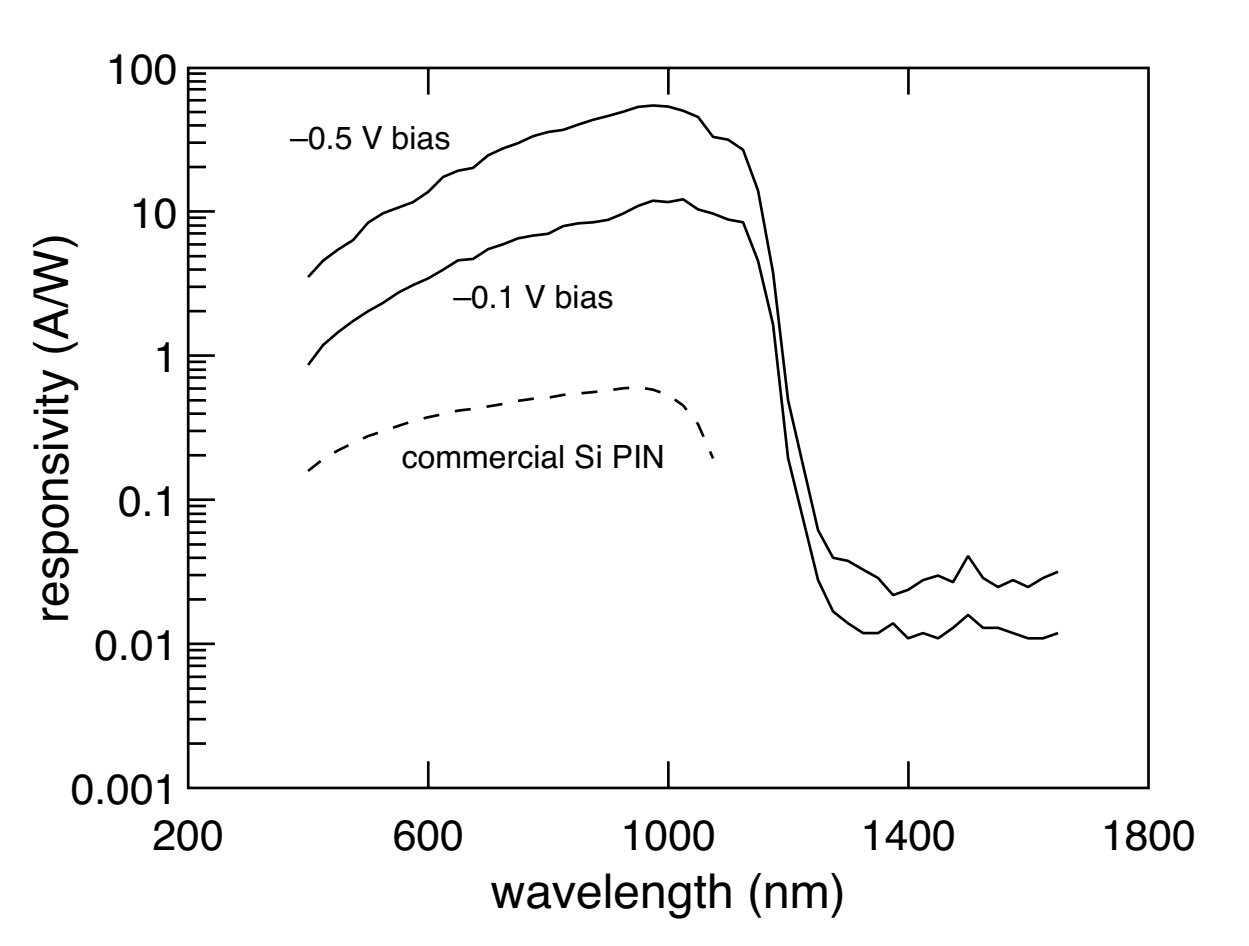
Black silicon

responsivity

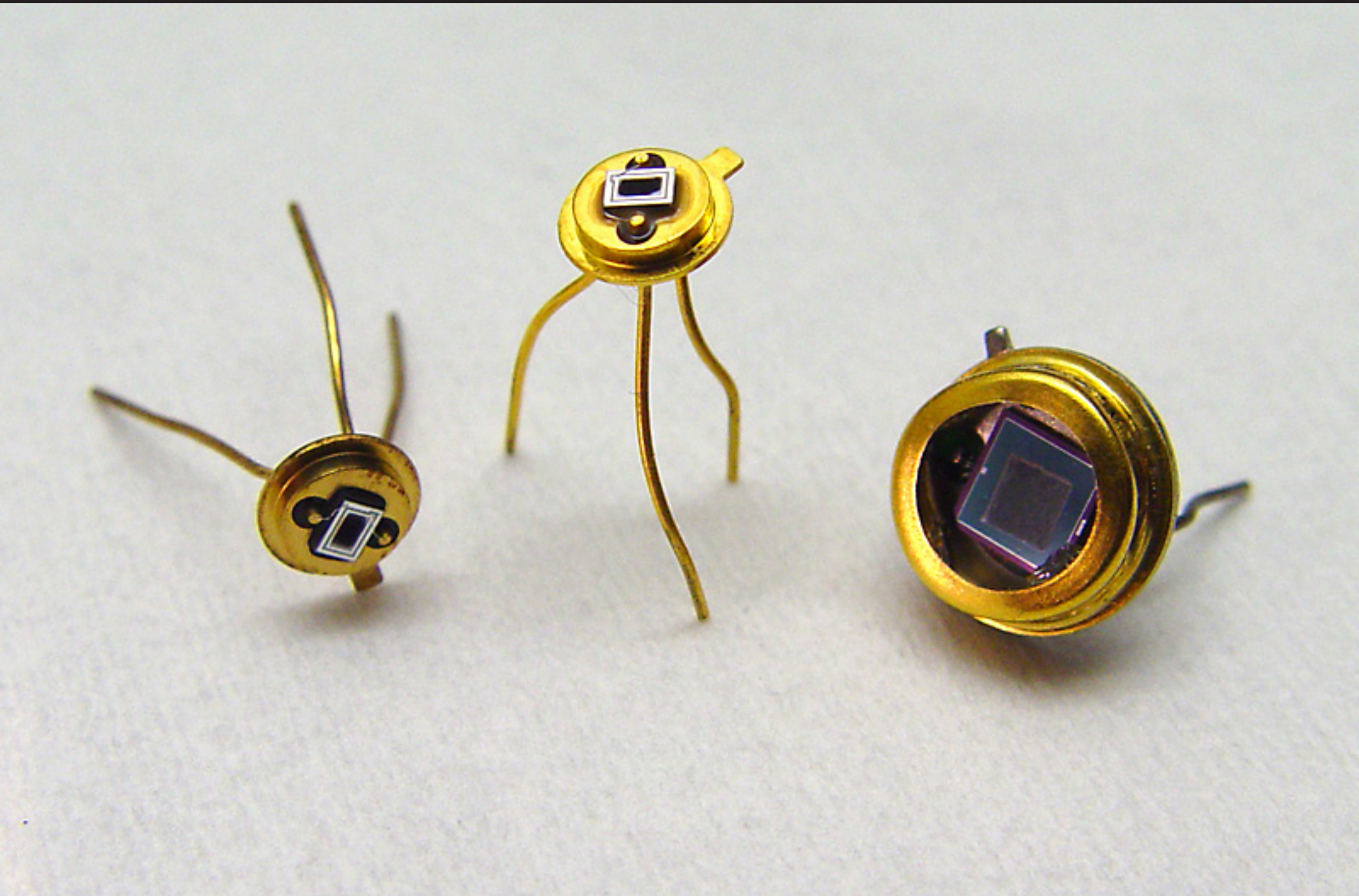


Black silicon

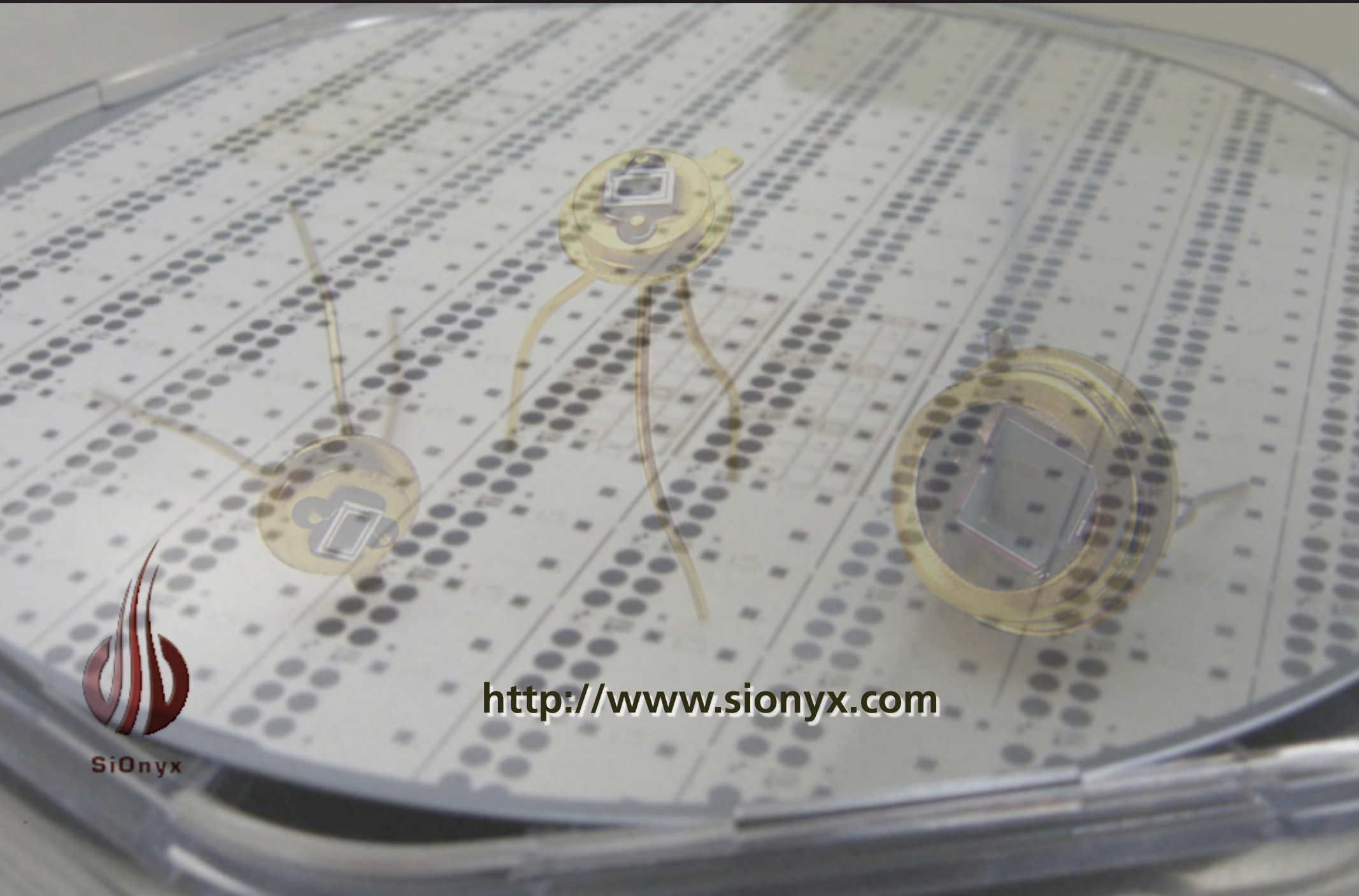
responsivity



Devices



Devices



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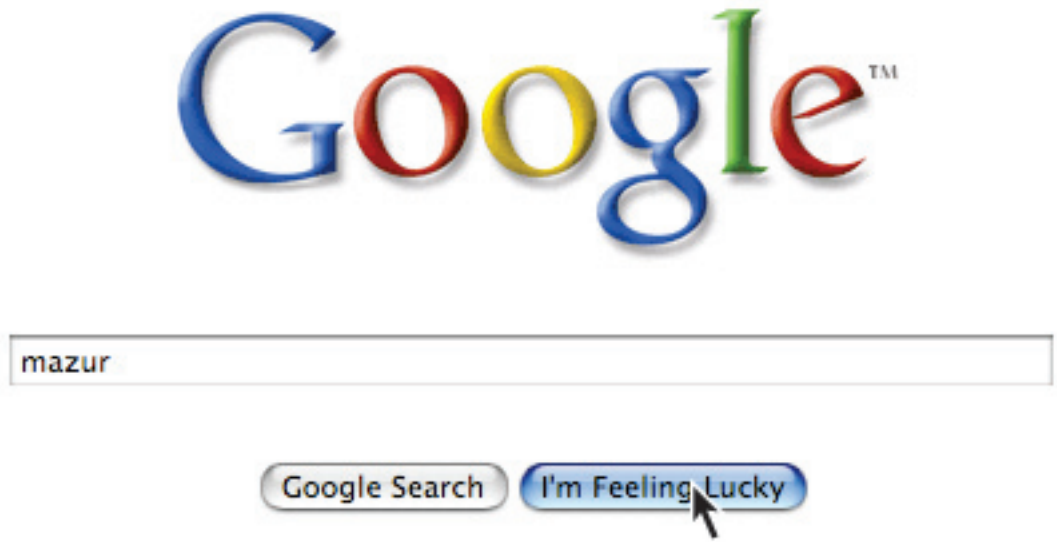
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