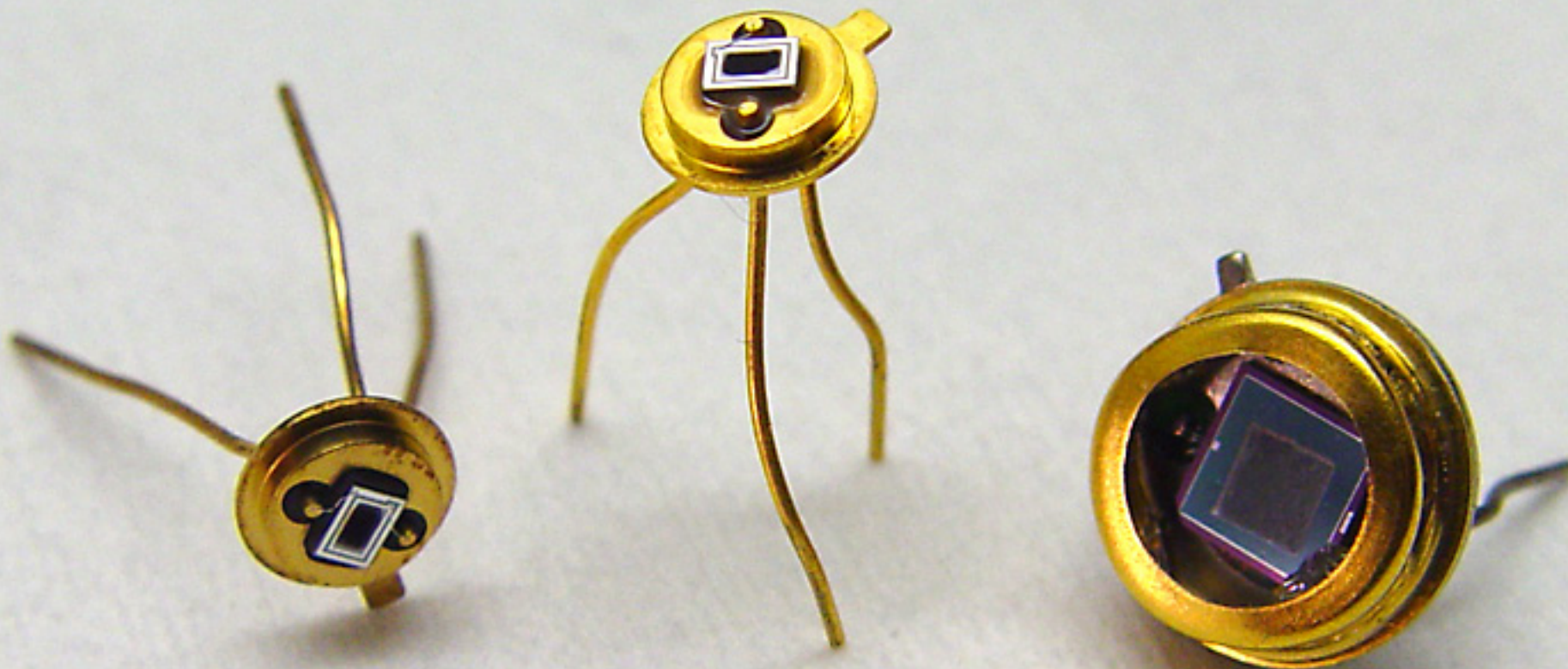


Pushing a physics discovery towards commercial impact

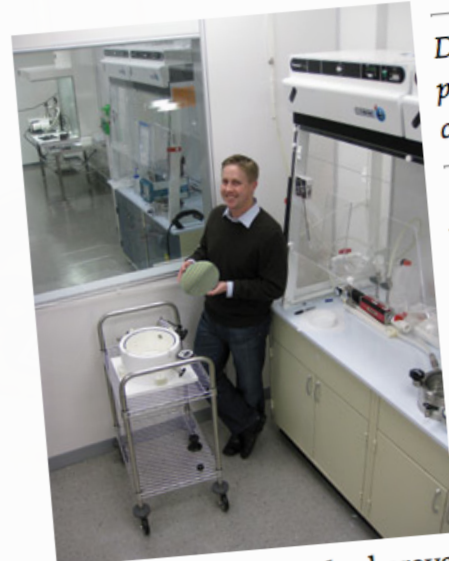


APS March meeting
Boston, MA, 1 March 2012



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.

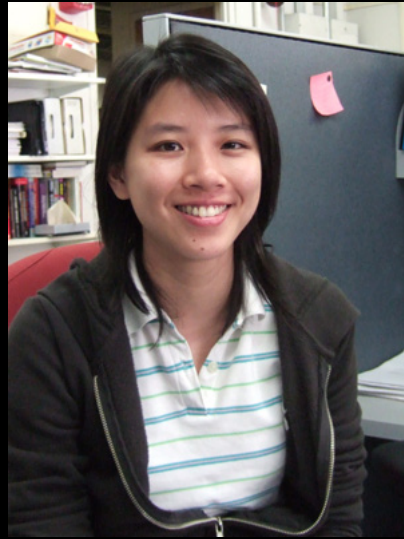
I recently sat down with Stephen D. Saylor, CEO of SiOnyx, and Dr. James E. Carey, its co-founder and principal scientist, at the company's headquarters in Beverly, Mass., which is about 20 miles northeast of Boston.

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

and also....

**Marc Winkler
Eric Diebold
Haifei Albert Zhang
William Whitney
Dr. Brian Tull
Dr. Jim Carey
Prof. Tsing-Hua Her
Dr. Shrenik Deliwala
Dr. Richard Finlay
Dr. Michael Sheehy
Dr. Claudia Wu
Dr. Rebecca Younkin
Prof. Catherine Crouch
Prof. Mengyan Shen
Prof. Li Zhao

Dr. John Chervinsky
Dr. Joshua Levinson

Prof. Michael Aziz
Prof. Cynthia Friend
Prof. Howard Stone**

**Prof. Tonio Buonassisi (MIT)
Prof. Silvija Gradecak (MIT)
Dr. Bonna Newman (MIT)
Joe Sullivan (MIT)
Matthew Smith (MIT)

Prof. Augustinus Asenbaum (Vienna)

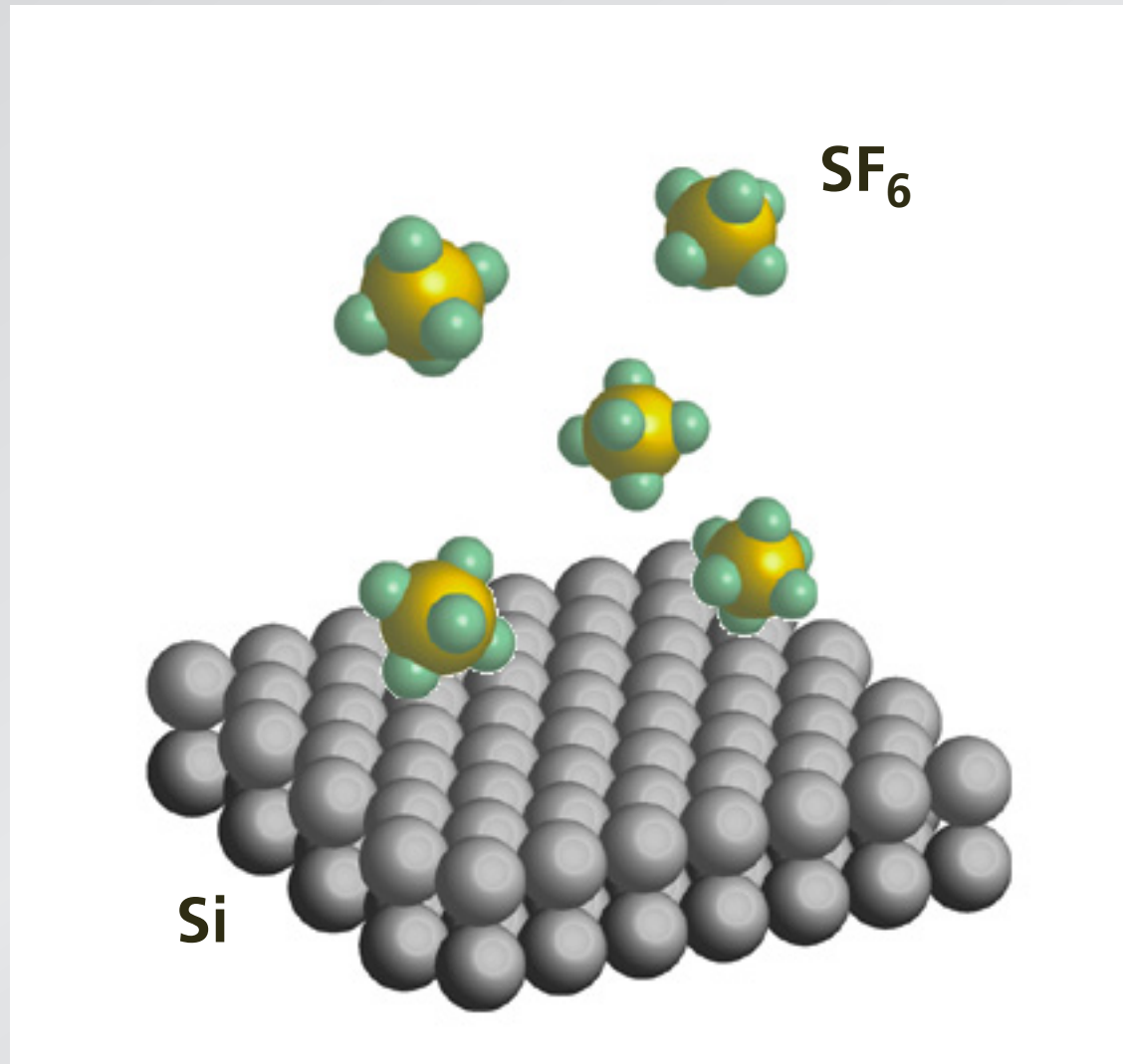
Dr. François Génin (LLNL)
Mark Wall (LLNL)

Dr. Richard Farrell (RMD)
Dr. Arie Karger (RMD)
Dr. Richard Meyers (RMD)

Dr. Pat Maloney (NVSED)

Dr. Jeffrey Warrander (ARDEC)**

Introduction



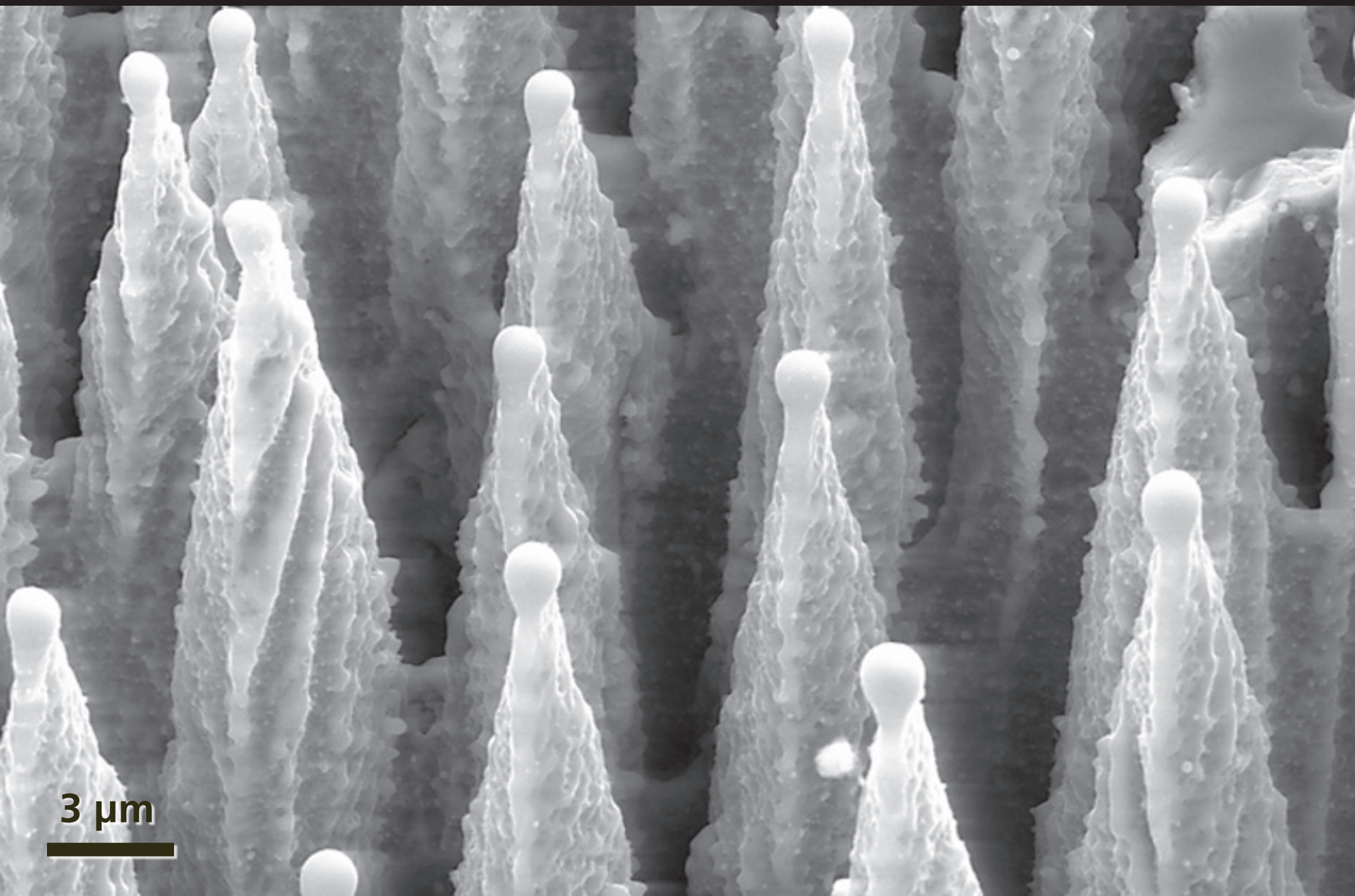
irradiate with 100-fs 10 kJ/m² pulses

Introduction



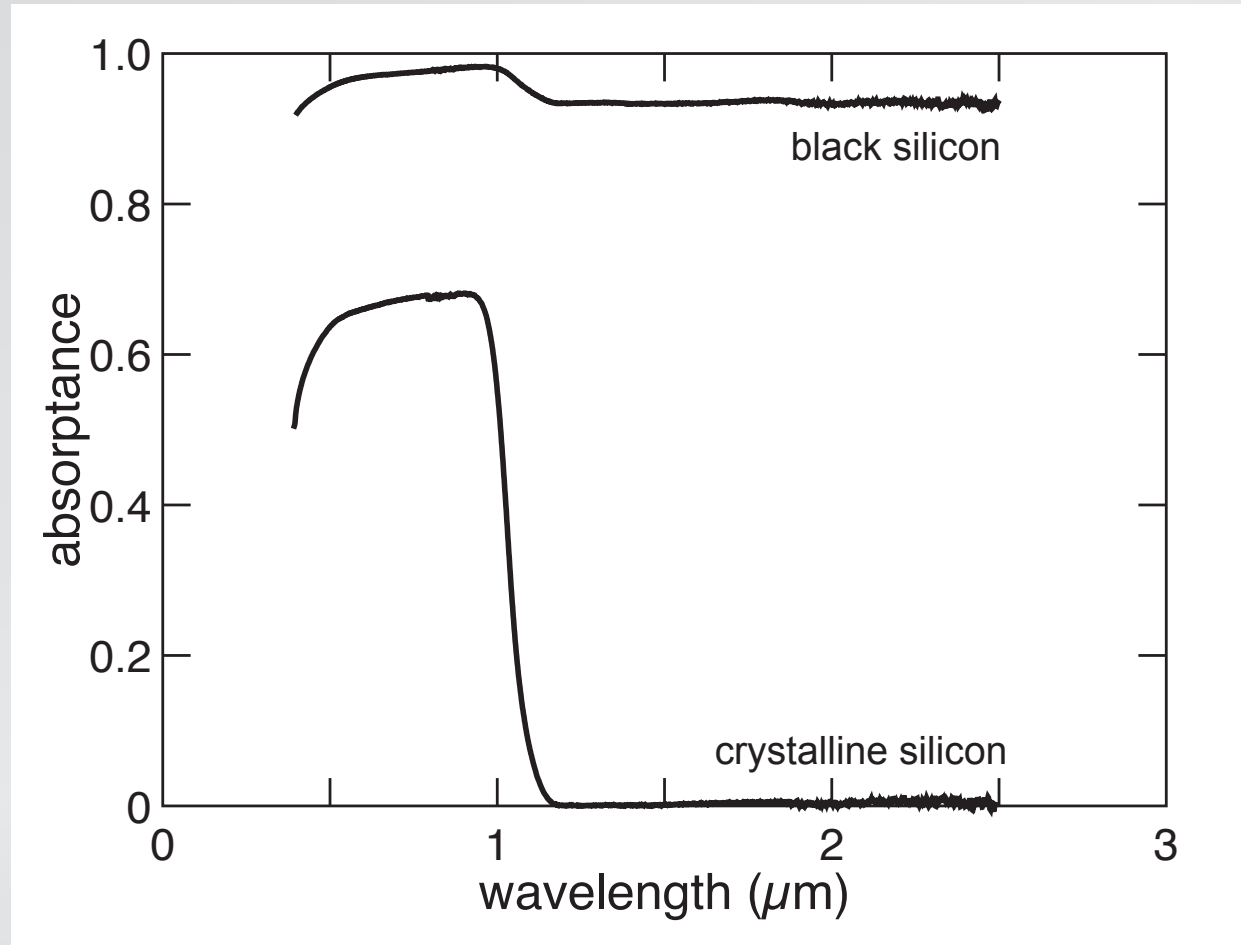
"black silicon"

Introduction

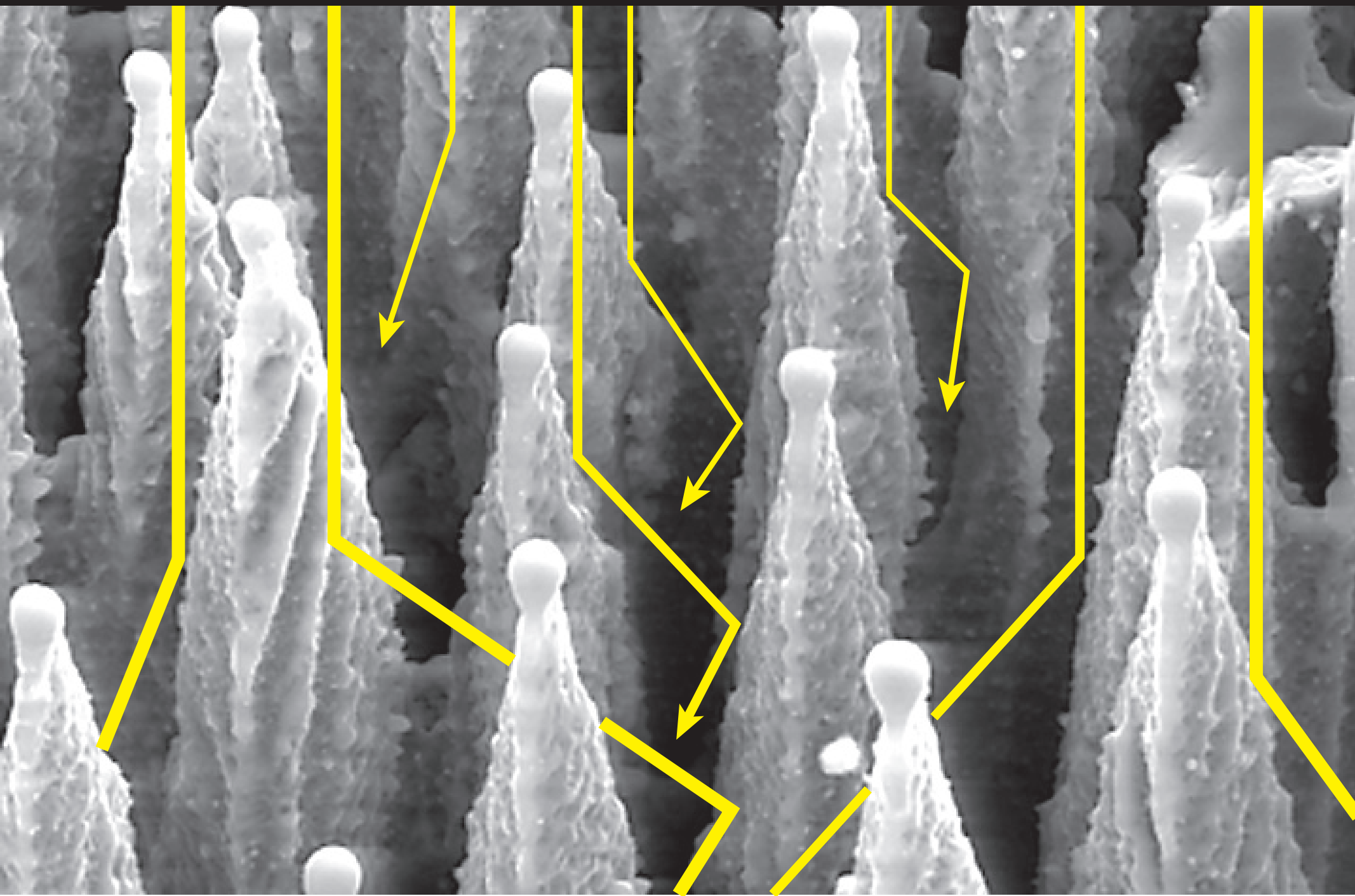


Introduction

absorptance ($1 - R_{int} - T_{int}$)

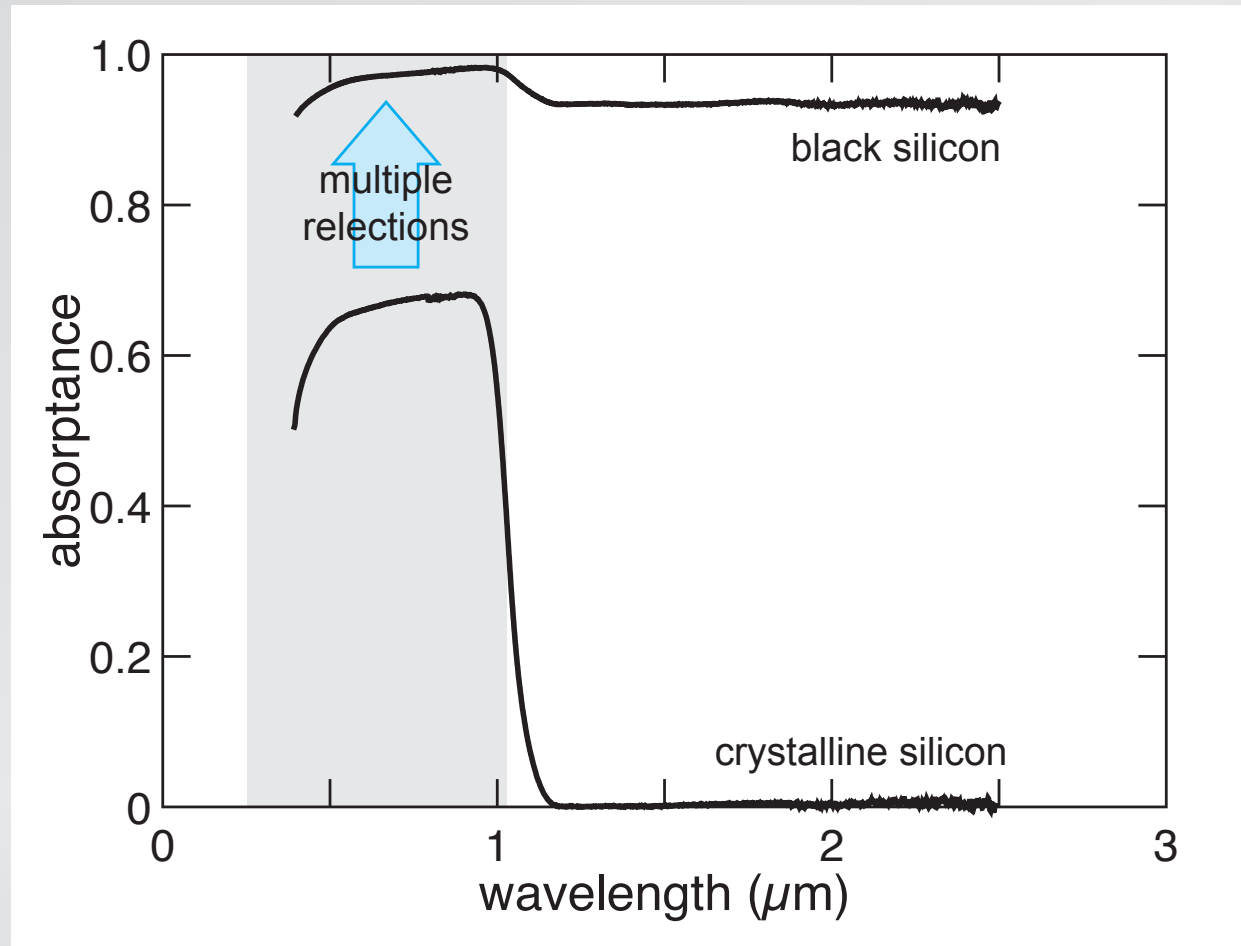


Introduction



Introduction

absorptance ($1 - R_{int} - T_{int}$)

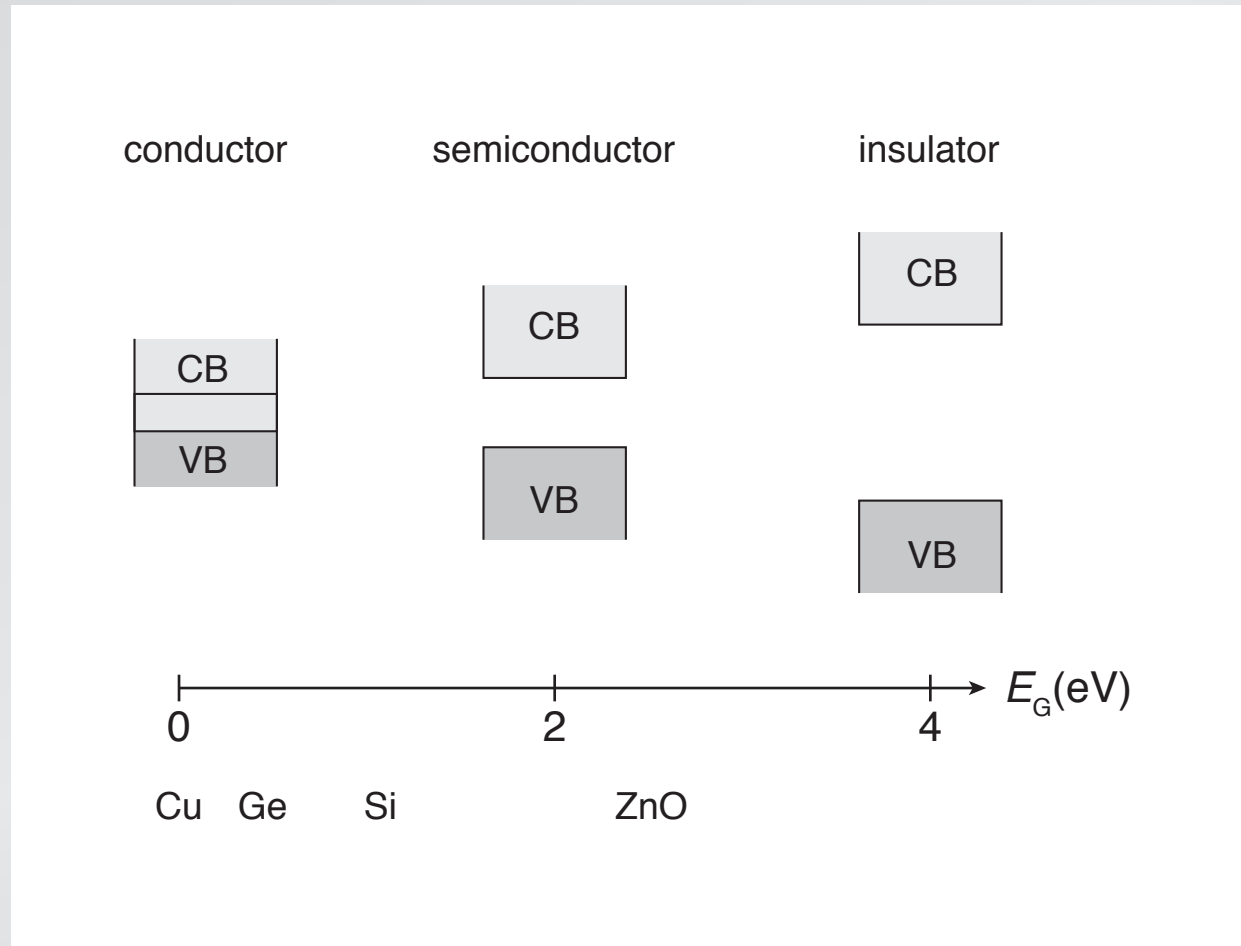


Introduction

band structure changes: defects and/or impurities

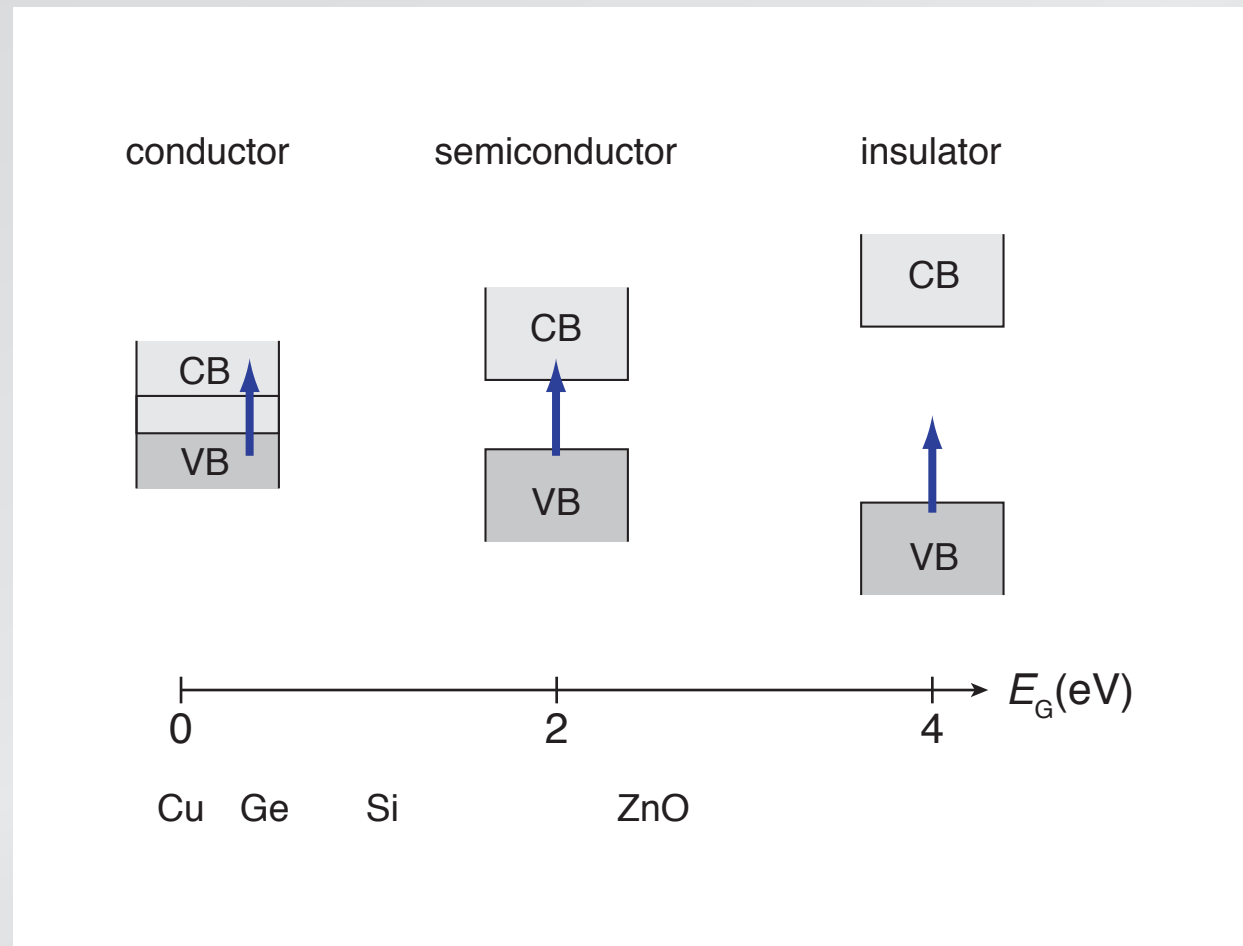
Introduction

new process & new class of material!



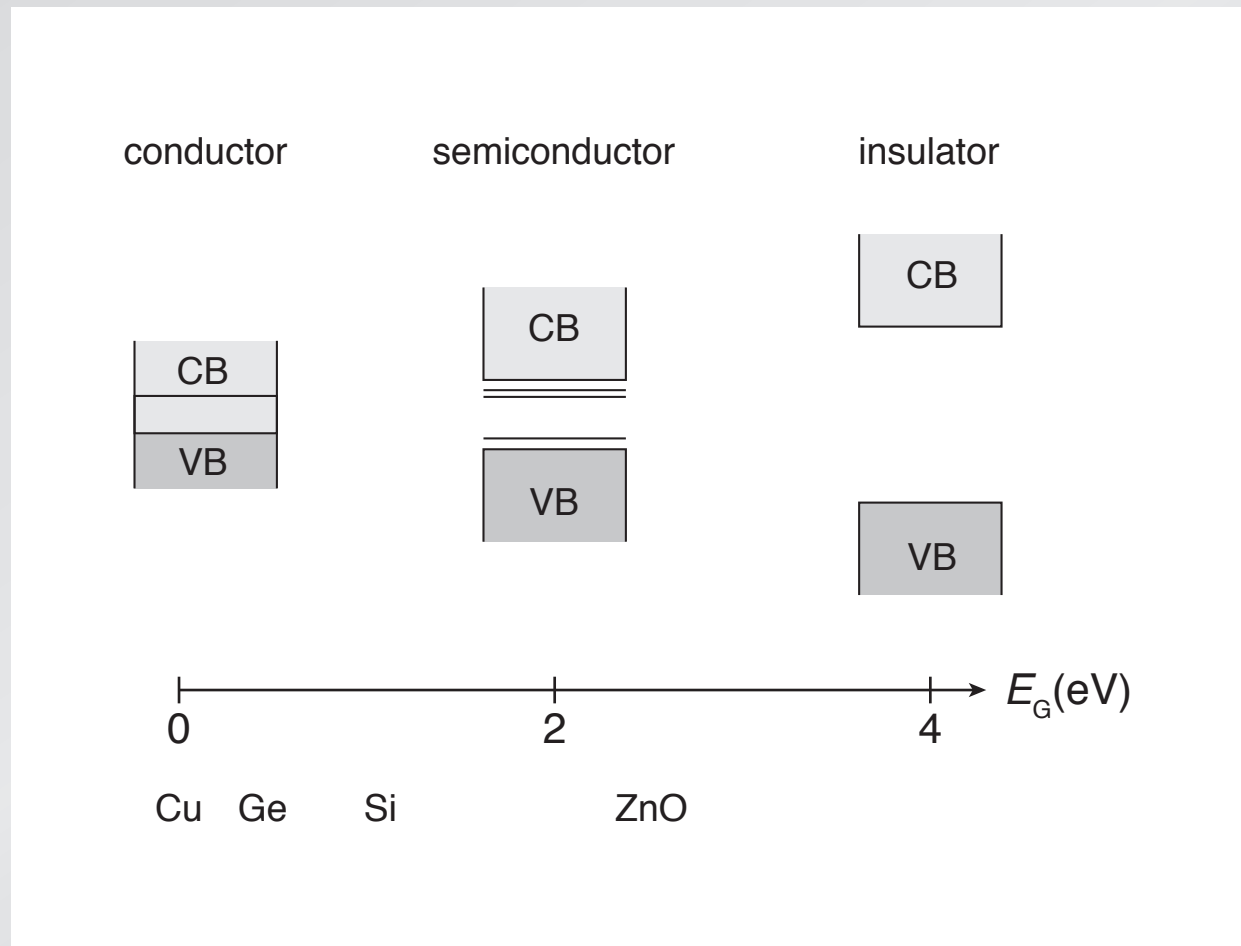
Introduction

gap determines optical and electronic properties



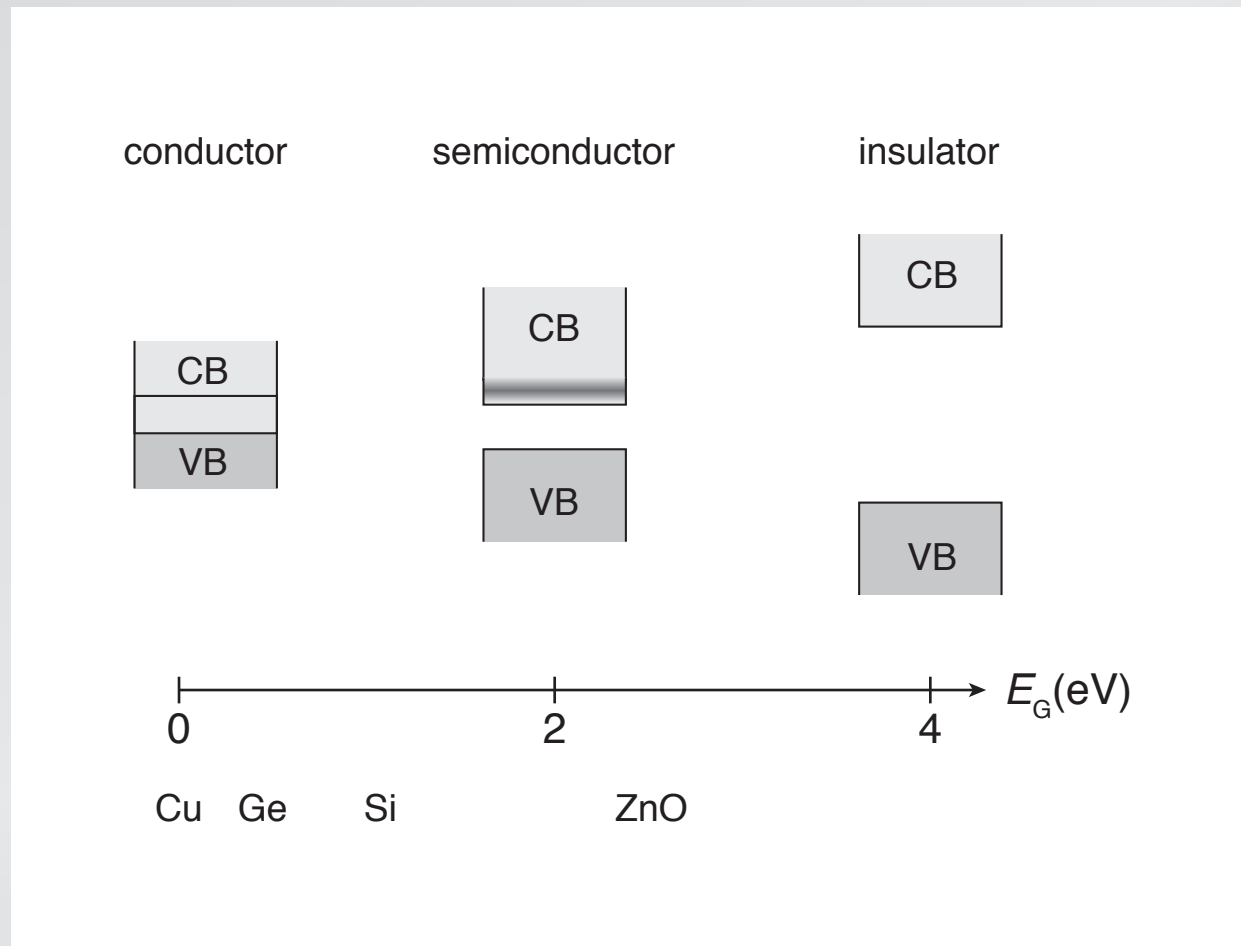
Introduction

shallow-level dopants control electronic properties



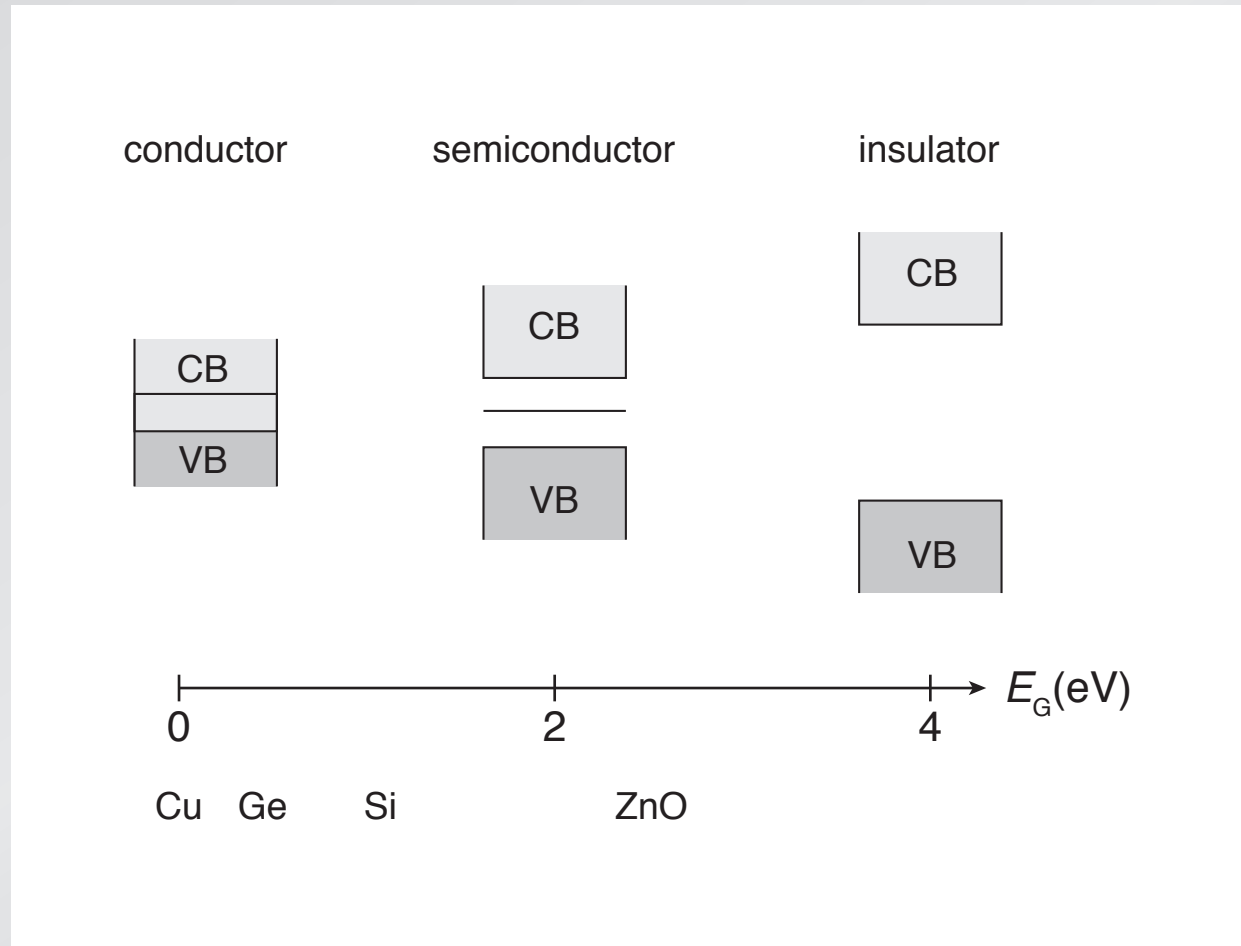
Introduction

shallow-level dopants control electronic properties



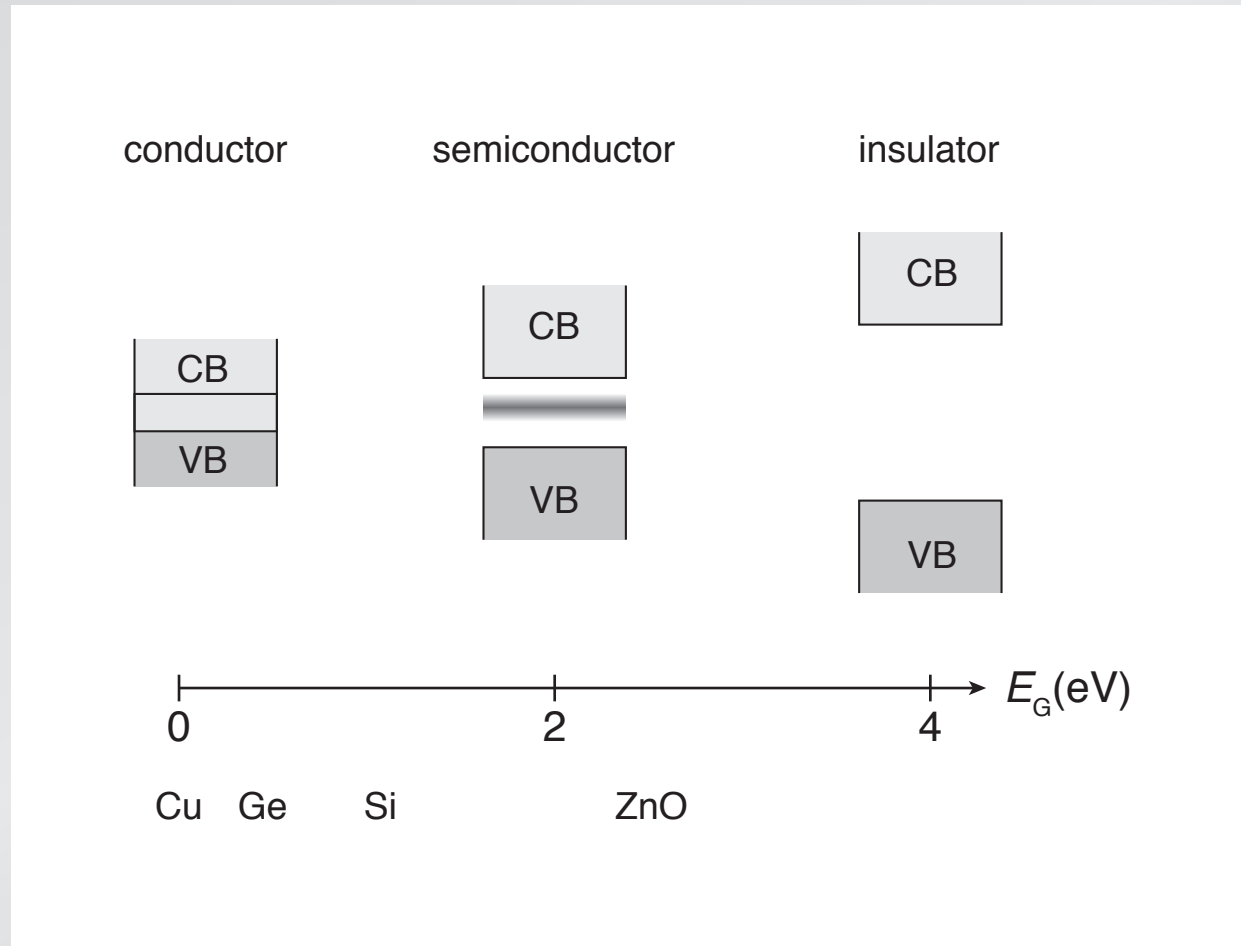
Introduction

deep-level dopants typically avoided



Introduction

femtosecond laser-doping gives rise to intermediate band



Introduction

substrate/dopant combinations

dopants:

N	O	F
P	S	Cl
	Se	
Sb	Te	

Introduction

substrate/dopant combinations

dopants:

N	O	F
P	S	Cl
	Se	
Sb	Te	

substrates:

Si Ge ZnO InP GaAs

Ti Ag Al Cu Pd Rh Ta Pt

Introduction

focus on chalcogen-doped silicon

dopants:

N	O	F
P	S	Cl
	Se	
Sb	Te	

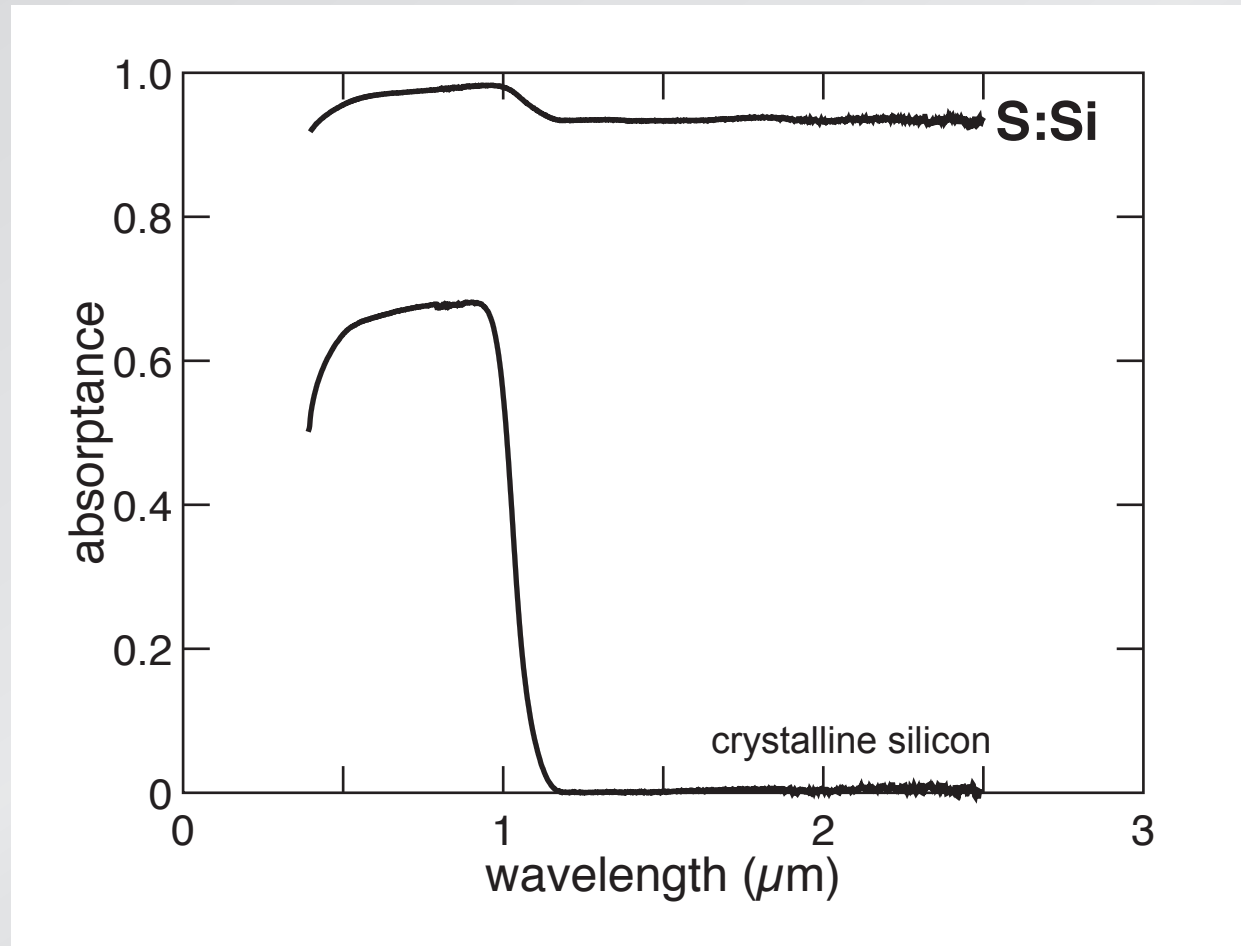
substrates:

Si Ge ZnO InP GaAs

Ti Ag Al Cu Pd Rh Ta Pt

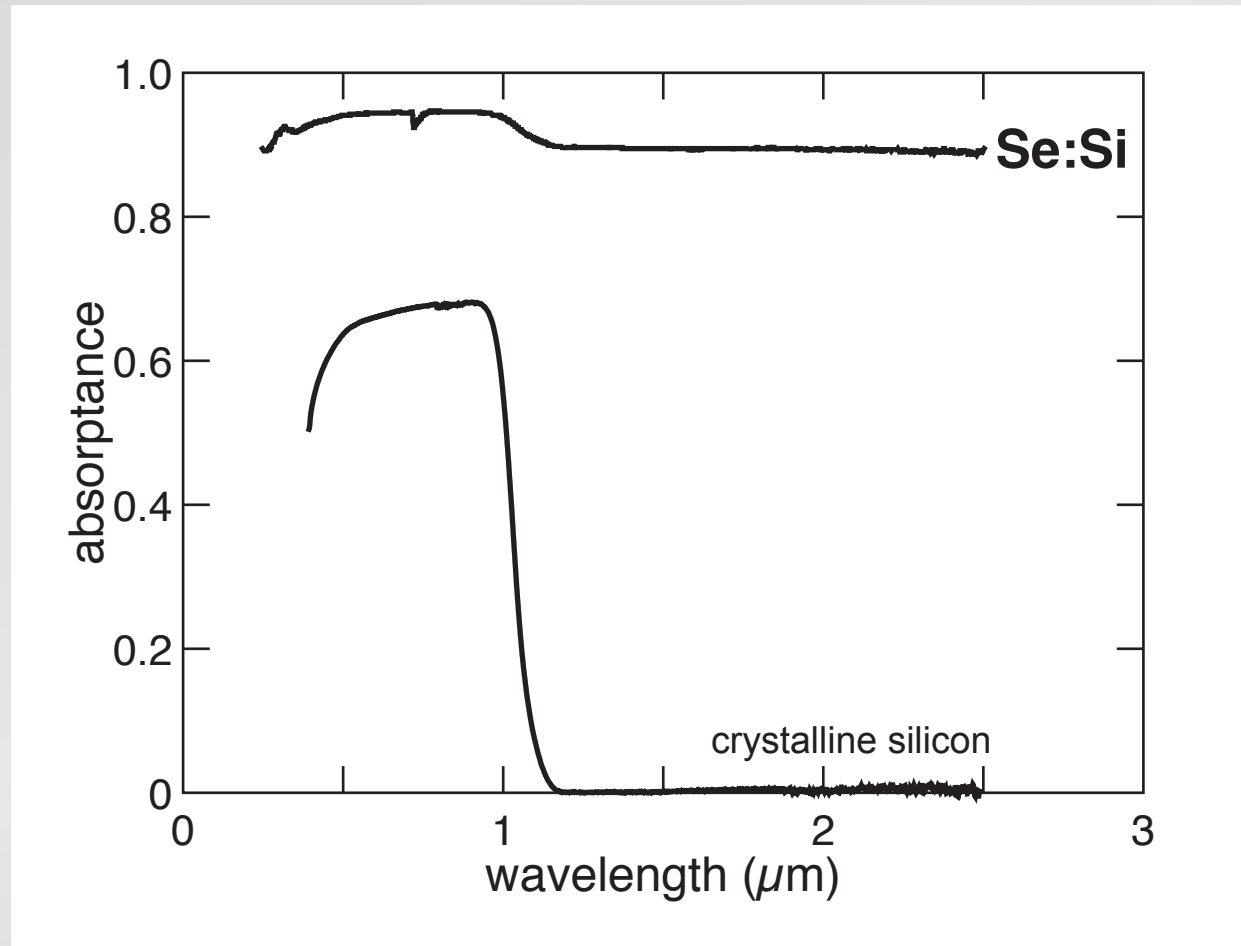
Introduction

focus on chalcogen-doped silicon



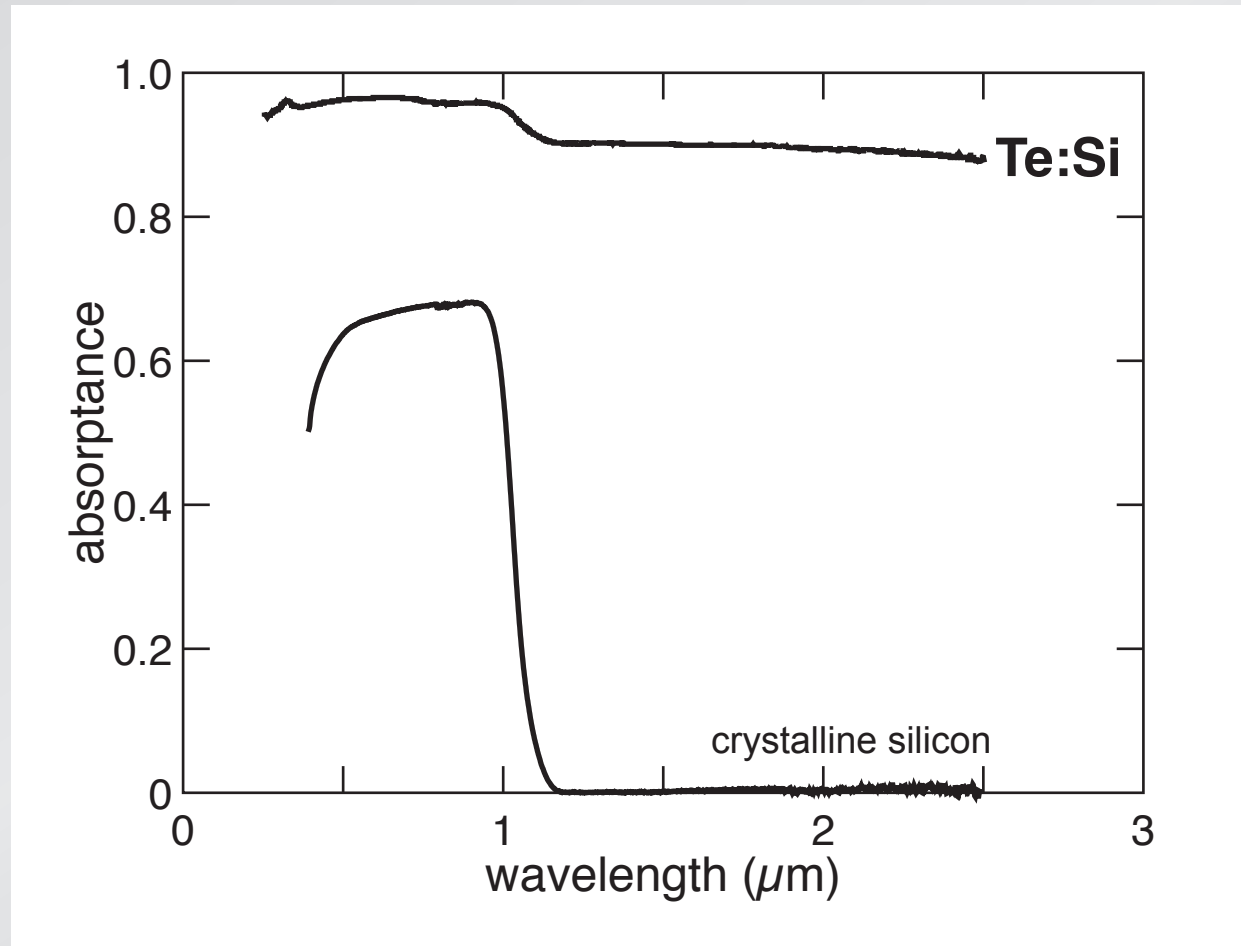
Introduction

focus on chalcogen-doped silicon

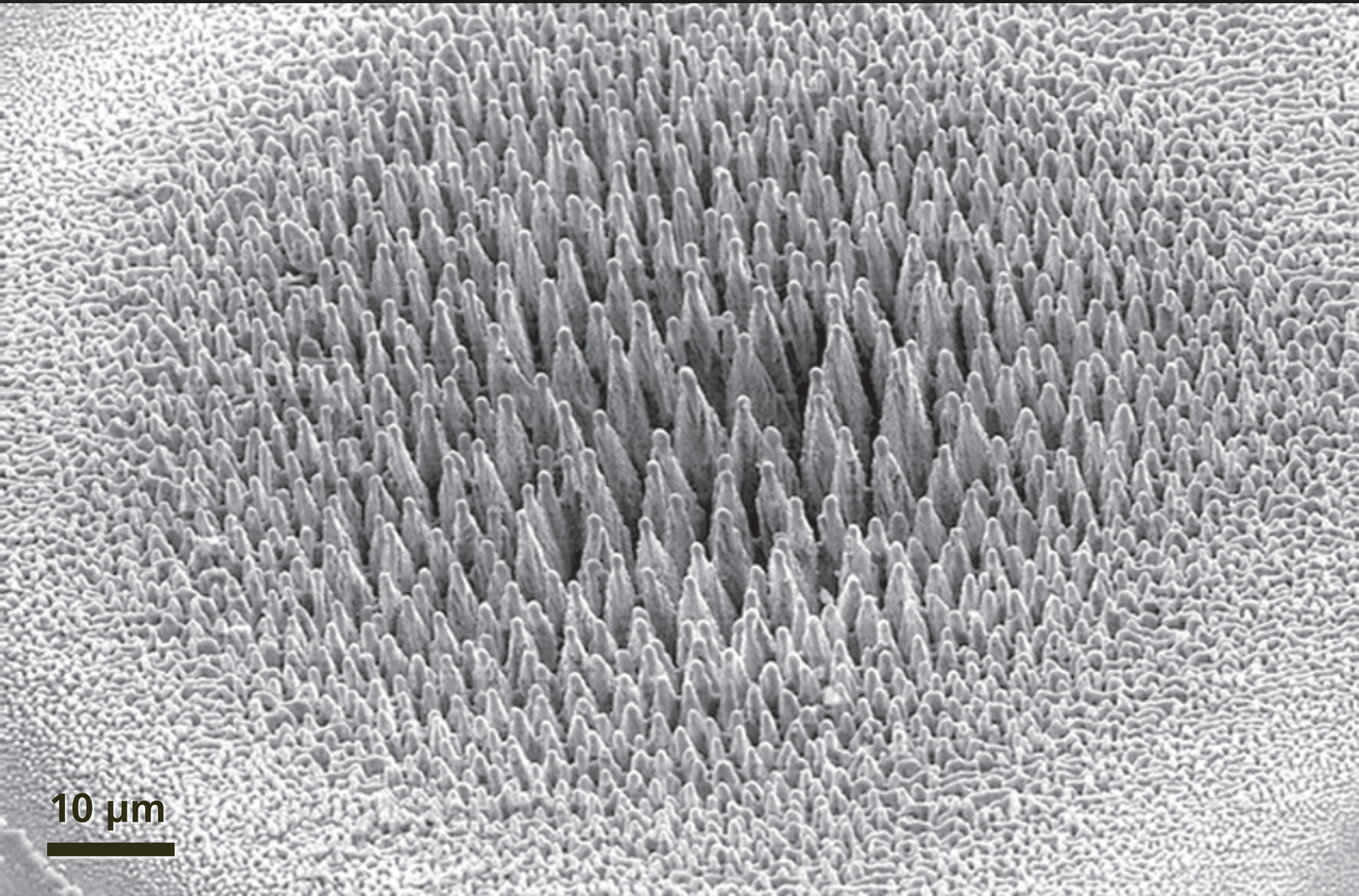


Introduction

focus on chalcogen-doped silicon



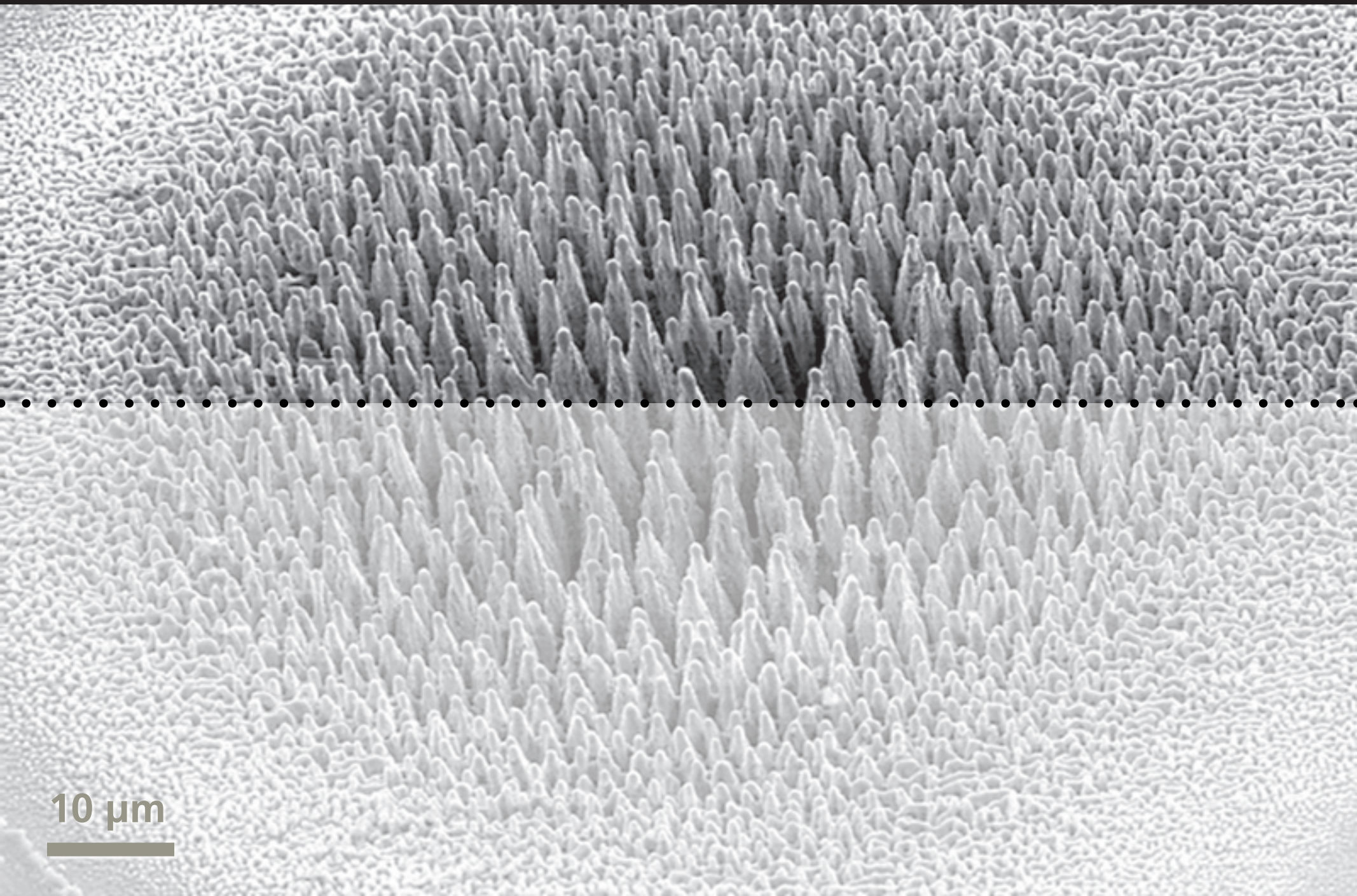
Structure



10 μm



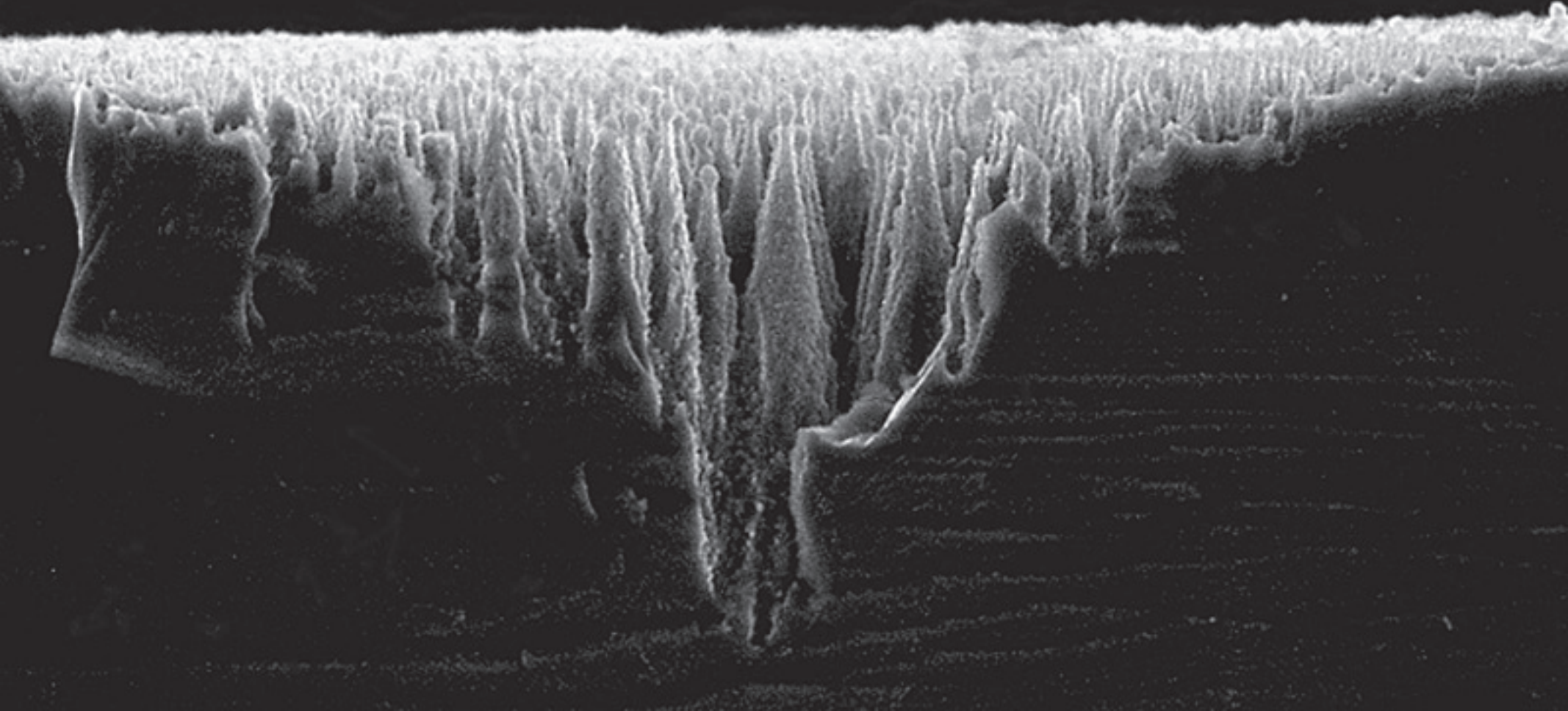
Structure



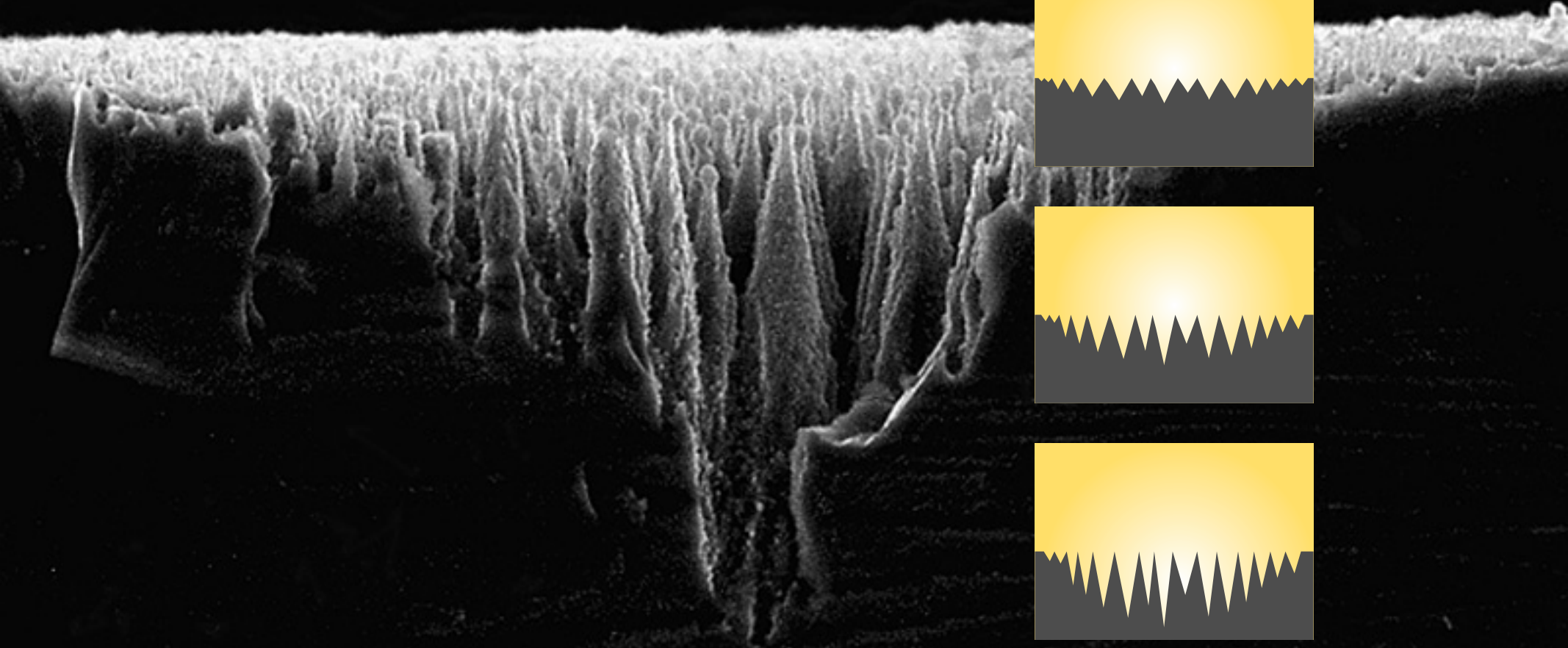
10 μm



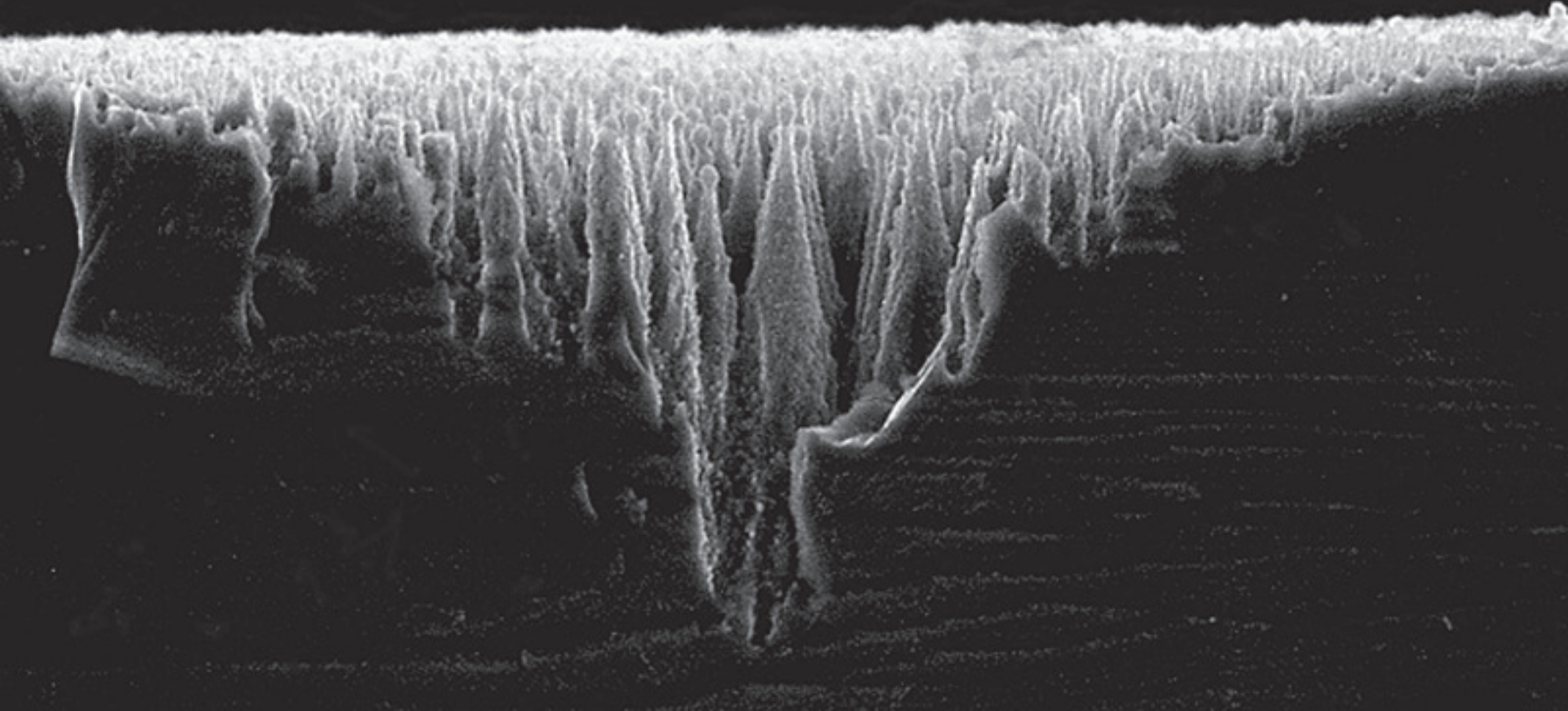
Structure



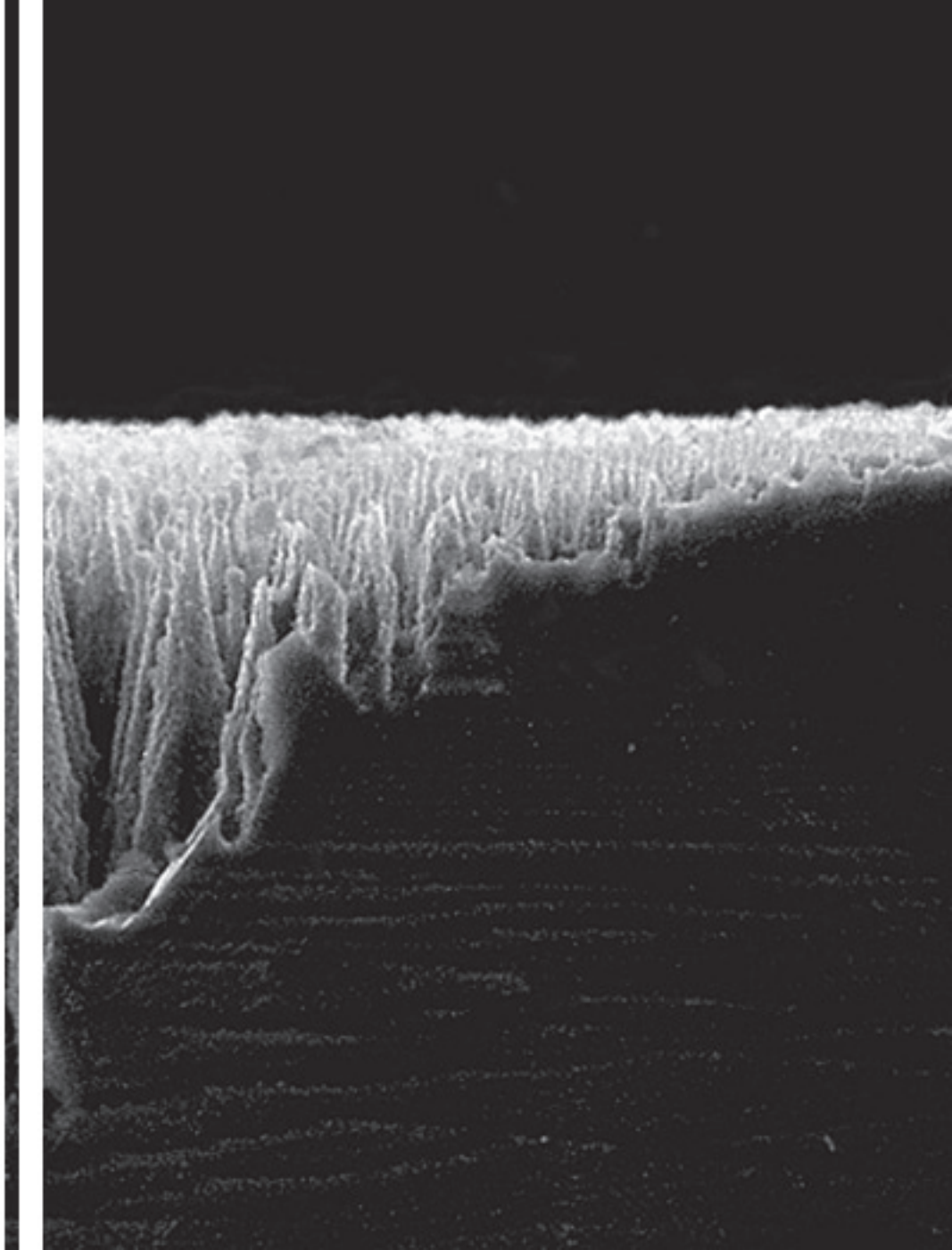
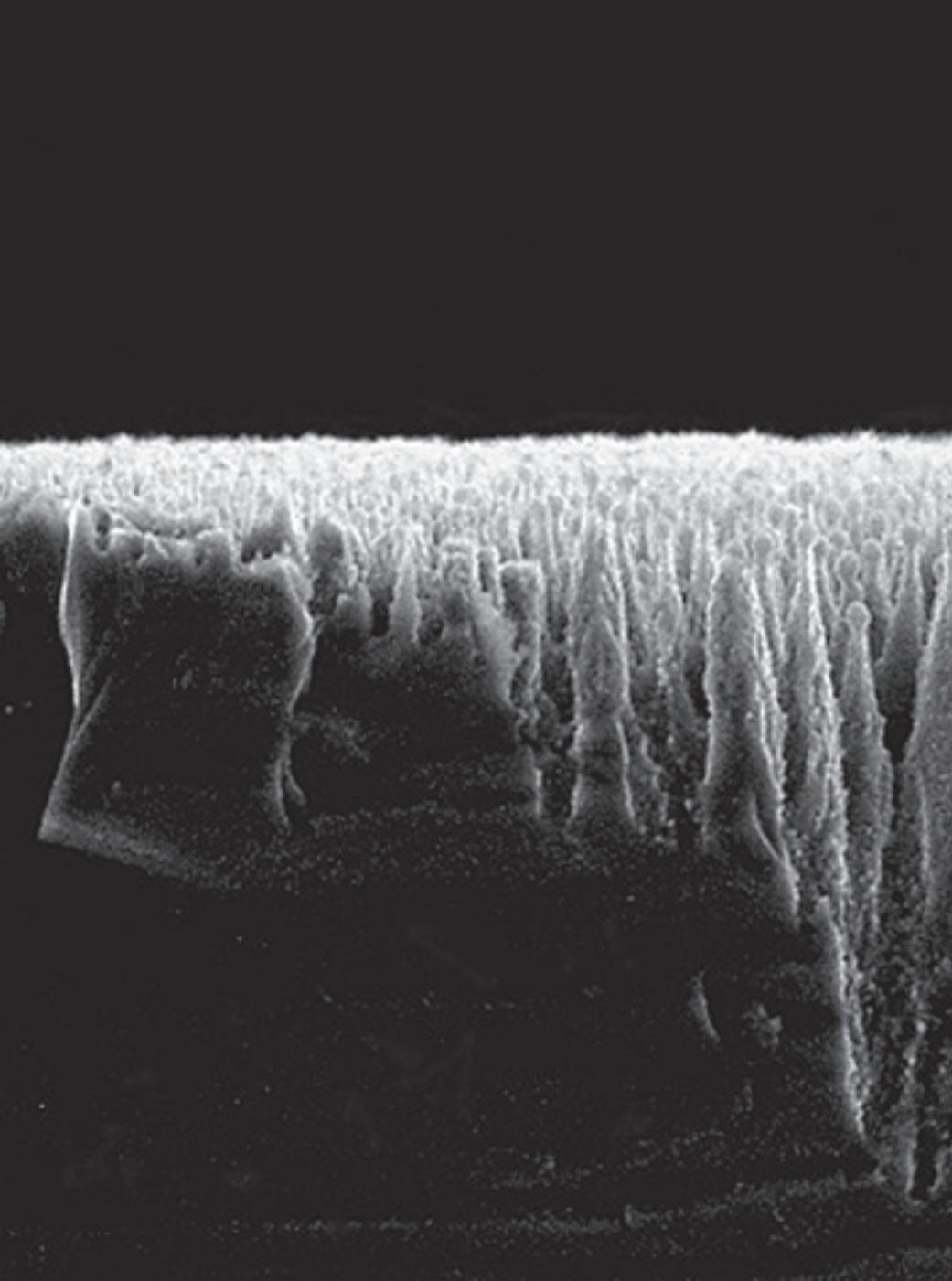
Structure



Structure

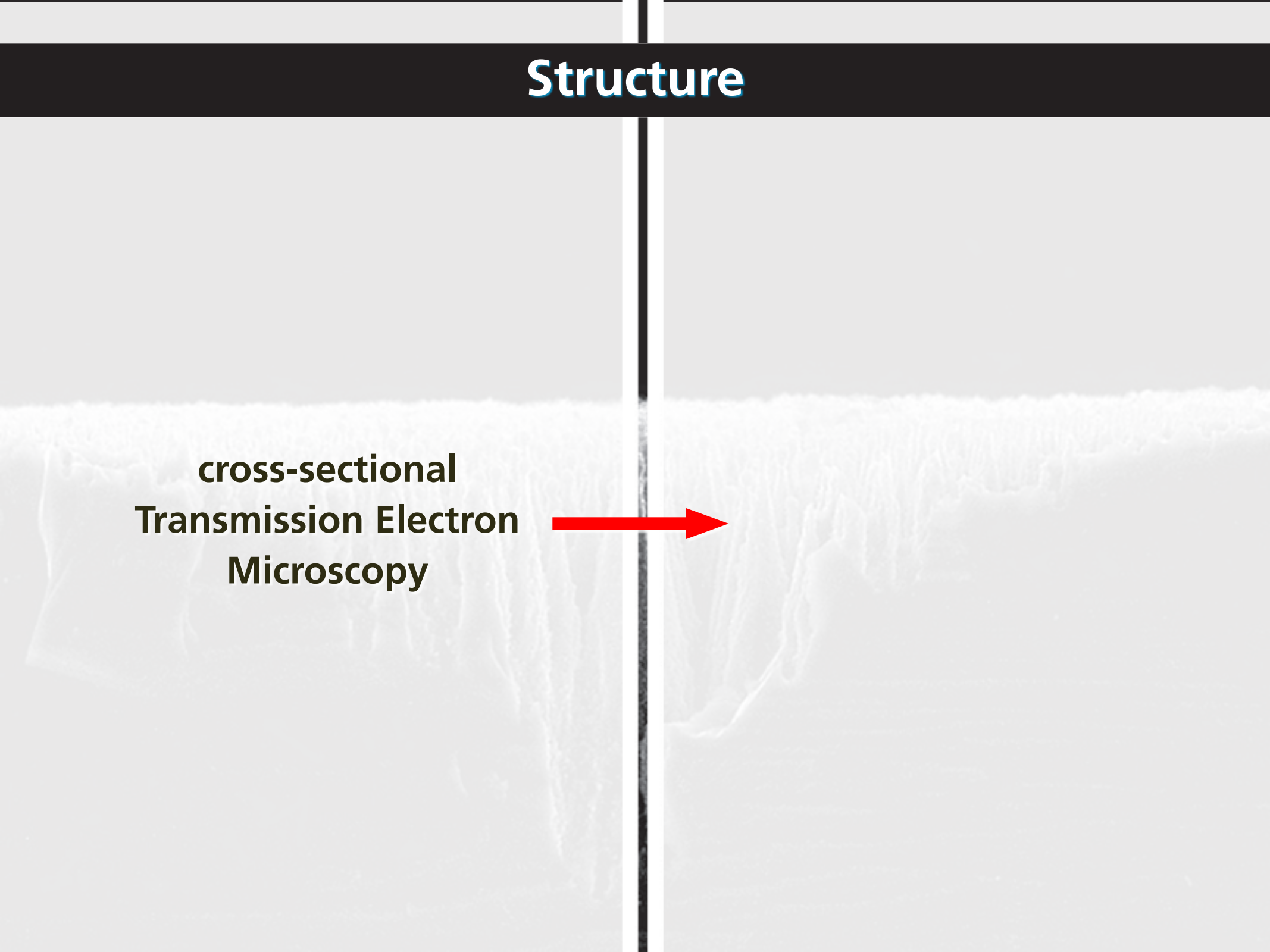


Structure



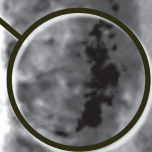
Structure

**cross-sectional
Transmission Electron
Microscopy**



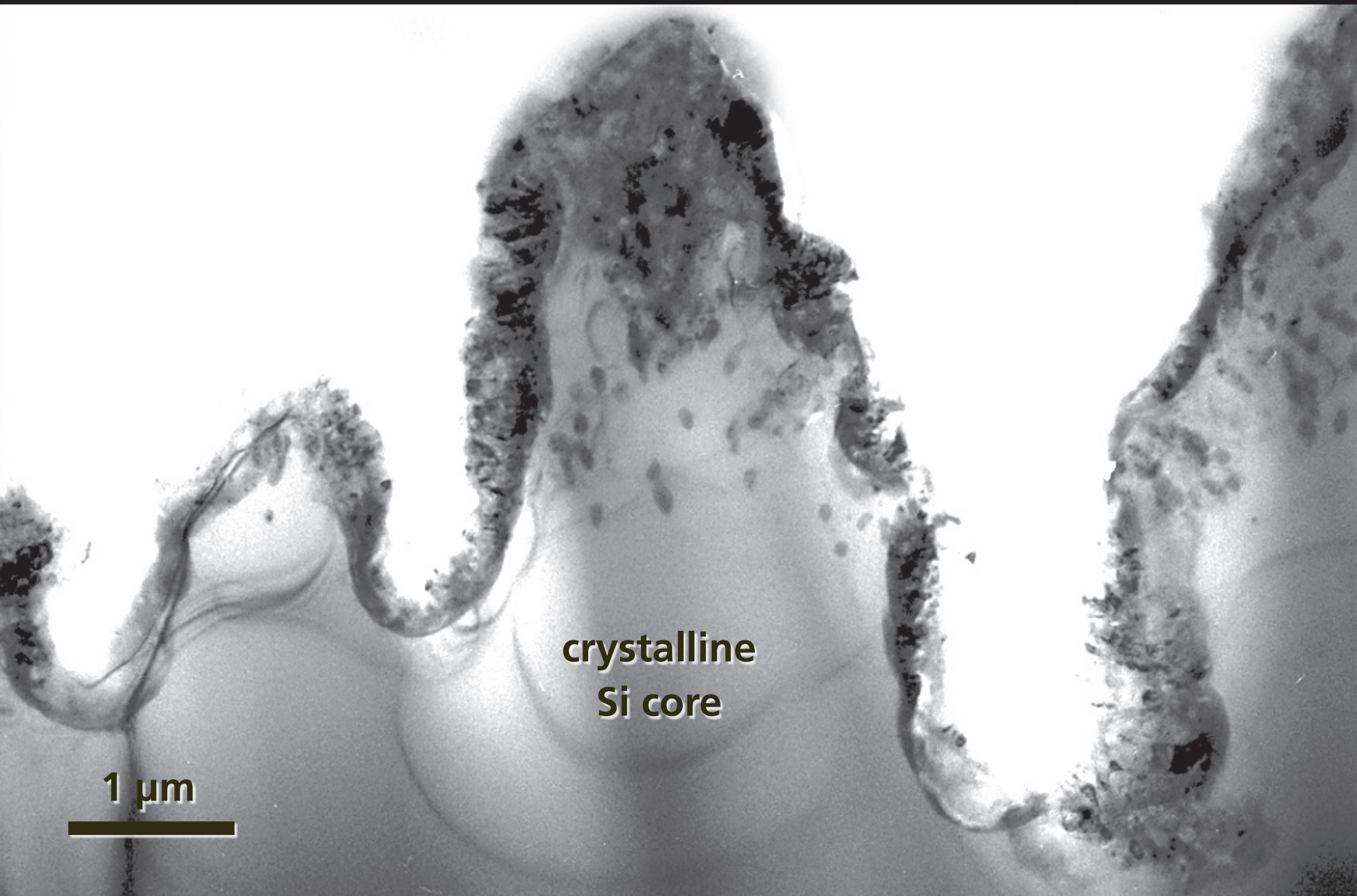
Structure

disordered
surface layer



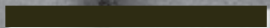
1 μm

Structure



crystalline
Si core

1 μm



Structure

- 300-nm disordered surface layer
- undisturbed crystalline core
- surface layer: nanocrystalline Si with 1.6% sulfur

1 μm

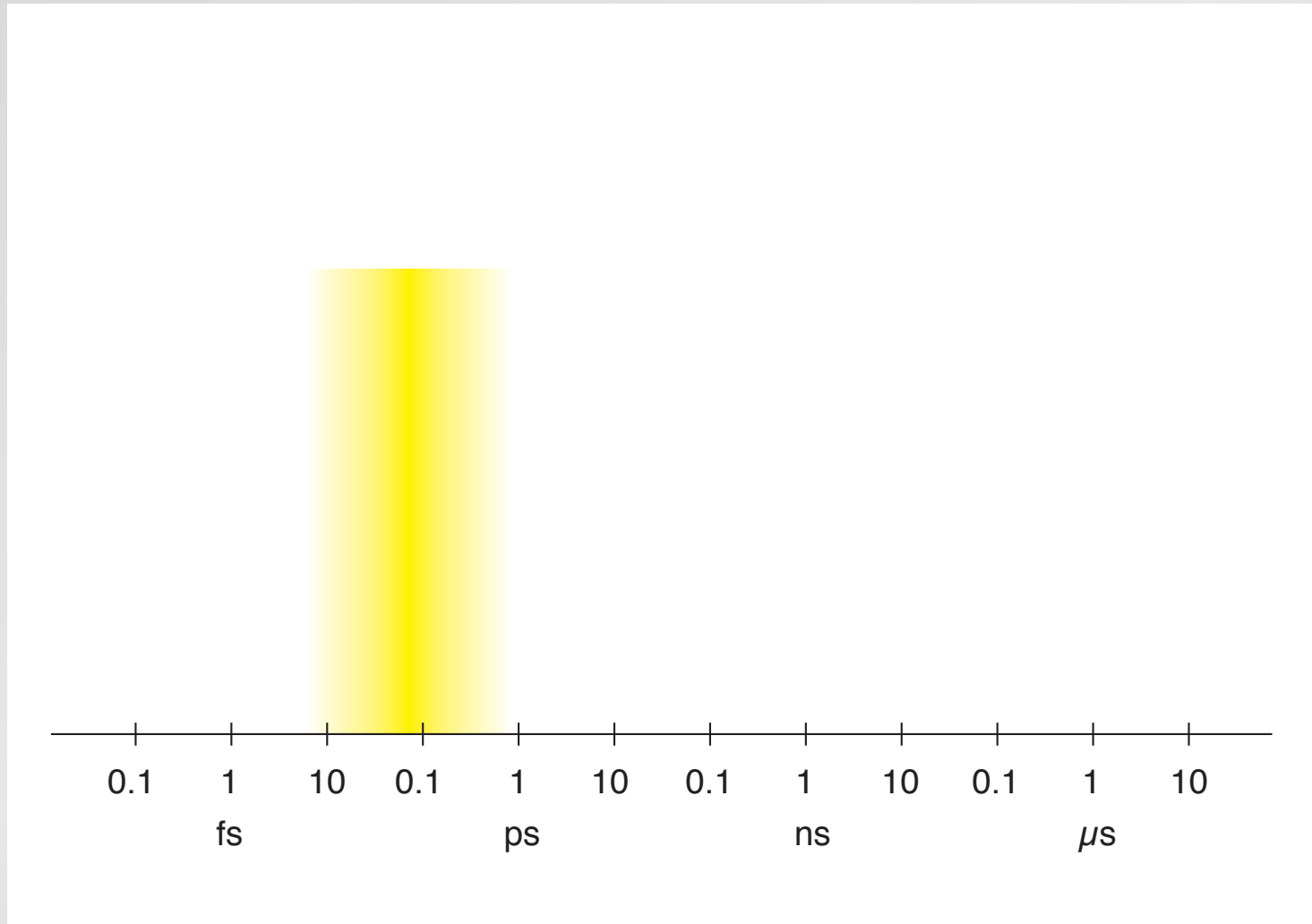
The image is a grayscale micrograph showing several elongated, finger-like structures. Each structure has a darker, textured outer layer and a lighter, smoother inner core. The structures are interconnected and appear to be part of a larger network. A scale bar at the bottom left indicates a length of 1 micrometer.

Structure

two processes: melting and ablation

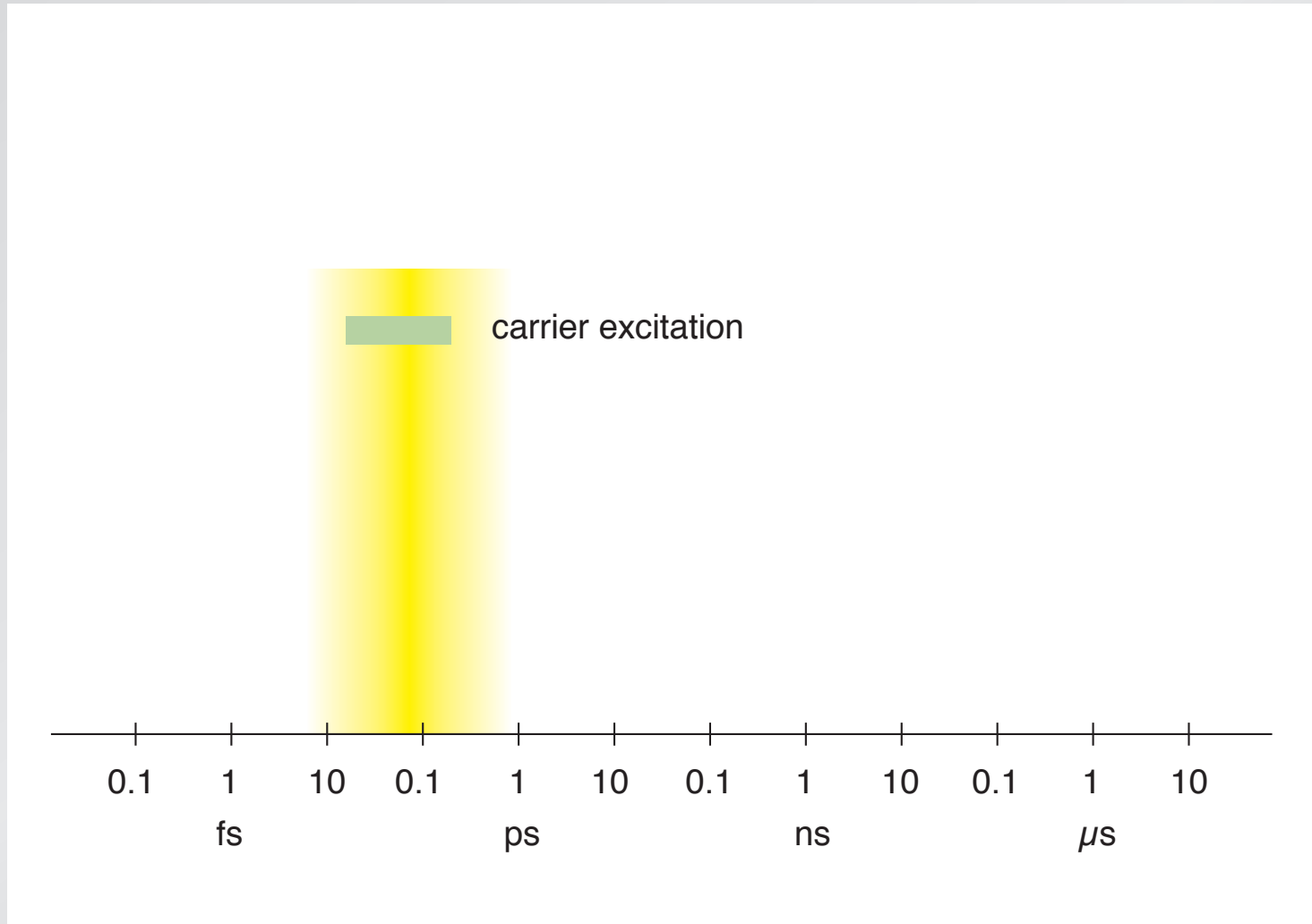
Structure

relevant time scales



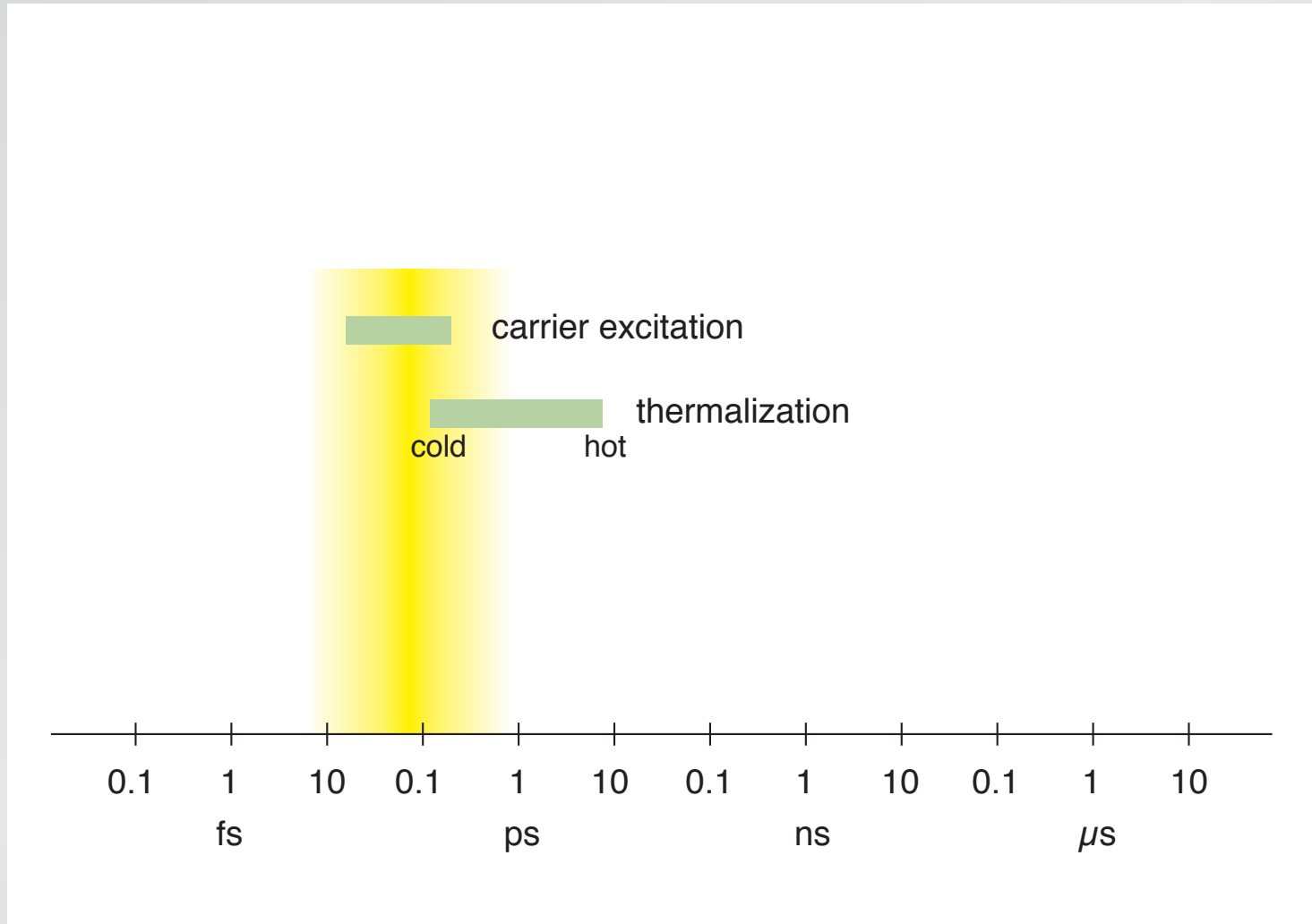
Structure

relevant time scales



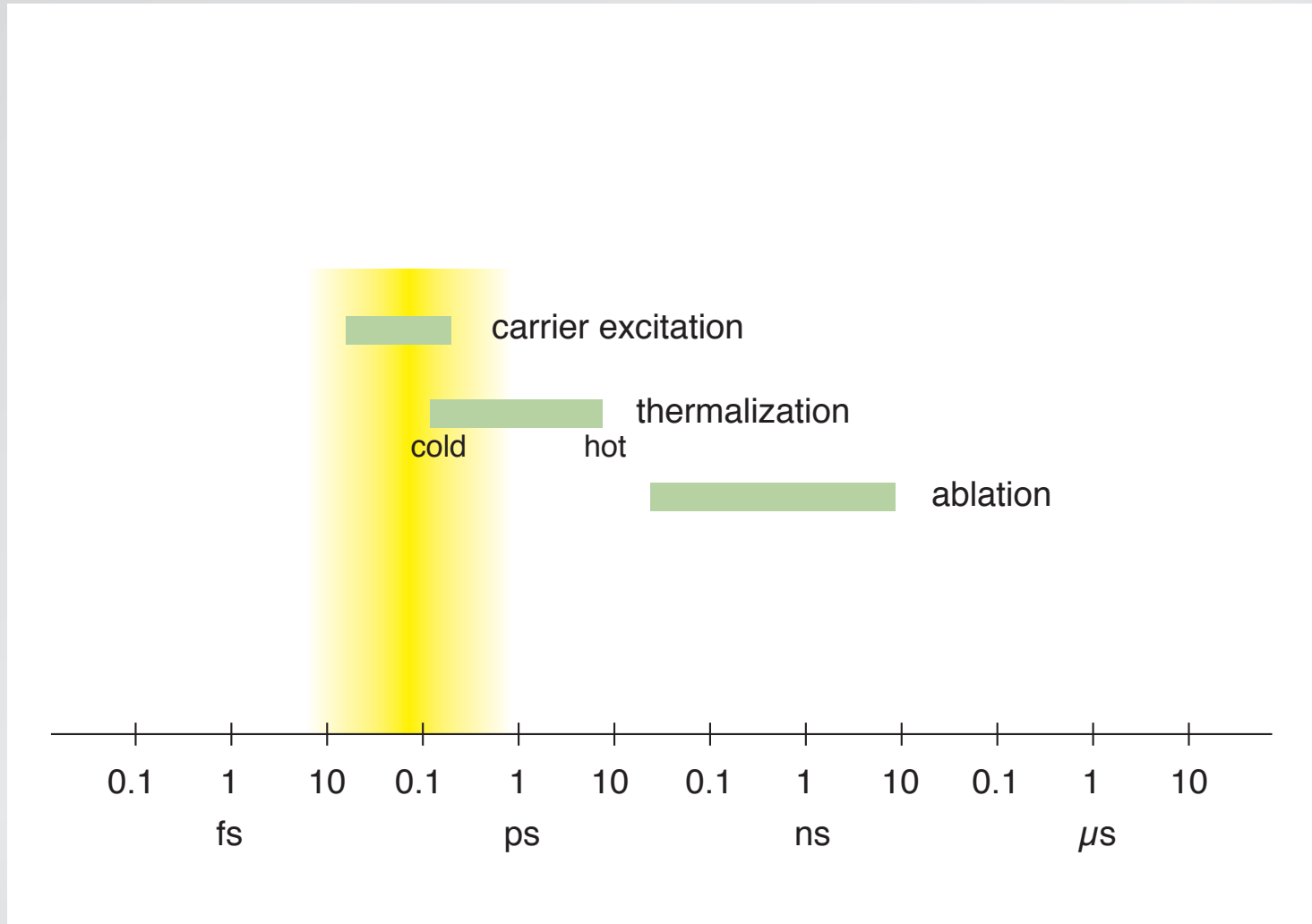
Structure

relevant time scales



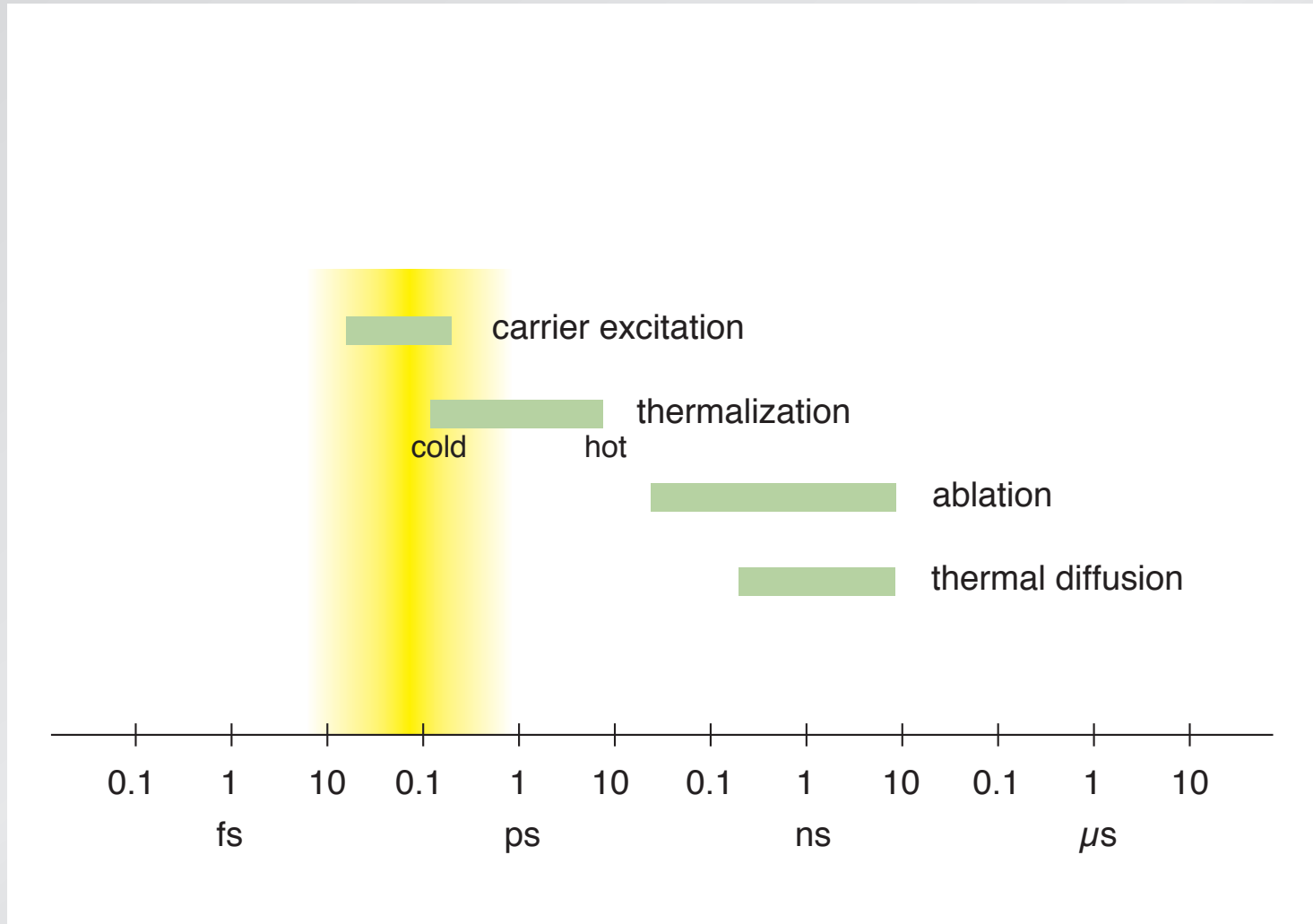
Structure

relevant time scales



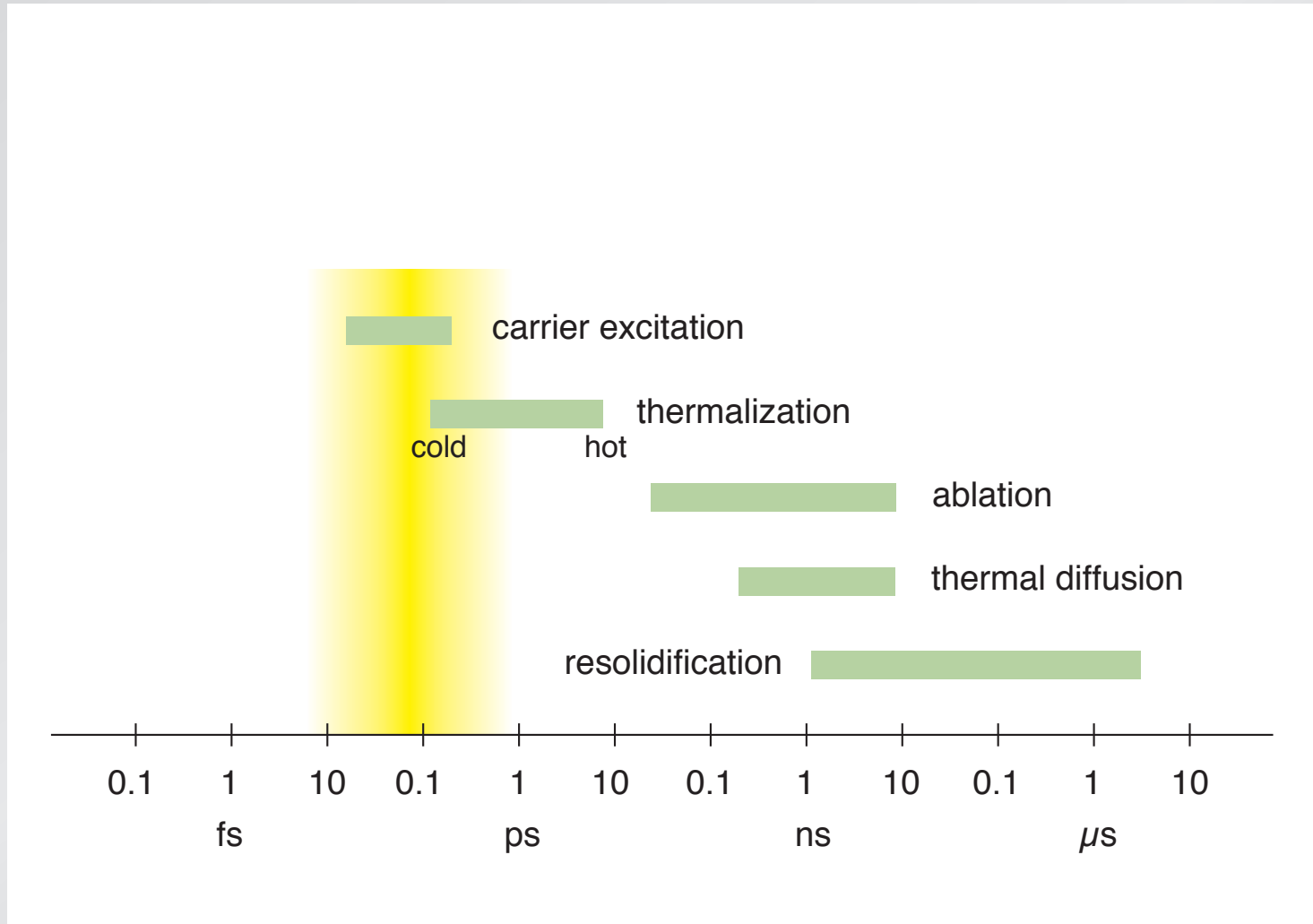
Structure

relevant time scales



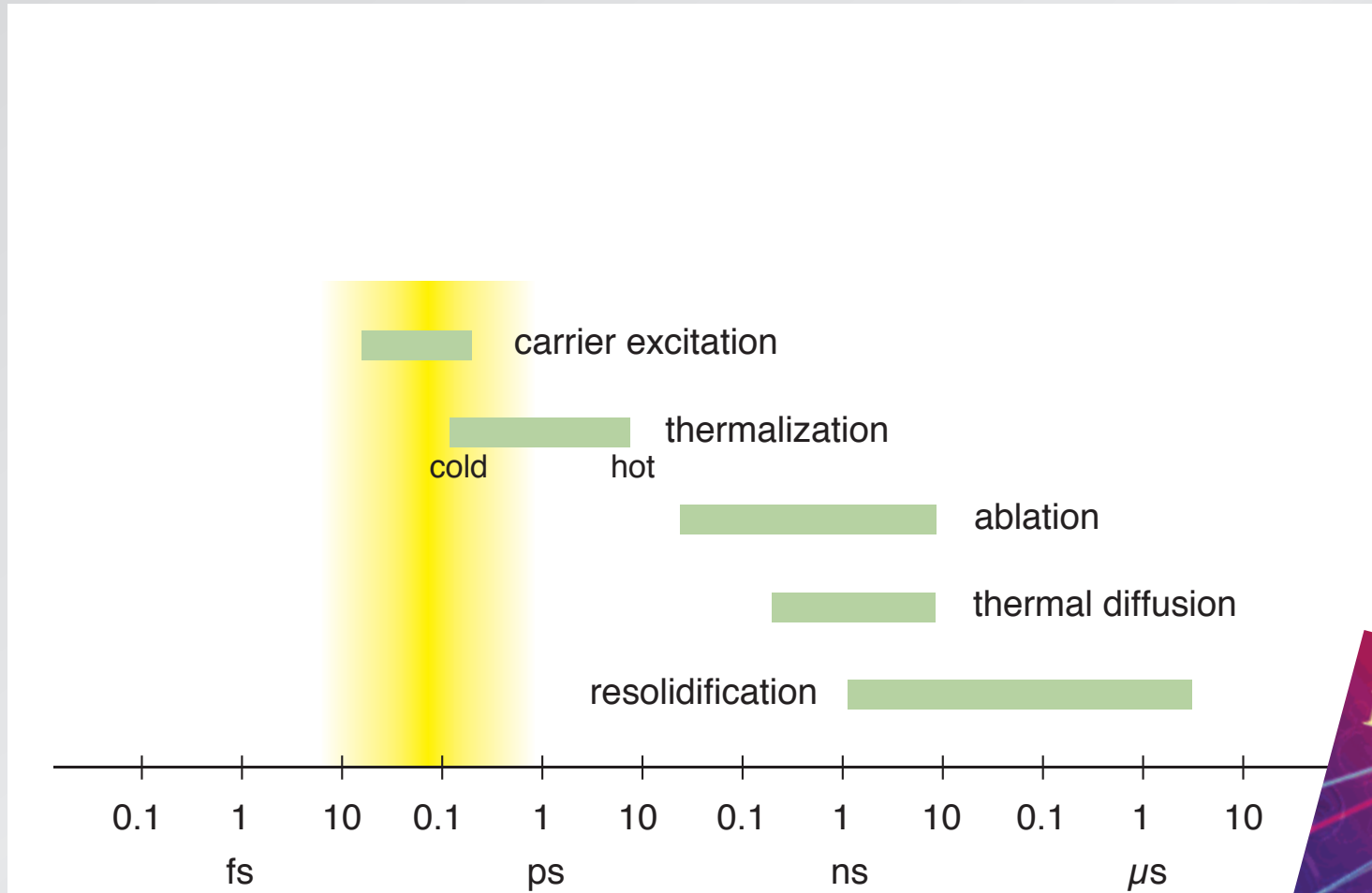
Structure

relevant time scales

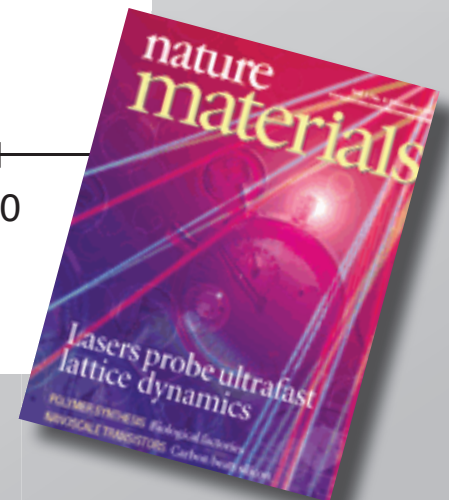


Structure

relevant time scales

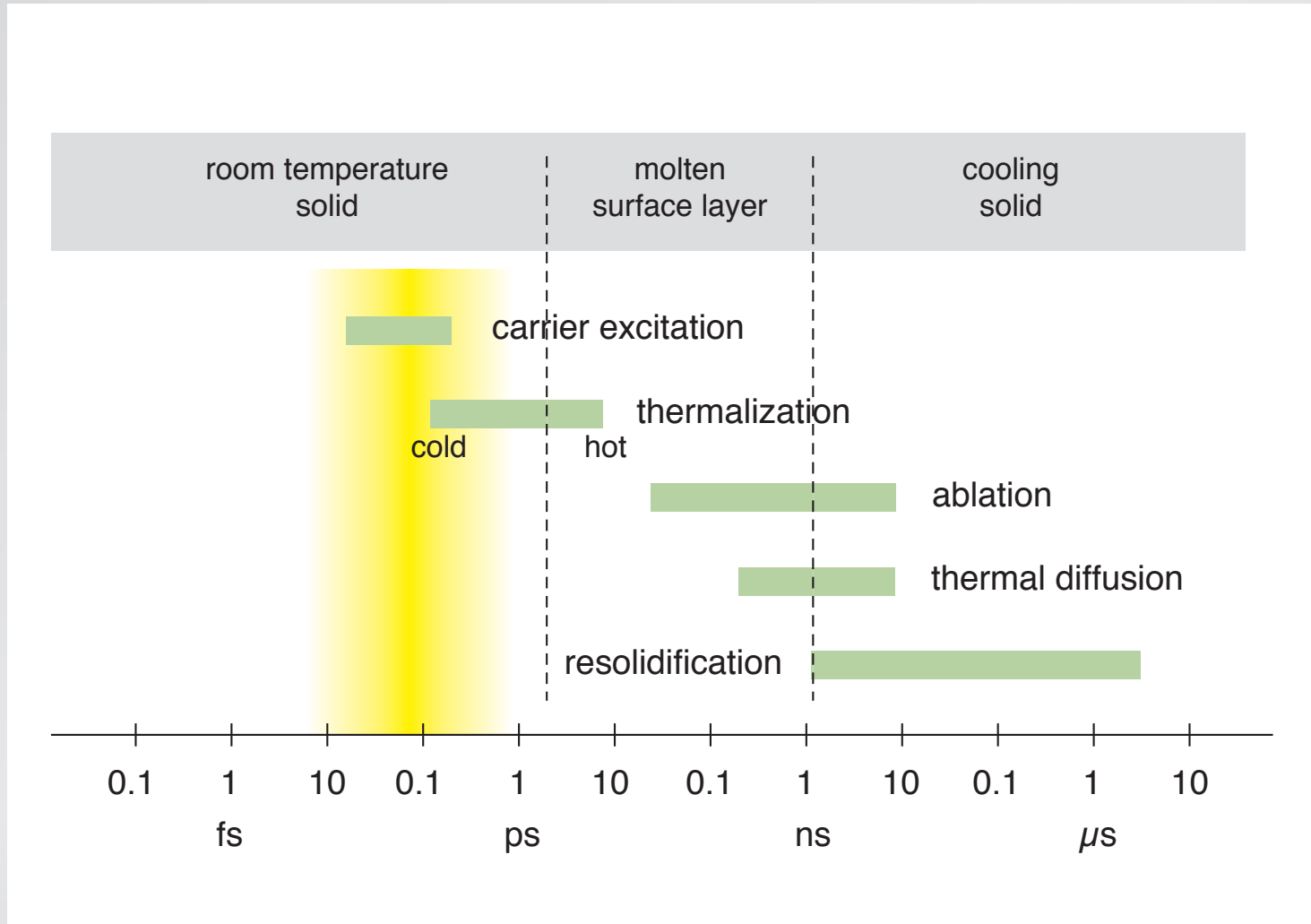


Nature Materials 1, 217 (2002)



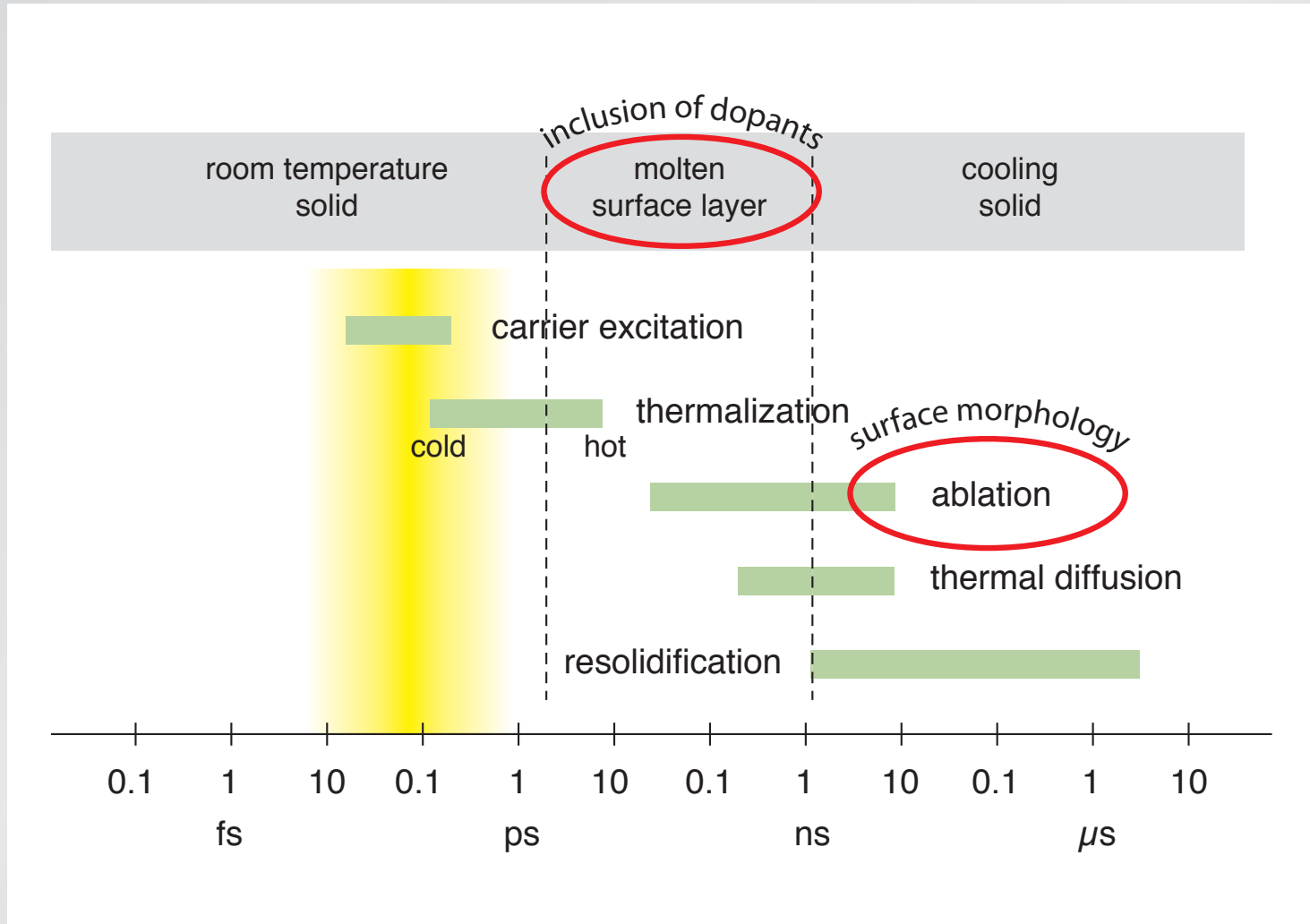
Structure

relevant time scales



Structure

relevant time scales



Structure

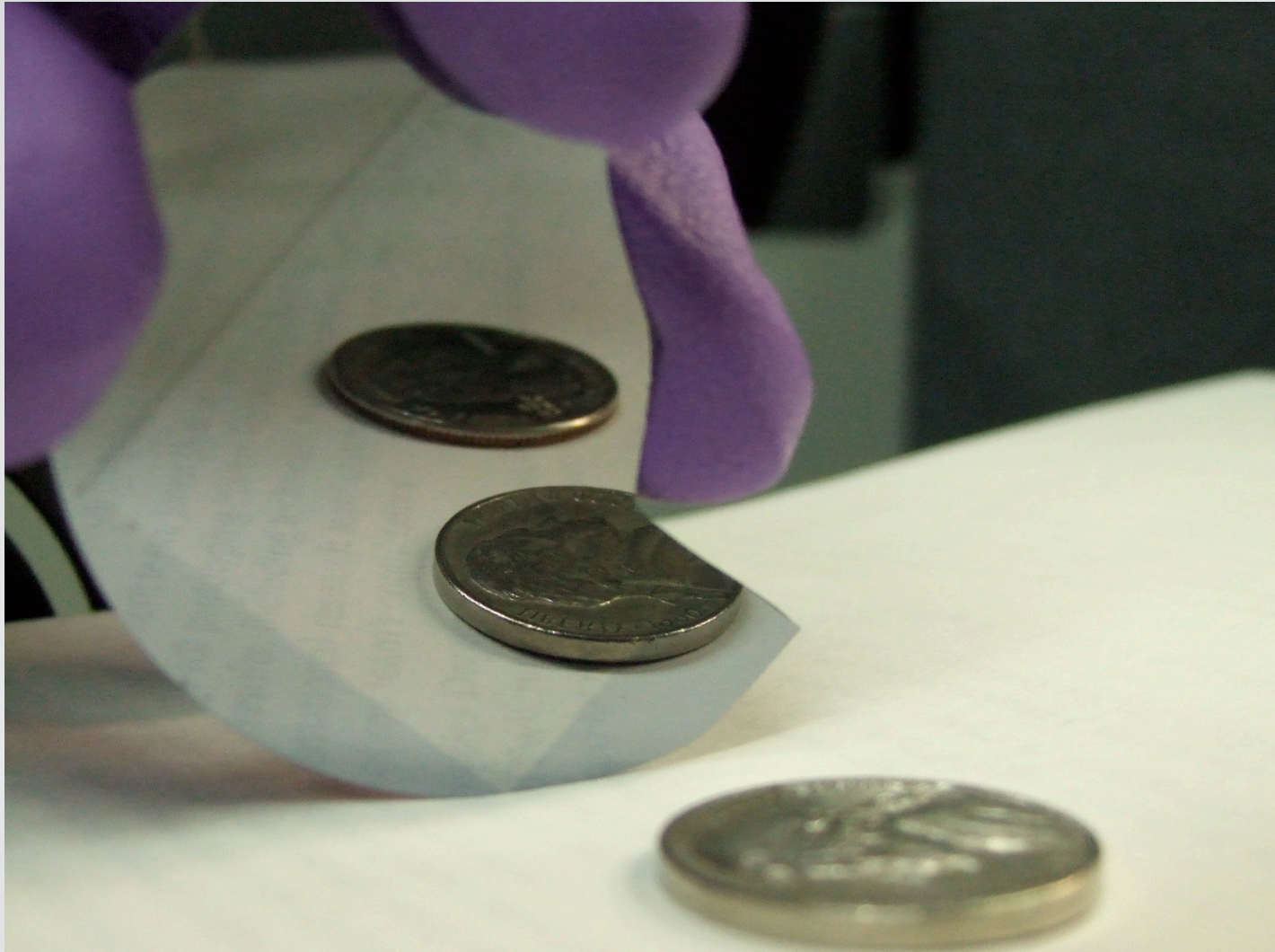
different thresholds:

melting: 1.5 kJ/m²

ablation: 3.1 kJ/m²

Structure

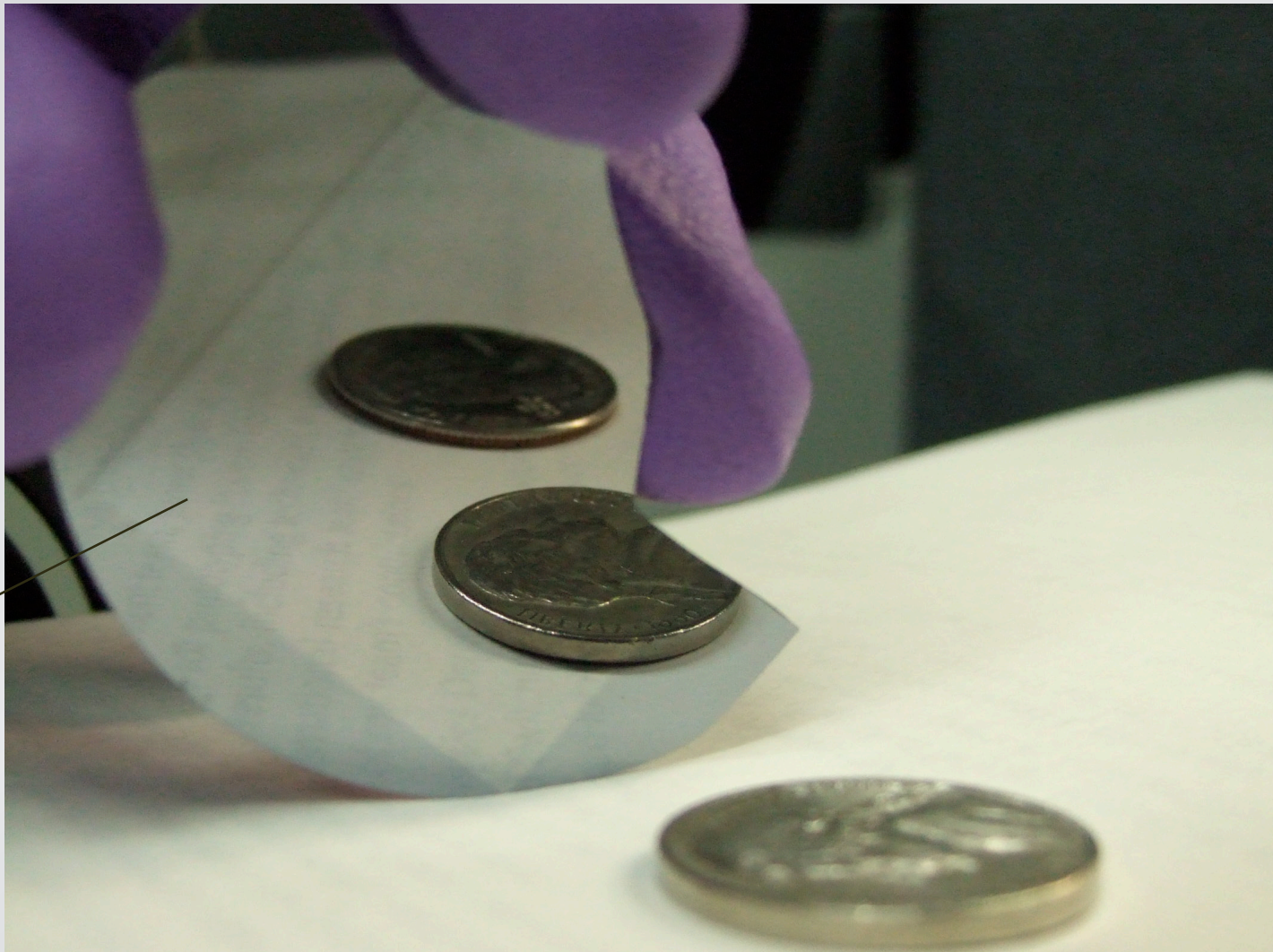
decouple ablation from melting



Structure

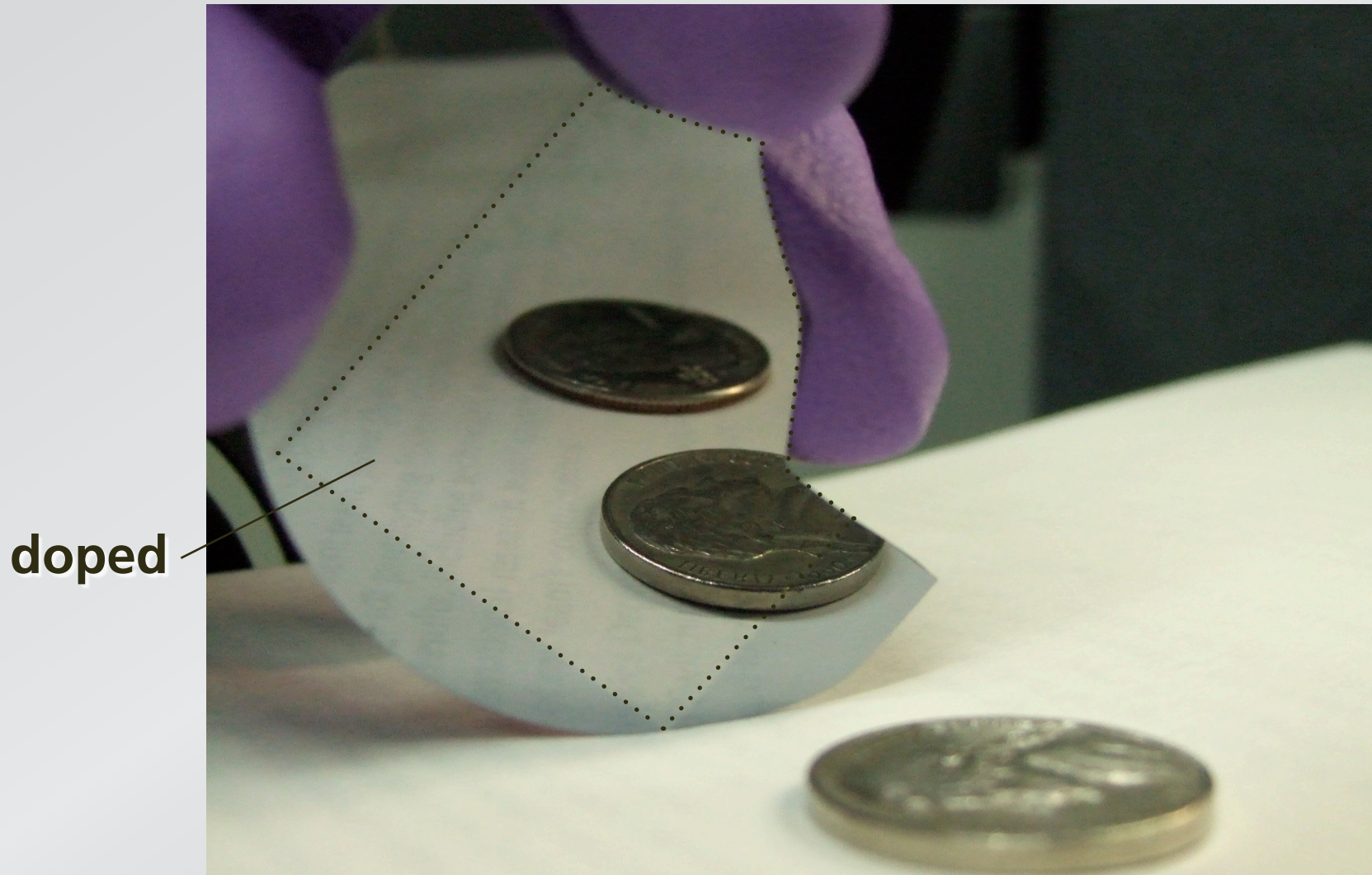
decouple ablation from melting

doped



Structure

decouple ablation from melting

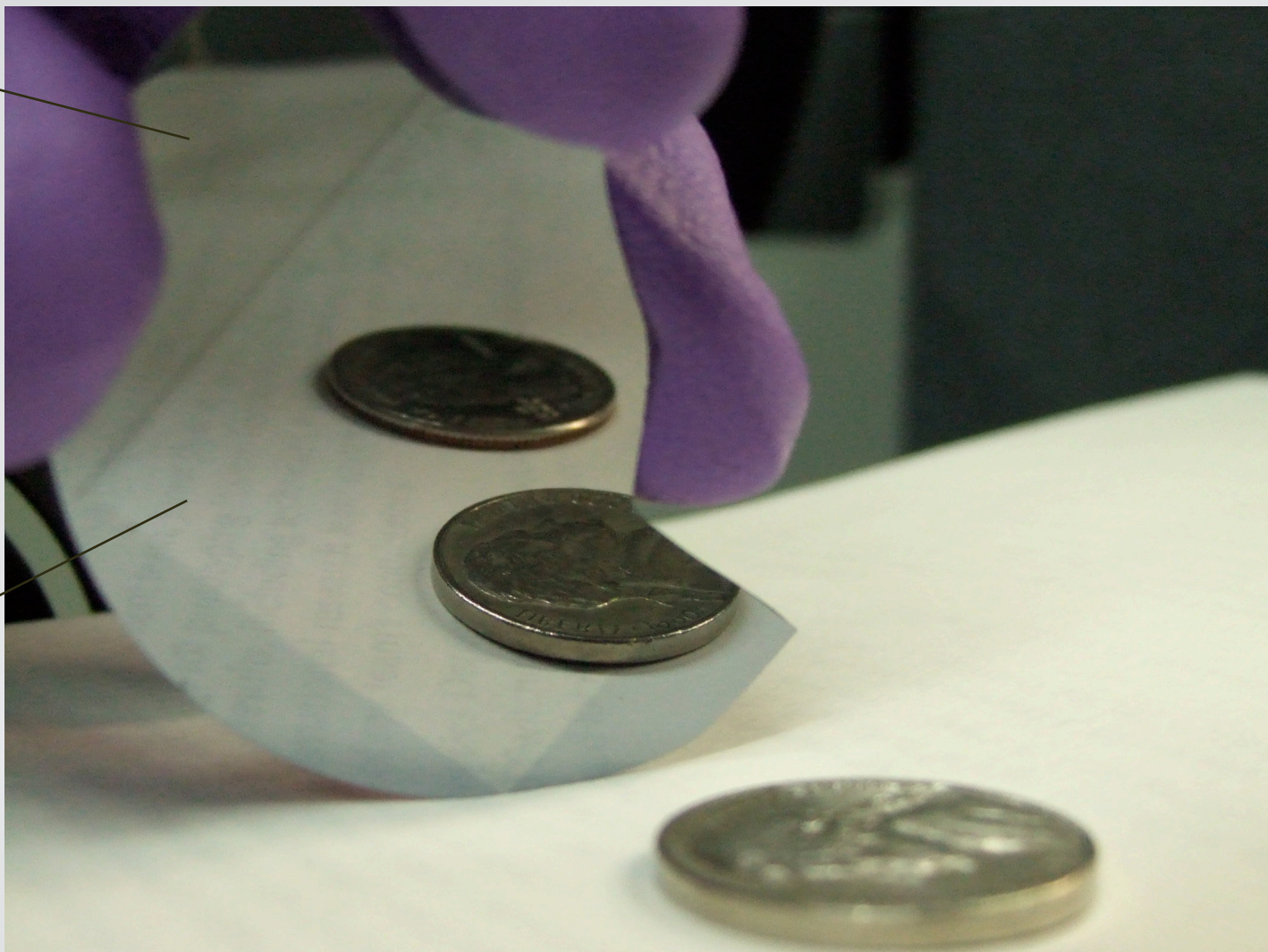


Structure

decouple ablation from melting

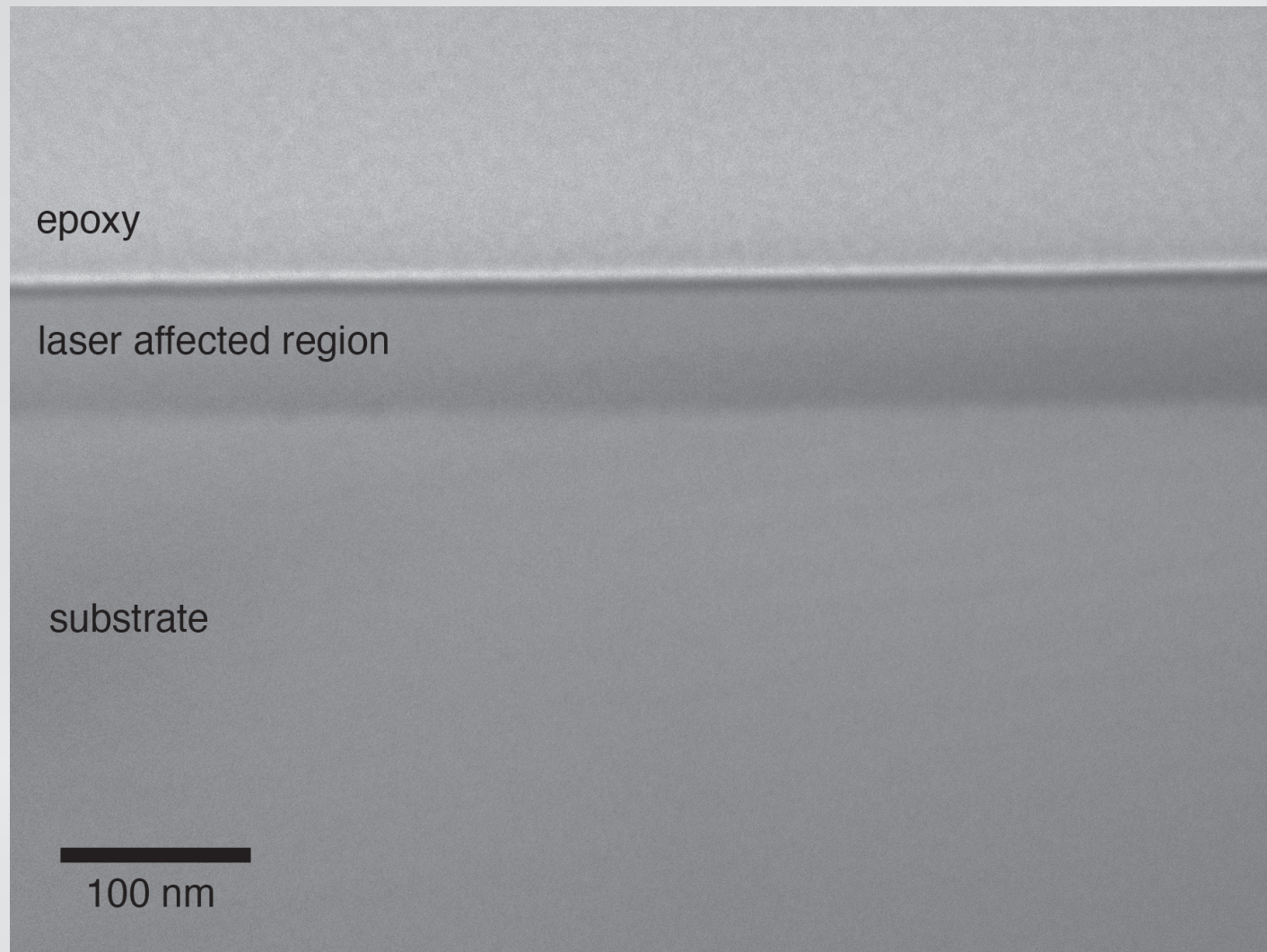
undoped

doped



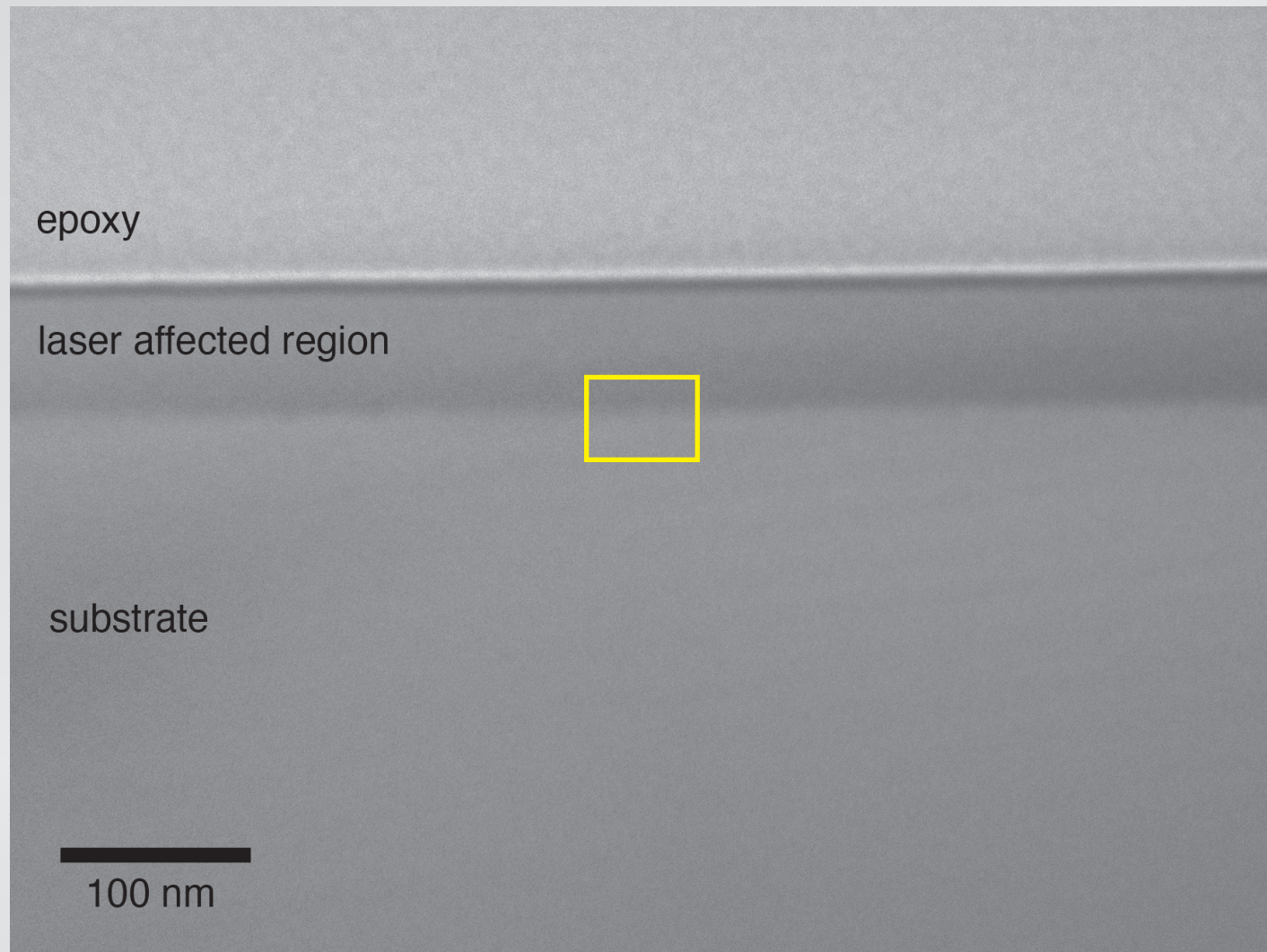
Structure

decouple ablation from melting



Structure

decouple ablation from melting



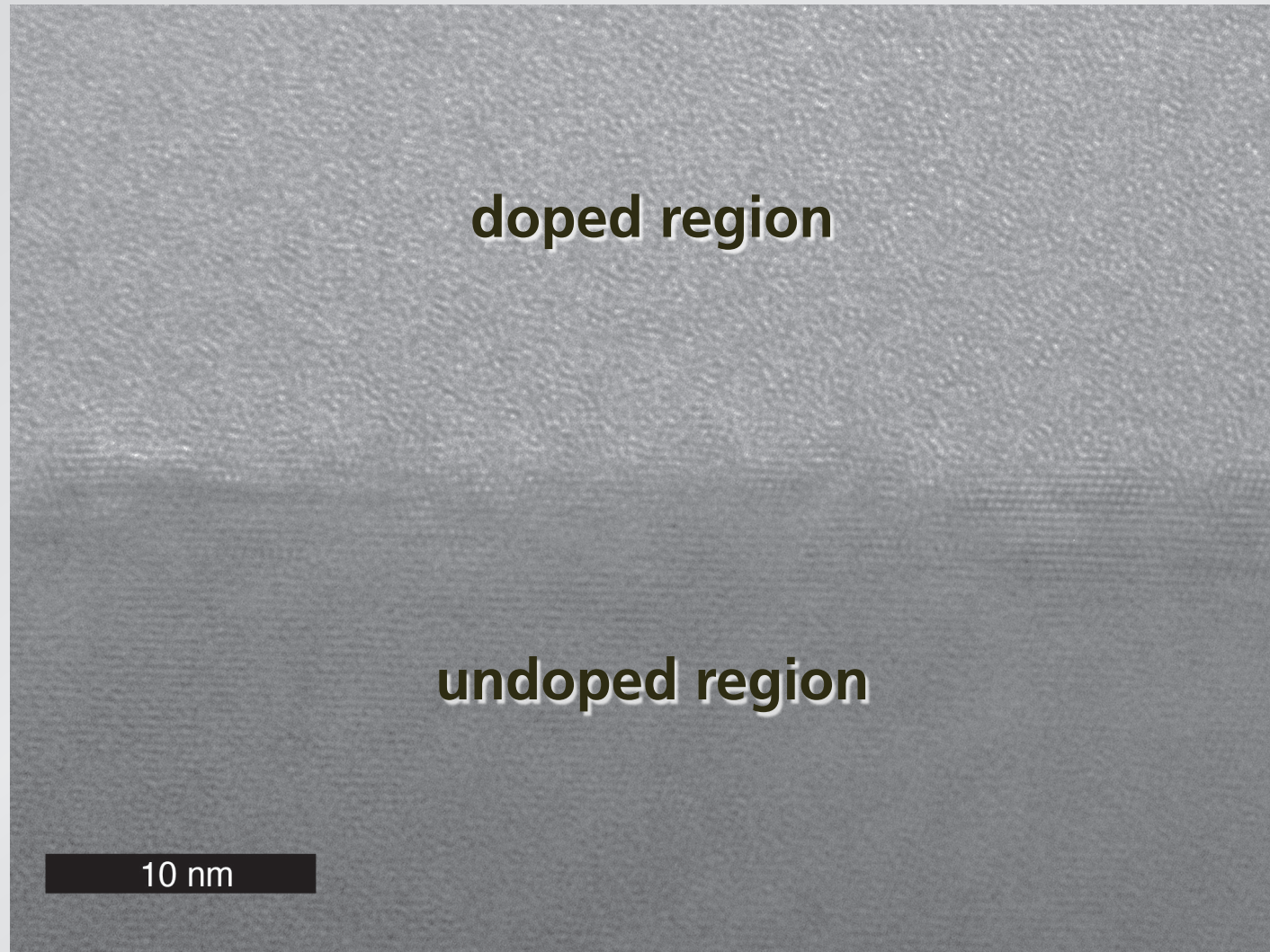
Structure

decouple ablation from melting



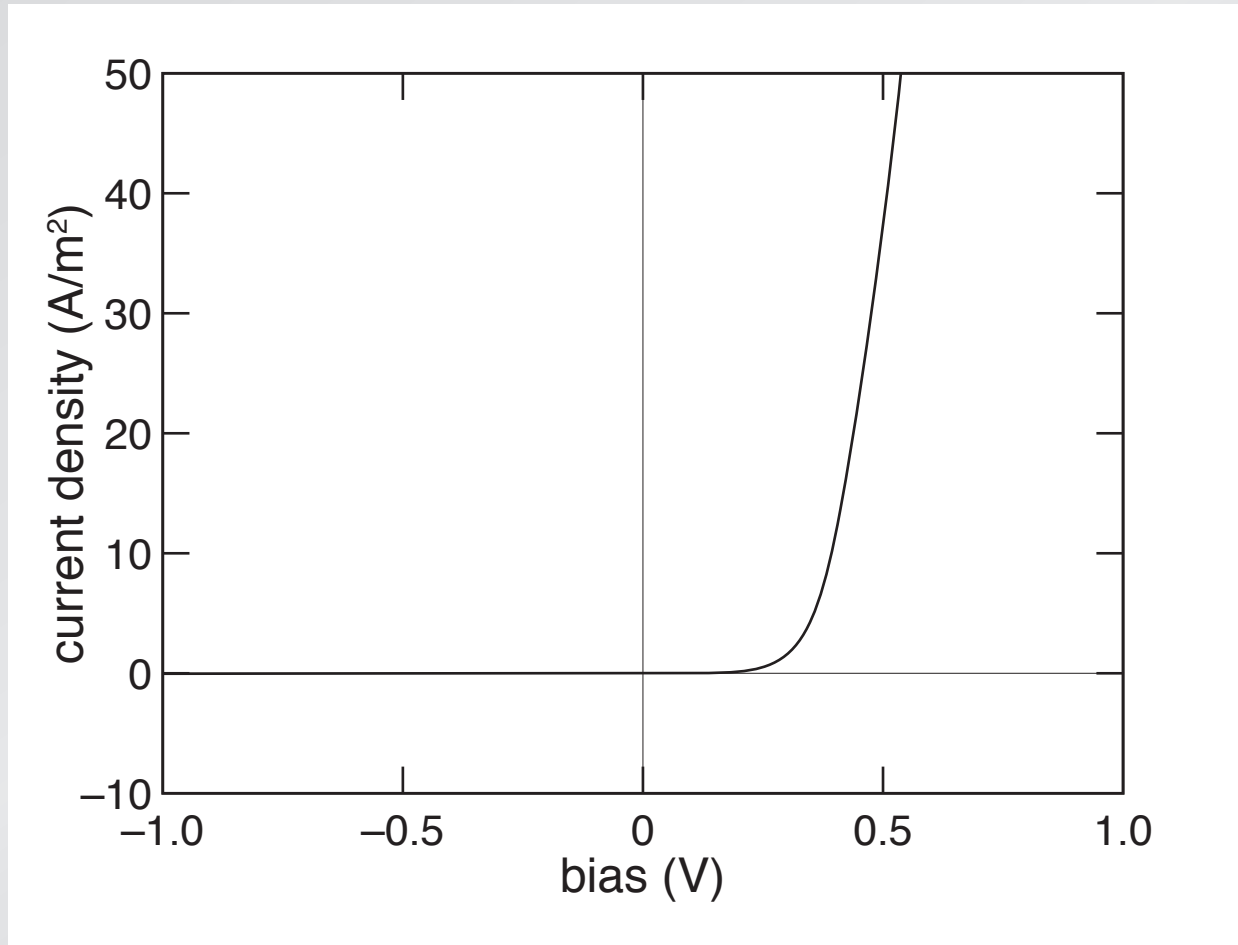
Structure

decouple ablation from melting

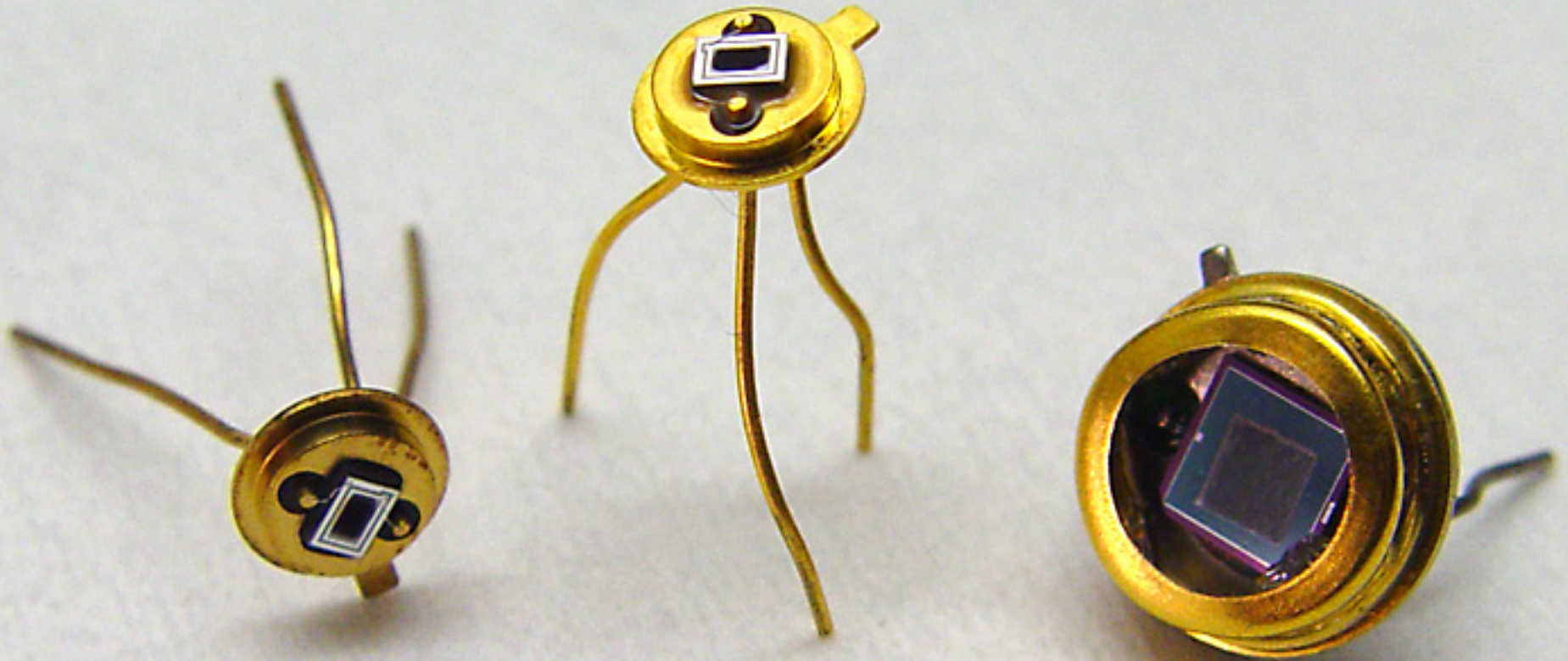


Optoelectronic properties

excellent rectification (after annealing)

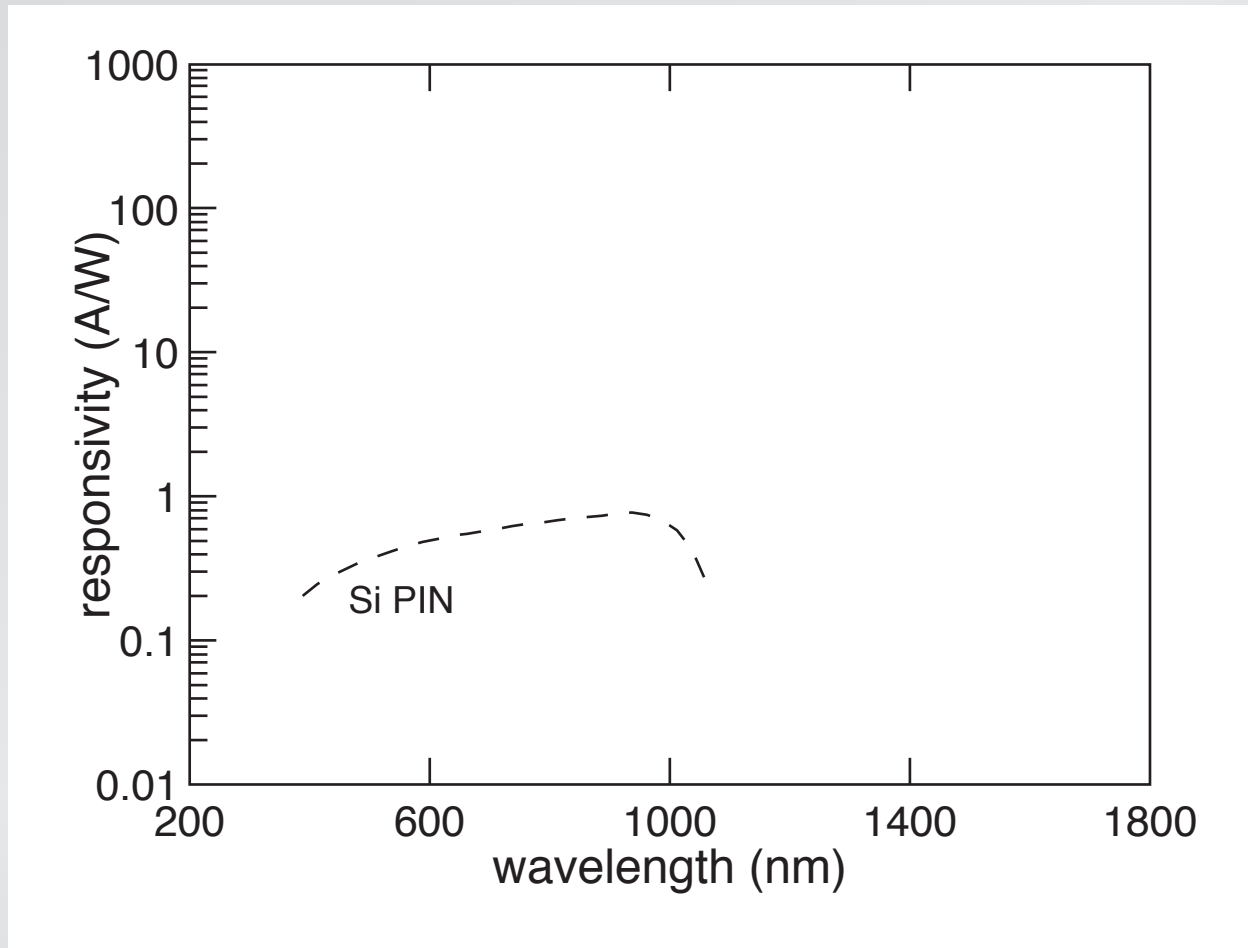


Devices



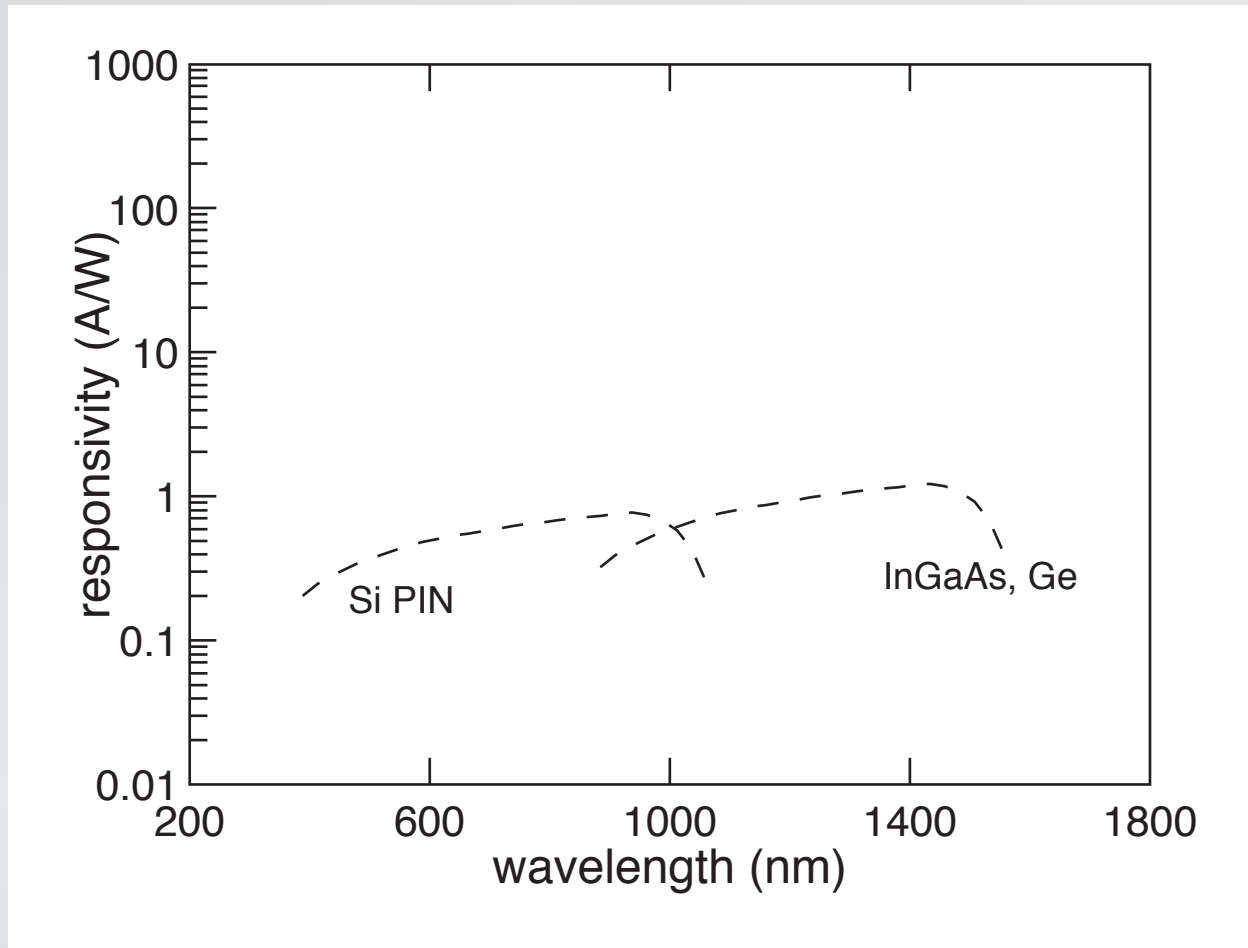
Devices

responsivity



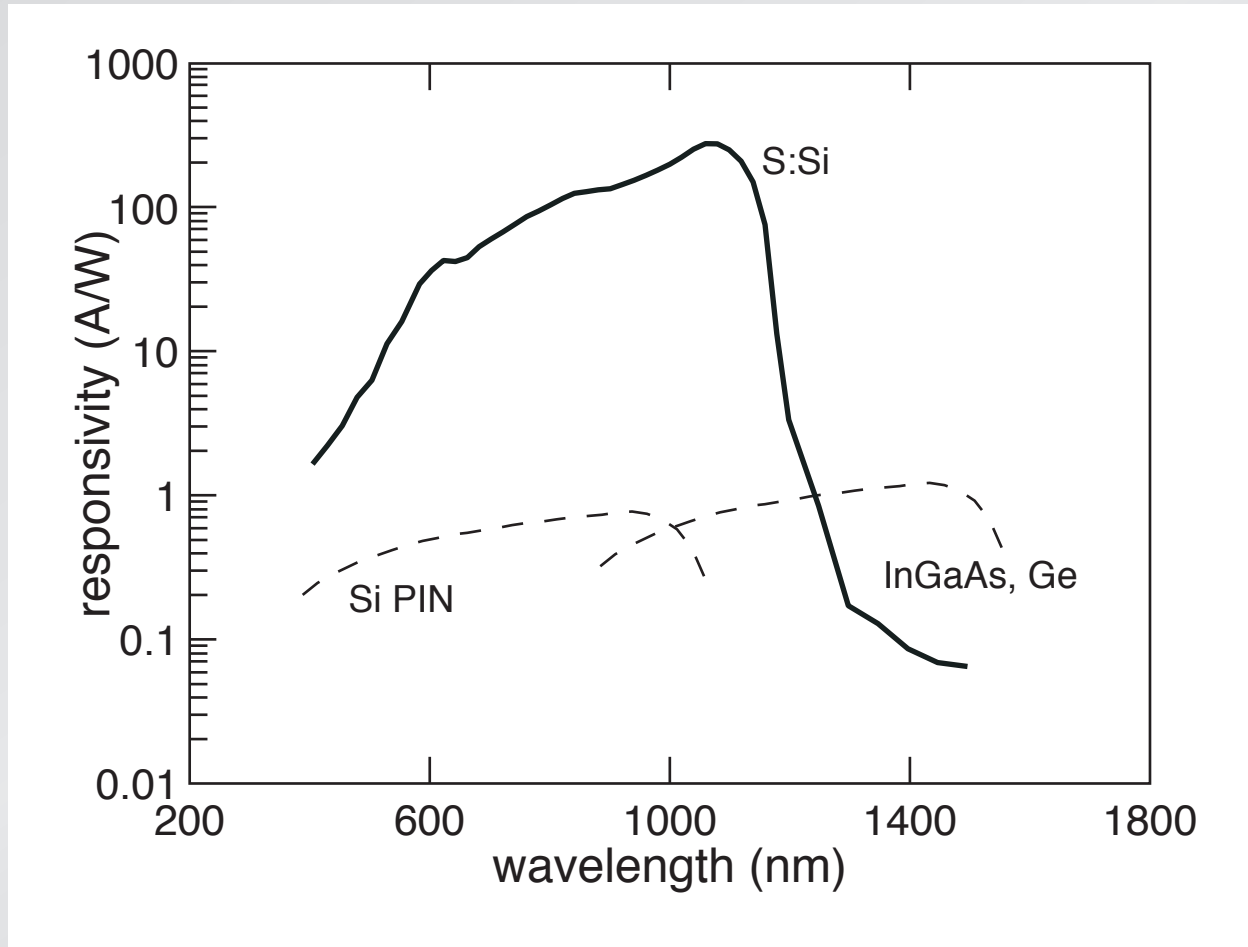
Devices

responsivity



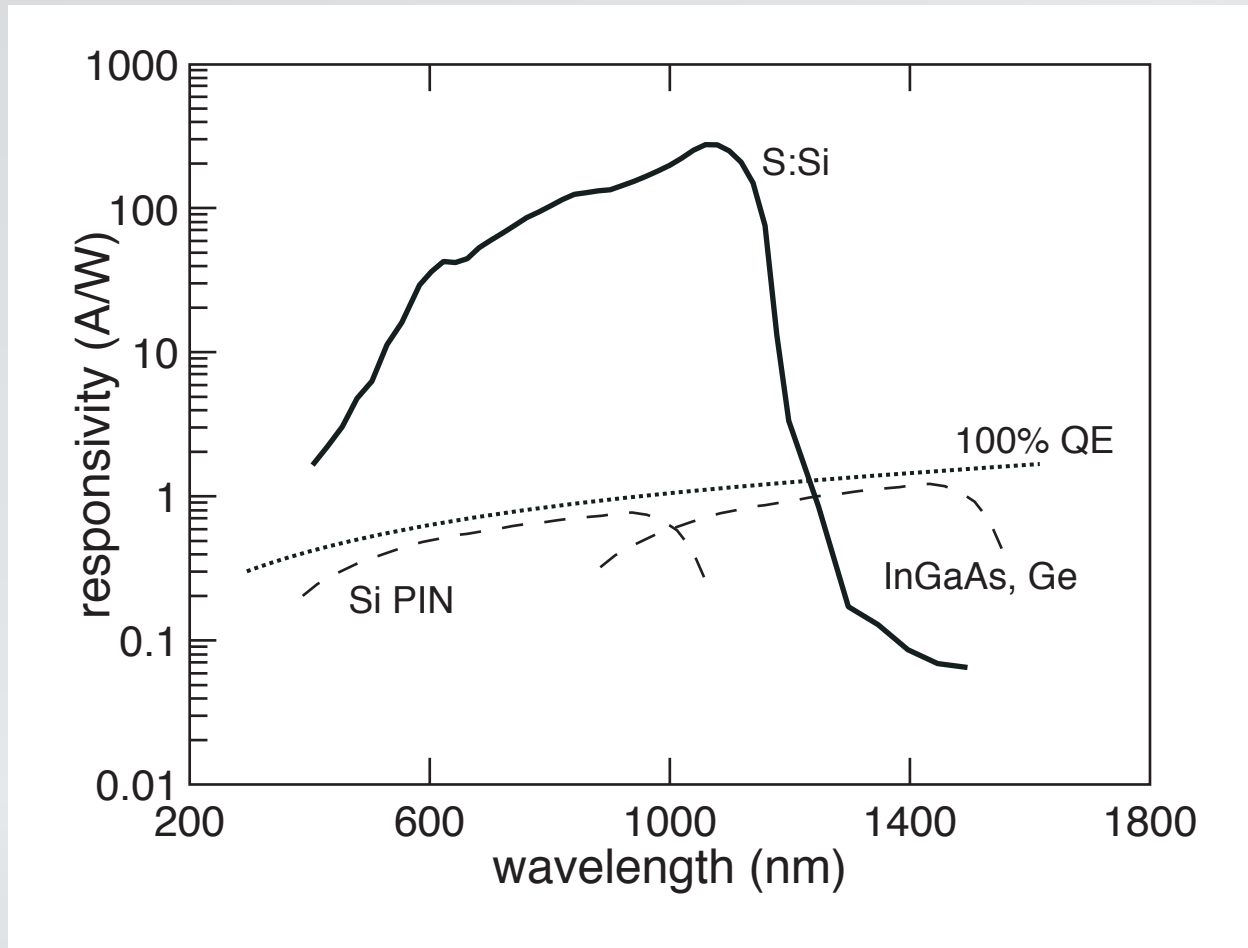
Devices

responsivity



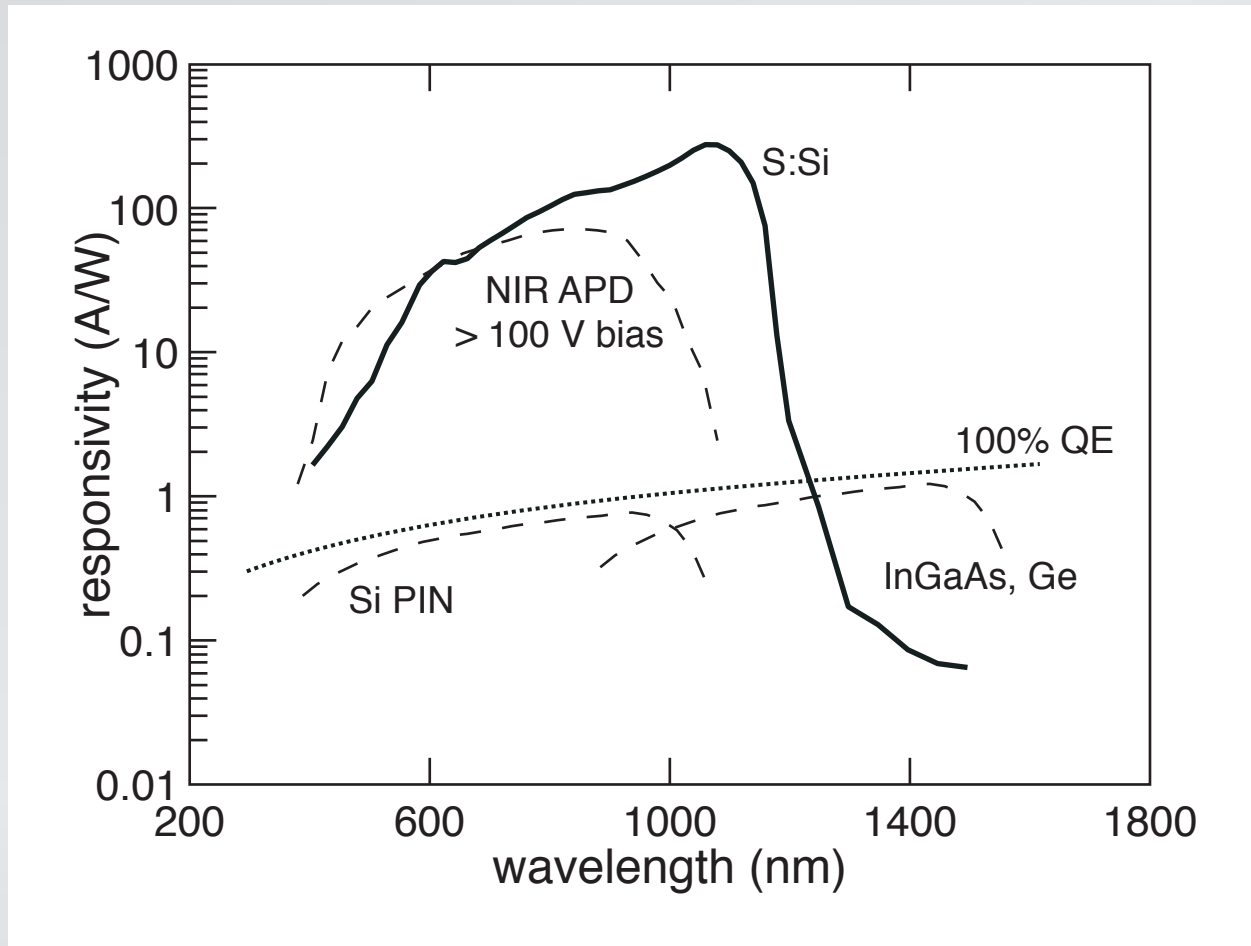
Devices

responsivity



Devices

responsivity



Devices



SiOnyx

<http://www.sionyx.com>

Innovation

Innovation

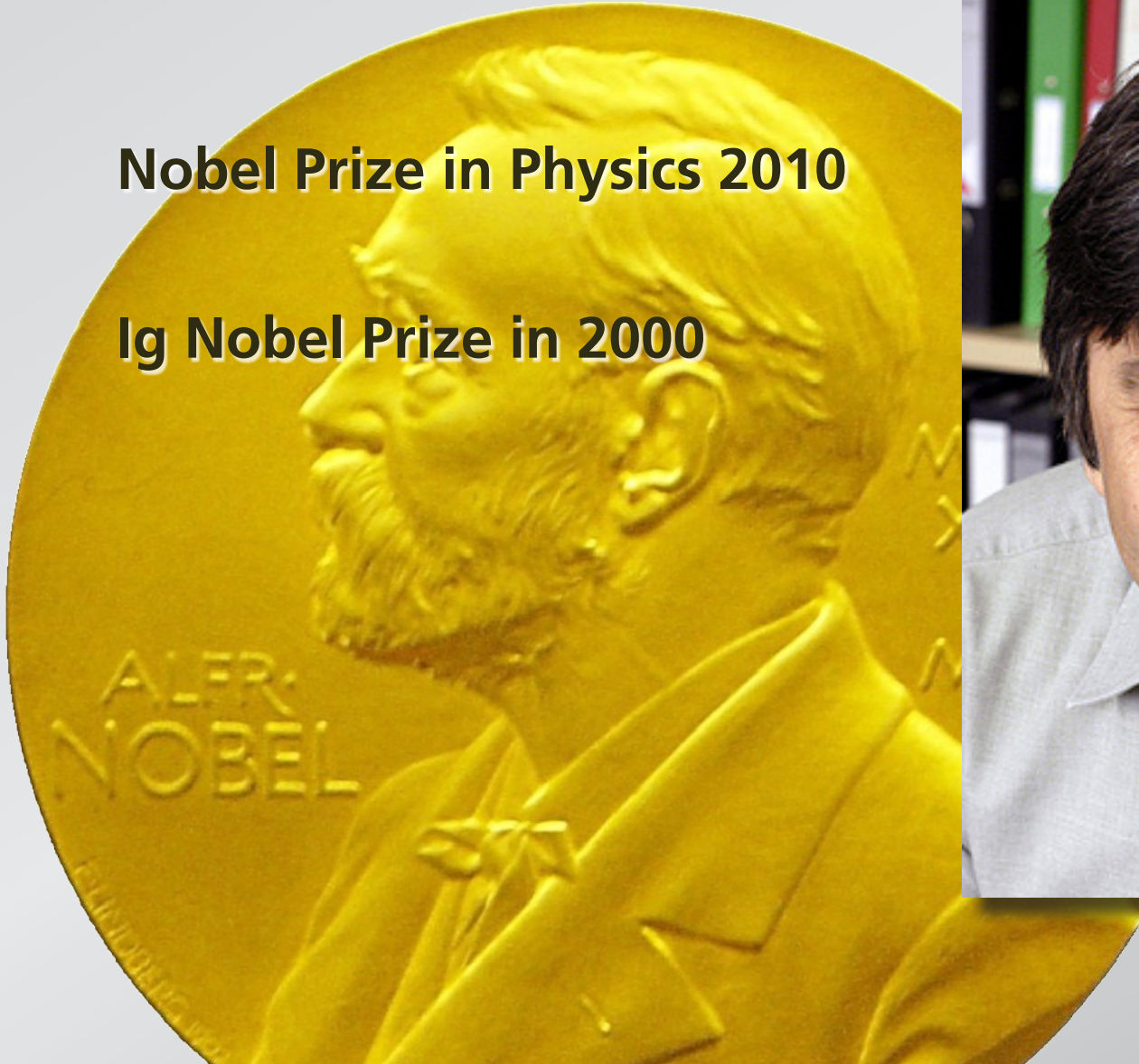
Nobel Prize in Physics 2010



Innovation

Nobel Prize in Physics 2010

Ig Nobel Prize in 2000



Innovation

**“For me it’s very boring to work
on the same thing year after year...”**

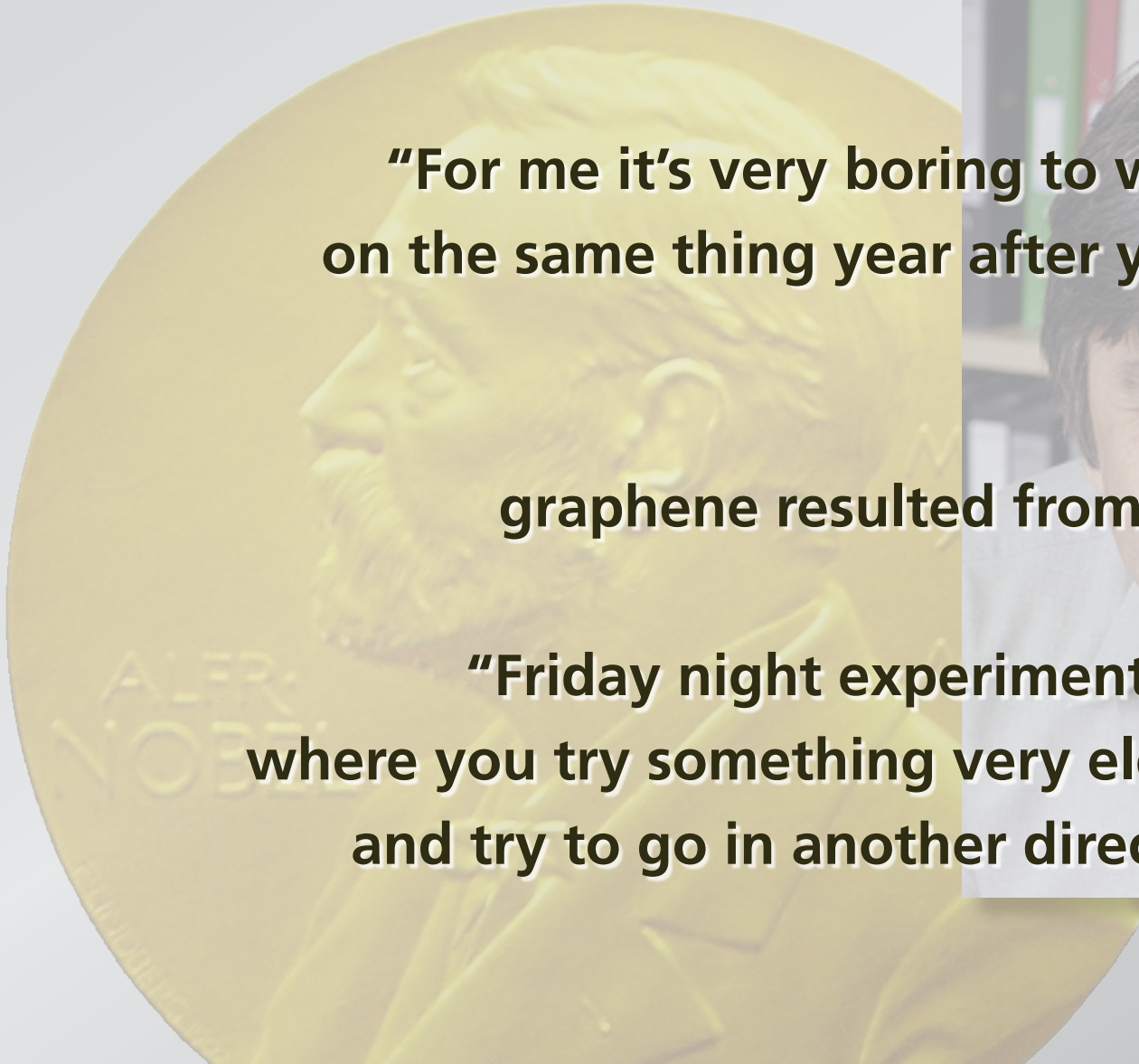
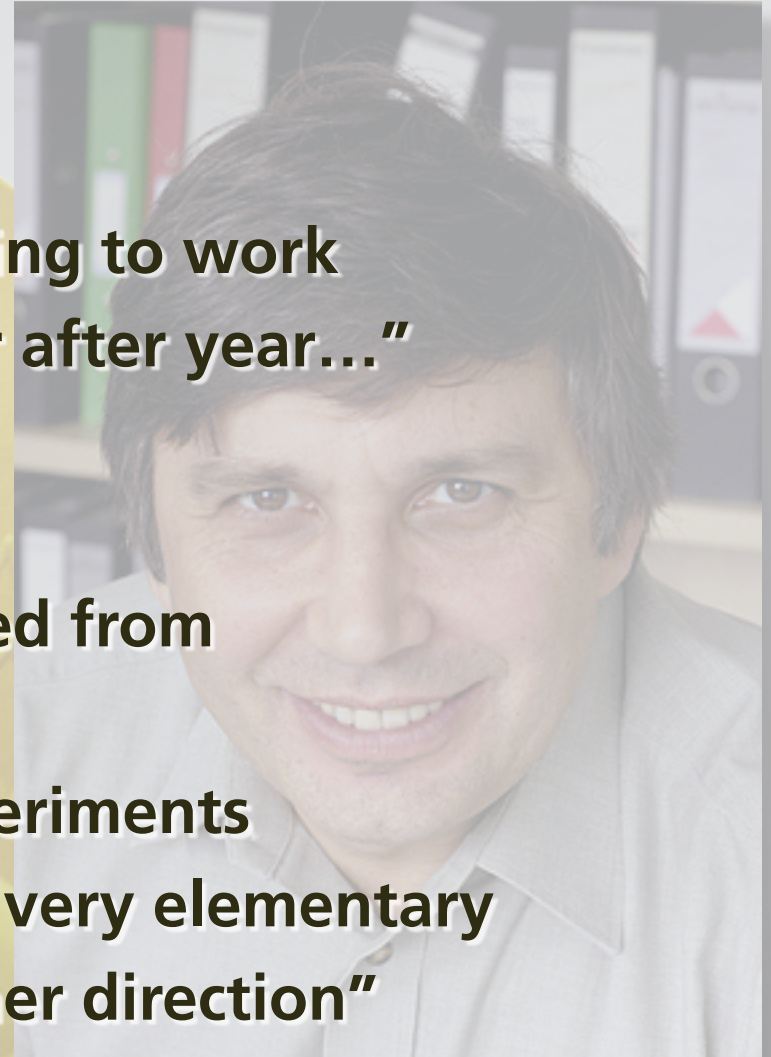


Innovation

“For me it’s very boring to work on the same thing year after year...”

graphene resulted from

“Friday night experiments where you try something very elementary and try to go in another direction”



Funding:

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