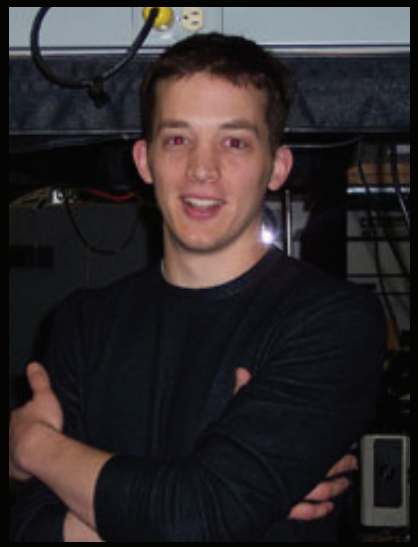
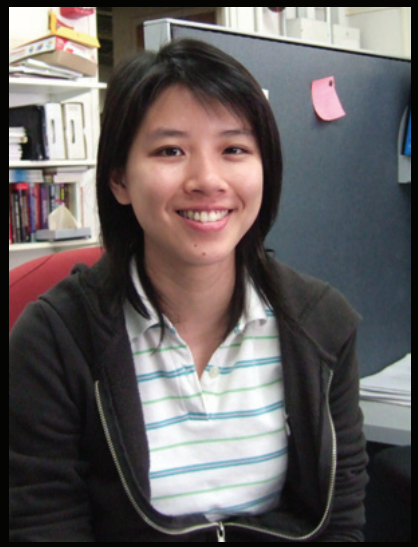
Black silicon: engineering an intermediate band in silicon for optical sensing and photovoltaics

G1 Faculty Lecture
Harvard University
Cambridge, MA, 31 October 2011



Mark Winkler

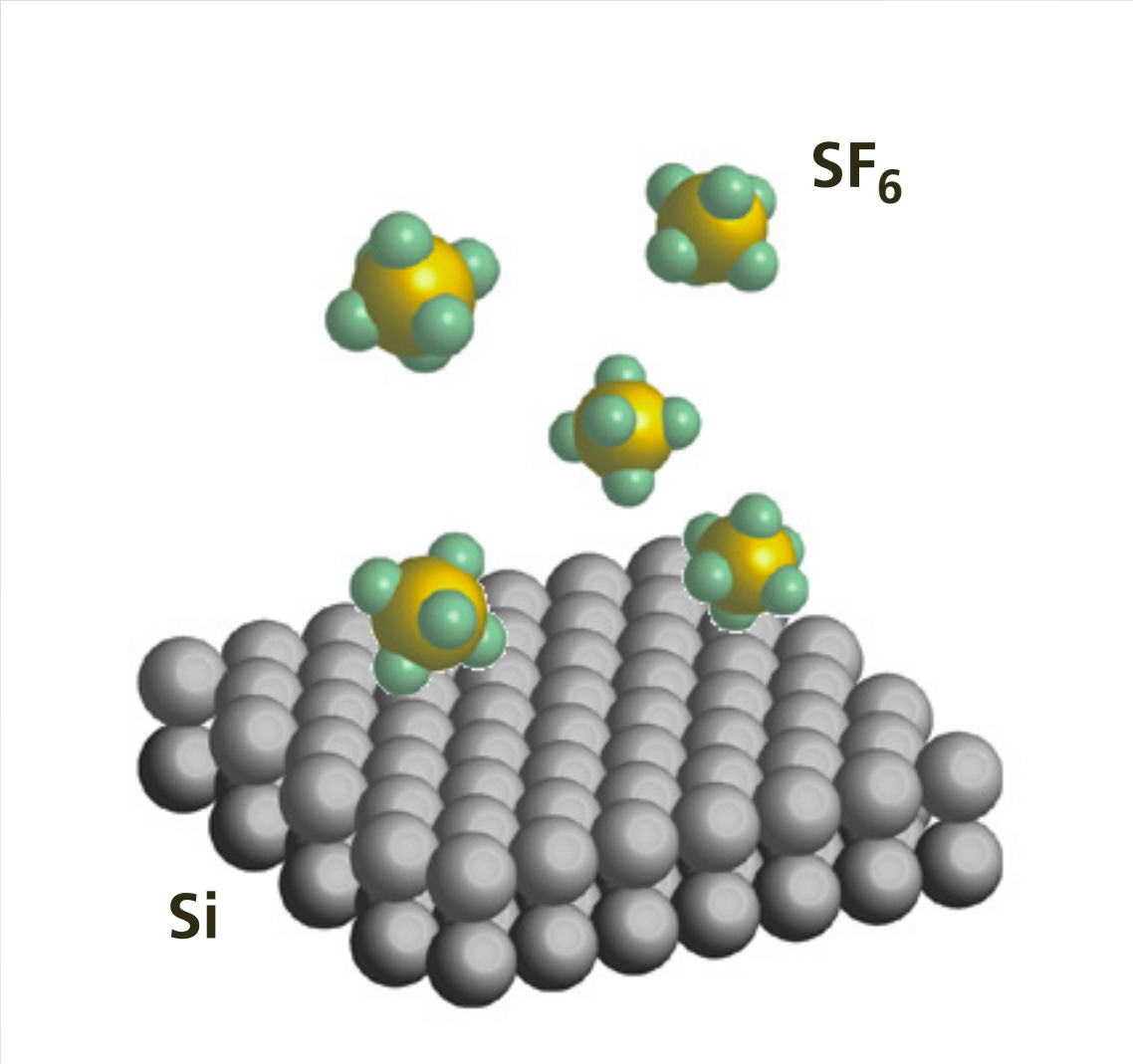
Renee Sher



Yu-Ting Lin

Eric Mazur

Introduction

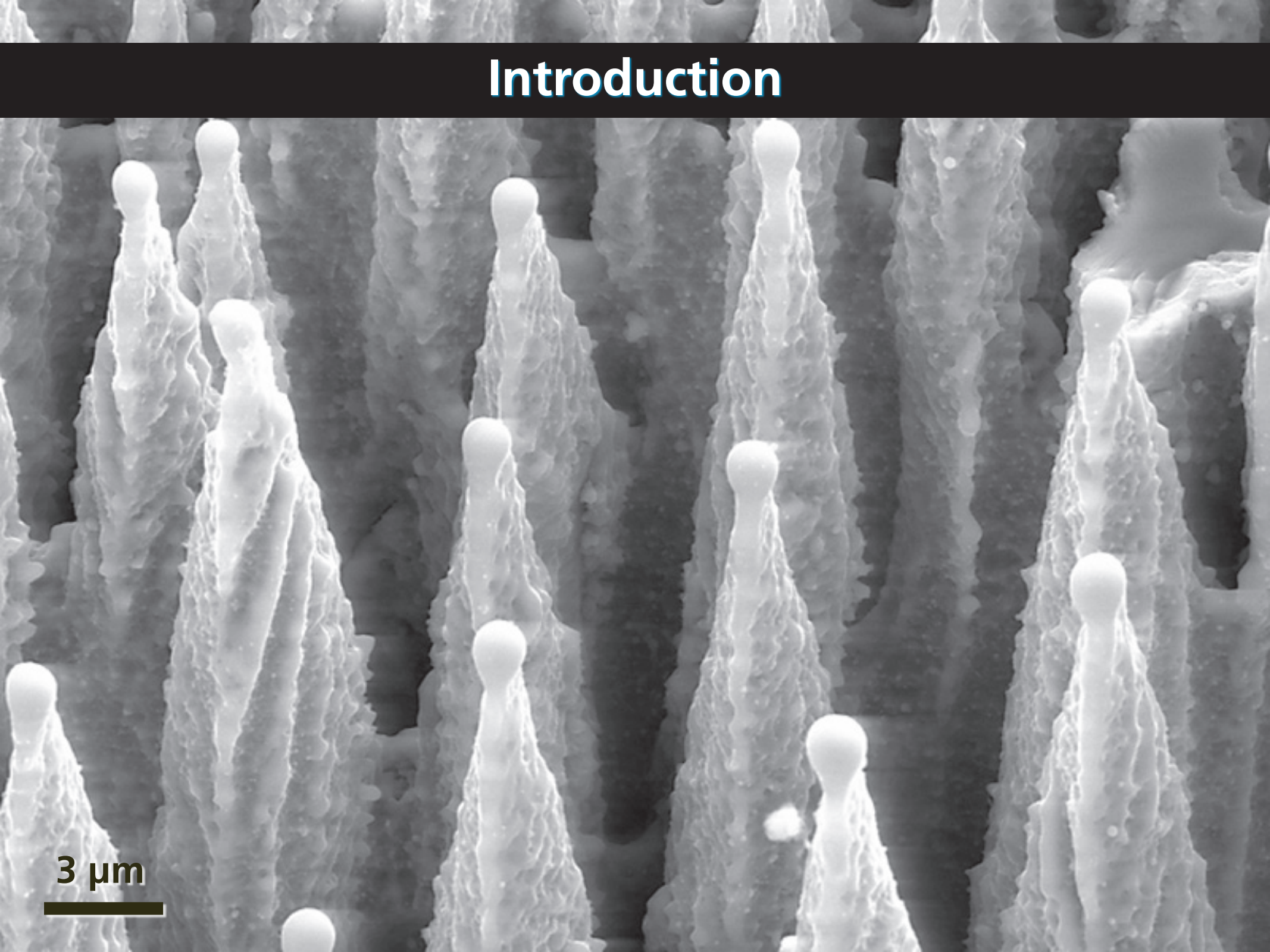


irradiate with 100-fs 10 kJ/m^2 pulses

Introduction

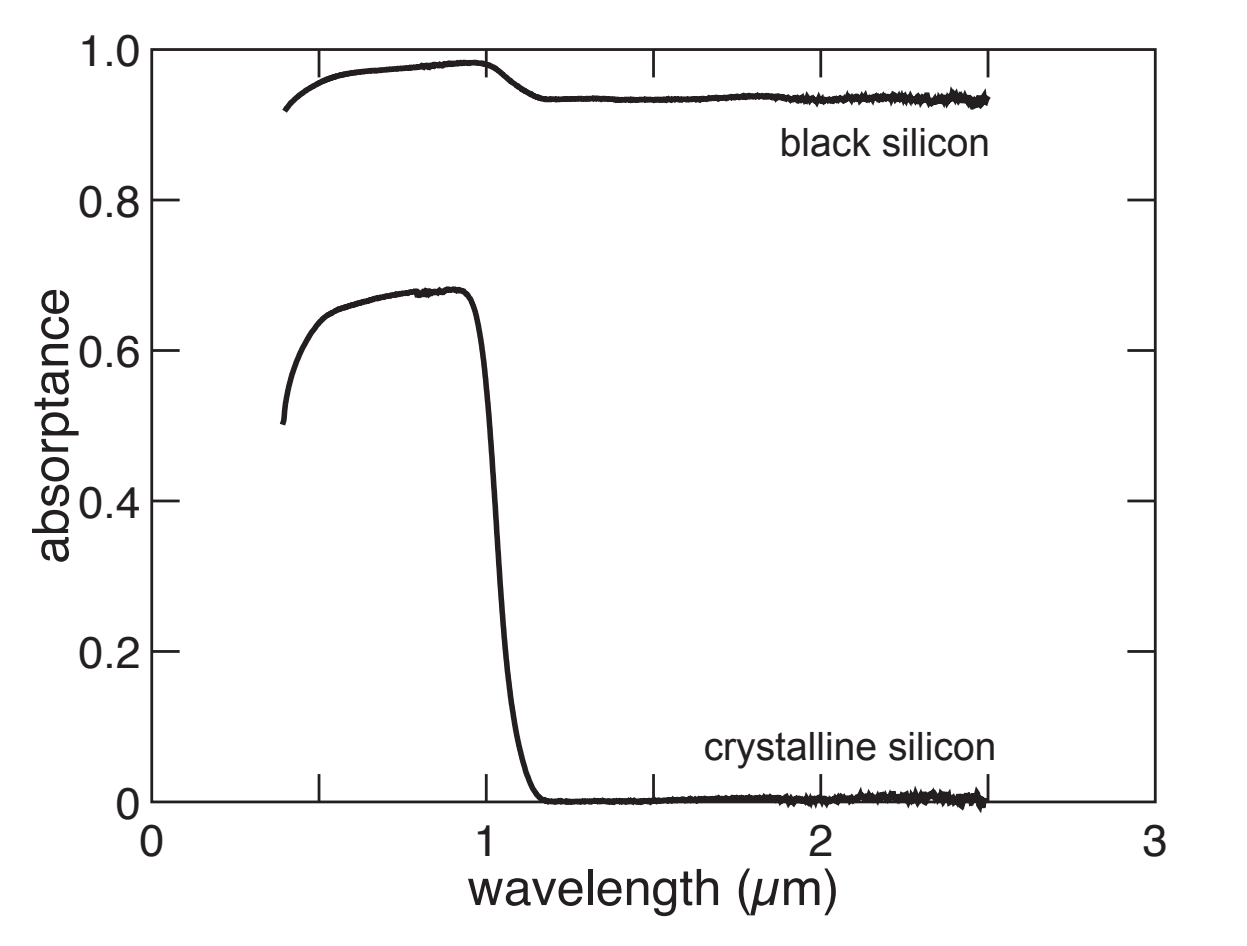
“black silicon”

Introduction



Introduction

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



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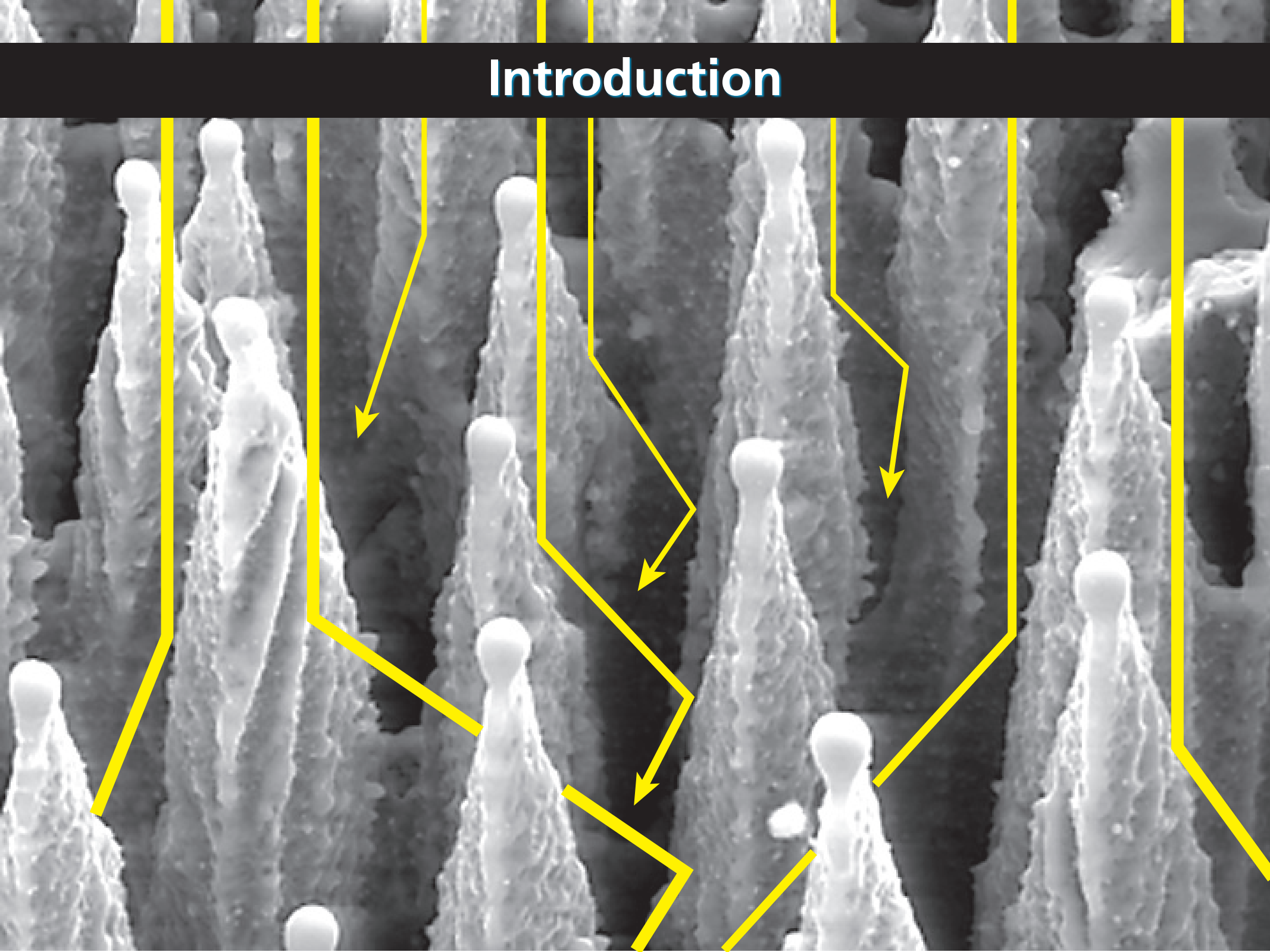

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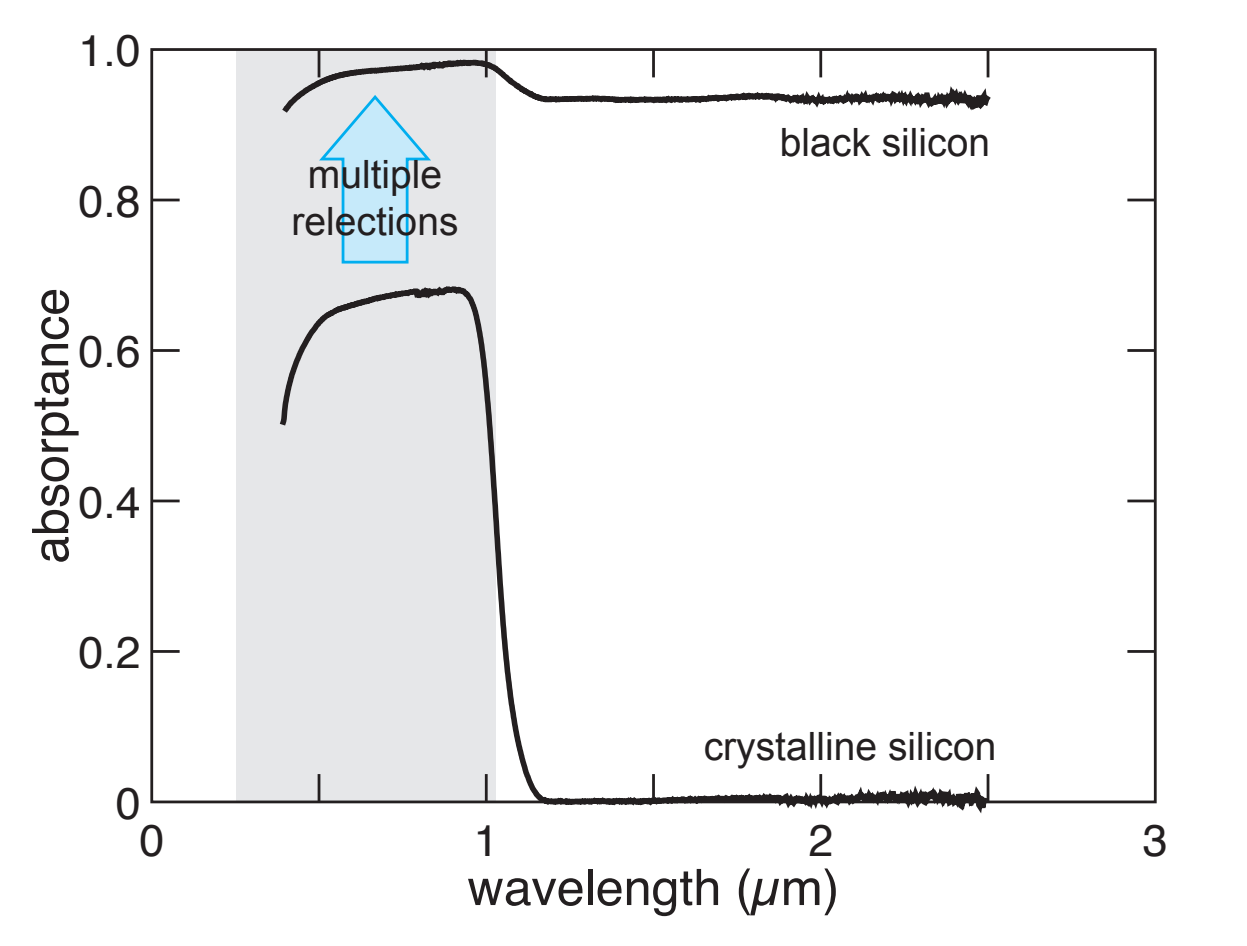
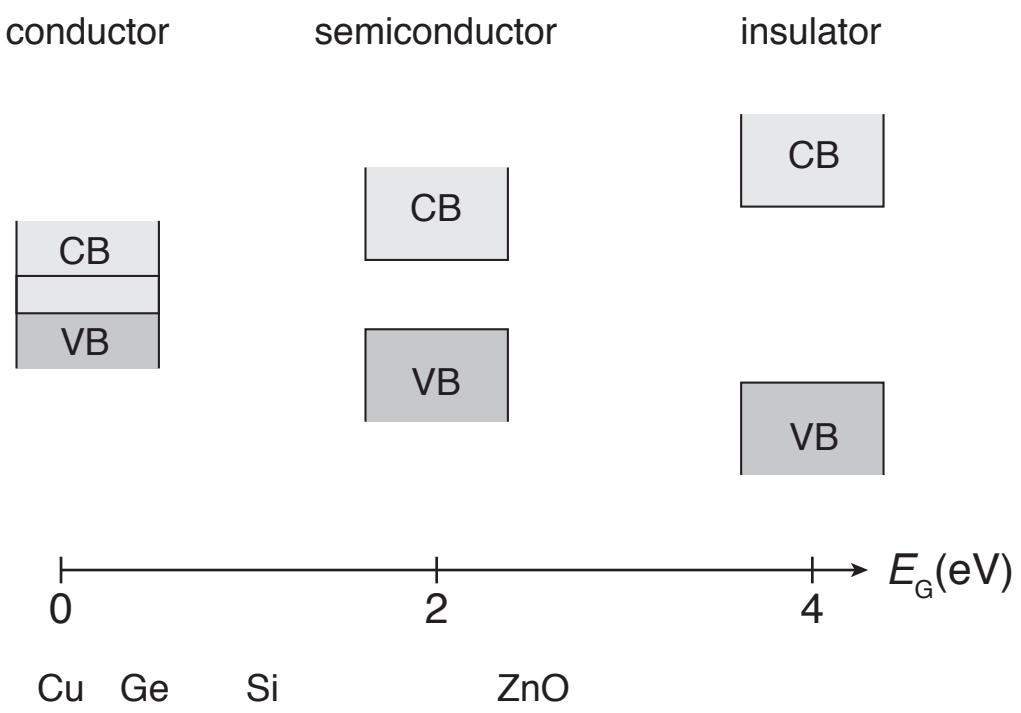


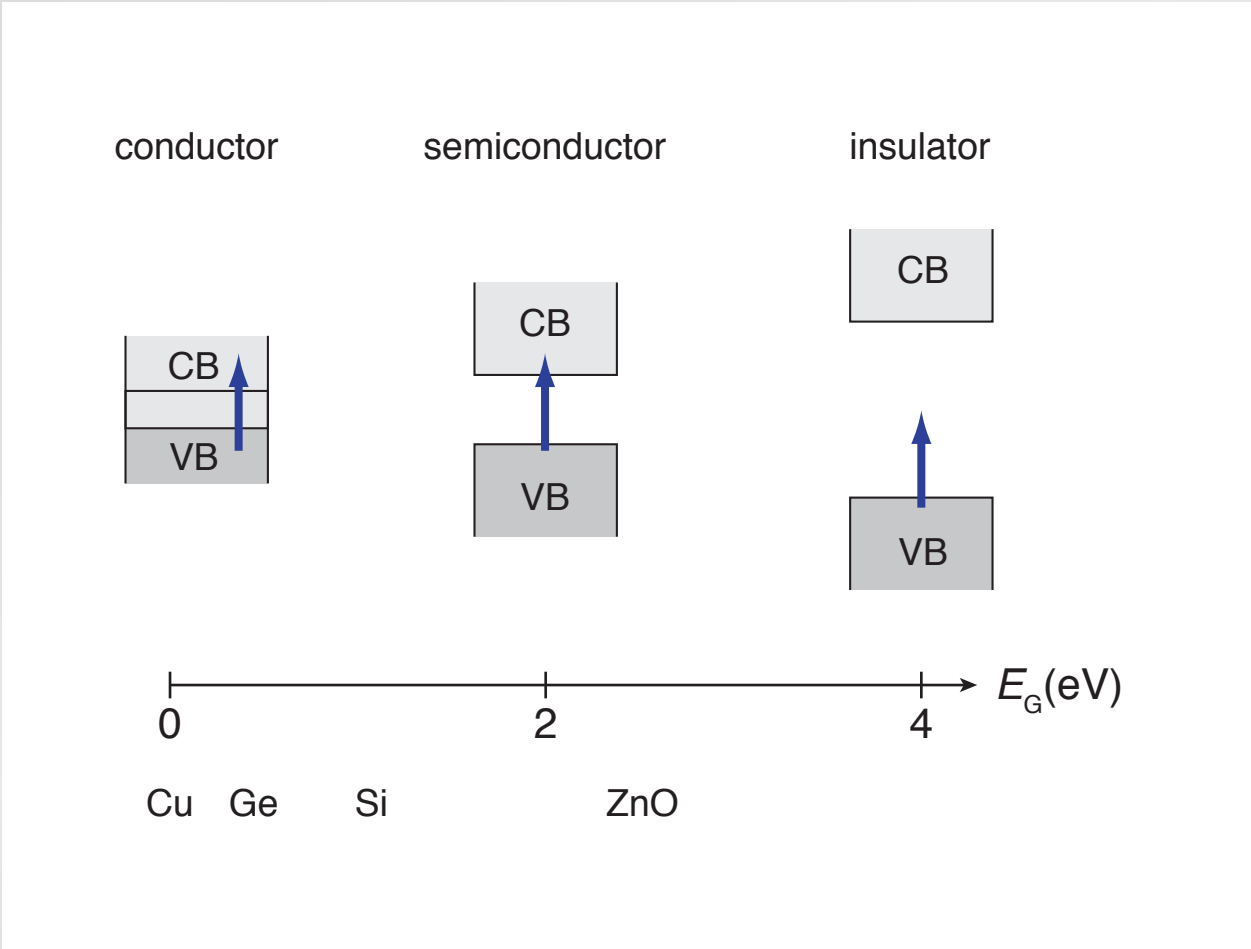
Introduction

new process & new class of material!



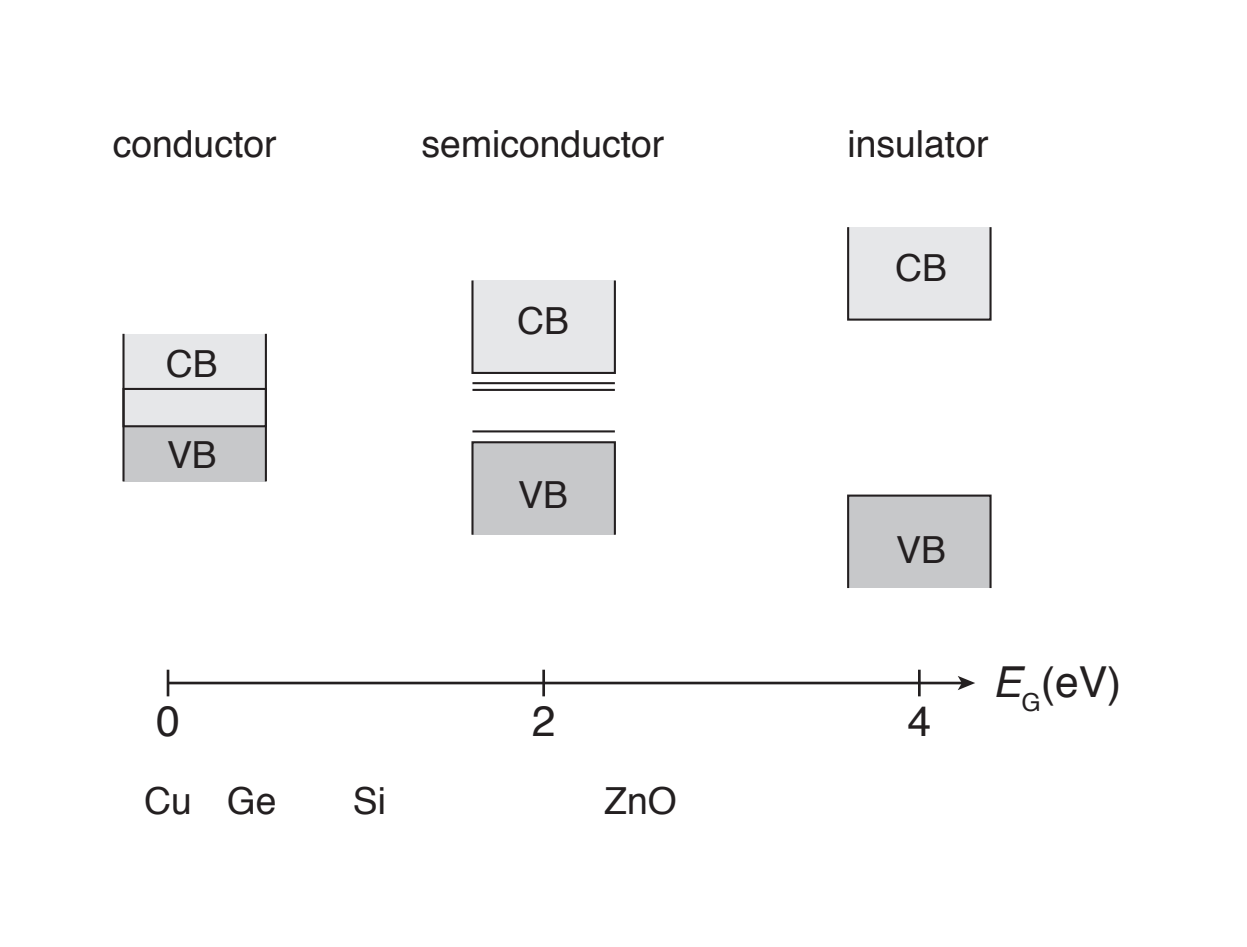
Introduction

gap determines optical and electronic properties



Introduction

shallow-level dopants control electronic properties



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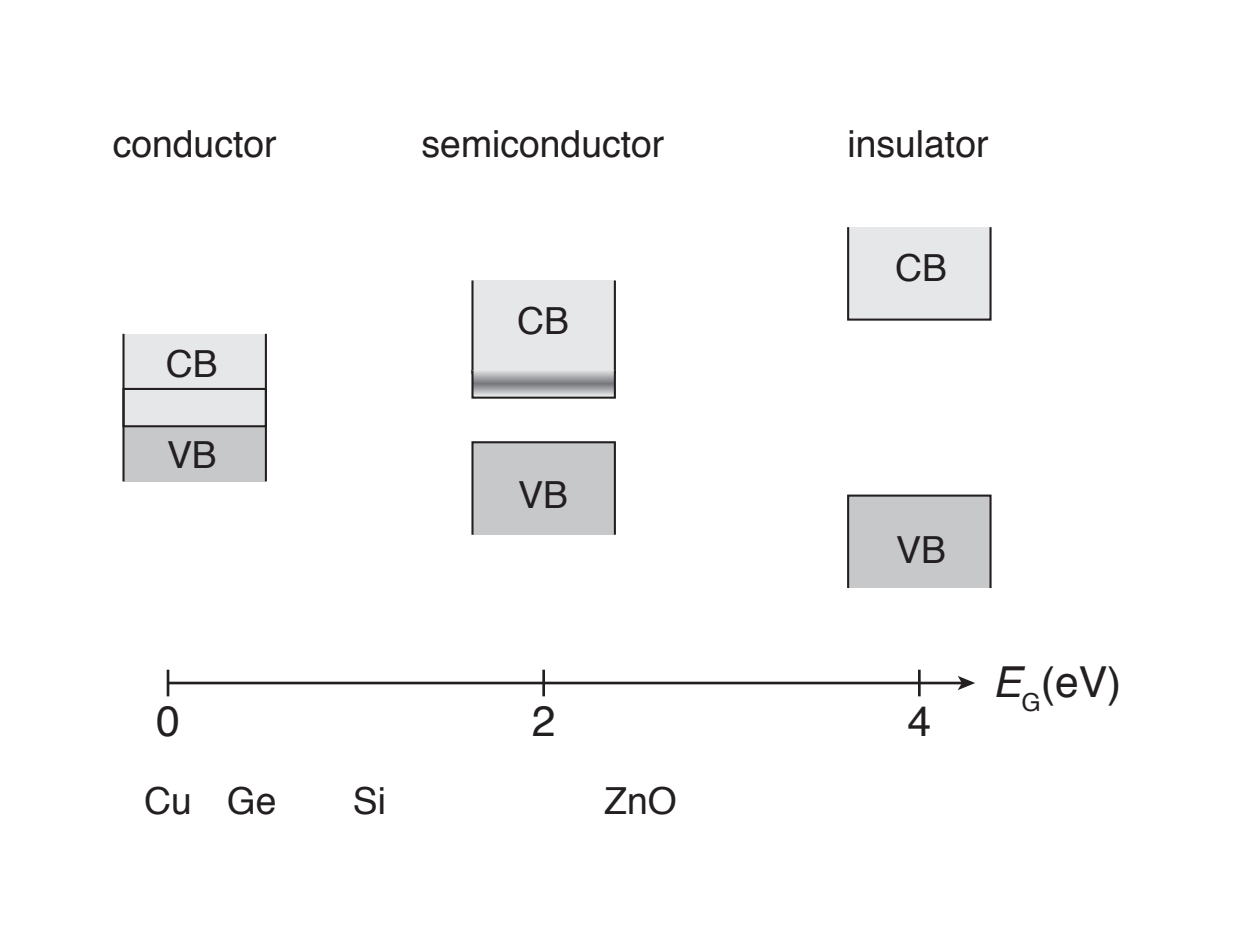
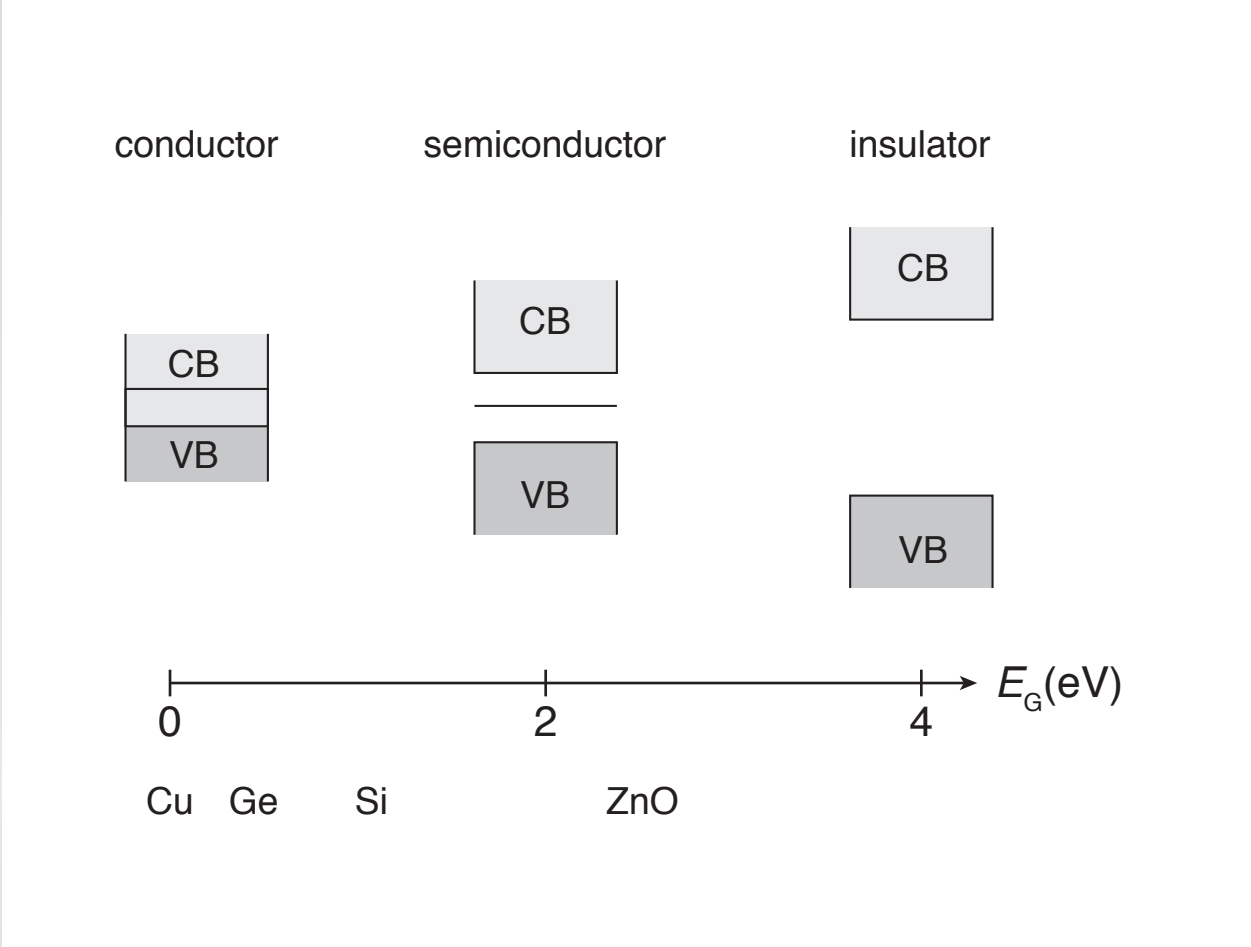


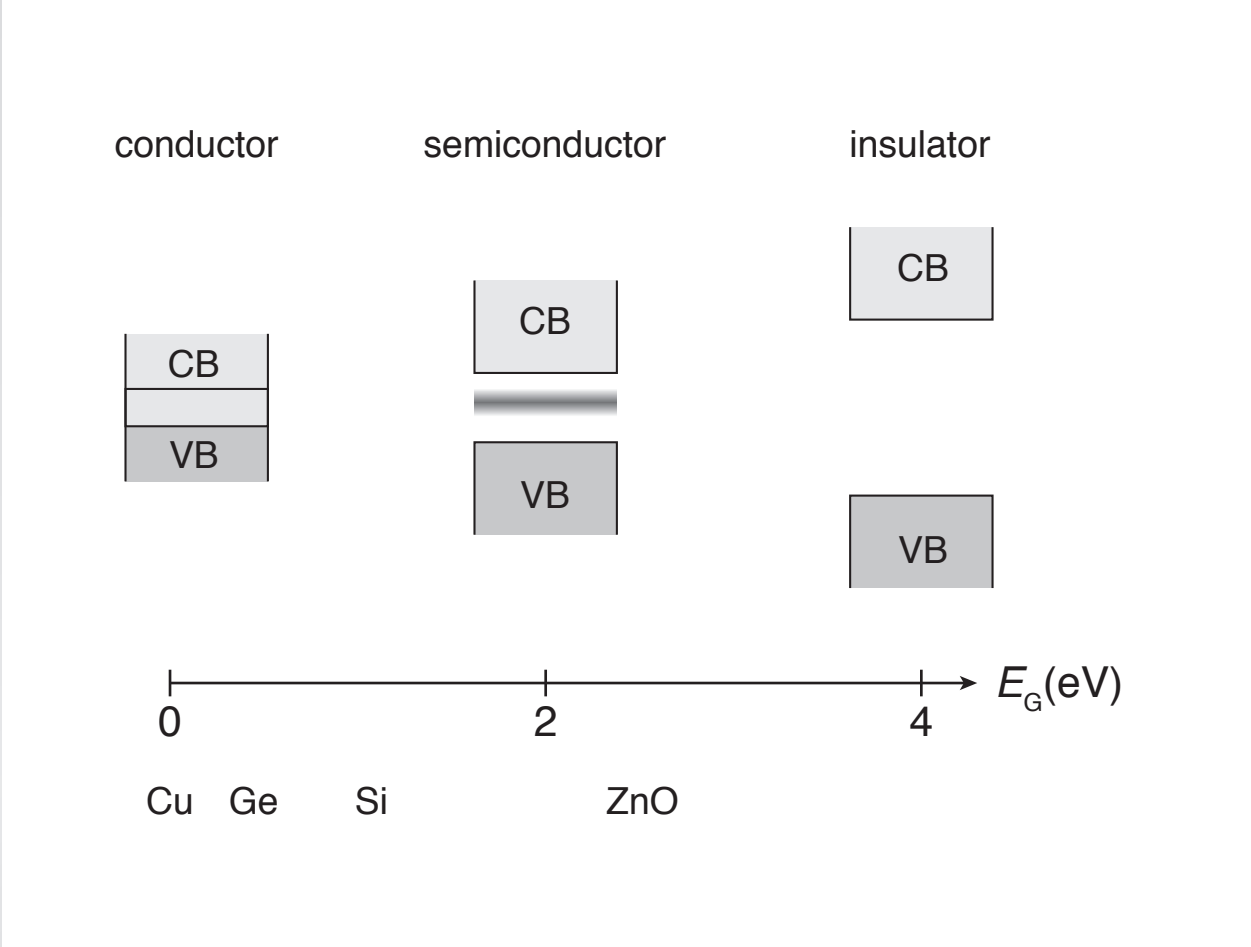
Introduction

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	

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Introduction

focus on chalcogen-doped silicon

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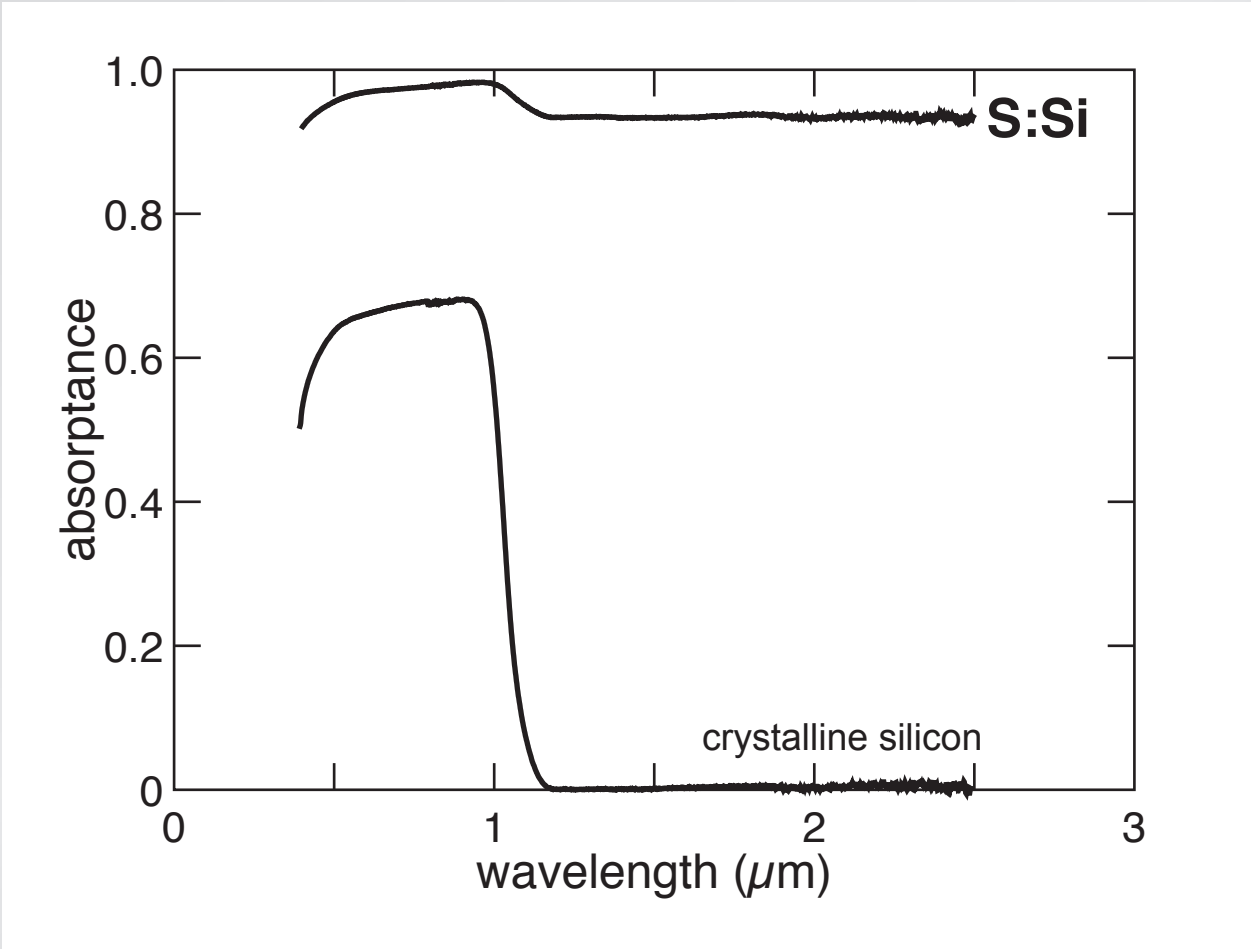

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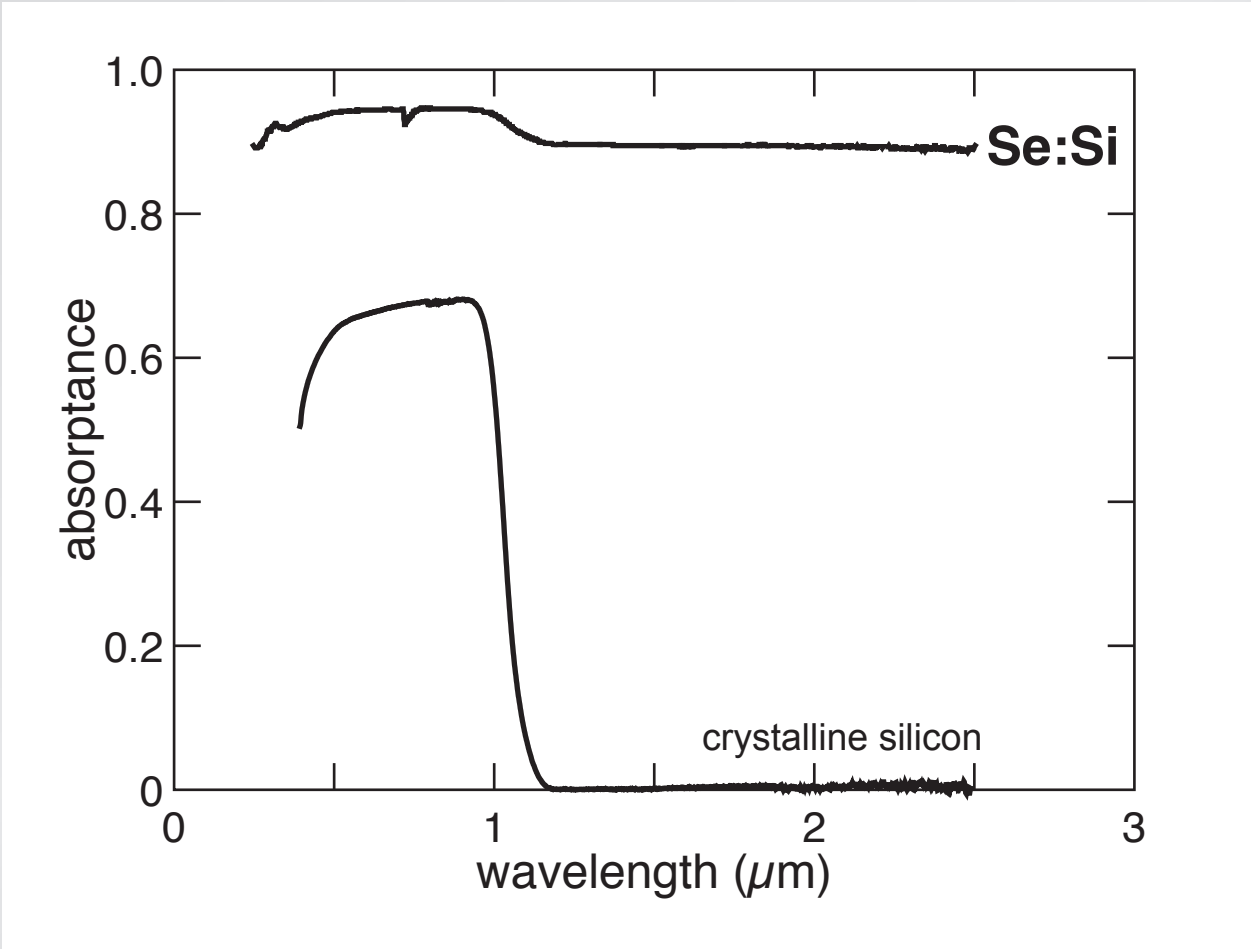
focus on chalcogen-doped silicon



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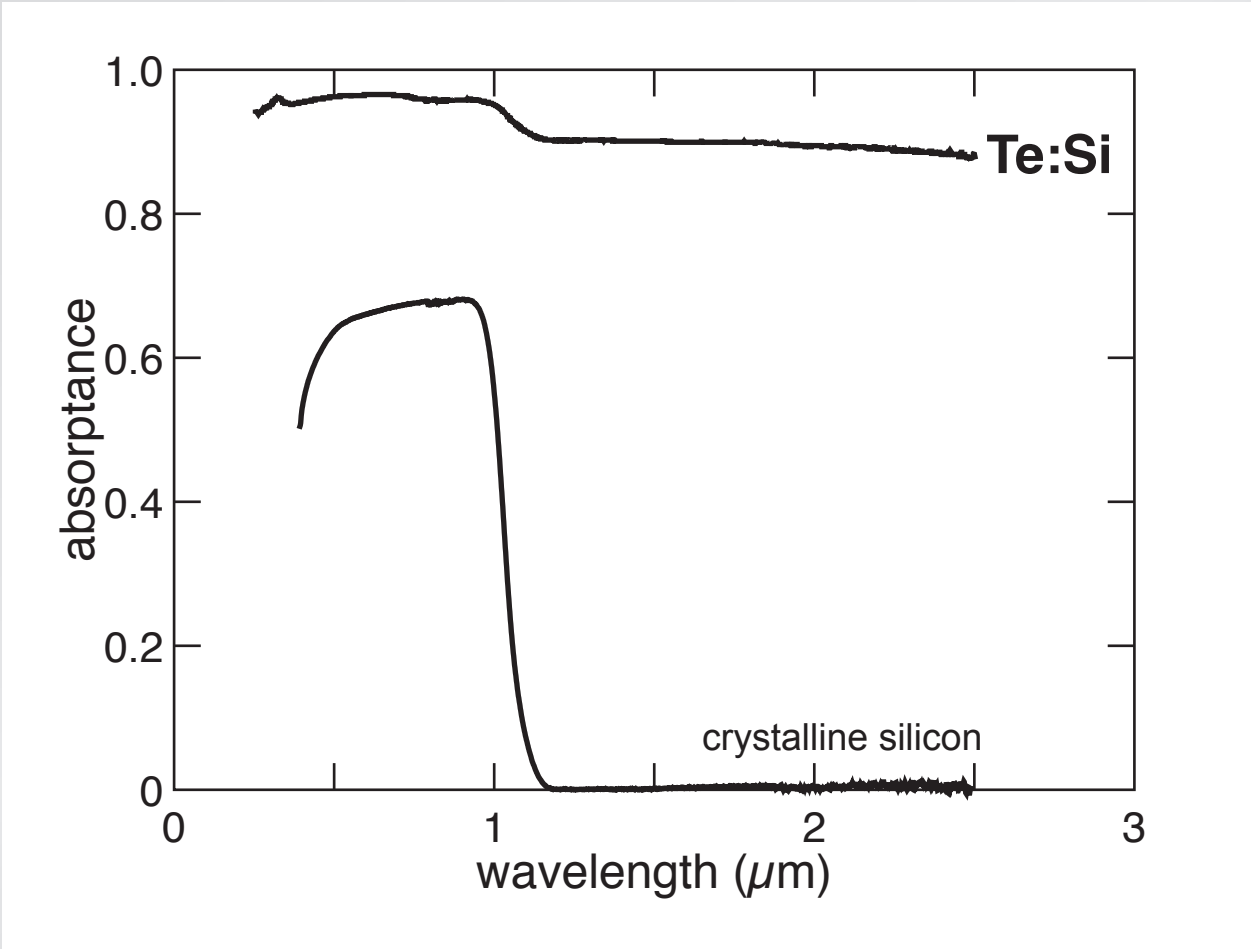
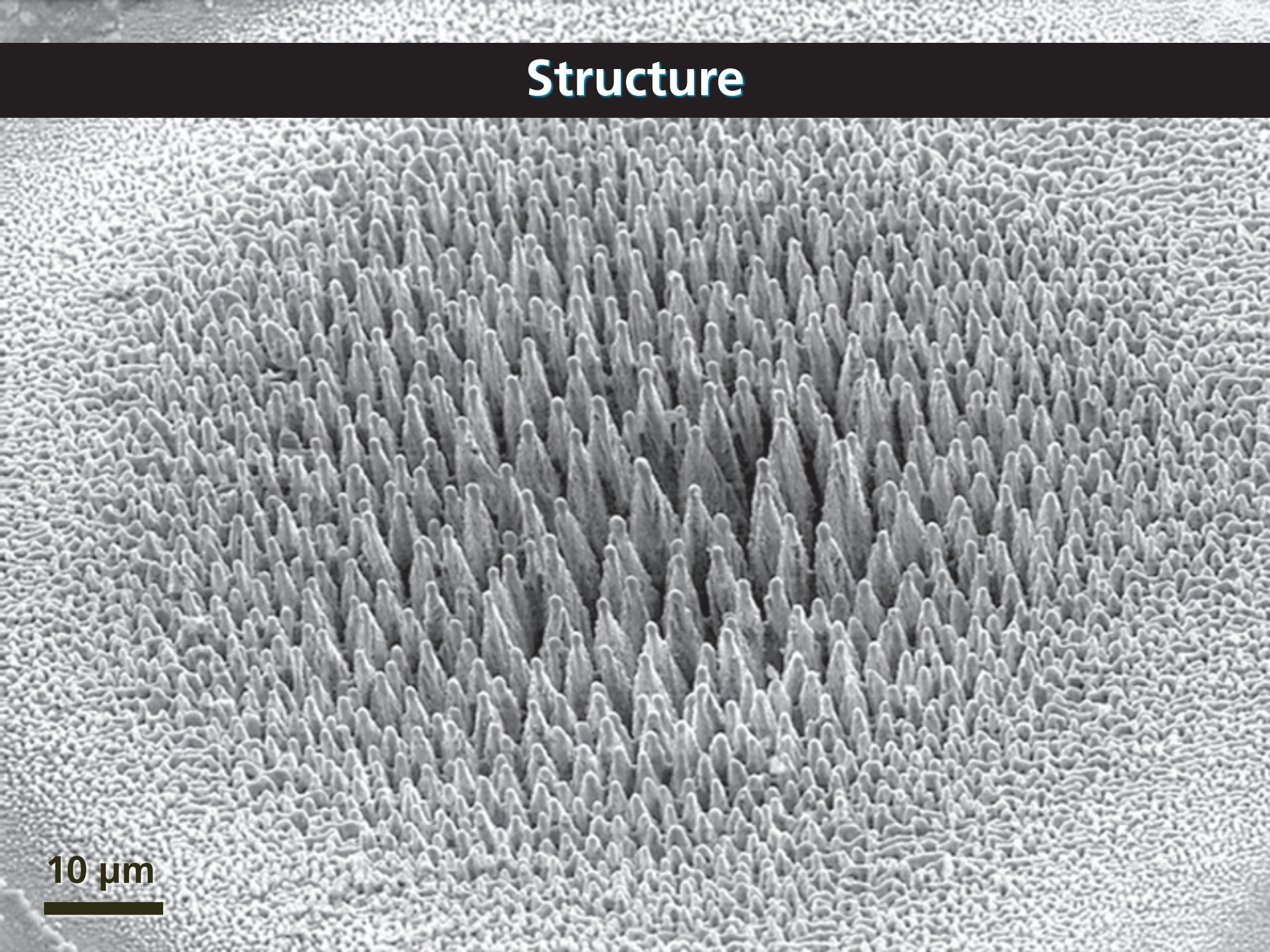


Structure



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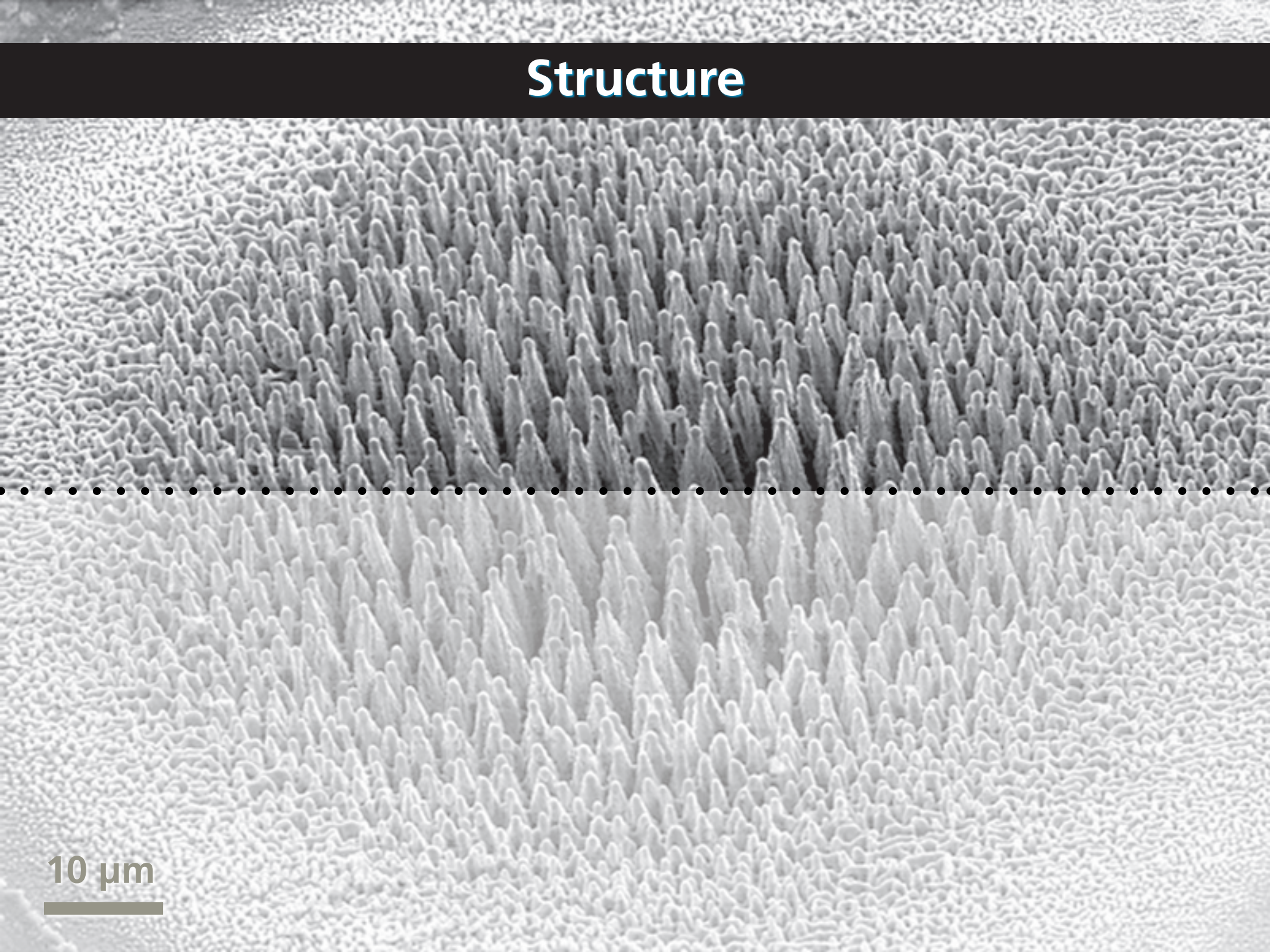

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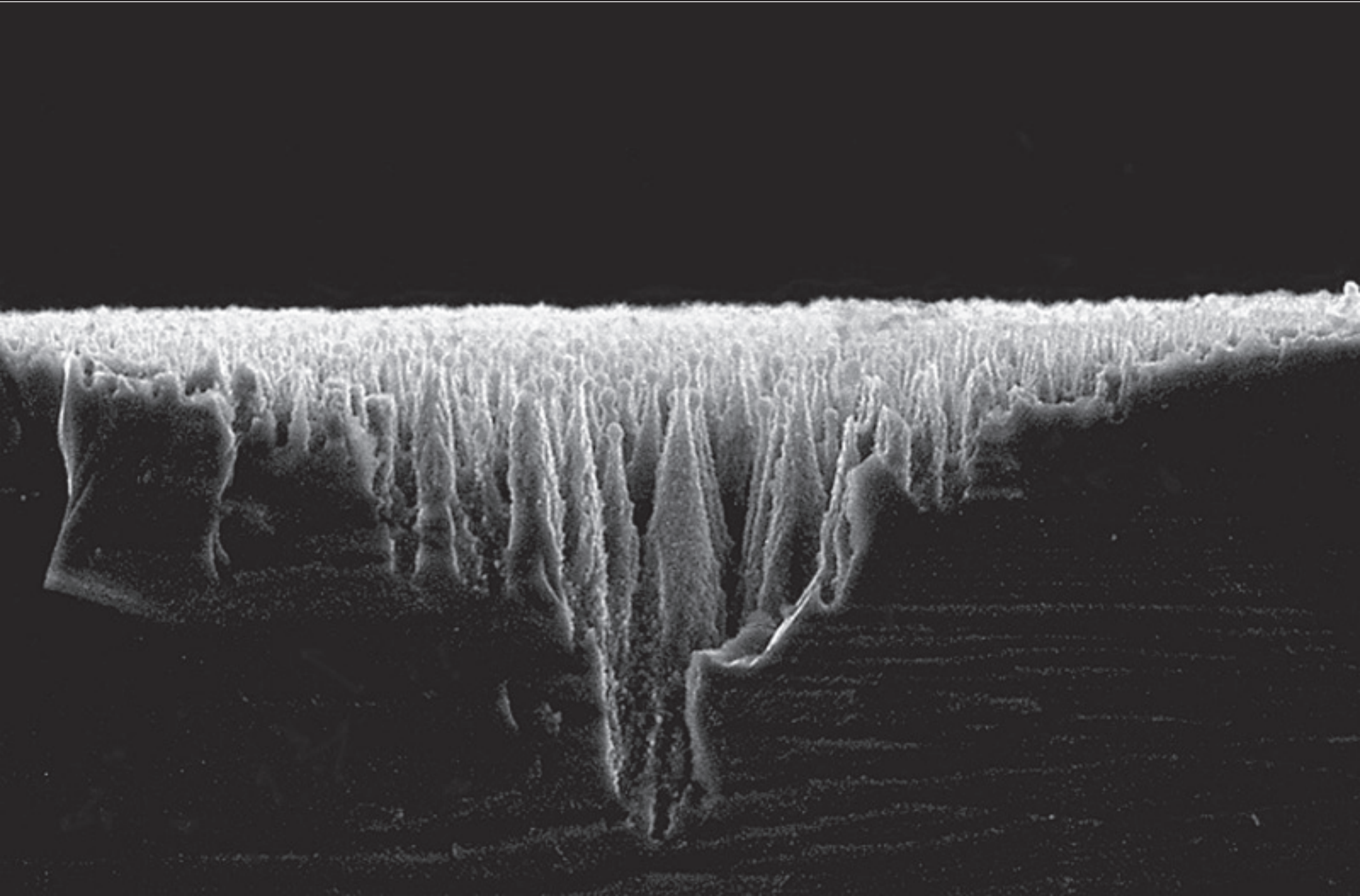

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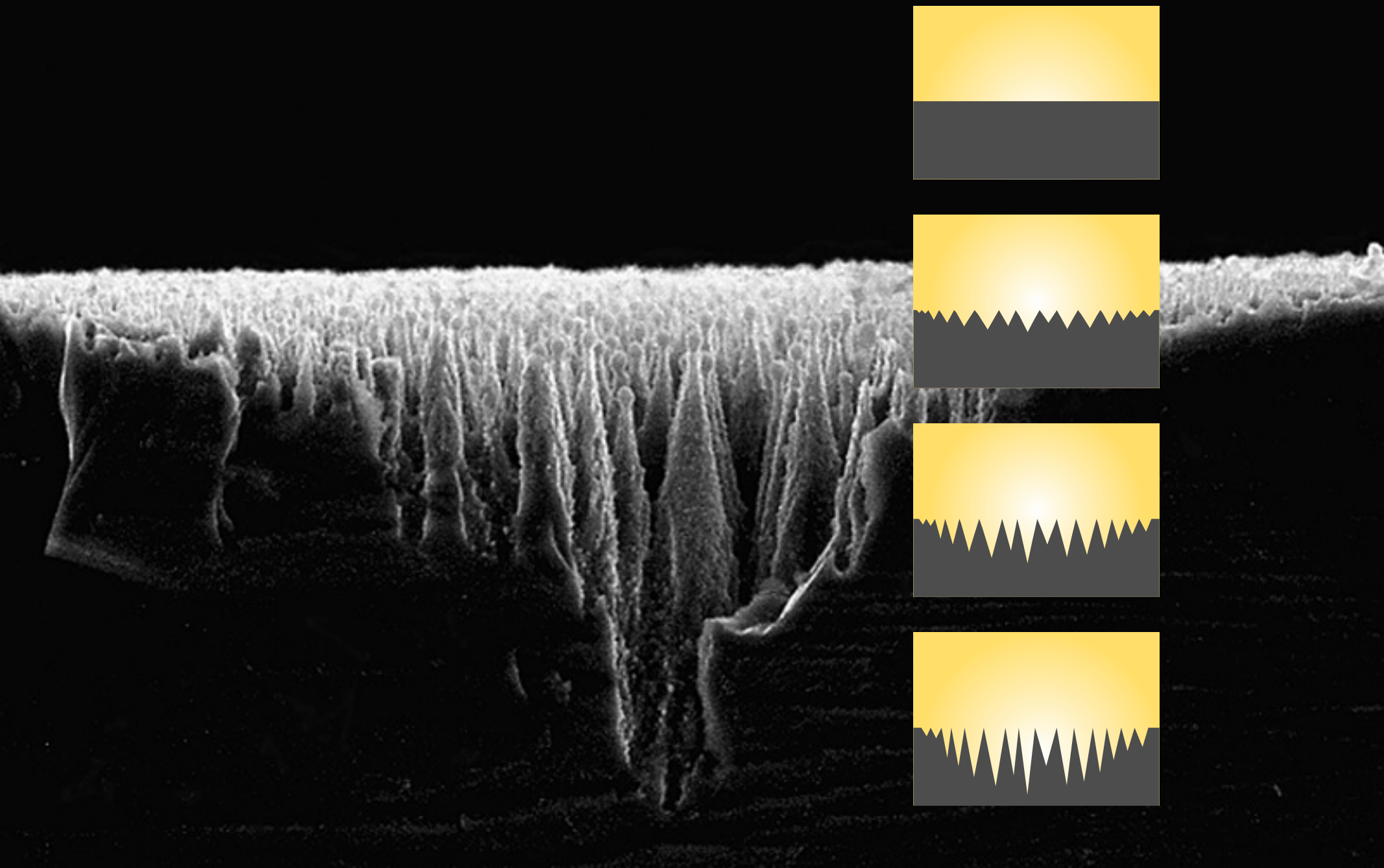

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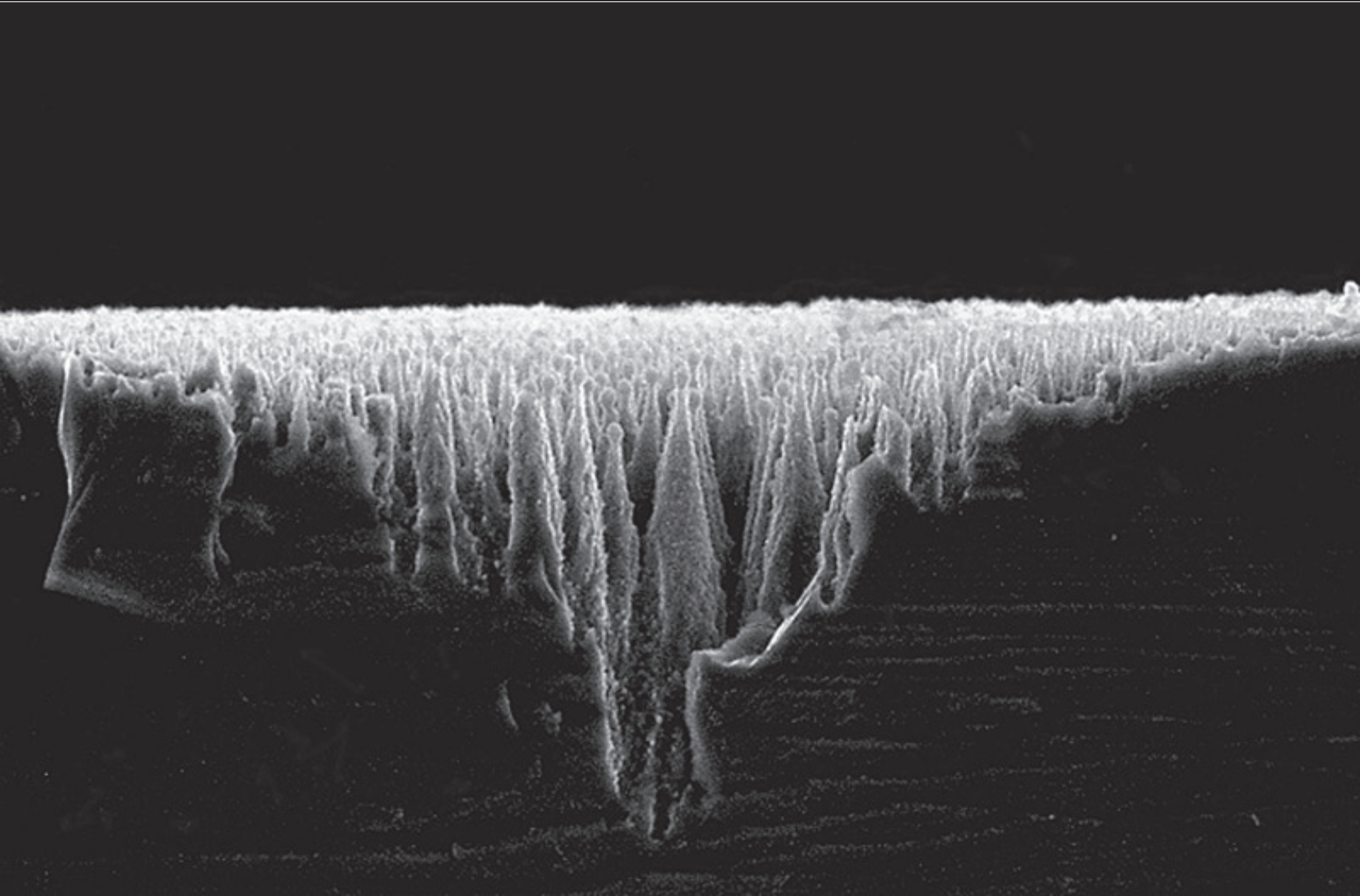

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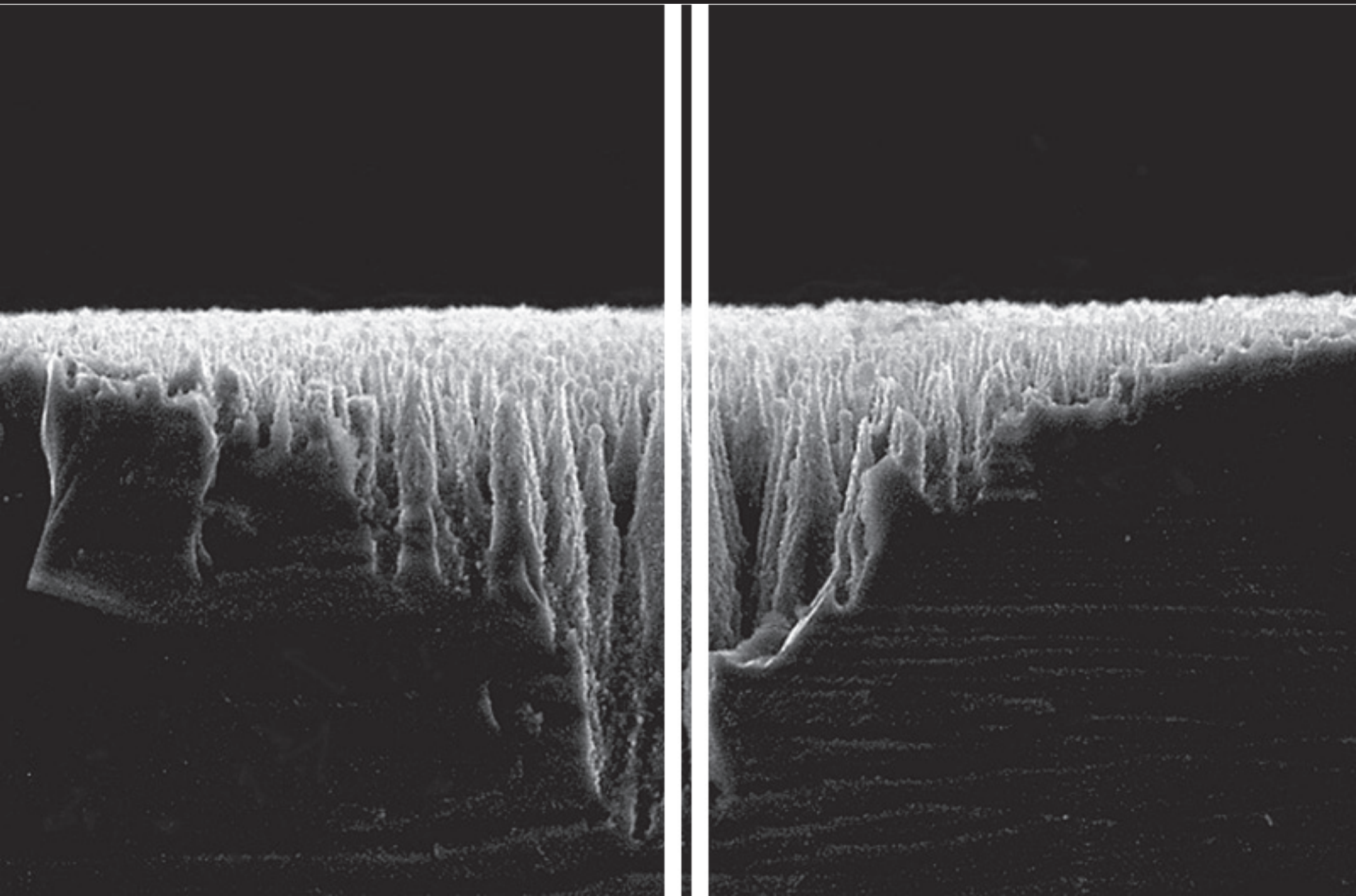
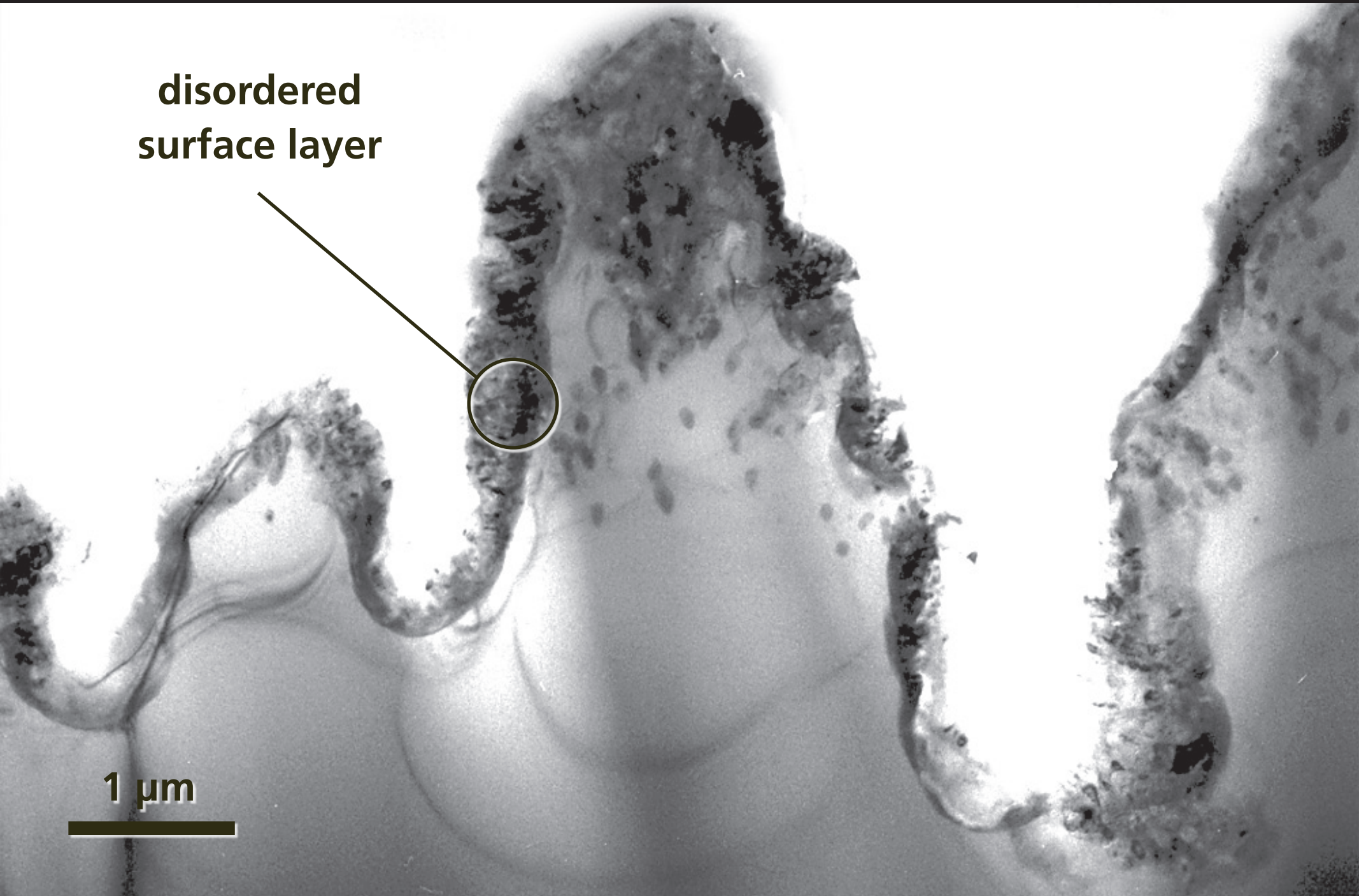


Structure

cross-sectional
Transmission Electron
Microscopy

Structure



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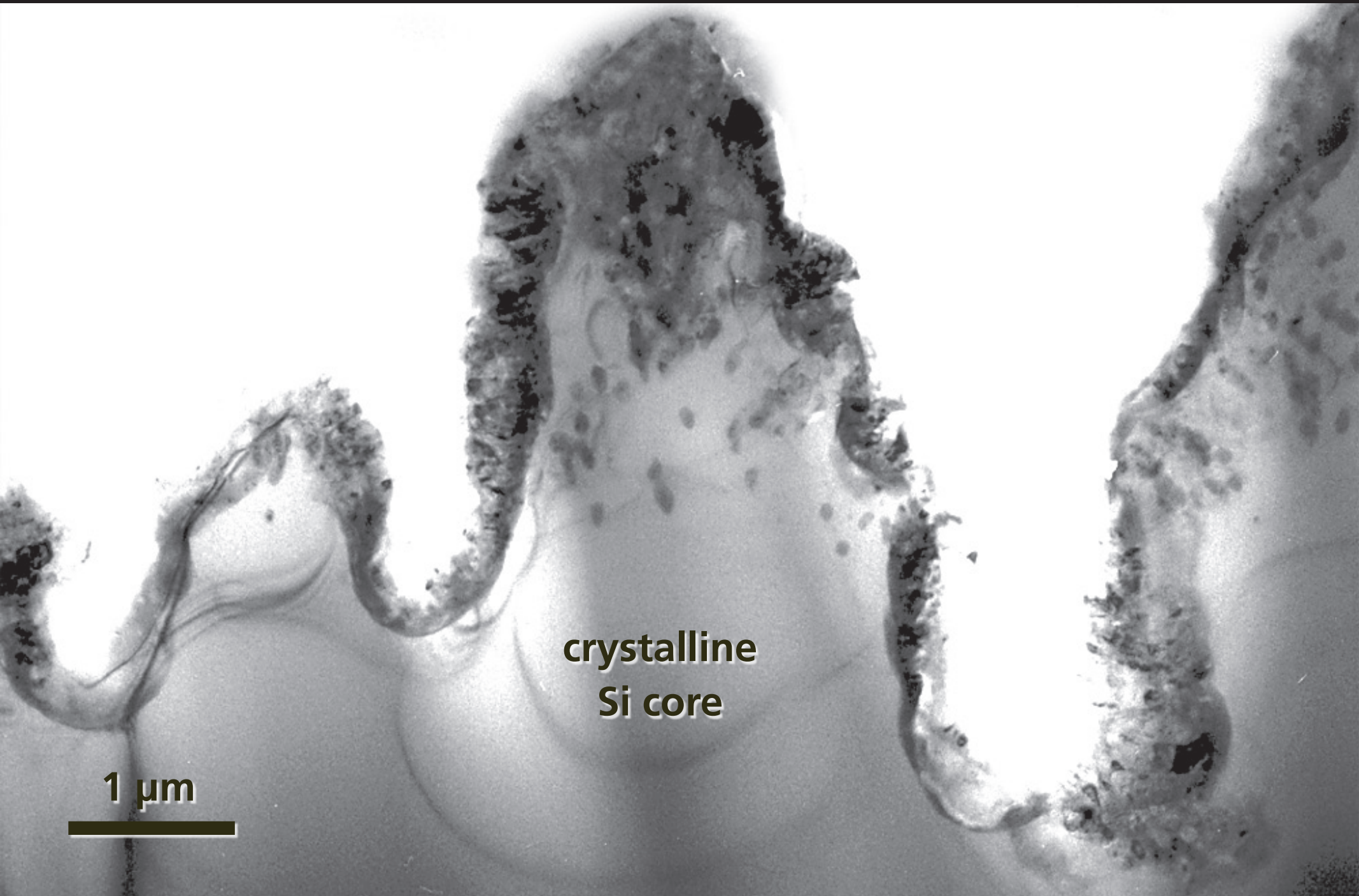

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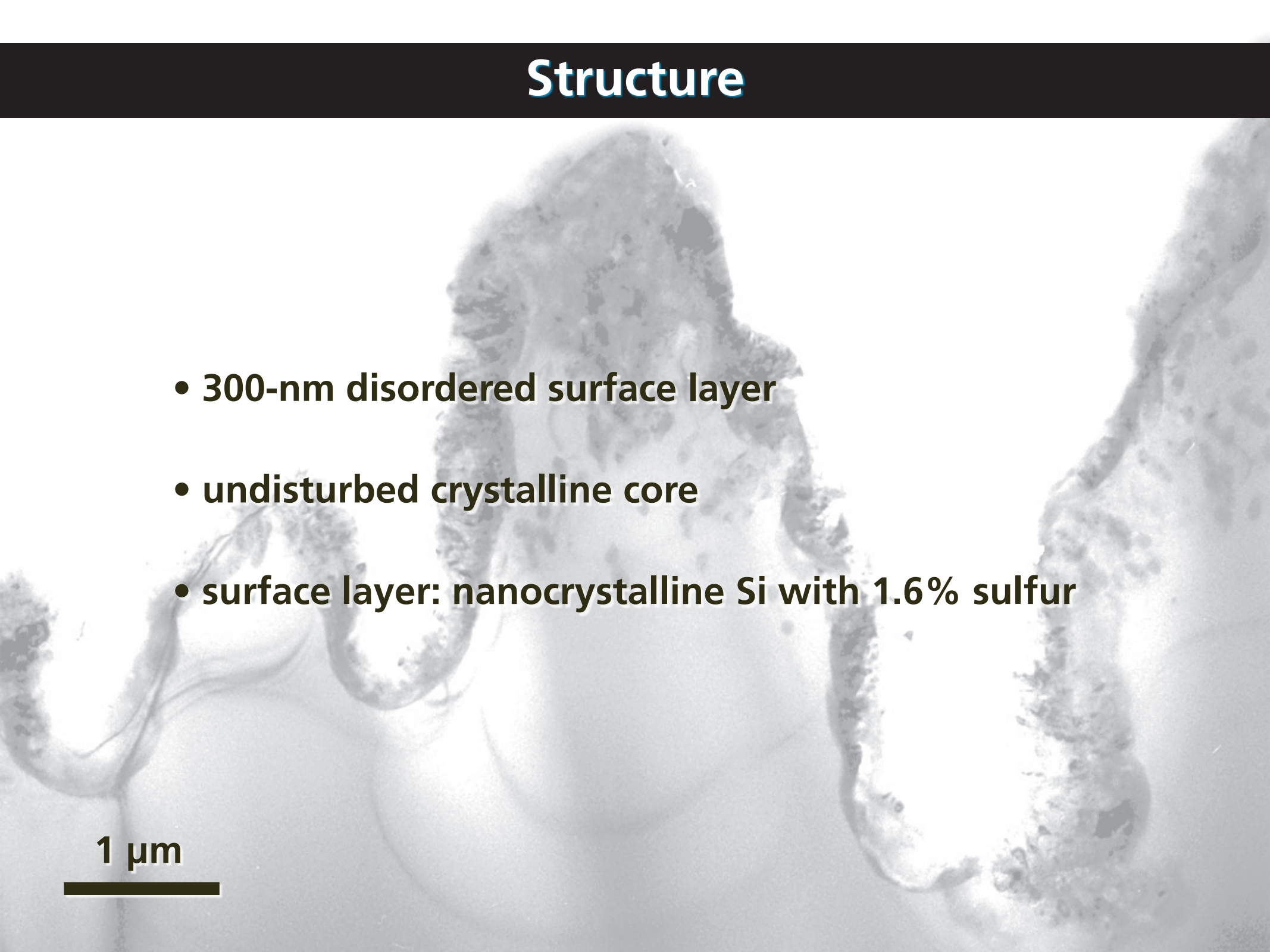


- 300-nm disordered surface layer
- undisturbed crystalline core
- surface layer: nanocrystalline Si with 1.6% sulfur

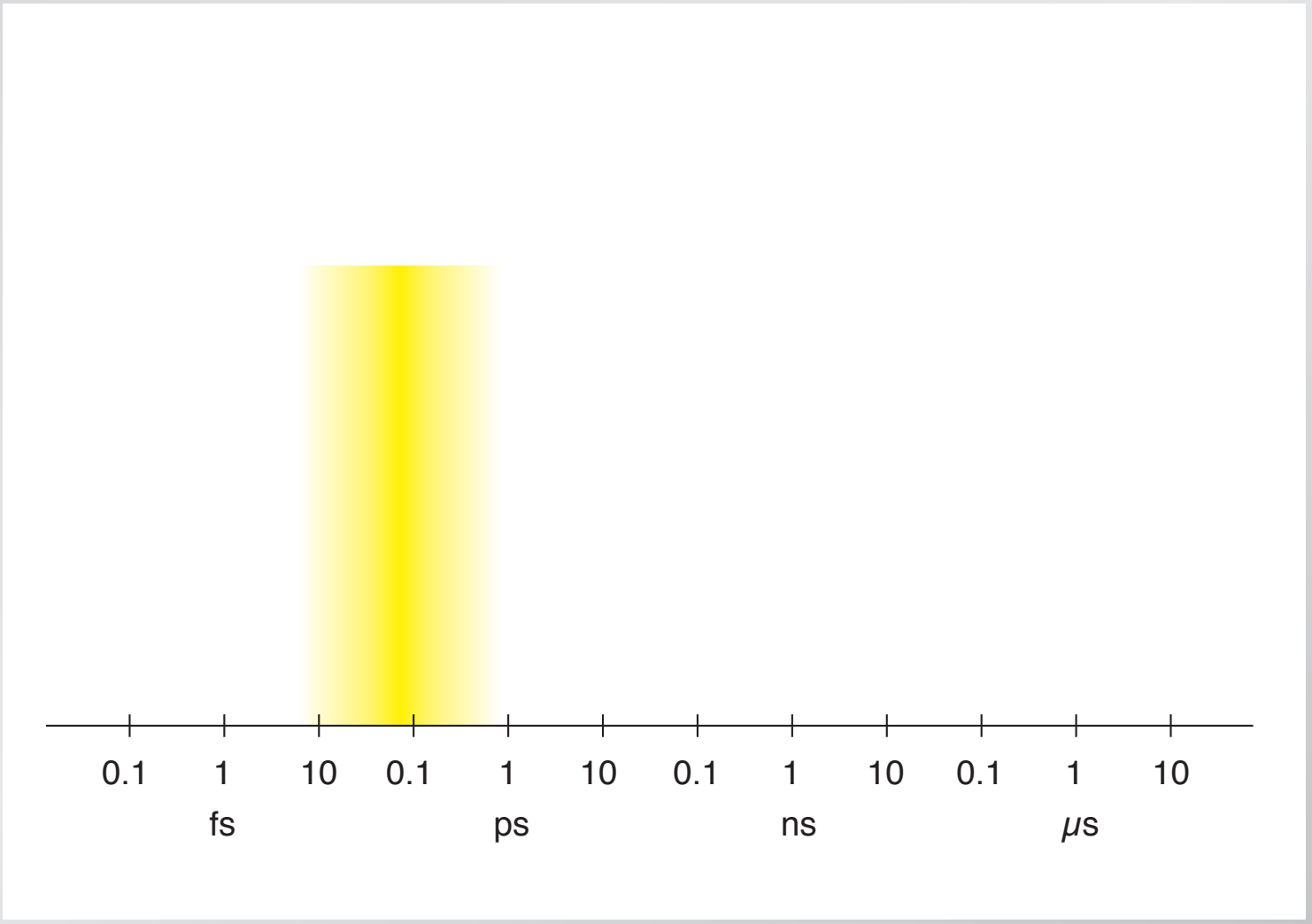
1 µm

Structure

two processes: melting and ablation

Structure

relevant time scales



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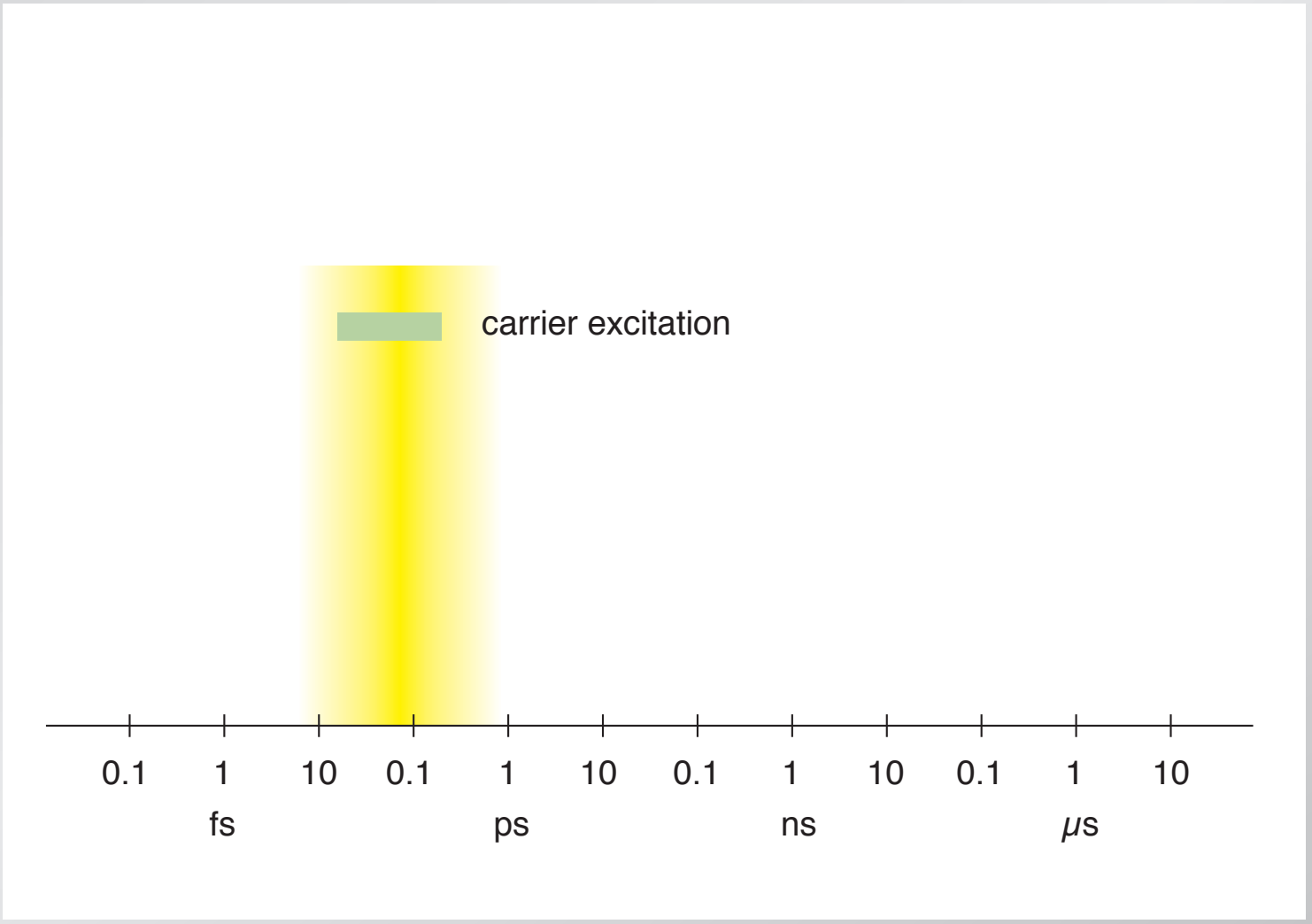

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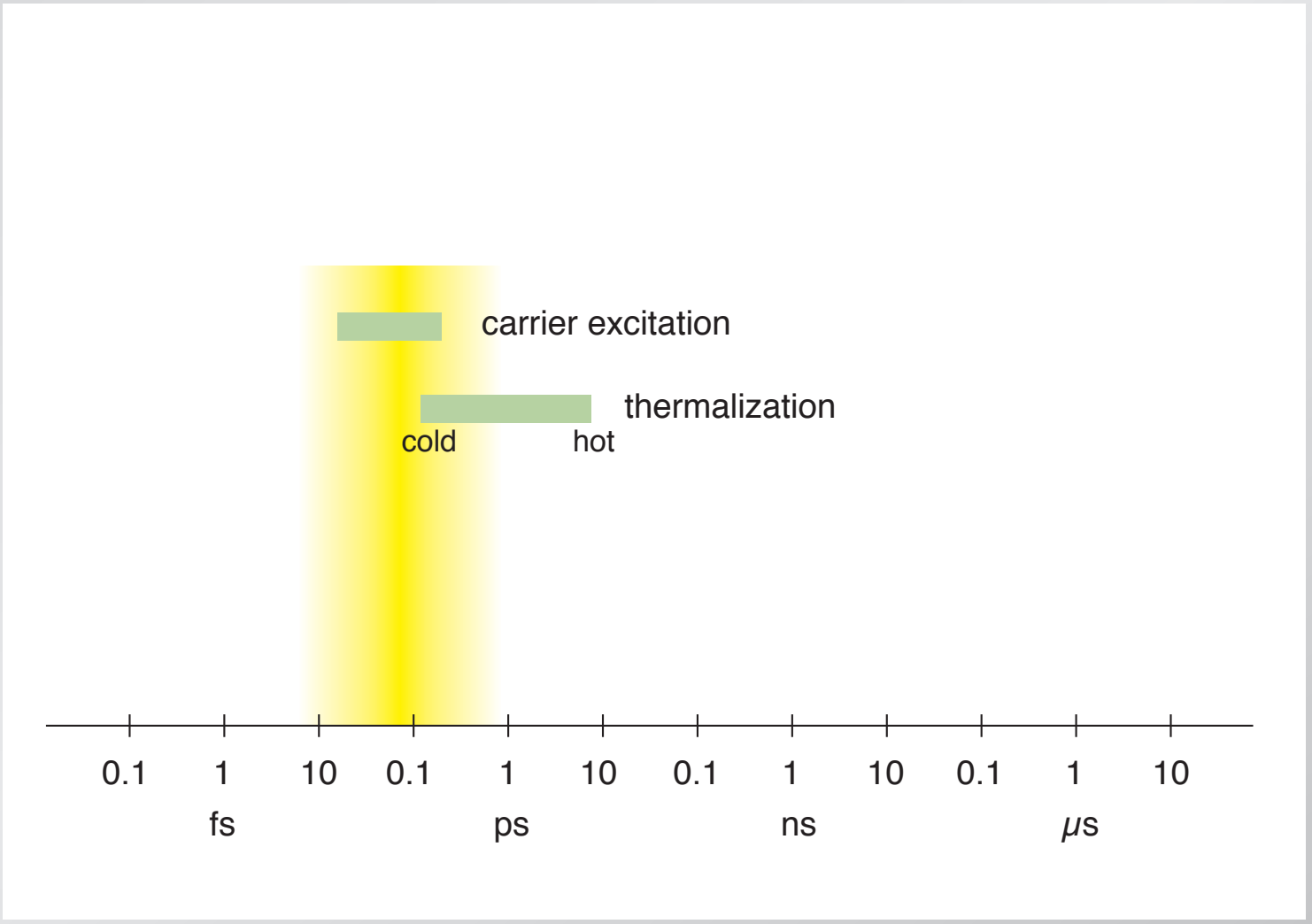

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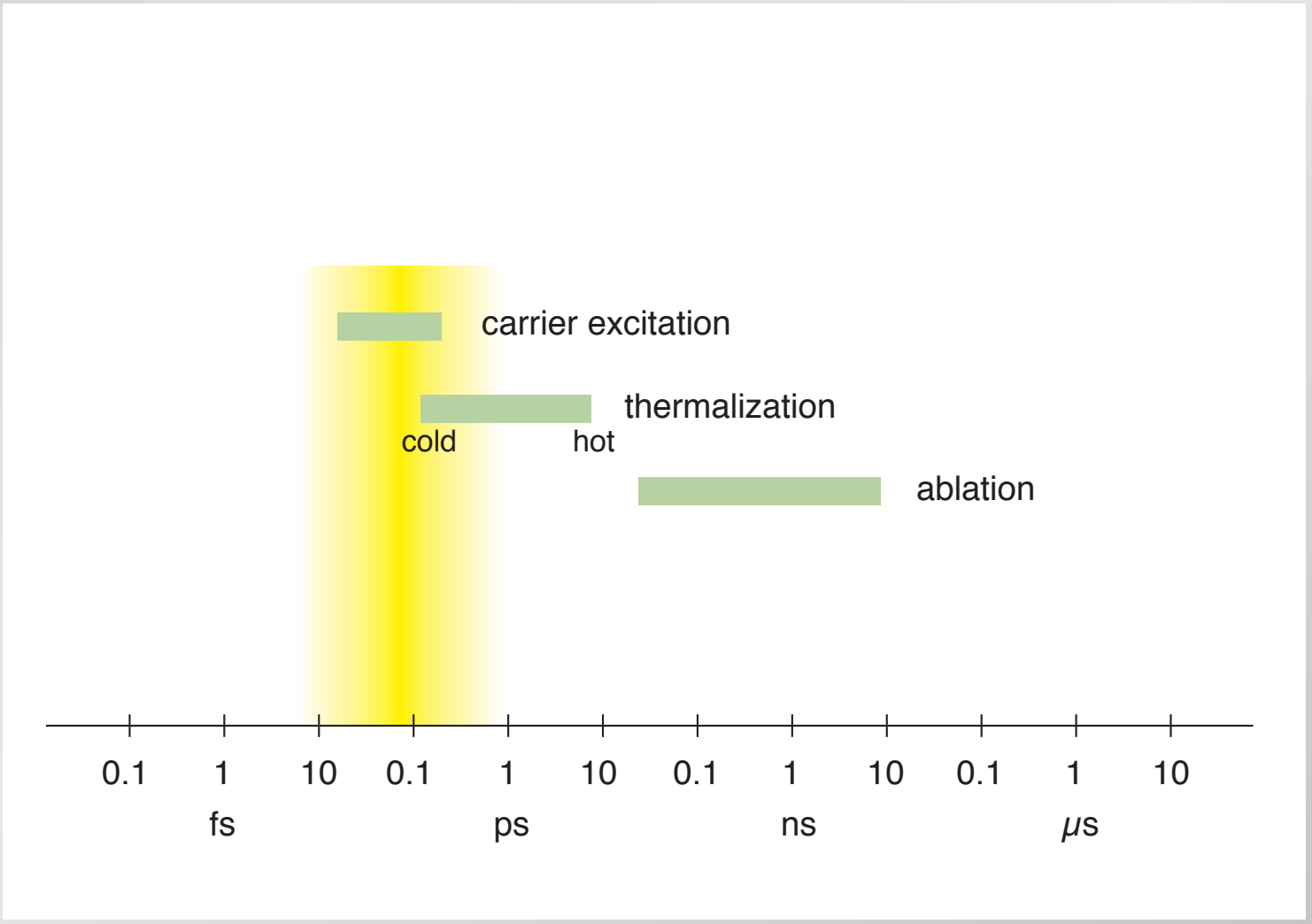

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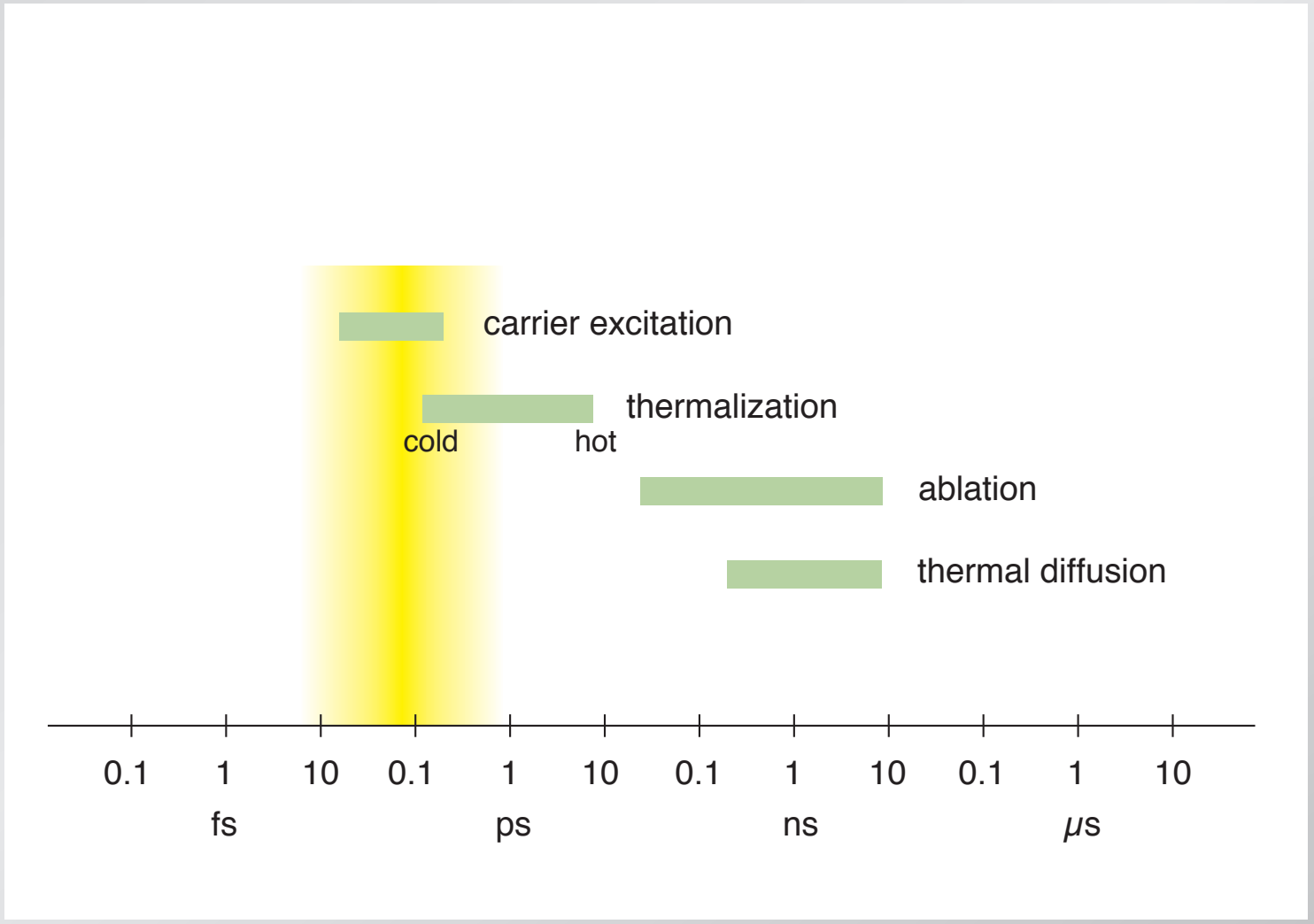

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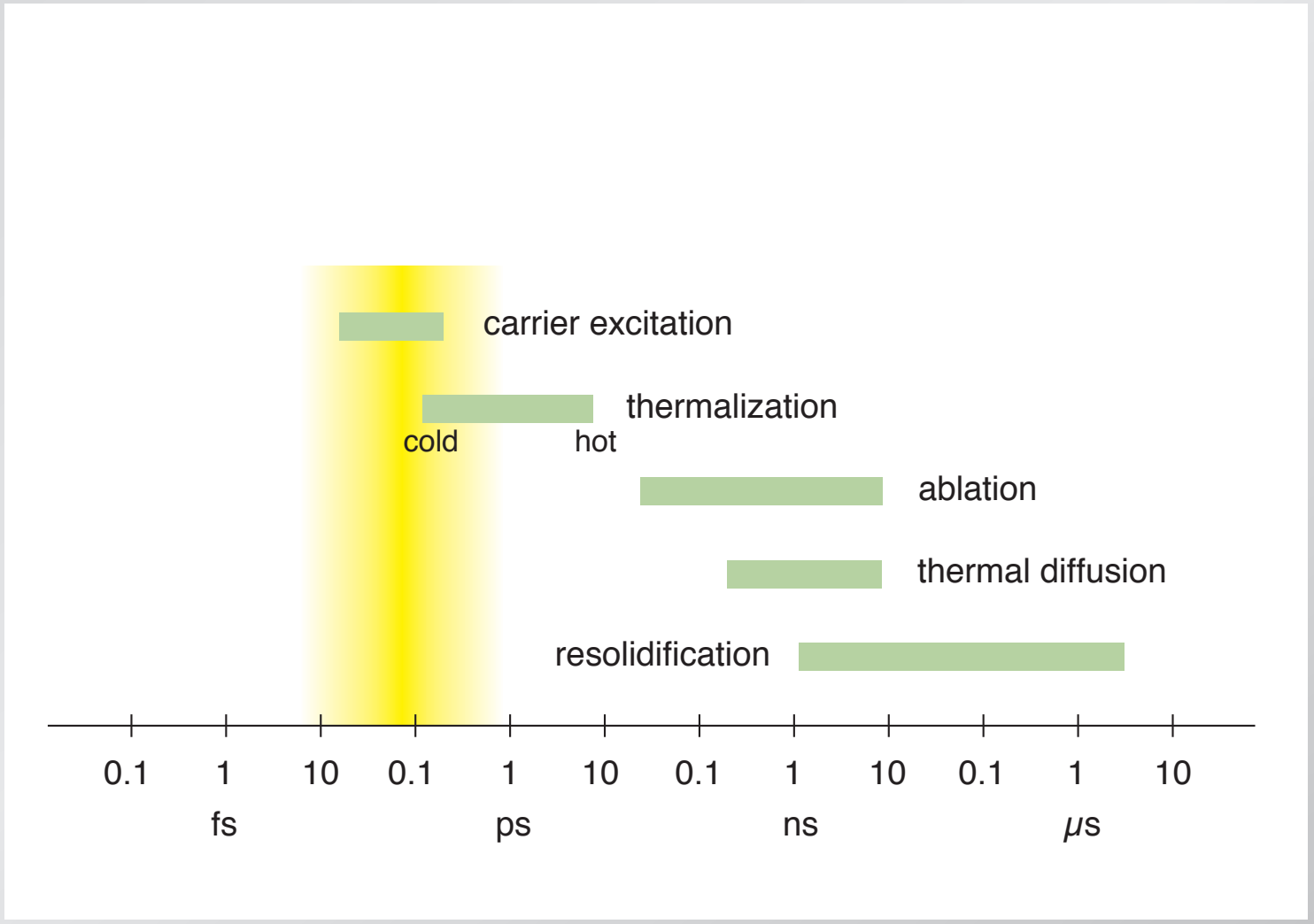

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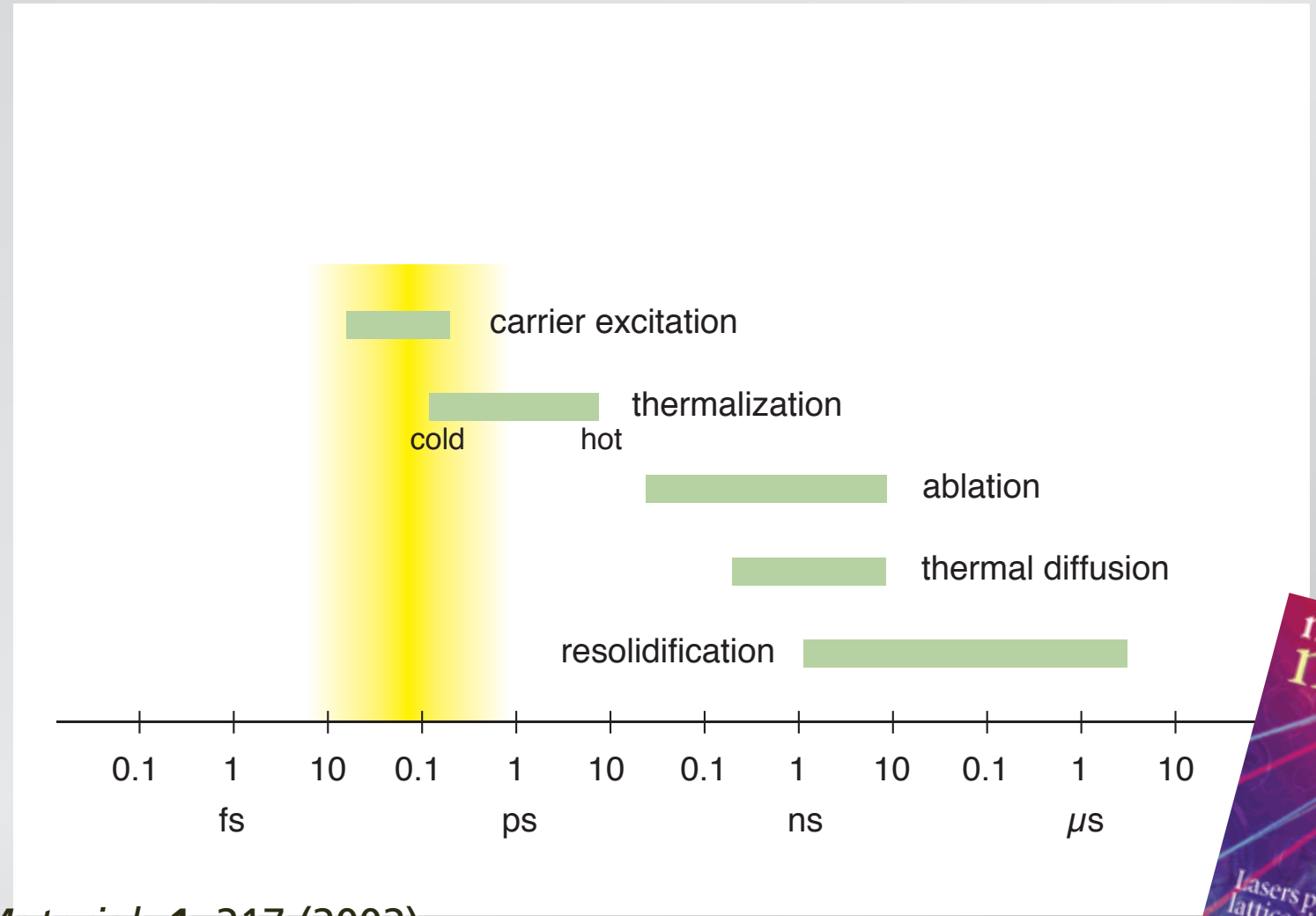

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Structure

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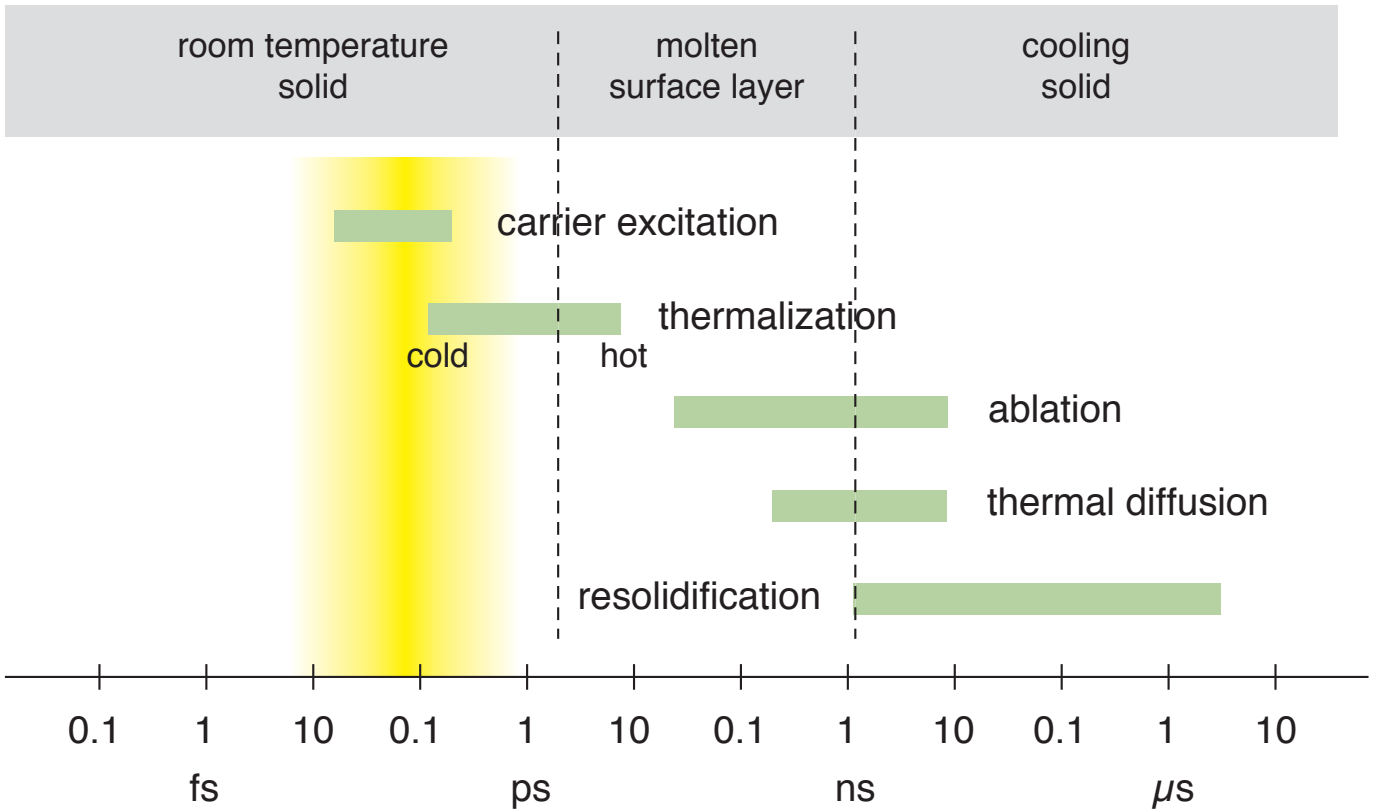

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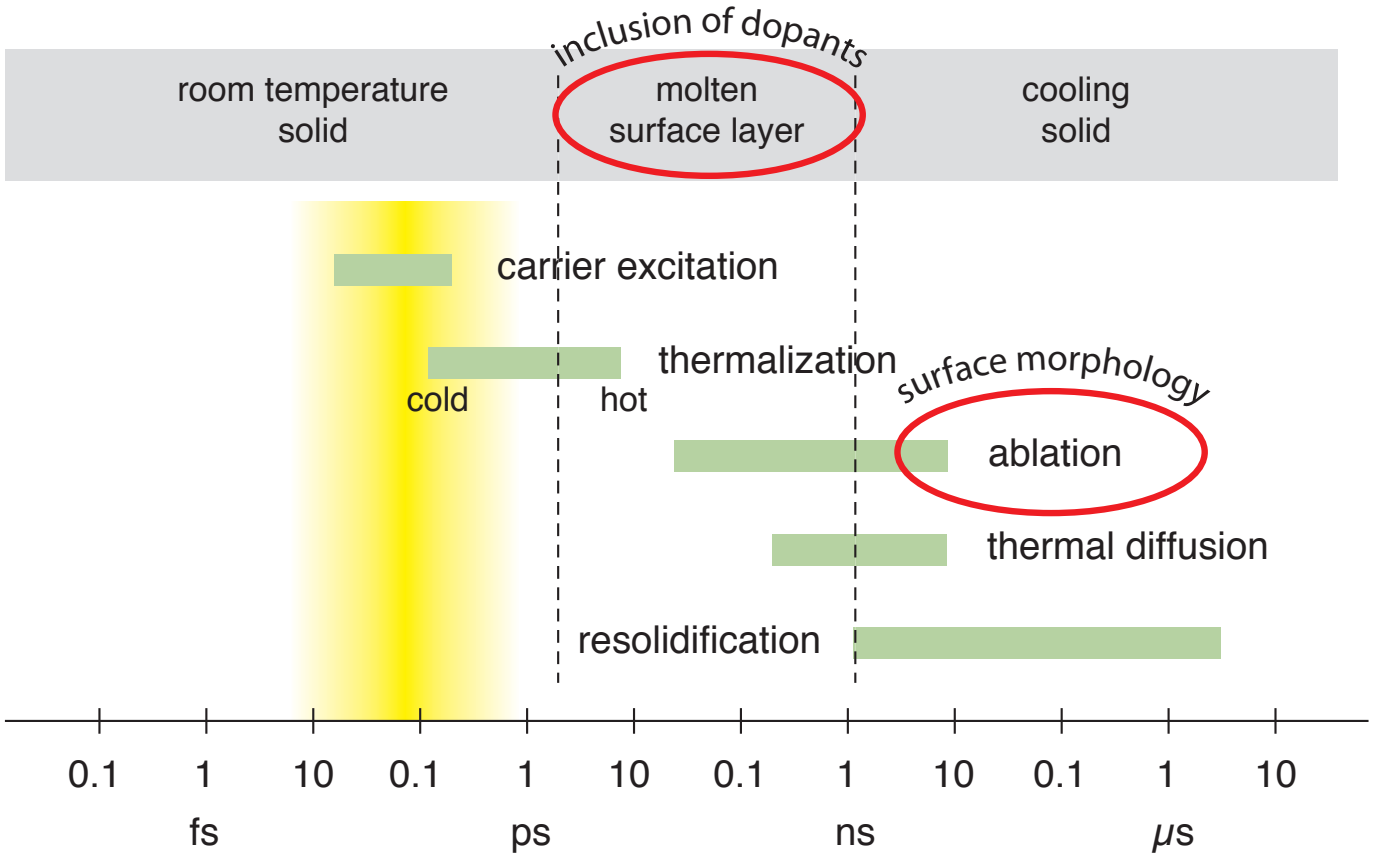


Structure

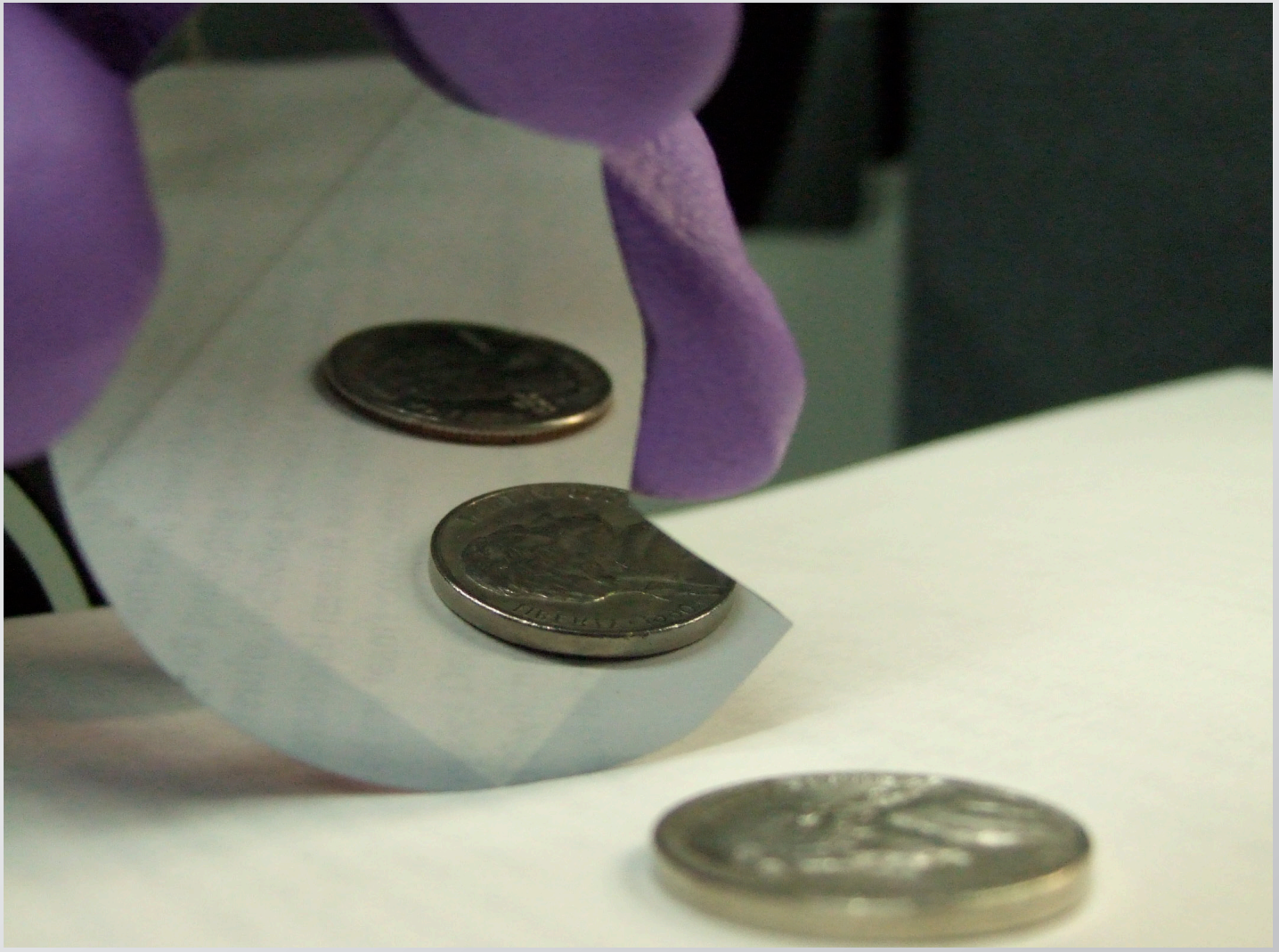
different thresholds:

melting: 1.5 kJ/m^2

ablation: 3.1 kJ/m^2

Structure

decouple ablation from melting



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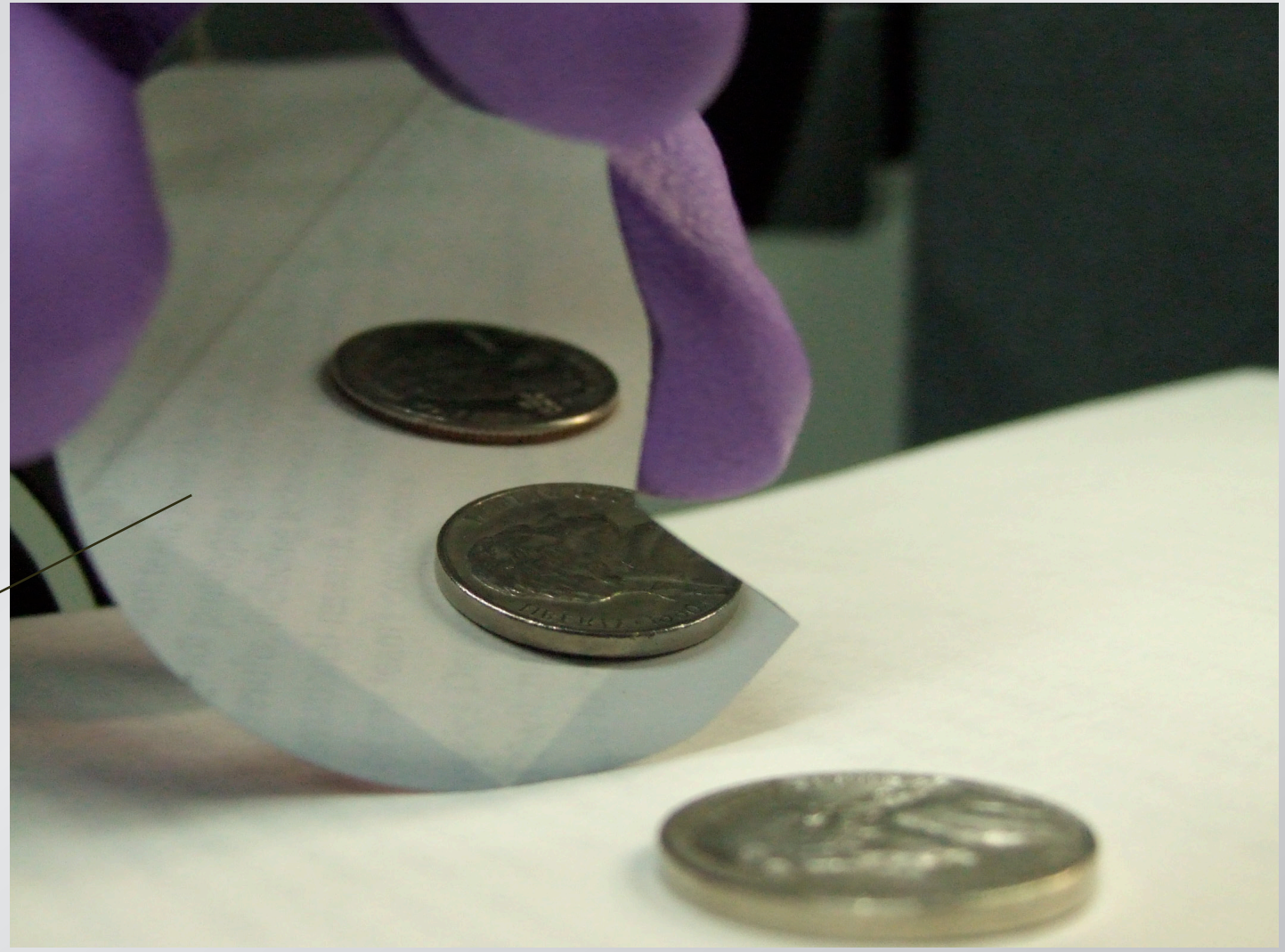

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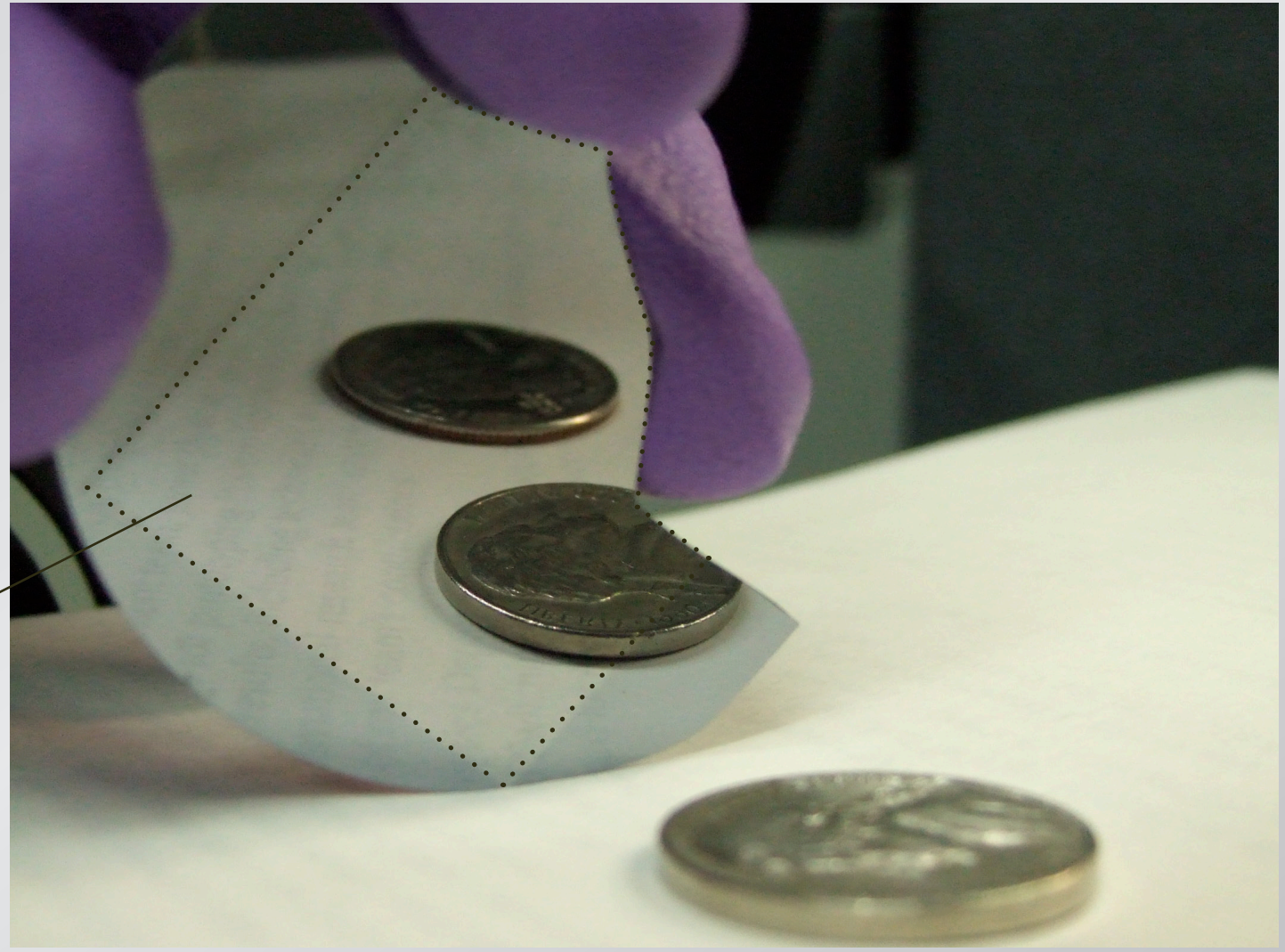

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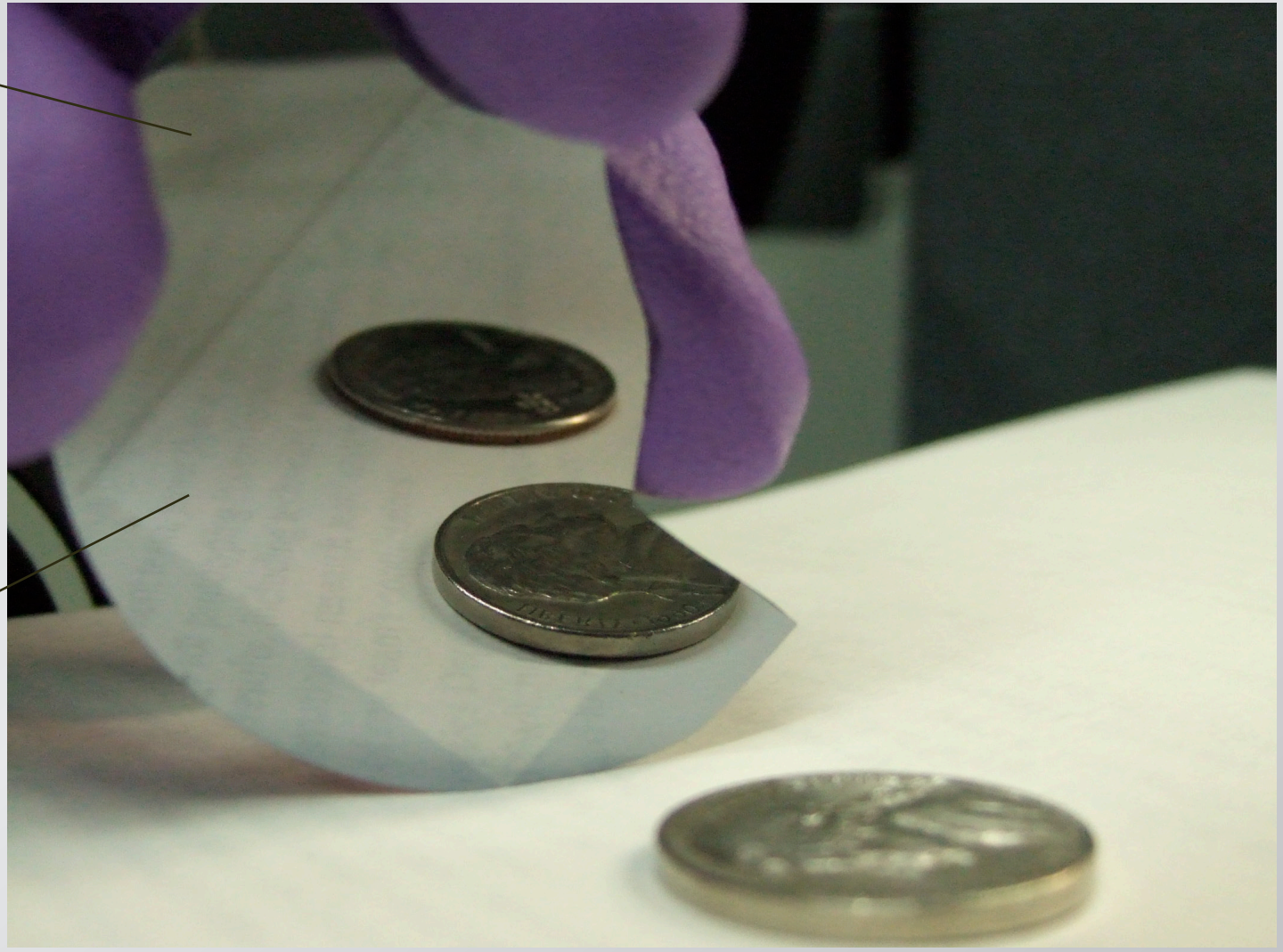

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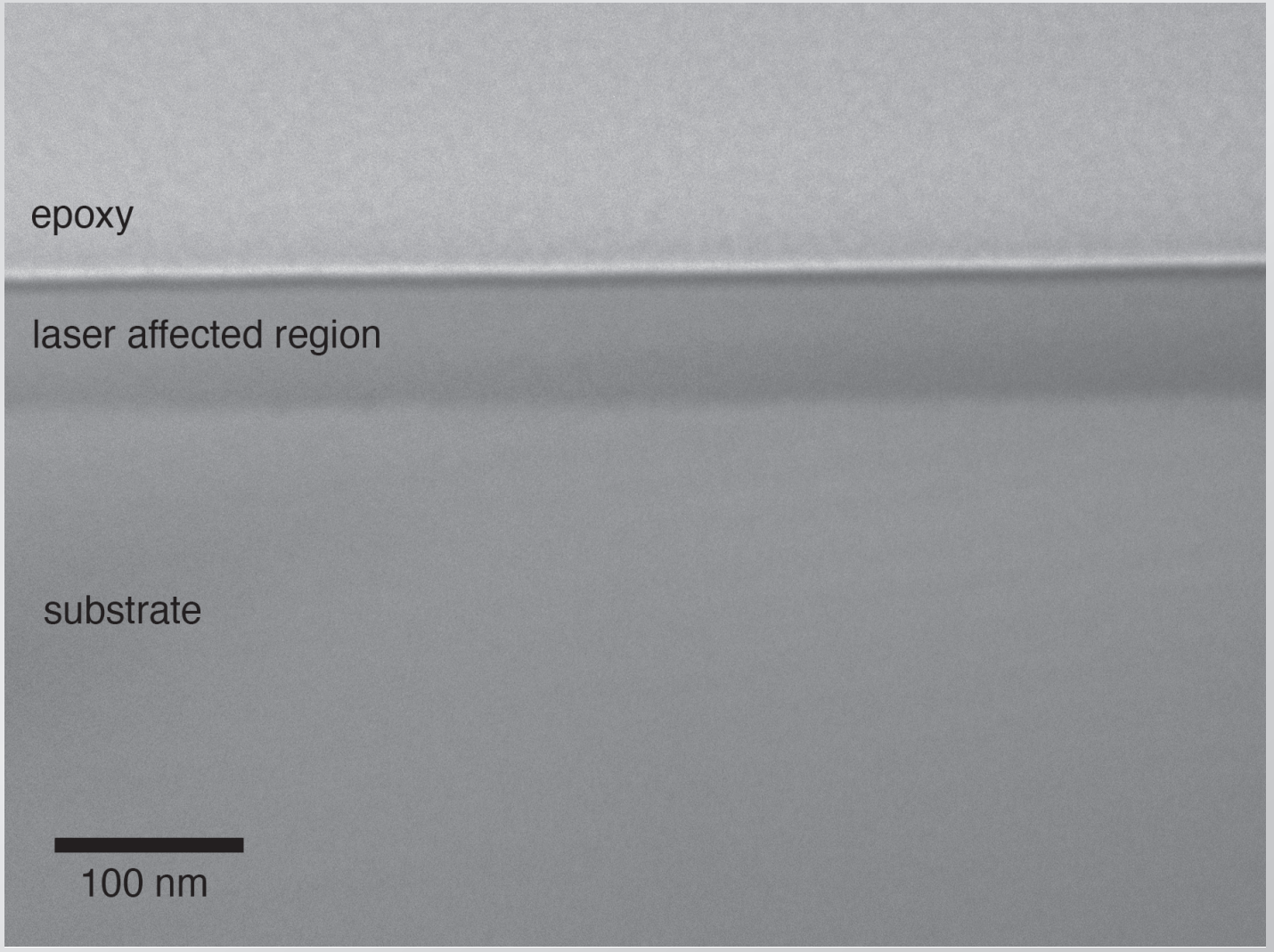

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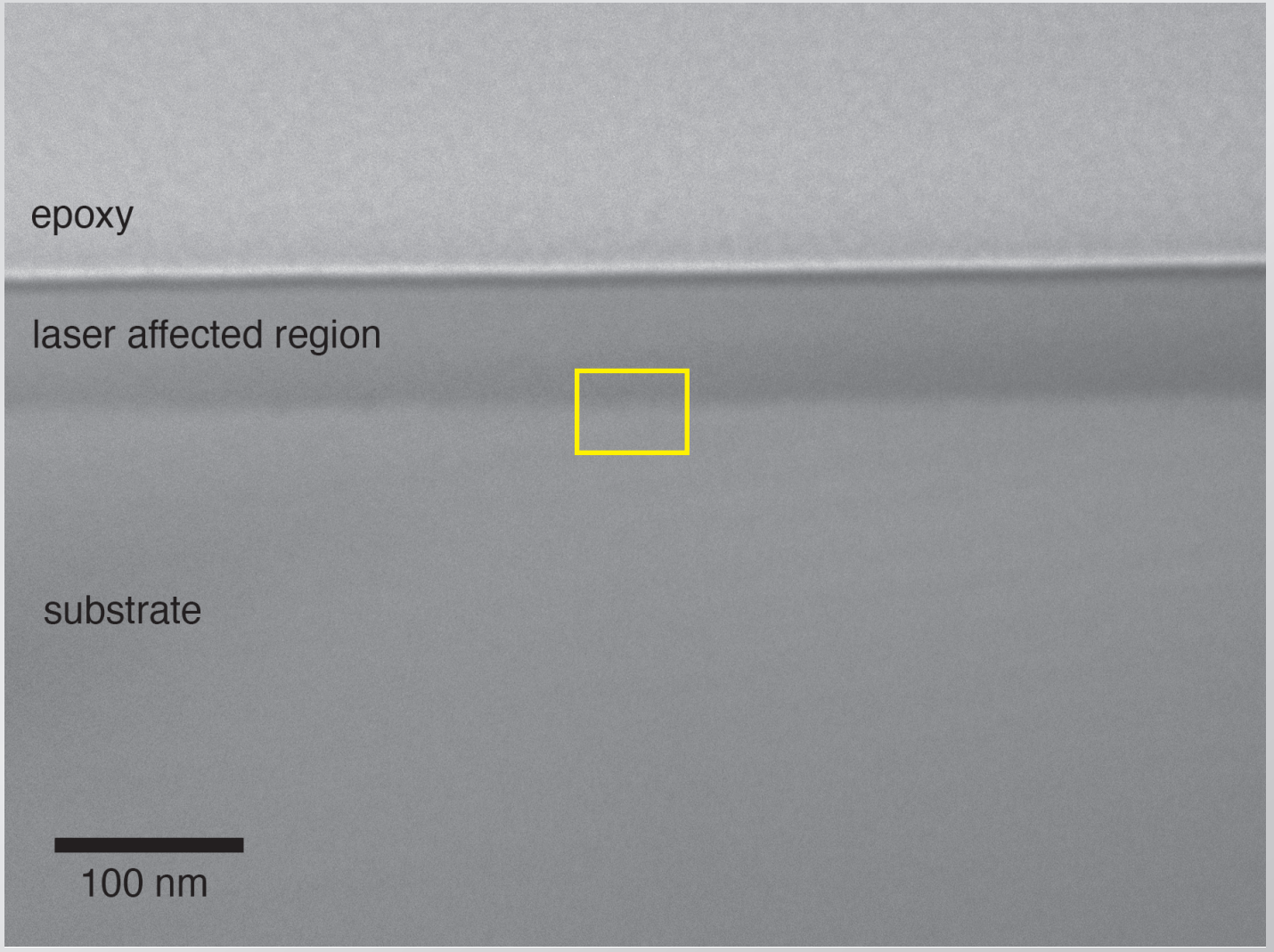

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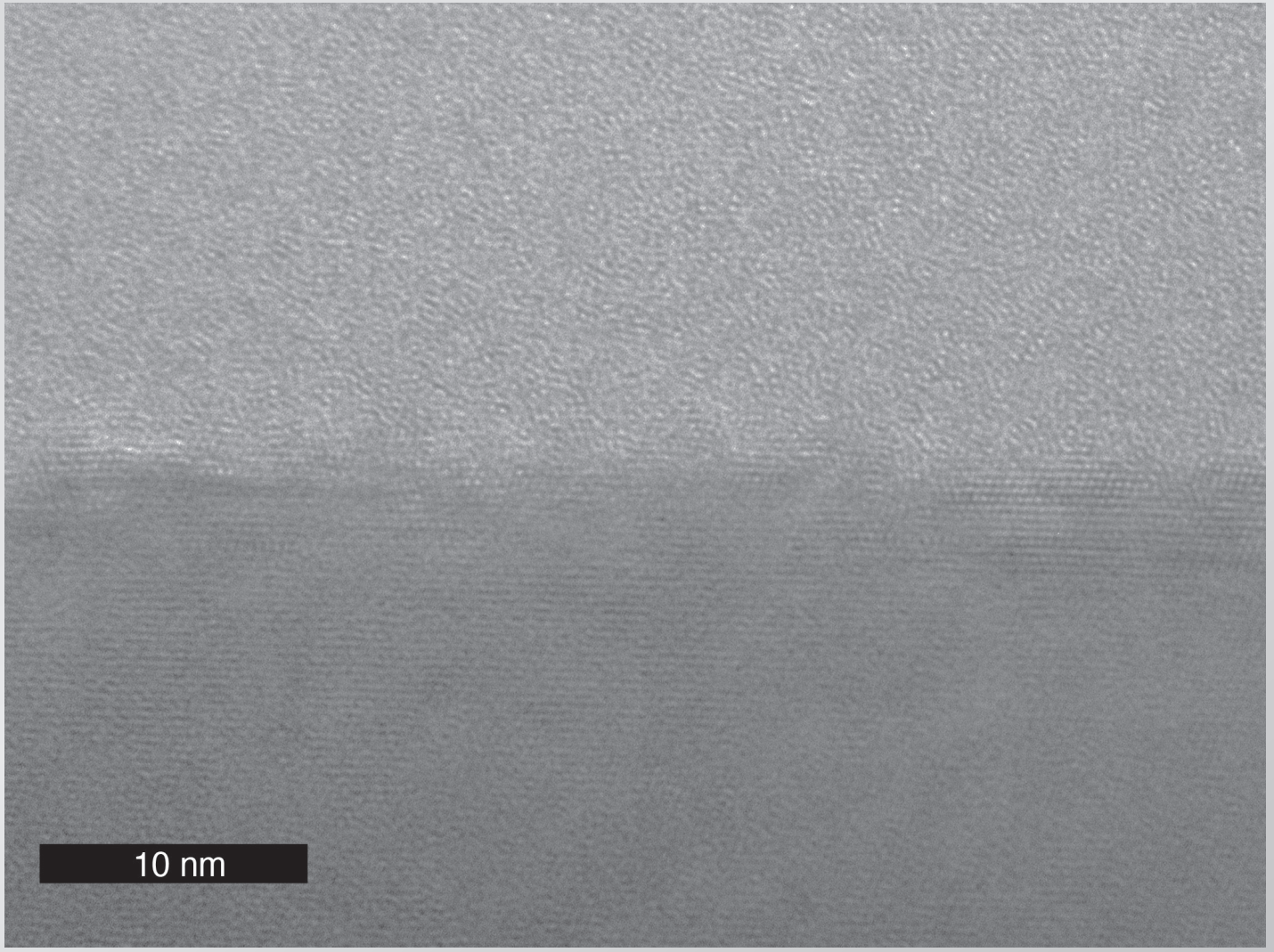

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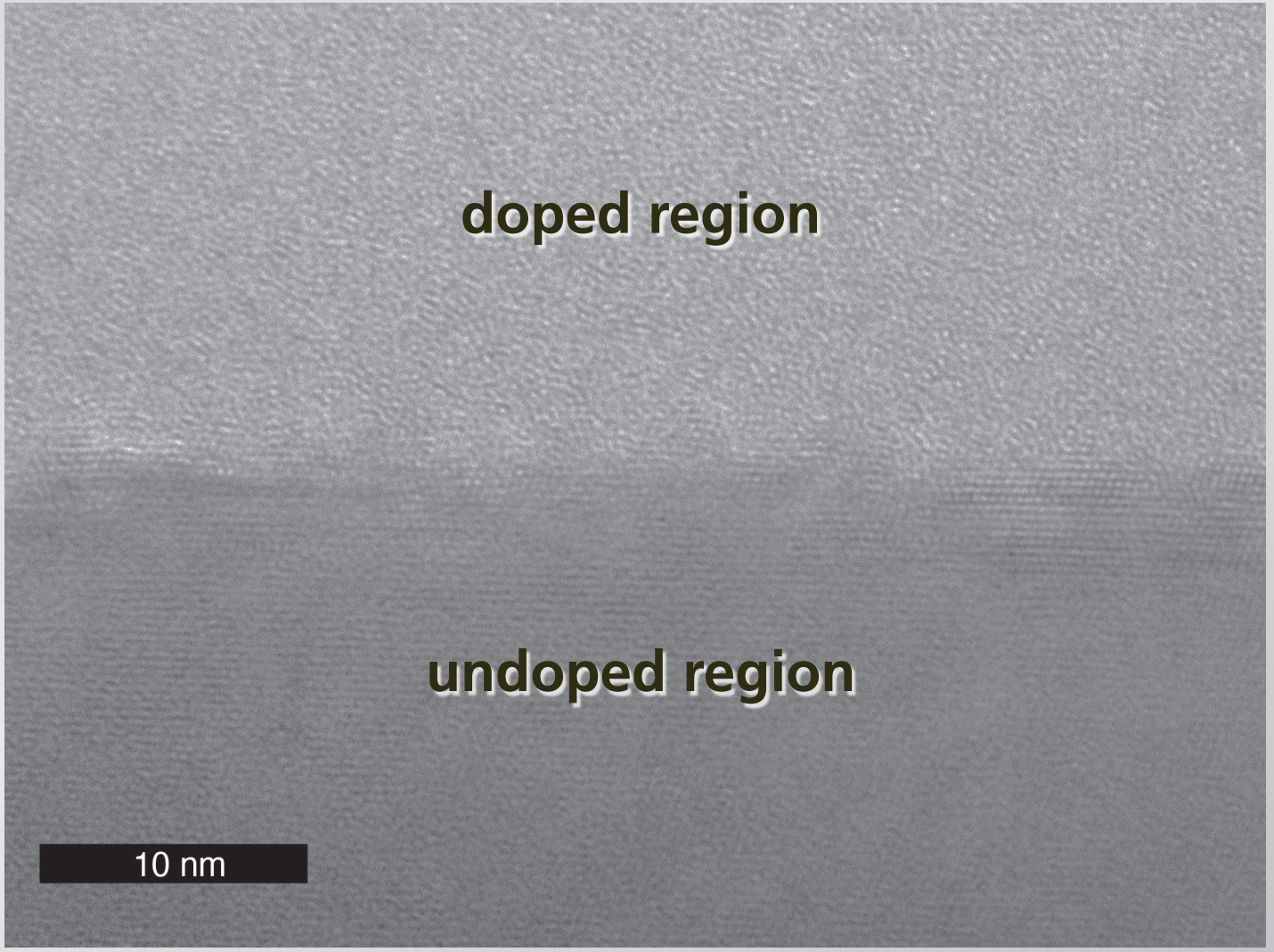
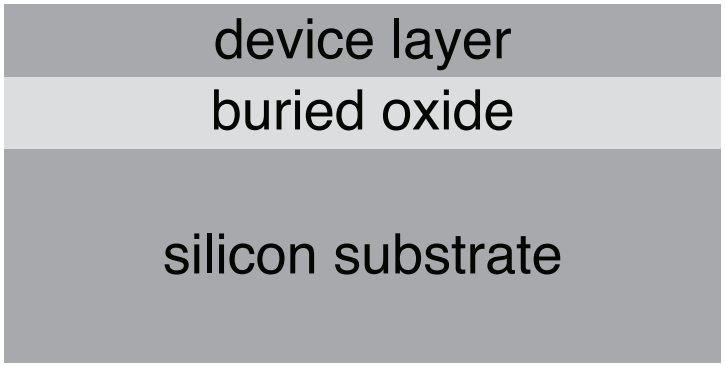


Optoelectronic properties

isolate surface layer for Hall measurements



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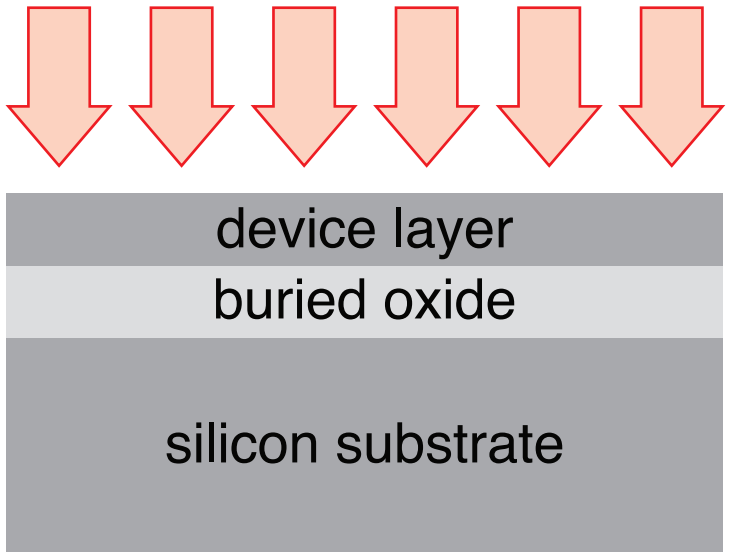

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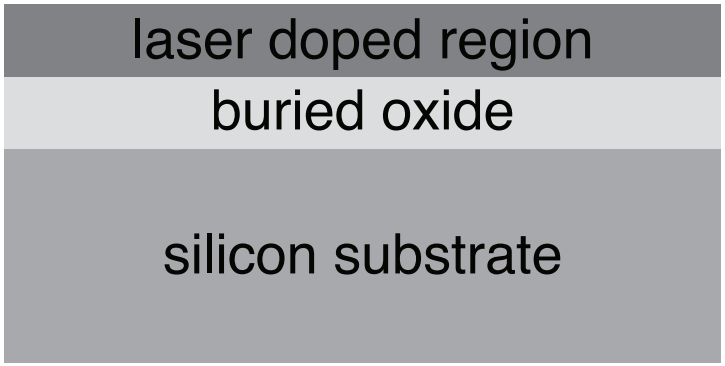

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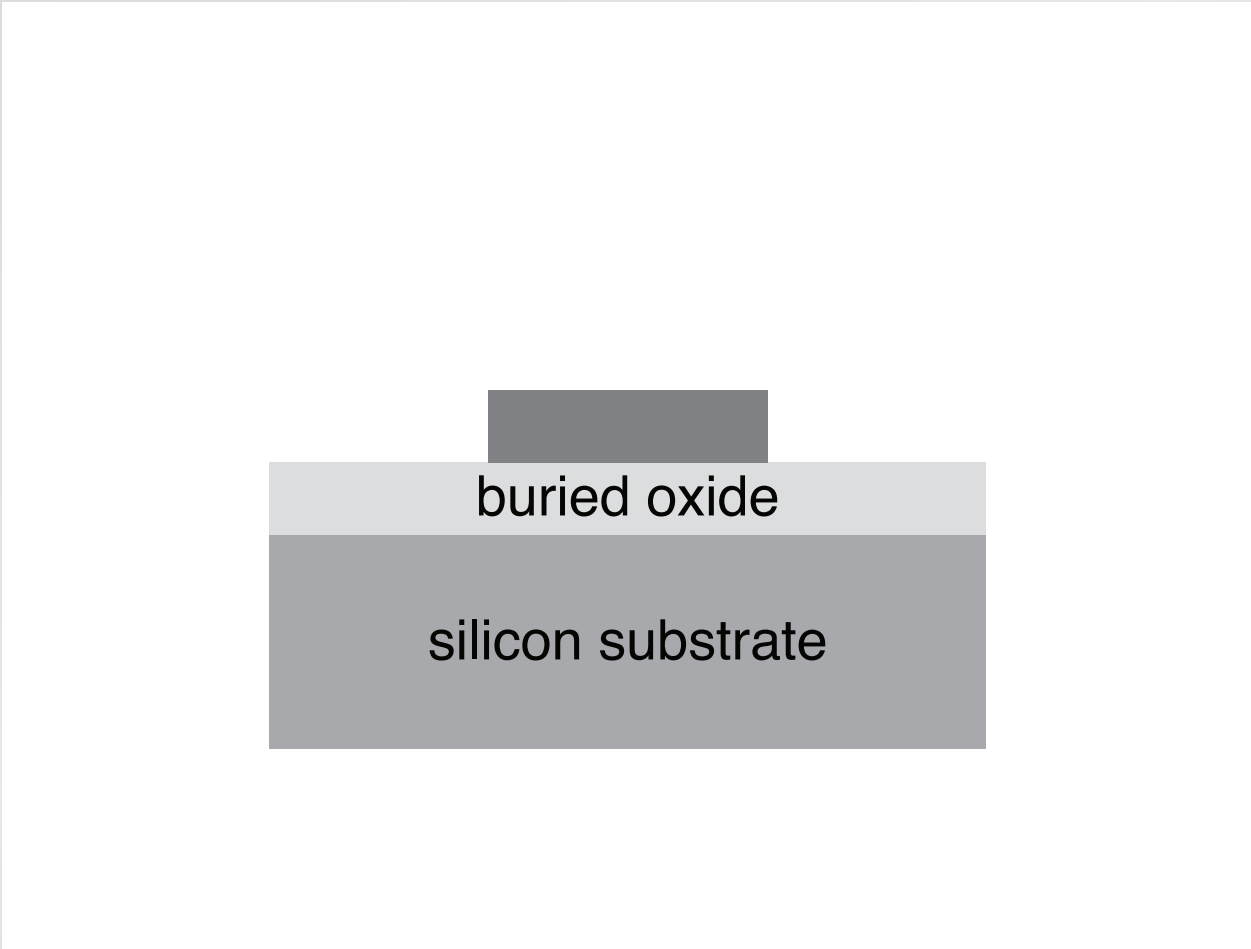

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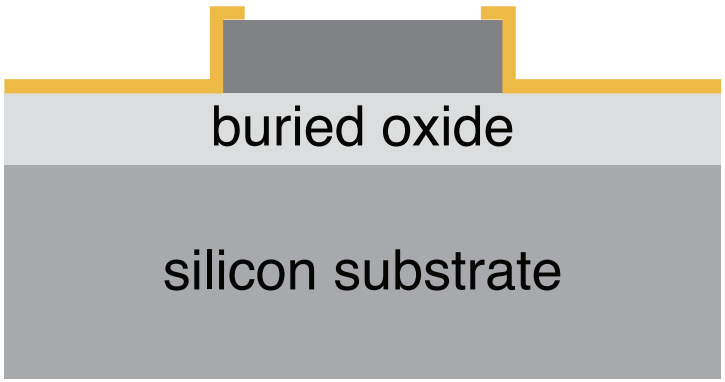

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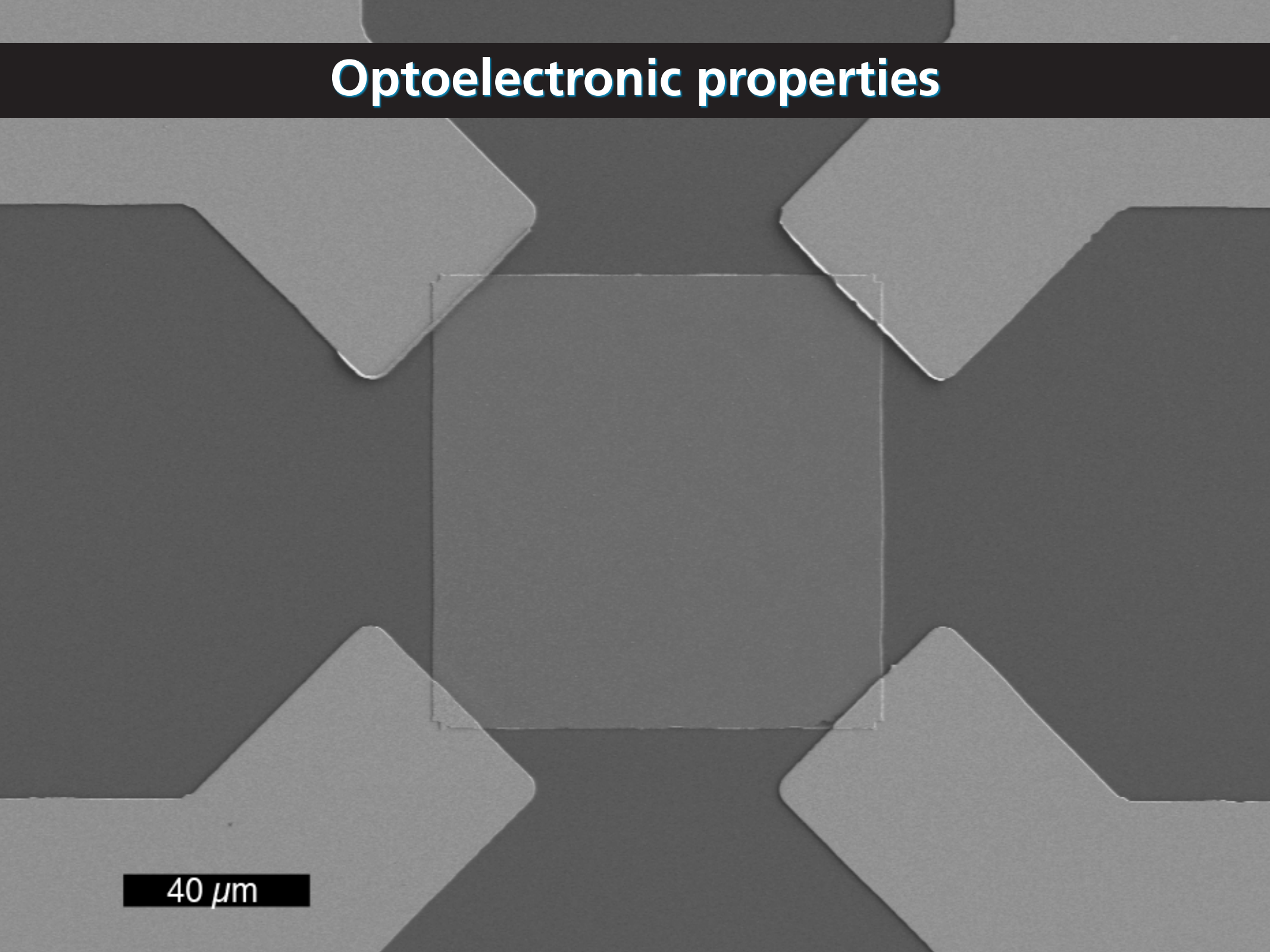
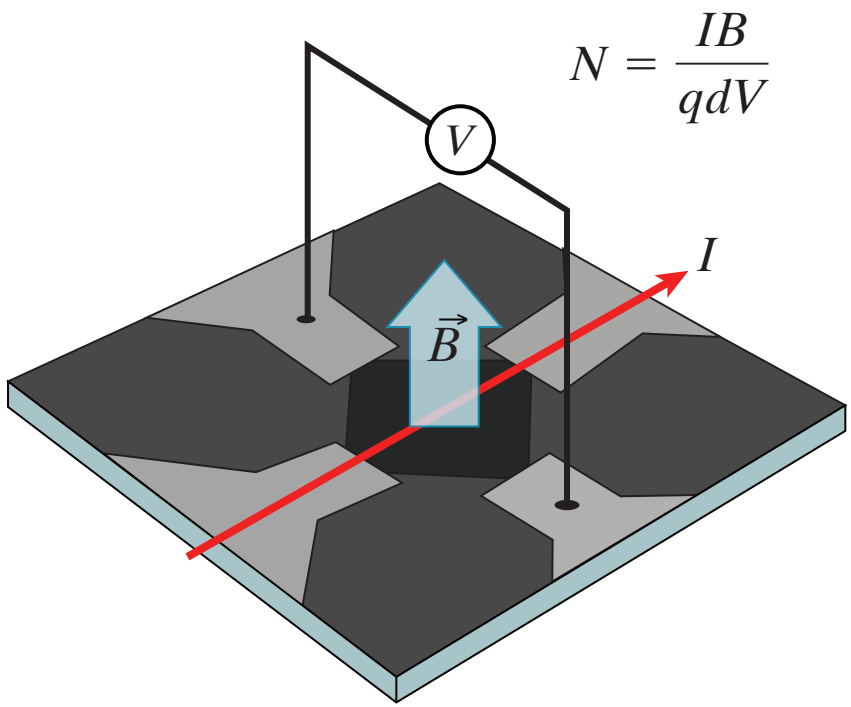


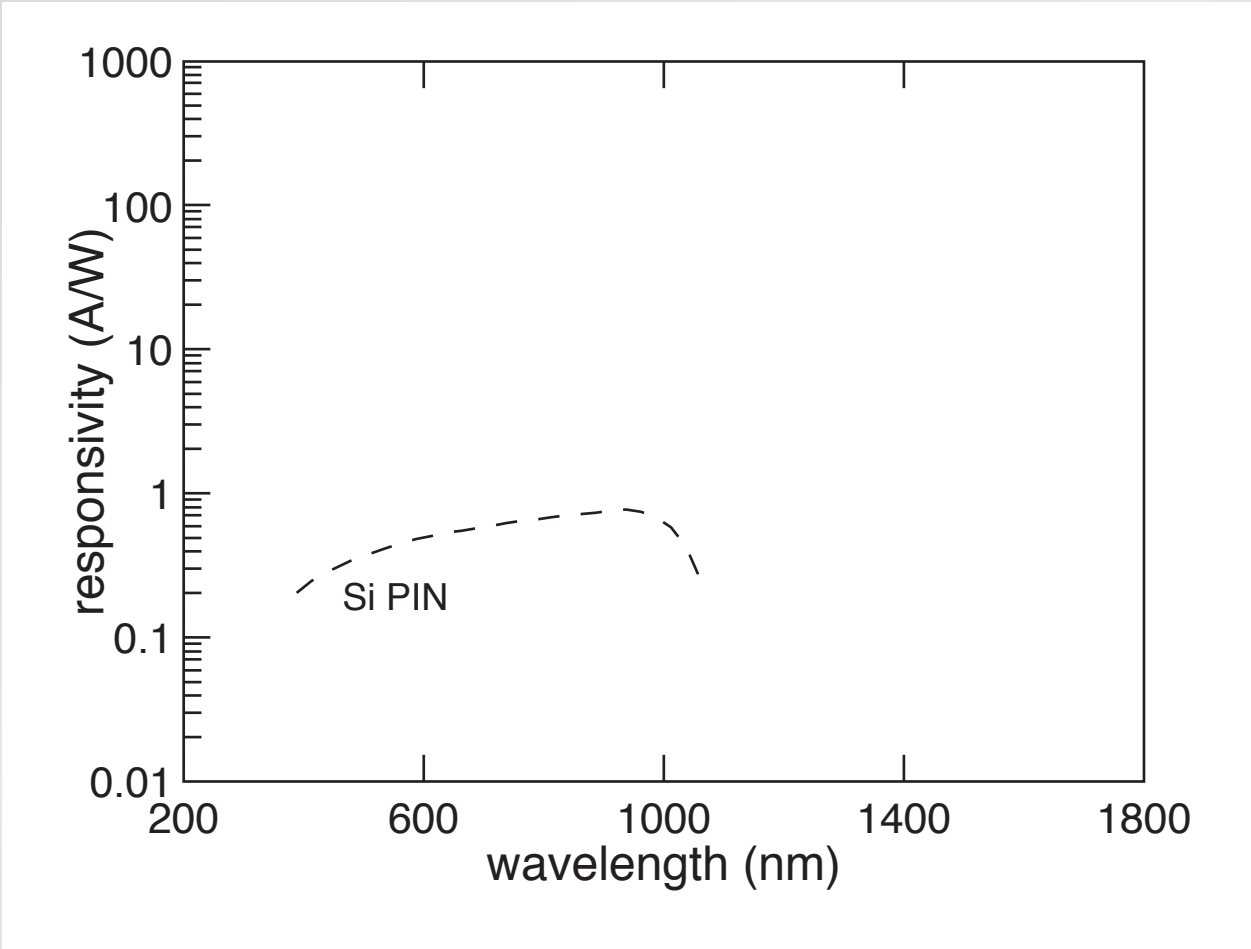
Optoelectronic properties

Hall measurements



Devices

responsivity



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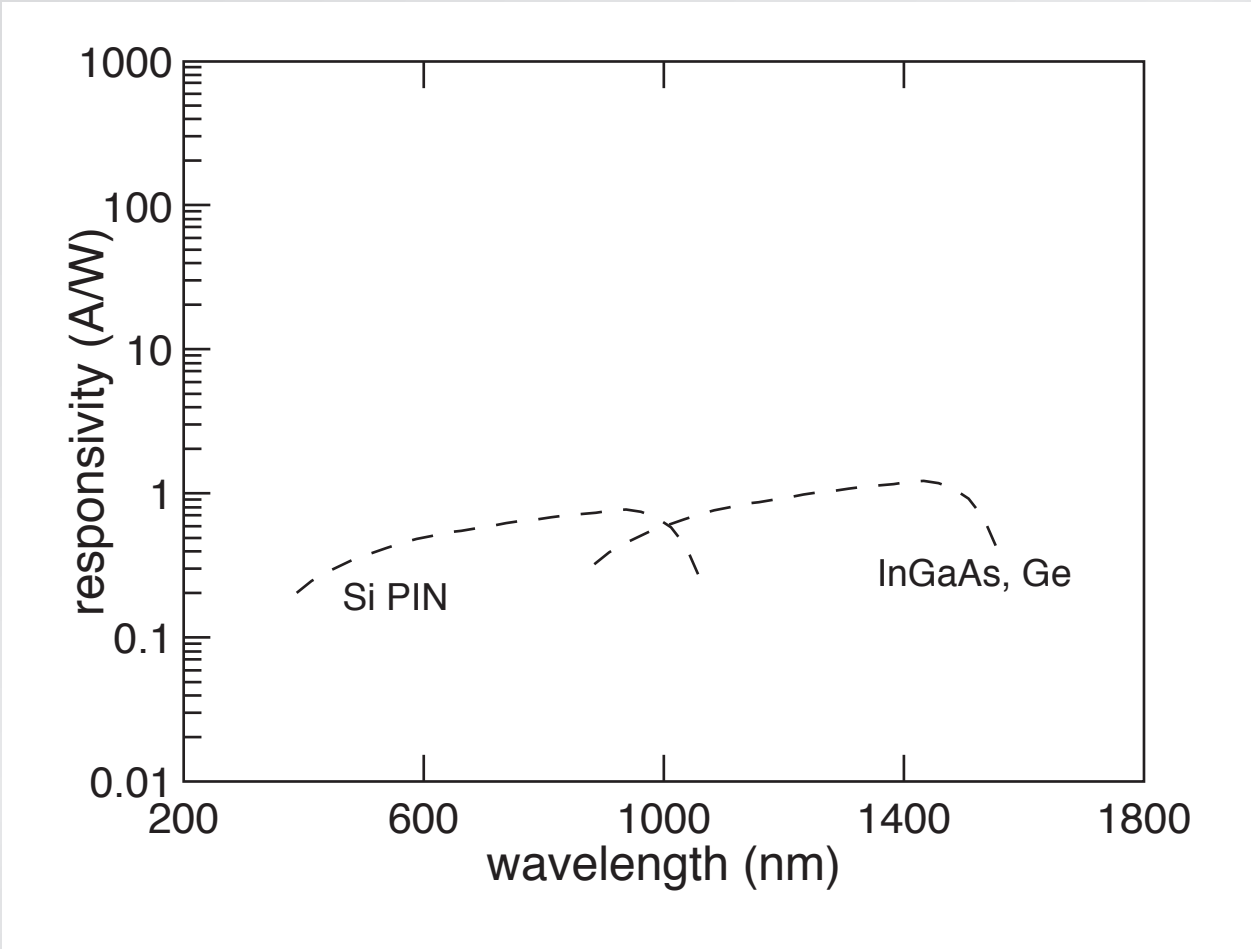

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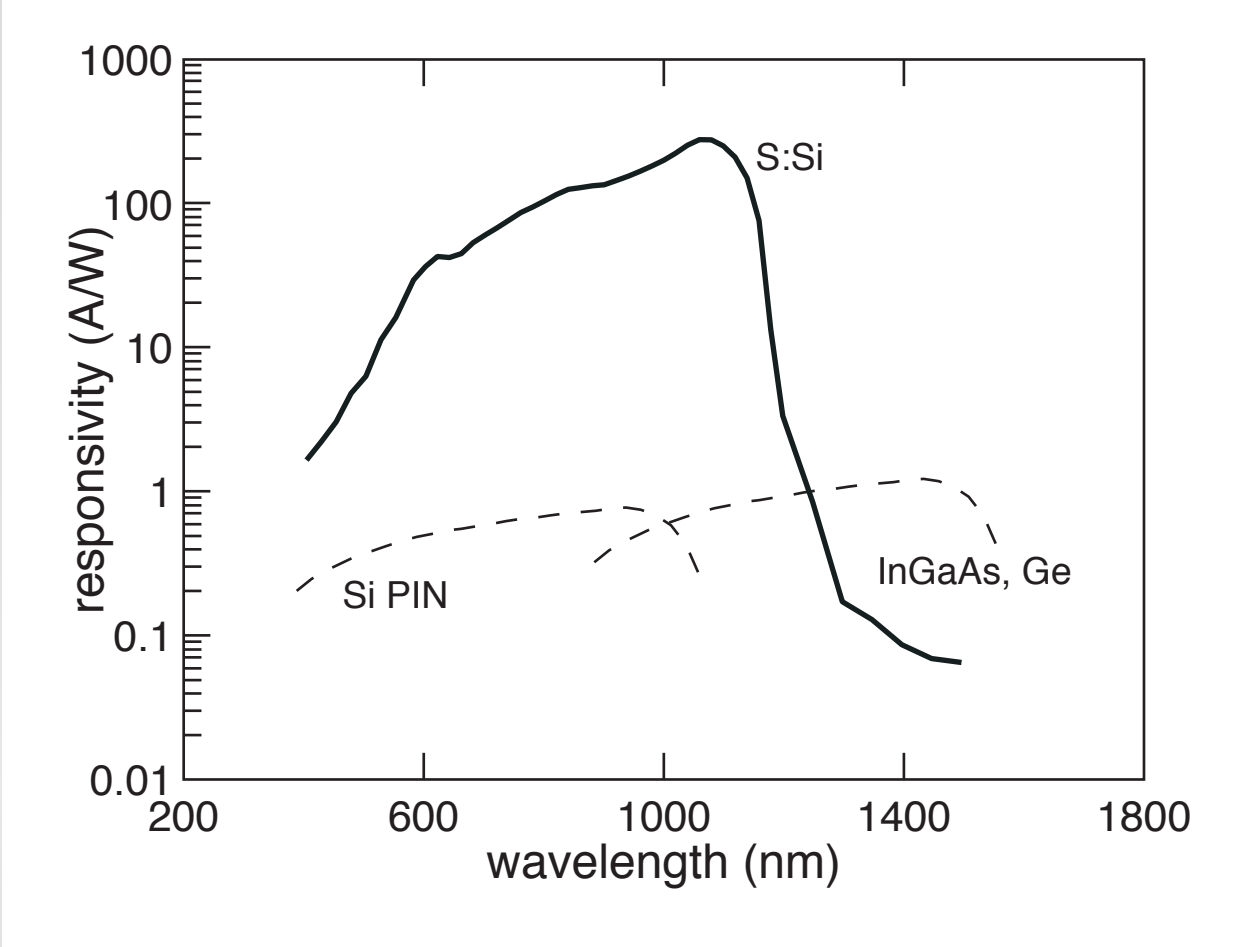
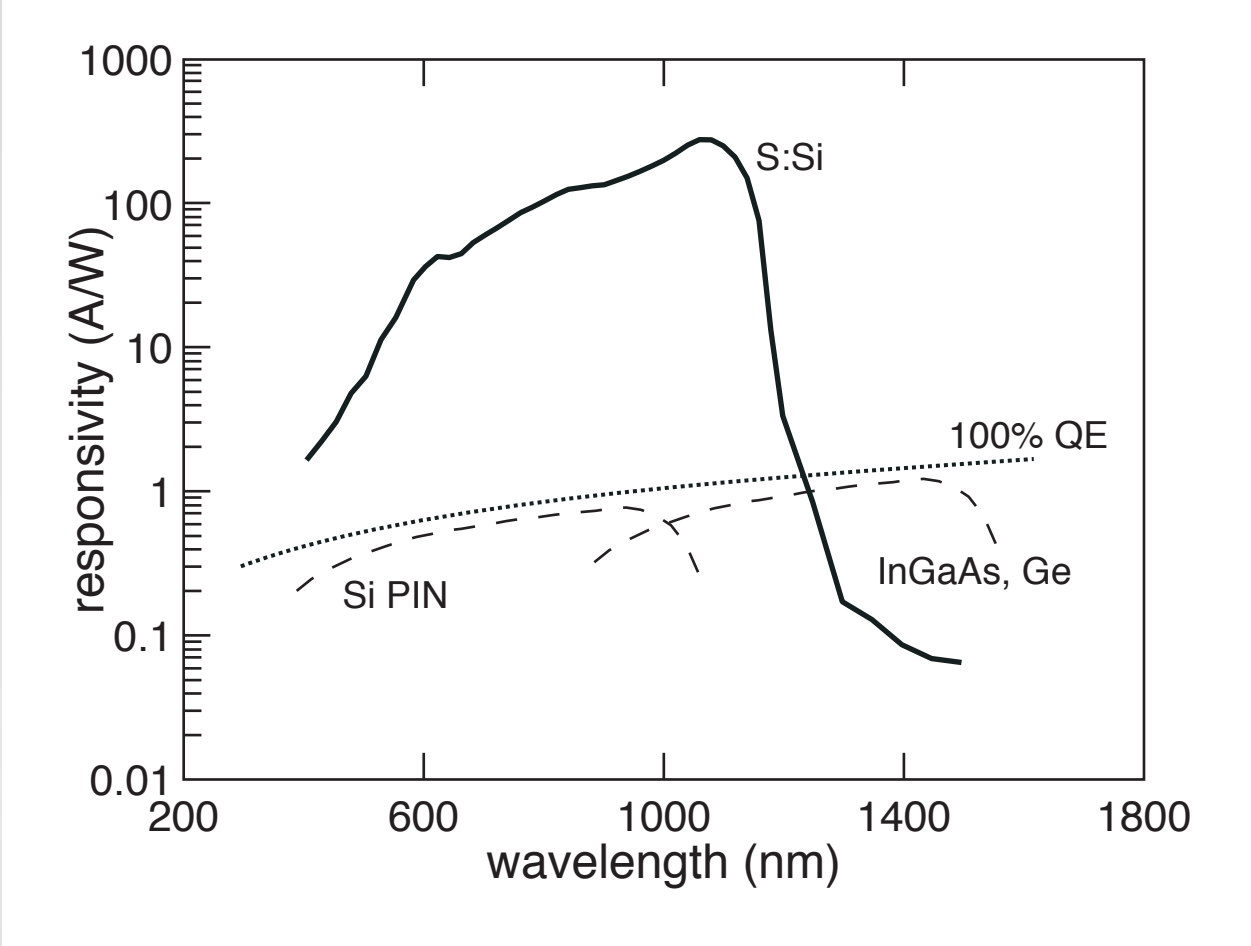


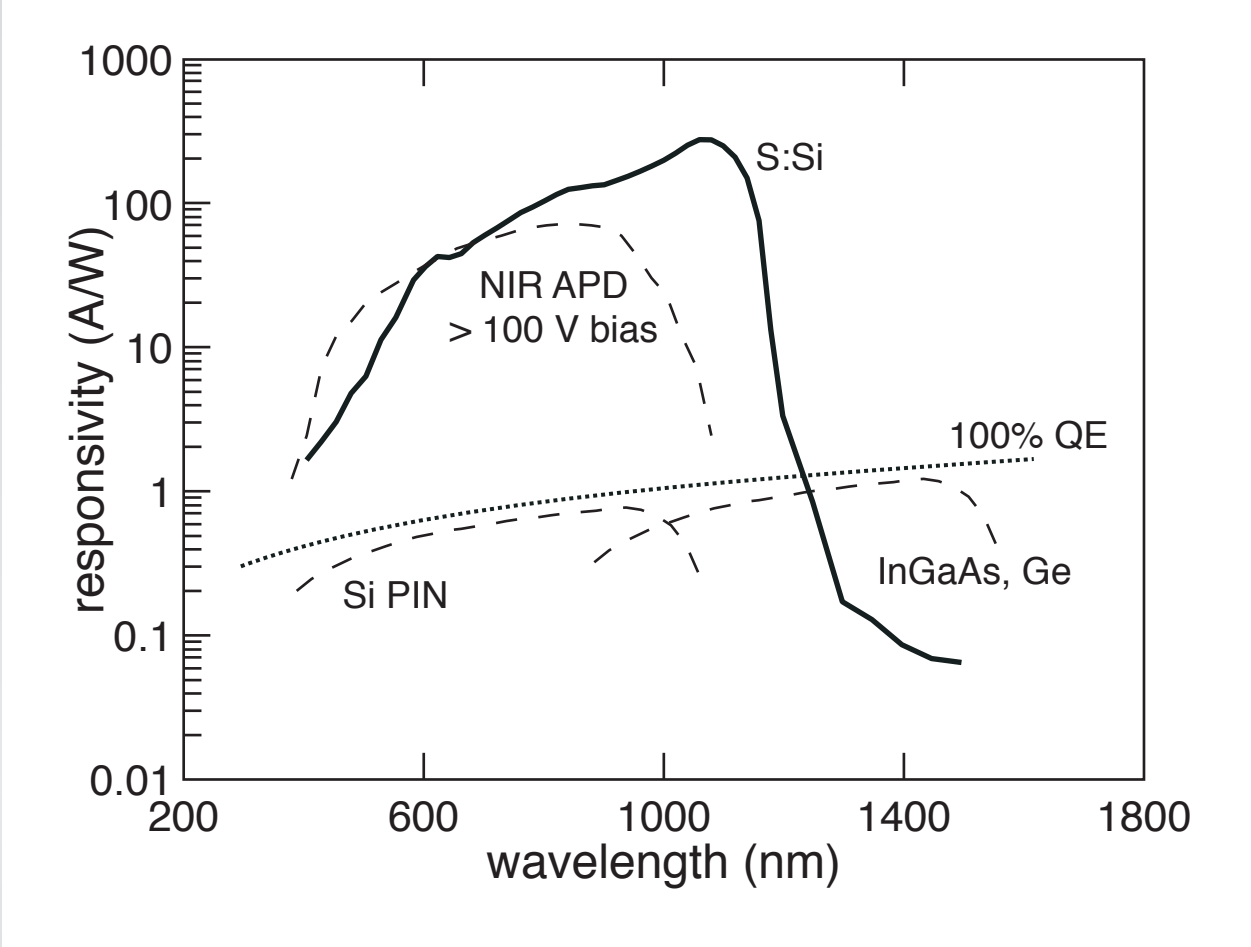
Devices

responsivity

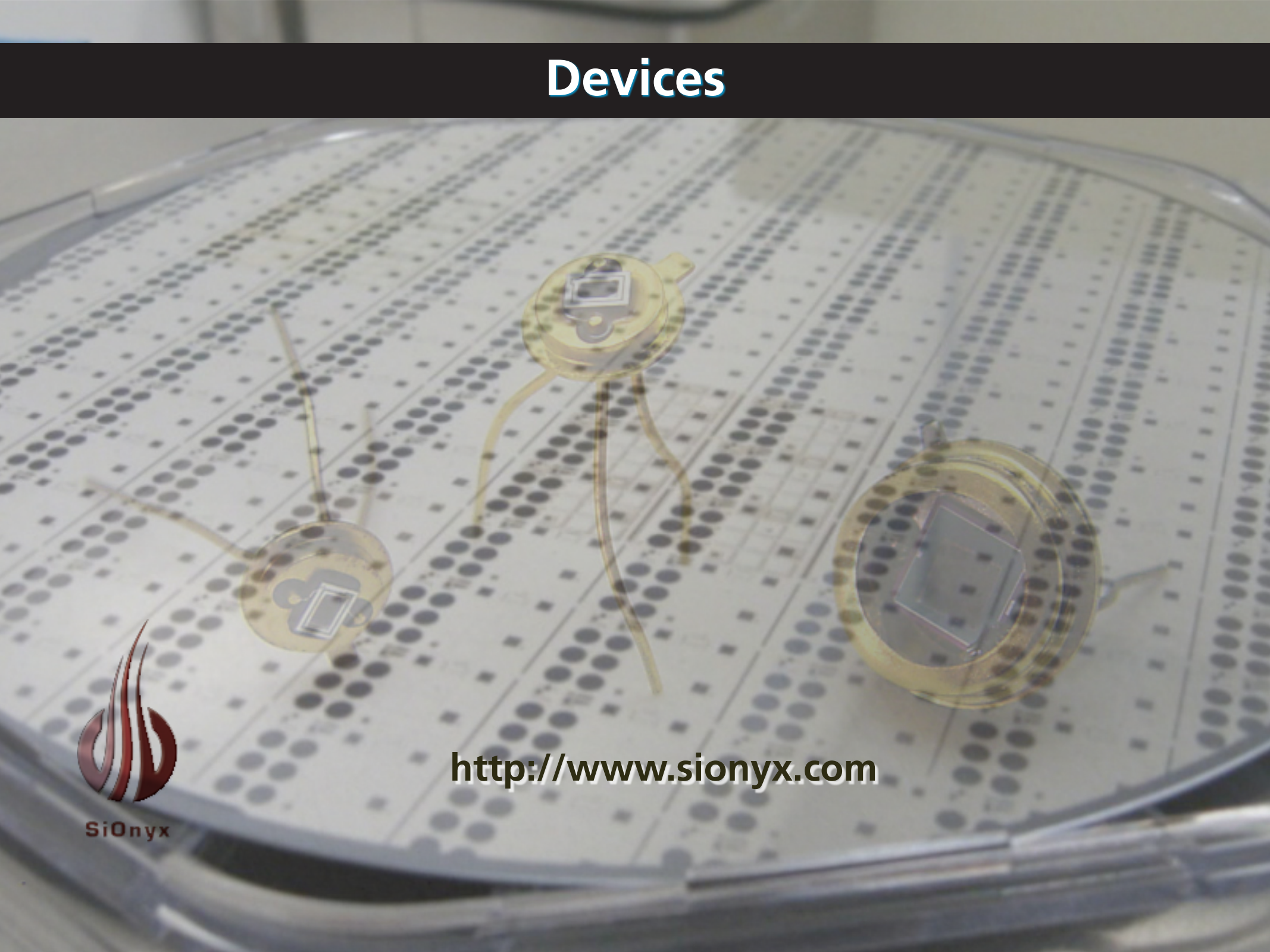


Devices

responsivity



Devices



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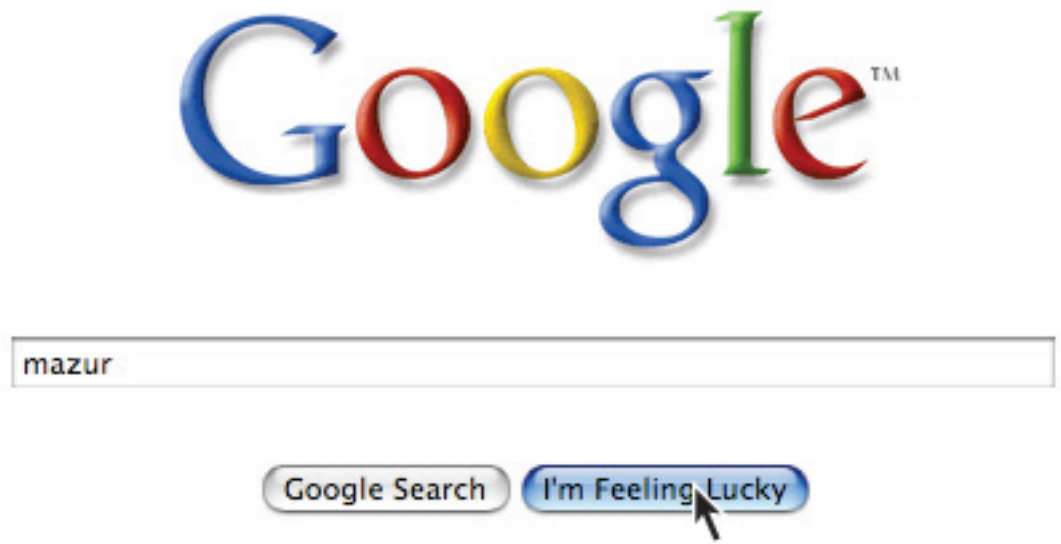
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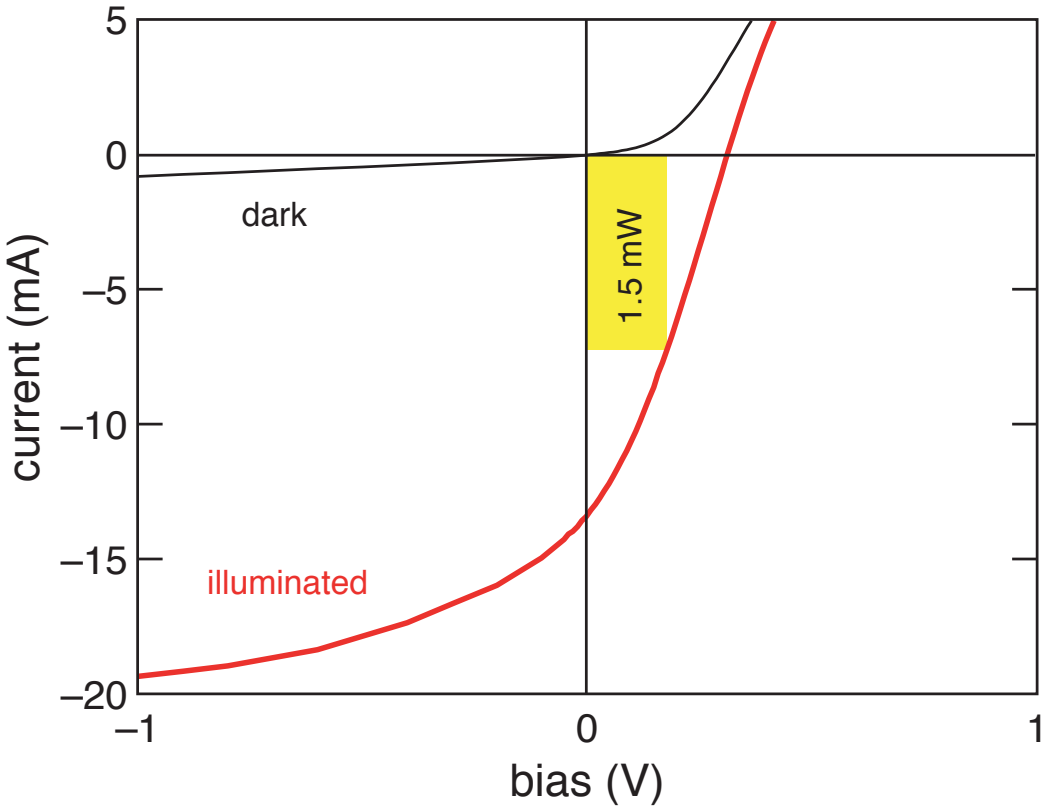
1.5% efficiency, a good beginning