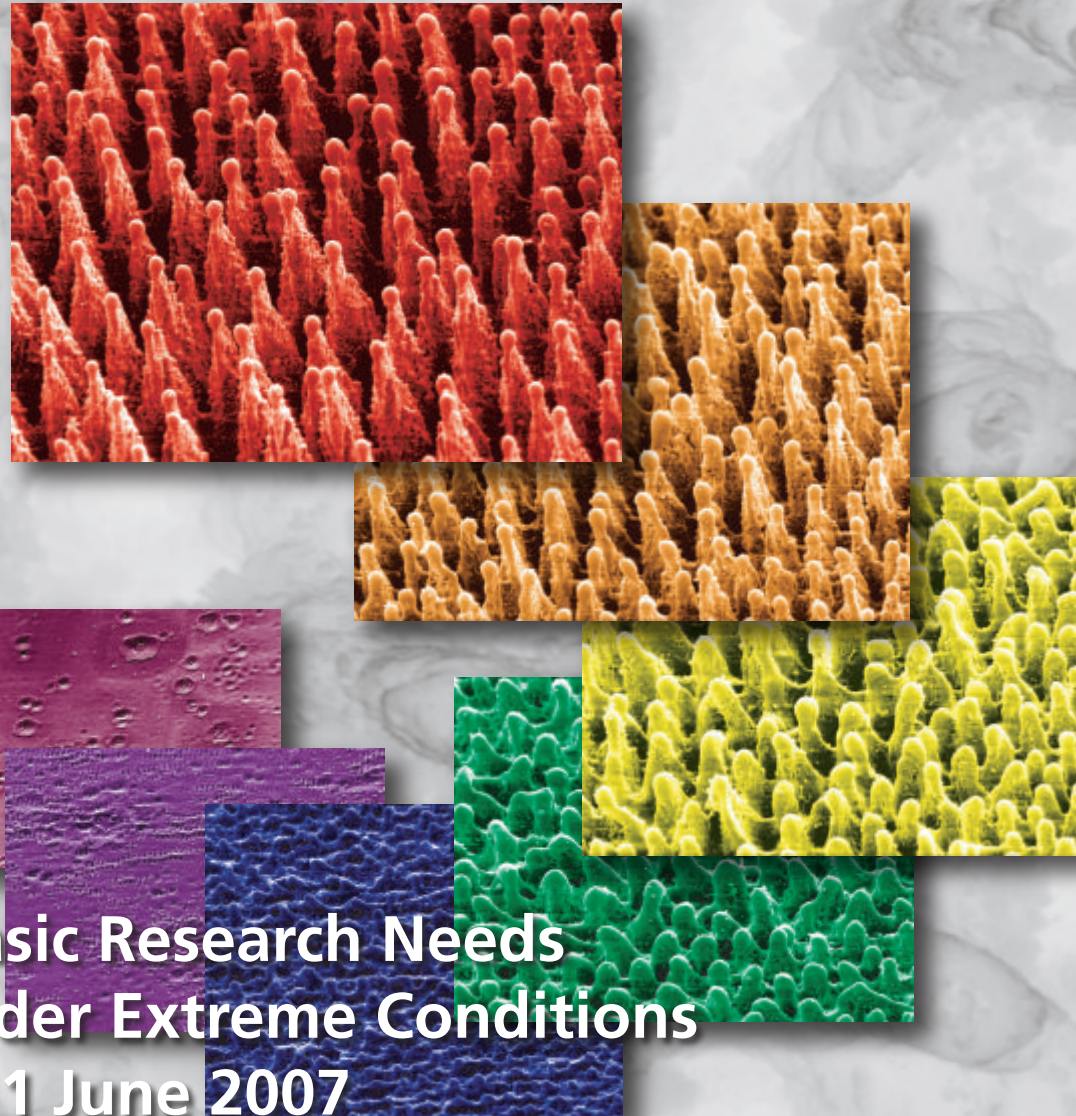


# Driving atoms into materials using extreme photon fluxes



Workshop on Basic Research Needs  
for Materials under Extreme Conditions  
Bethesda, MD, 11 June 2007



# Challenge

**failing to see problem as an *opportunity***

# Introduction

ASTM  
STP 1141

**DAMAGED**

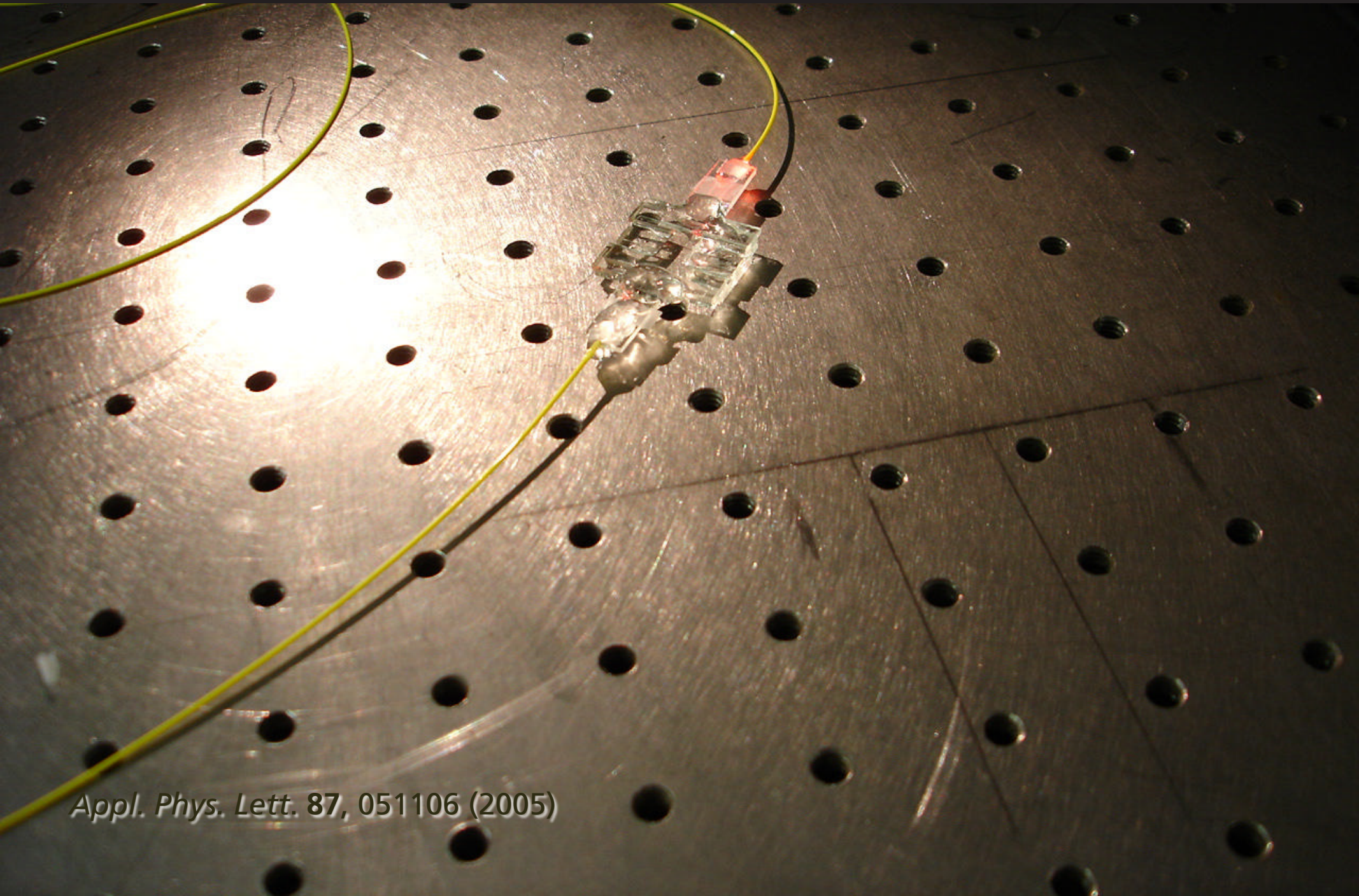
22nd ANNUAL BOULDER DAMAGE SYMPOSIUM  
Proceedings



LASER-INDUCED DAMAGE  
IN OPTICAL MATERIALS: 1990

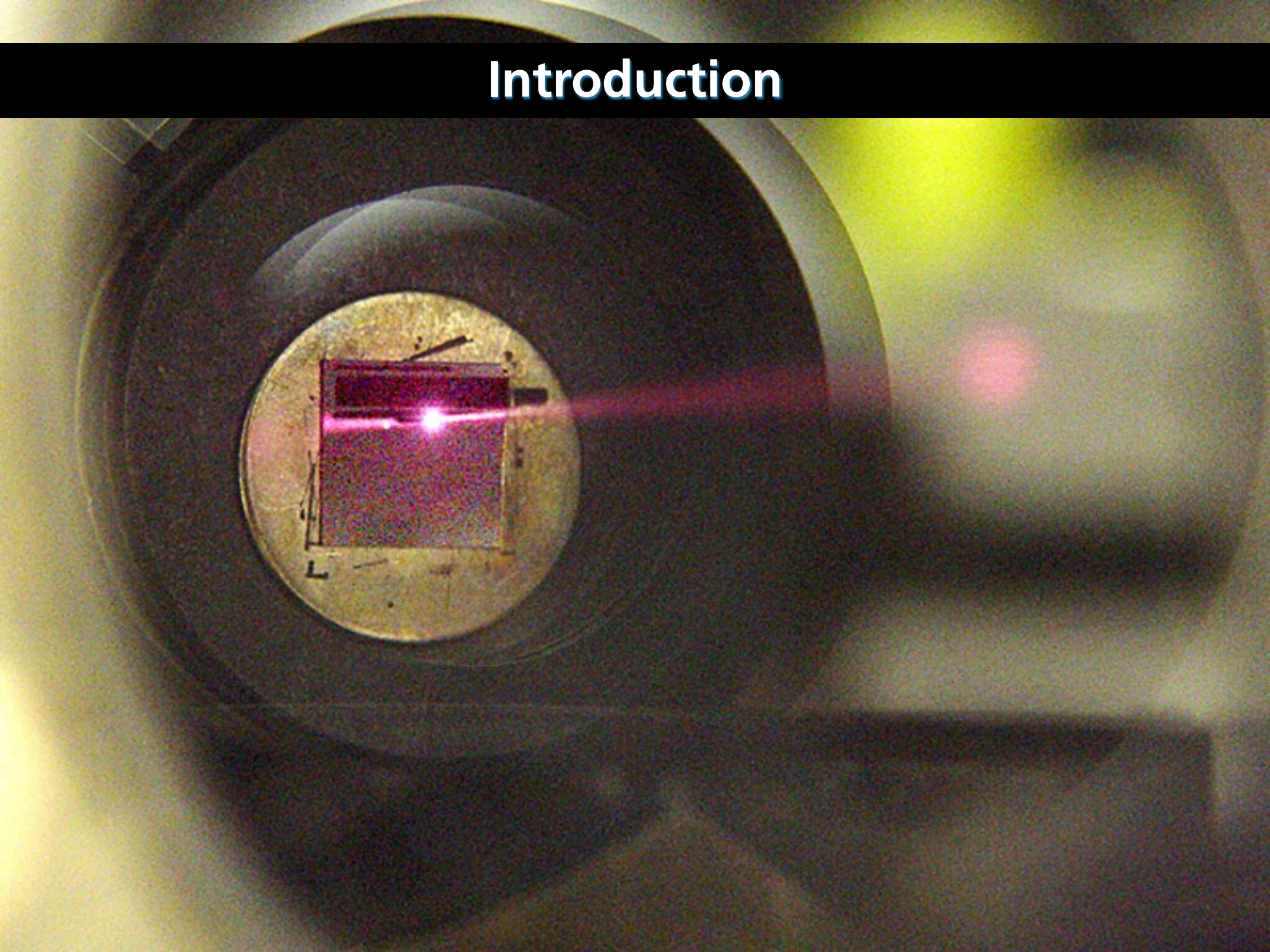
24-26 OCTOBER 1990  
BOULDER, COLORADO

# Introduction

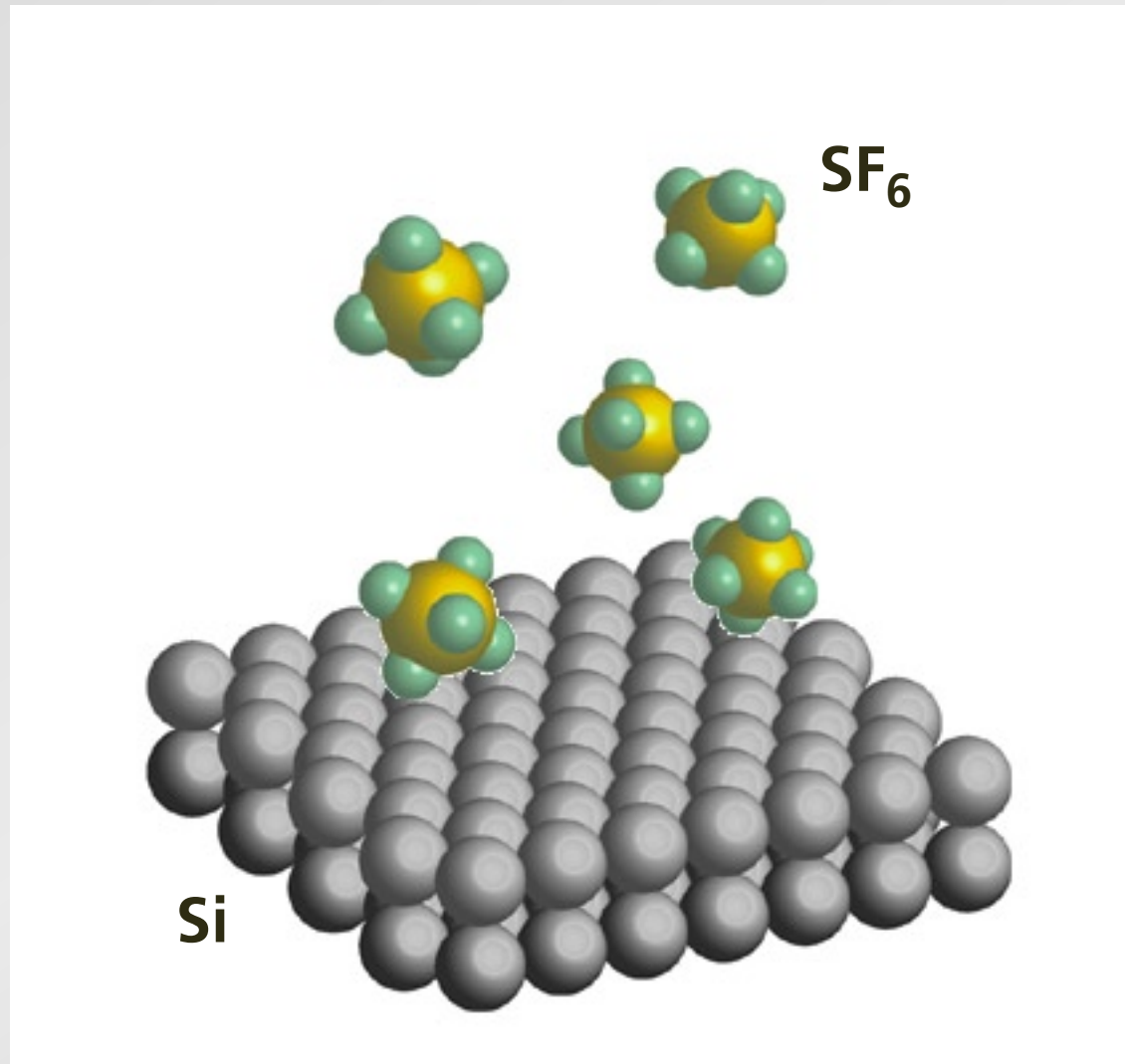


*Appl. Phys. Lett.* 87, 051106 (2005)

# Introduction

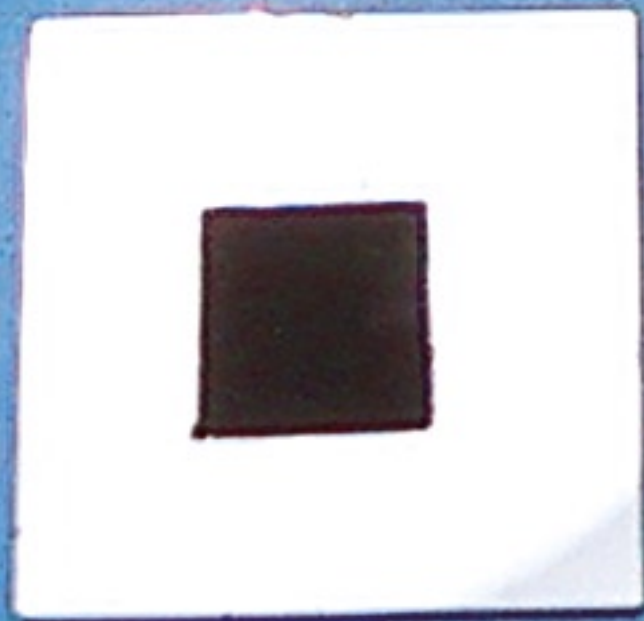


# Introduction



irradiate with 100-fs 10 kJ/m<sup>2</sup> pulses

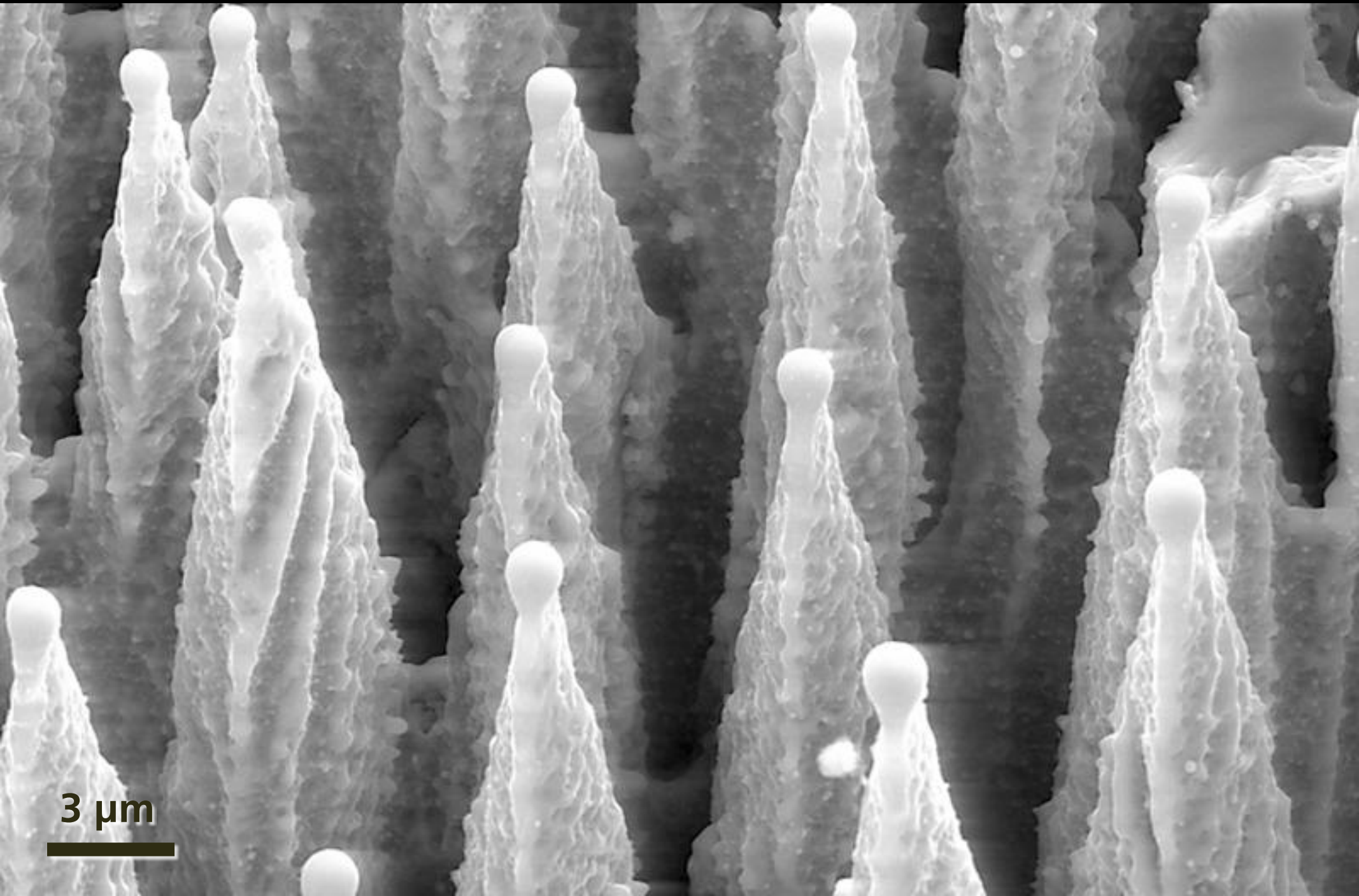
# Introduction



**"black silicon"**



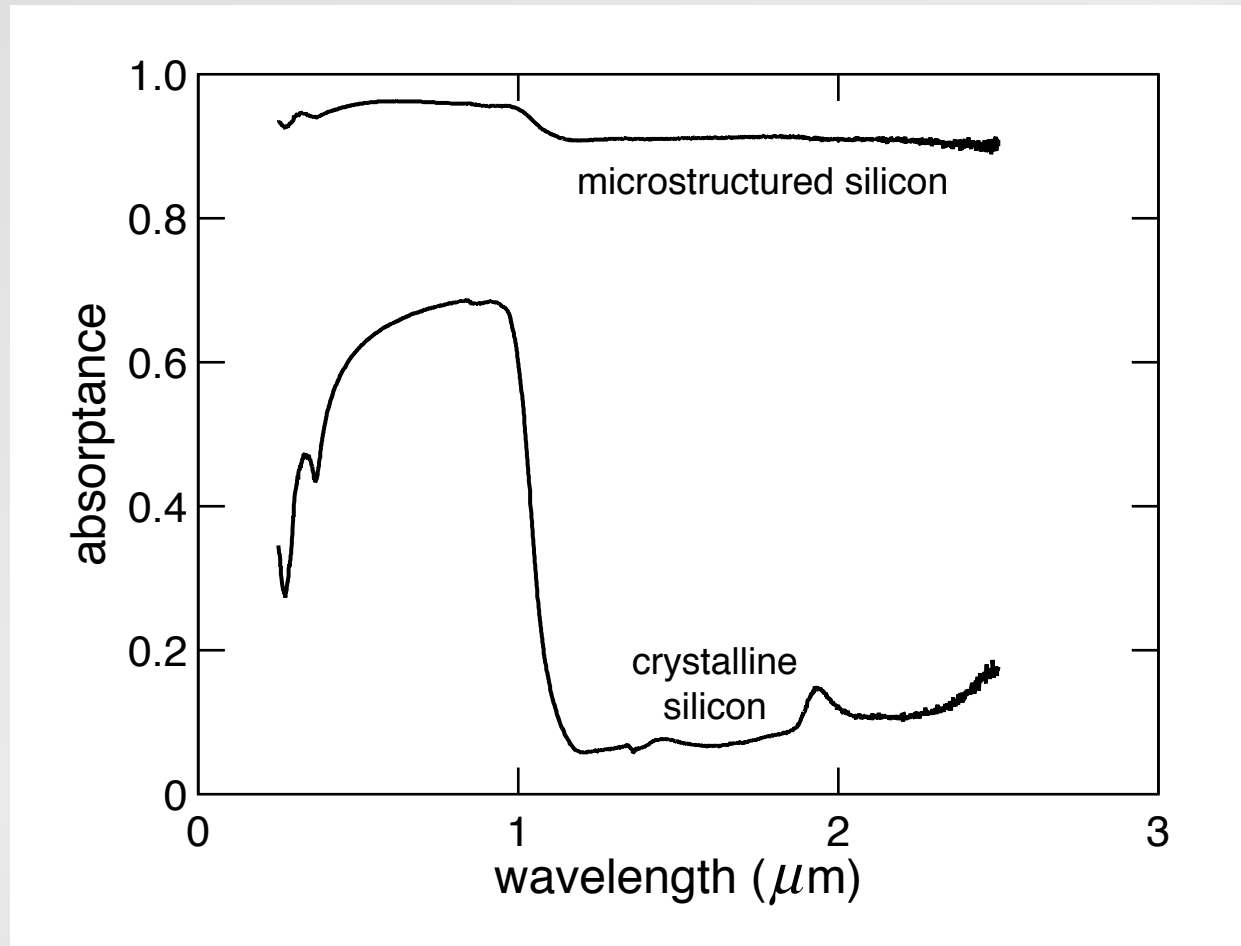
# Introduction



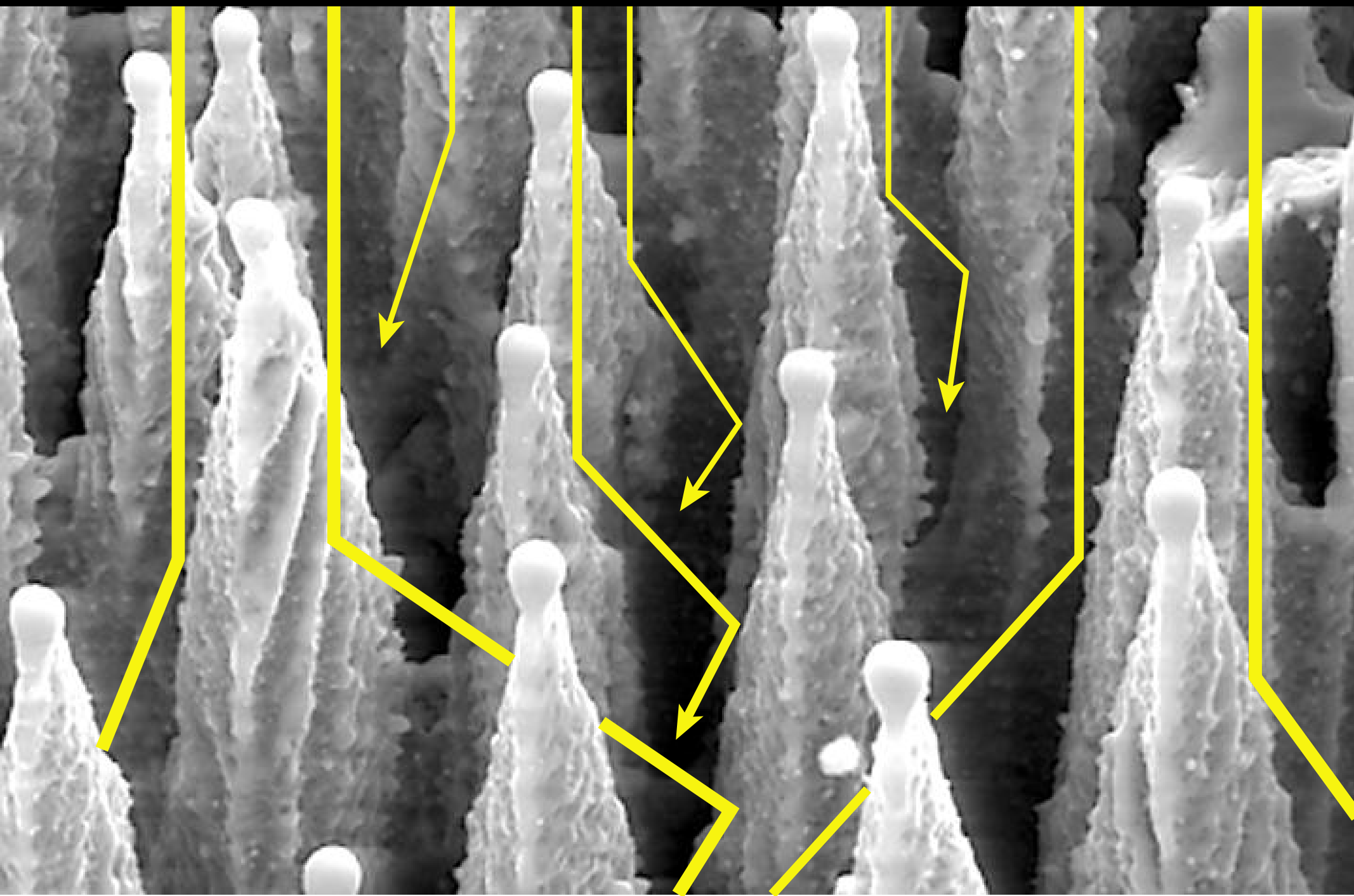


# Properties

absorptance ( $1 - R - T$ )

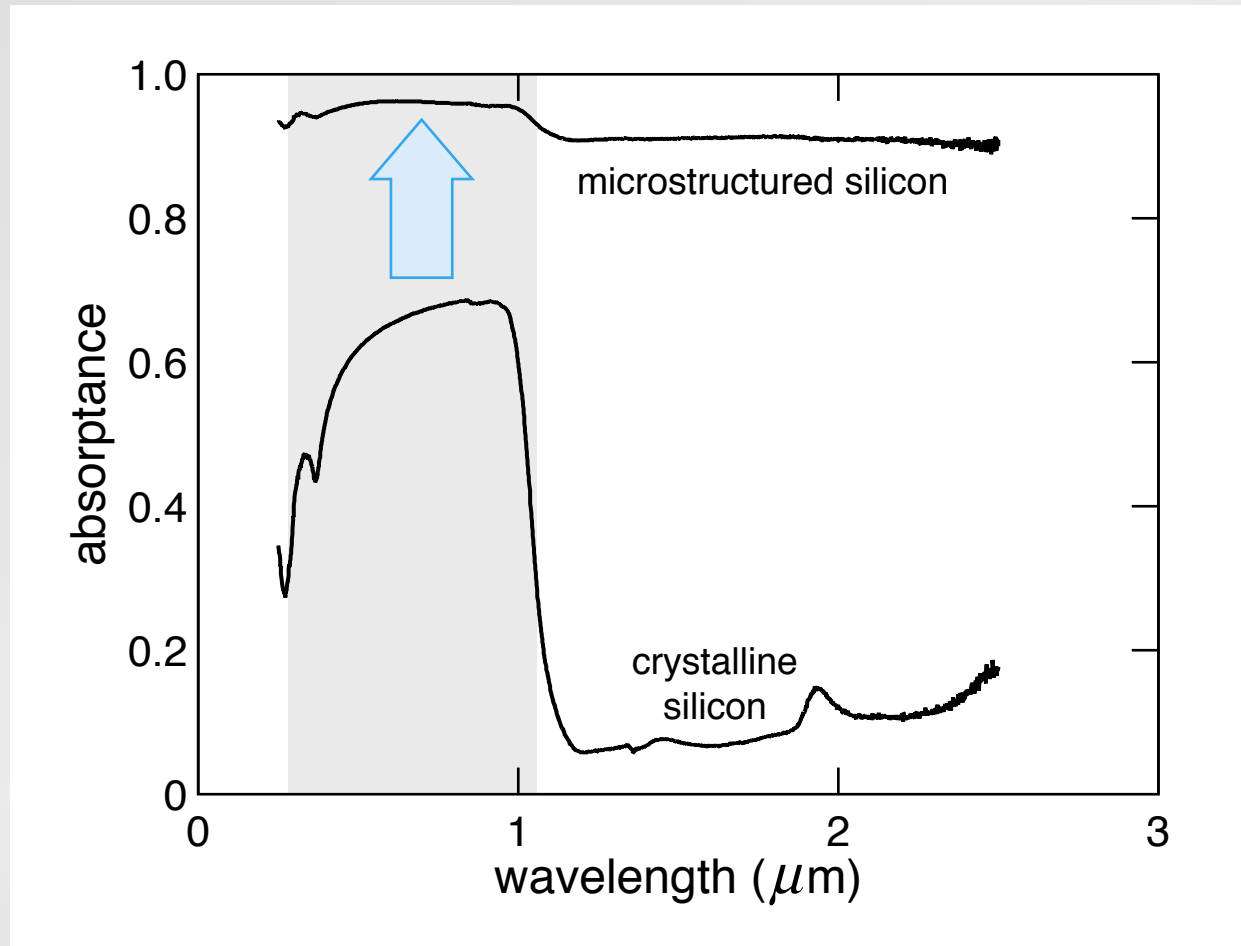


# Properties



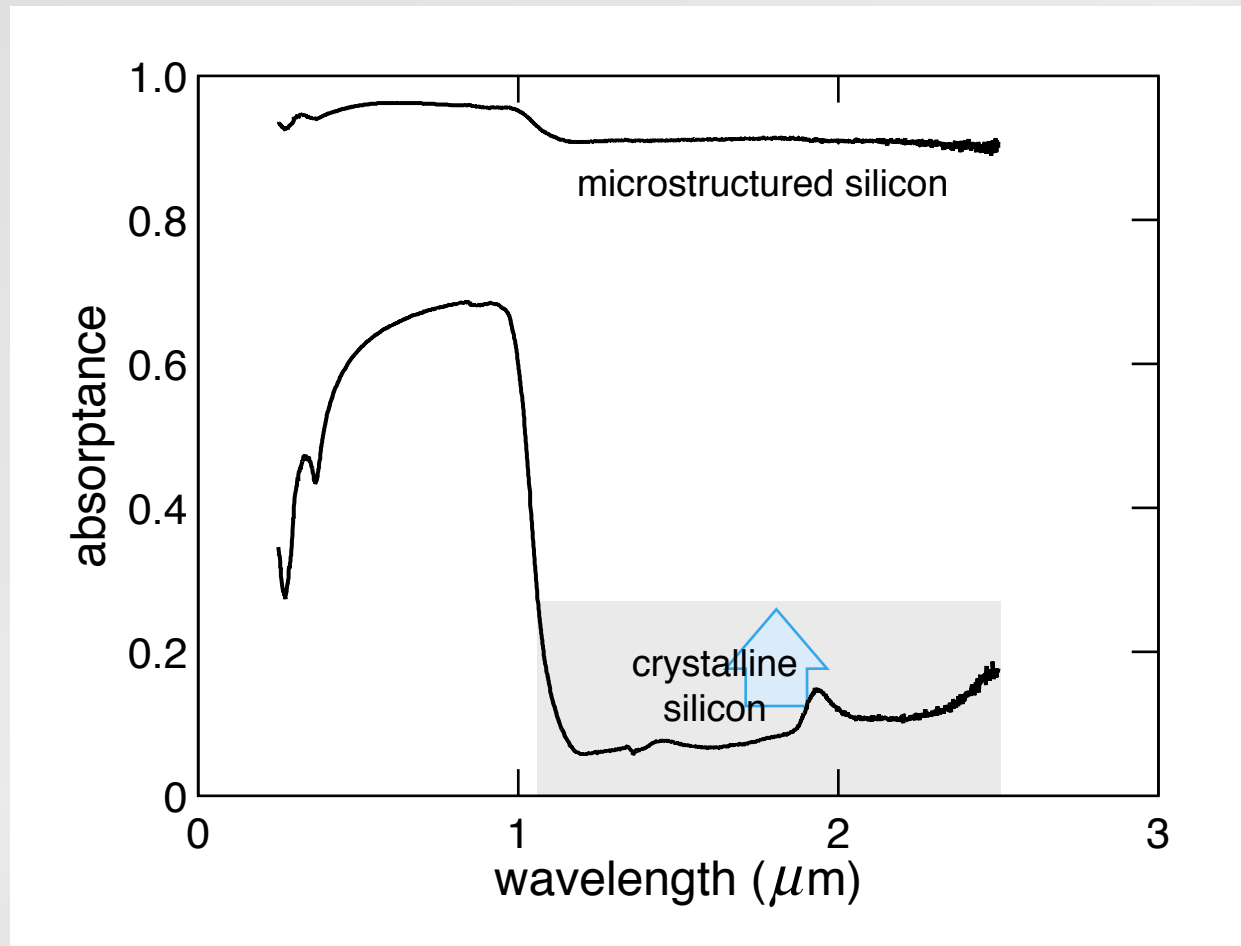
# Properties

multiple reflections enhance absorption



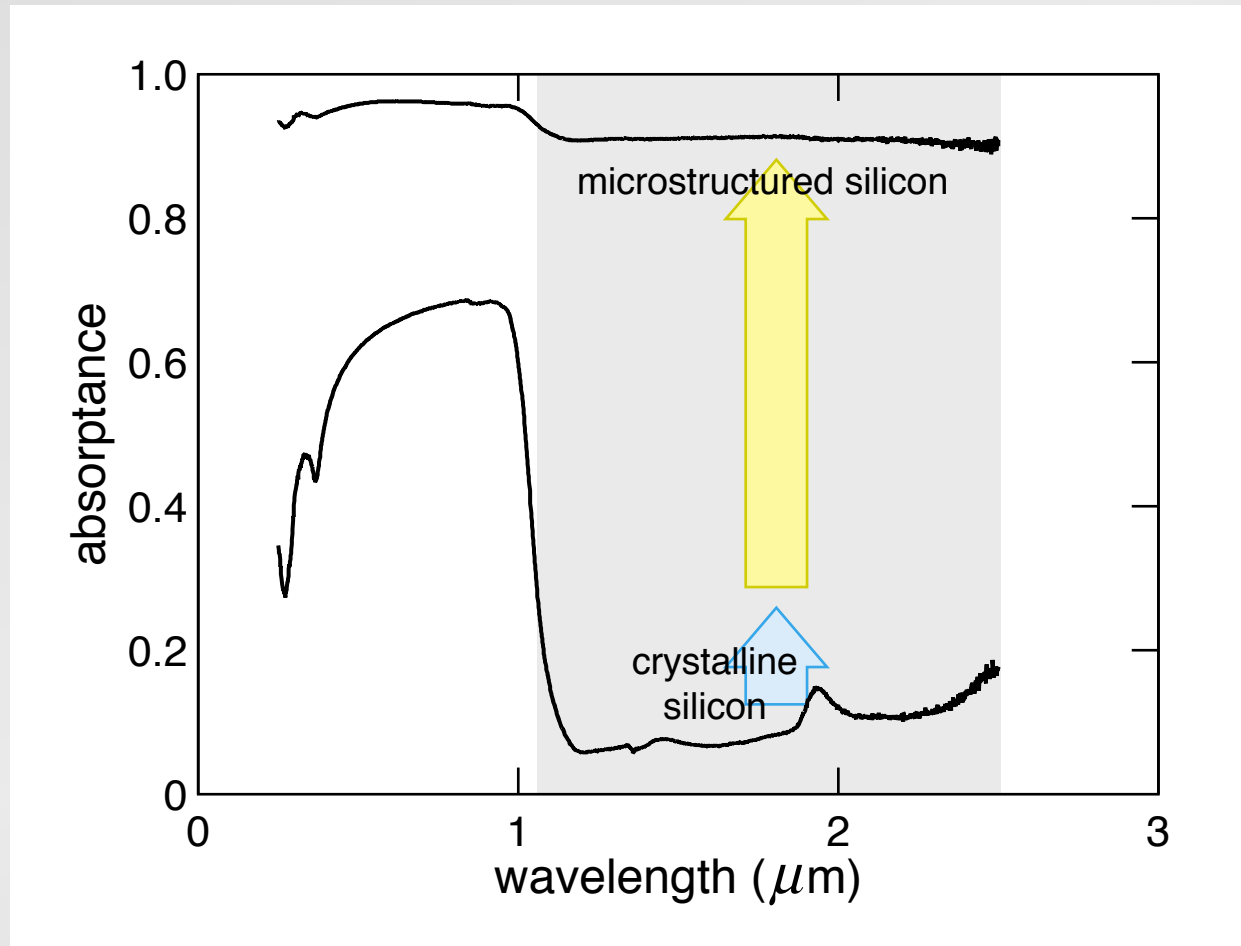
# Properties

multiple reflections enhance absorption

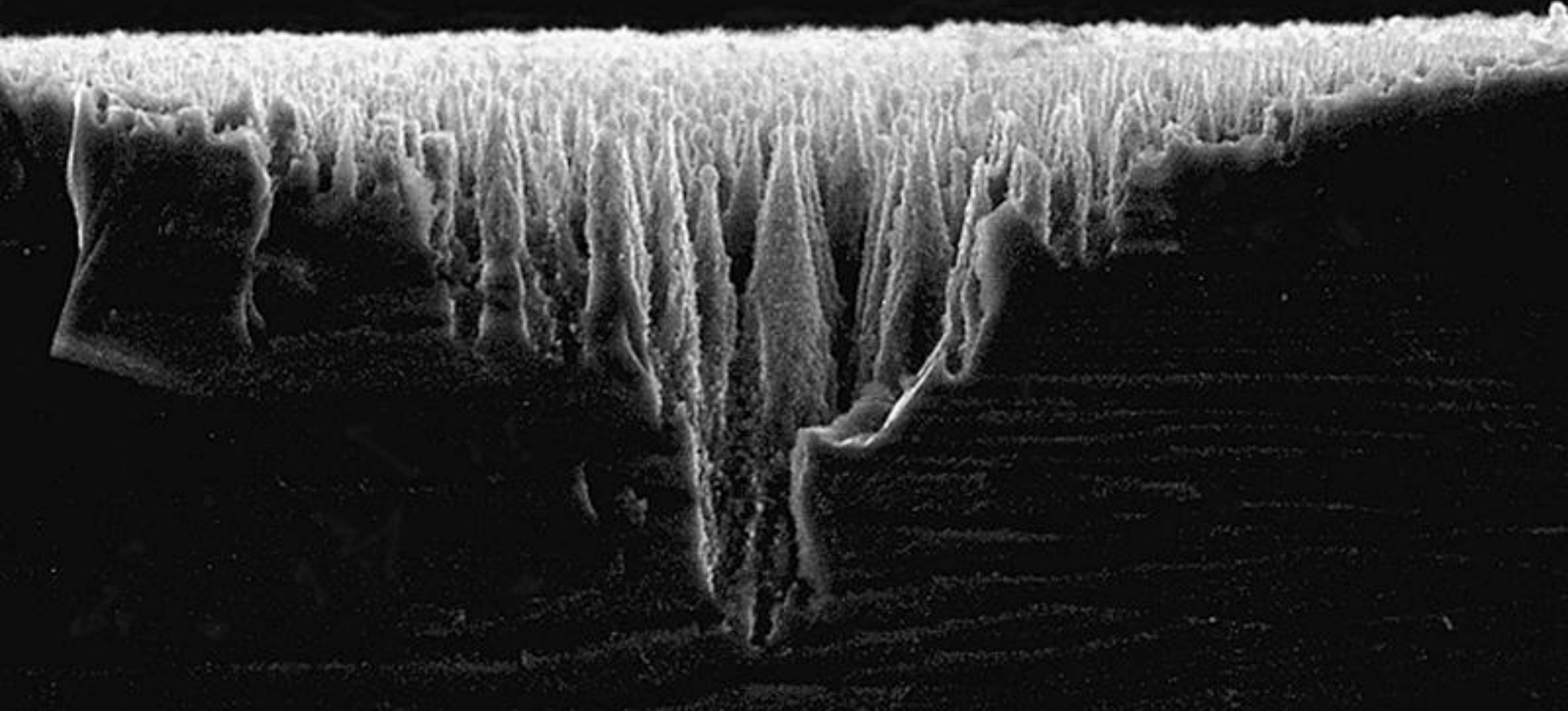


# Properties

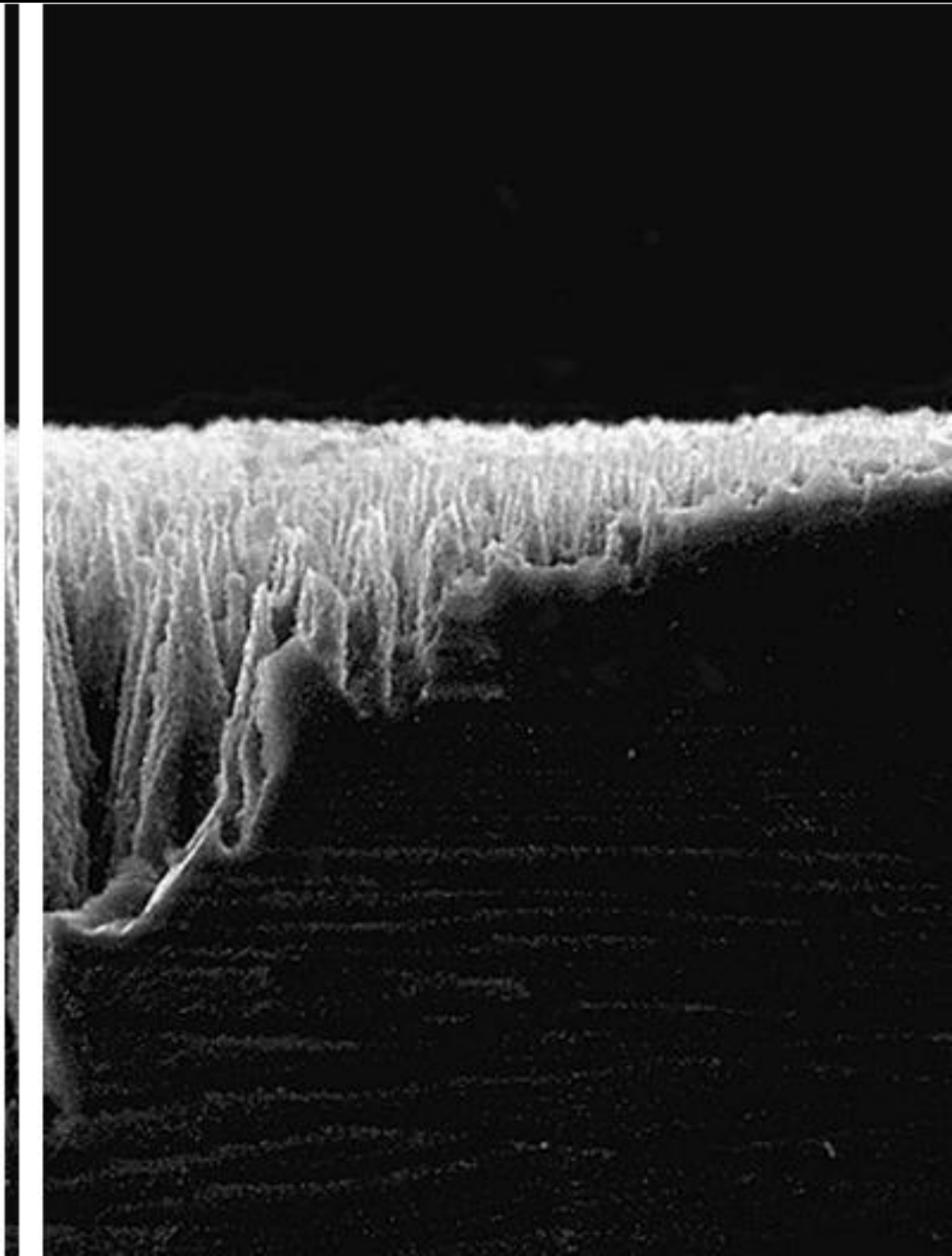
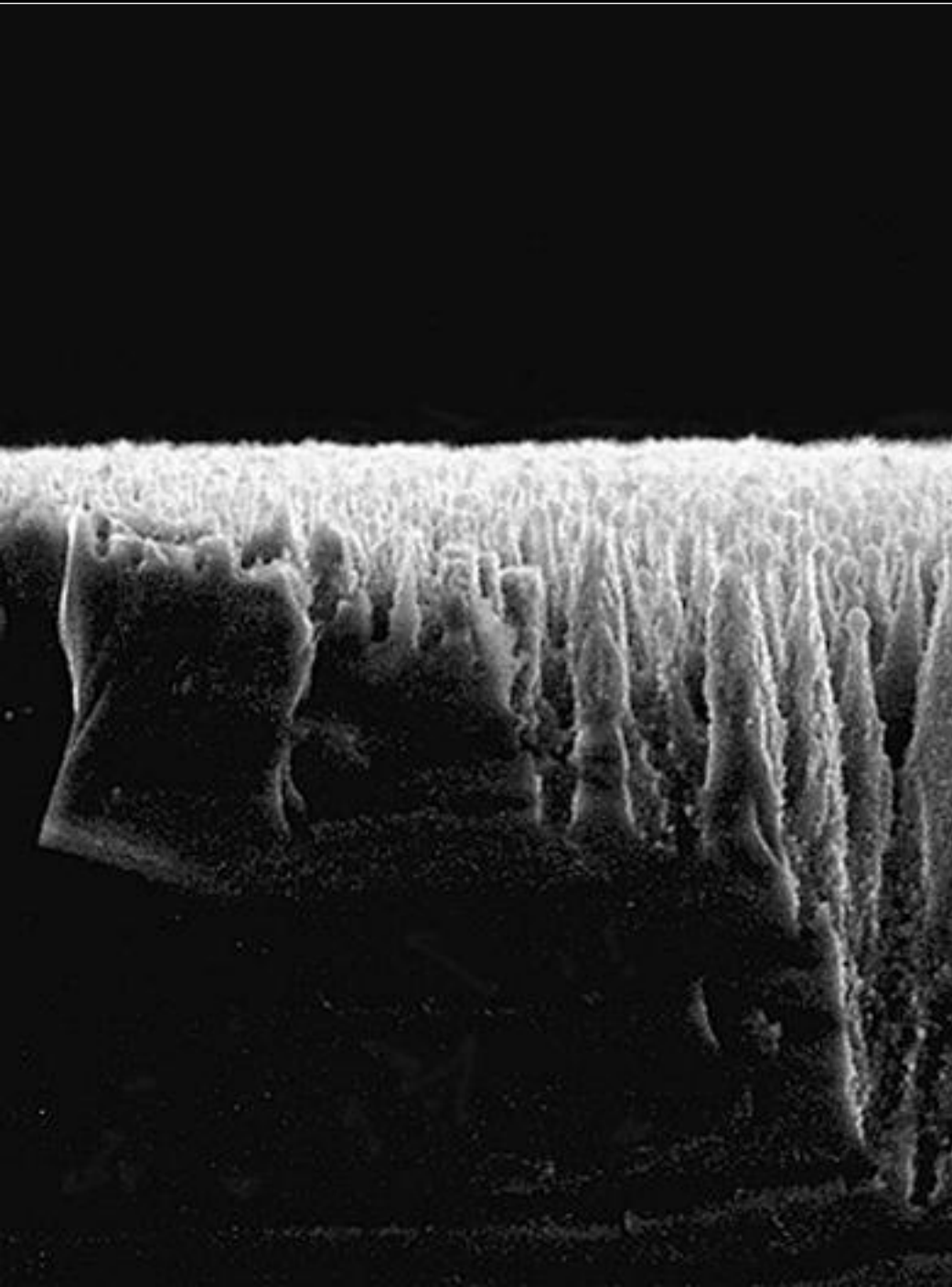
electronic band structure changes



# Structural and chemical analysis

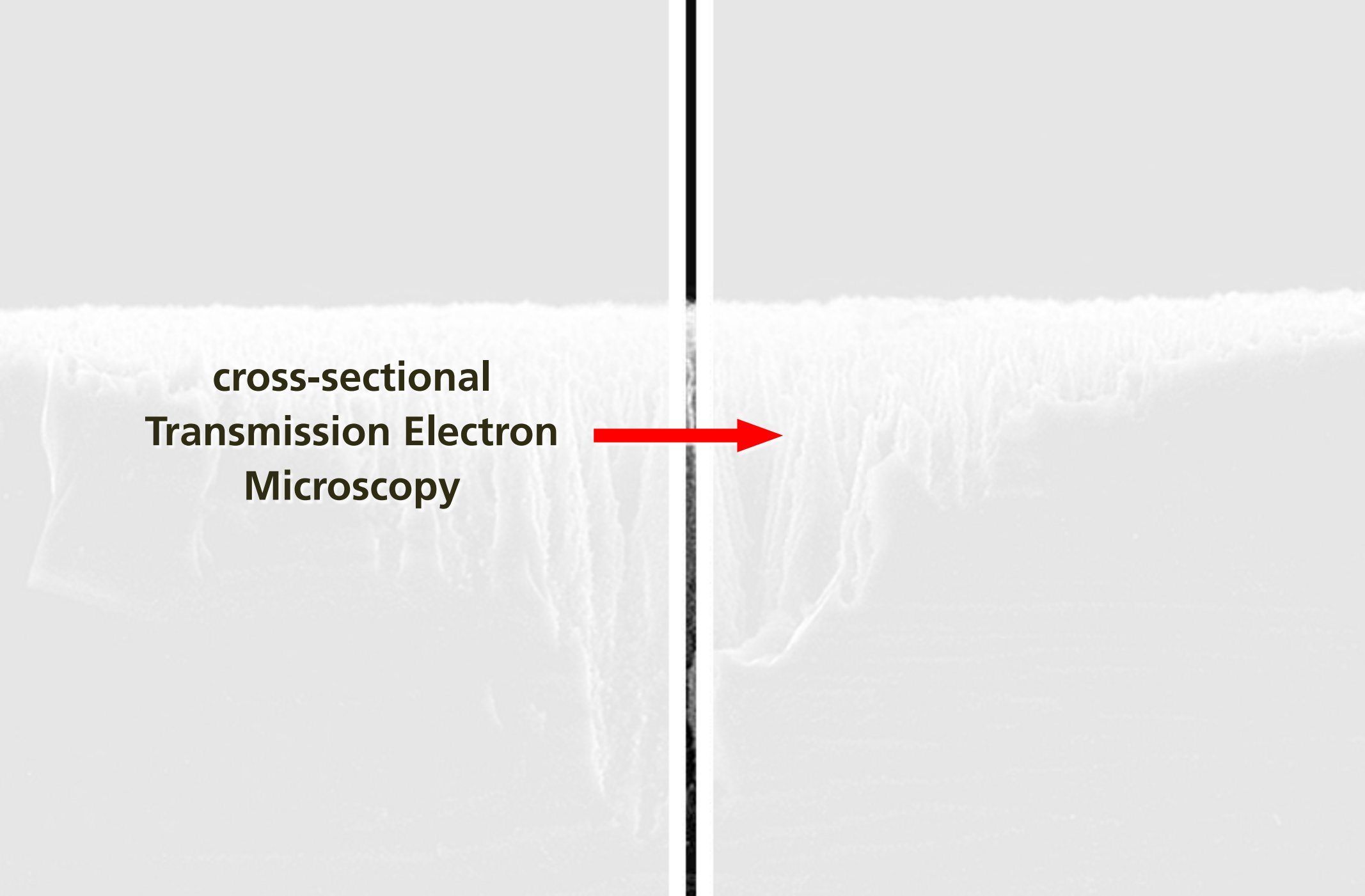


# Structural and chemical analysis



# Structural and chemical analysis

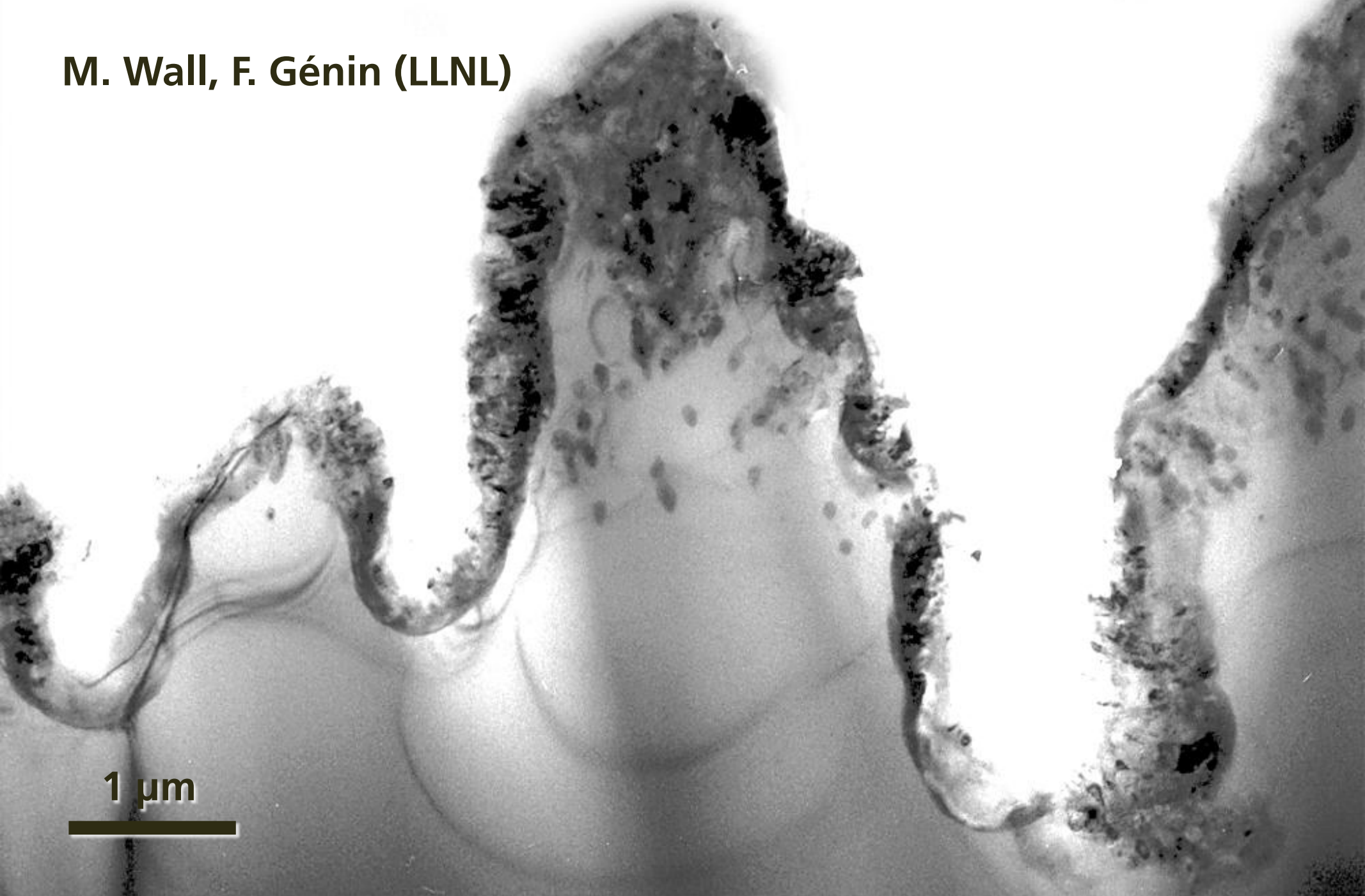
**cross-sectional  
Transmission Electron  
Microscopy**





# Structural and chemical analysis

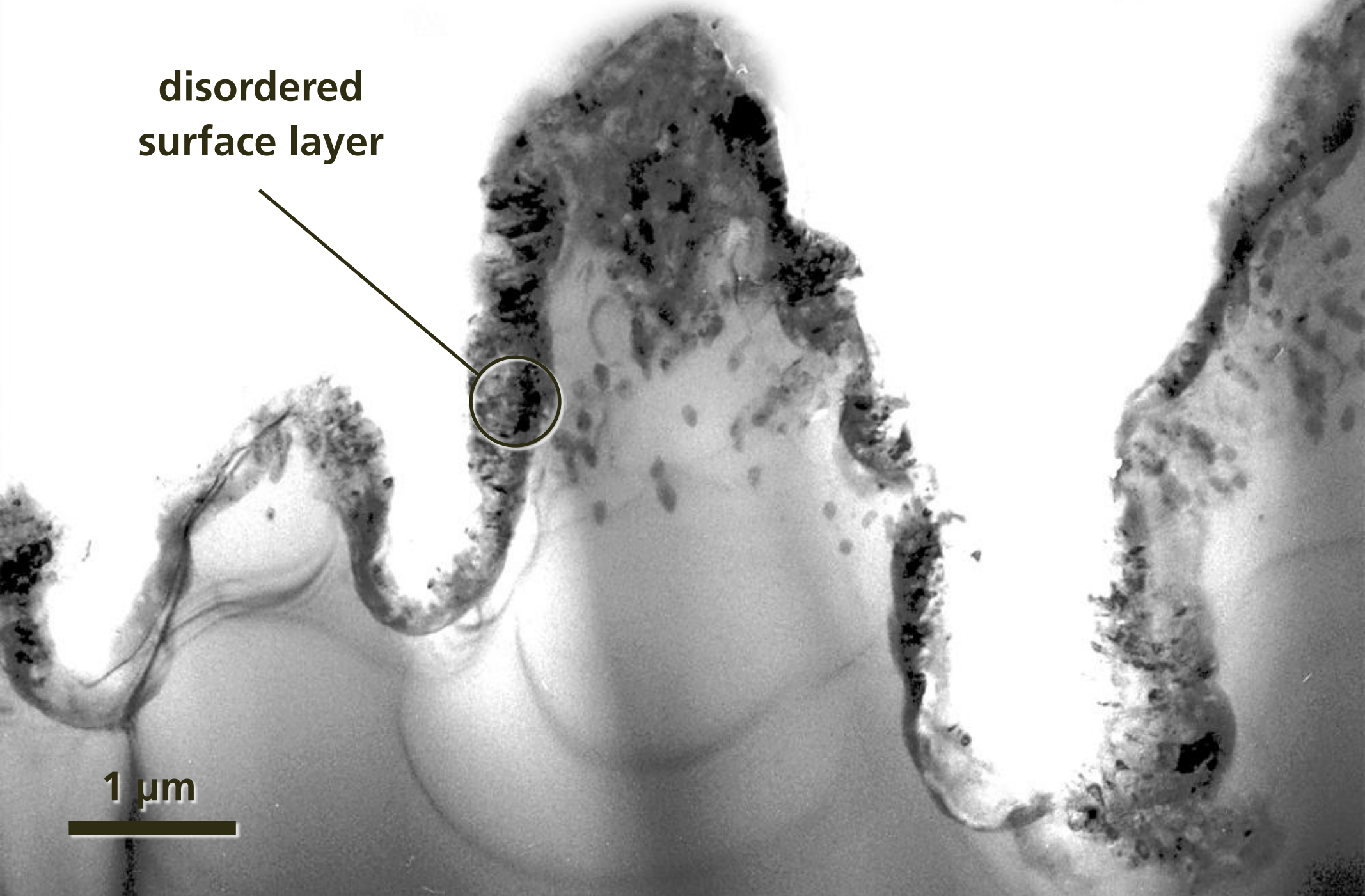
M. Wall, F. Génin (LLNL)



1  $\mu\text{m}$

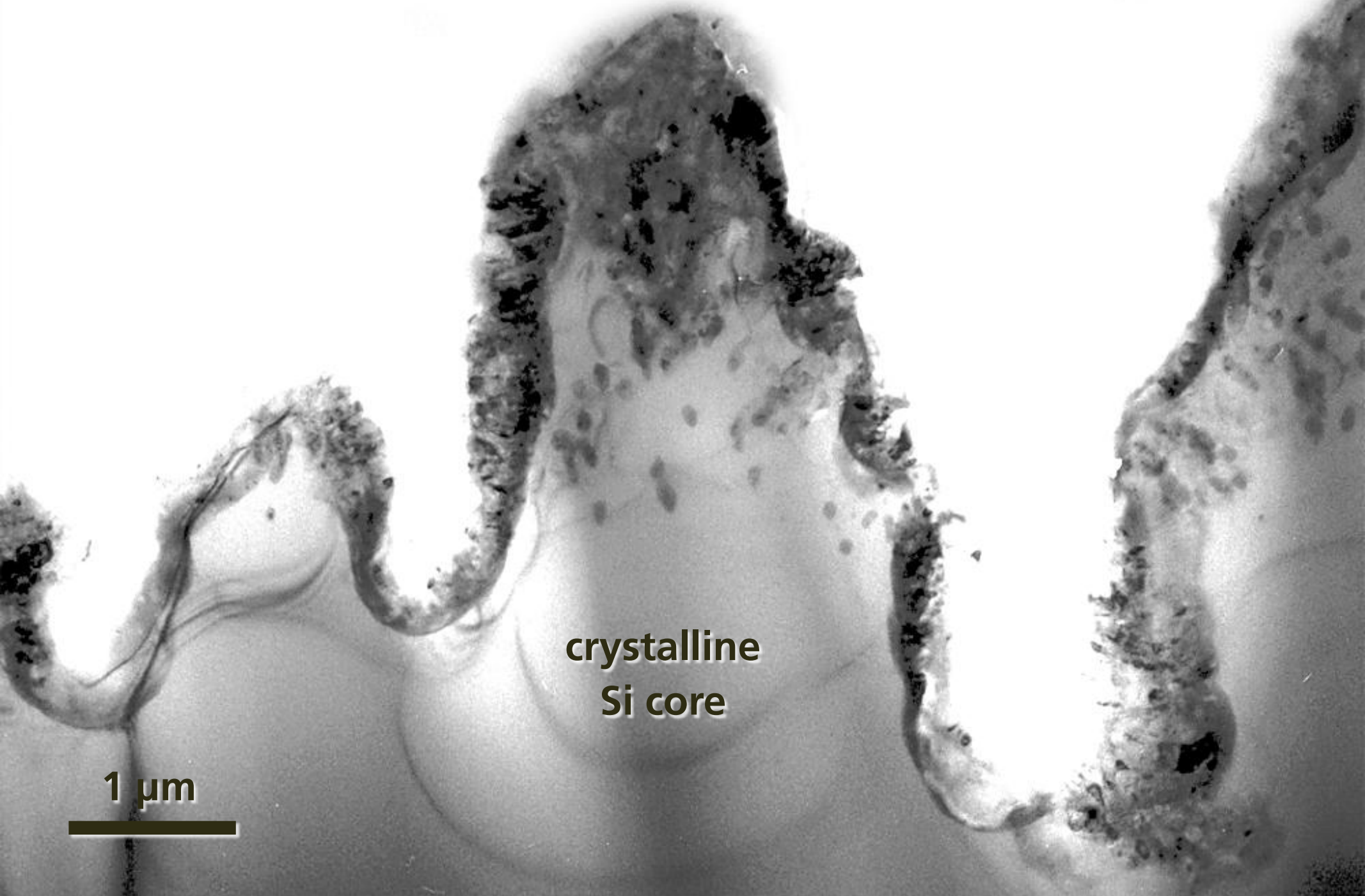
# Structural and chemical analysis

disordered  
surface layer



1 μm

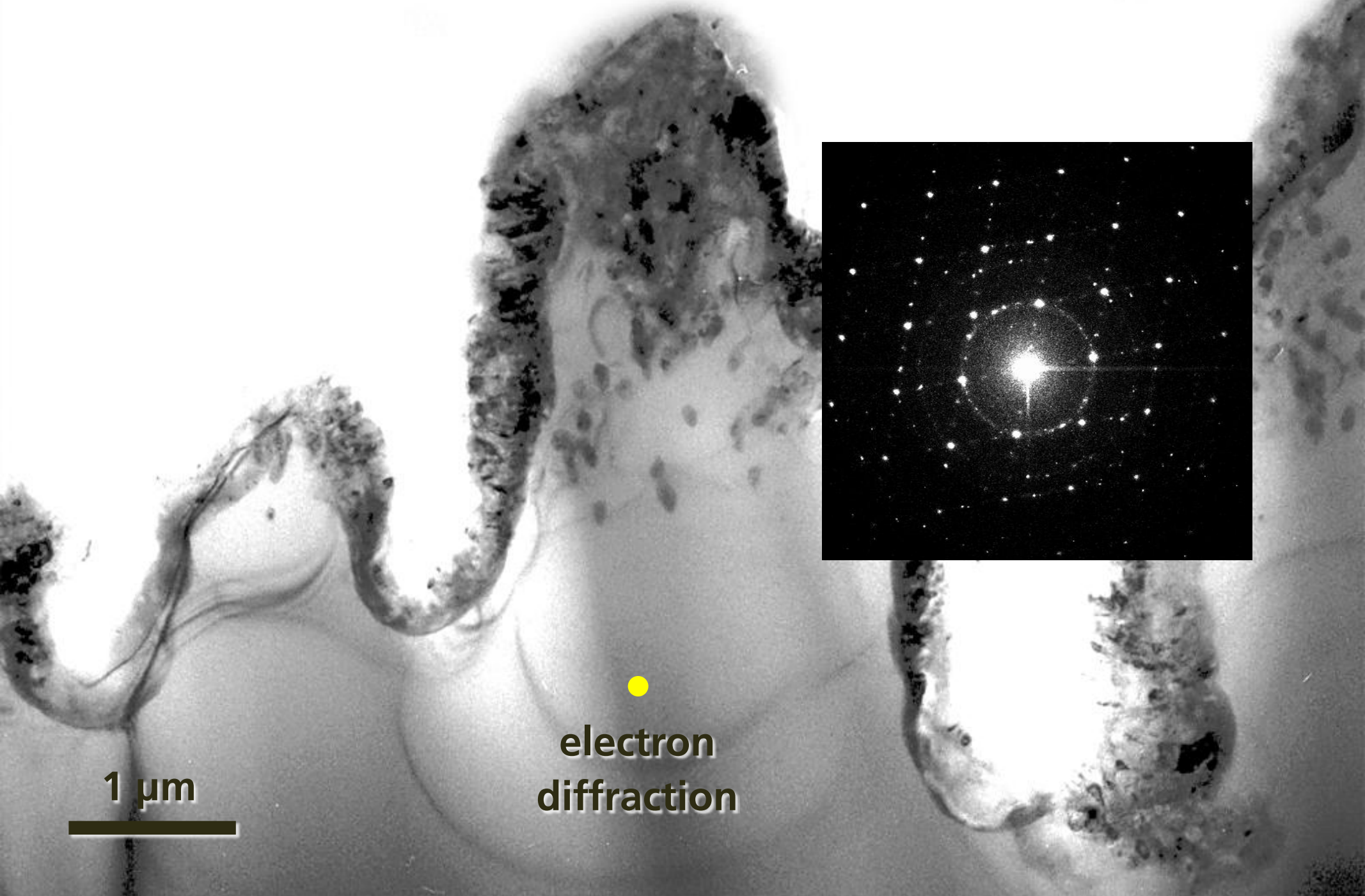
# Structural and chemical analysis



crystalline  
Si core

1 μm

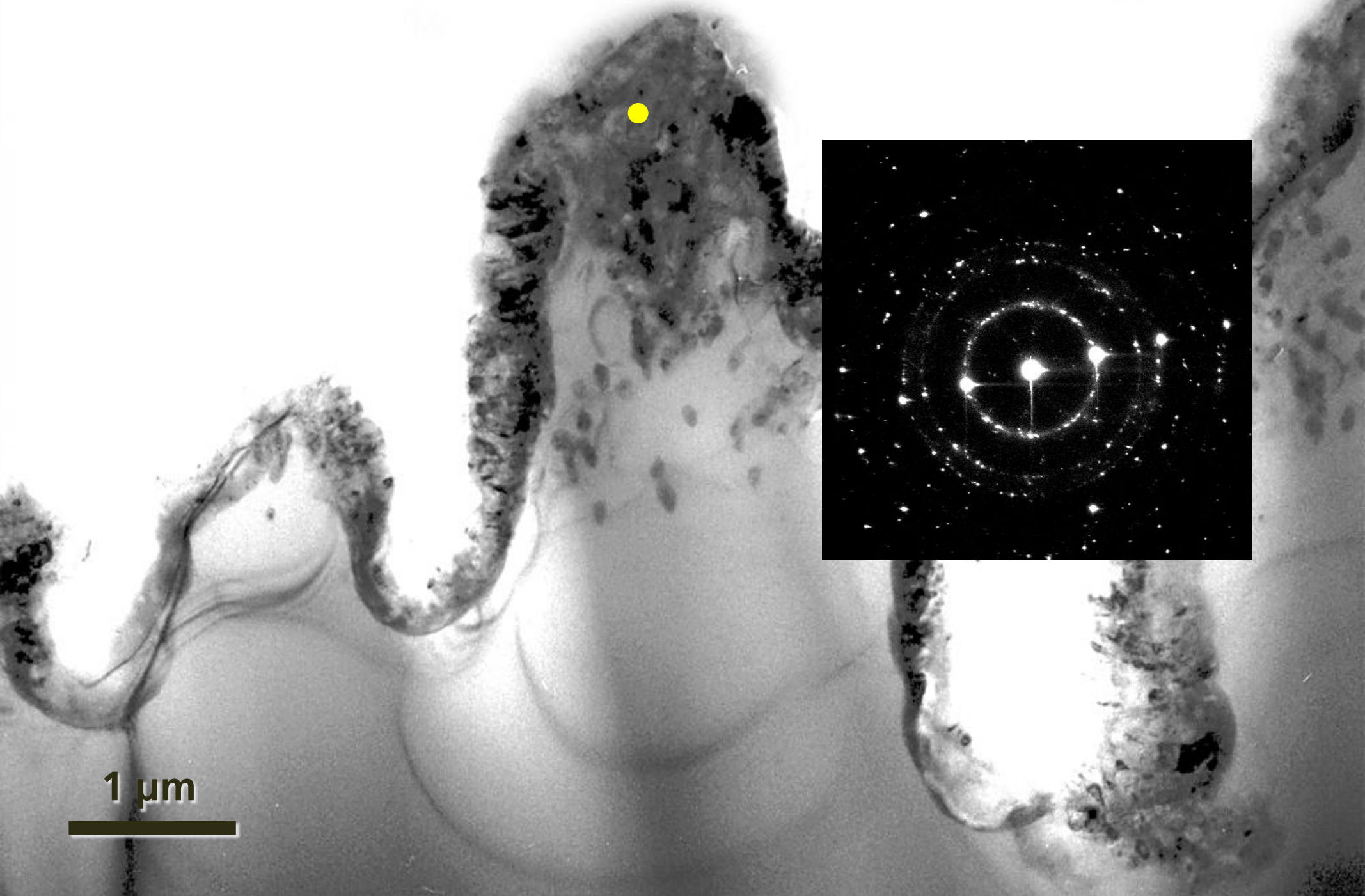
# Structural and chemical analysis



1  $\mu\text{m}$

●  
electron  
diffraction

# Structural and chemical analysis



1  $\mu\text{m}$

# Structural and chemical analysis

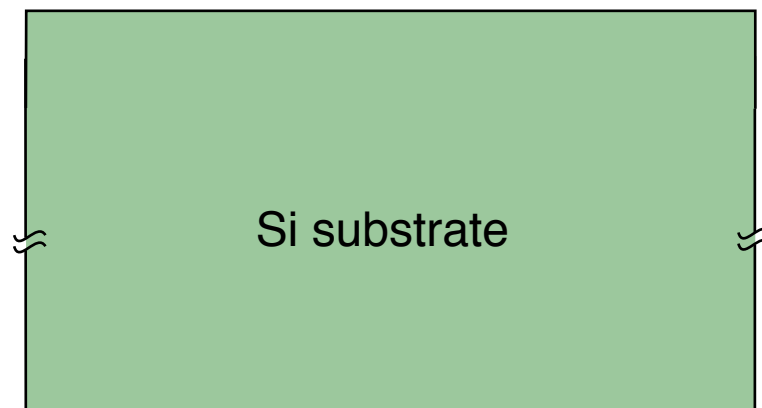
- 300-nm disordered surface layer
- undisturbed crystalline core
- surface layer: polycrystalline Si with 1.6% sulfur

1  $\mu\text{m}$

A grayscale micrograph showing a cross-section of a material. The structure consists of a central, smoother region (the crystalline core) surrounded by a darker, more textured outer layer (the disordered surface layer). The surface layer appears to be composed of small, interconnected grains. A scale bar in the bottom left corner indicates a length of 1 micrometer.

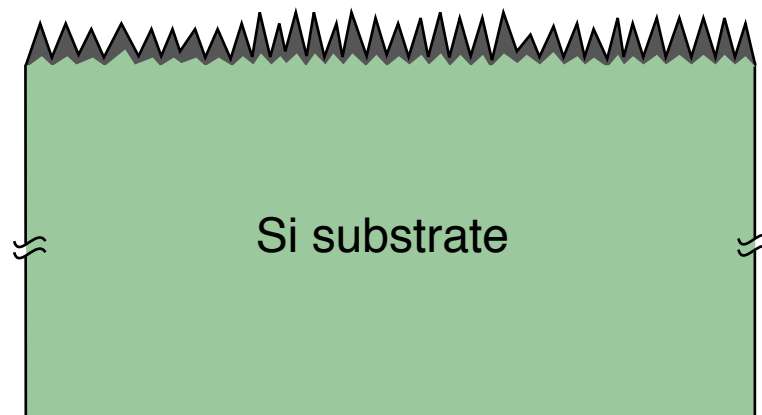
# Detectors

black silicon/silicon junction



# Detectors

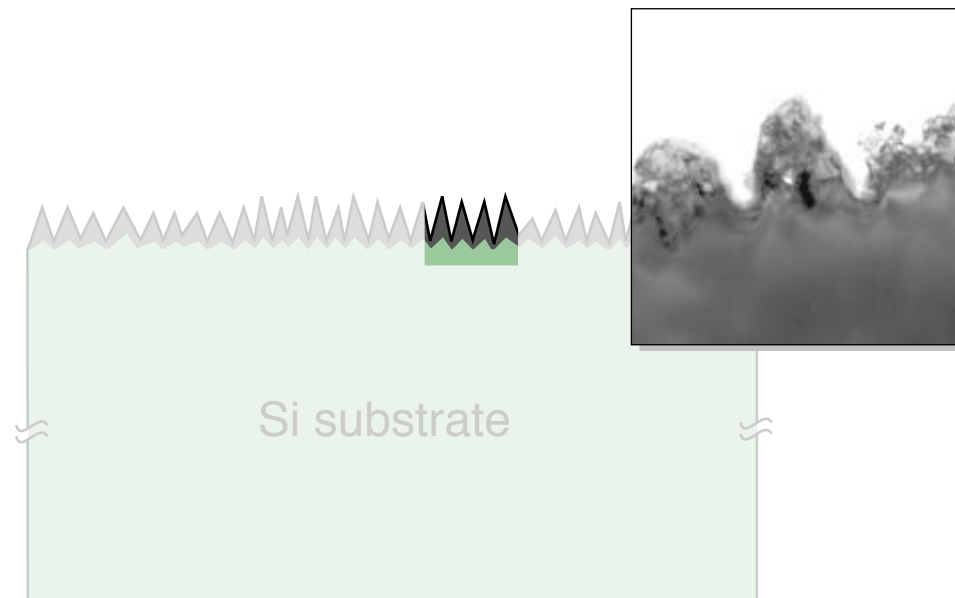
## black silicon/silicon junction





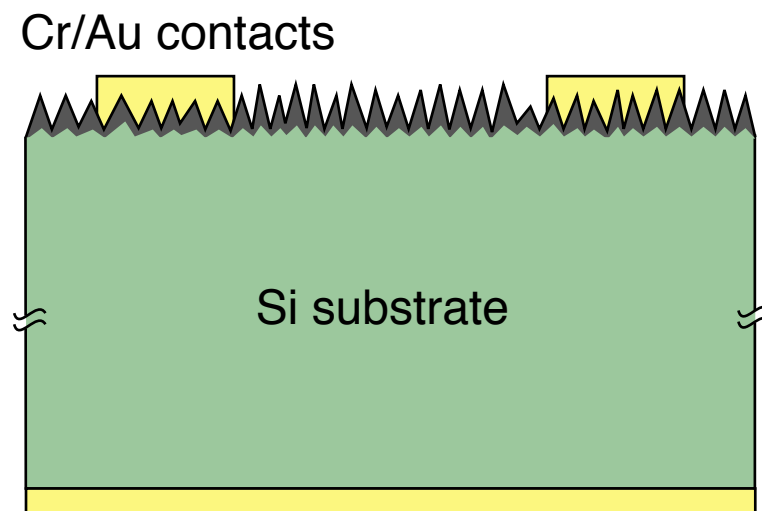
# Detectors

## black silicon/silicon junction



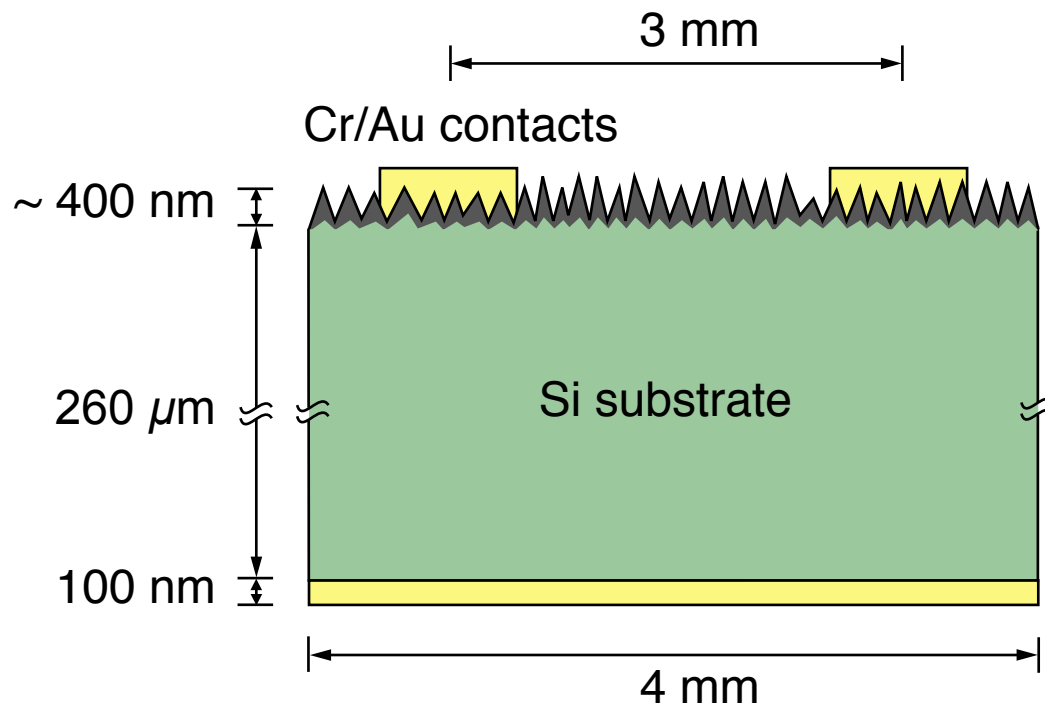
# Detectors

## black silicon/silicon junction



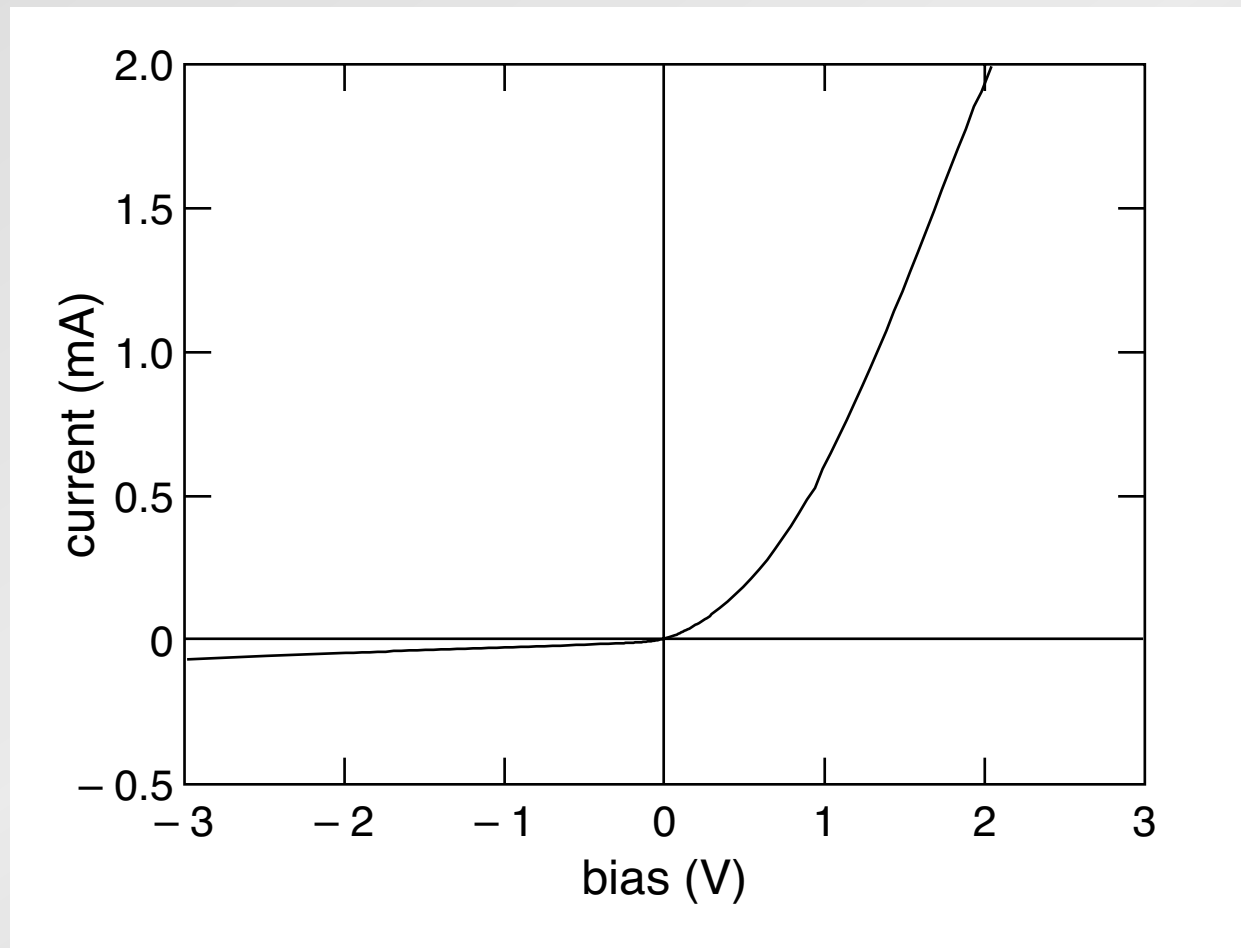
# Detectors

## black silicon/silicon junction



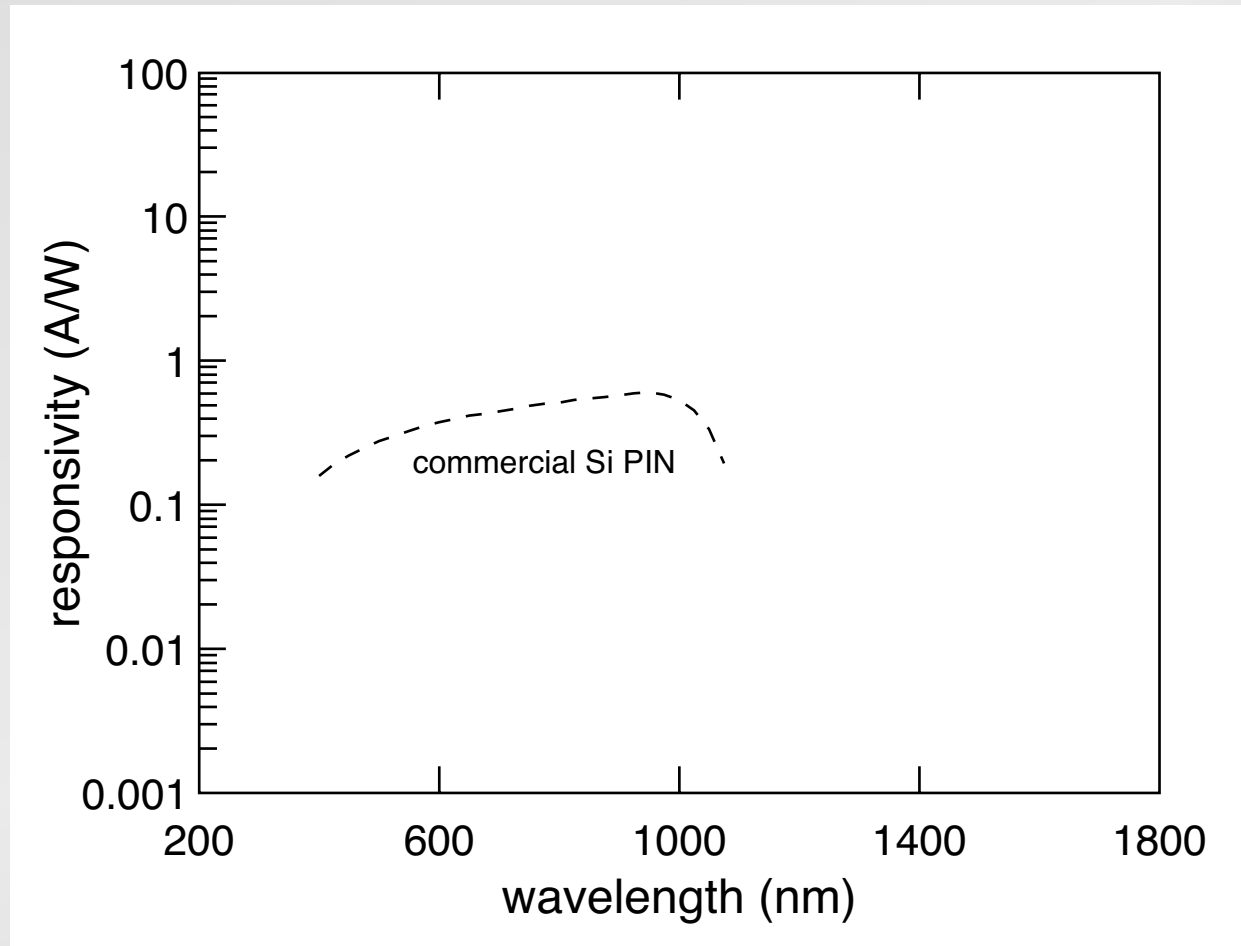
# Detectors

## *I*V characteristics



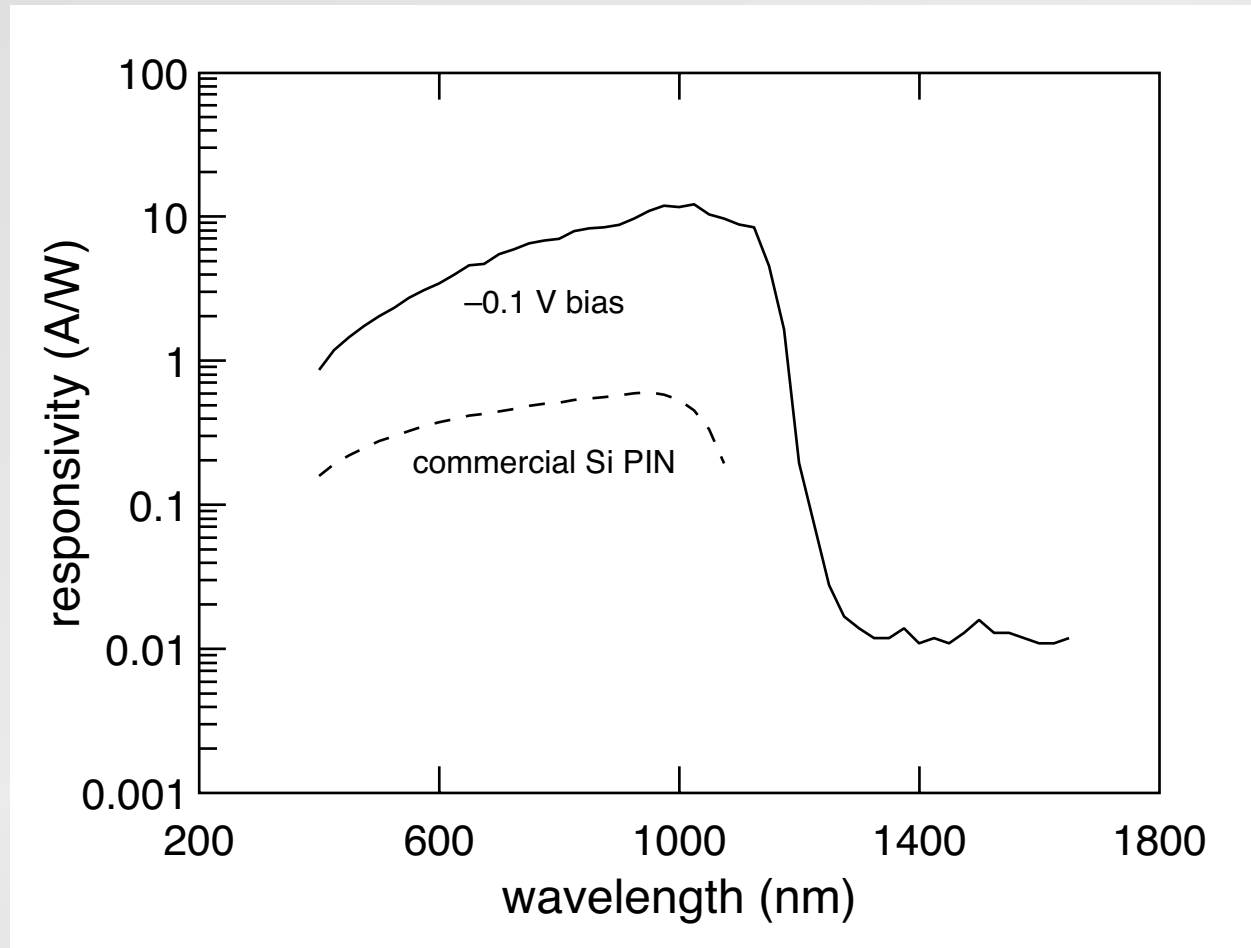
# Detectors

responsivity



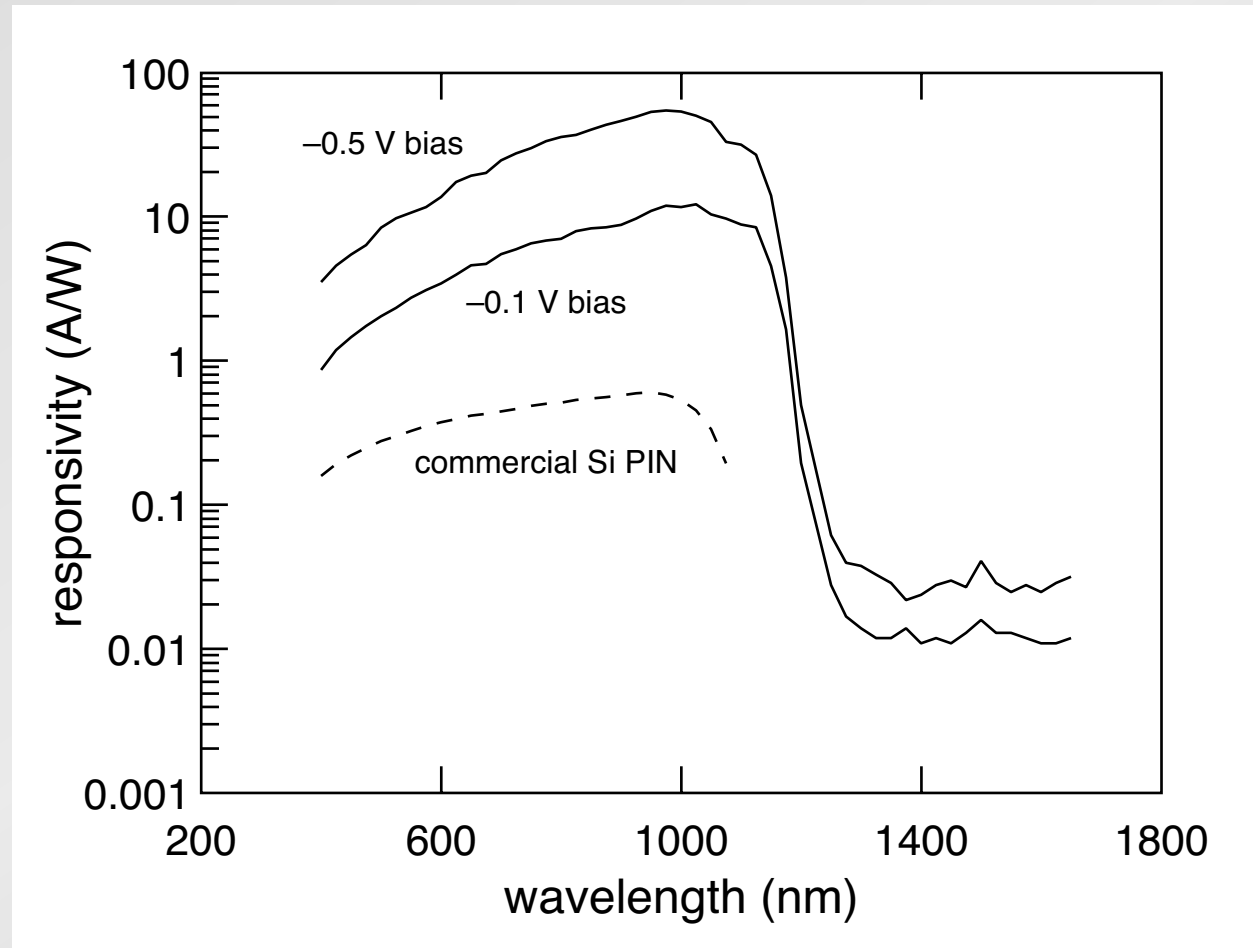
# Detectors

## responsivity



# Detectors

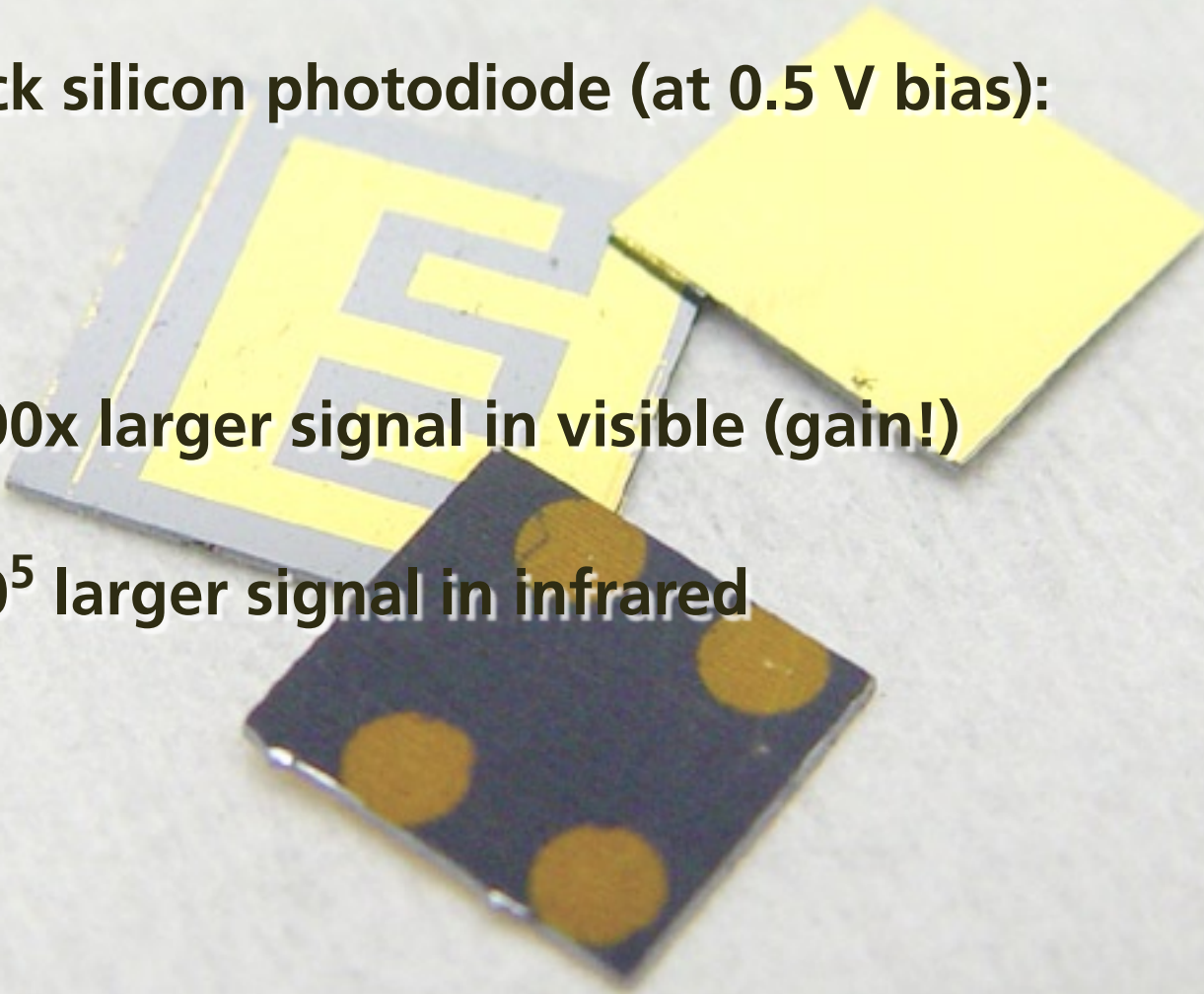
## responsivity



# Detectors

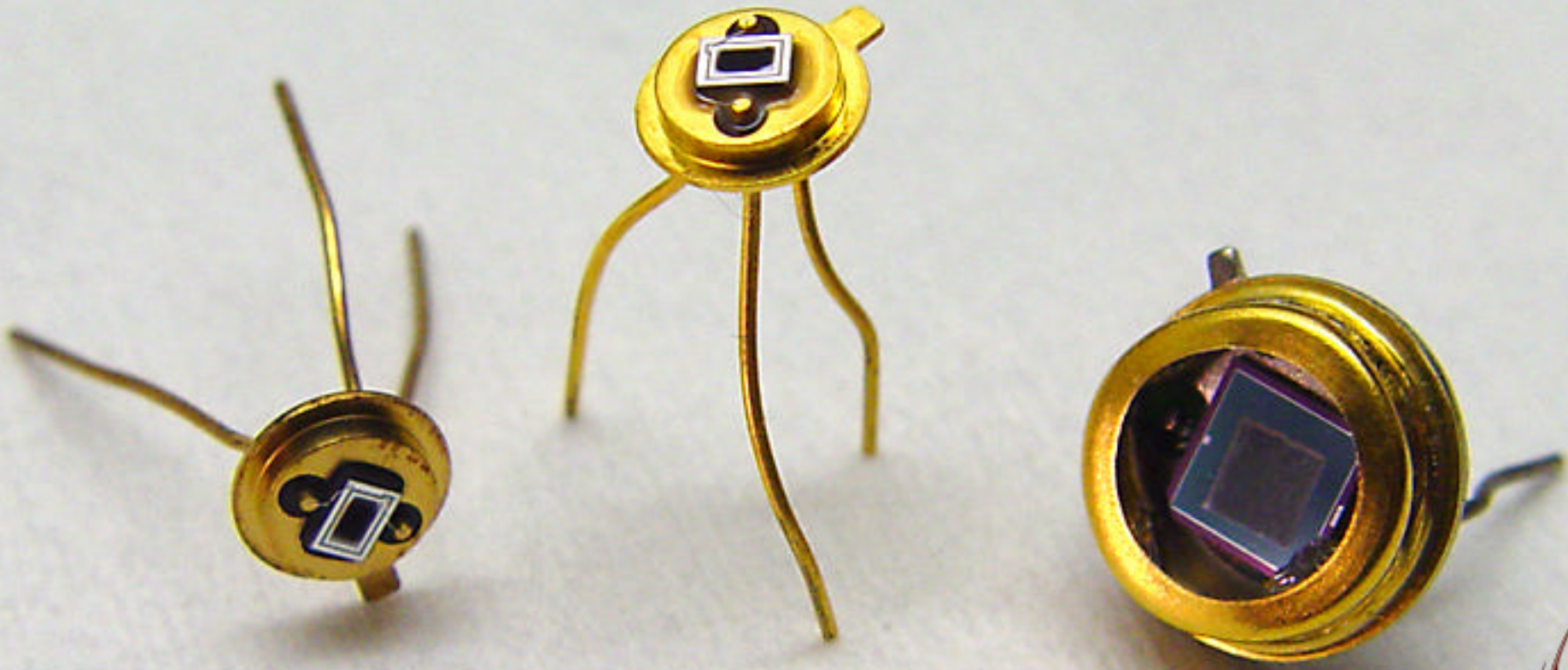
**Black silicon photodiode (at 0.5 V bias):**

- **100x larger signal in visible (gain!)**
- **$10^5$  larger signal in infrared**



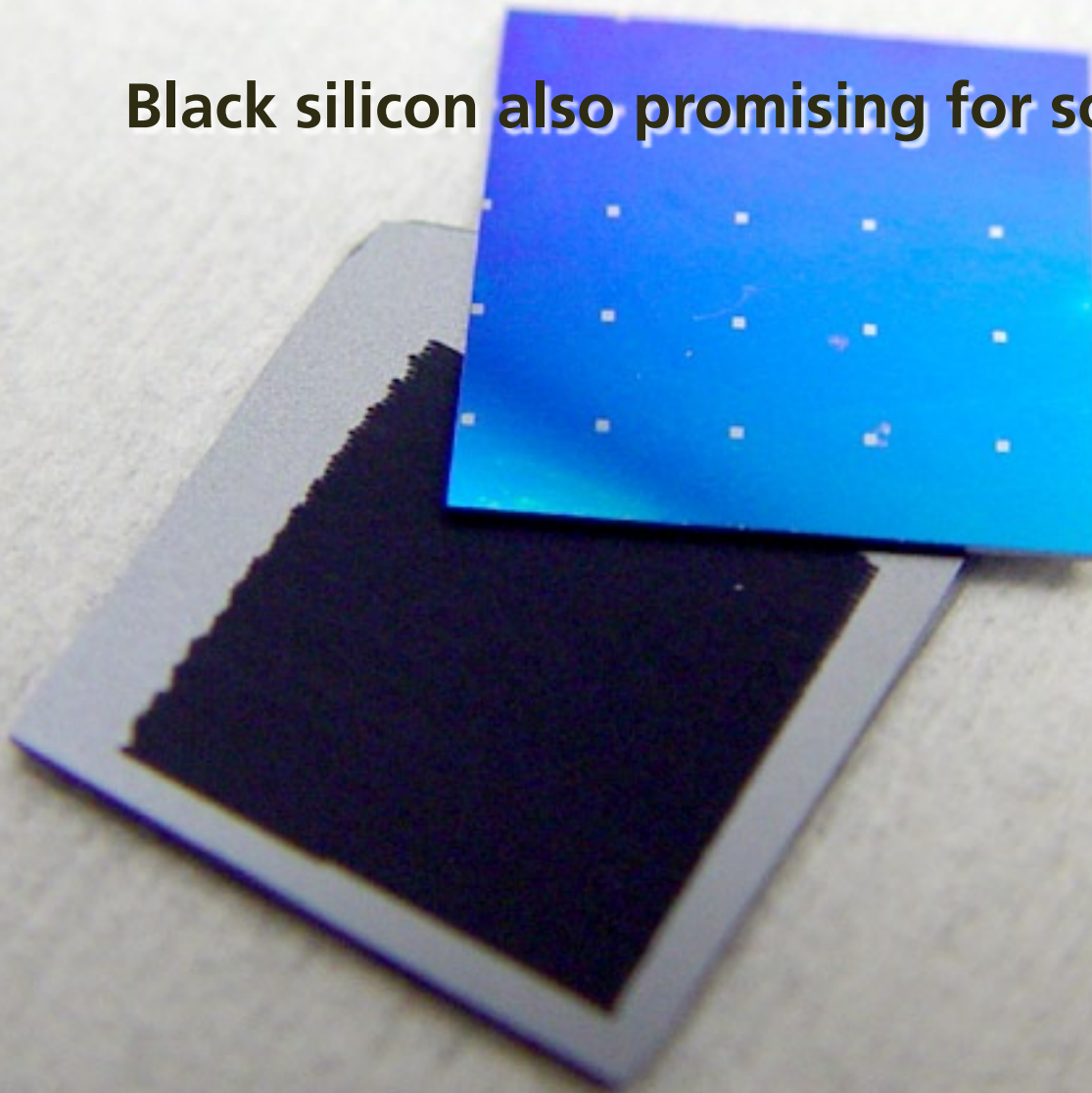


# Detectors

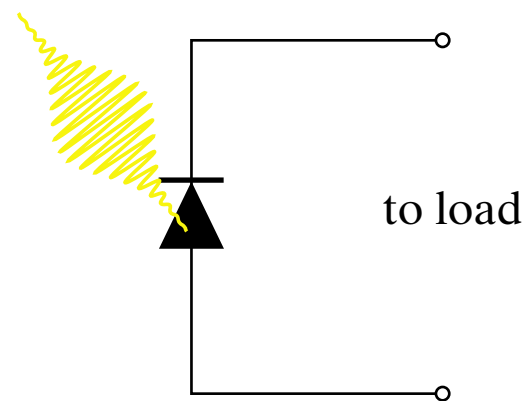
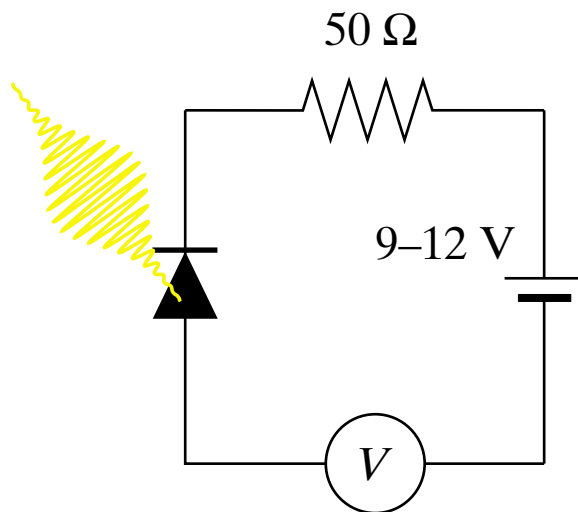


# Detectors

**Black silicon also promising for solar cells**

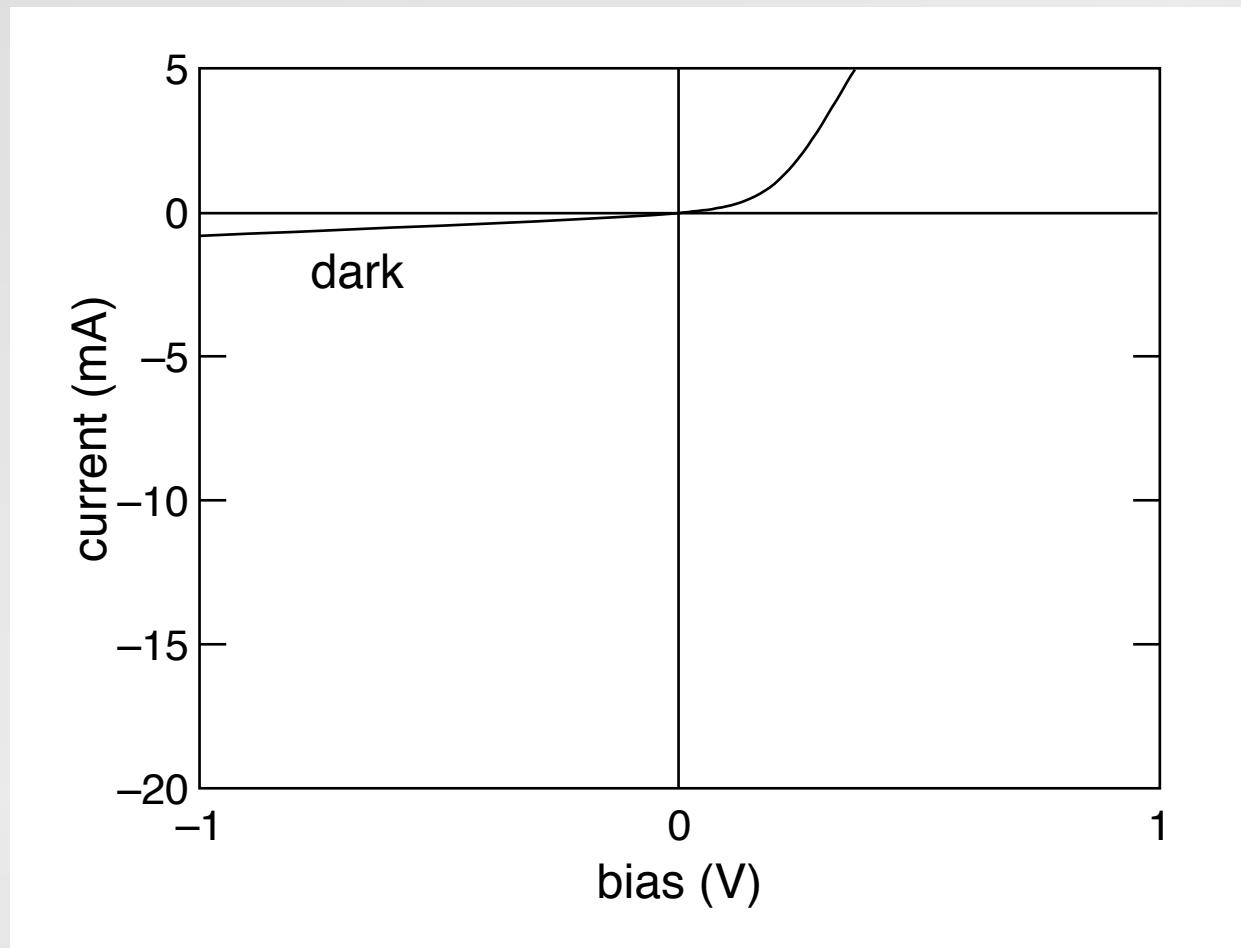


# Detectors



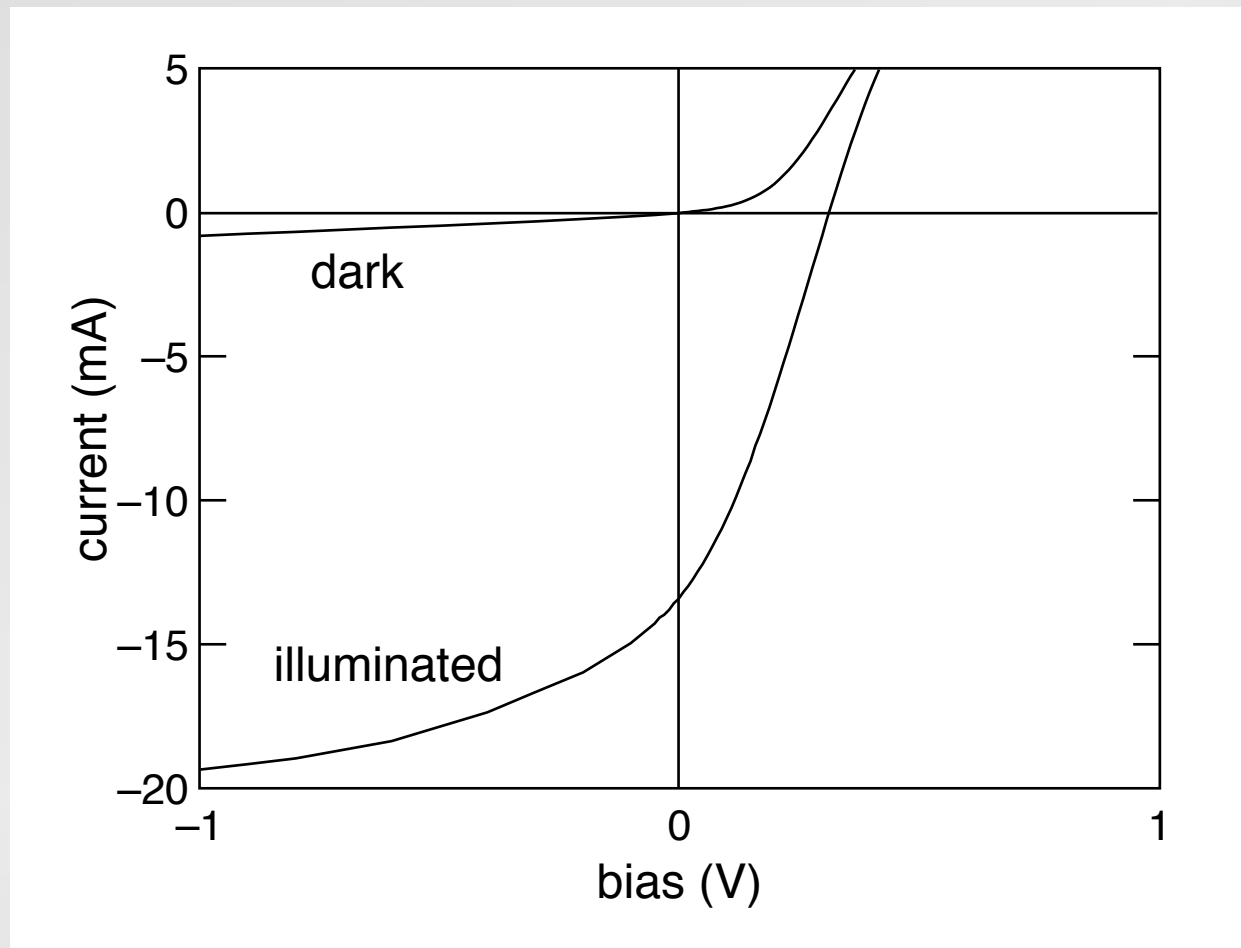
# Detectors

## *I*V characteristics



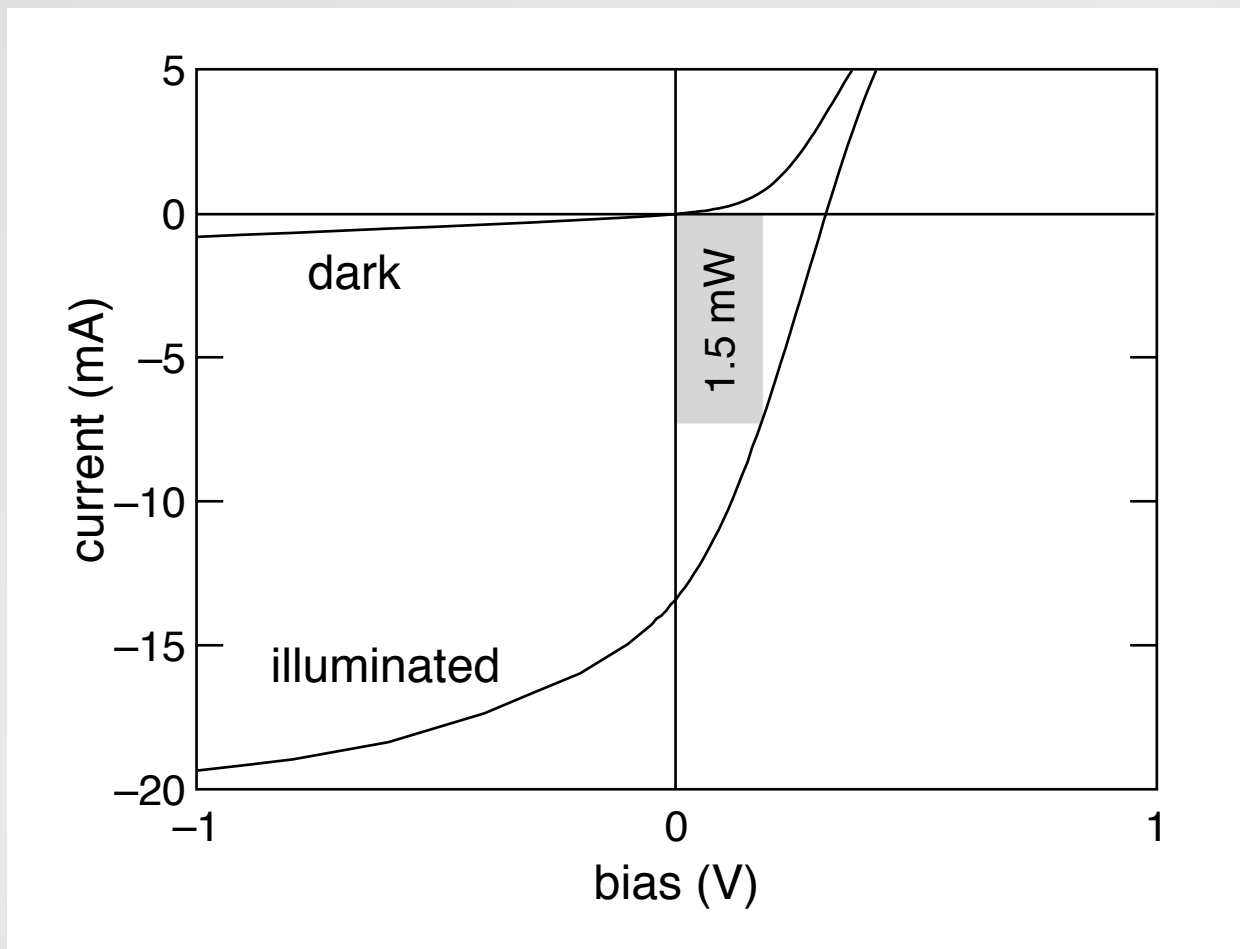
# Detectors

## *I*/*V* characteristics



# Detectors

## *I*/*V* characteristics



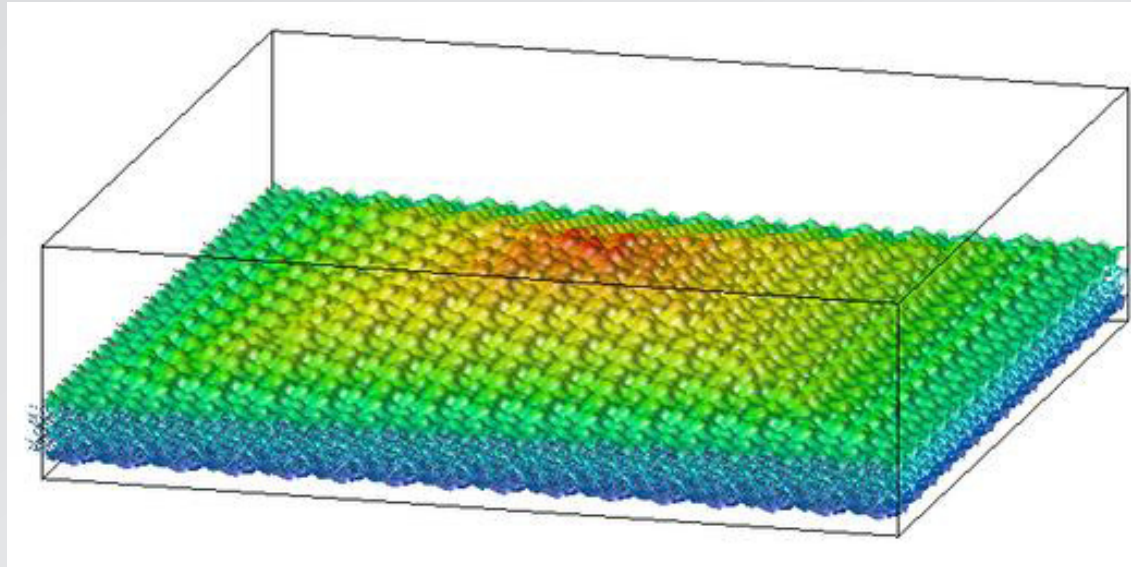
# Detectors

**Black silicon solar cell (preliminary):**

- **2–3% efficiency**
- **photocurrent generated in thin layer**

# Needs

Understanding the resulting properties



full DFT code for very large numbers of atoms

(CONQUEST beta: [www.conquest.ucl.ac.uk](http://www.conquest.ucl.ac.uk))



# Needs

- **develop tools to model embedding process**
- **develop tools to model properties of resulting materials**
- **explore heavily doped materials and their properties**

# Conclusion

**High photon flux doping: new class of materials!**

The background of the image is a dense, repeating pattern of small, light-colored, pointed structures. These structures resemble a forest of tiny, upright, conical or needle-like shapes, possibly representing a biological surface like a leaf or a material with a specific microstructure. The overall appearance is a textured, monochromatic field of these small elements.

**For more information:**

**<http://mazor-www.harvard.edu>**