

Nano-textured Surfaces

Tsing-Hua Her

Claudia Wu

Jim Carey

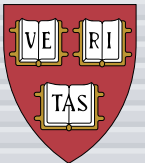
Mike Sheehy

Brian Tull

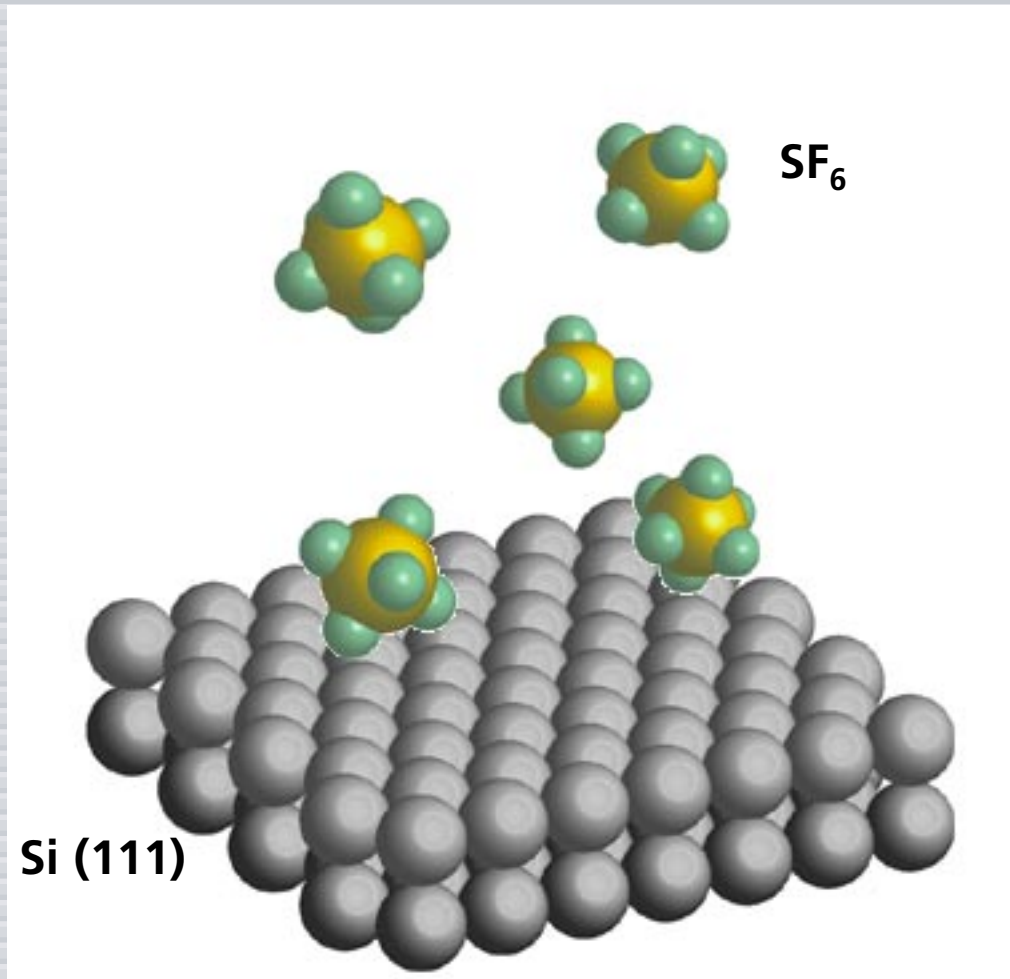
Meng Yan Shen

Catherine Crouch

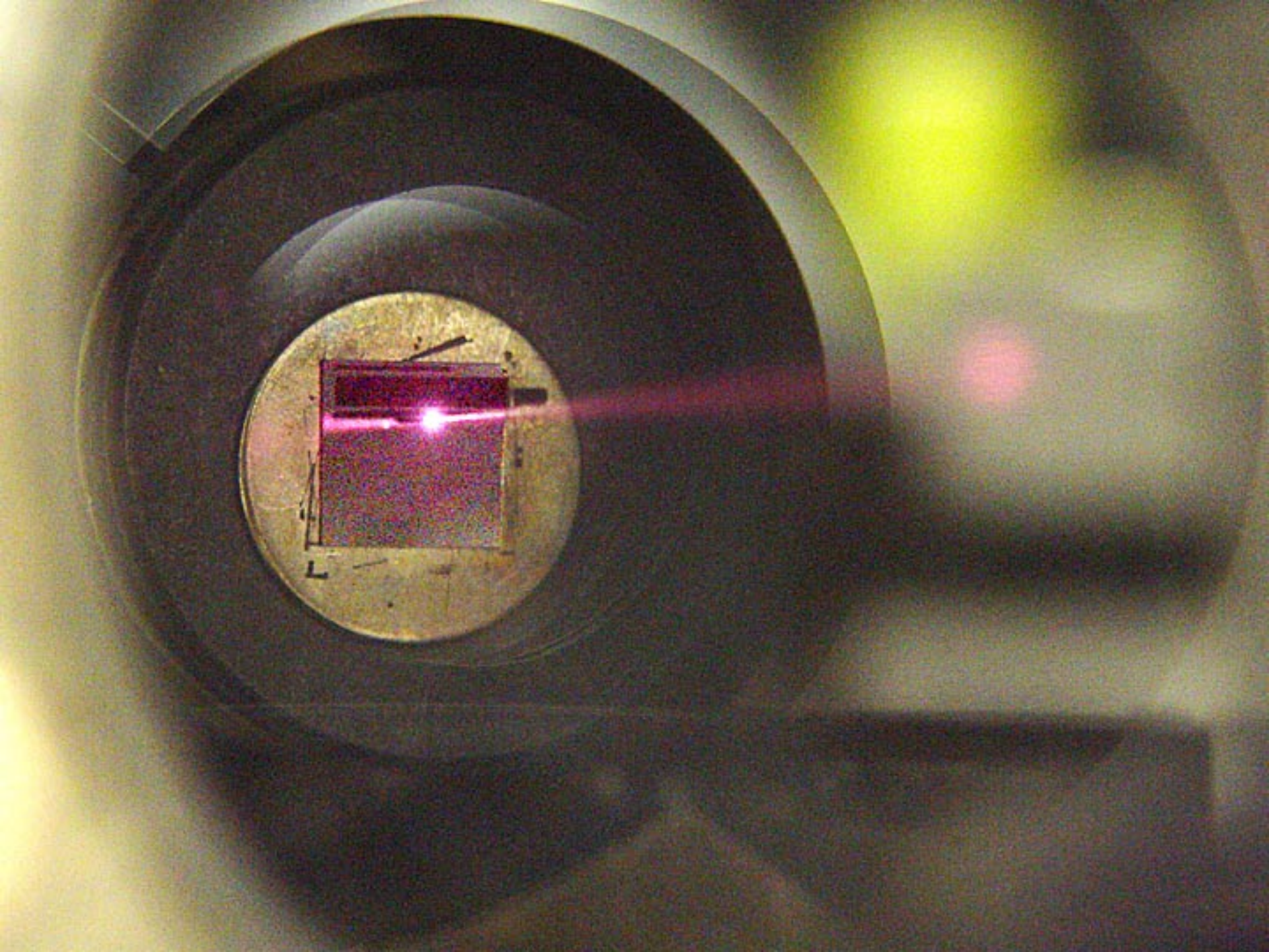
Cynthia Friend



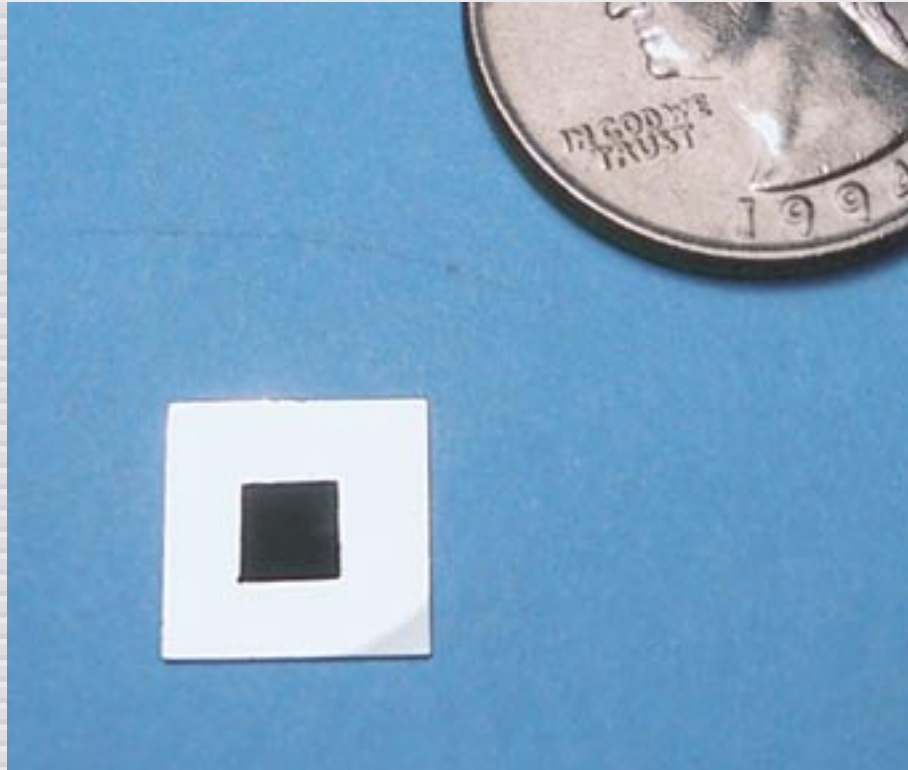
Introduction



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



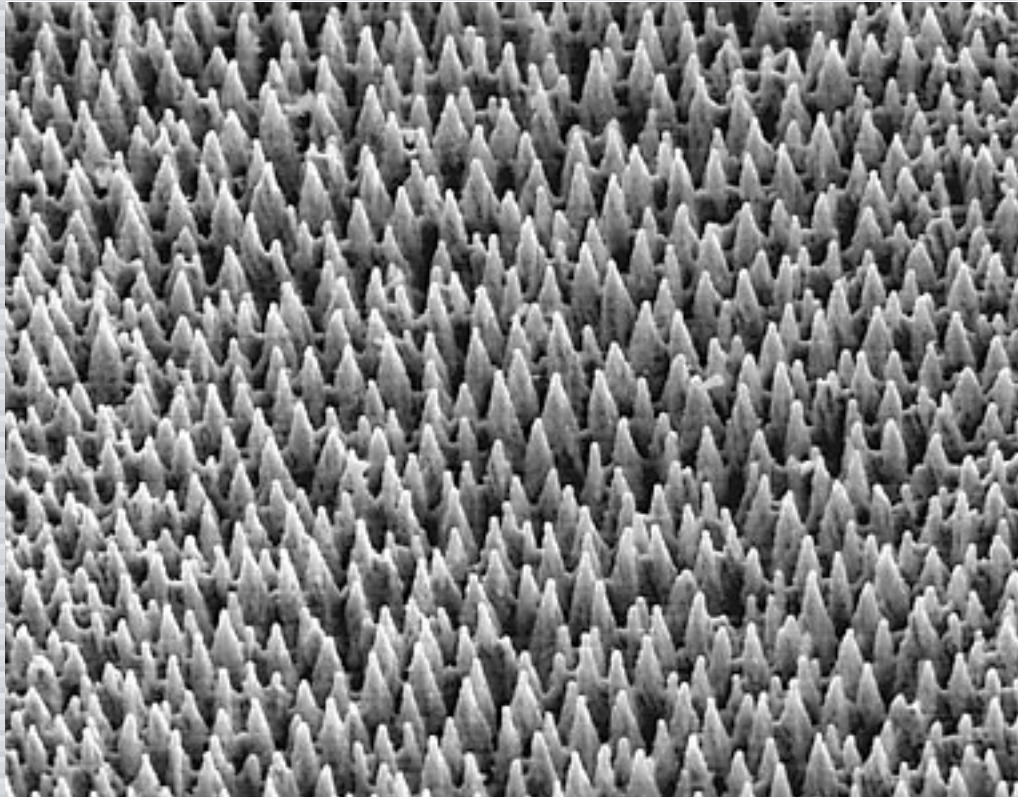
Introduction



'black silicon'

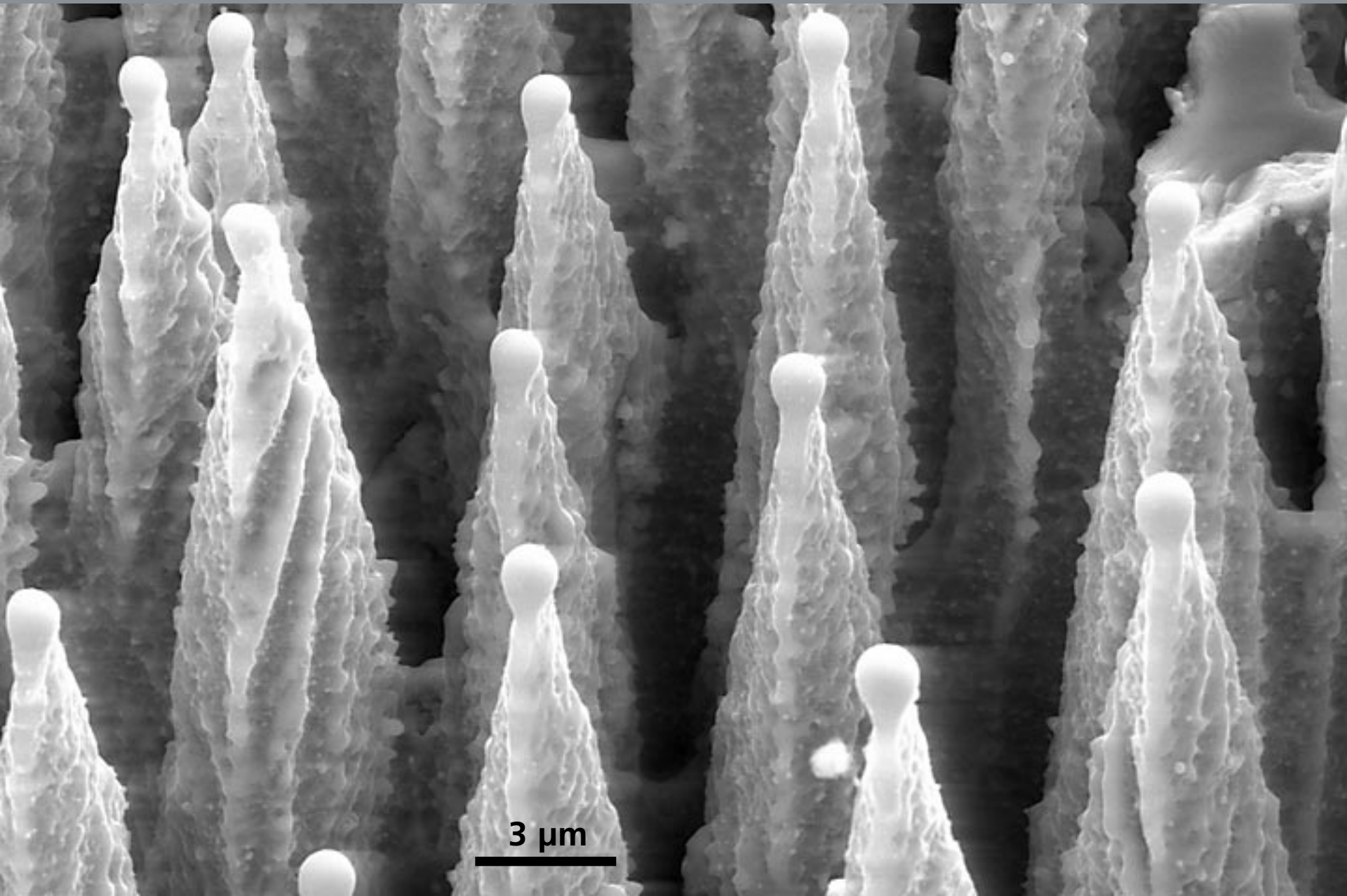
Appl. Phys. Lett. 73, 1673 (1998)

Introduction

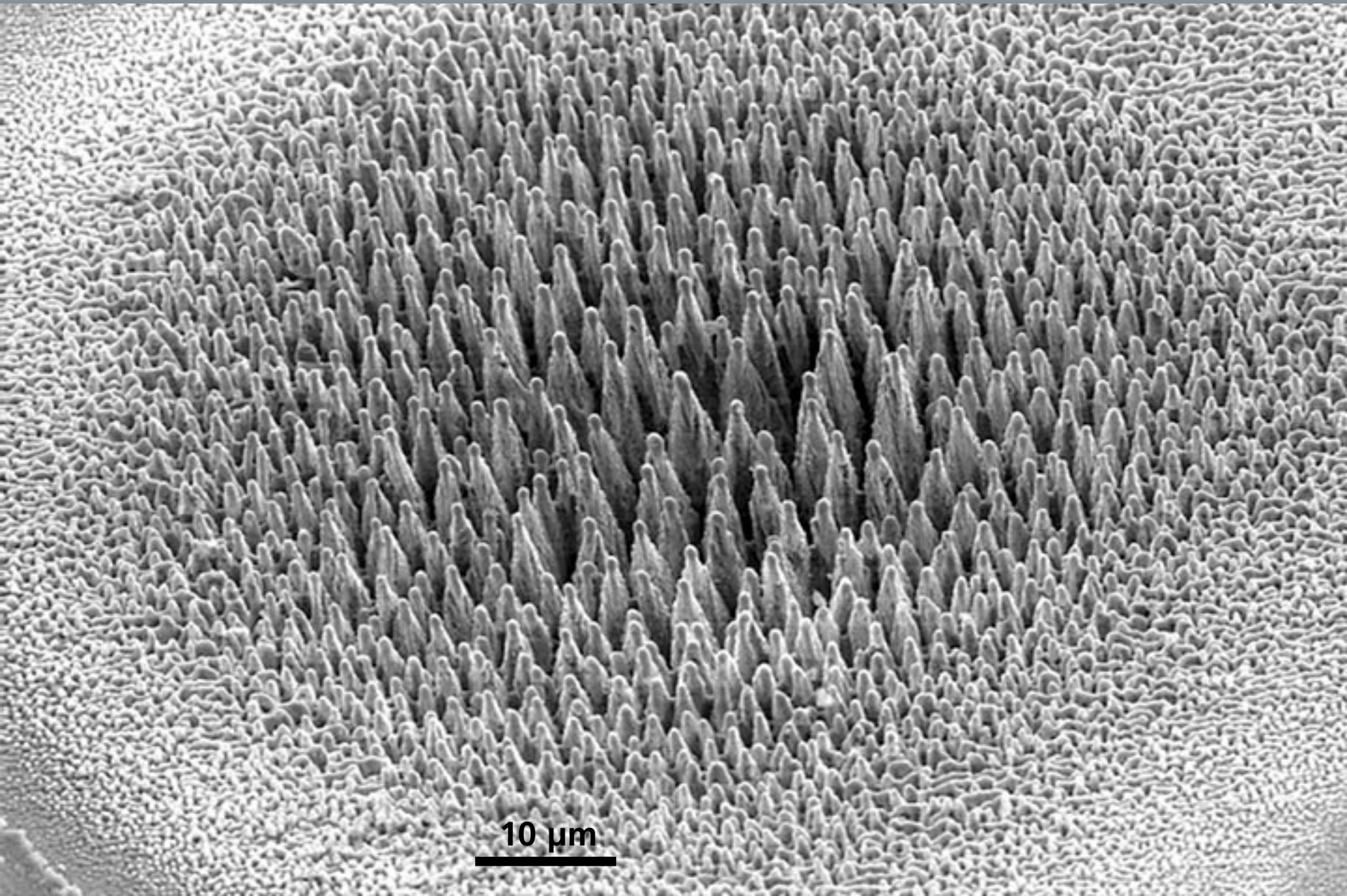


20 μm

Introduction

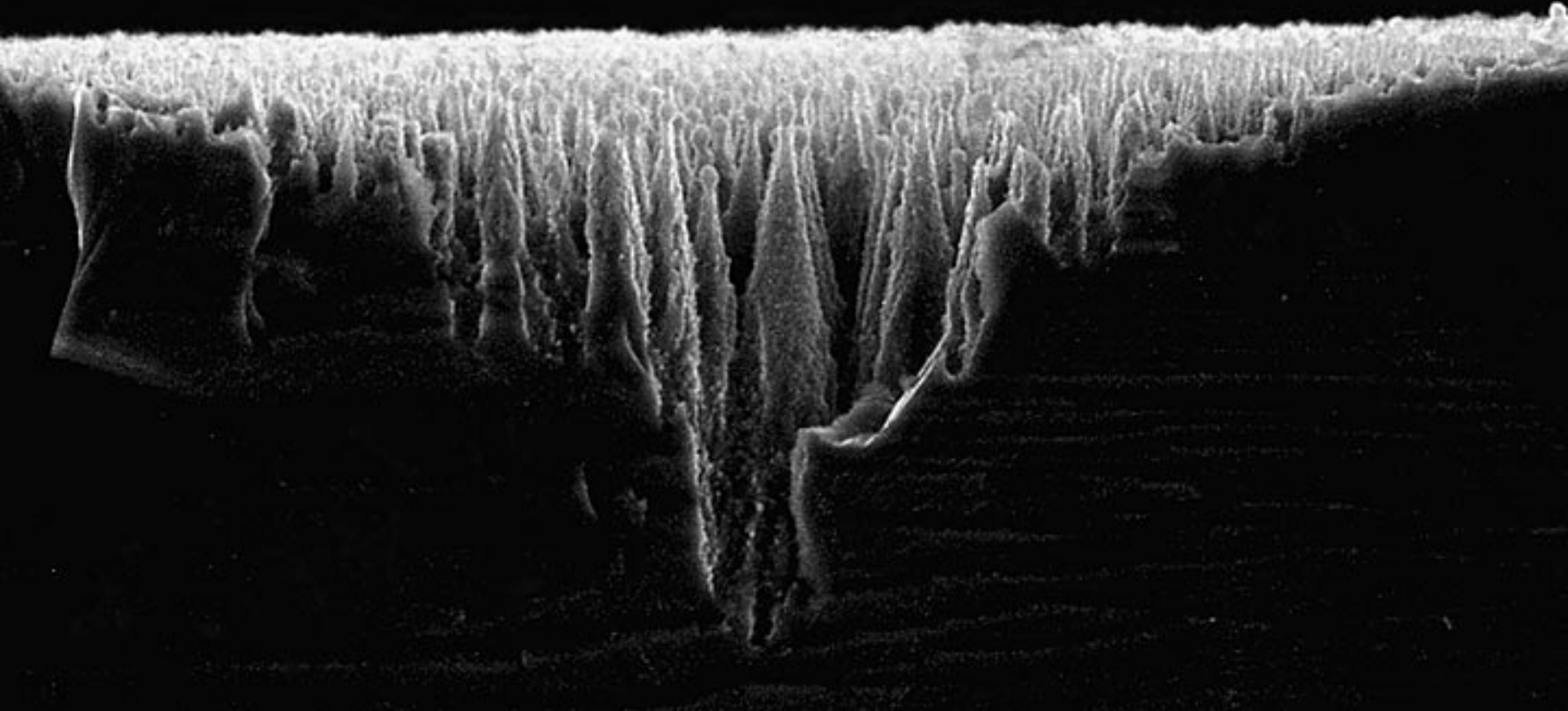


Introduction



10 μm

Introduction



Introduction

Introduction

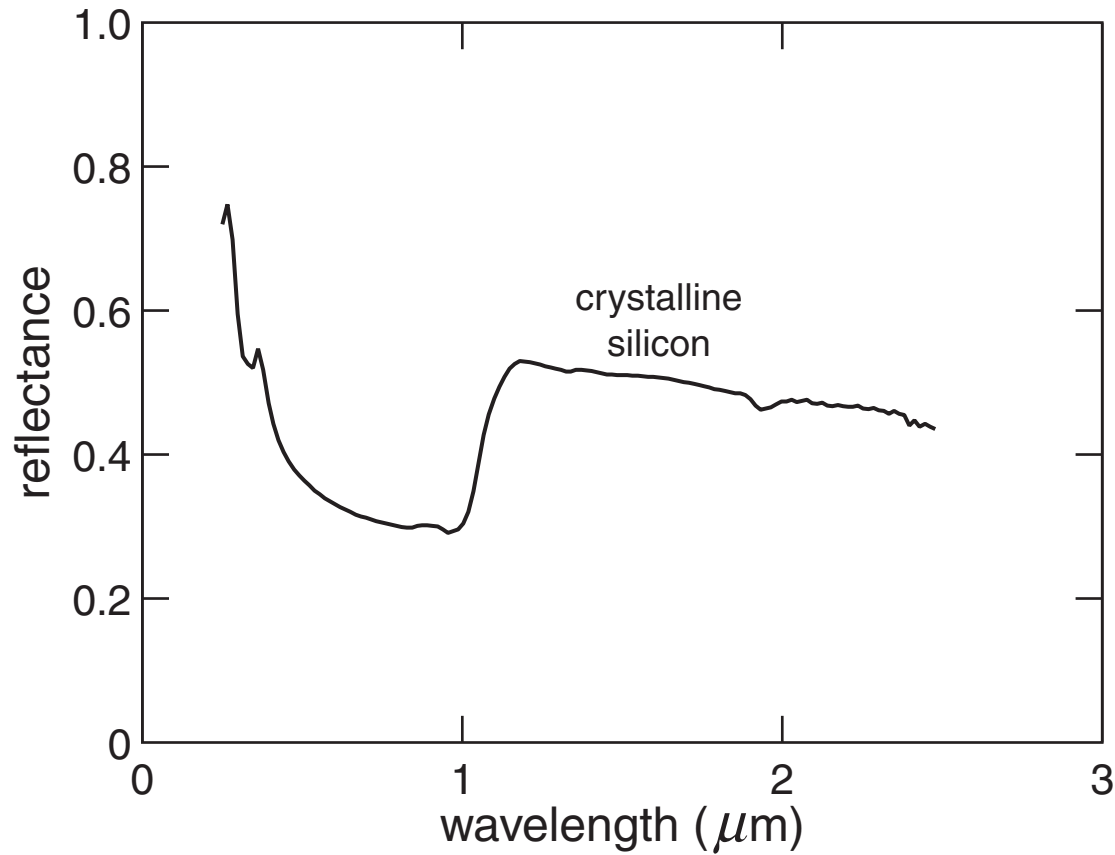
- ▶ **maskless etching process**
- ▶ **self-organized, tall, sharp structures**
- ▶ **nanoscale structure on spikes**

Outline

- ▶ **Properties**
- ▶ **Structural and chemical analysis**
- ▶ **Outlook**

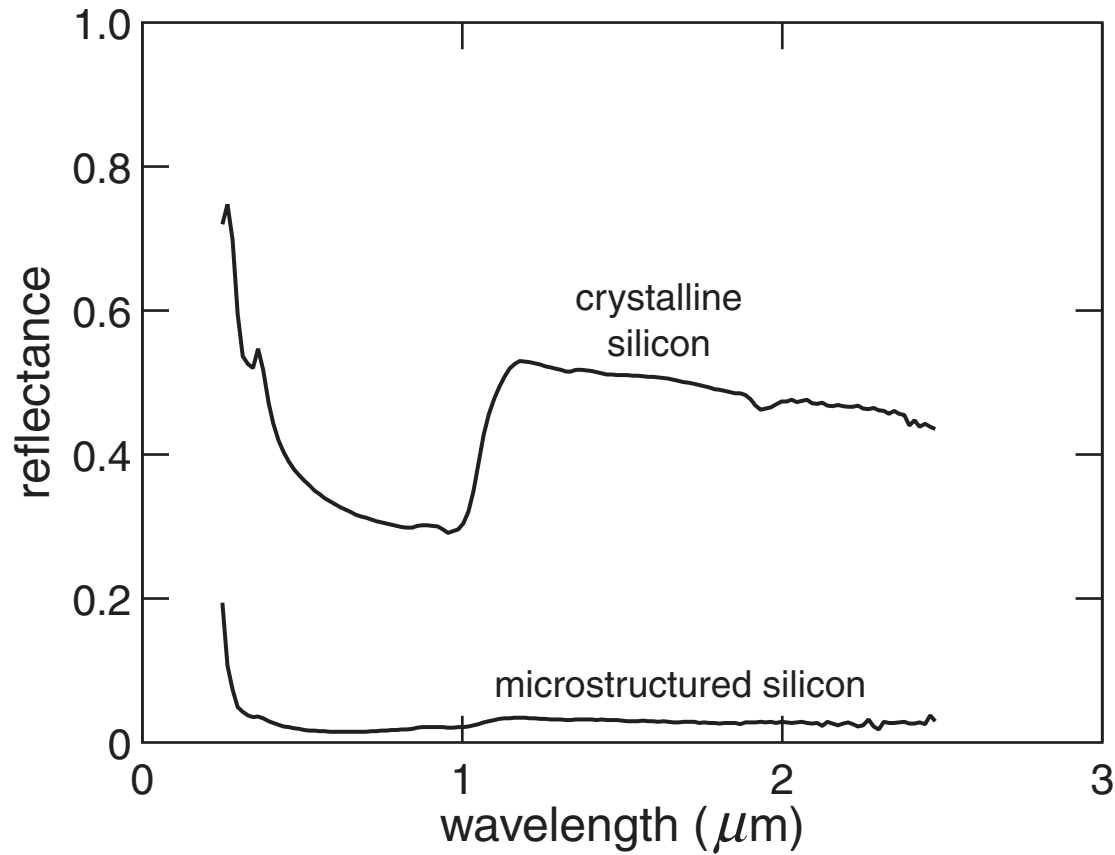
Properties

reflectance (integrating sphere)



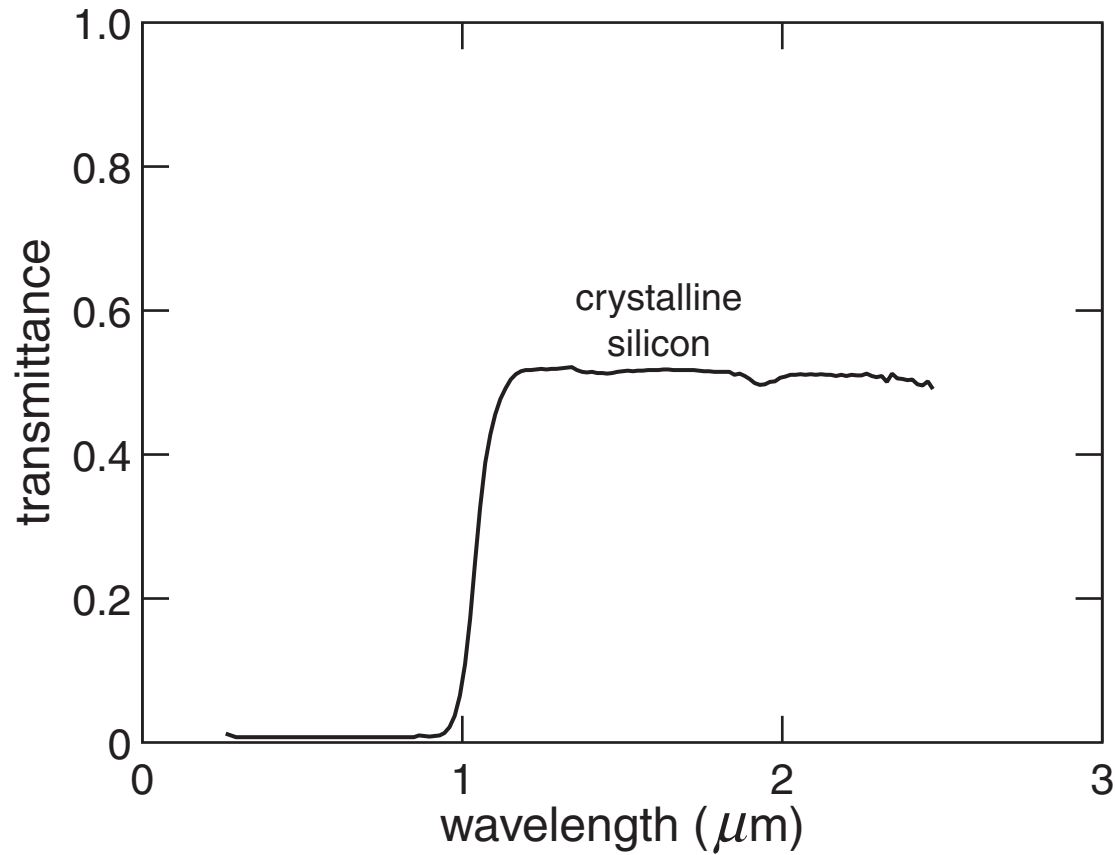
Properties

reflectance (integrating sphere)



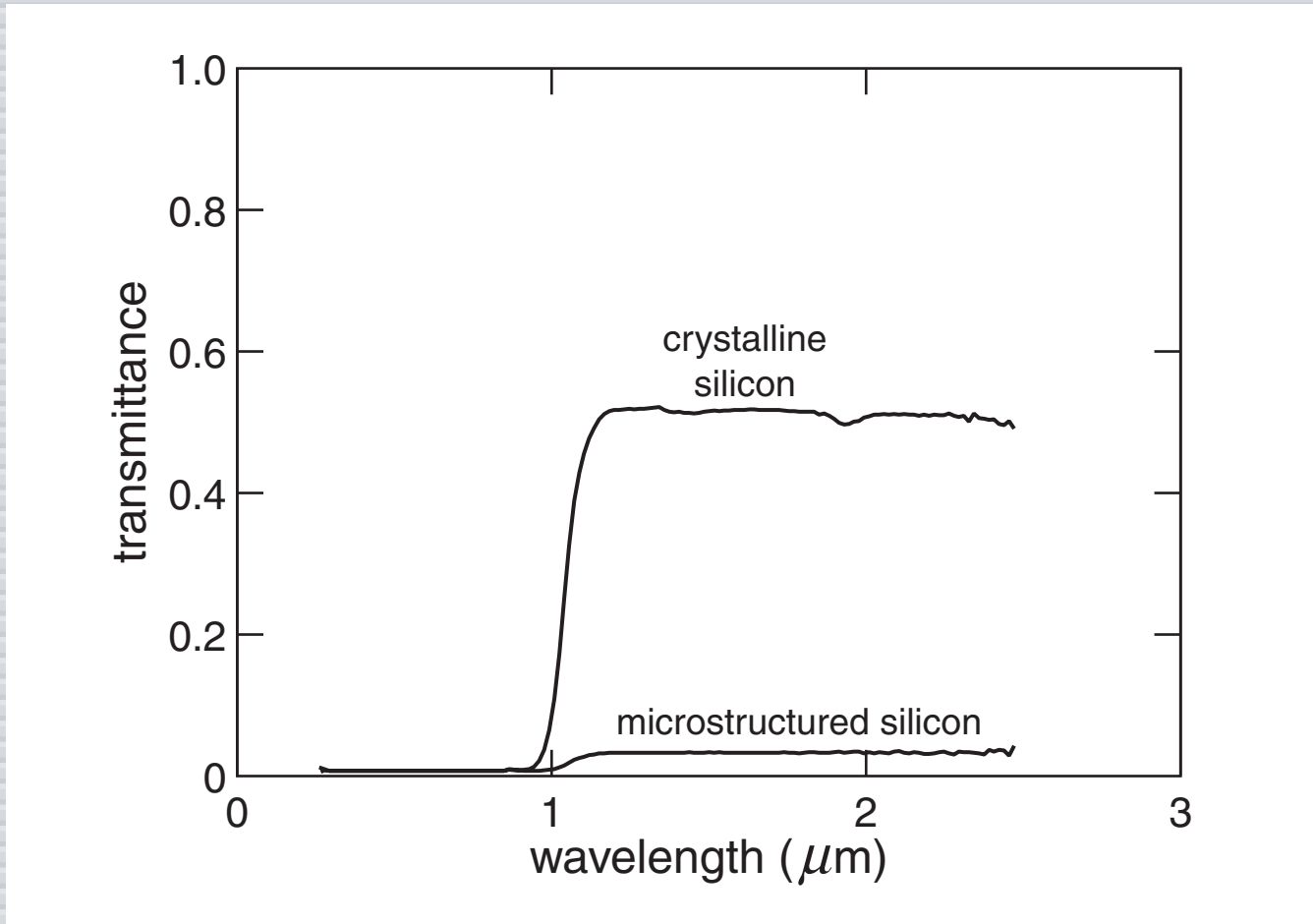
Properties

transmittance (integrating sphere)



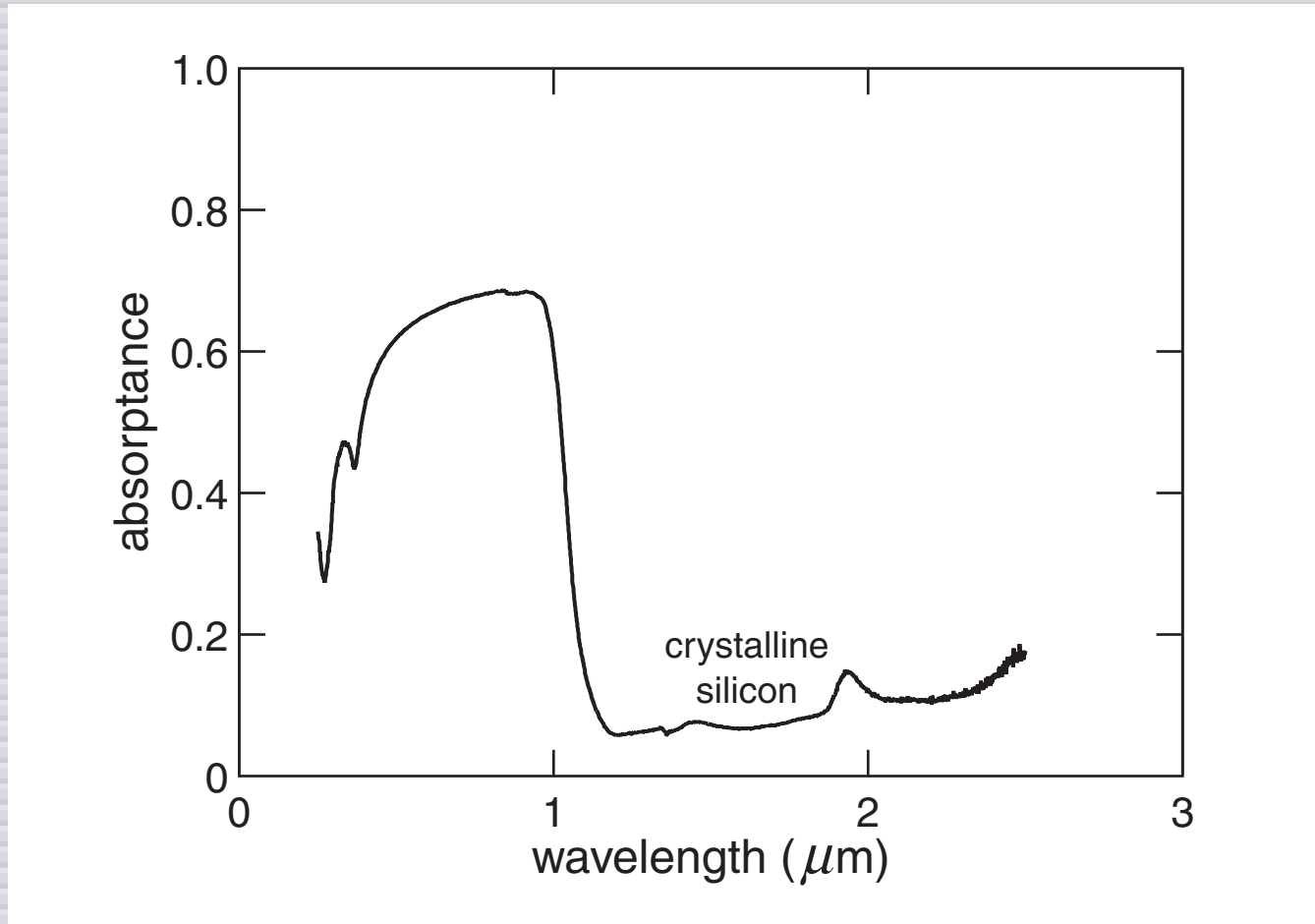
Properties

transmittance (integrating sphere)



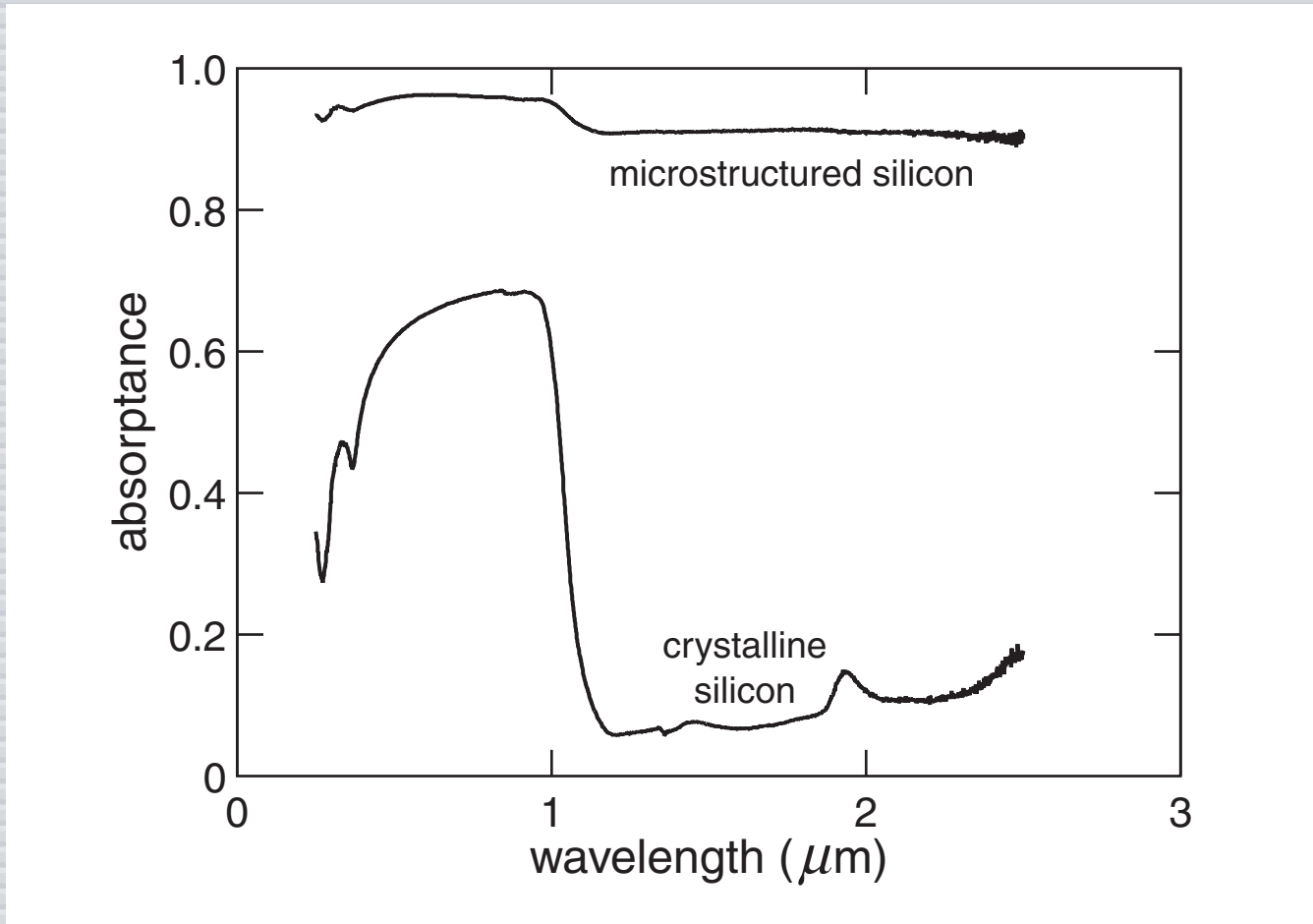
Properties

absorptance ($1 - R - T$)



Properties

absorptance ($1 - R - T$)



Properties

Points to keep in mind:

- ▶ **near unity absorption**
- ▶ **sub-band gap absorption**
- ▶ **IR photoelectron generation**

Properties

Points to keep in mind:

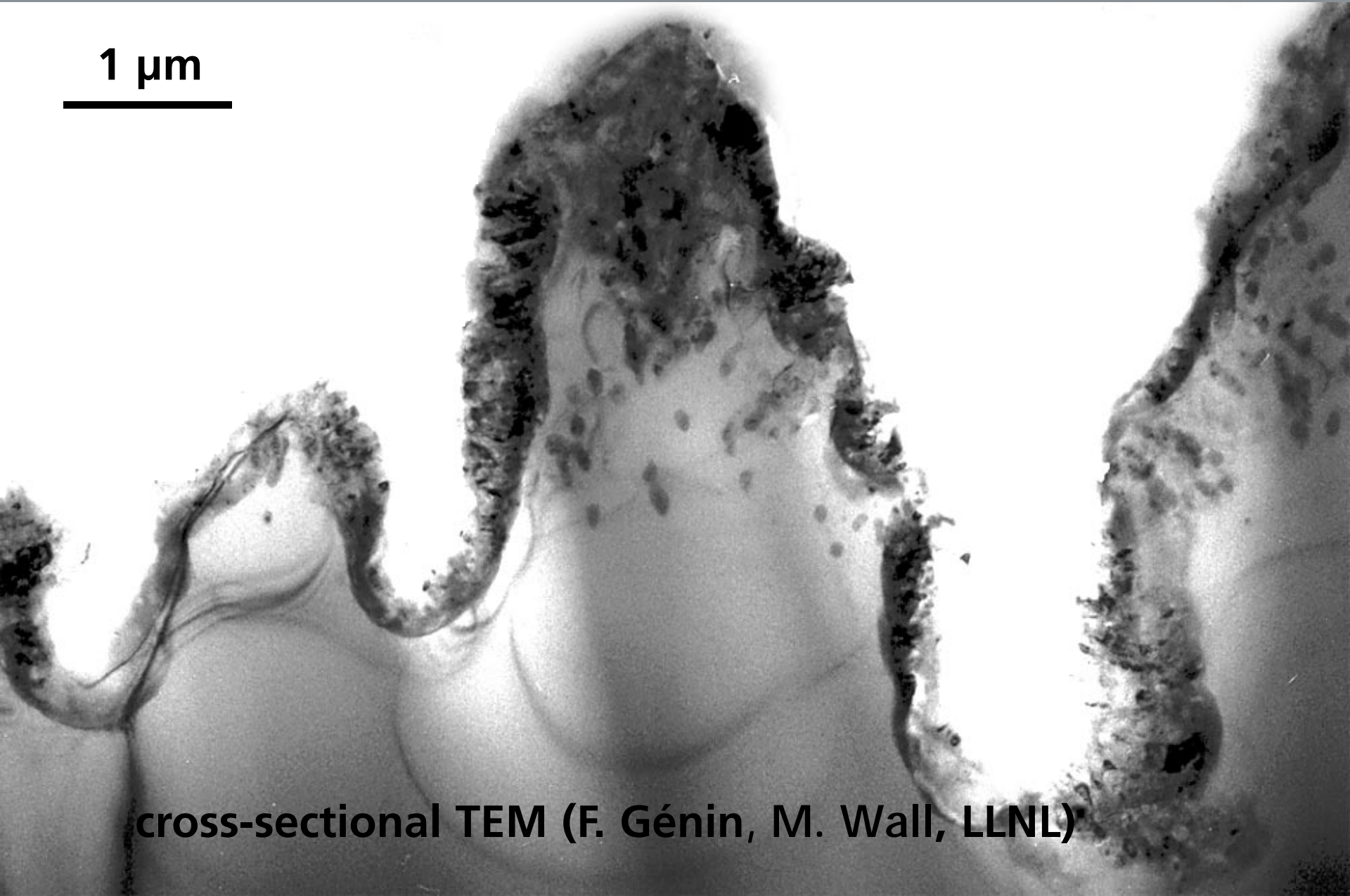
- ▶ **near unity absorption**
- ▶ **sub-band gap absorption**
- ▶ **IR photoelectron generation**
- ▶ **high field emission at low fields**

Outline

- ▶ Properties
- ▶ **Structural and chemical analysis**
- ▶ Outlook

Structural and chemical analysis

1 μm

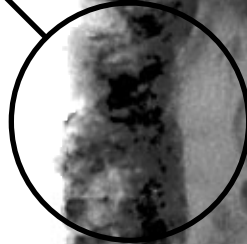


cross-sectional TEM (F. Génin, M. Wall, LLNL)

Structural and chemical analysis

1 μm

porous "fuzz"



cross-sectional TEM (F. Génin, M. Wall, LLNL)

Structural and chemical analysis

1 μm



nanocrystallites



cross-sectional TEM (F. Génin, M. Wall, LLNL)

Structural and chemical analysis

1 μm



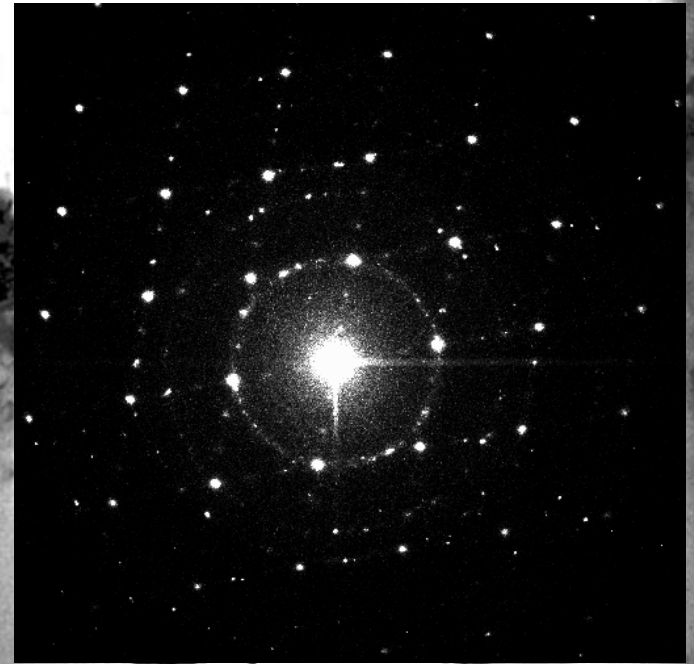
crystalline Si



cross-sectional TEM (F. Génin, M. Wall, LLNL)

Structural and chemical analysis

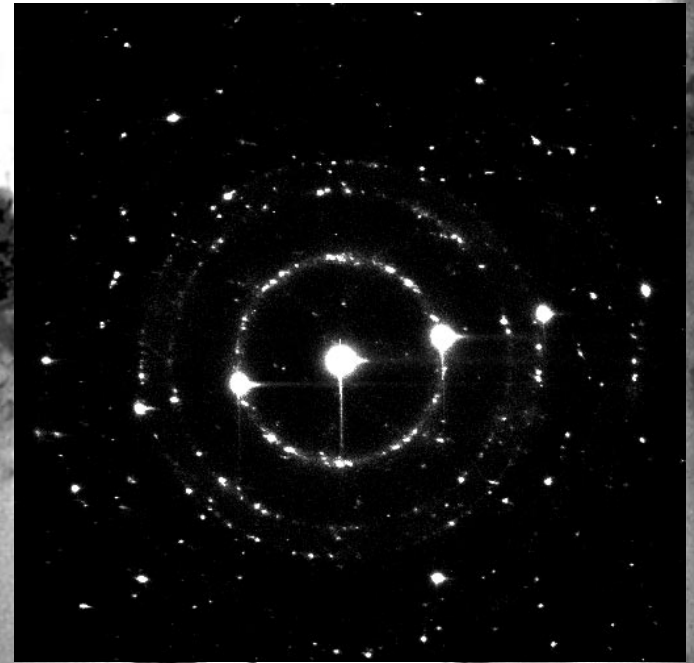
1 μm



electron diffraction (F. Génin, M. Wall, LLNL)

Structural and chemical analysis

1 μm

A transmission electron micrograph (TEM) showing a biological specimen, possibly a cross-section of a plant stem or root. The specimen exhibits a central, elongated, and somewhat irregular structure with a darker, more textured interior. A yellow dot is placed on the upper part of this central structure. To the left of the specimen, a horizontal scale bar is labeled "1 μm".

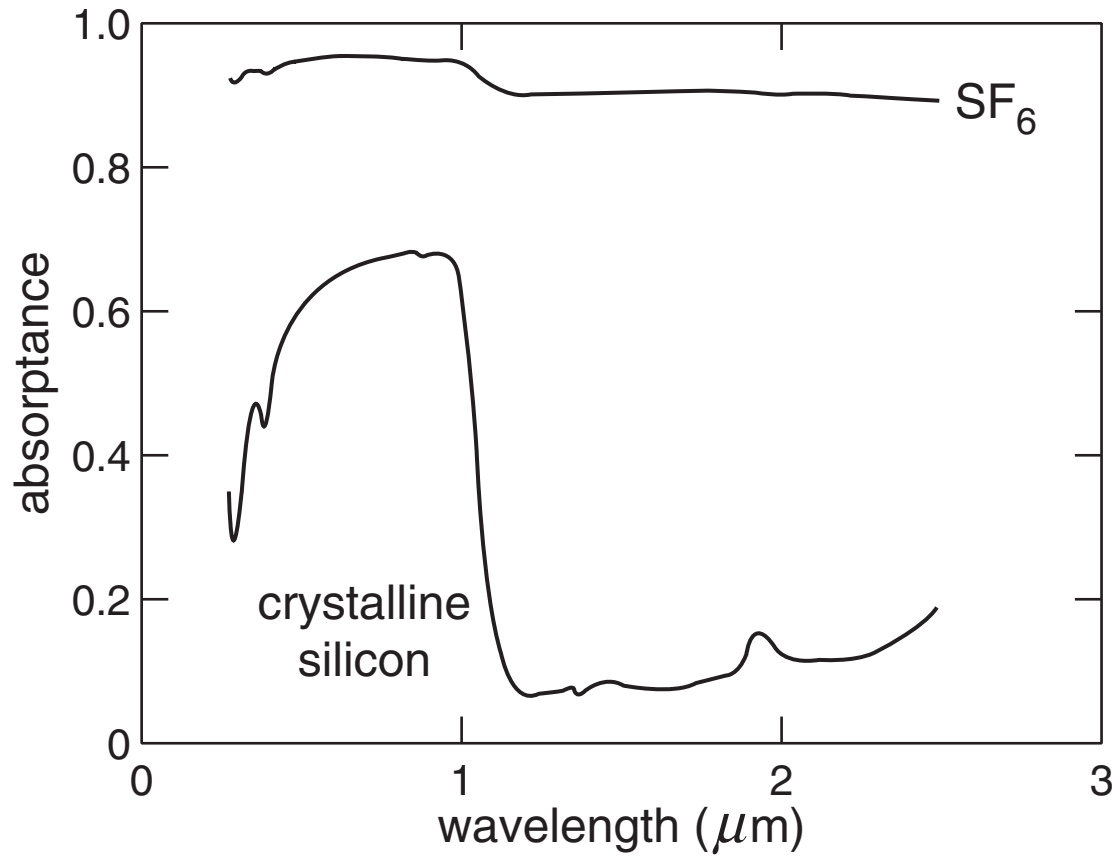
electron diffraction (F. Génin, M. Wall, LLNL)

cross-sectional TEM:

- ▶ **core of spikes: undisturbed Si**
- ▶ **surface layer: disordered Si, impurities, nanocrystallites and pores**

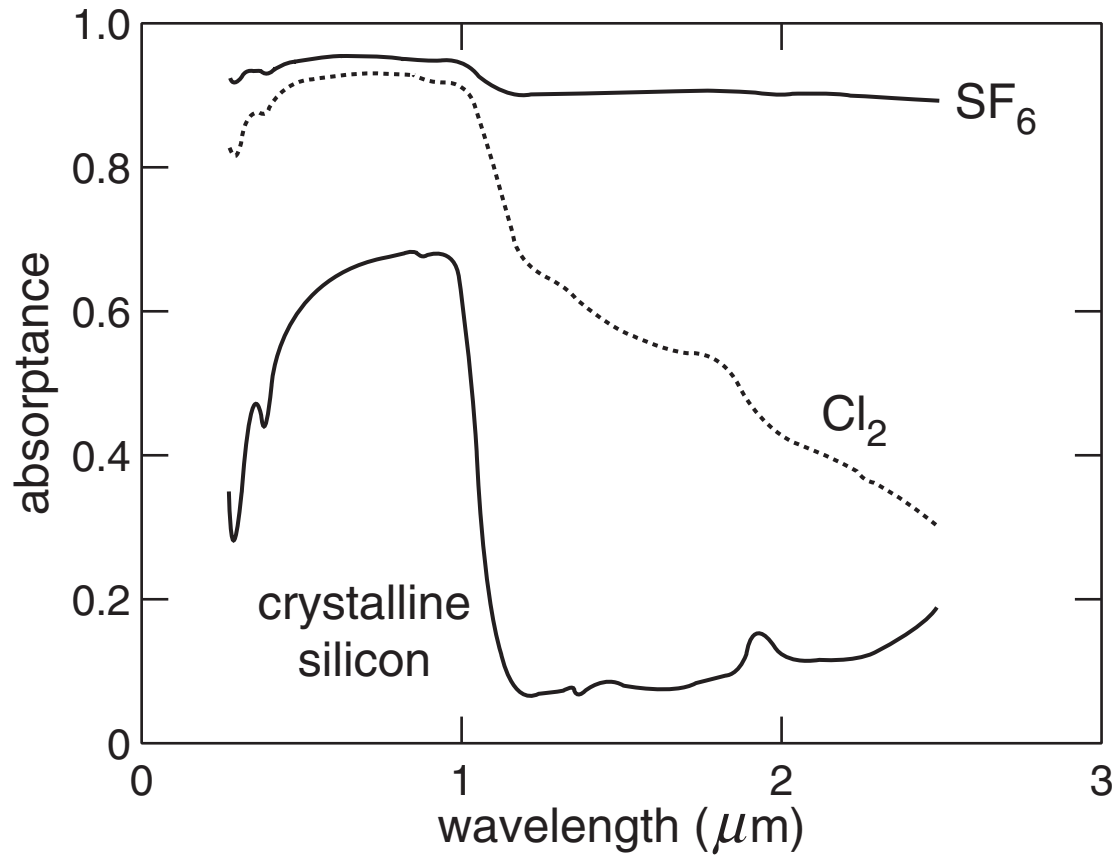
Structural and chemical analysis

effect of ambient gas on absorptance



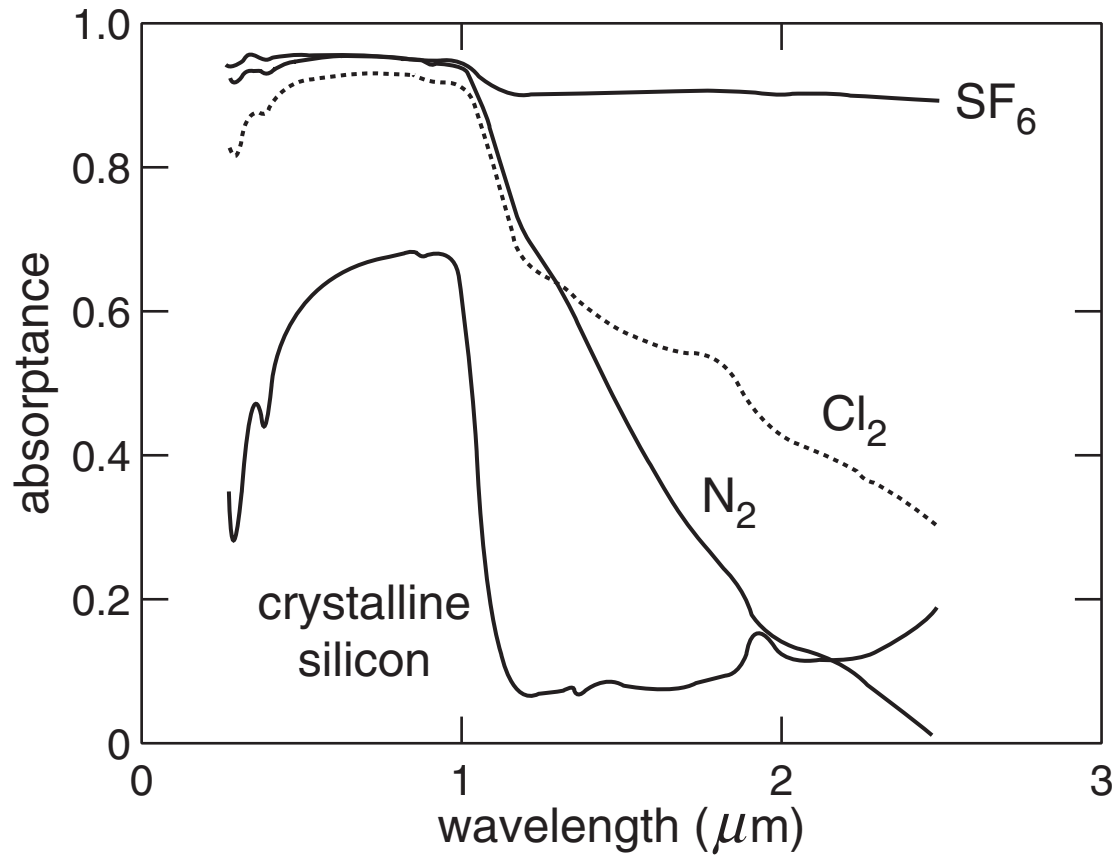
Structural and chemical analysis

effect of ambient gas on absorptance



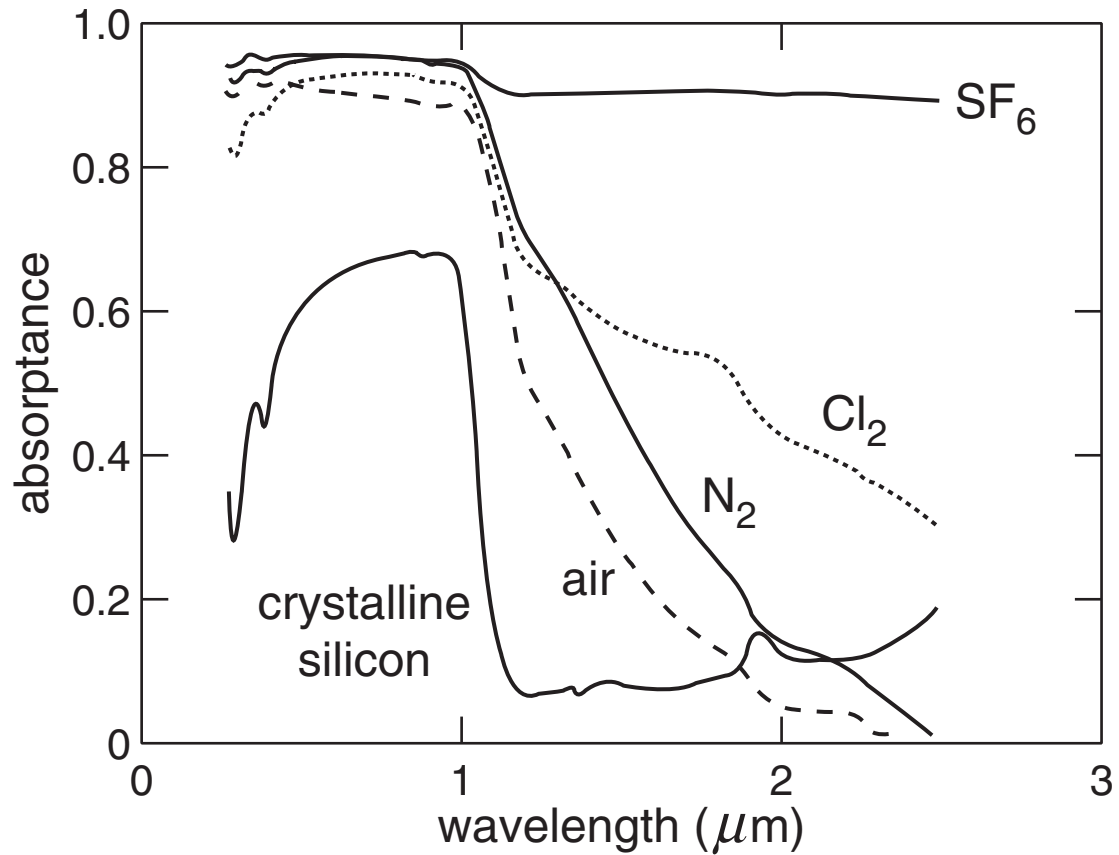
Structural and chemical analysis

effect of ambient gas on absorptance



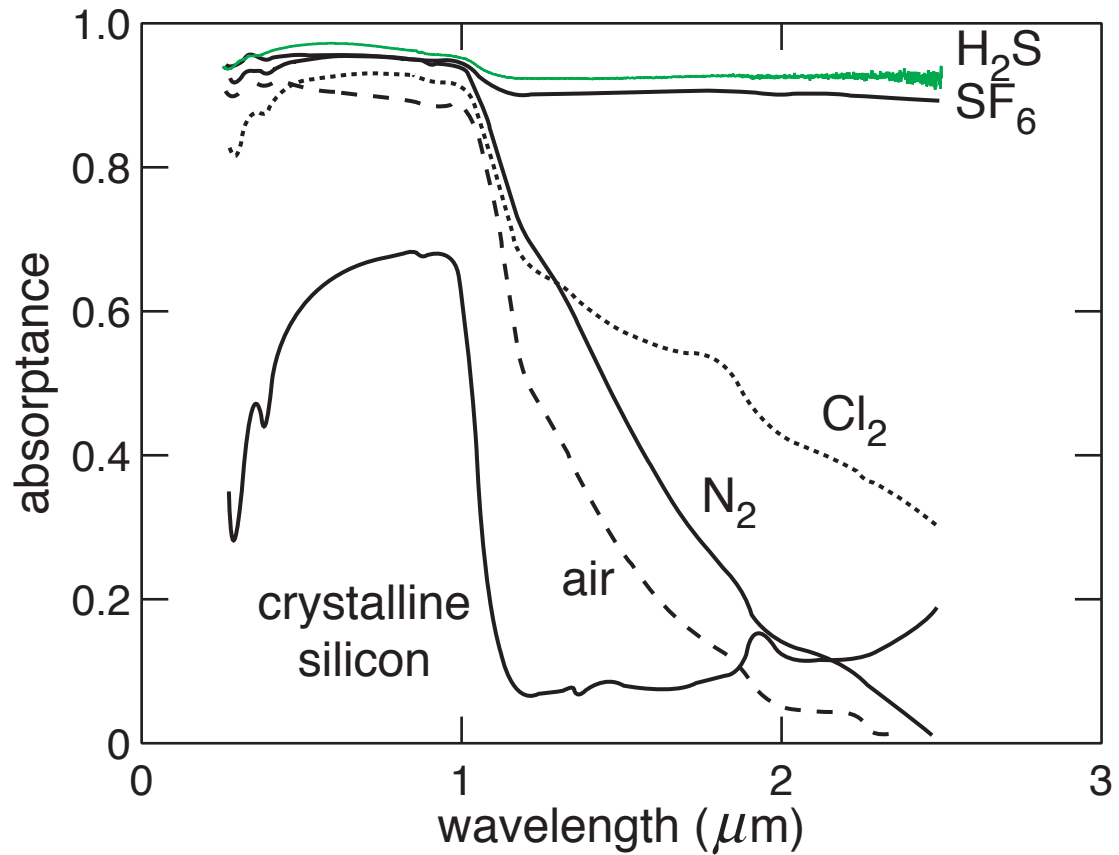
Structural and chemical analysis

effect of ambient gas on absorptance



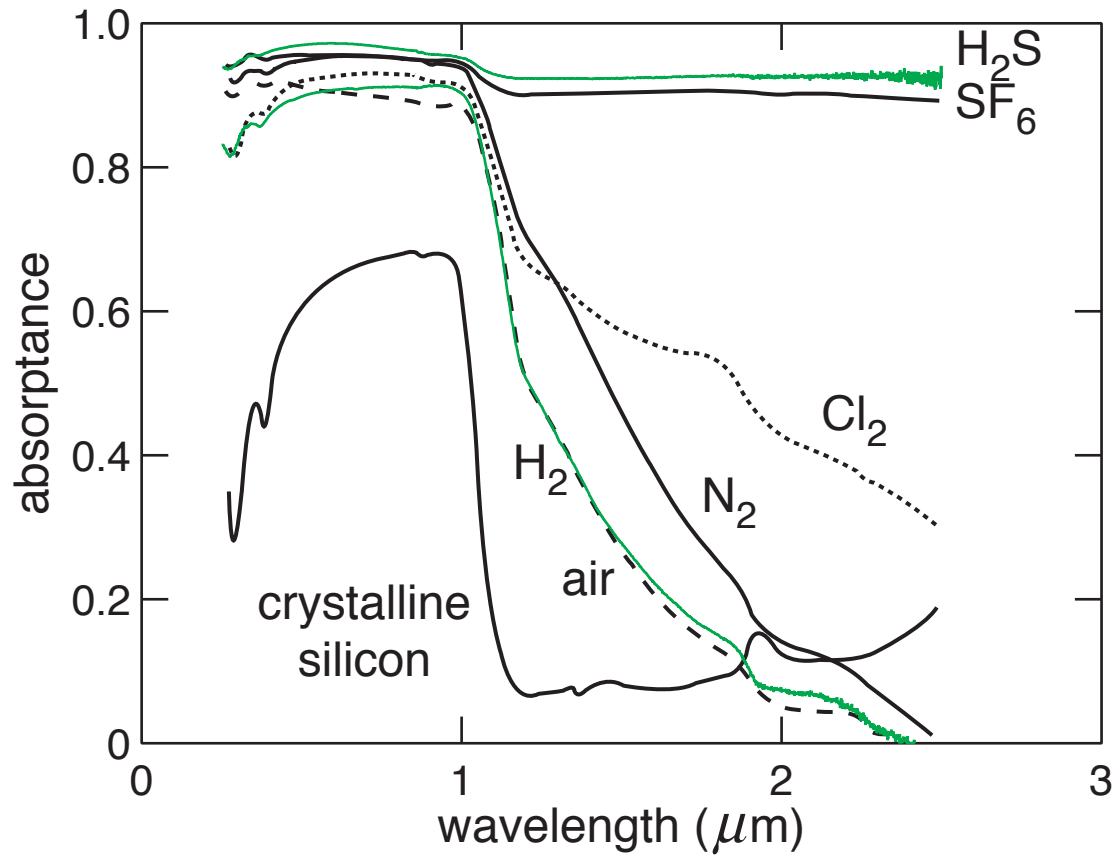
Structural and chemical analysis

effect of ambient gas on absorptance



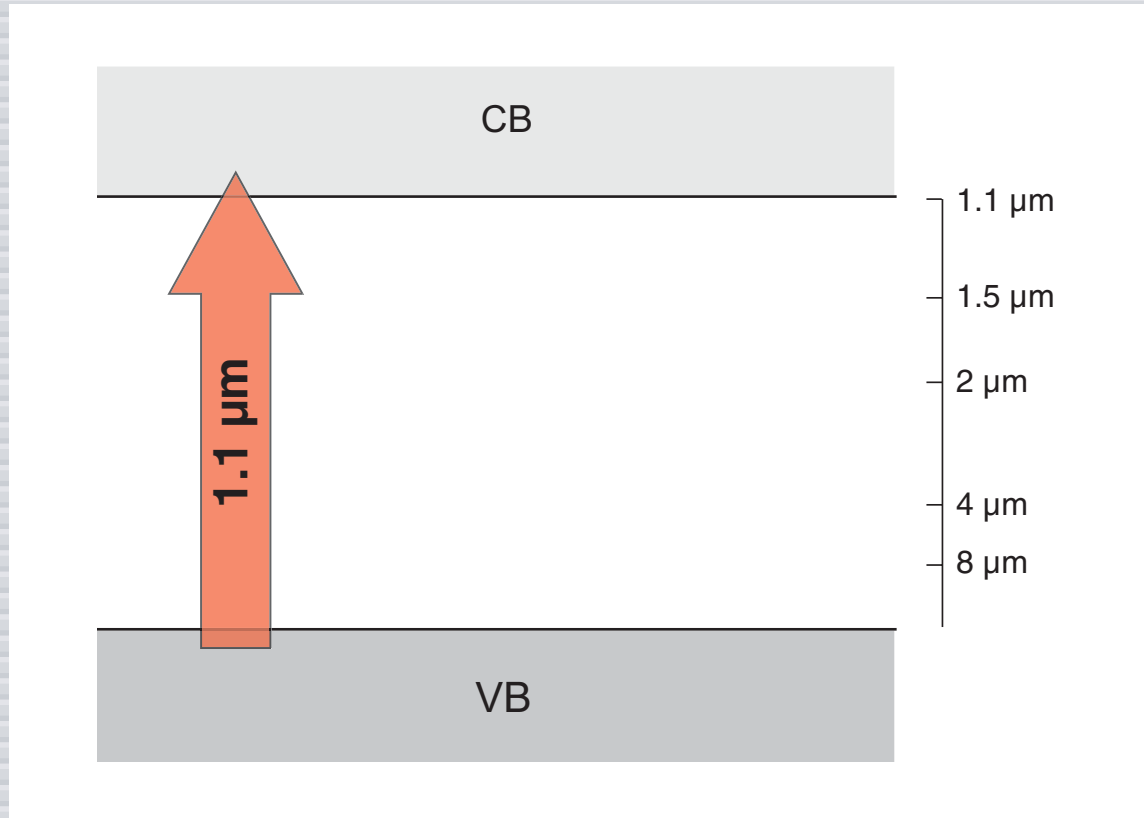
Structural and chemical analysis

effect of ambient gas on absorptance



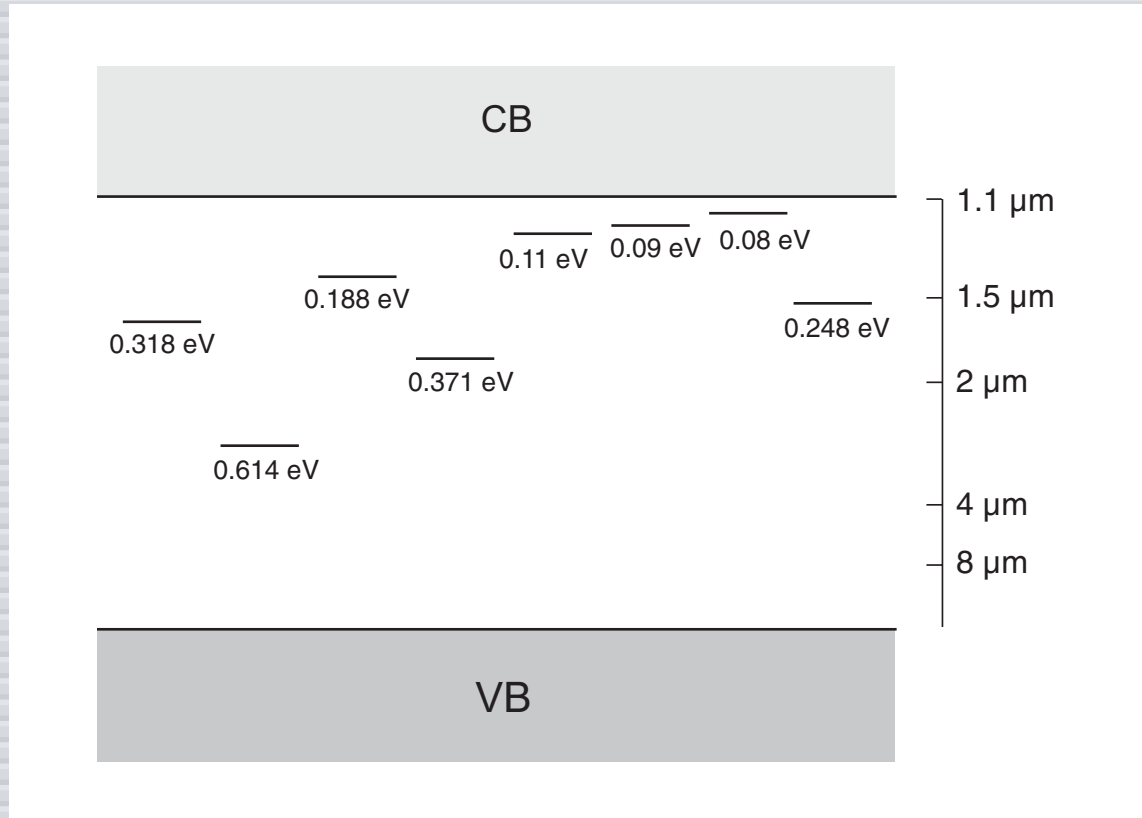
Structural and chemical analysis

sulfur introduces states in the gap



Structural and chemical analysis

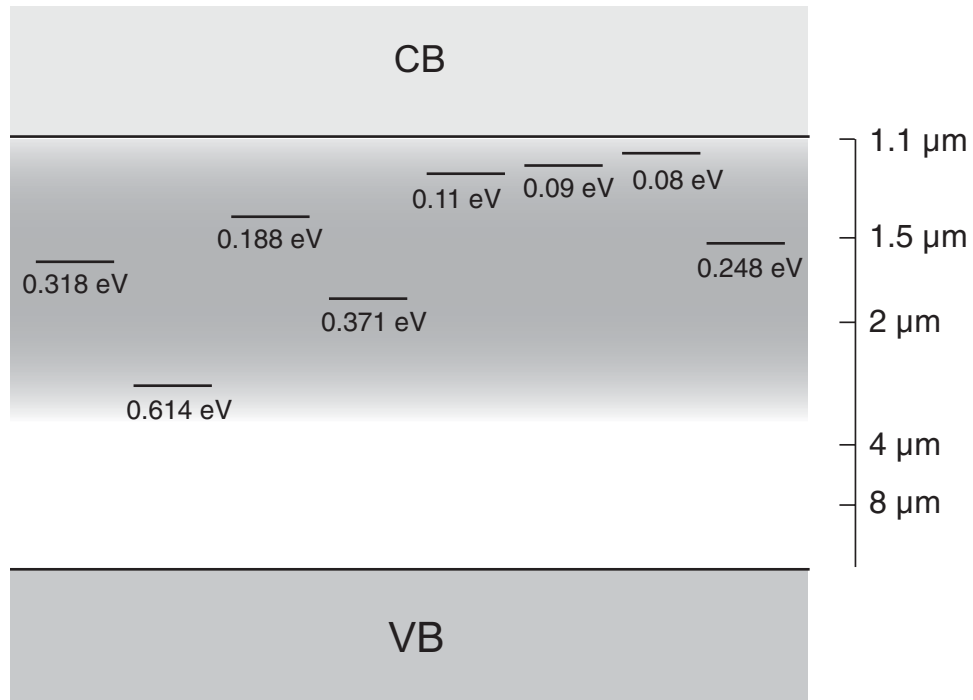
sulfur introduces states in the gap



Janzén, et al., *Phys. Rev. B* 29,1907 (1984)

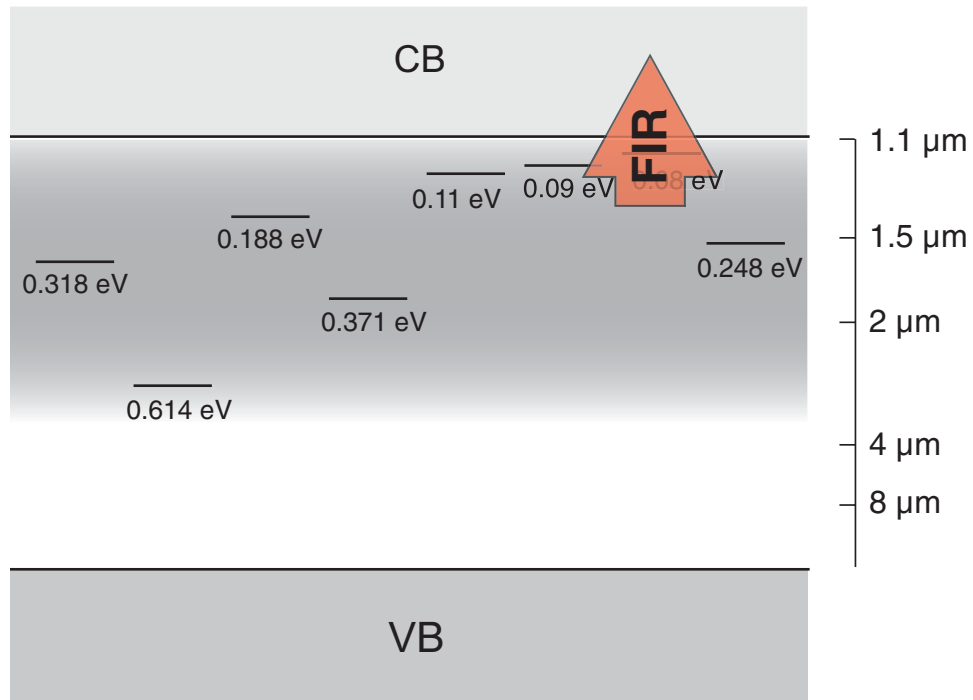
Structural and chemical analysis

states broaden into a band



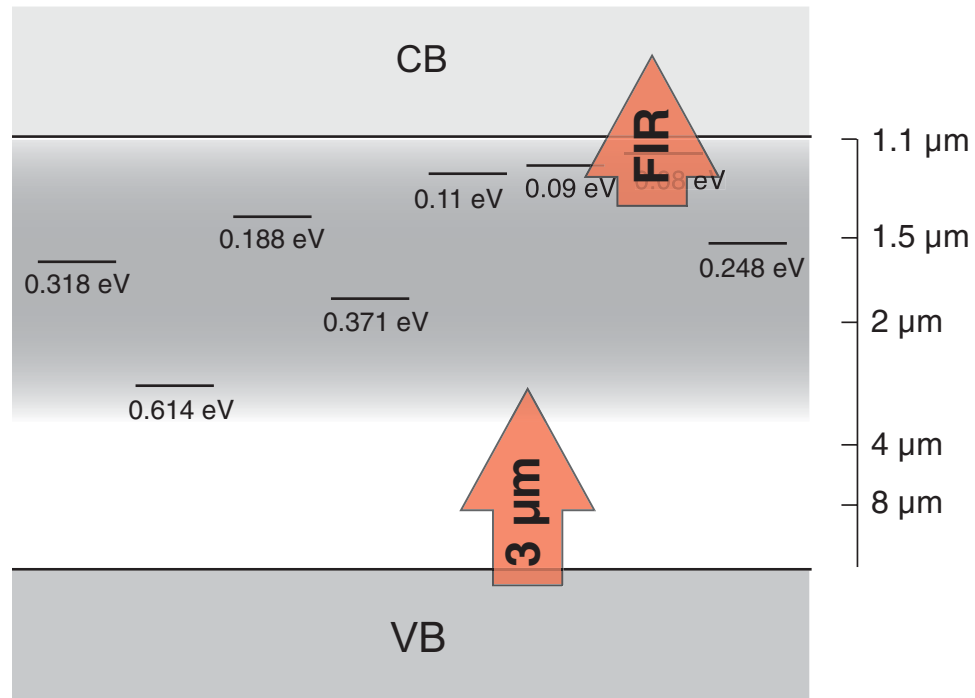
Structural and chemical analysis

donor: metal-like behavior



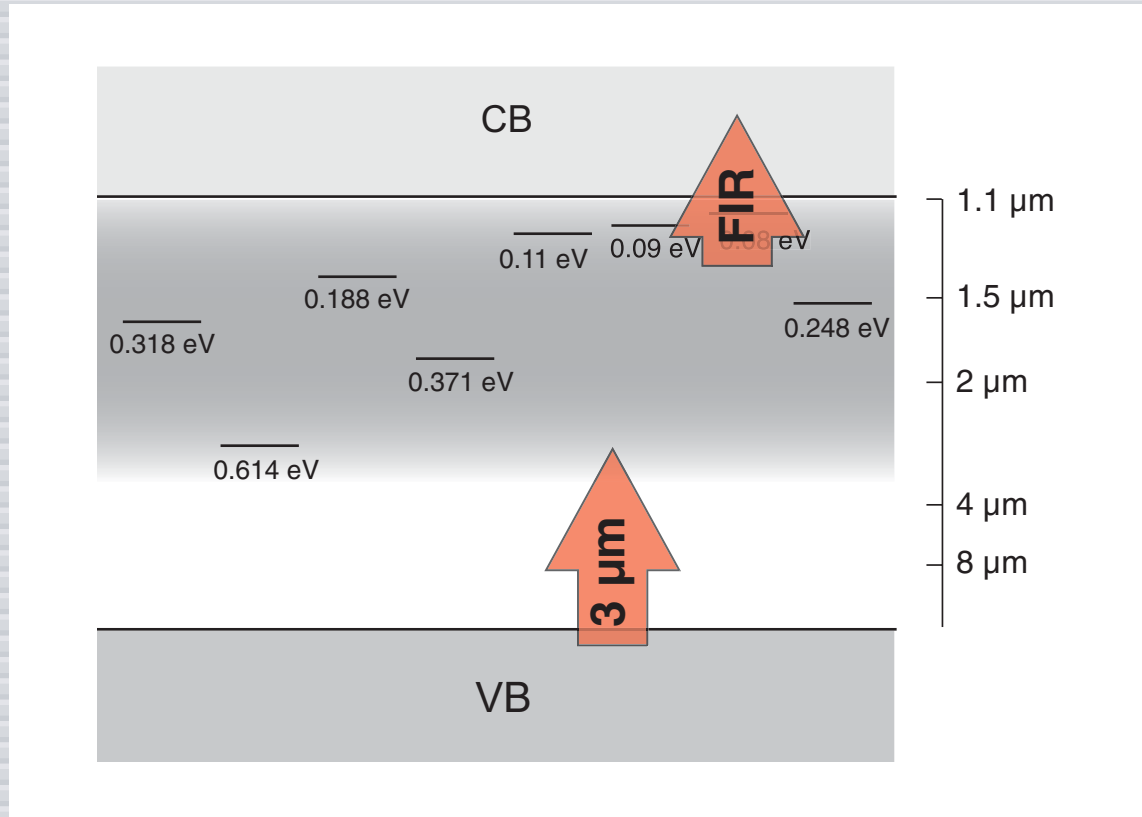
Structural and chemical analysis

acceptor: absorption until 3 μm



Structural and chemical analysis

acceptor: absorption out to 3 μm



near-IR transmittance rises around 3 μm

Outline

- ▶ **Properties**
- ▶ **Structural and chemical analysis**
- ▶ **Outlook**

Outlook

New Scientist 13, 34 (2001)

A forest of silicon spikes could revolutionise solar cells and give you painless injections. **Bruce Schechter** peers into the mysterious world of black silicon

TALL, DARK AND STRANGER

WE ALL love stories of serendipity. They seem to hark back to a time when a fogged plate or a filthy Petri dish today, when

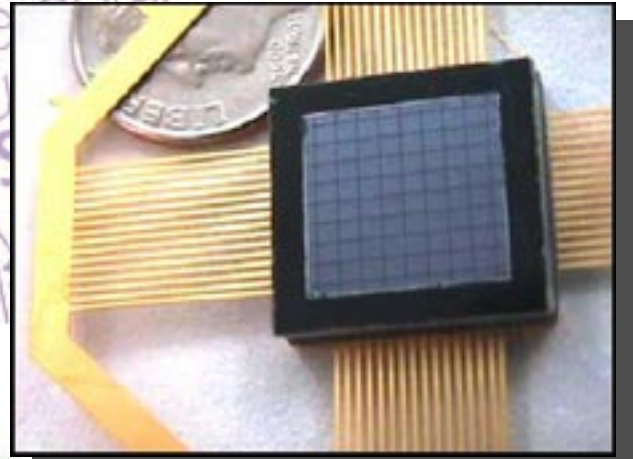
semiconductors with a powerful laser. In the early 1990s, Mazur's was the first academic lab in the world to get its hands on a femtosecond laser. This device produces pulses of light that are hundreds of times brighter than the Sun. and extremely

around the laboratory," he claims. Well, it was almost the only reason a short laser pulse will break down into sulphur and fluorine radicals, which will attack a silicon substrate. "Hydrogen fluoride is used to etch silicon. I thought maybe the SF₆ would do it and then the fluorine would so... the silicon," Mazur explains. than

Outlook

▶ detector technology

A forest of silicon spikes could revolutionise solar cells and give you injections. Bruce peers into the mysterious world of black silicon



TALL, DARK AND STRANGER

We'll all love stories of sci-fi... This...
...to look back to a time when a single...
...of a life's journey when...

semiconductors with a powerful laser...
the early 1960s. Major's was the first...
academic lab in the world to do so...
hard over a ten-year period. This...
...as a source of light that included...
...times brighter than the Sun...
...and extremely

around the laboratory, he claims...
"Well, it was a great time to be...
...the sun and the moon...
...with a lot of...
...through the...
...the silicon. Most ex...

Outlook

- ▶ detector technology
- ▶ solar cells

A forest of silicon spikes could revolutionise solar cells and give you power injections. Bruce S. ... peers into the mysterious world of black silicon



TALL, DARK AND STRANGER

We'll all agree that it's weird to see a tall man to ask for a machine when a single ... of a fifty ... when

semiconductors with a potential use for the early 1960s. Major's was the first academic lab in the world to do so hard over a ten-year period. This device ... in silicones ... light that ... from the Sun ... and extremely

around the ... he claims. ... the only ... break ... and ... the ... would ... silicon. Most ...

Outlook

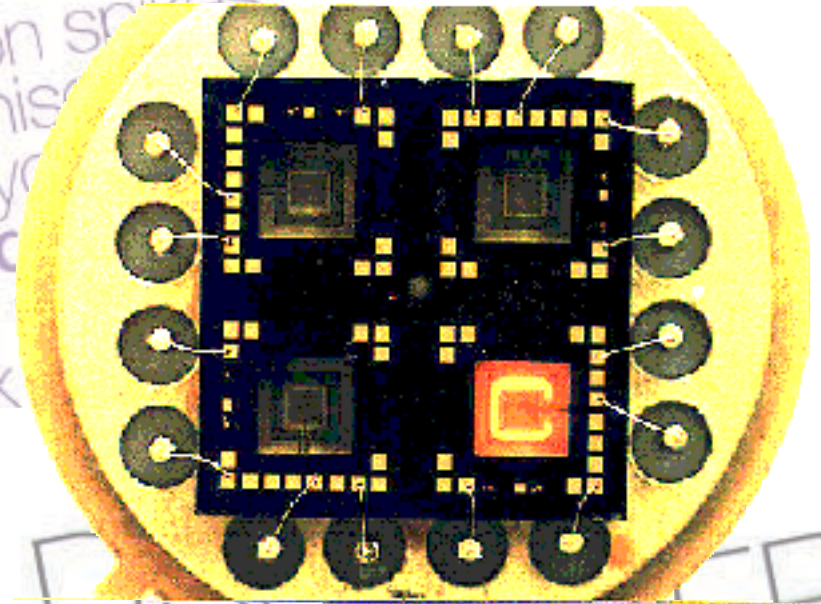
- ▶ detector technology
- ▶ solar cells
- ▶ display technology



Outlook

- ▶ detector technology
- ▶ solar cells
- ▶ display technology
- ▶ sensors

A forest of silicon spikes
could revolutionise
cells and give you
injections. Bruce
peers into the
world of black



TALL, DARK
AND STRANGER

We'll all have stories of weird jobs. This
one to ask for a long time when a legend
of a life's time. You'll find
only when

semiconductors with a potential use for
the early 1960s. Major's was the first
academic lab in the world to do so.
hard-core computer work. That's why
you'll see you'll see light that in the
computer's light from the Sun
and extremely

around the laboratory," he claims.
Well, it was a great time to make
about 1960, "I was not happy to see
into a flat and become a major
will attack a serious disease. But
there is a need to see silicon
through the hole. It would be
and then the silicon would be
the silicon. Most ex-

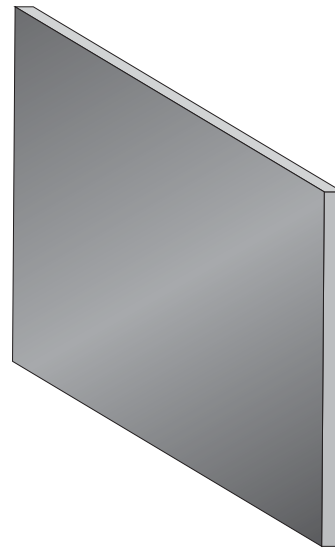
Outlook

- ▶ **development of spikes**
- ▶ **spike formation through grids**
- ▶ **cell adhesion**
- ▶ **functionalization**

Outlook

can ordering of spikes be improved by using a grid?

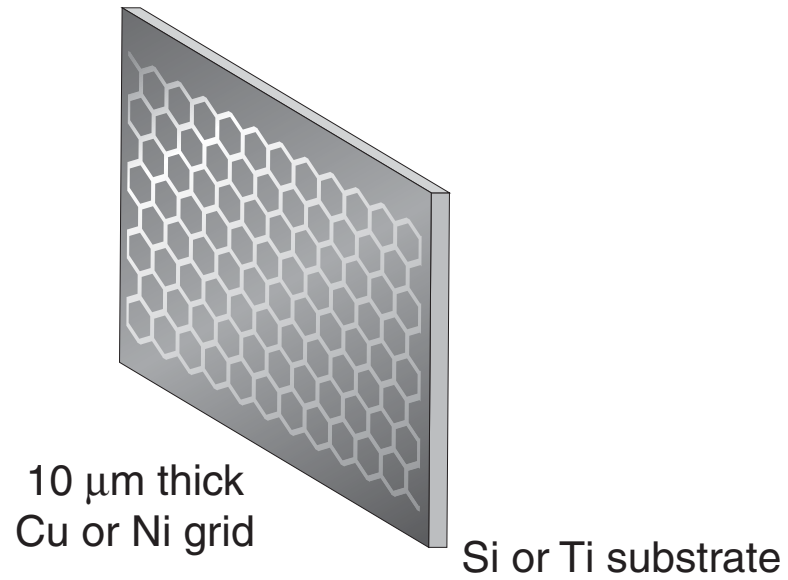
Outlook



Si or Ti substrate

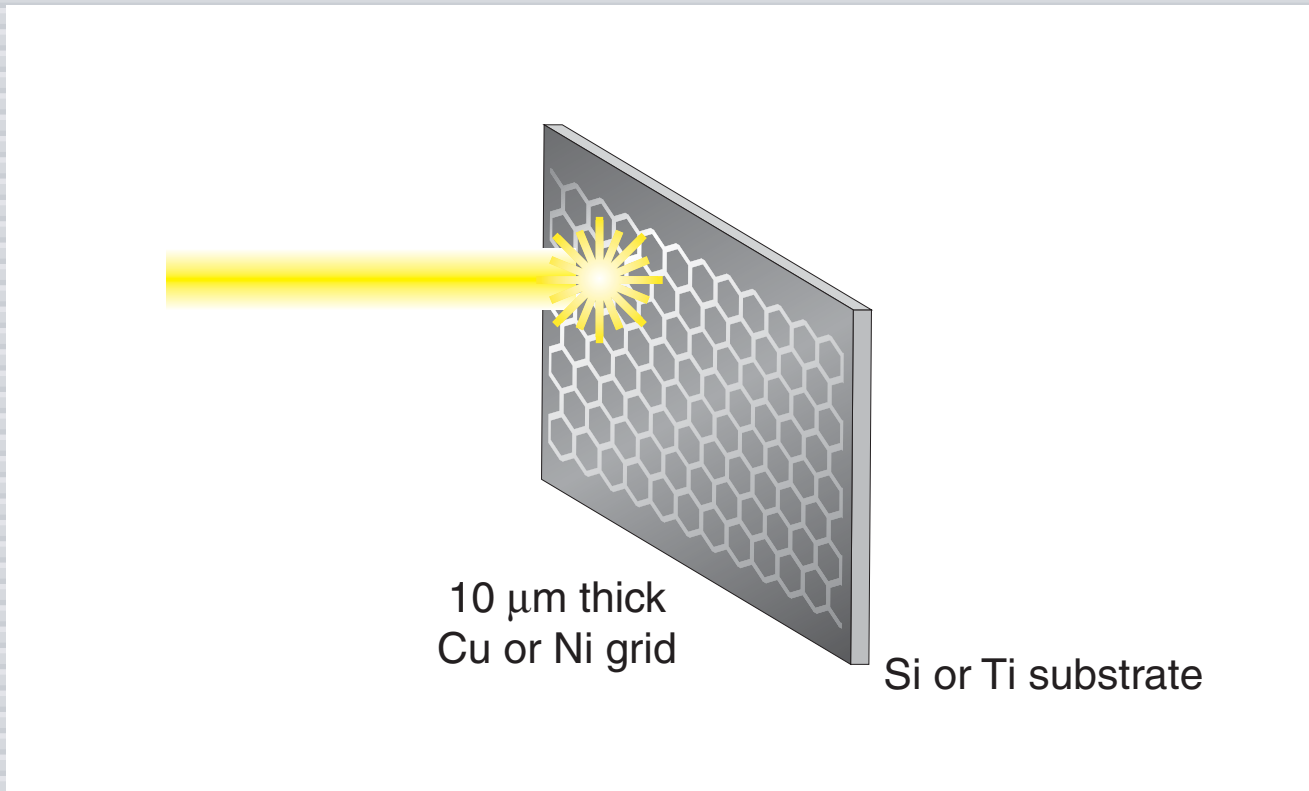
Outlook

place grid in front of substrate



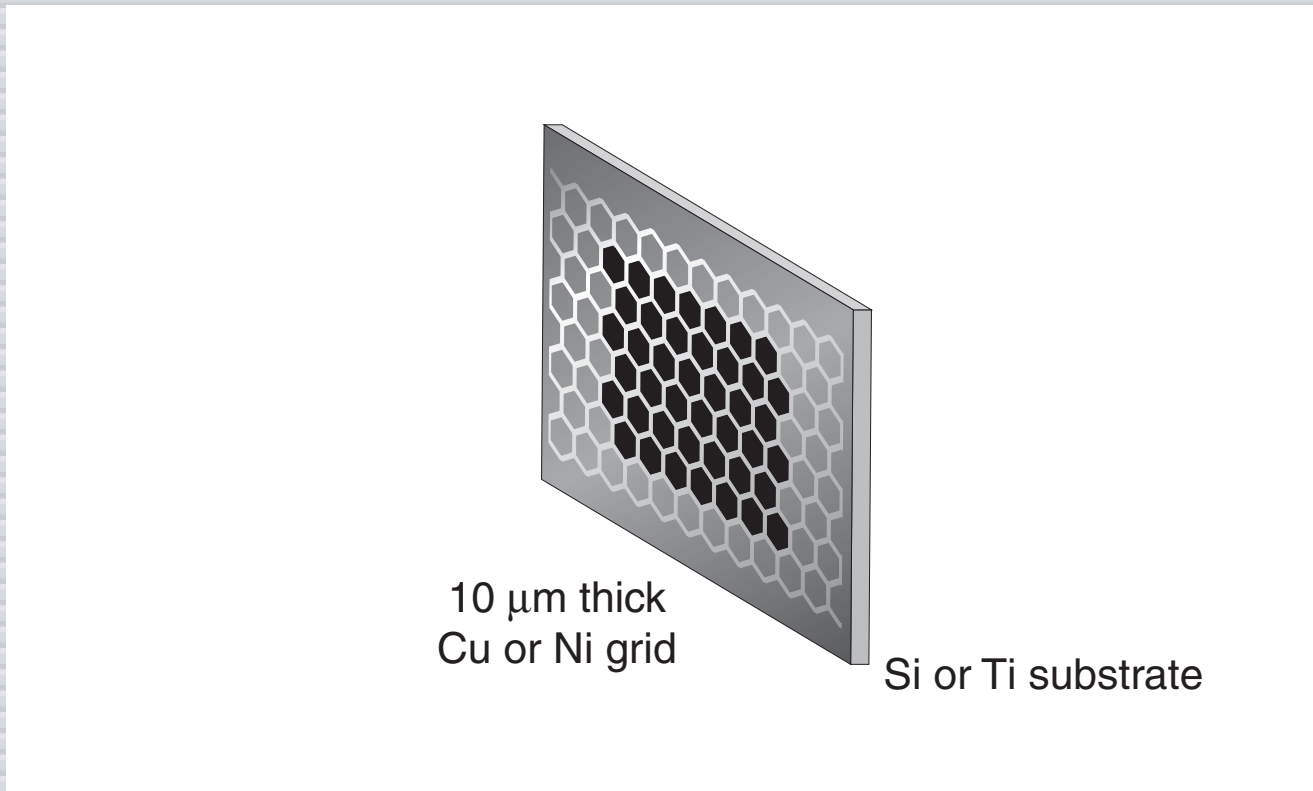
Outlook

scan laser beam



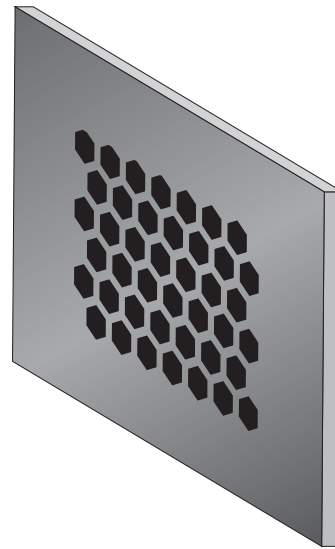
Outlook

scan laser beam

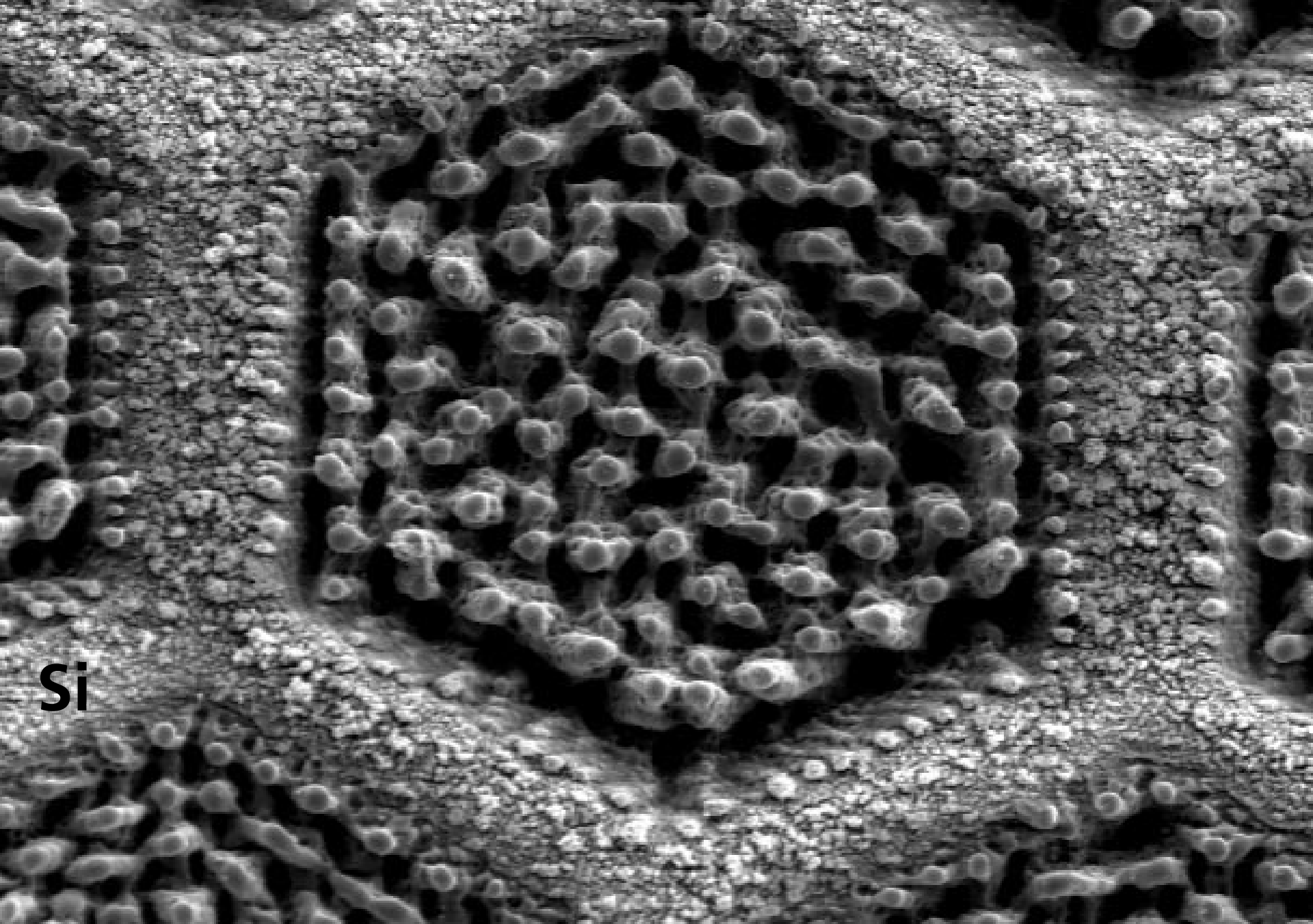


Outlook

remove grid



Si or Ti substrate

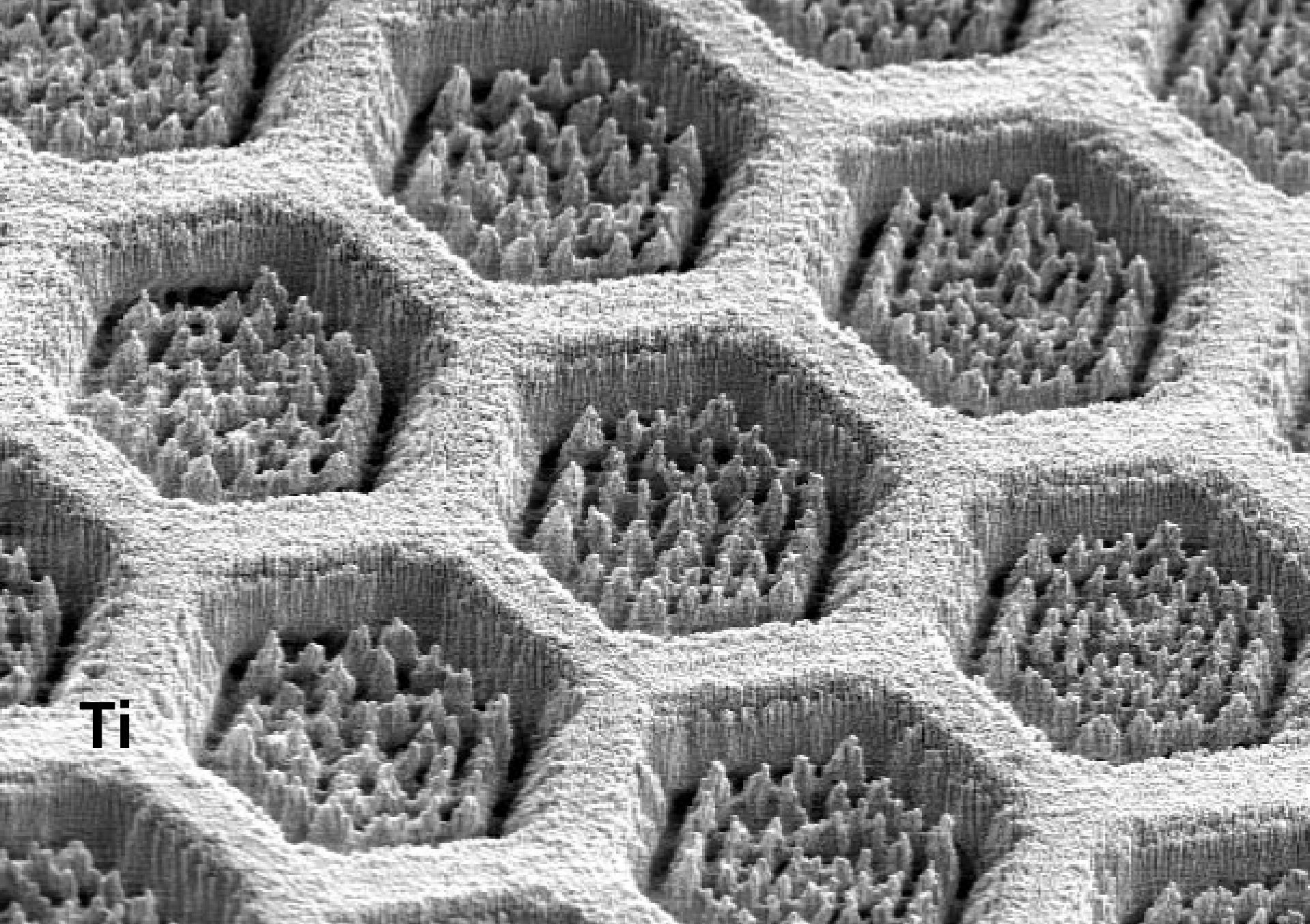


Si

x2000
512 x 480

20 μ m

5kV 24mm
H300.TIF

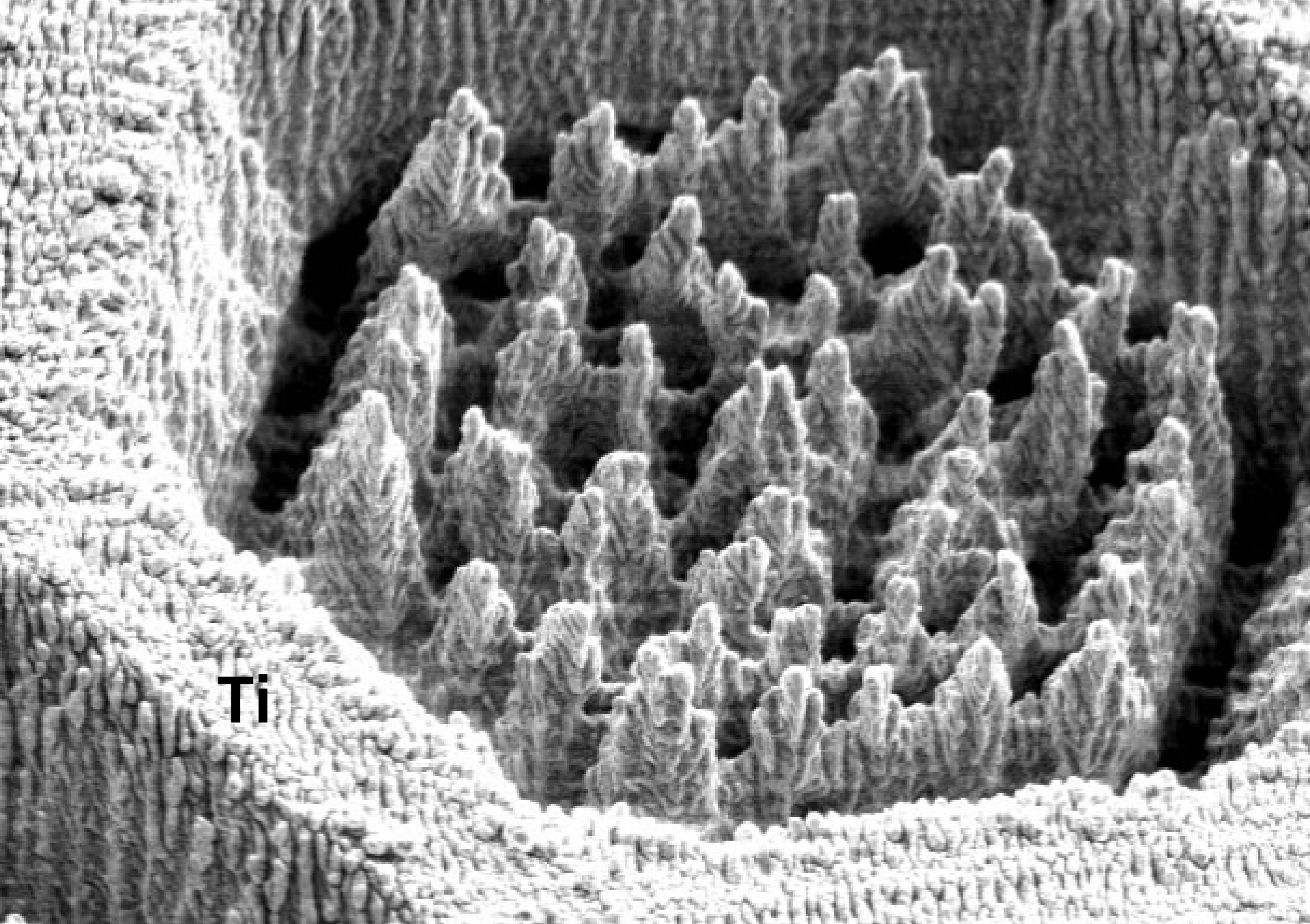


Ti

20 μ m

5kV

17mm



Ti

10 μ m

5kV

17mm

Outlook

Summary

Microstructured silicon

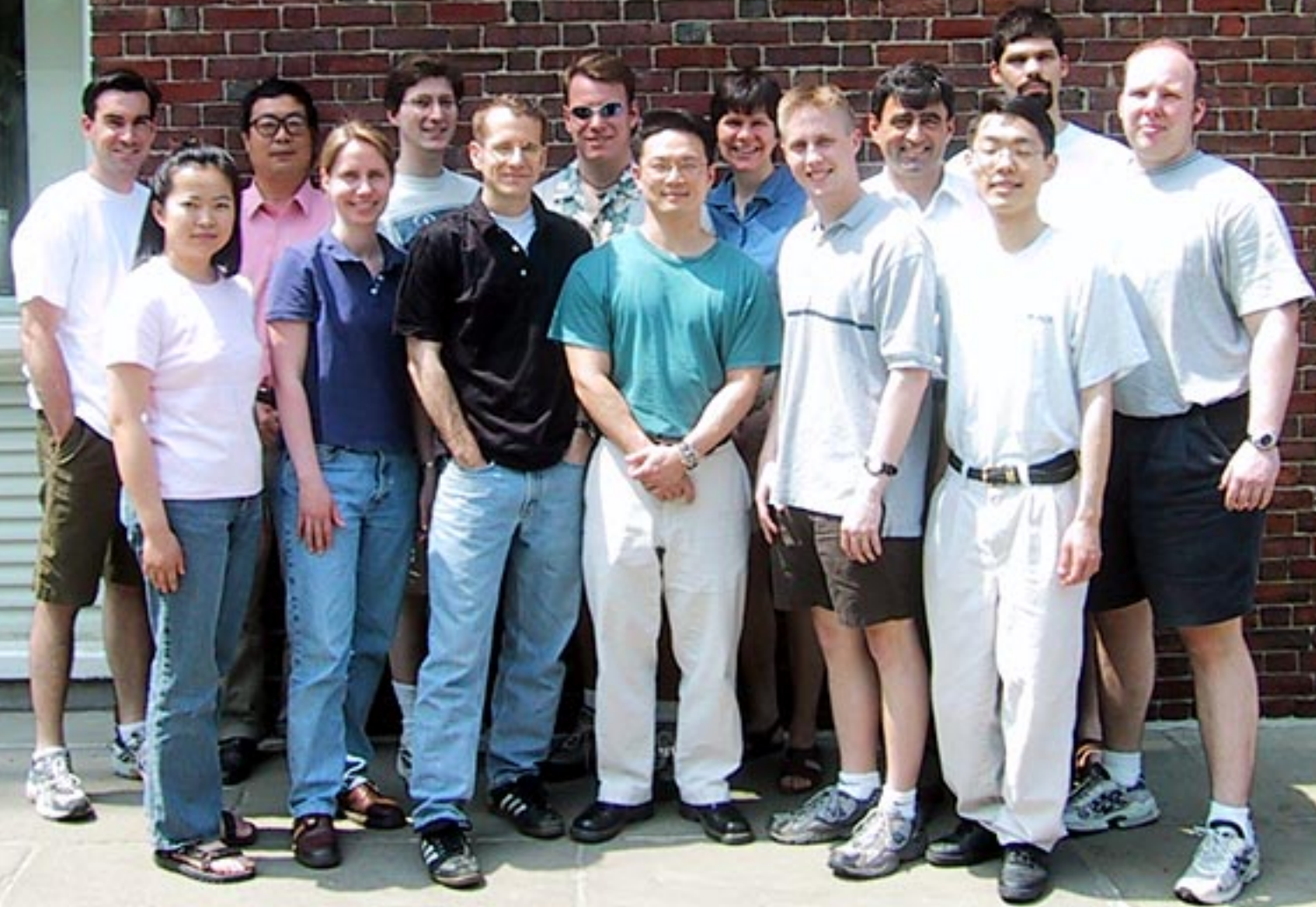
- ▶ **fabricated by simple, maskless process**

Summary

Microstructured silicon

- ▶ **fabricated by simple, maskless process**
- ▶ **can be integrated with microelectronics**

CORDON MCKAY
LABORATORY OF
APPLIED SCIENCE



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Dr. John Chervinsky (Harvard University)

Prof. Mike Aziz (Harvard University)

**For a copy of this talk and
additional information, see:**

<http://mazur-www.harvard.edu>