

Infrared absorption by conical silicon microstructures made in a variety of background gases using femtosecond-laser pulses

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**CLEO, Baltimore, MD
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Cambridge, MA**

Fabrication of conical microstructures

Optical properties of structures made in SF₆

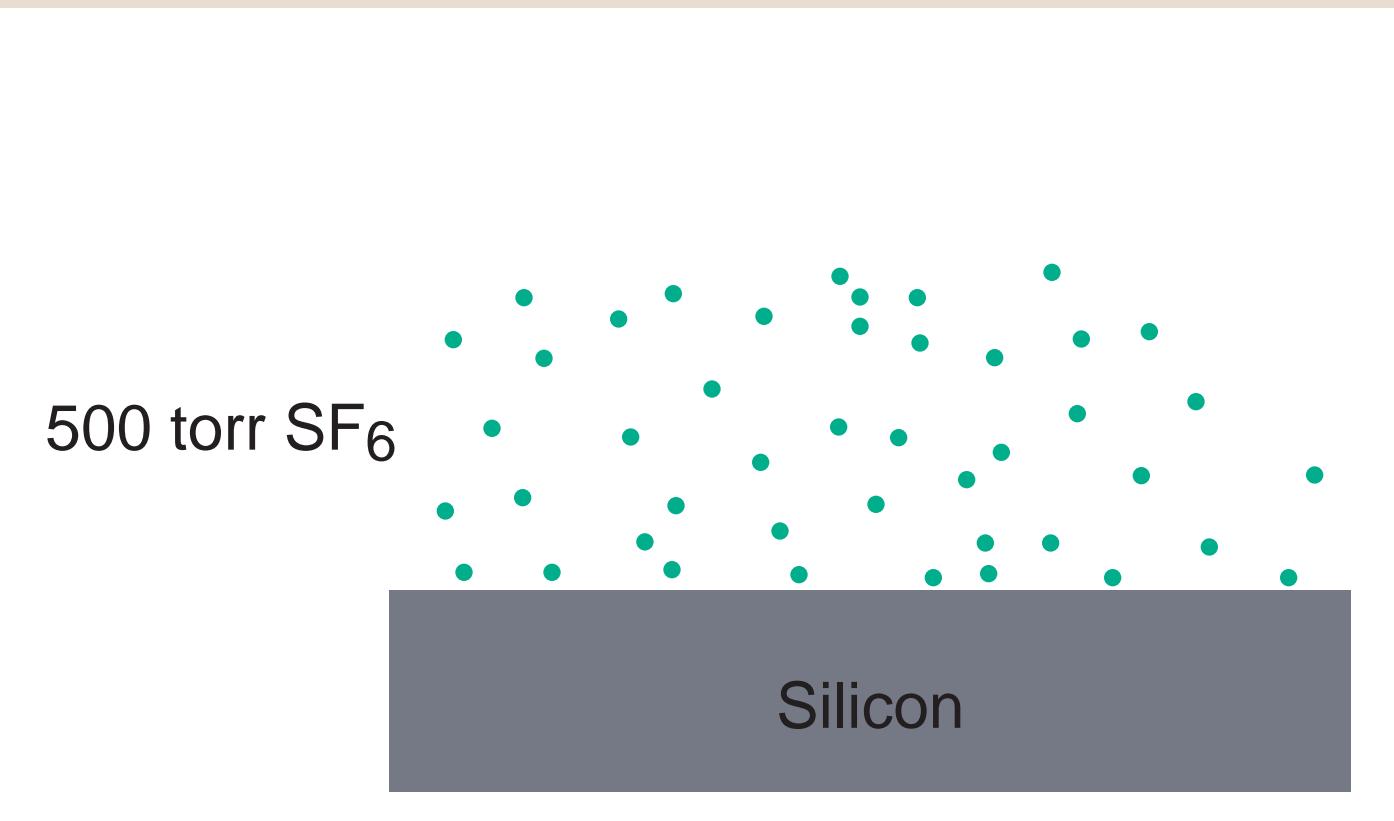
- **high absorptance**
- **explanations**

Structures made in other ambient gases

- **morphology**
- **optical and optoelectronic properties**

Microstructured silicon

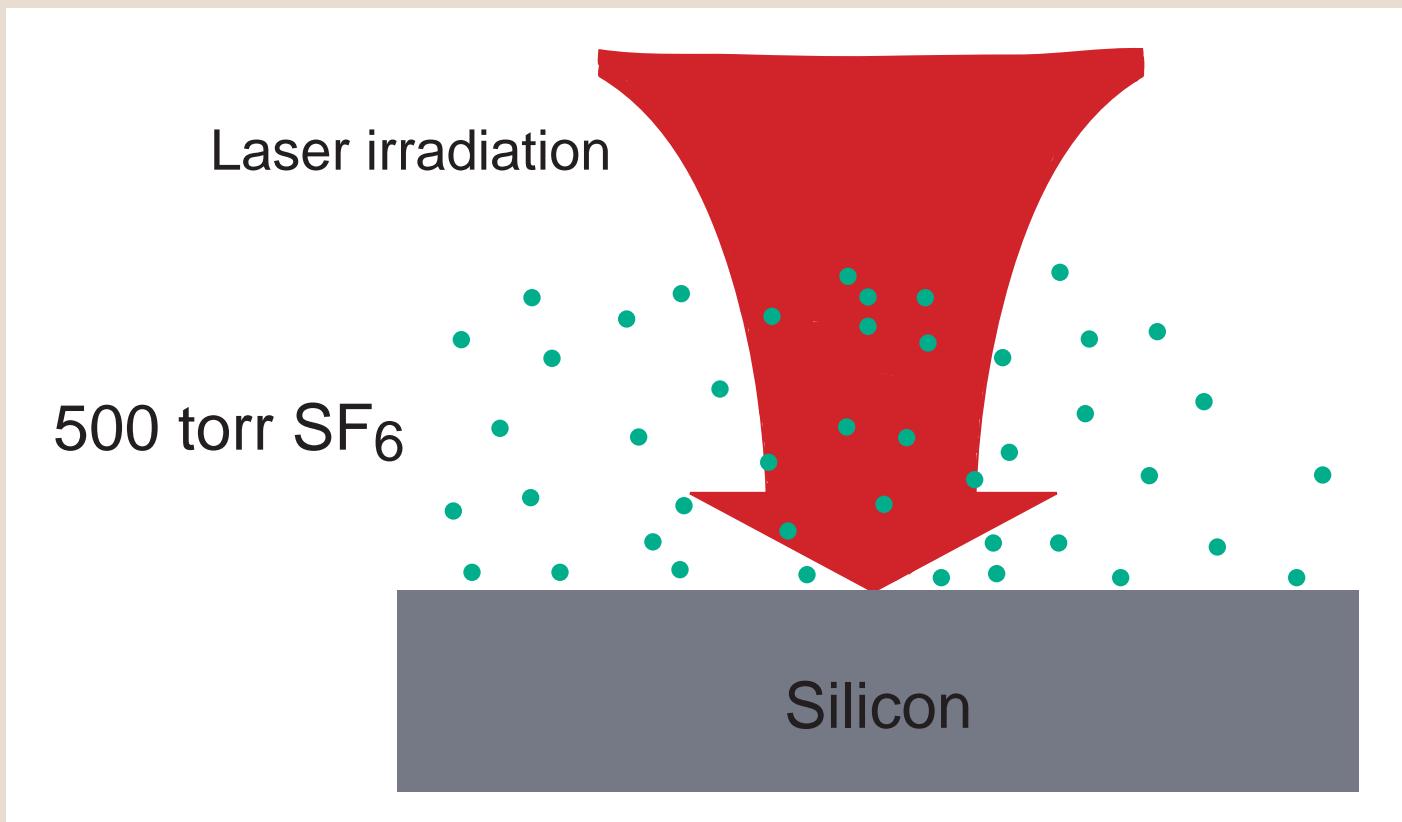
Si (111) placed in background of SF₆



Her et al., Appl. Phys. Lett. 73, 1673 (1998)

Microstructured silicon

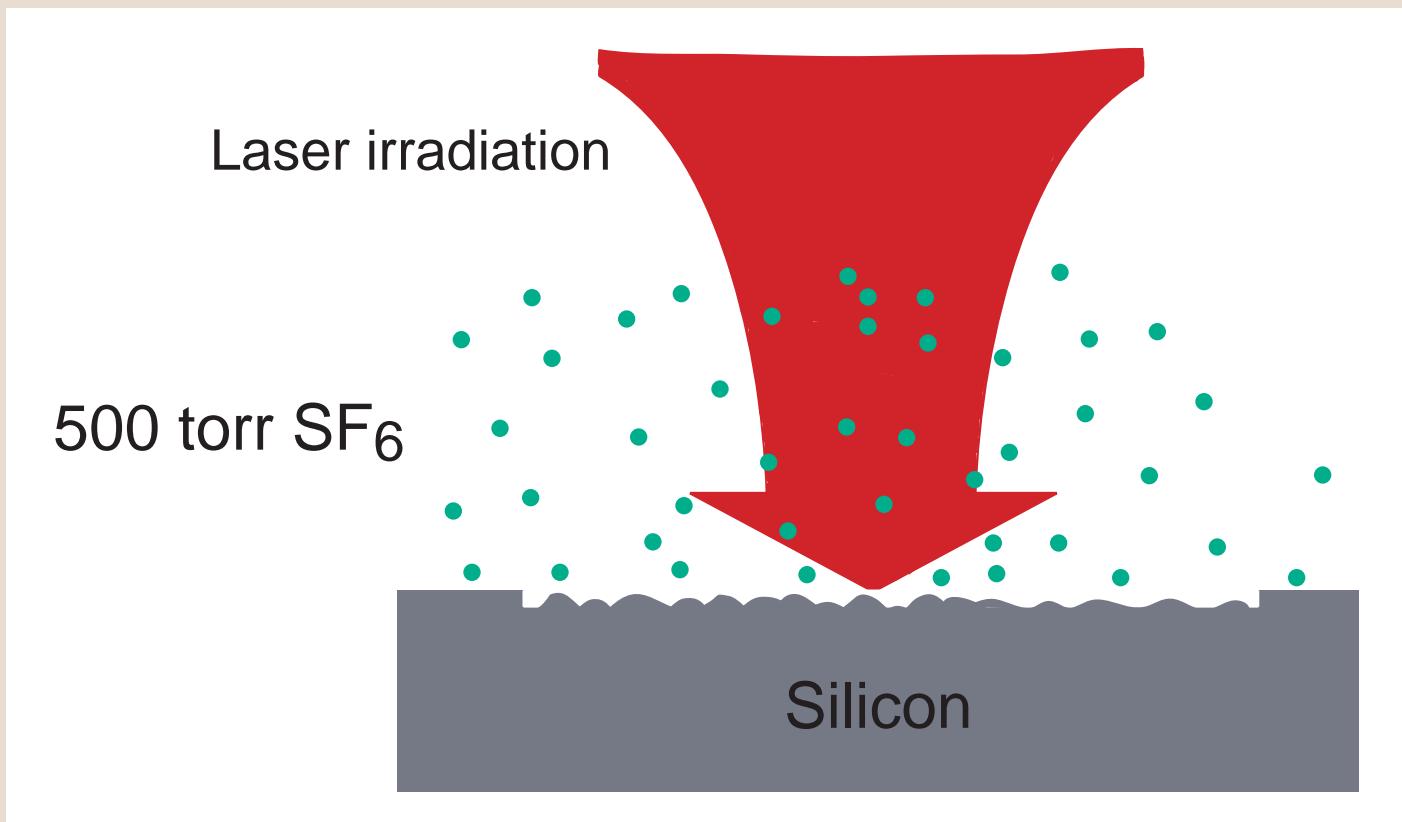
irradiate with 100 fs, 10 kJ/m² laser pulses in SF₆



Her et al., *Appl. Phys. Lett.* 73, 1673 (1998)

Microstructured silicon

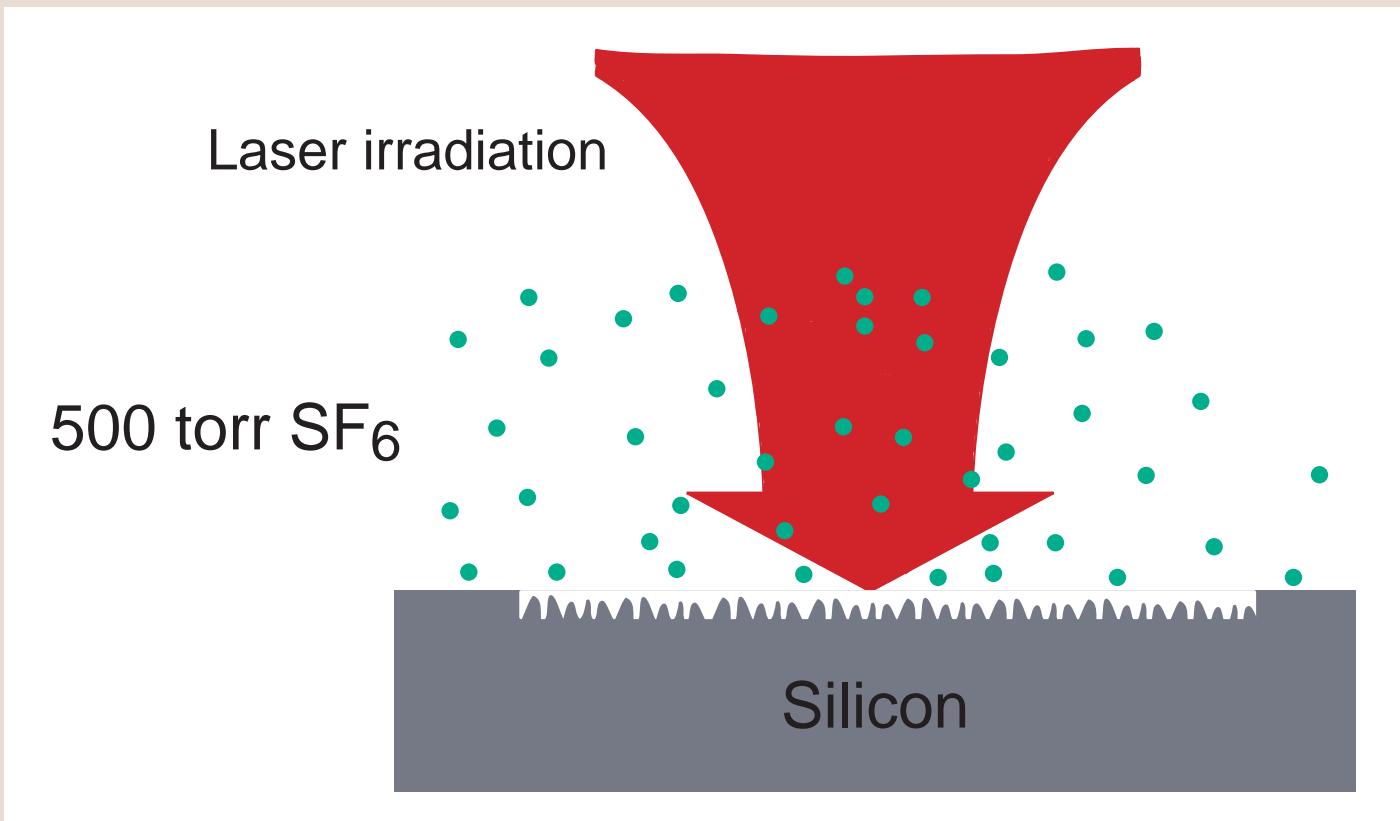
irradiate with 100 fs, 10 kJ/m² laser pulses in SF₆



Her et al., Appl. Phys. Lett. 73, 1673 (1998)

Microstructured silicon

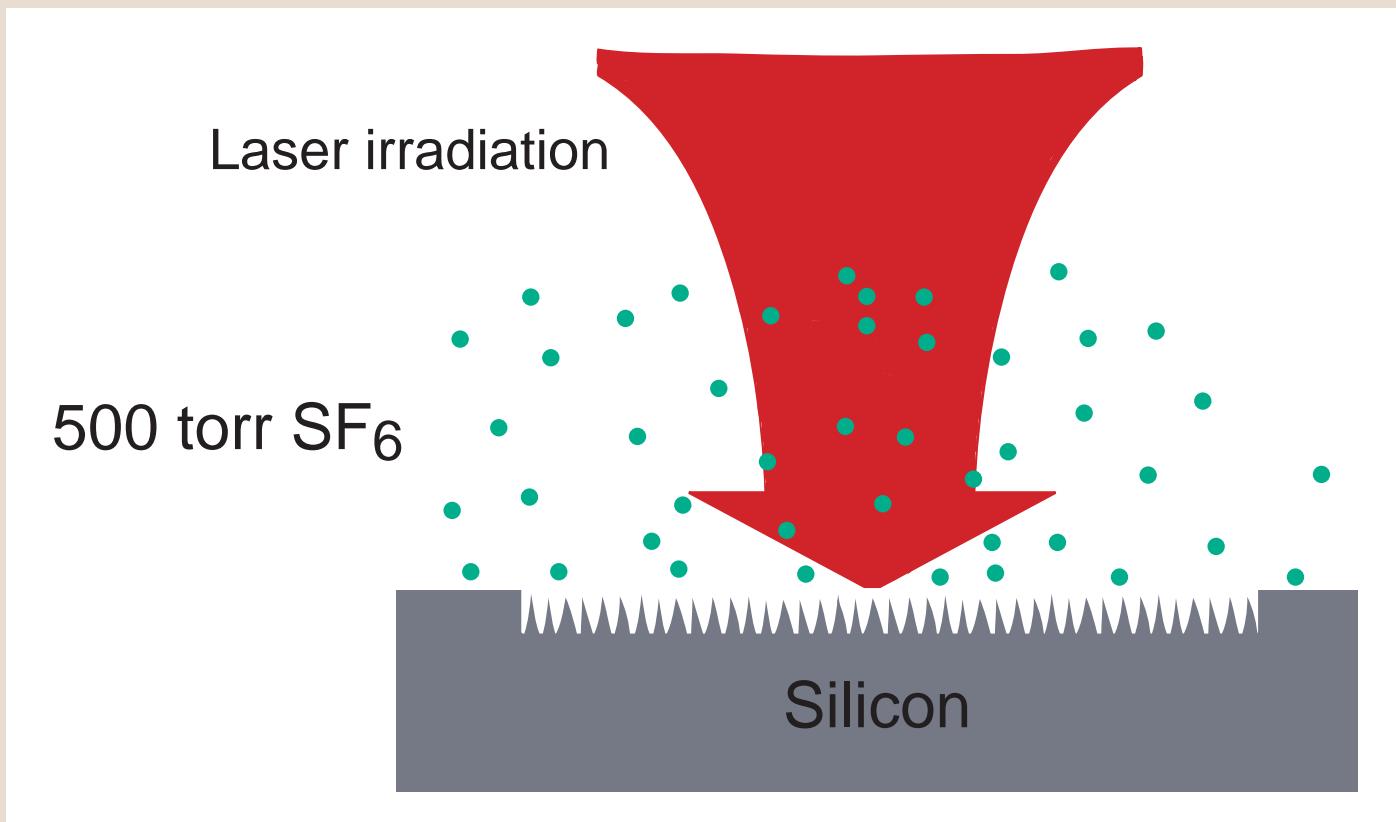
irradiate with 100 fs, 10 kJ/m² laser pulses in SF₆



Her et al., Appl. Phys. Lett. 73, 1673 (1998)

Microstructured silicon

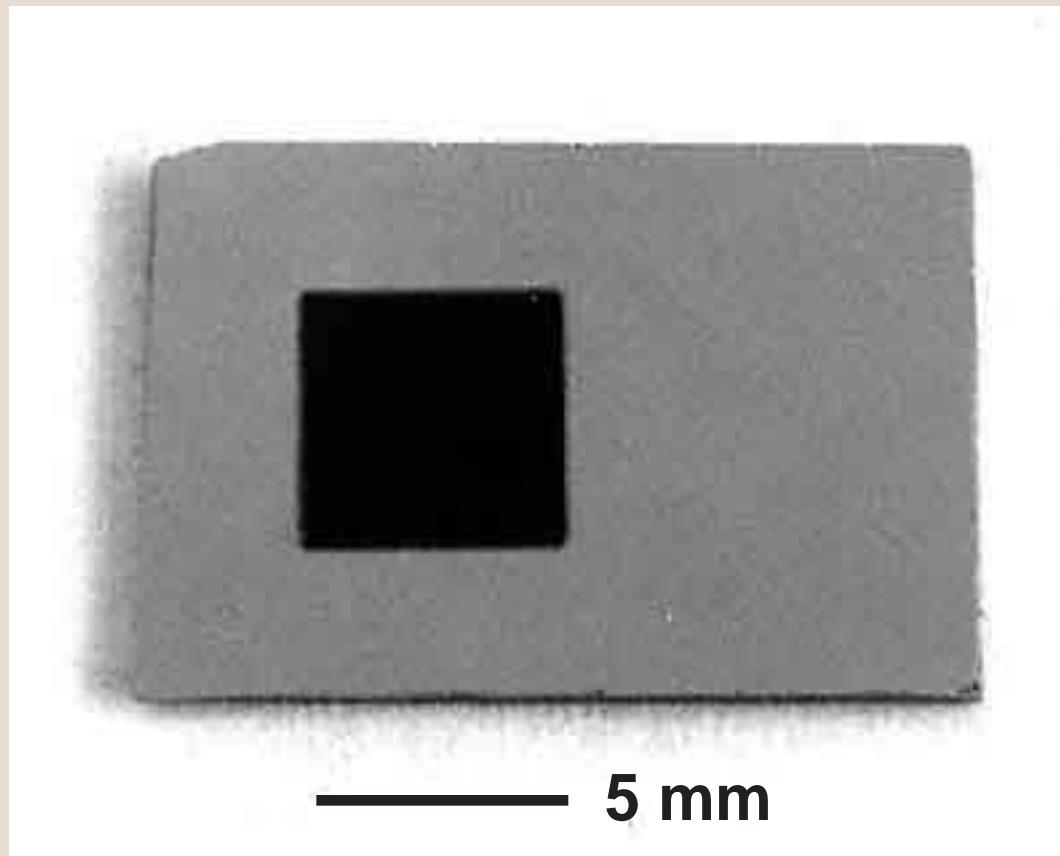
irradiate with 100 fs, 10 kJ/m² laser pulses in SF₆



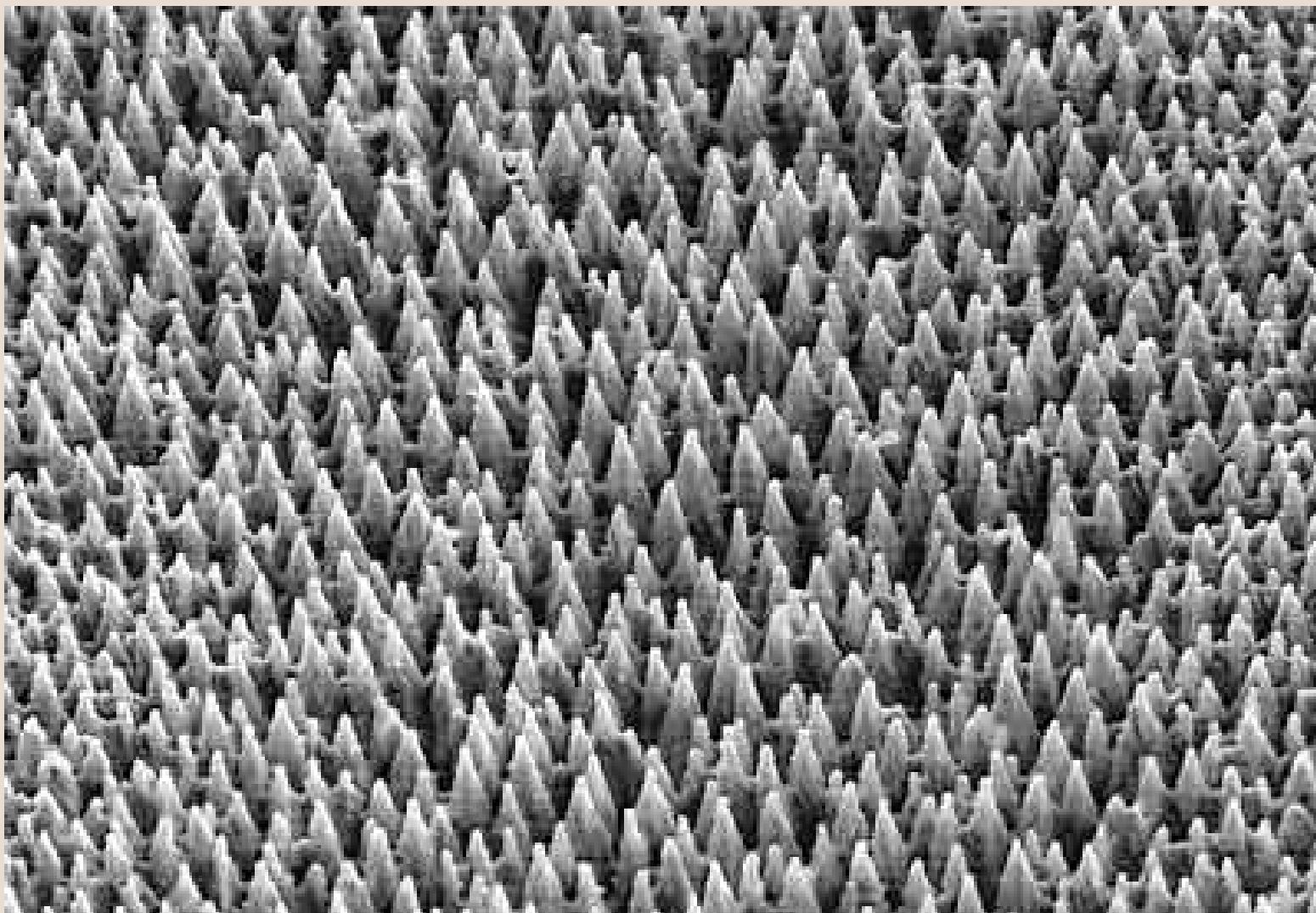
Her et al., *Appl. Phys. Lett.* 73, 1673 (1998)

Microstructured silicon

Irradiated silicon appears black

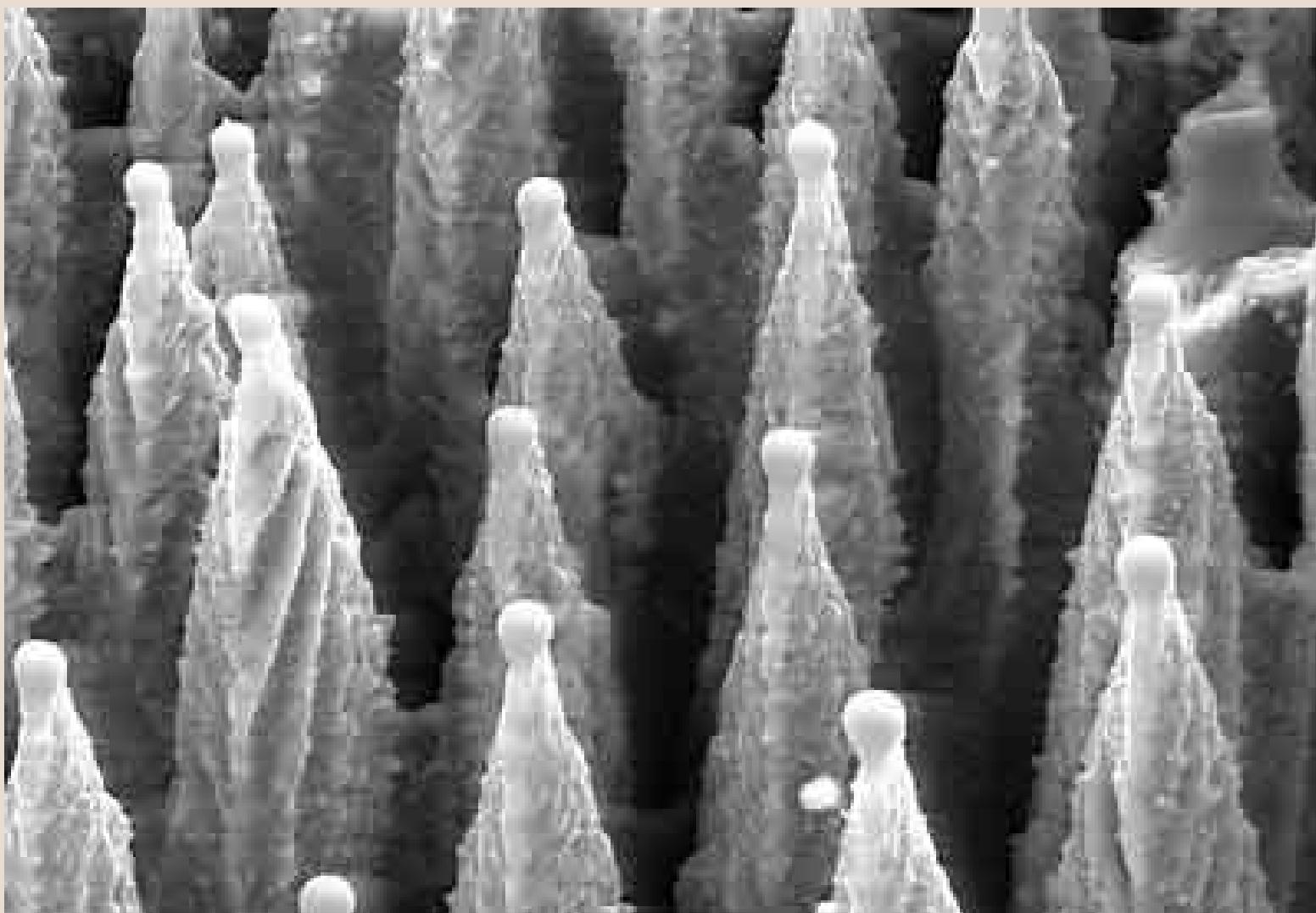


Microstructured silicon



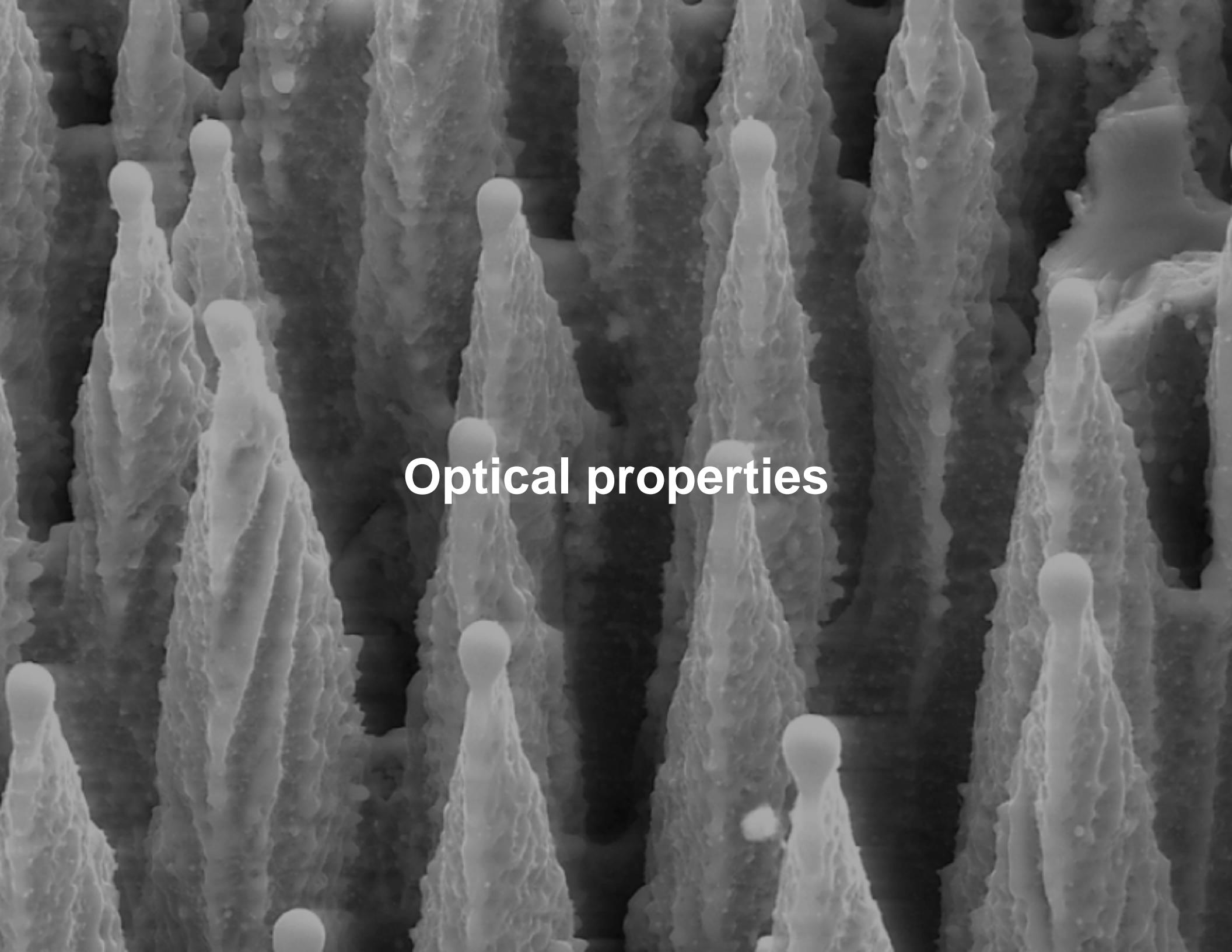
20 μm

Microstructured silicon



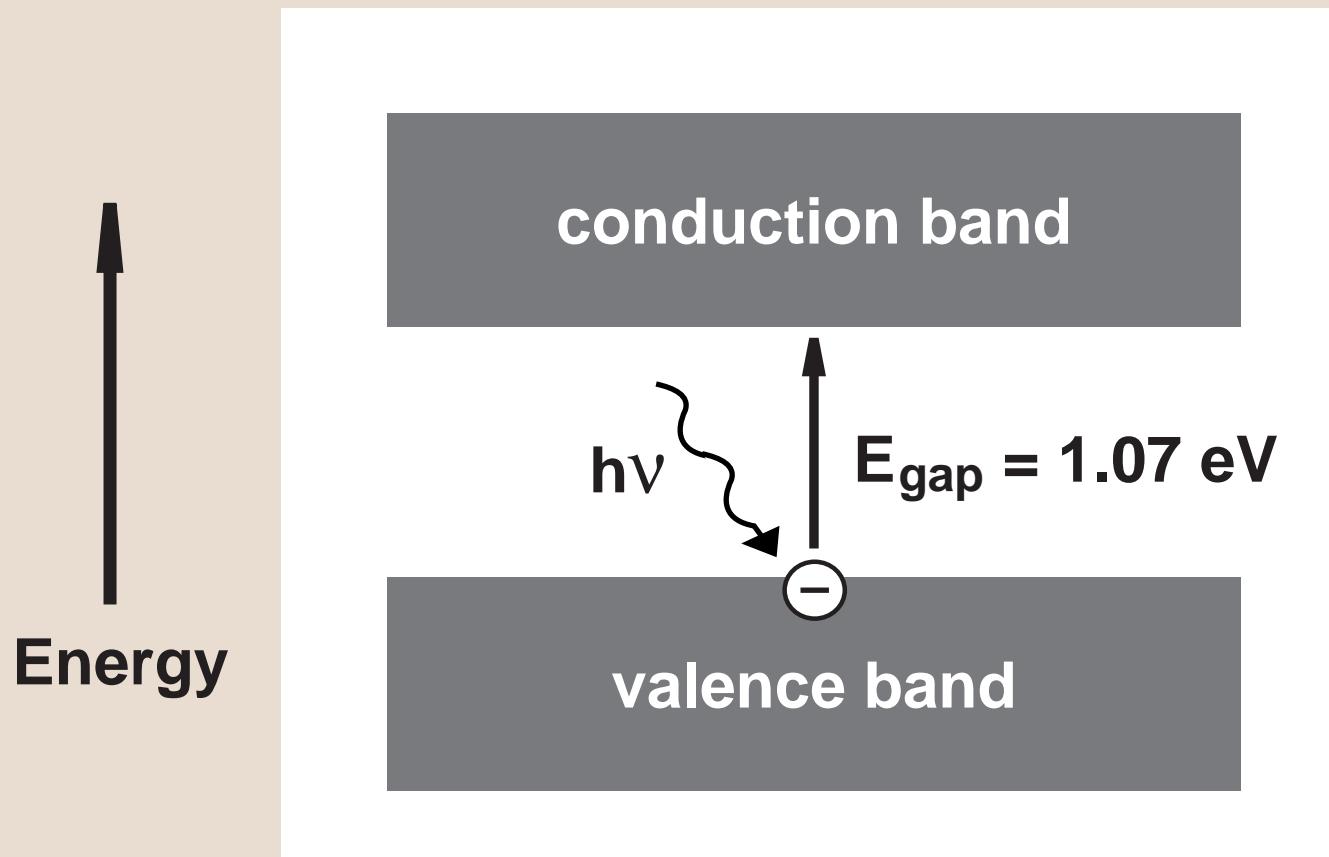
—

4 μm

A scanning electron micrograph (SEM) showing a complex, three-dimensional surface texture. The surface is covered in numerous vertical, elongated, and slightly wavy ridges that stand upright. Between these ridges are deep, narrow, and irregularly shaped horizontal grooves. The overall appearance is reminiscent of a microscopic view of a mineral surface or a highly processed material like carbon nanotubes.

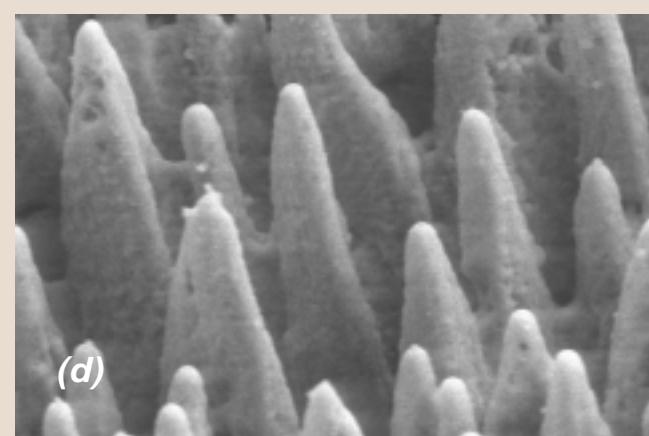
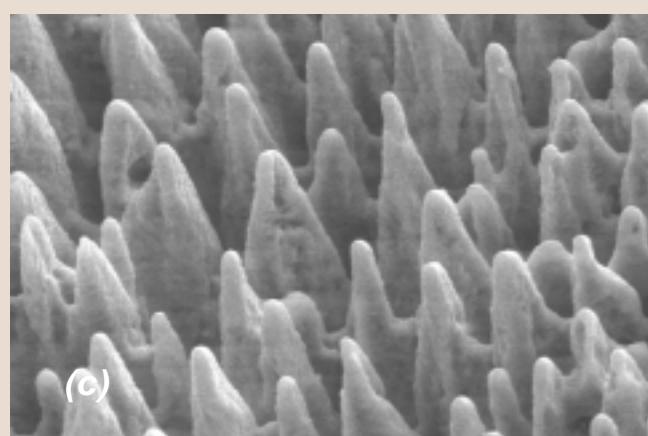
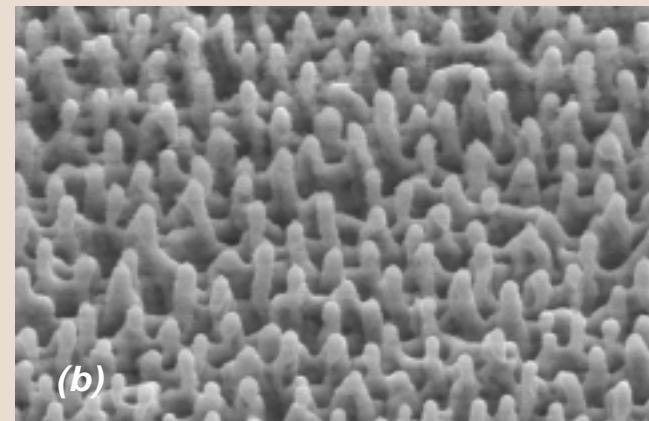
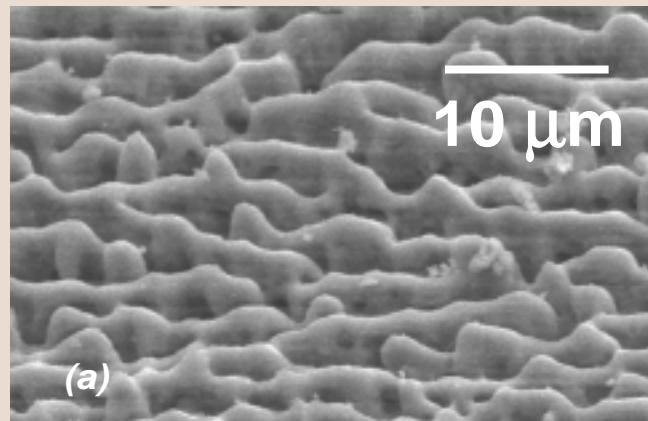
Optical properties

Ordinary silicon

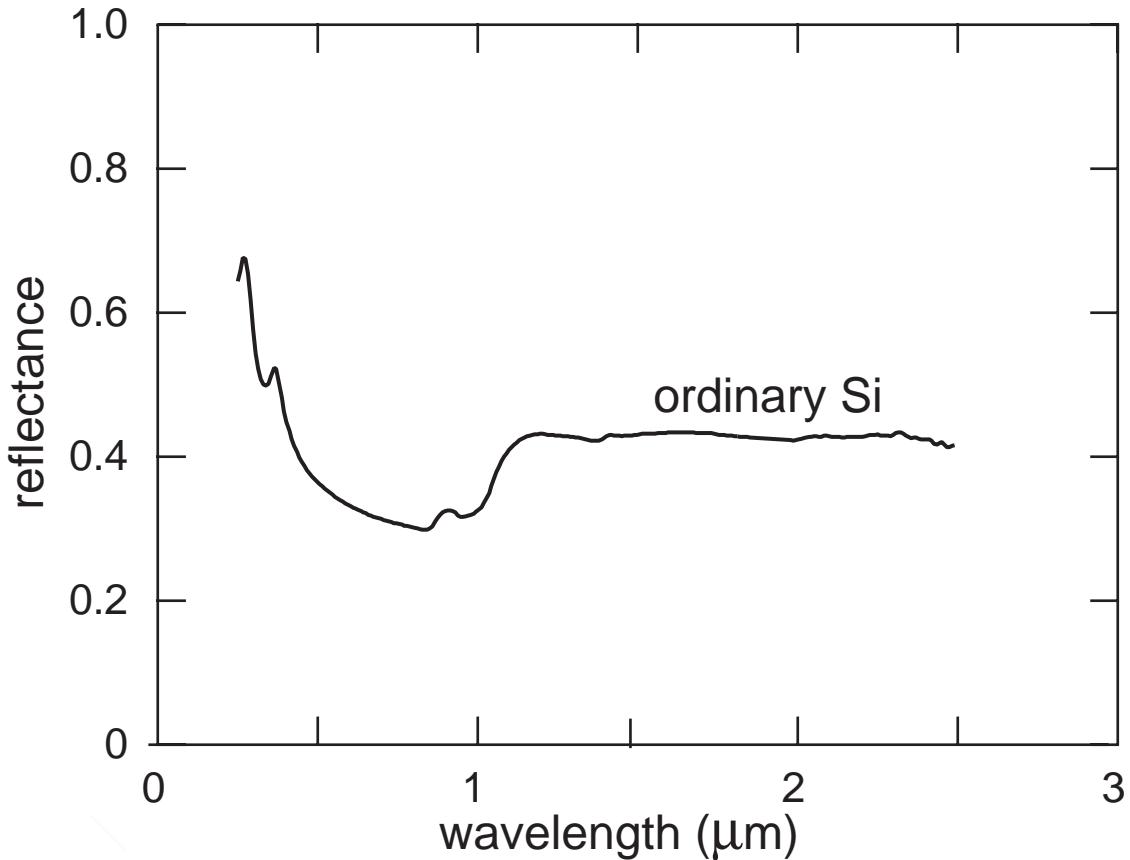


Only wavelengths $< 1.1 \mu\text{m}$ are absorbed

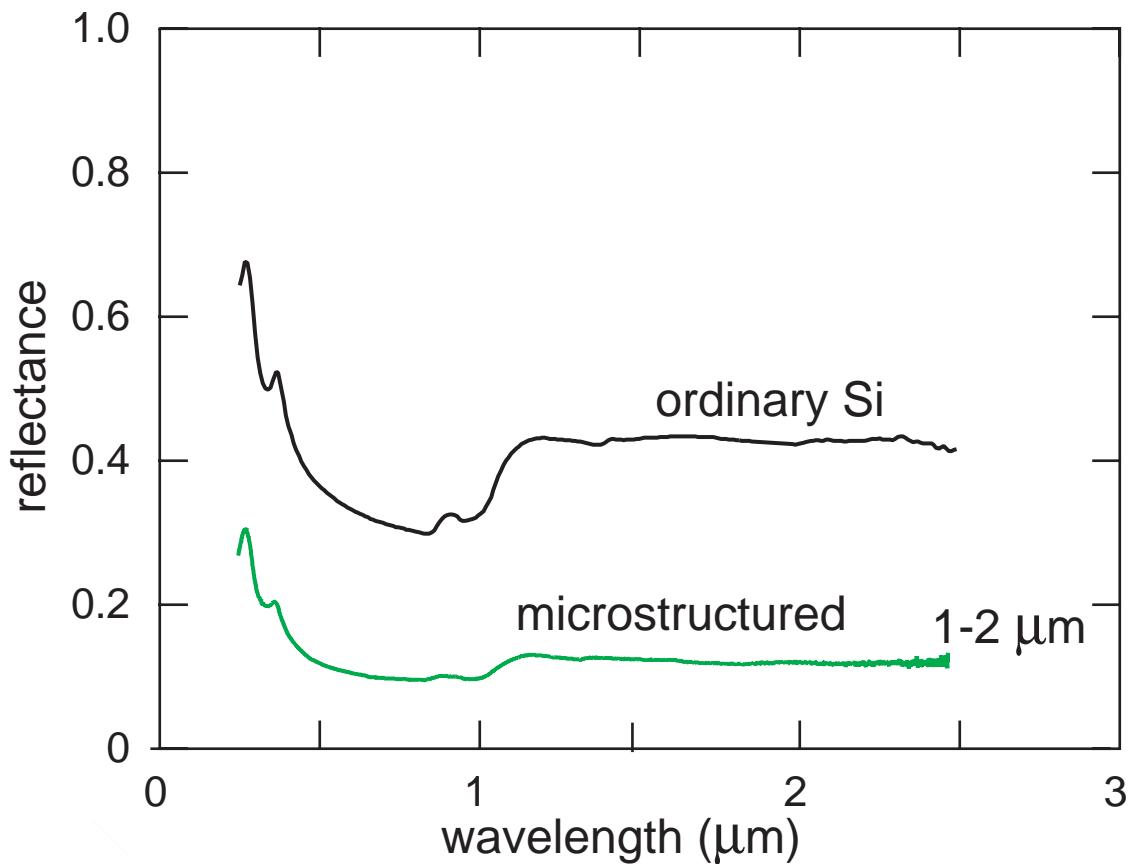
Microstructured silicon



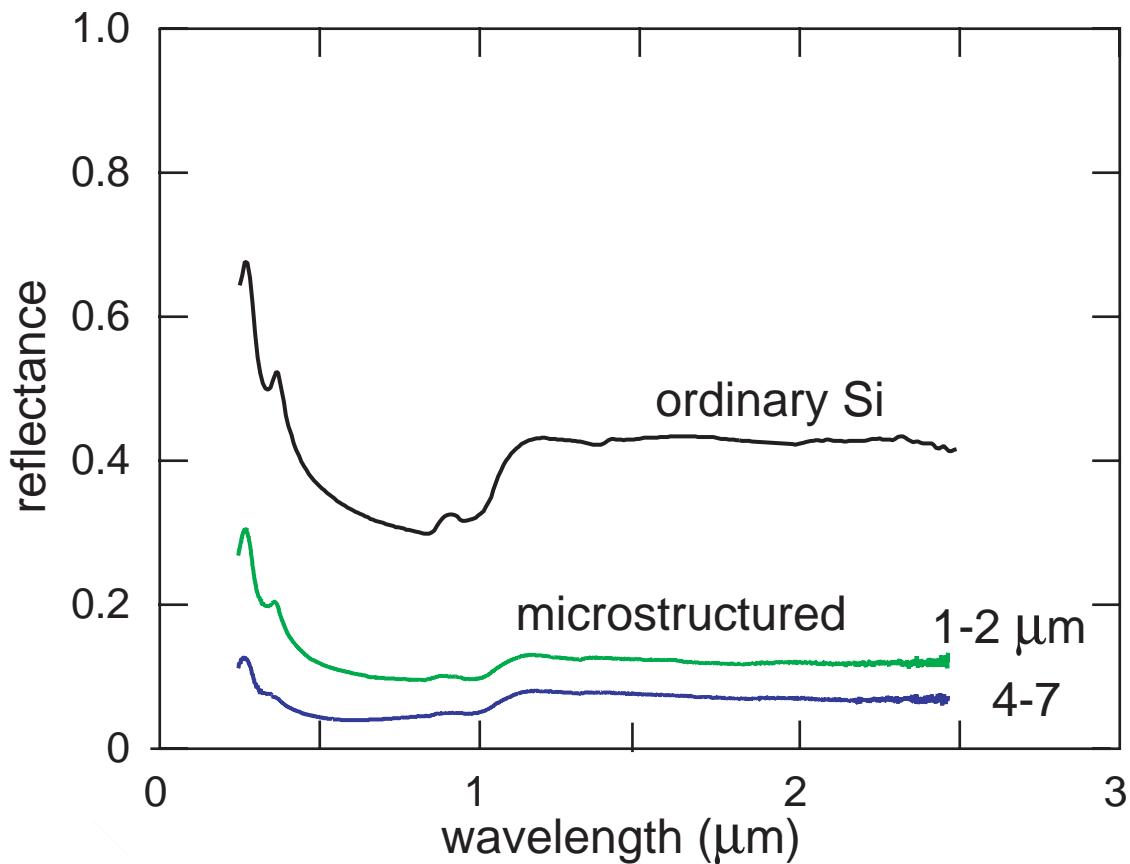
Total integrated reflectance



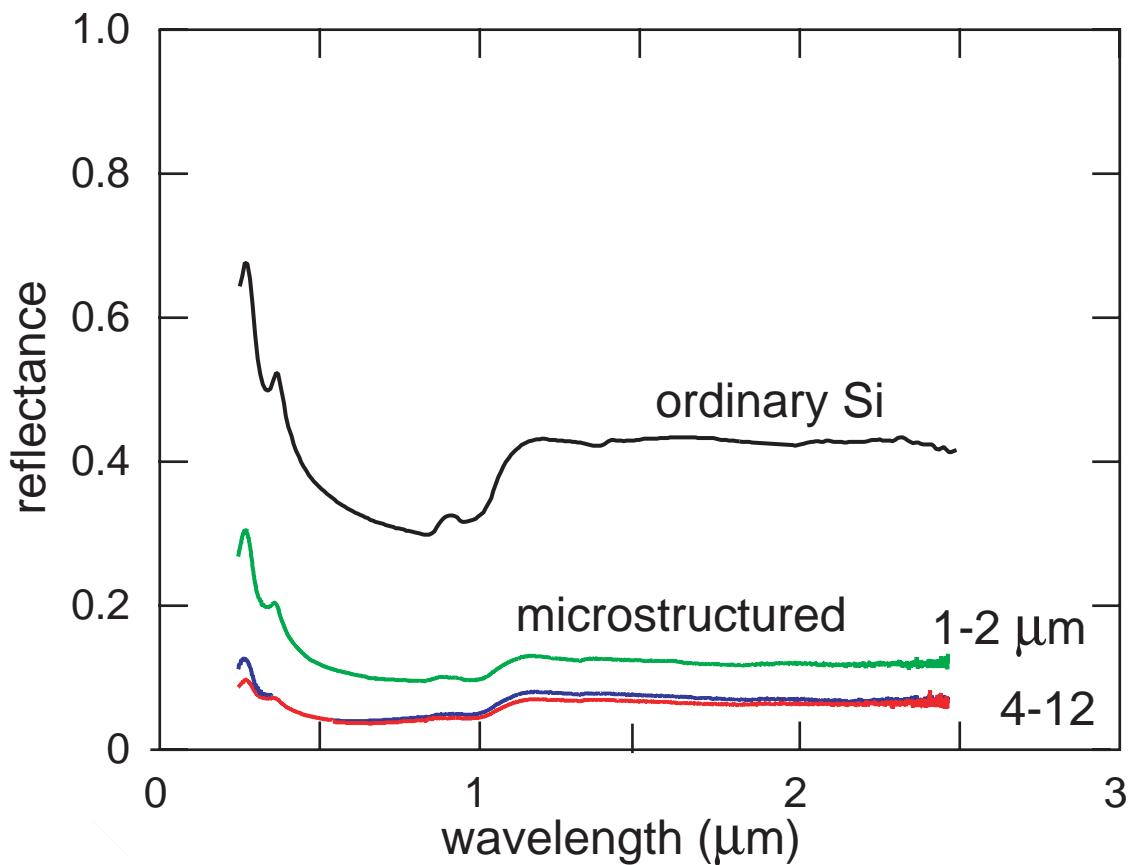
Total integrated reflectance



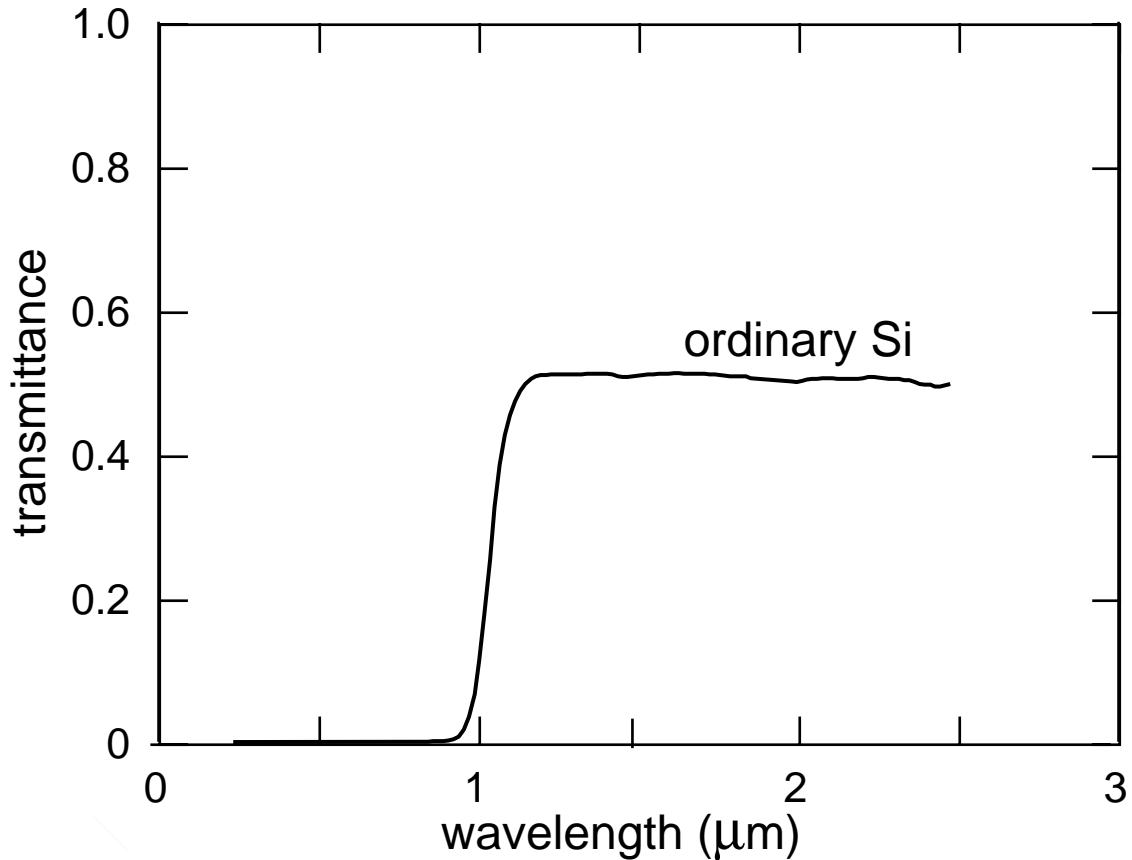
Total integrated reflectance



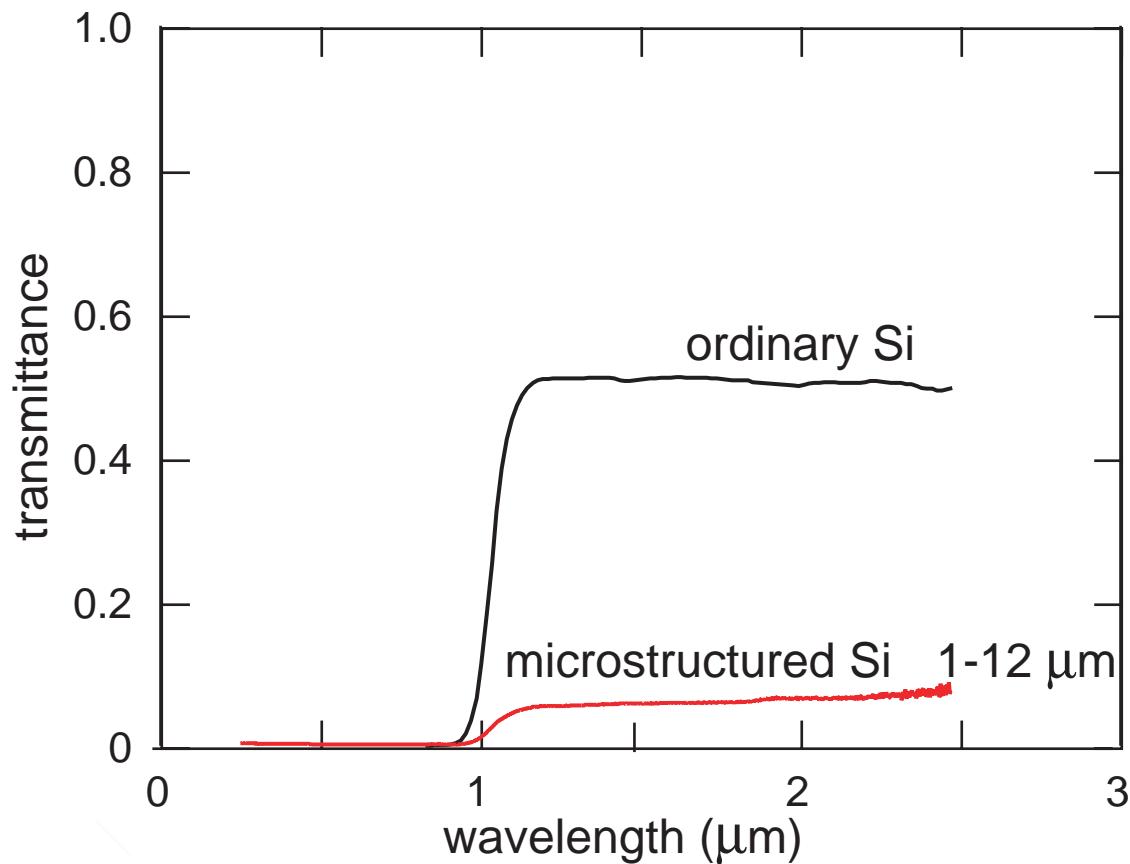
Total integrated reflectance



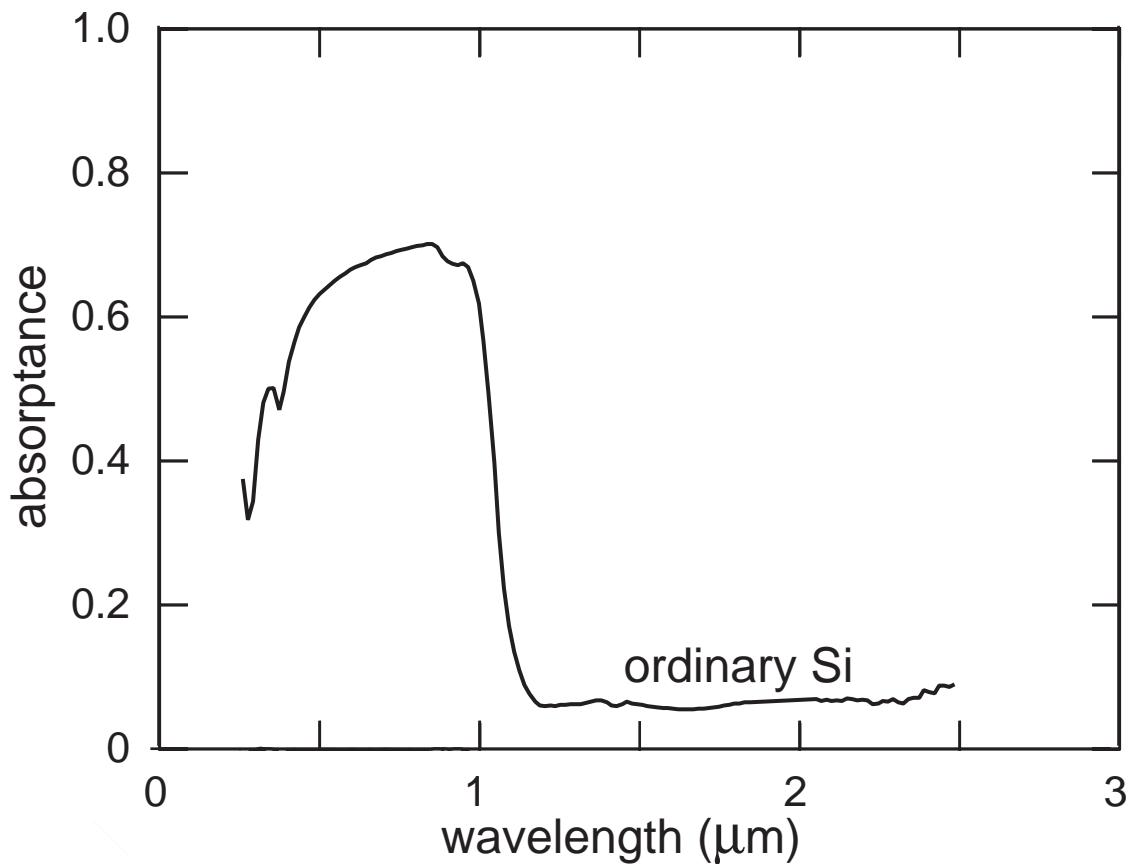
Total integrated transmittance



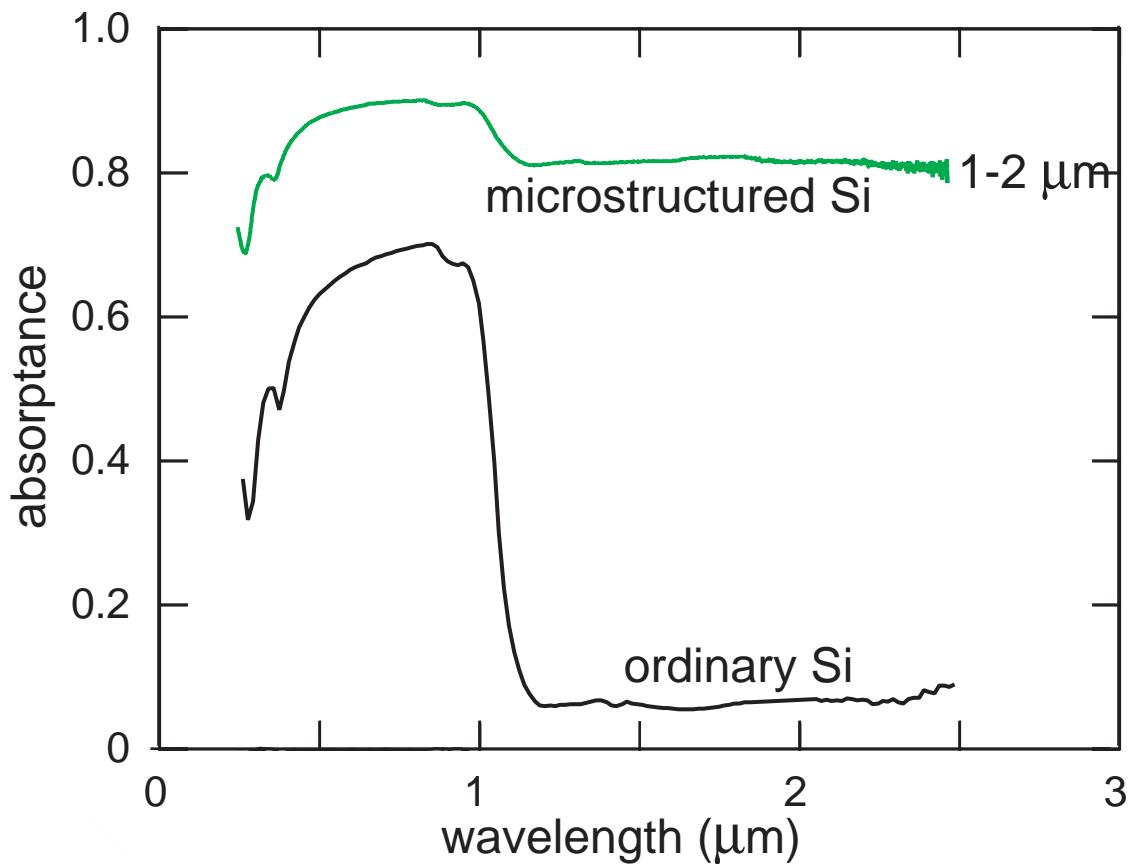
Total integrated transmittance



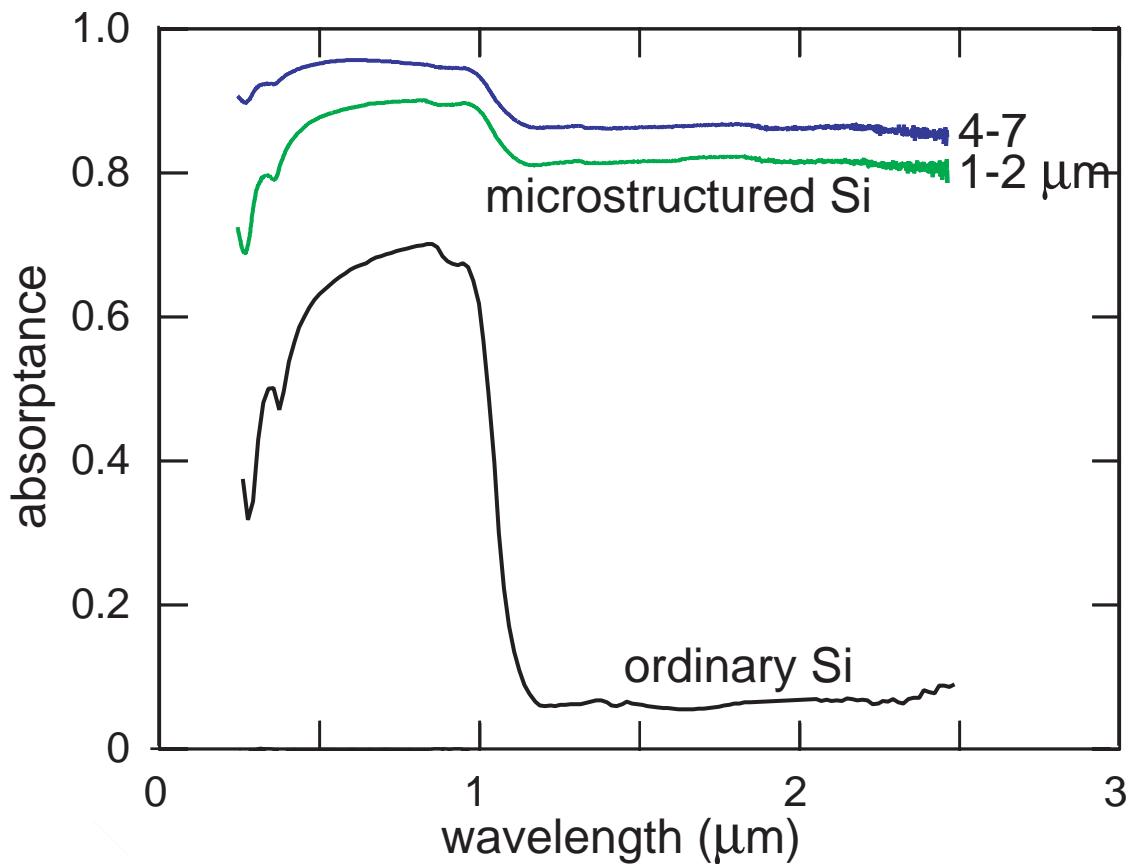
Total integrated absorptance



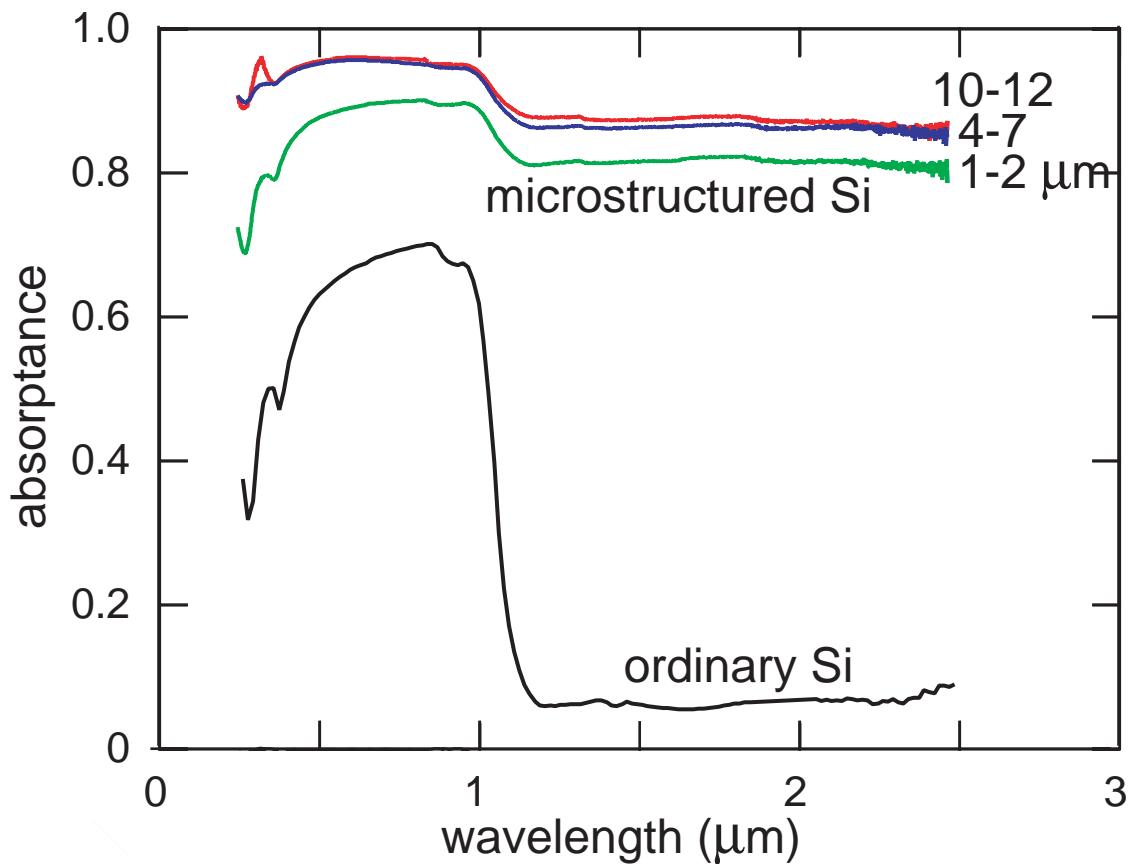
Total integrated absorptance



Total integrated absorptance



Total integrated absorptance

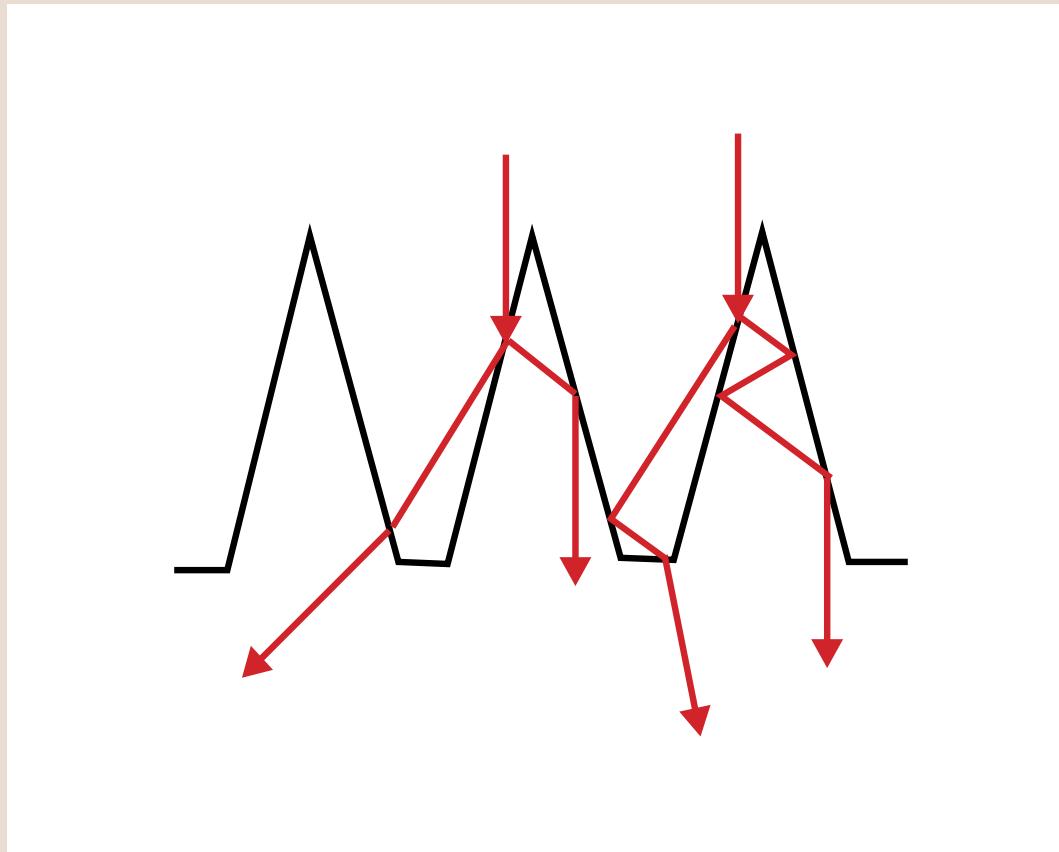


A scanning electron micrograph showing a dense array of finger-like intestinal villi. The villi are covered in numerous microvilli, which appear as small, rounded protrusions. The overall texture is highly detailed and three-dimensional.

What causes the absorption?

Why such high absorptance?

Microstructure shape can increase absorption



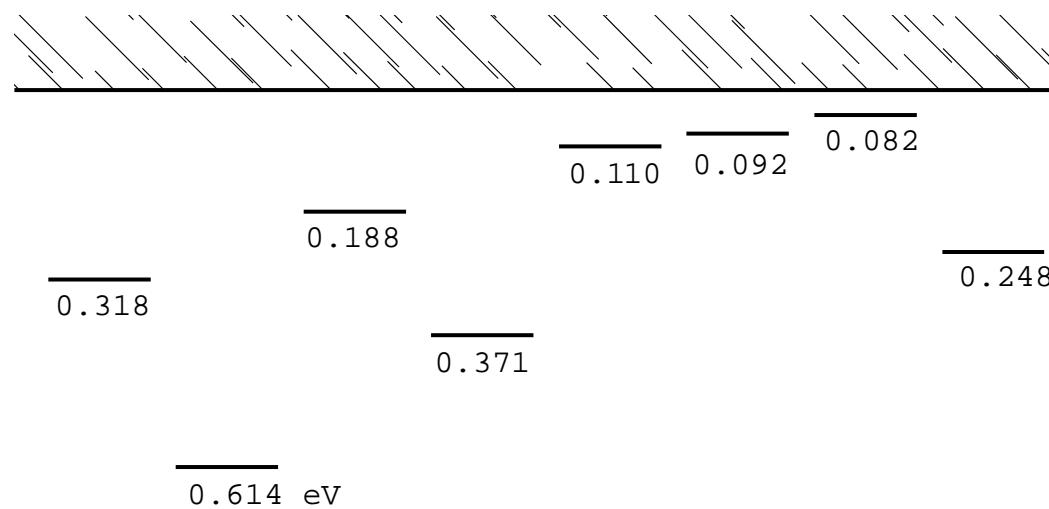
Why such high absorptance?

Secondary ion mass spectrometry

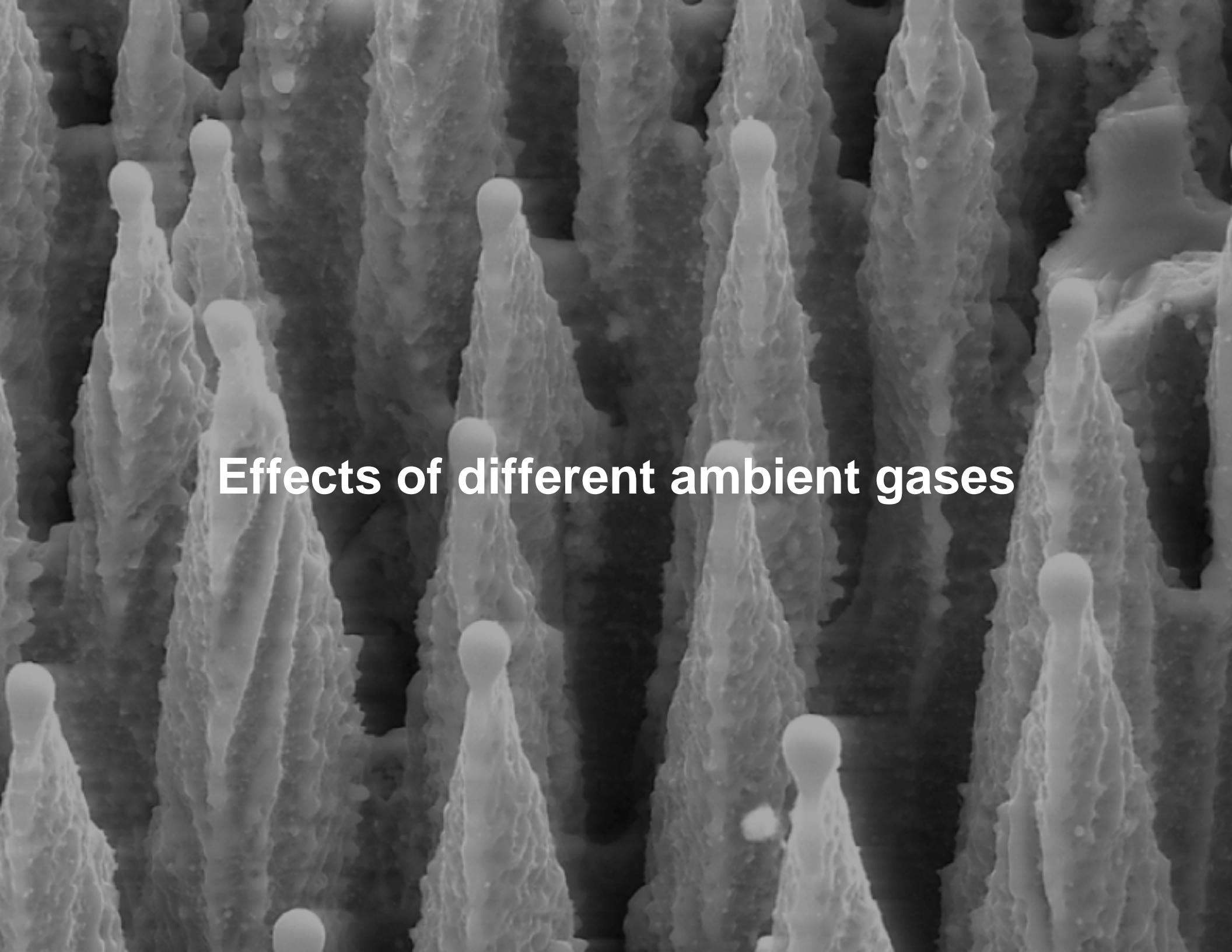
- High concentration of sulfur ($\sim 10^{20} \text{ cm}^{-3}$)
- Fluorine ($\sim 10^{17} \text{ cm}^{-3}$)

Why such high absorptance?

Sulfur adds states in Si band gap

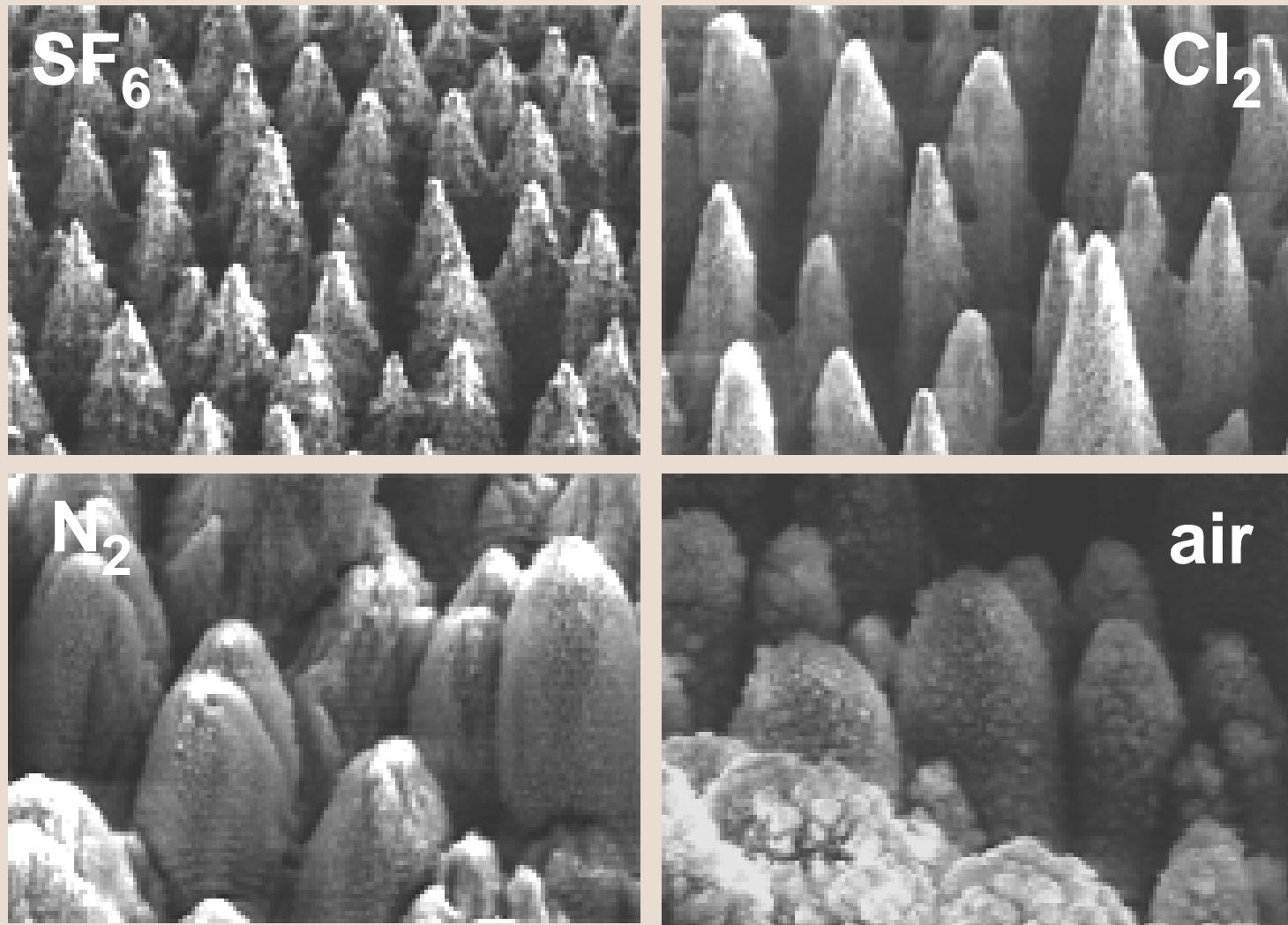


States in gap allow subgap absorption

A scanning electron micrograph (SEM) showing a complex, three-dimensional surface structure. The surface is covered in numerous vertical, finger-like projections of varying heights and widths. Between these projections, there are horizontal, wavy grooves that run across the entire width of the image. The overall texture is highly detailed and organic in appearance.

Effects of different ambient gases

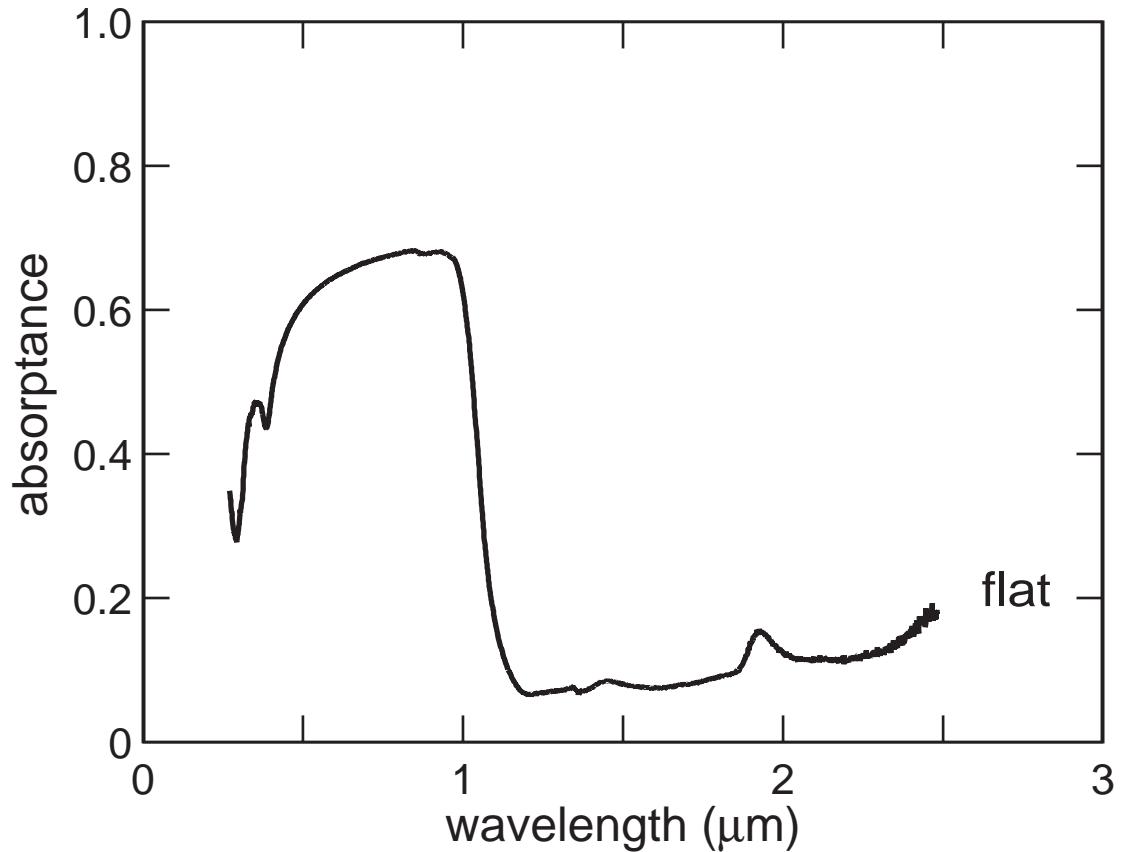
Different ambient gases



— $10 \mu\text{m}$

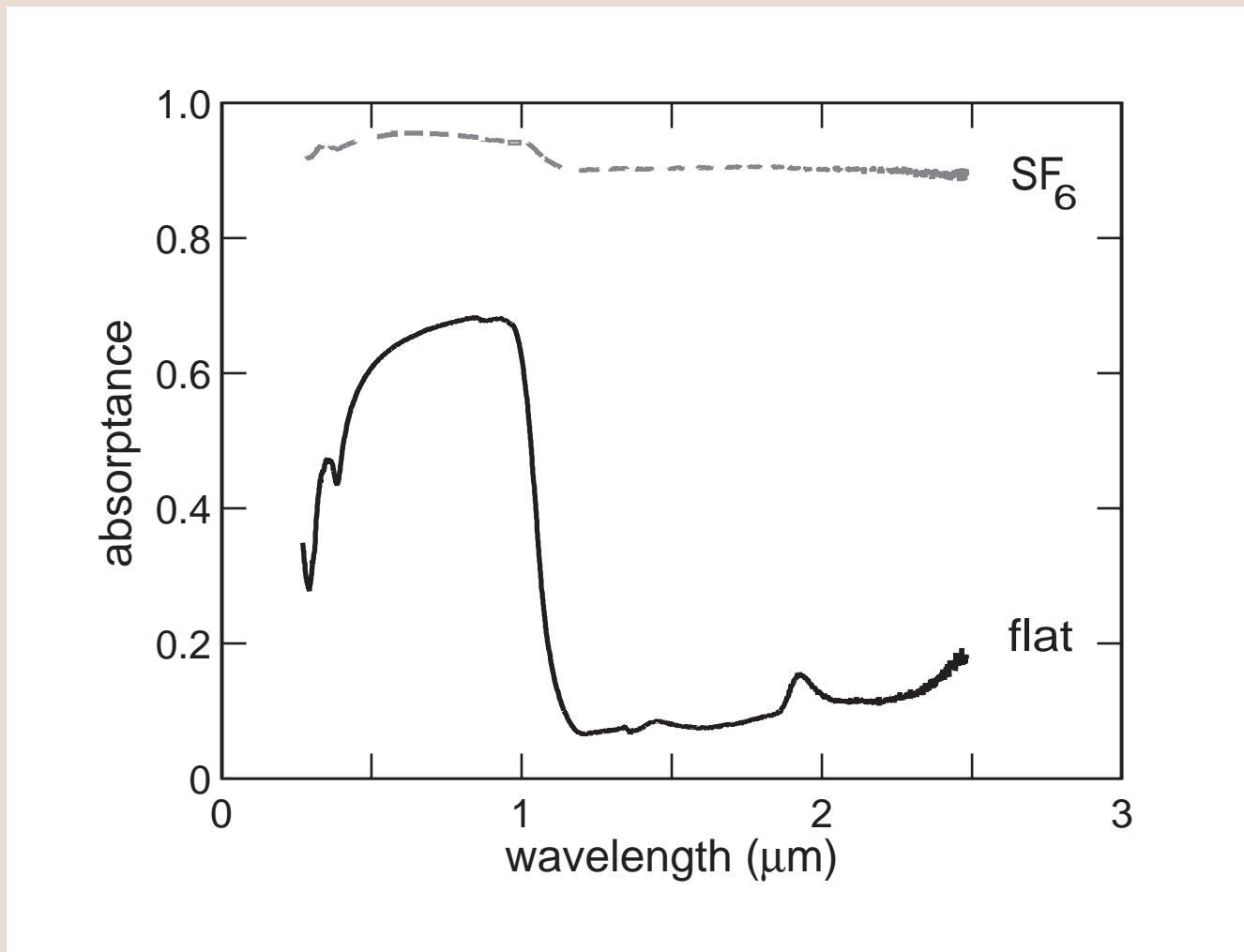
Different ambient gases

Absorptance



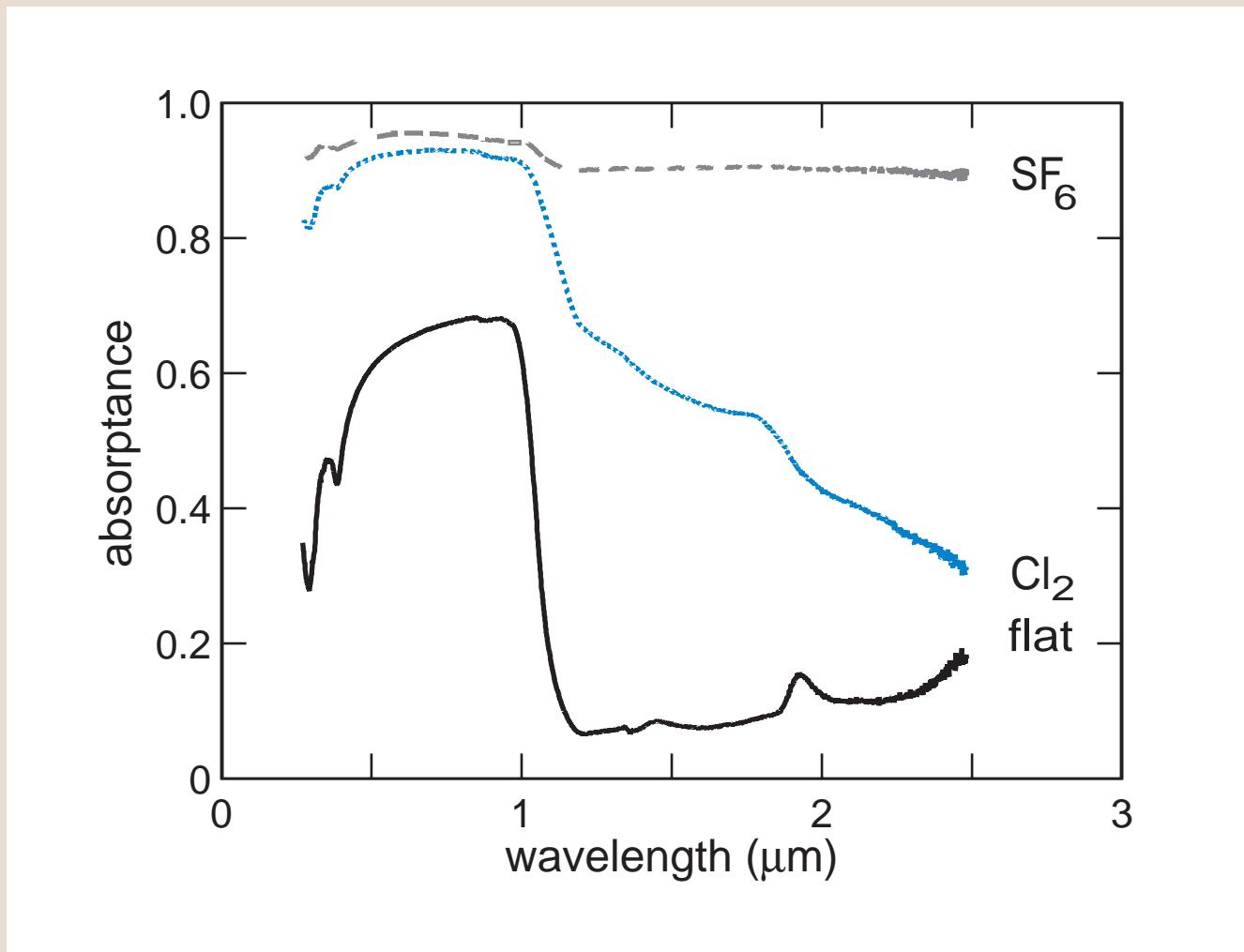
Different ambient gases

Absorptance



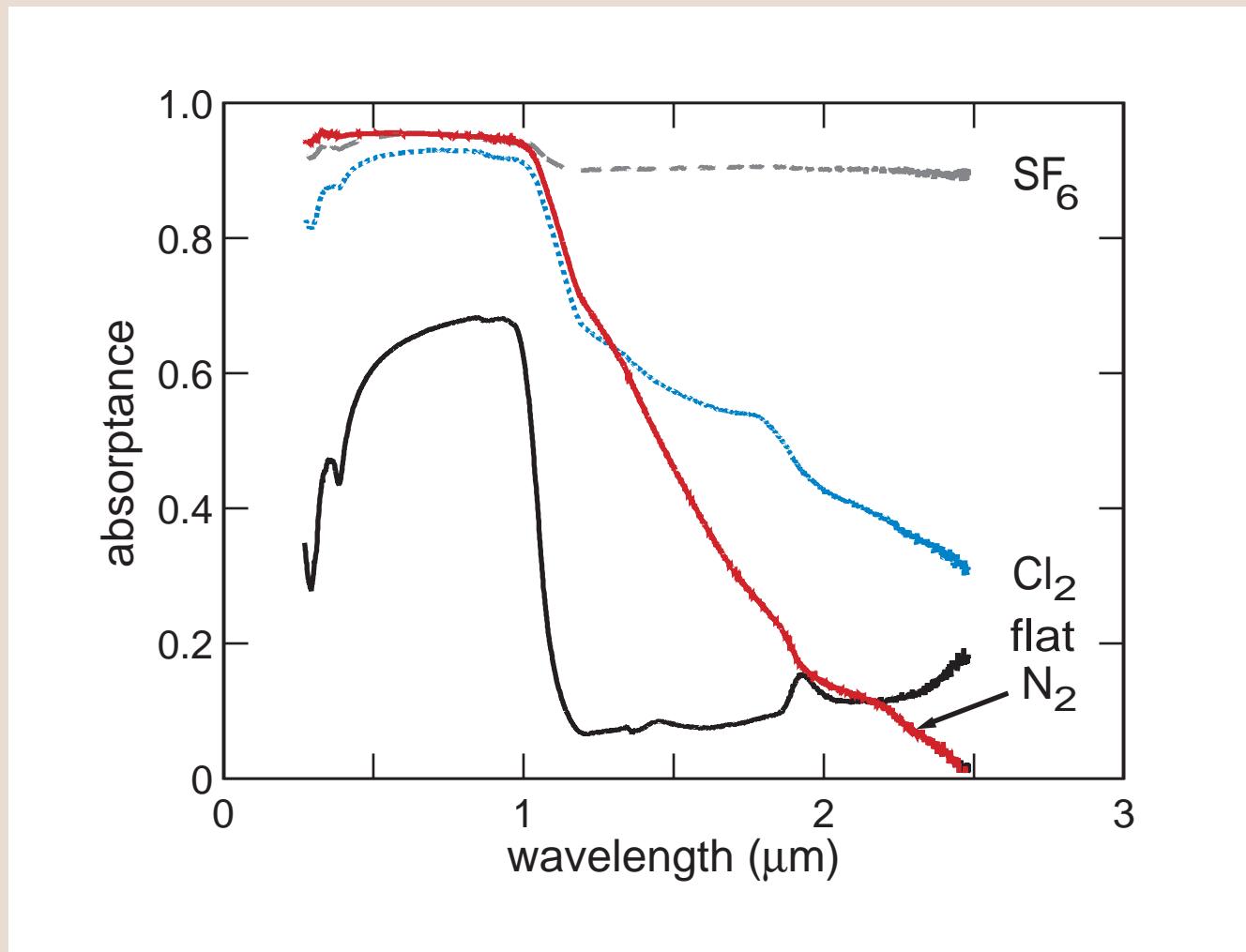
Different ambient gases

Absorptance



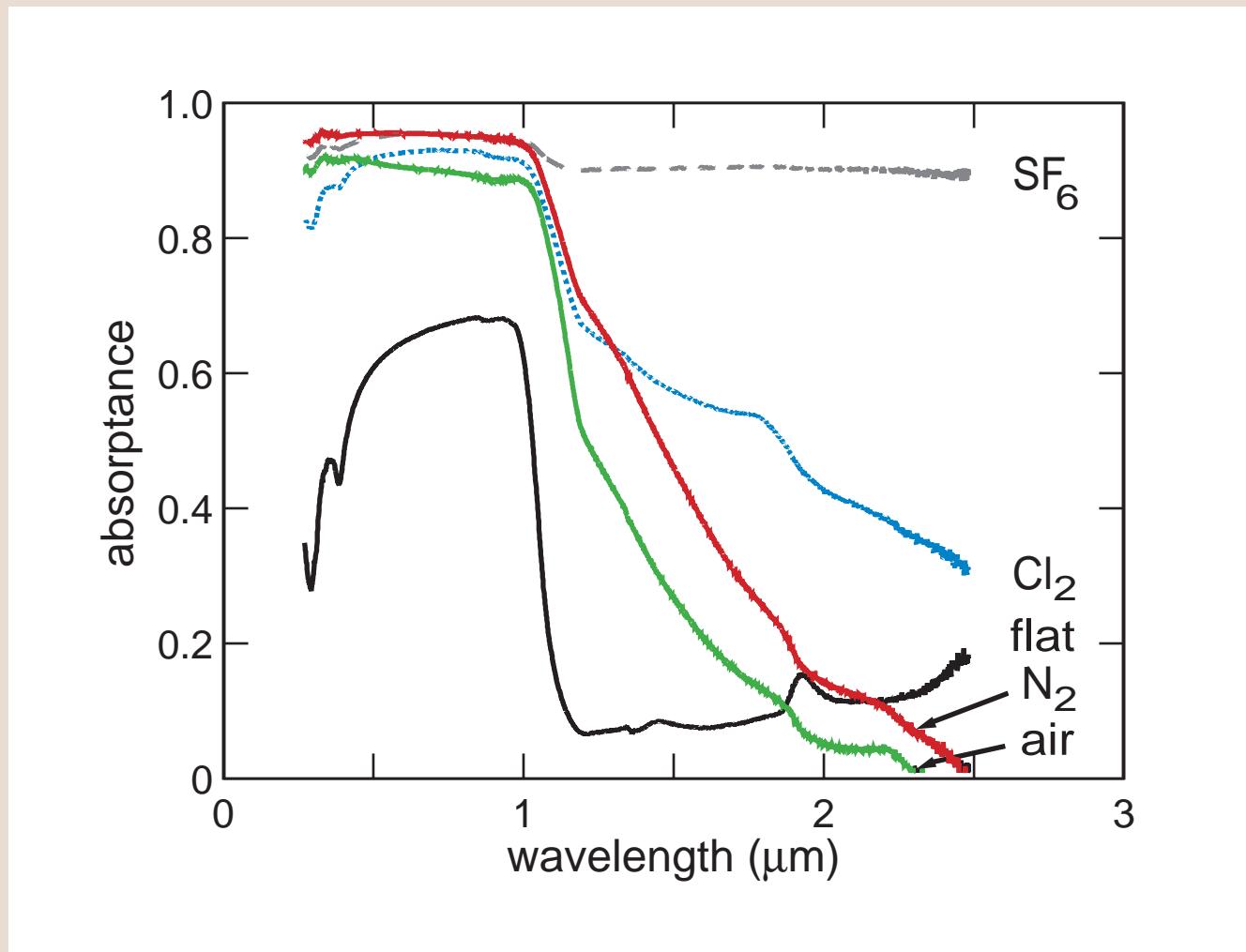
Different ambient gases

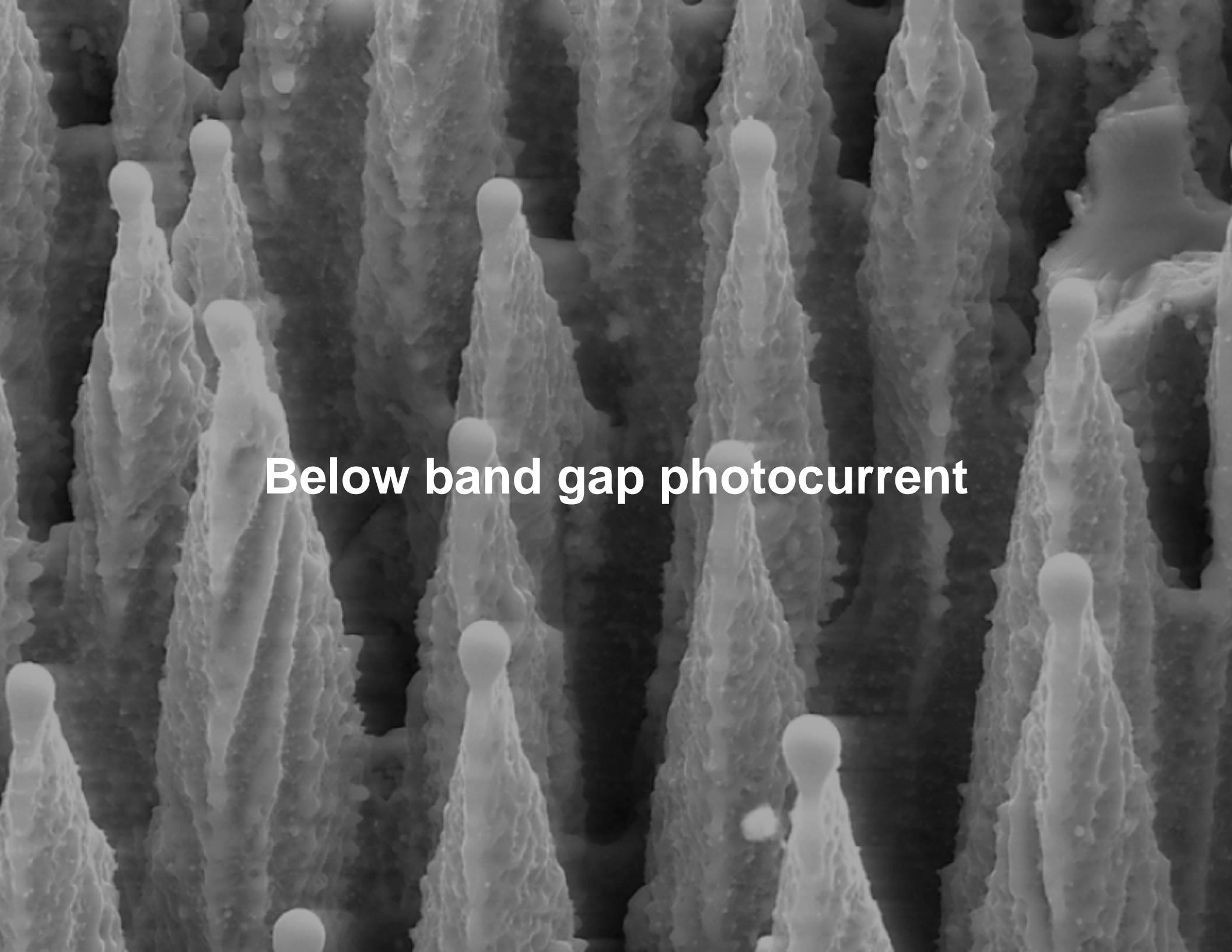
Absorptance



Different ambient gases

Absorptance

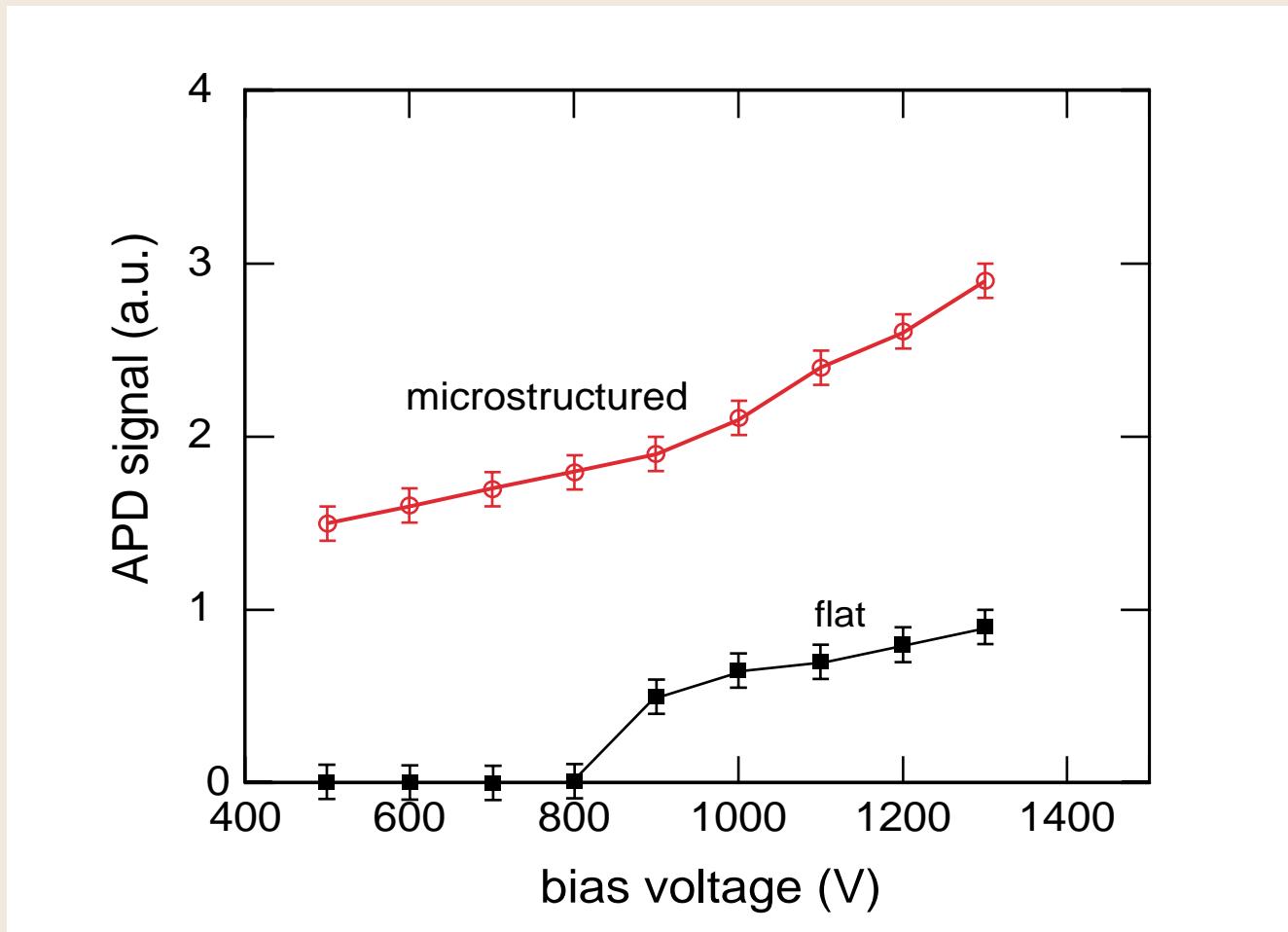


A scanning electron micrograph (SEM) showing a complex, three-dimensional surface morphology. The surface is covered in numerous vertical, finger-like protrusions of varying heights. Between these protrusions, there are horizontal, wavy grooves that create a stepped or terraced appearance. The overall texture is highly irregular and organic in nature.

Below band gap photocurrent

Below band gap photocurrent

Avalanche photodiode response at 1.3 μm



Conclusions

- Up to 90% infrared absorption
→ increased infrared photocurrent
- Absorption dependent on ambient gas
- Applications in infrared photodetectors,
silicon solar cells, other possible devices

Acknowledgements

**R.M. Farrell, P. Gothoskar, A. Karger,
Radiation Monitoring Devices, Watertown, MA**

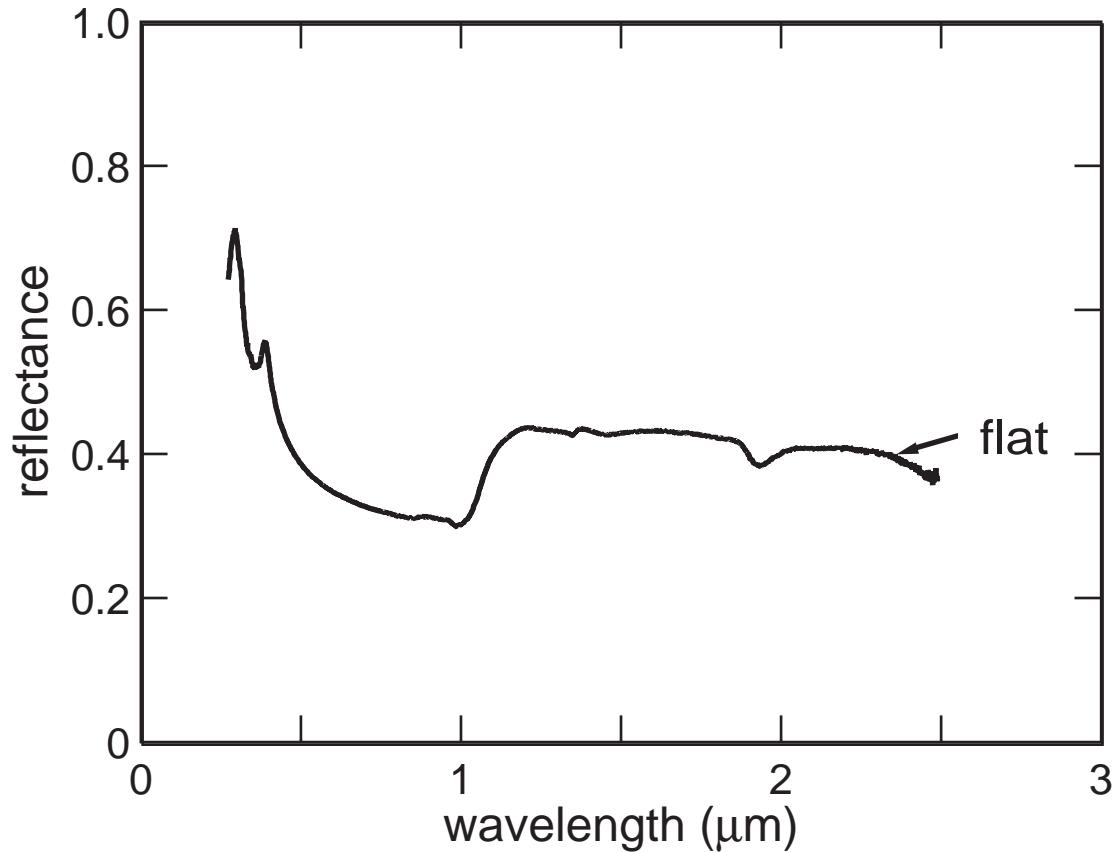
Li Zhao, Fudan University, Shanghai, China

funding: NSF, ARO

**for more information, see:
Appl. Phys. Lett. 78, 1850 (2001).
<http://mazur-www.harvard.edu>**

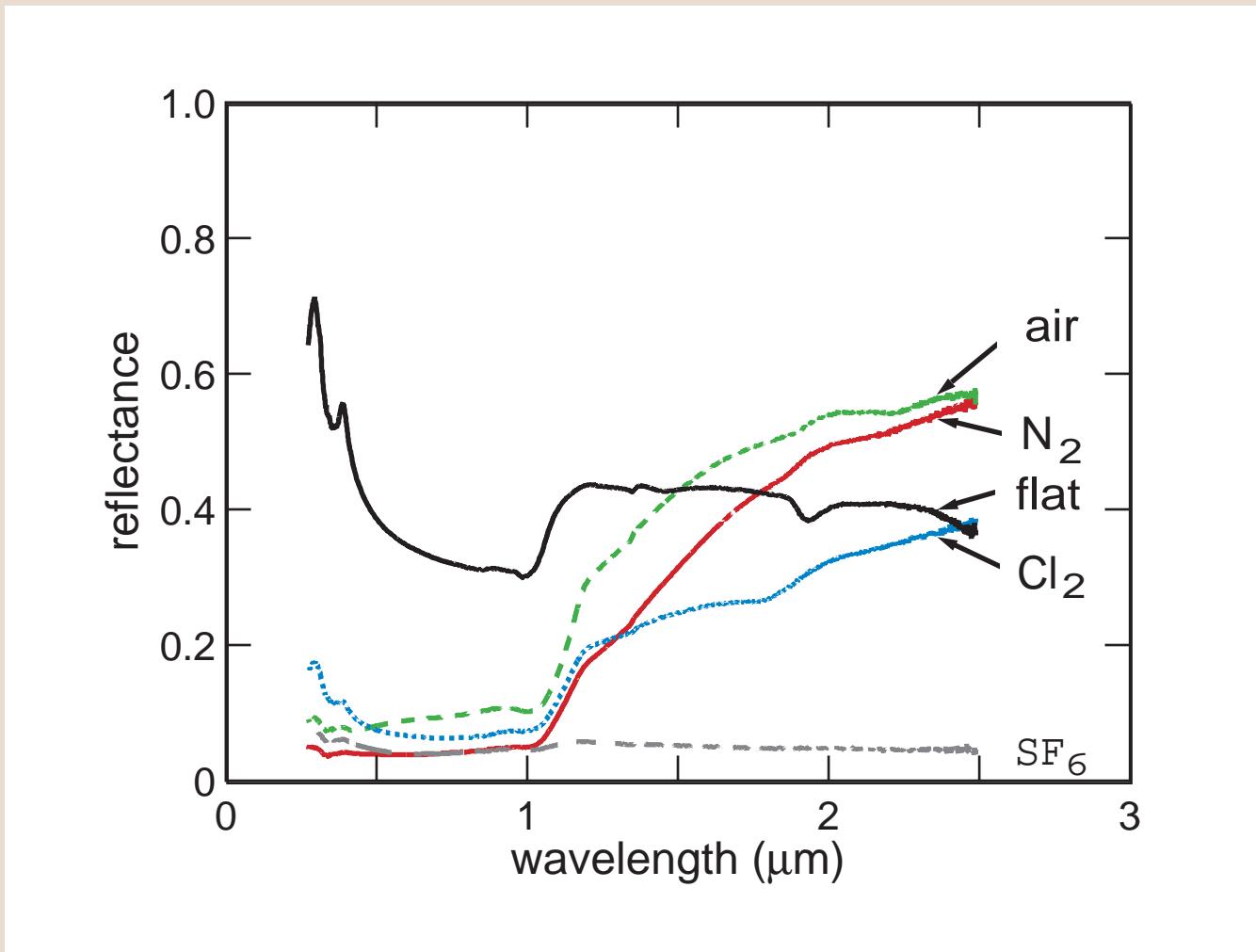
Different ambient gases

Reflectance

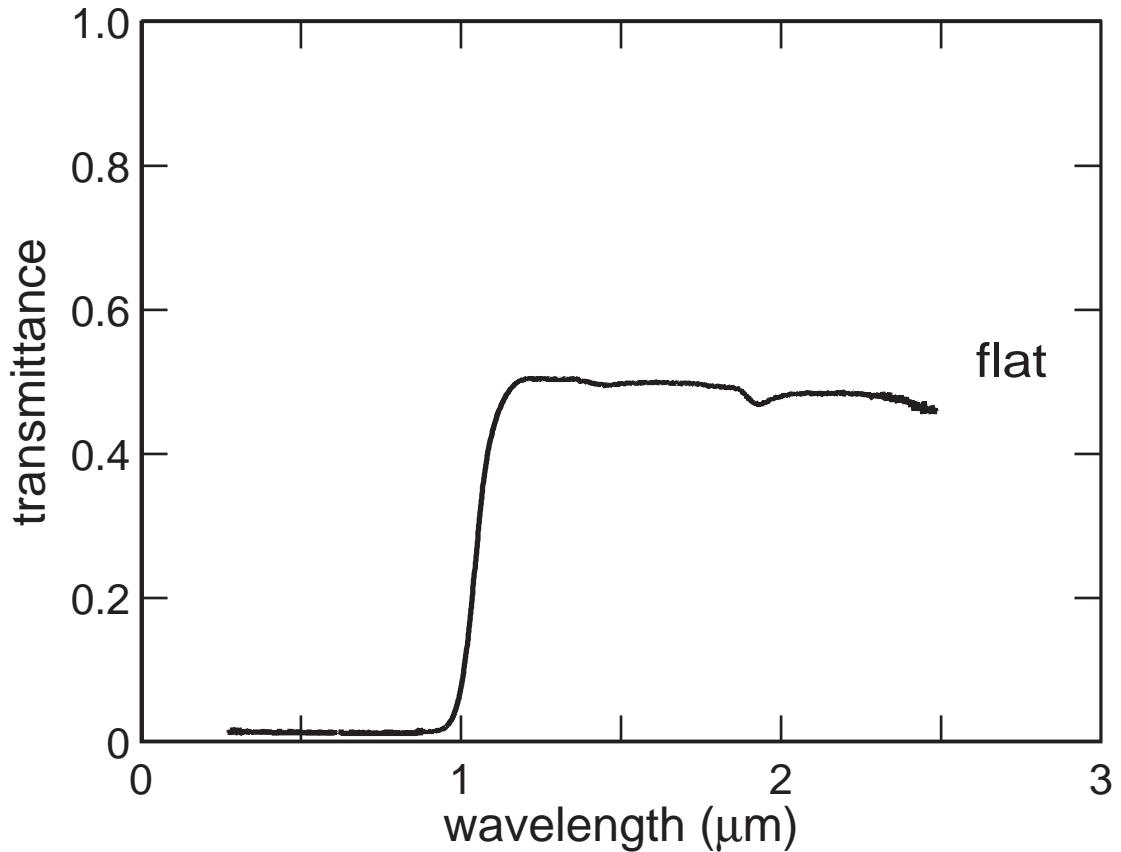


Different ambient gases

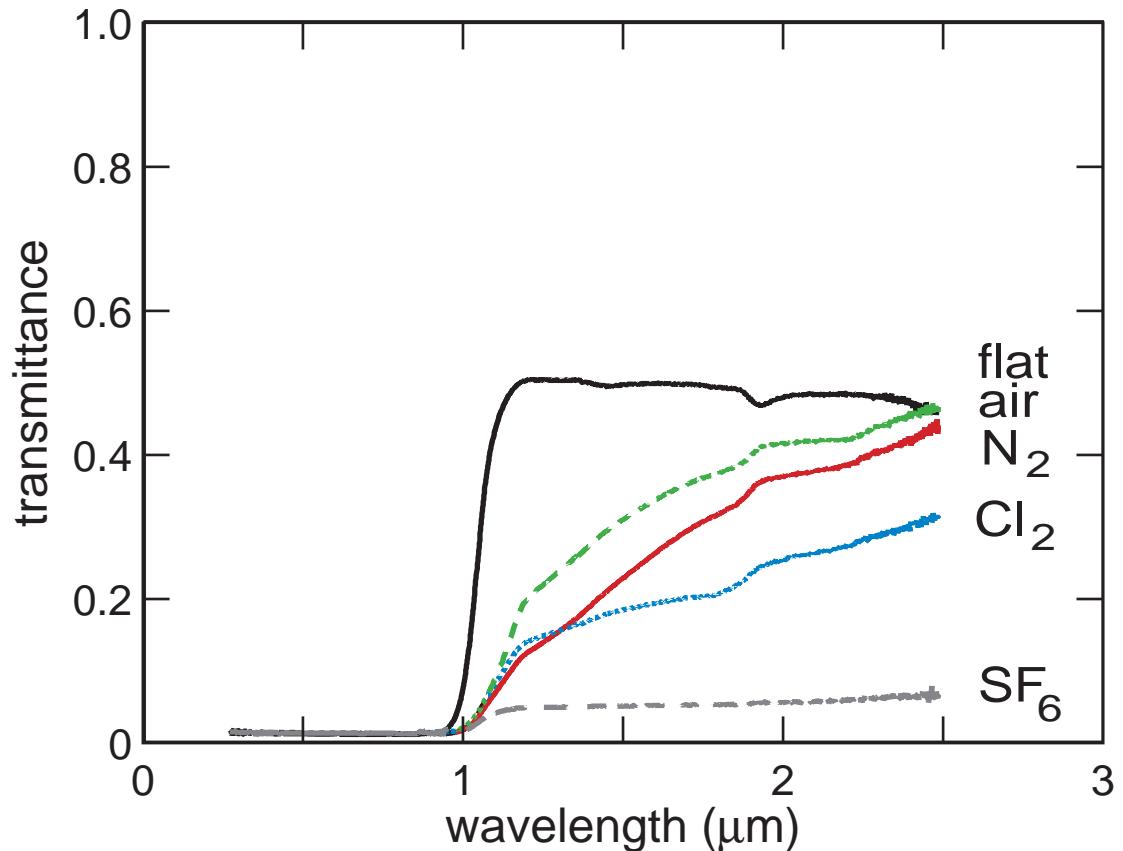
Reflectance



Transmittance

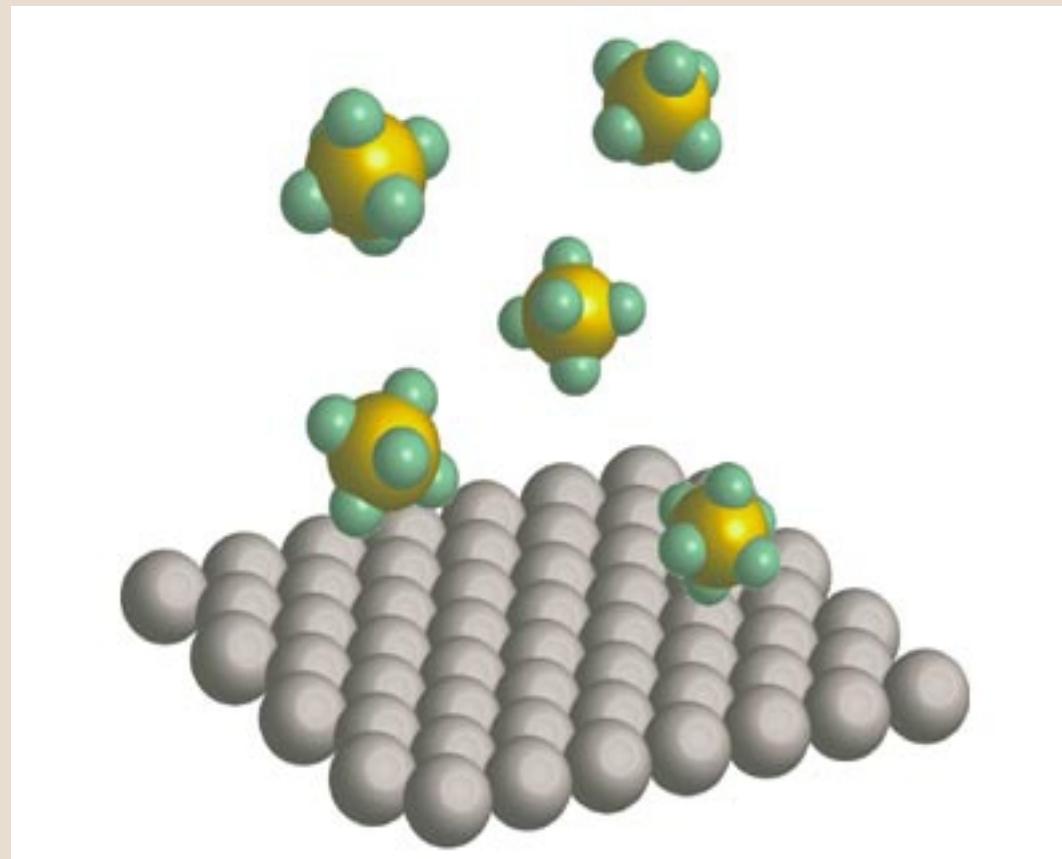


Transmittance



Microstructured silicon

irradiate with 100 fs, 10 kJ/m² laser pulses in SF₆



Her et al., *Appl. Phys. Lett.* **73**, 1673 (1998)