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

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Fabrication of conical microstructures

Optical properties of structures made in SF$_6$
- high absorptance
- explanations

Structures made in other ambient gases
- morphology
- optical and optoelectronic properties
Si (111) placed in background of SF$_6$

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

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

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

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Her et al., Appl. Phys. Lett. 73, 1673 (1998)
Irradiated silicon appears black
Microstructured silicon

20 µm
Microstructured silicon

4 \mu m
Optical properties
Ordinary silicon

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

\[ h\nu = E_{\text{gap}} = 1.07 \text{ eV} \]
Microstructured silicon

- (a) 1-2 \( \mu \text{m} \)
- (b) 4-7 \( \mu \text{m} \)
- (c) 10-12 \( \mu \text{m} \)
- (d) 18-20 \( \mu \text{m} \)
Total integrated reflectance

![Graph showing total integrated reflectance versus wavelength (µm). The reflectance is plotted on the y-axis ranging from 0 to 1 and the wavelength is plotted on the x-axis ranging from 0 to 3. The graph includes a curve labeled ordinary Si.](Image)
Microstructured silicon

Total integrated reflectance

![Graph showing total integrated reflectance for ordinary Si and microstructured Si across different wavelengths.](image)
Total integrated reflectance

- Microstructured silicon

Graph showing the total integrated reflectance against wavelength (μm) with different lines representing ordinary Si and microstructured silicon in wavelength ranges 1-2 μm and 4-7 μm.
Total integrated reflectance

- Microstructured silicon
- Ordinary Si
- Microstructured
Microstructured silicon

Total integrated transmittance

![Graph showing total integrated transmittance](attachment:image.png)

- Ordinary Si
Microstructured silicon

Total integrated transmittance

![Graph showing the total integrated transmittance of ordinary Si and microstructured Si against wavelength (µm). The graph demonstrates a significant increase in transmittance for microstructured Si compared to ordinary Si, particularly in the 1-12 µm wavelength range.]
Microstructured silicon

Total integrated absorptance

Graph showing the absorptance of ordinary Si over different wavelengths (µm).
Microstructured silicon

Total integrated absorptance

![Graph showing the absorptance of ordinary Si and microstructured Si over different wavelengths. The graph indicates that microstructured Si has a higher absorptance in the 1-2 µm wavelength range.]
Total integrated absorptance
Microstructured silicon

Total integrated absorptance

![Graph showing total integrated absorptance for ordinary Si and microstructured Si at different wavelengths (1-2 µm, 4-7 µm, 10-12 µm).]
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
Effects of different ambient gases
Different ambient gases

$\text{SF}_6$  $\text{Cl}_2$

$\text{N}_2$  $\text{air}$

10 µm
Different ambient gases

Absorptance

![Graph showing absorptance vs. wavelength for SF₆ and flat samples.](chart.png)
Different ambient gases

Absorptance

![Graph showing absorptance vs. wavelength for different gases.](image-url)
Different ambient gases

Absorptance

![Absorptance graph showing absorption spectra for different gases.](image-url)
Different ambient gases

Absorptance

![Graph showing absorptance vs. wavelength for different gases]
Below band gap photocurrent
Avalanche photodiode response at 1.3 μm

Radiation Monitoring Devices, Watertown MA 02472
Conclusions

• Up to 90% infrared absorption
  → increased infrared photocurrent

• Absorption dependent on ambient gas

• Applications in infrared photodetectors, silicon solar cells, other possible devices

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for more information, see:
http://mazur-www.harvard.edu
Microstructured silicon

Conclusions

Absorption dependent on shape, impurities

Up to 90% infrared absorption

Increased infrared photocurrent

Applications in infrared photodetectors, silicon solar cells, other possible devices
Different ambient gases

Reflectance

![Graph showing reflectance as a function of wavelength (μm).]
Different ambient gases

Reflectance

![Graph showing reflectance vs. wavelength for different gases including air, N₂, Cl₂, and SF₆.](image-url)
Different ambient gases

Transmittance

![Graph showing transmittance versus wavelength (µm)]

- Transmittance values range from 0 to 1.
- The graph indicates a sharp increase in transmittance at a particular wavelength, followed by a plateau.
- The y-axis represents transmittance, and the x-axis represents wavelength (µm).
- The label "flat" is present on the graph.
Different ambient gases

Transmittance

![Graph showing transmittance vs. wavelength for different gases: air, N₂, Cl₂, and SF₆.](image)
Microstructured silicon

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

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