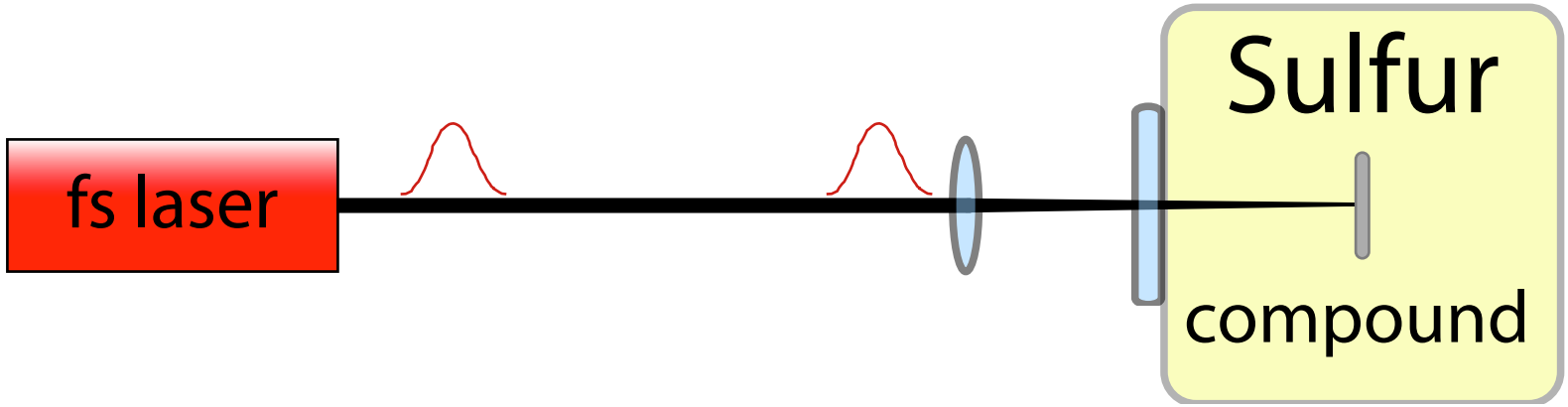
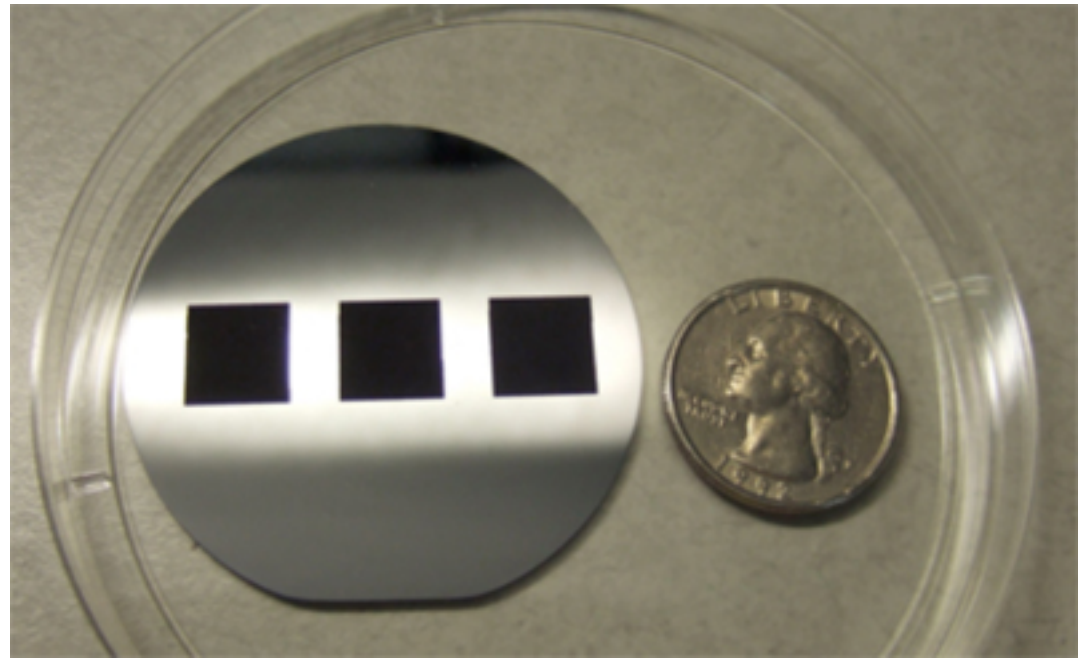
Femtosecond laser doping of silicon: electronic structure

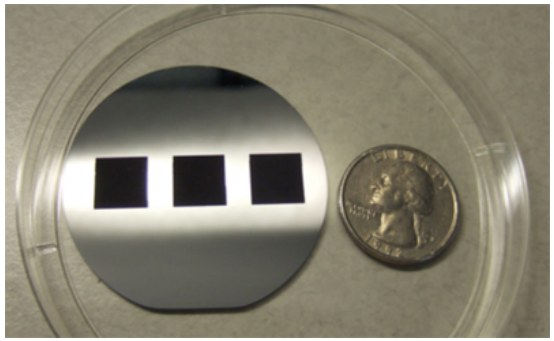
Mark Winkler and Eric Mazur
Harvard University
5/8/2008

femtosecond laser doped silicon





fs laser
Sulfur
compound



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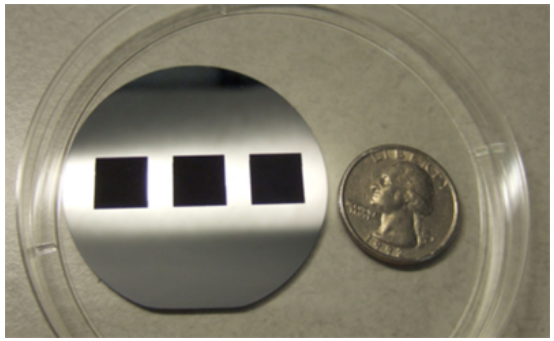
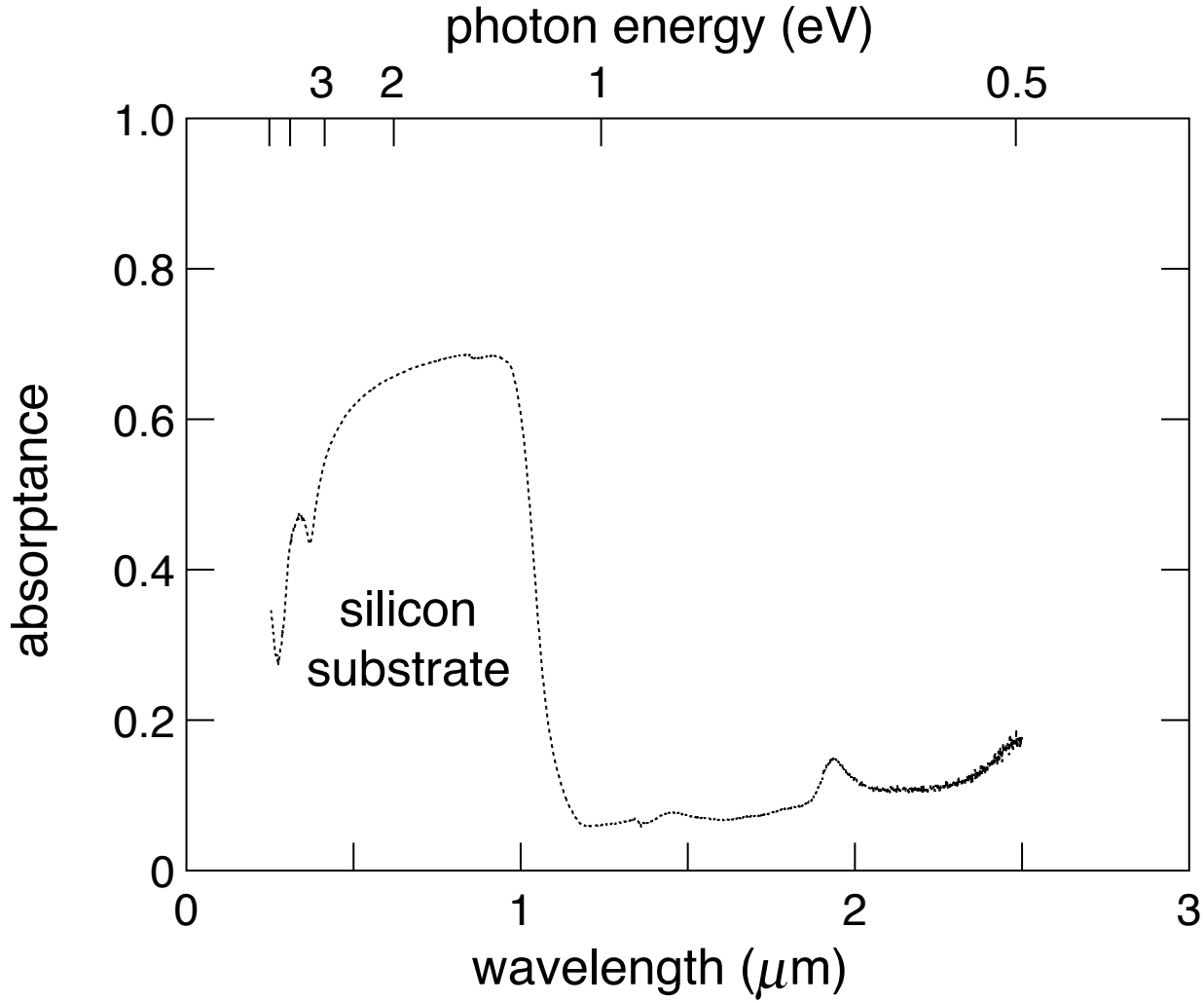
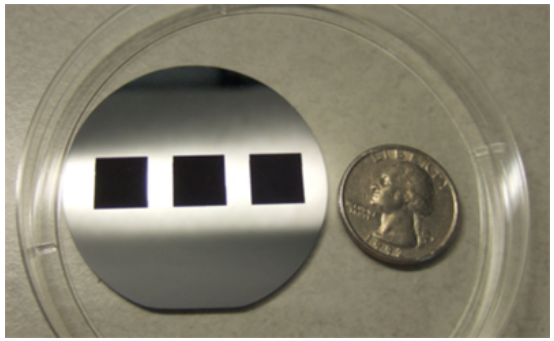
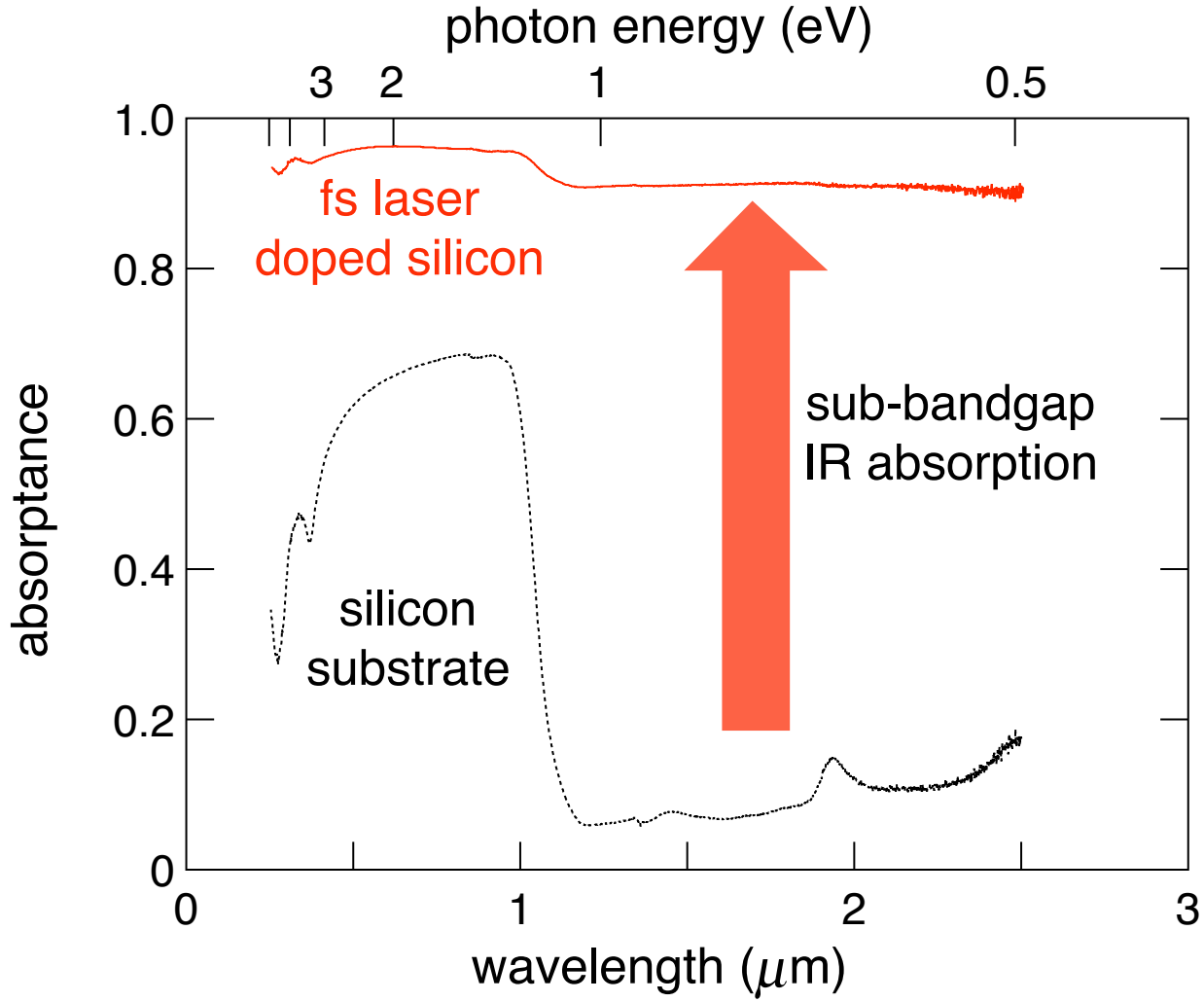



photon energy (eV)
3
2
1
0.5
1.0
0.8
0.6
0.4
0.2
0
absorptance
silicon
substrate
0
1
2
3
wavelength (μm)

fs laser
Sulfur
compound




photon energy (eV)
3
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0.5
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0.6
0.4
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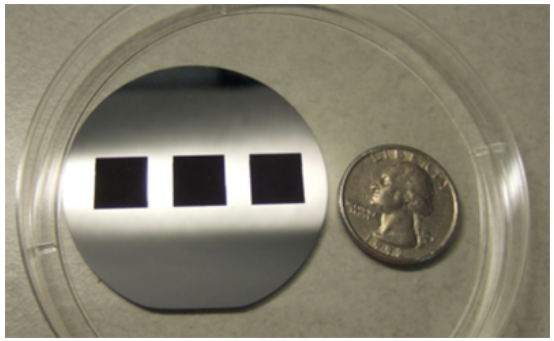
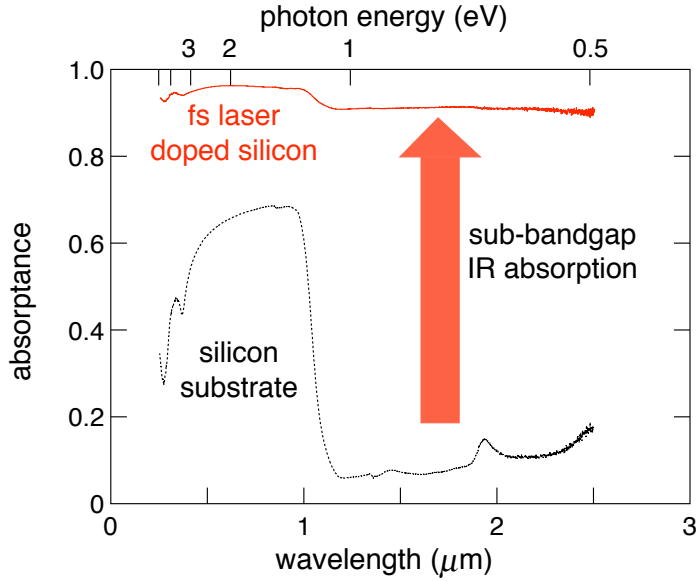
absorptance
fs laser
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)

fs laser
Sulfur
compound

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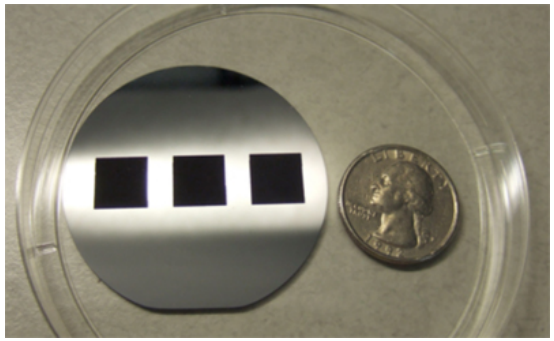

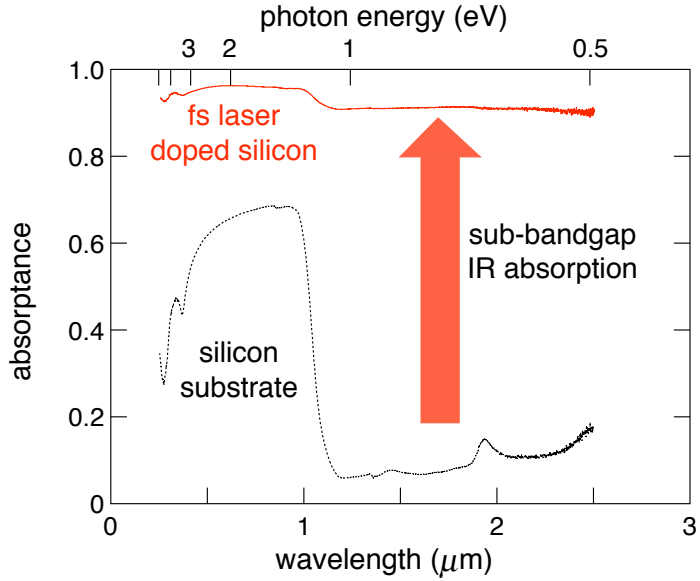
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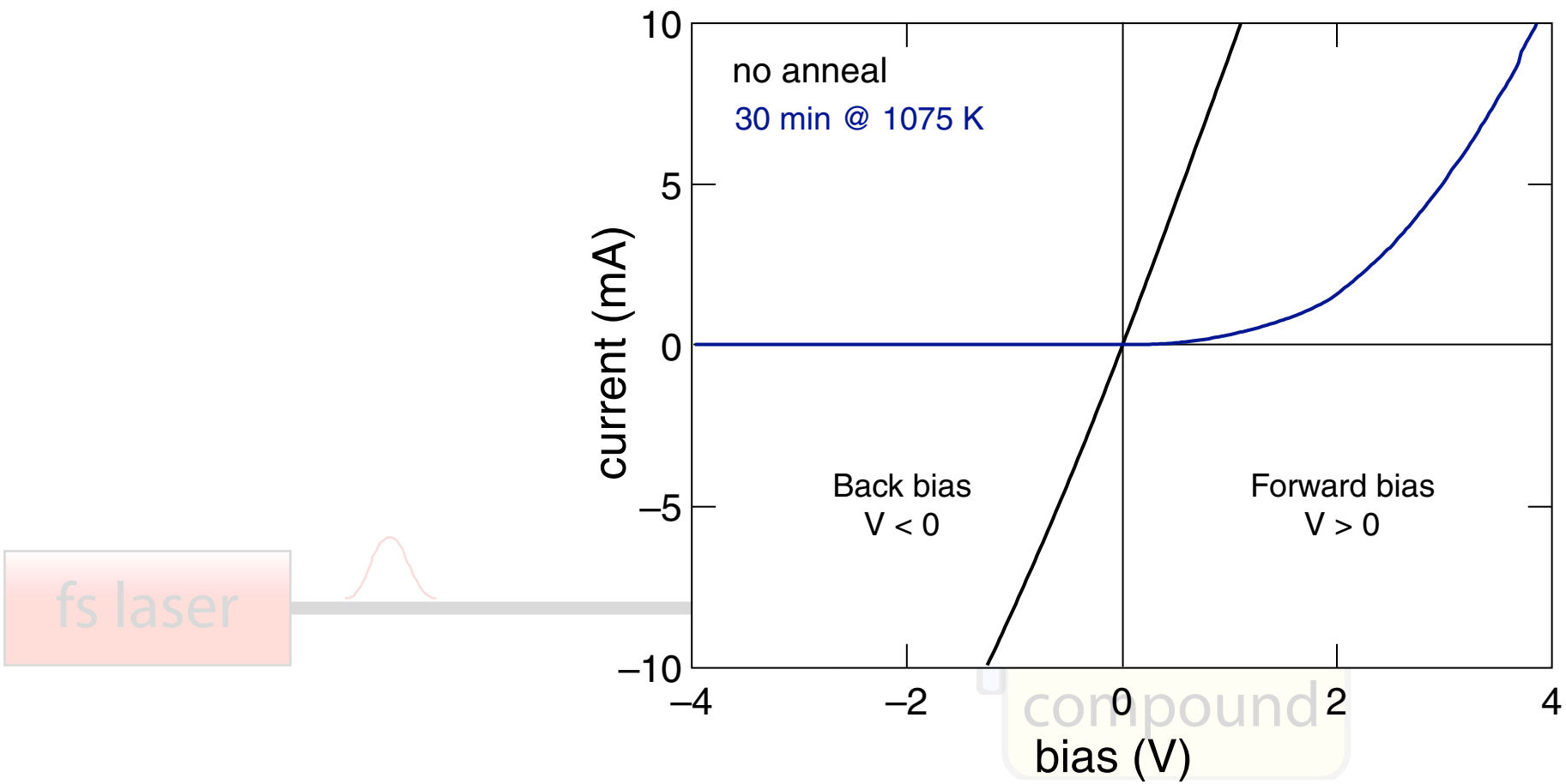
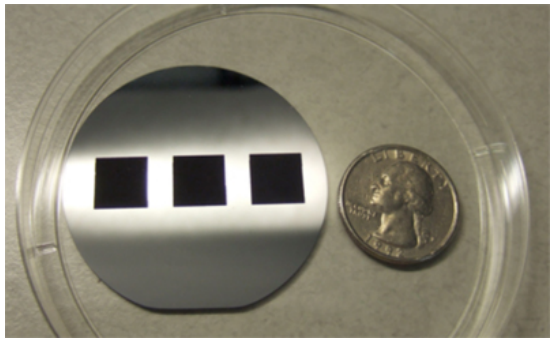
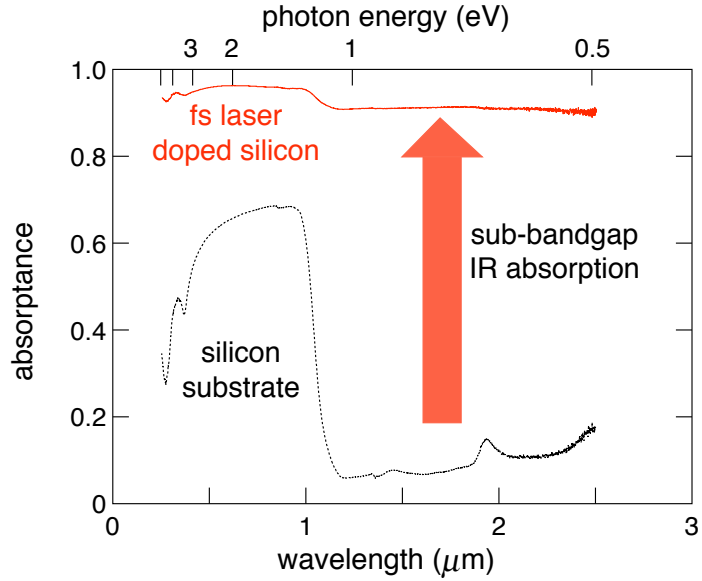
wavelength (μm)


10
5
0
–5
–10
current (mA)
no anneal
30 min @ 1075 K
Back bias
V < 0
Forward bias
V > 0
–4
–2
0
2
4
bias (V)
fs laser
compound

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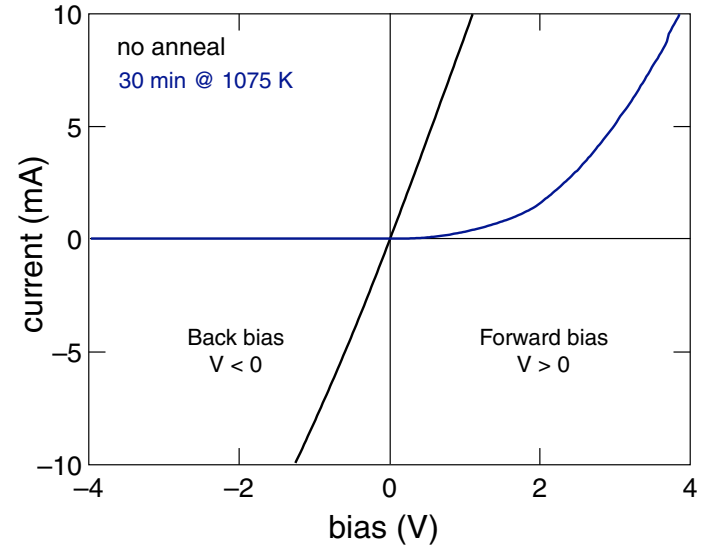
0.8
0.6
0.4
0.2
0
absorptance
fs laser
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)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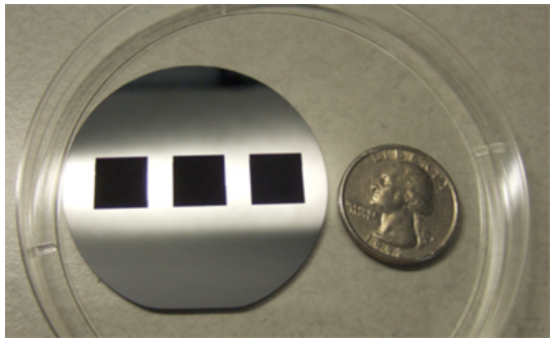
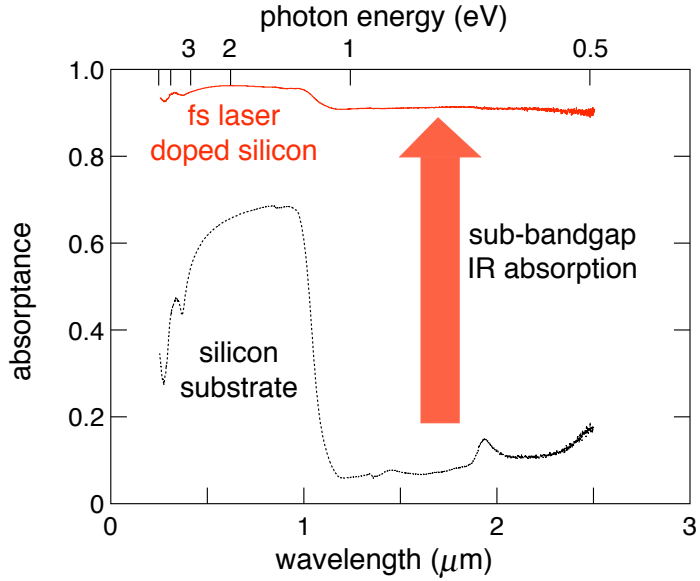
bias (V)

fs laser
Sulfur
compound

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absorptance
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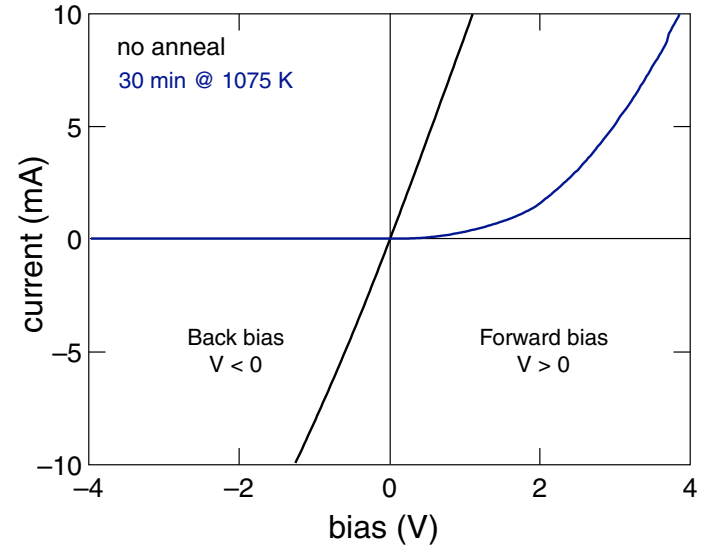
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)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Forward bias
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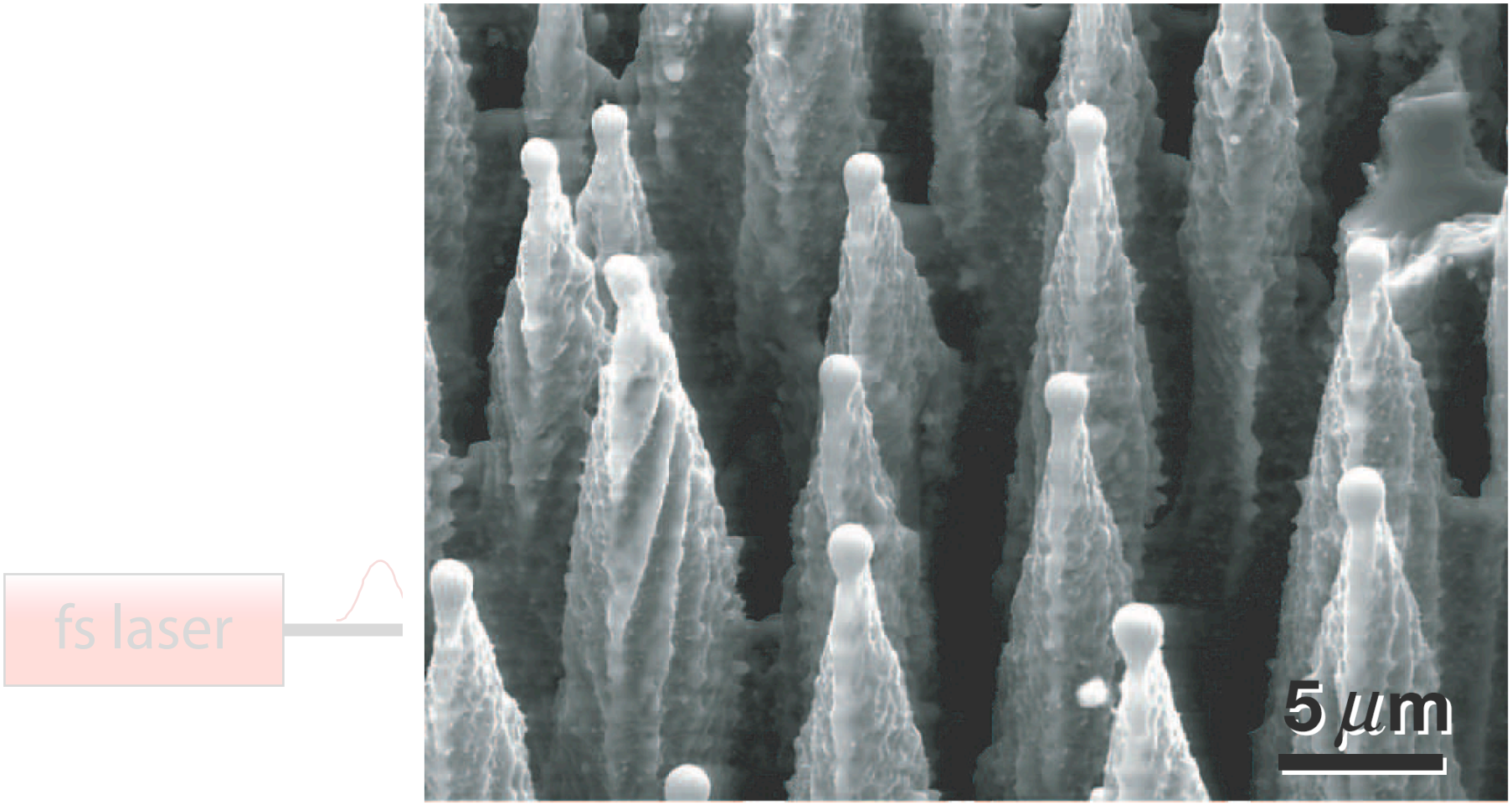
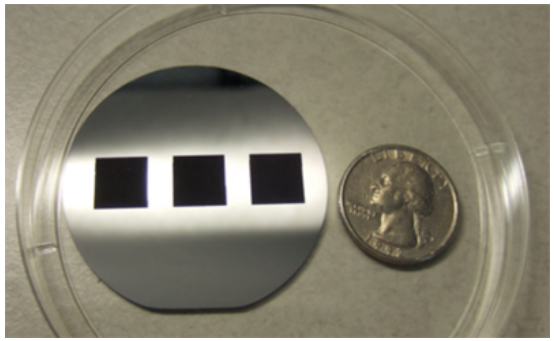
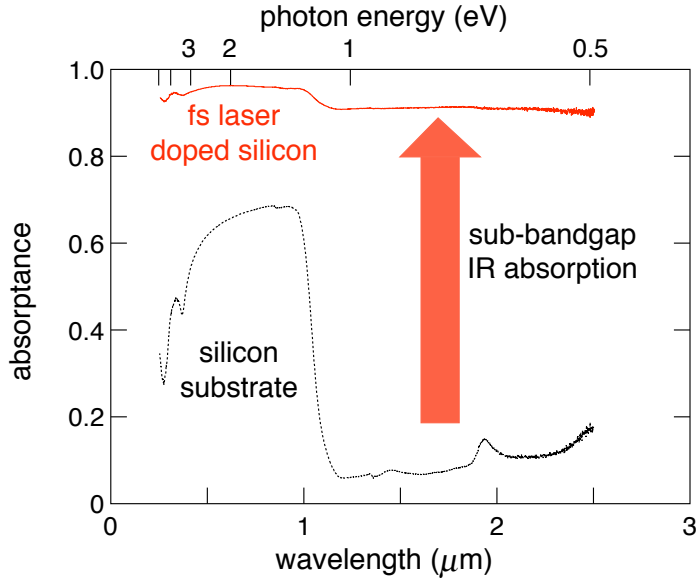
bias (V)


fs laser
5 μm




photon energy (eV)
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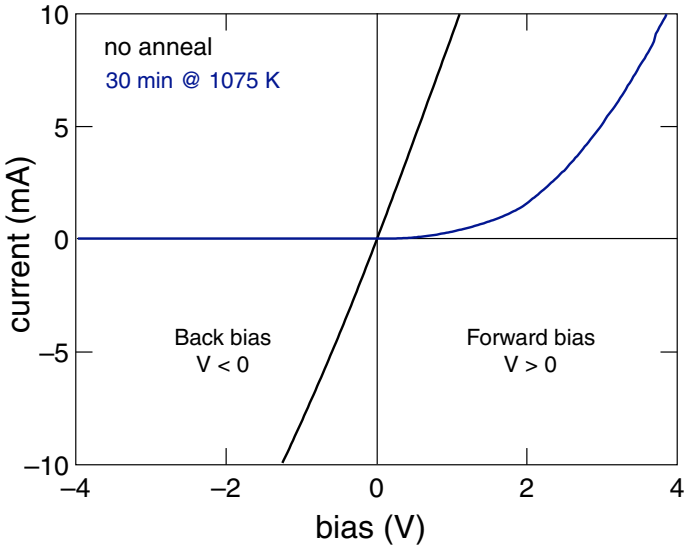
1
0.5
1.0
0.8
0.6
0.4
0.2
0
absorptance
fs laser
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)


10
5
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30 min @ 1075 K
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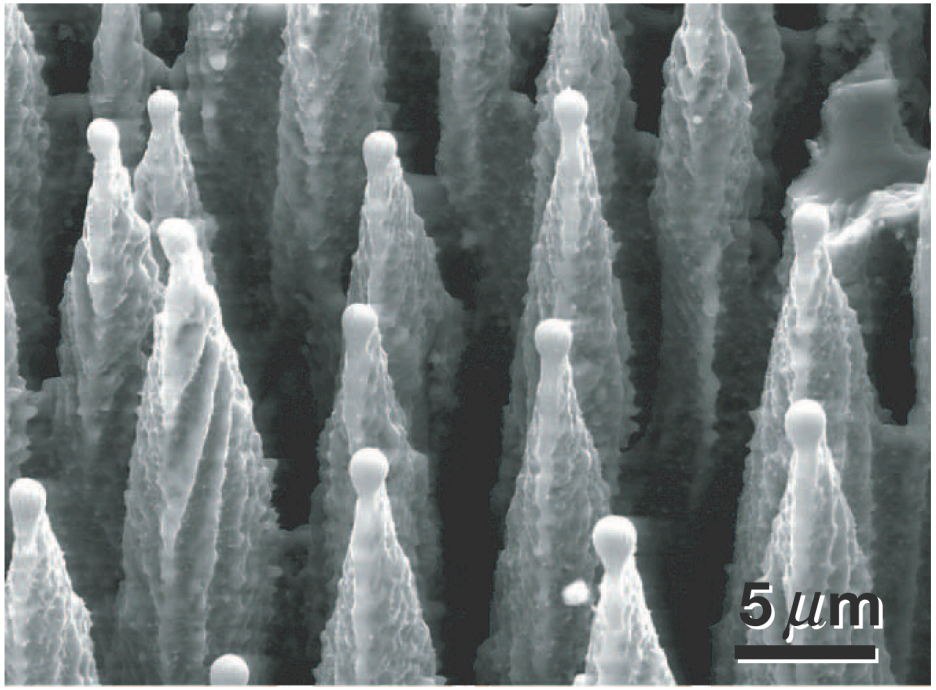
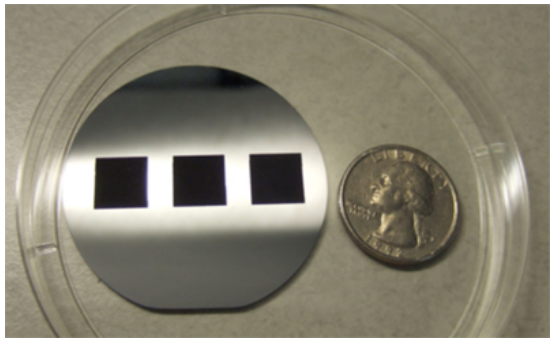
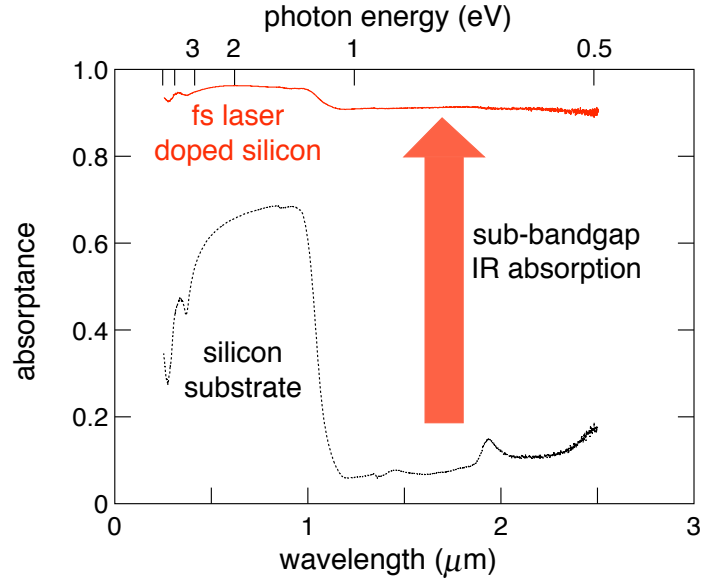
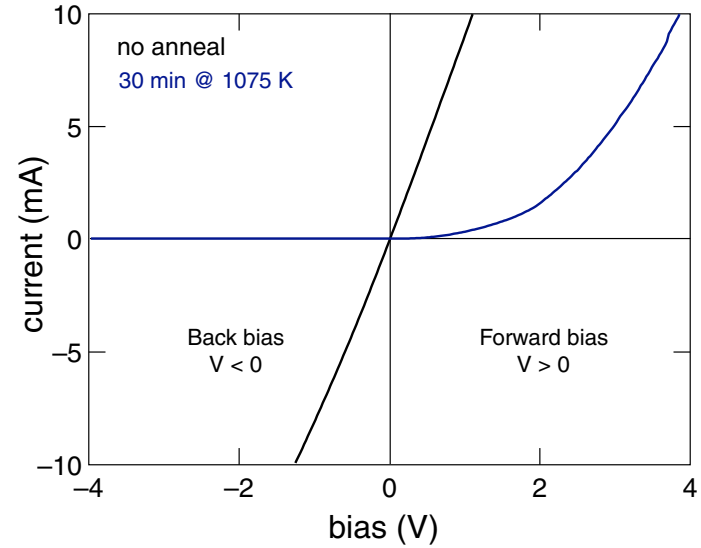
V < 0
Forward bias
V > 0
−4
−2
0
2
4
bias (V)


5 μm

Sulfur
compound




photon energy (eV)
3
2
1
0.5
1.0
0.8
0.6
0.4
0.2
0
absorptance
fs laser
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)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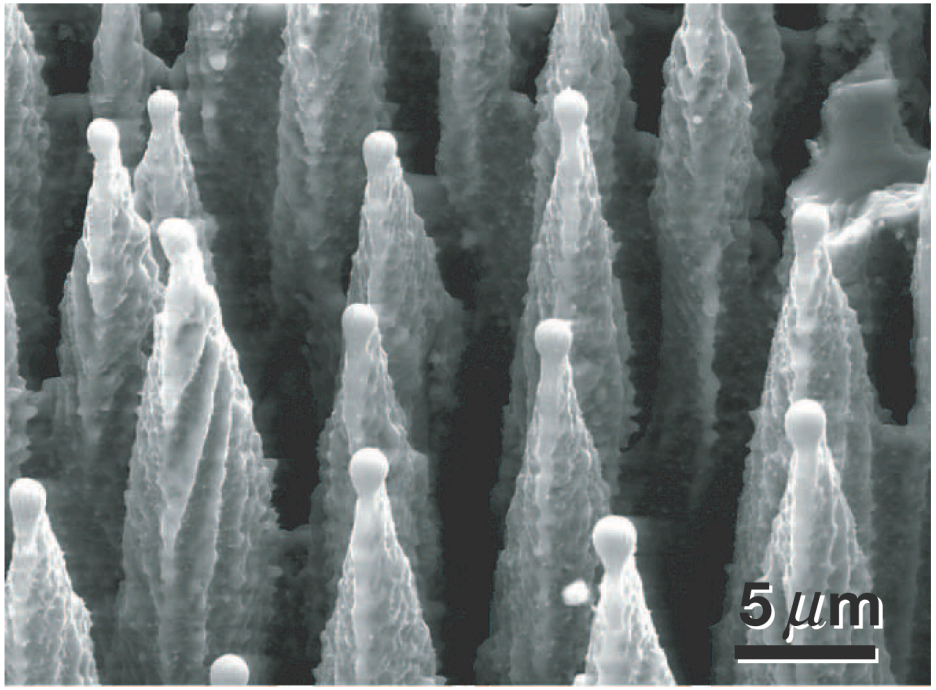
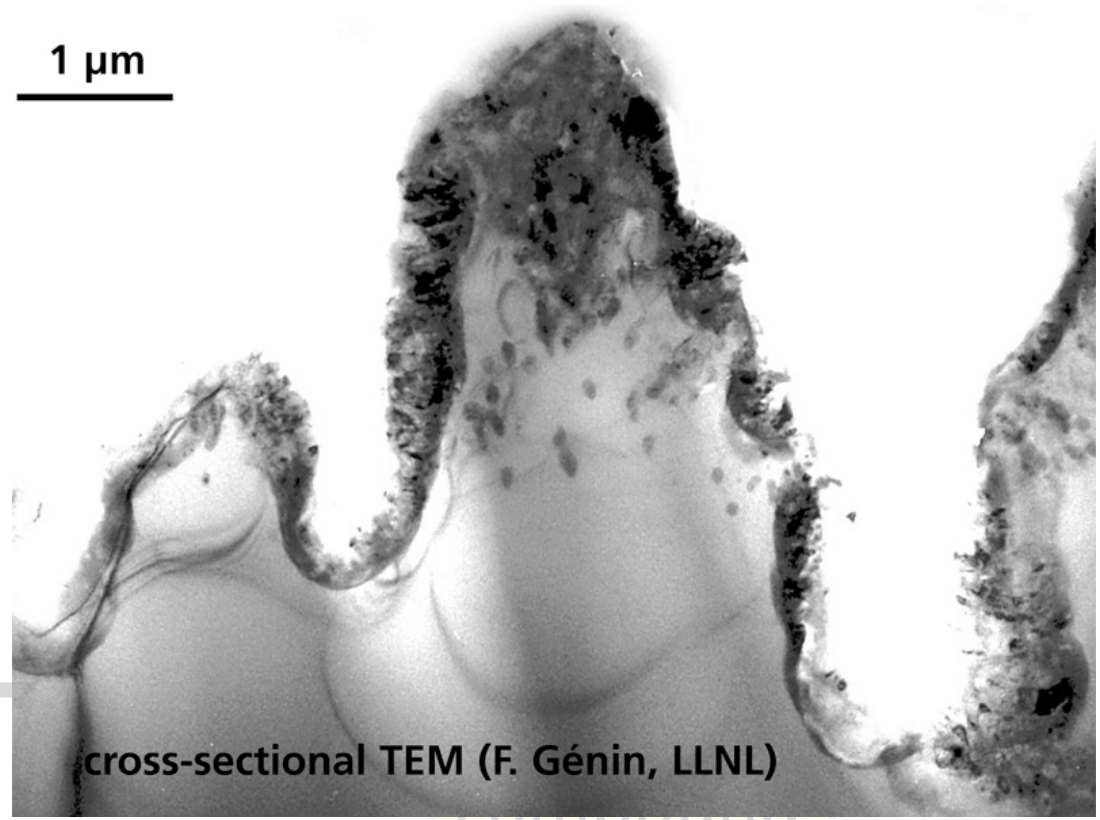
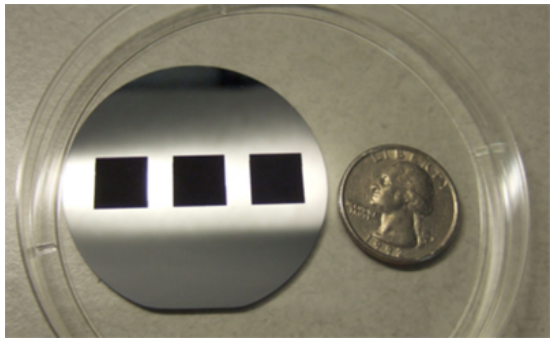
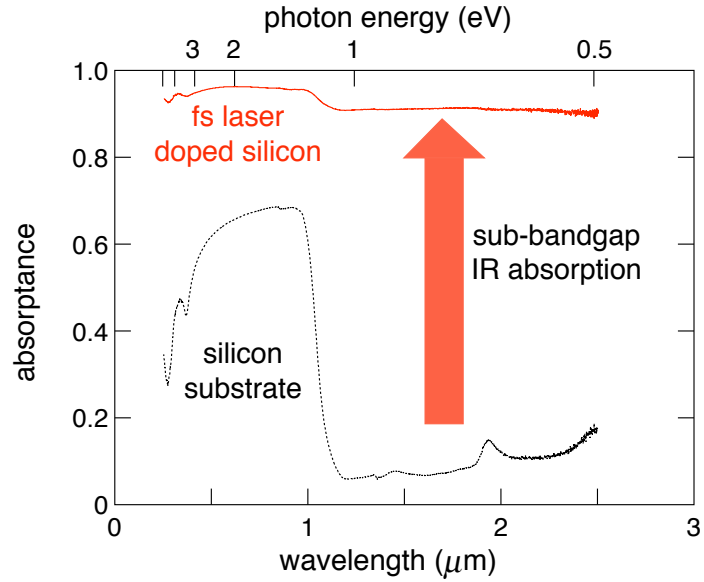
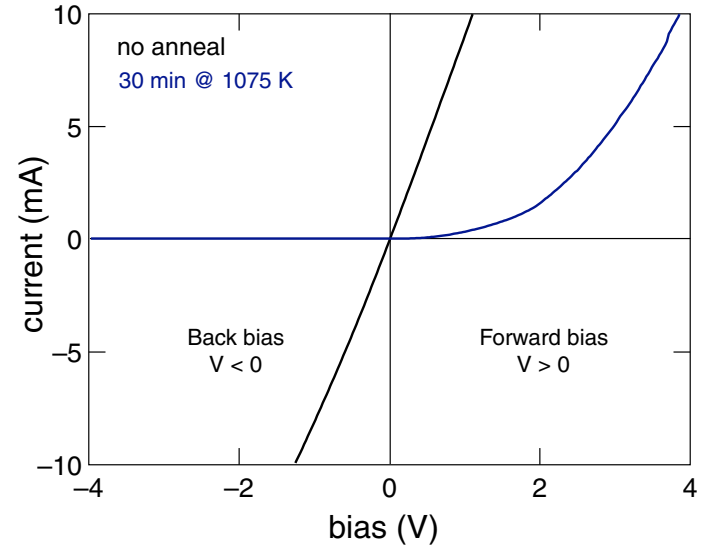

5 μm


1 μm
cross-sectional TEM (F. Génin, LLNL)




photon energy (eV)
3
2
1
0.5
1.0
0.8
0.6
0.4
0.2
0
absorptance
fs laser
doped silicon
sub-bandgap
IR absorption
silicon
substrate
0
1
2
3
wavelength (μm)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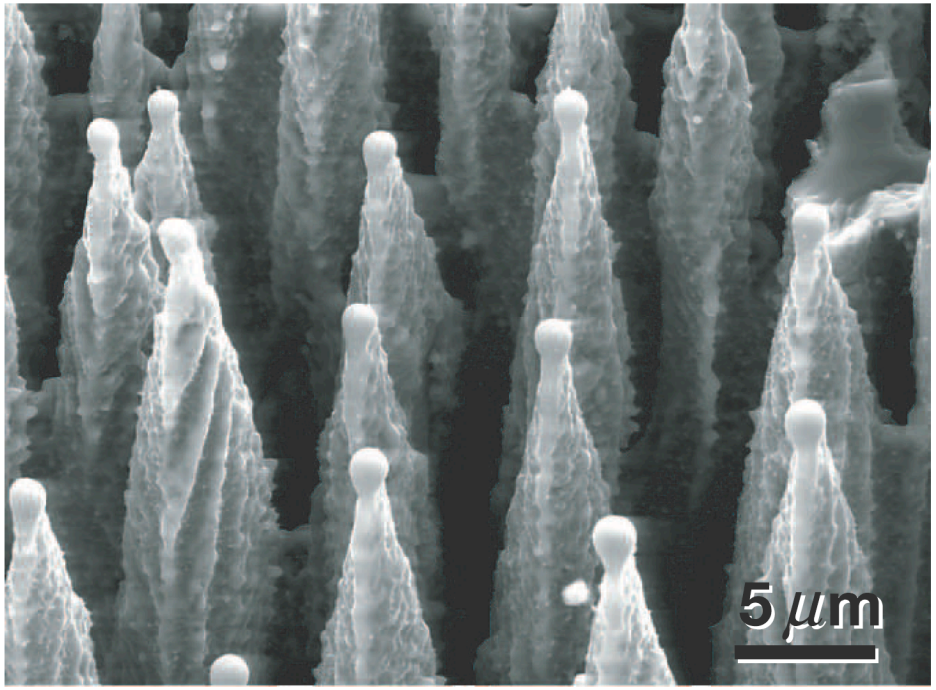
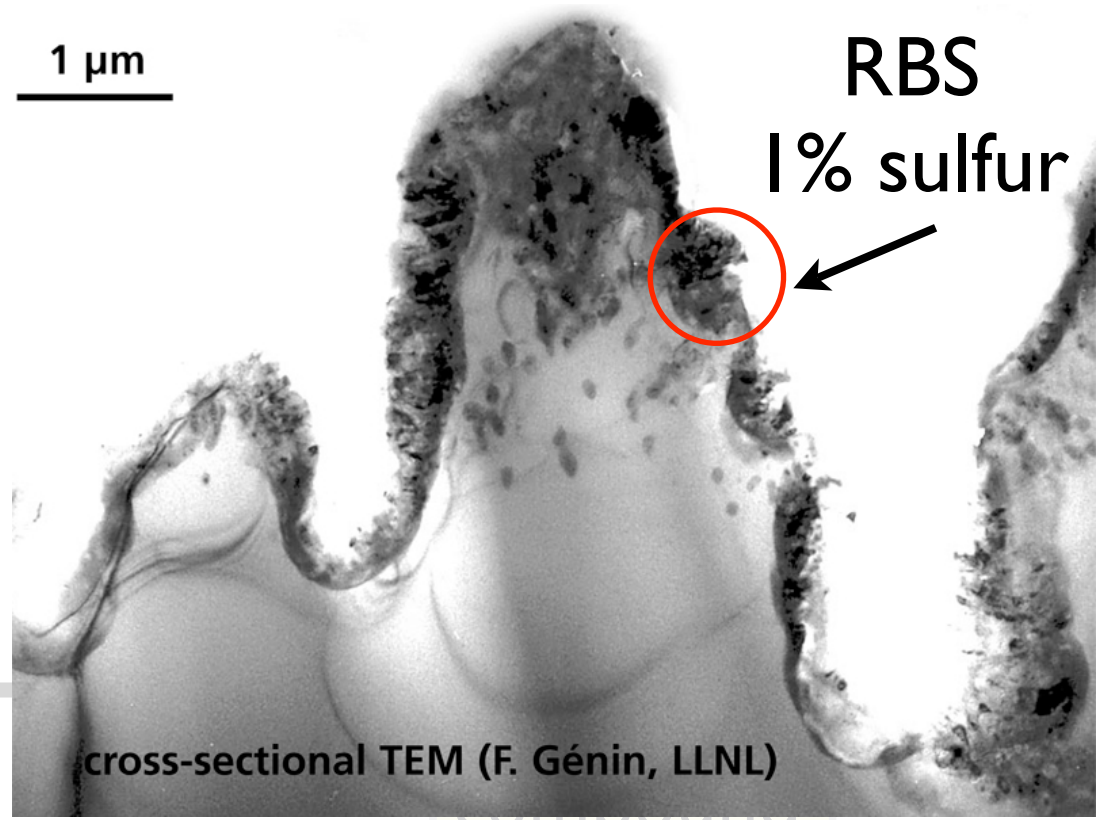
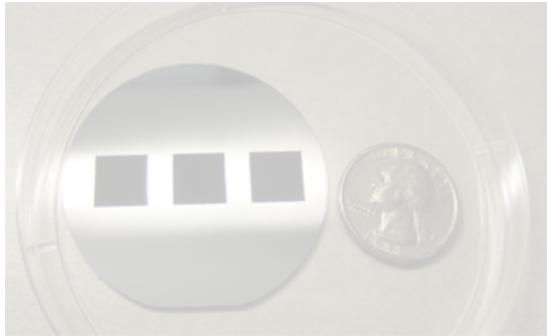
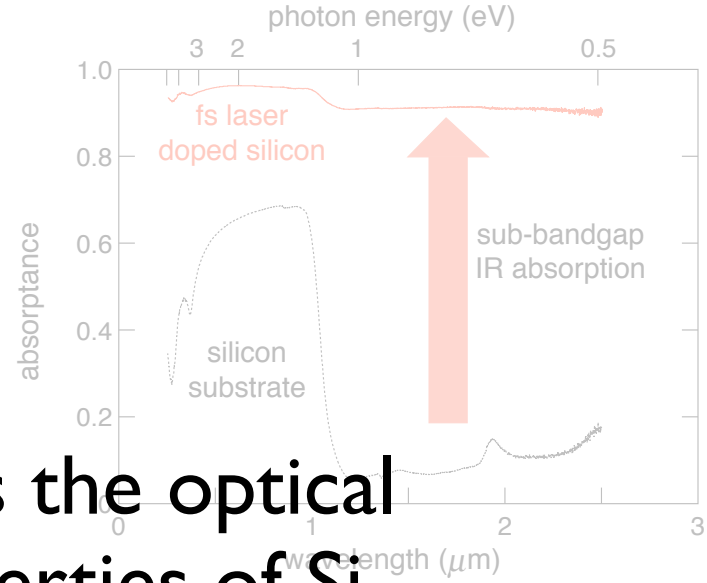
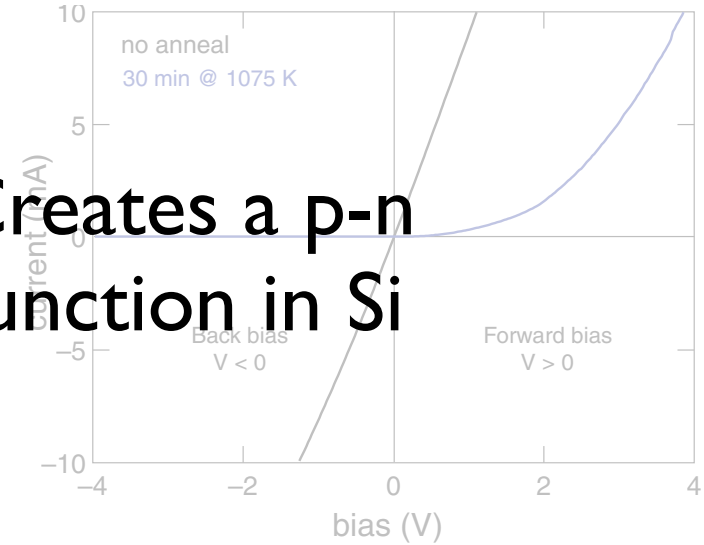

5 μm


1 μm
RBS
1% sulfur
cross-sectional TEM (F. Génin, LLNL)

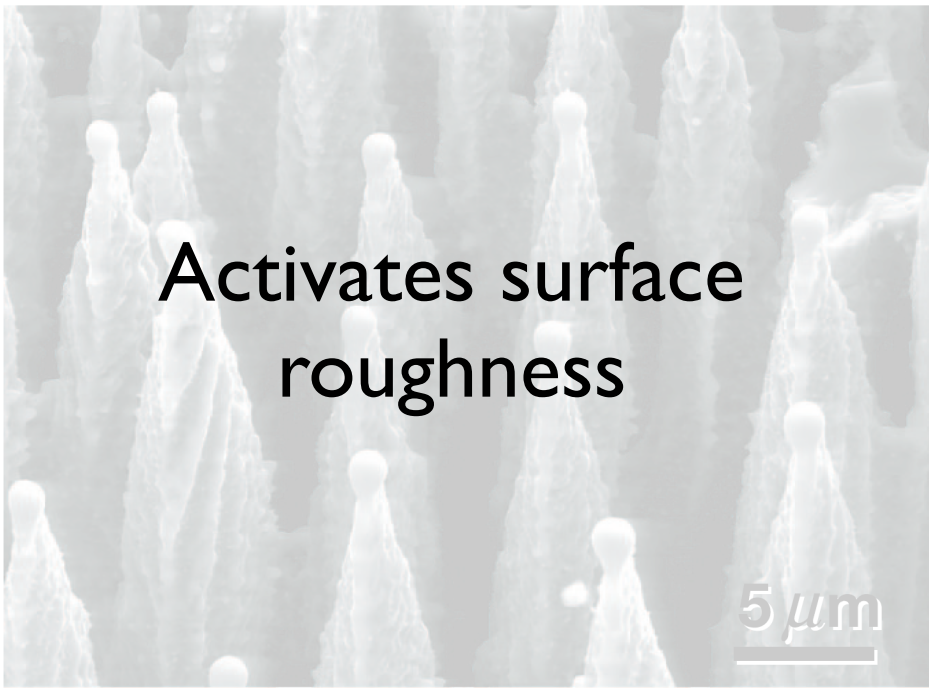




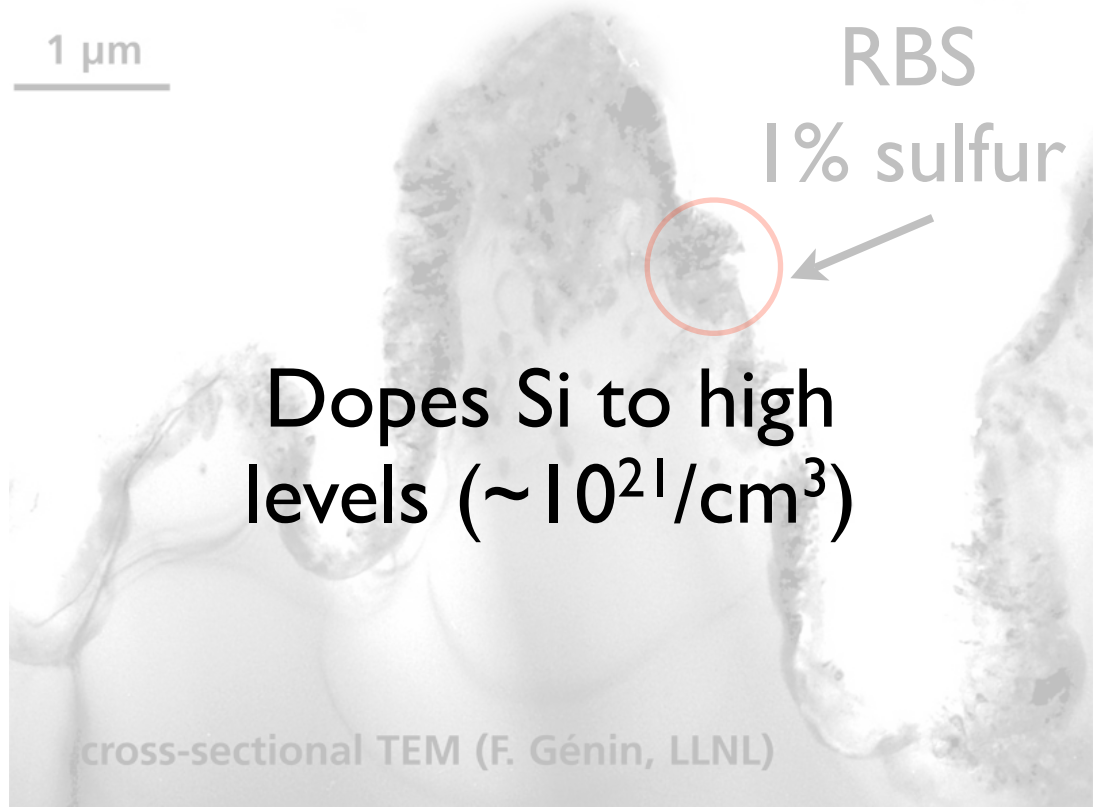
Alters the optical properties of Si



Creates a p-n junction in Si

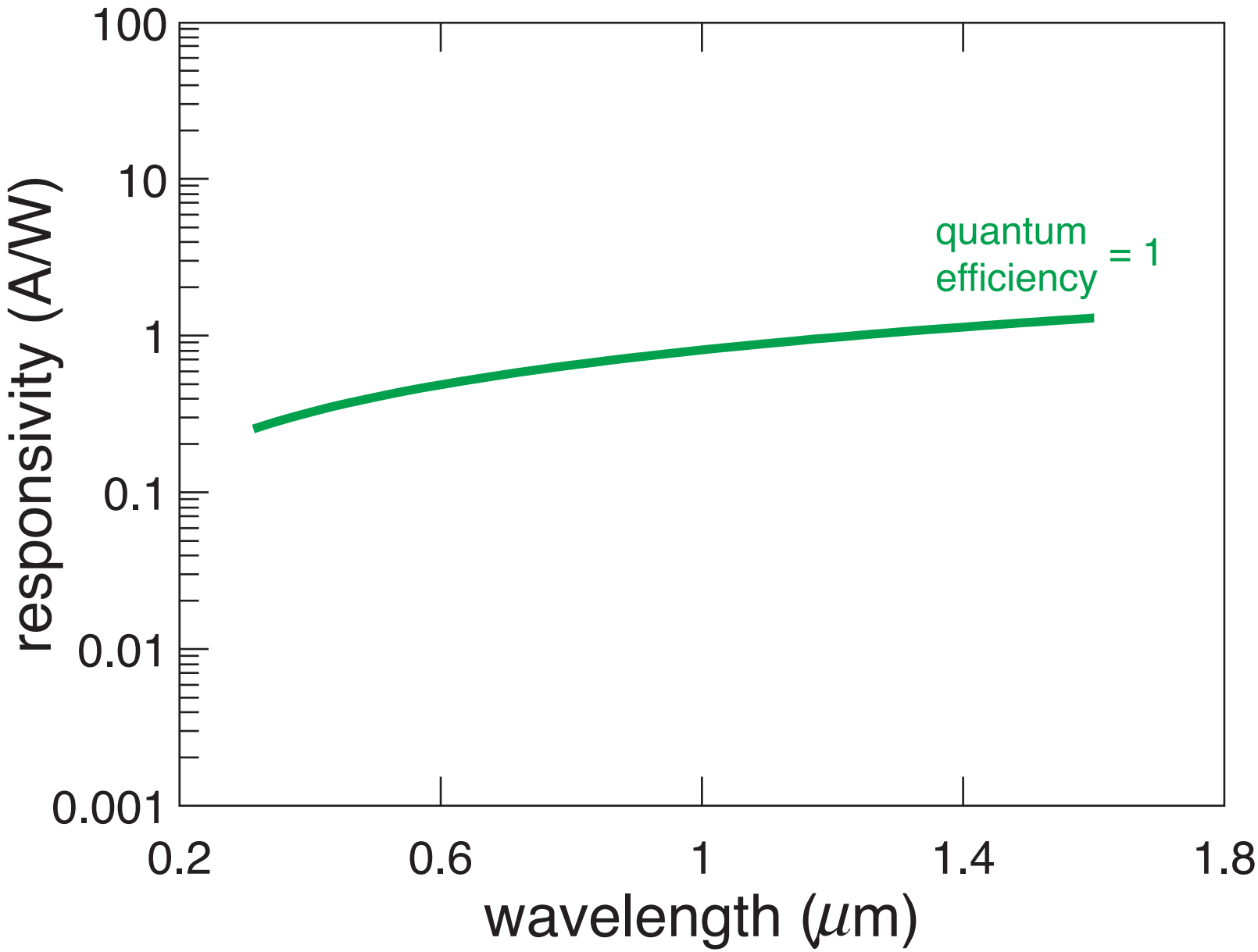


Activates surface roughness

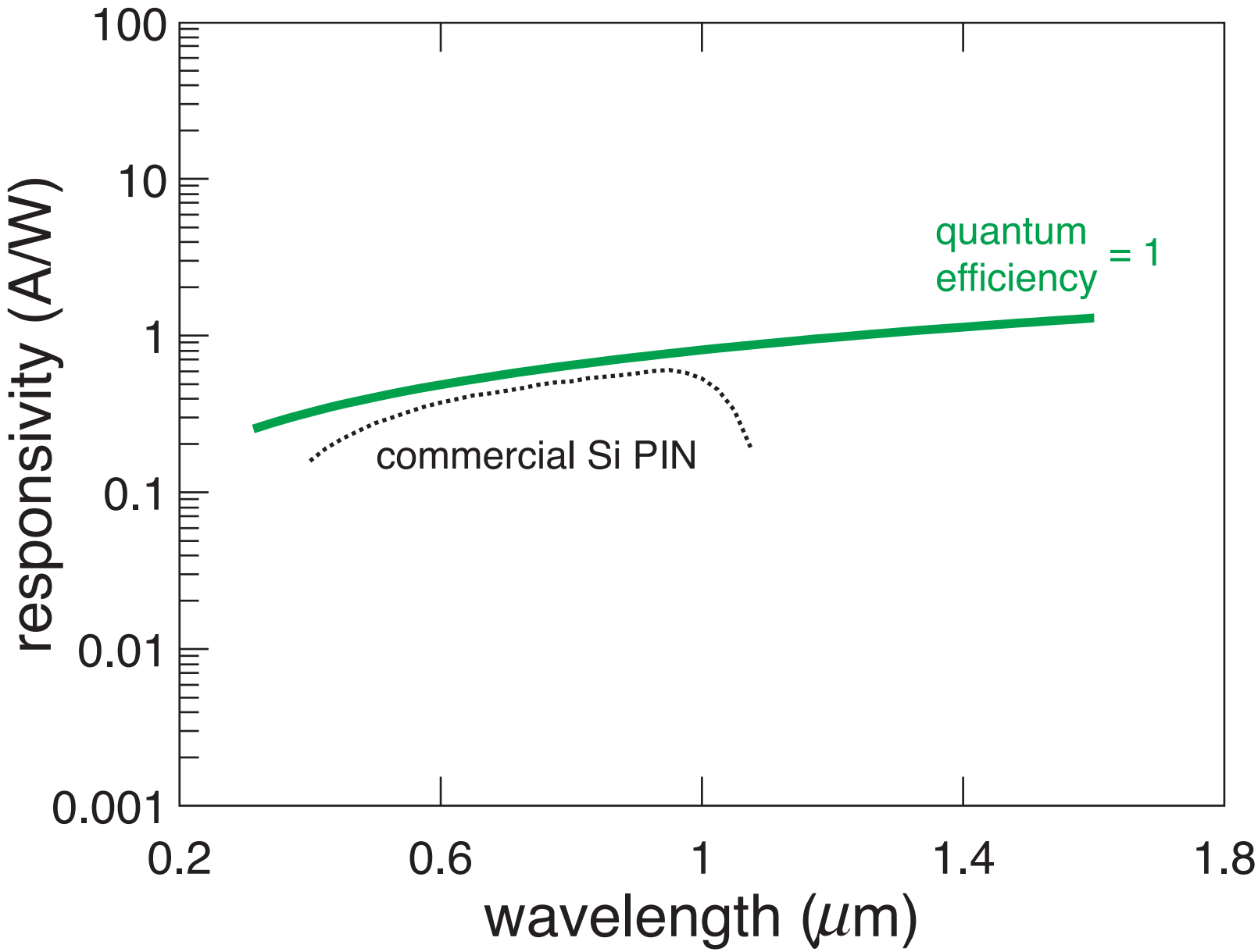


Dopes Si to high levels (~$10^{21}/cm^3$)

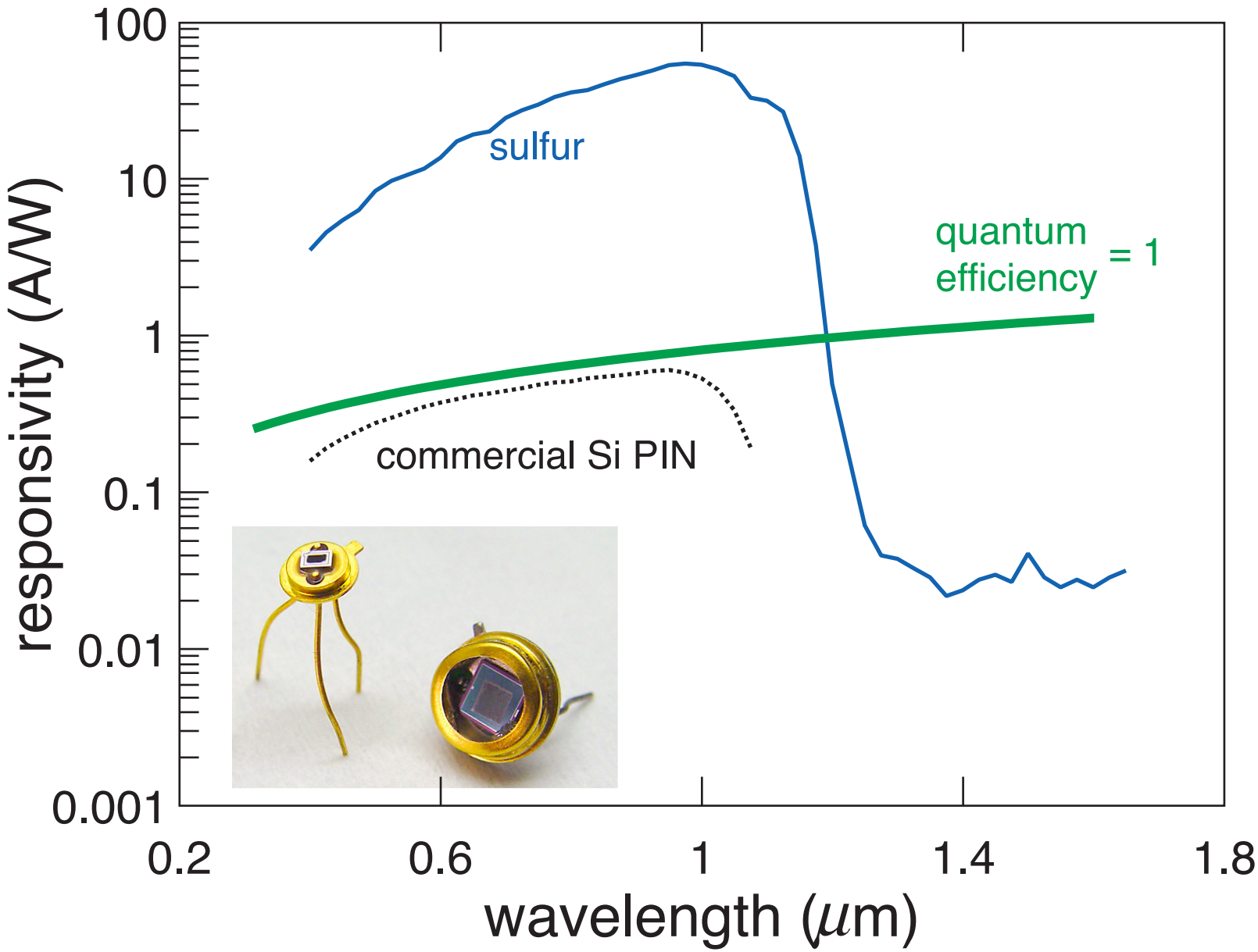
Laser-doping yields interesting optoelectronic devices



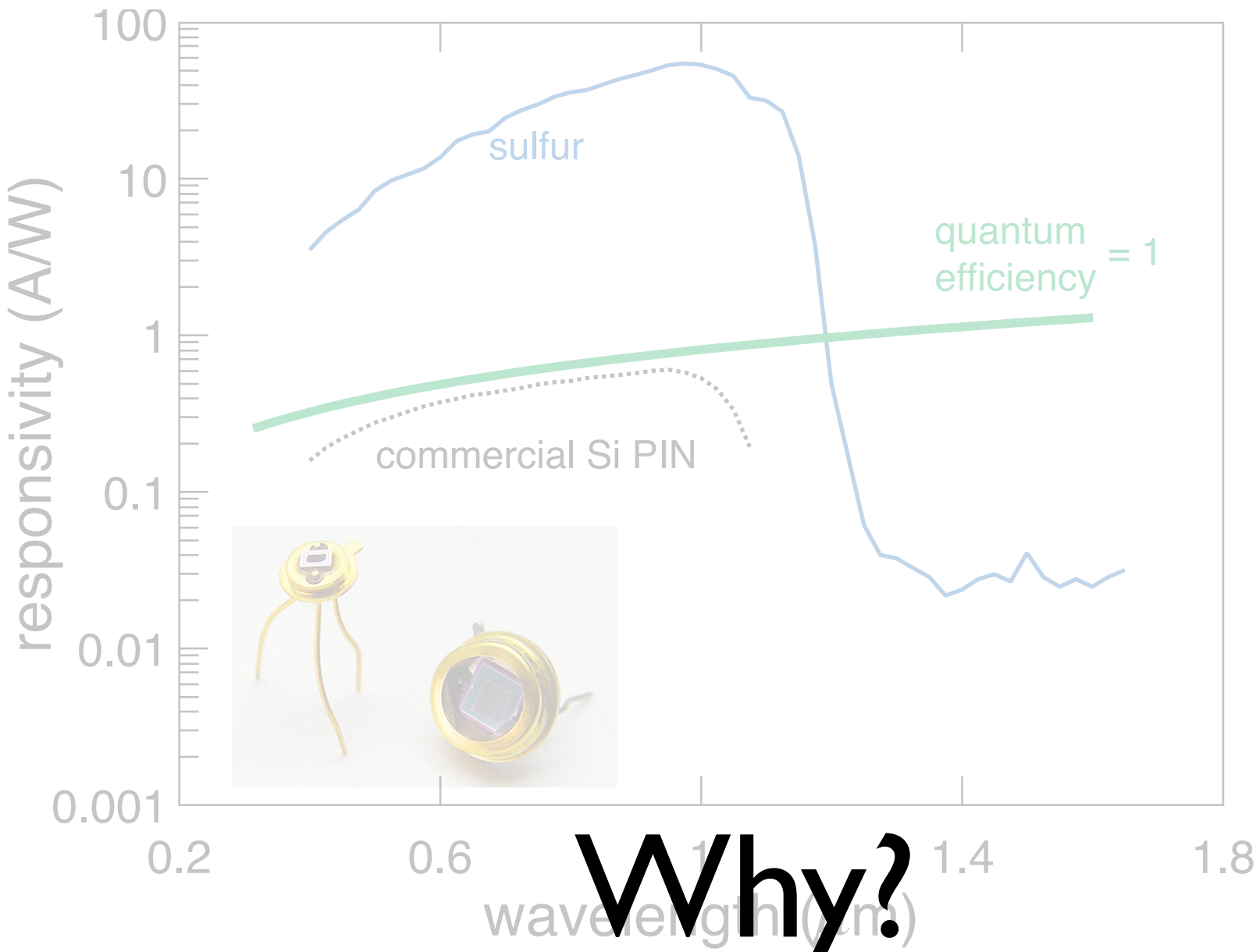
Laser-doping yields interesting optoelectronic devices



Laser-doping yields interesting optoelectronic devices

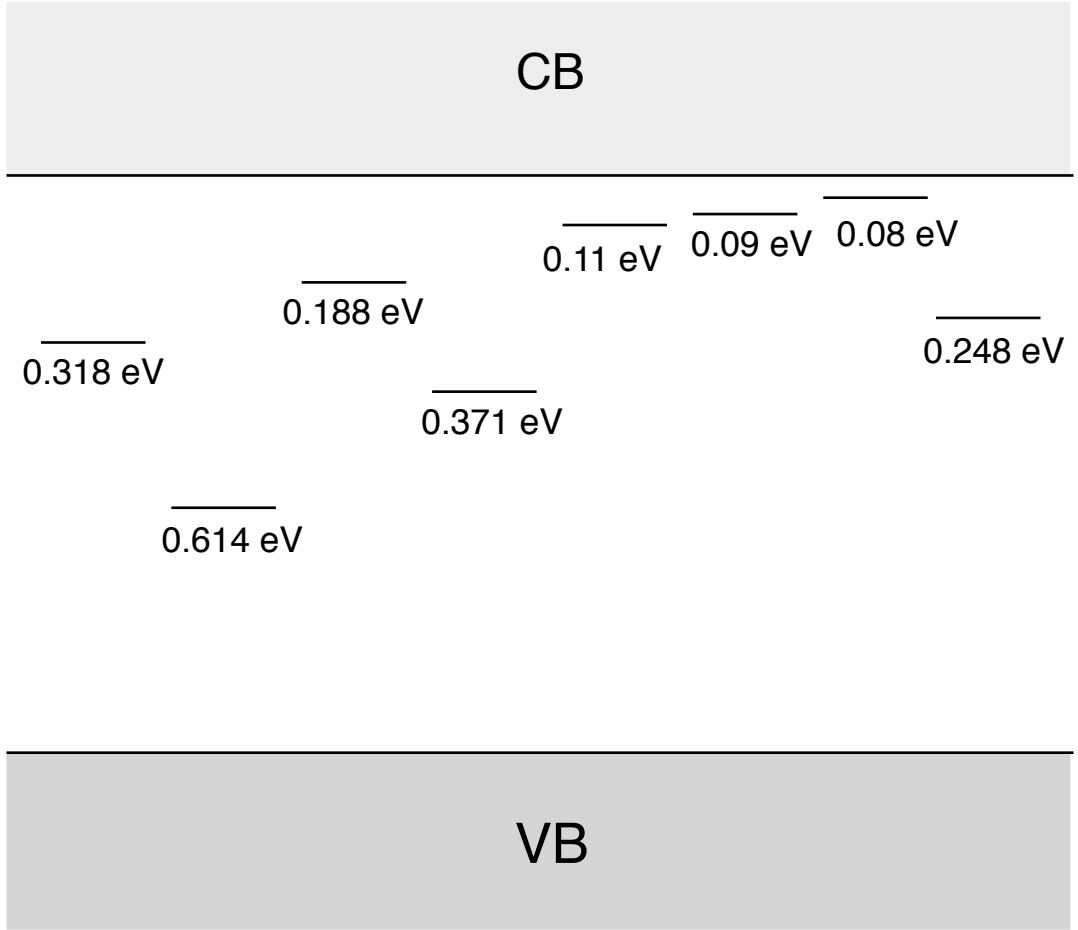


Laser-doping yields interesting optoelectronic devices



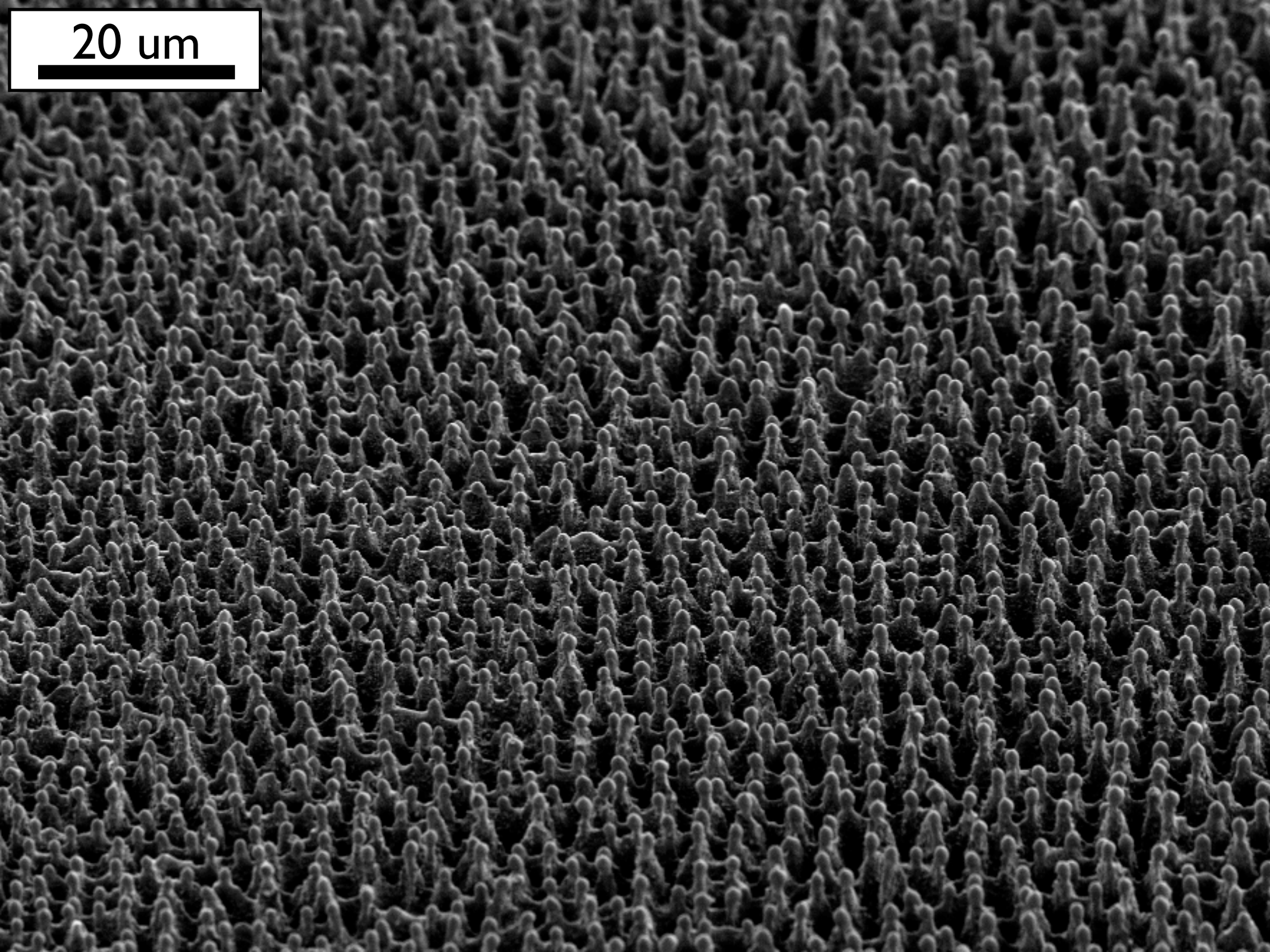
Why?

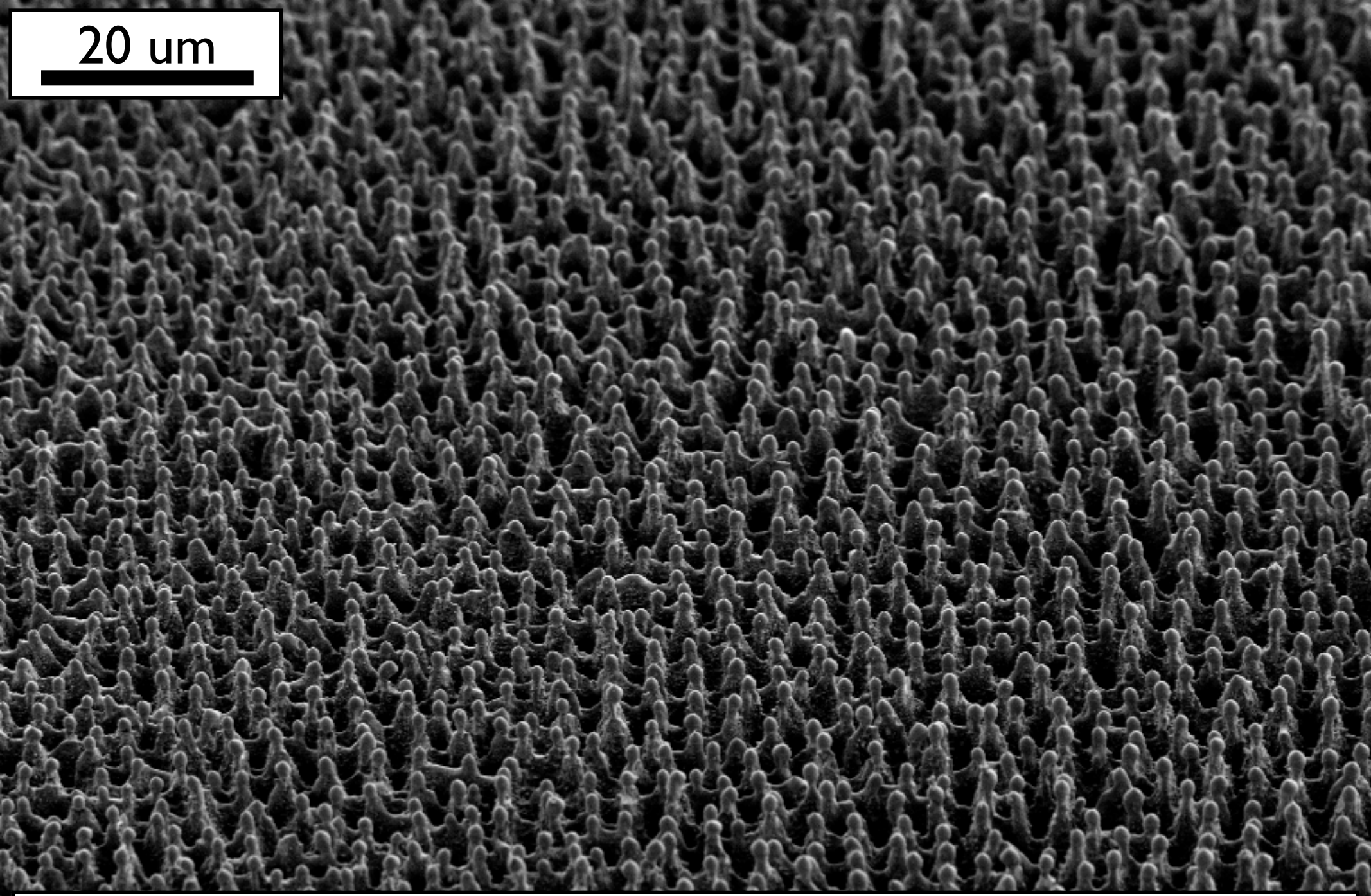
Laser-doping yields interesting optoelectronic devices



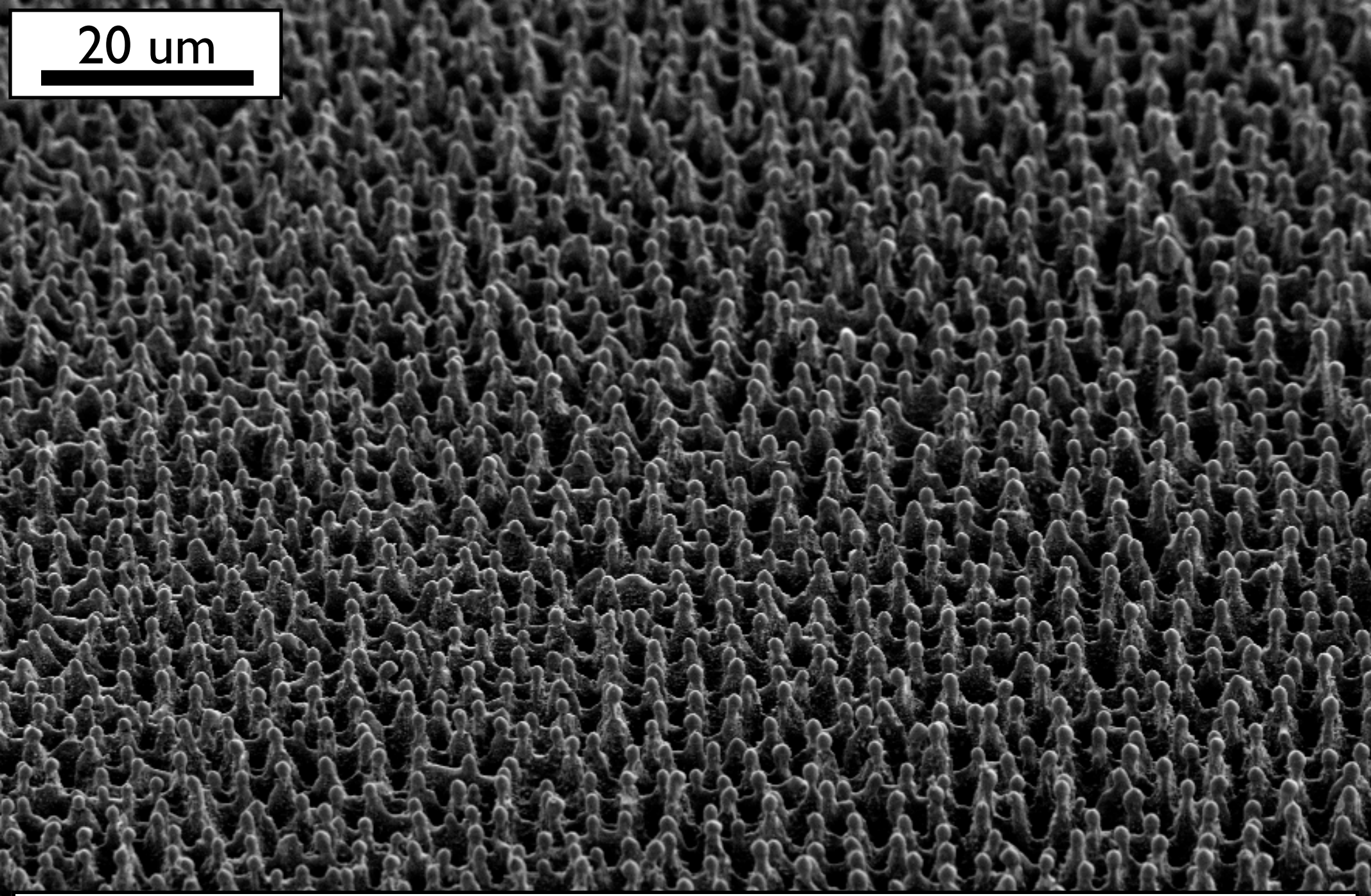
Janzén et al. , Phys. Rev. B 29, 1907 (1984)

Why?


20 um



Rough surfaces → Hard to characterize



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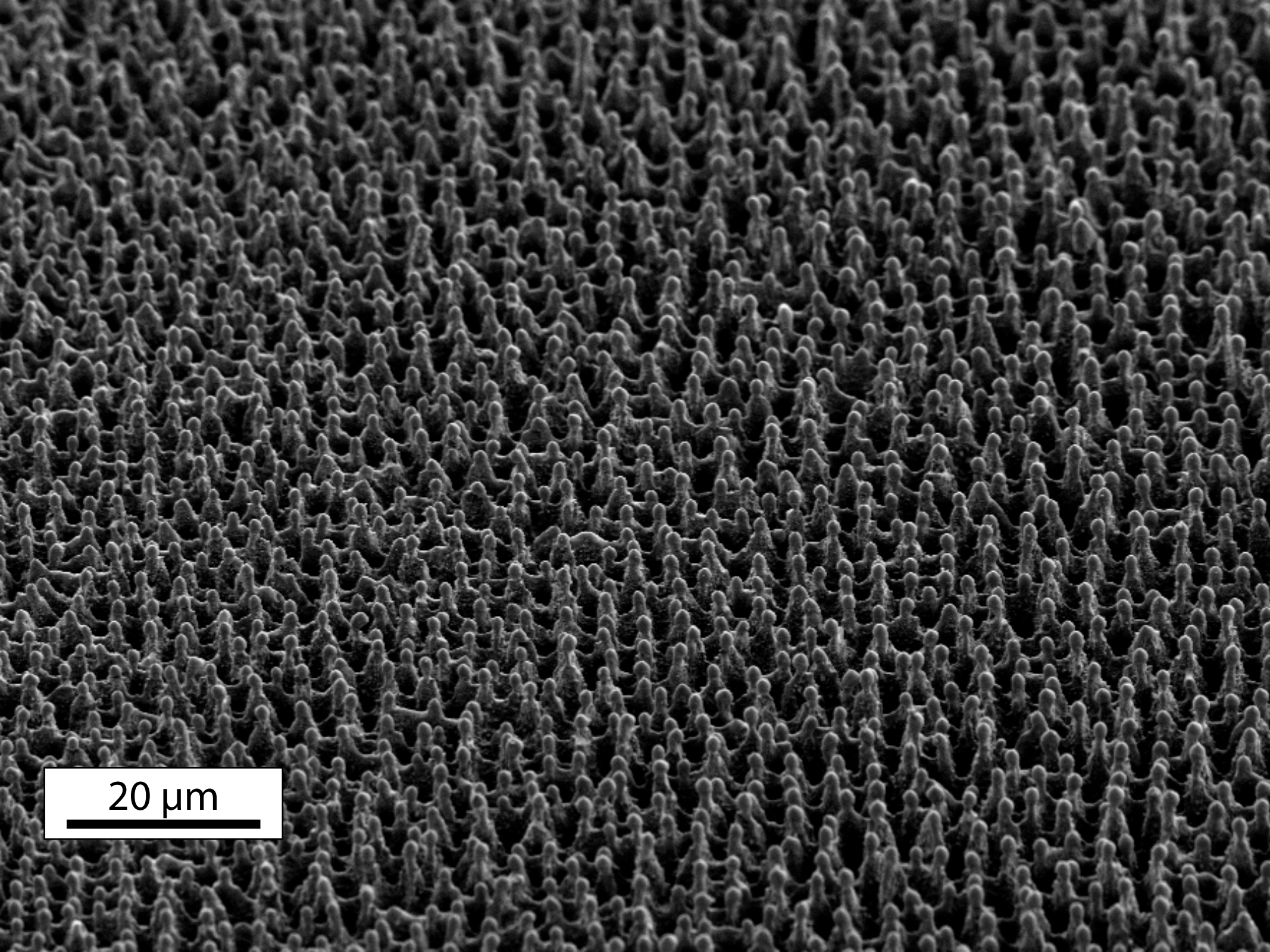
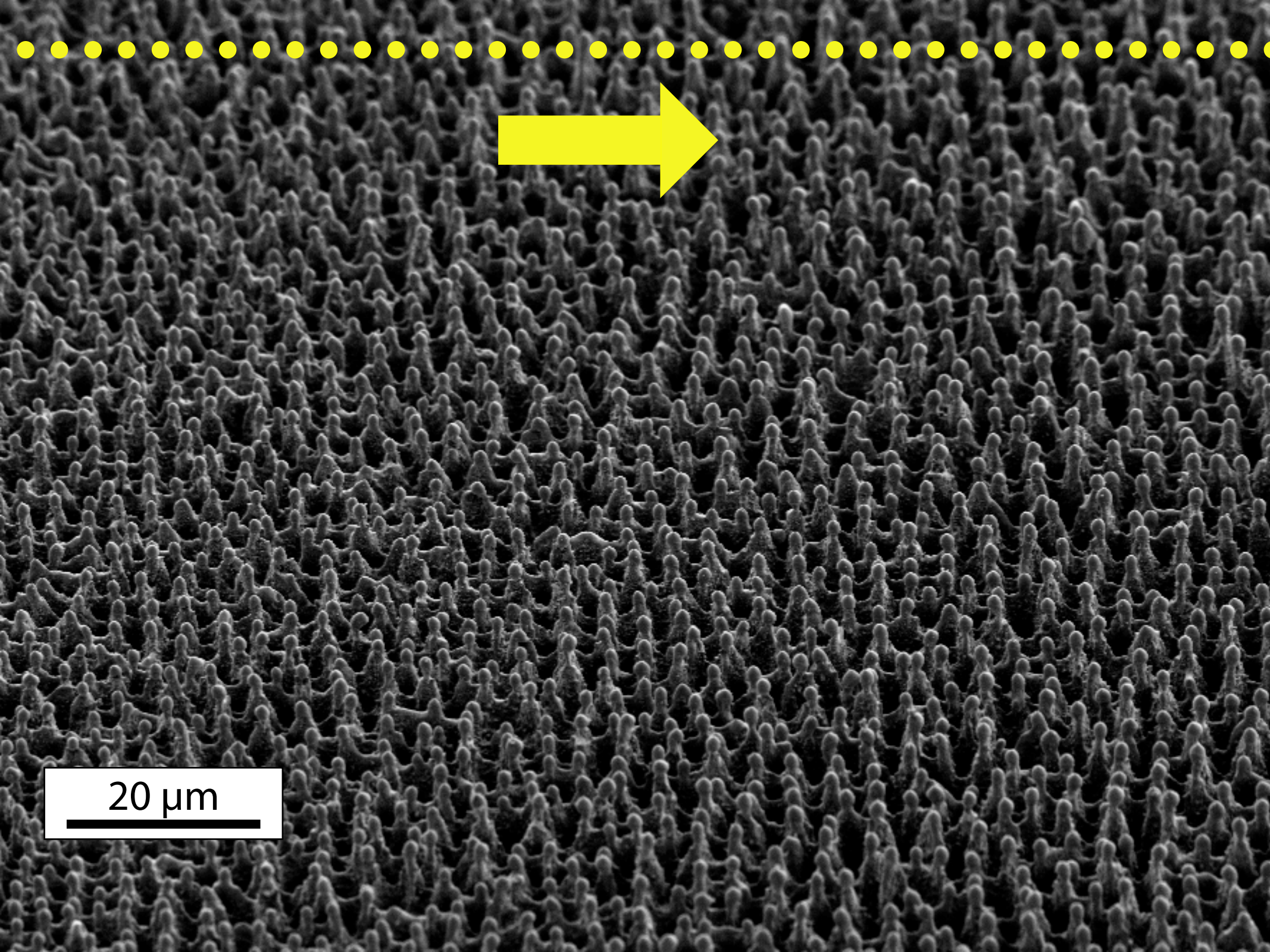
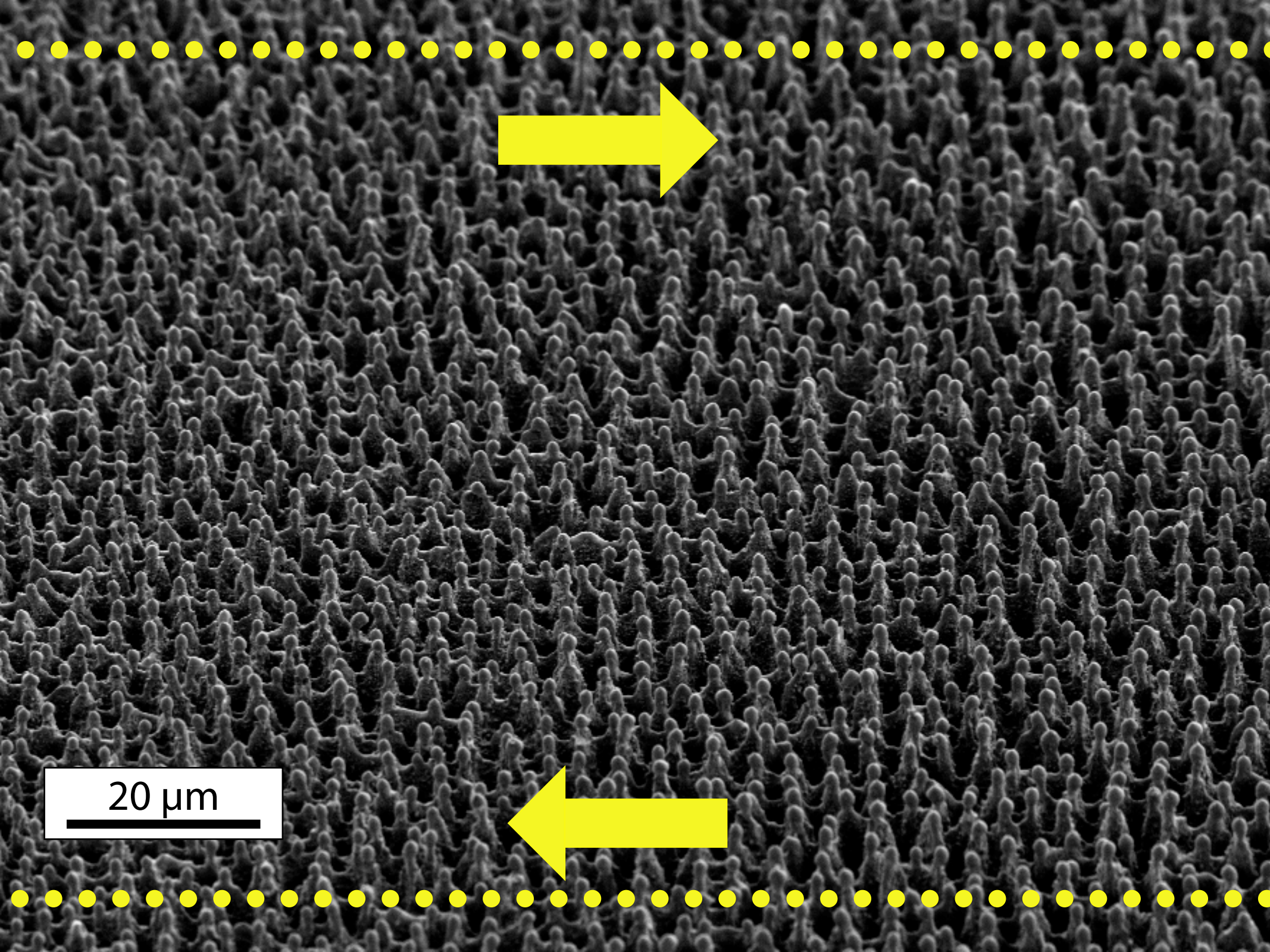
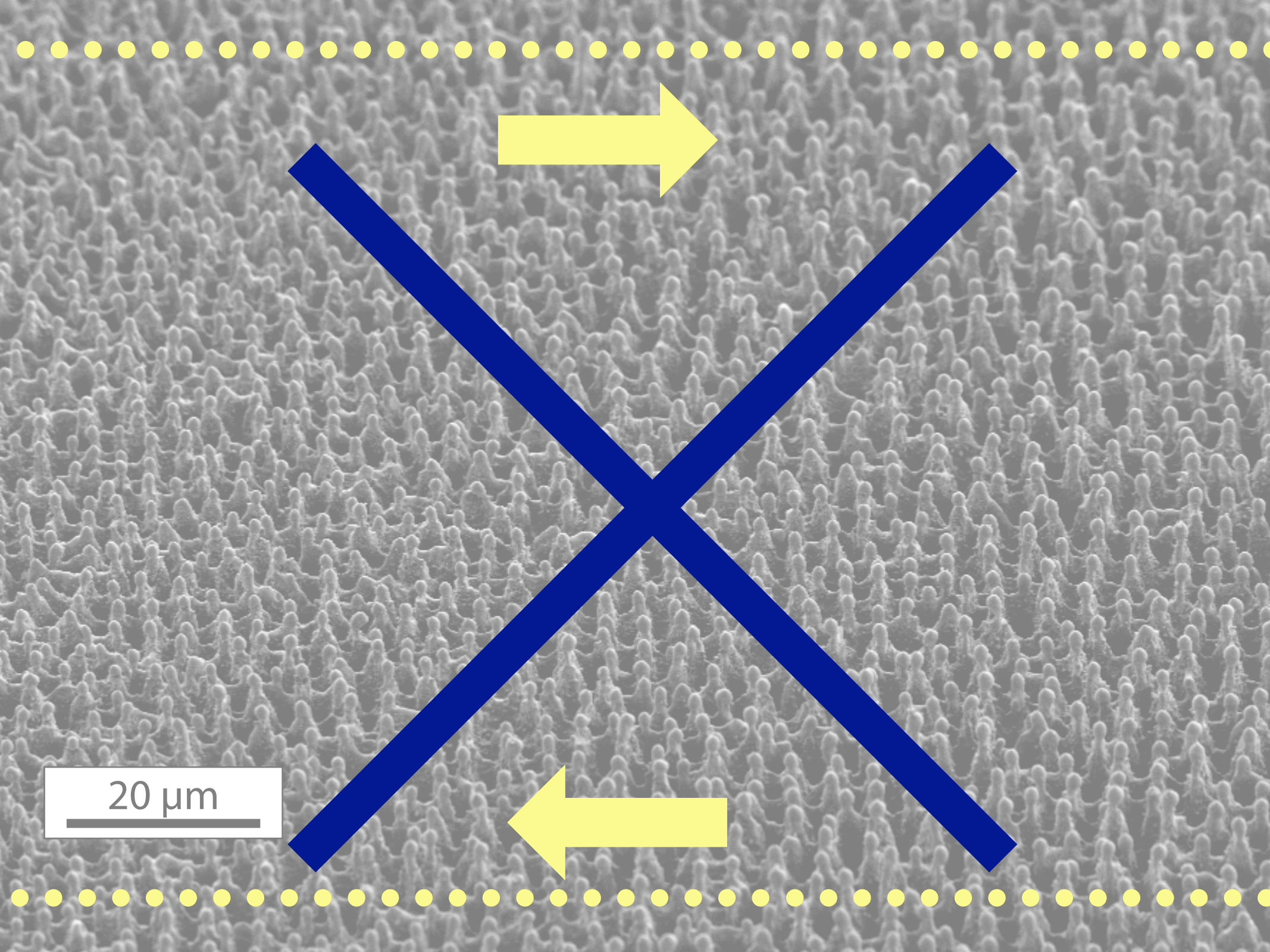
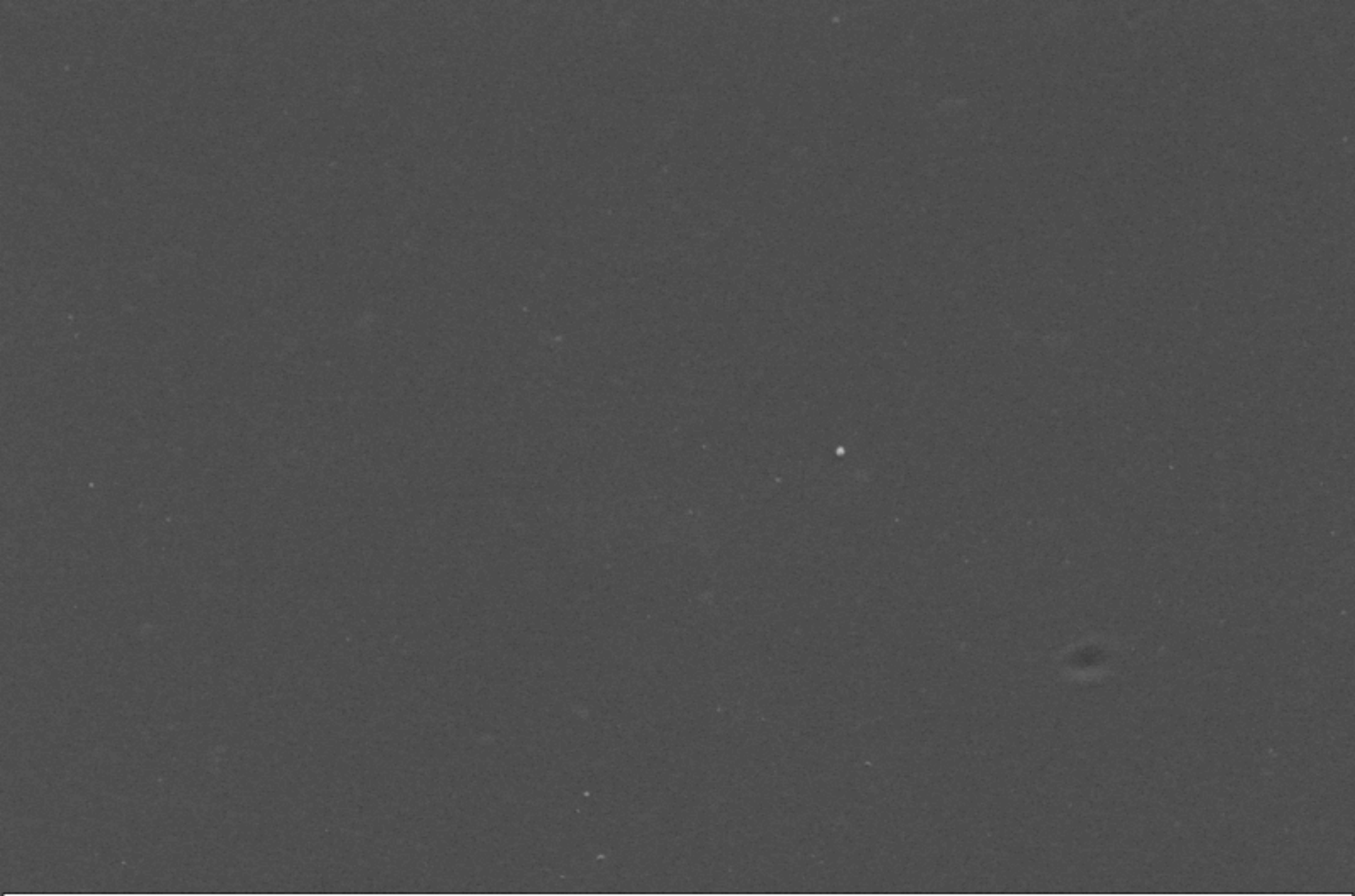

20 µm


20 µm


20 µm


20 µm



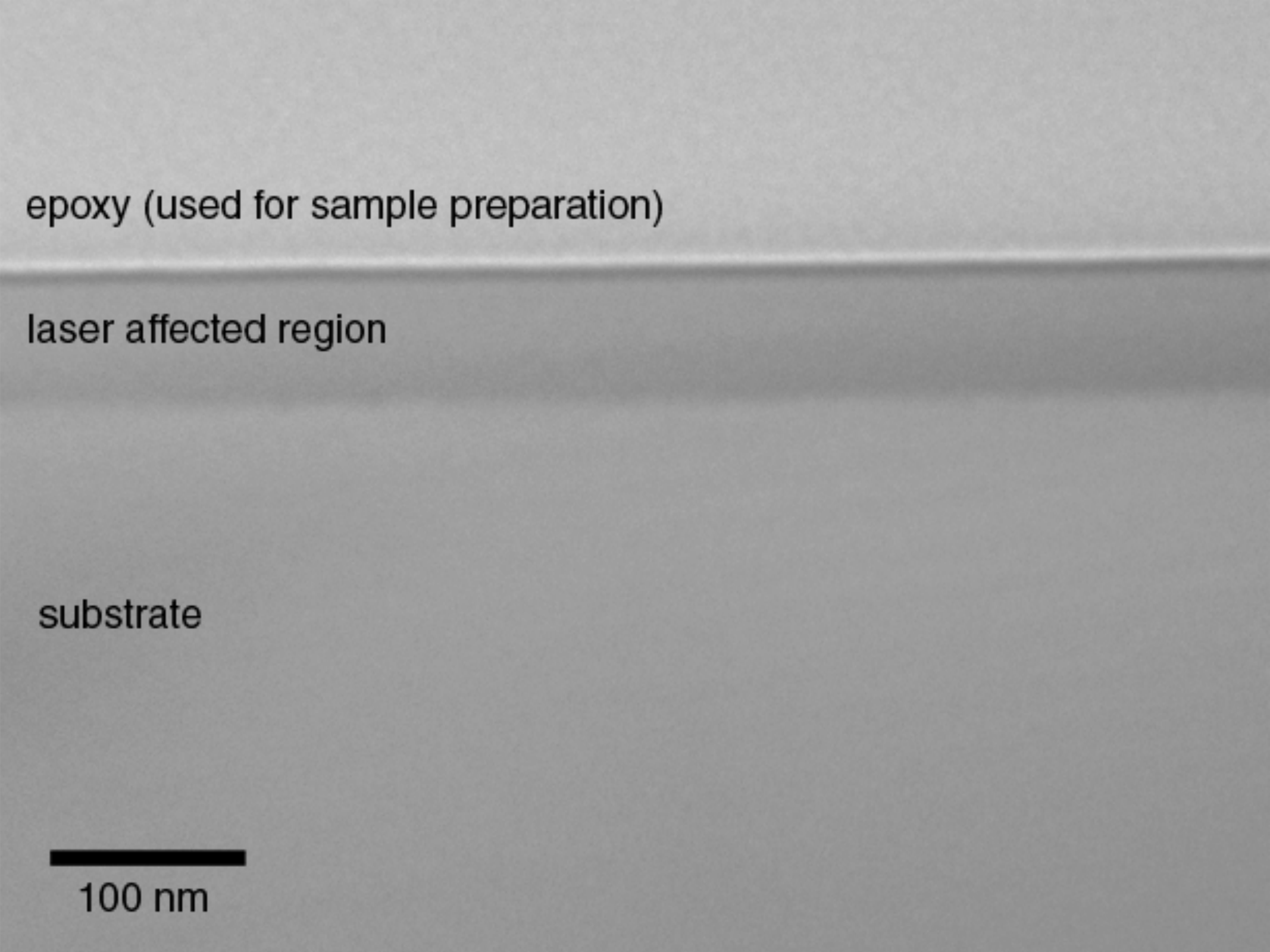
2 µm

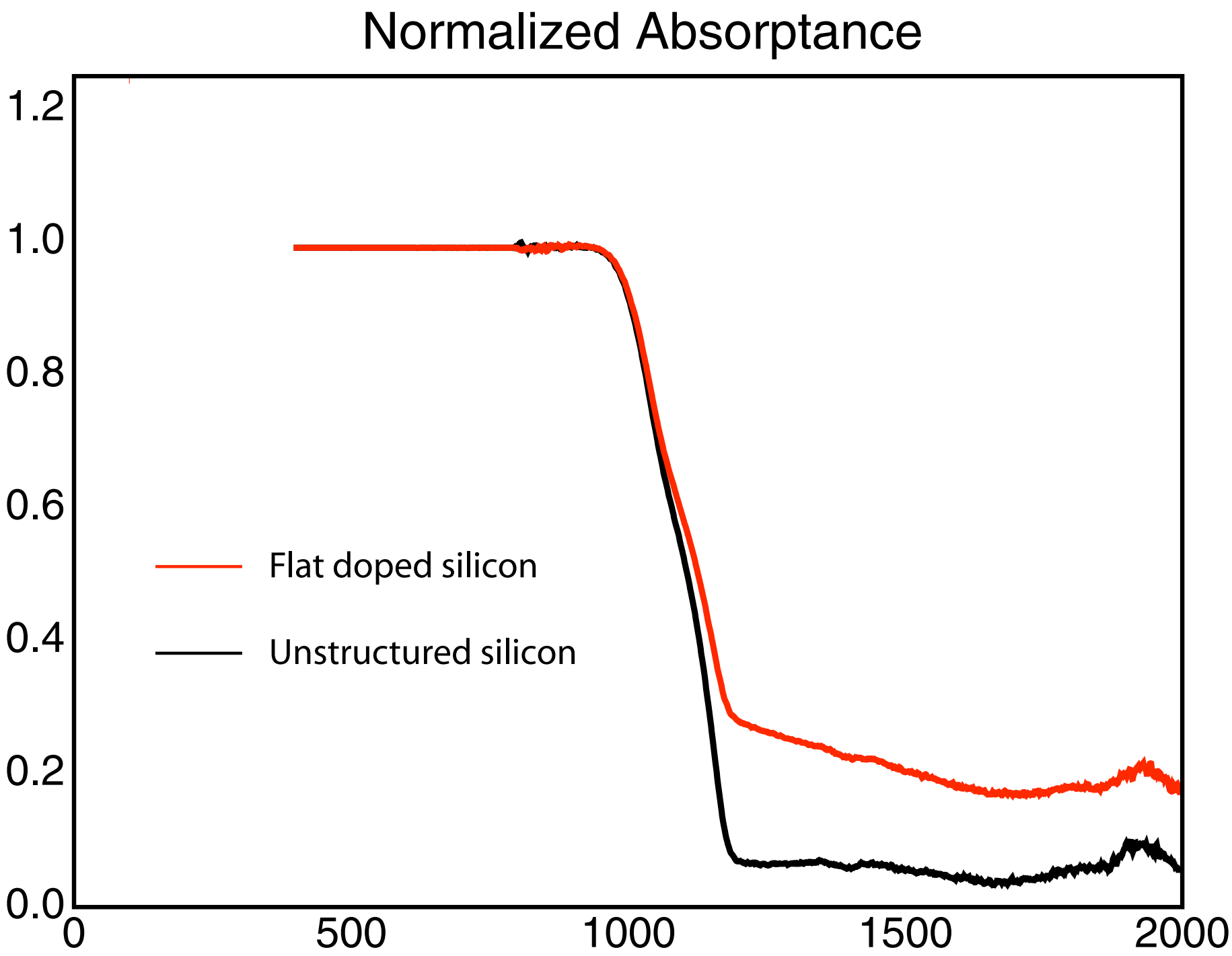
EHT = 10.00 kV
WD = 18.8 mm

Signal A = SE2
Photo No. = 5089

Date :24 Jan 2008
Time :8:54:17

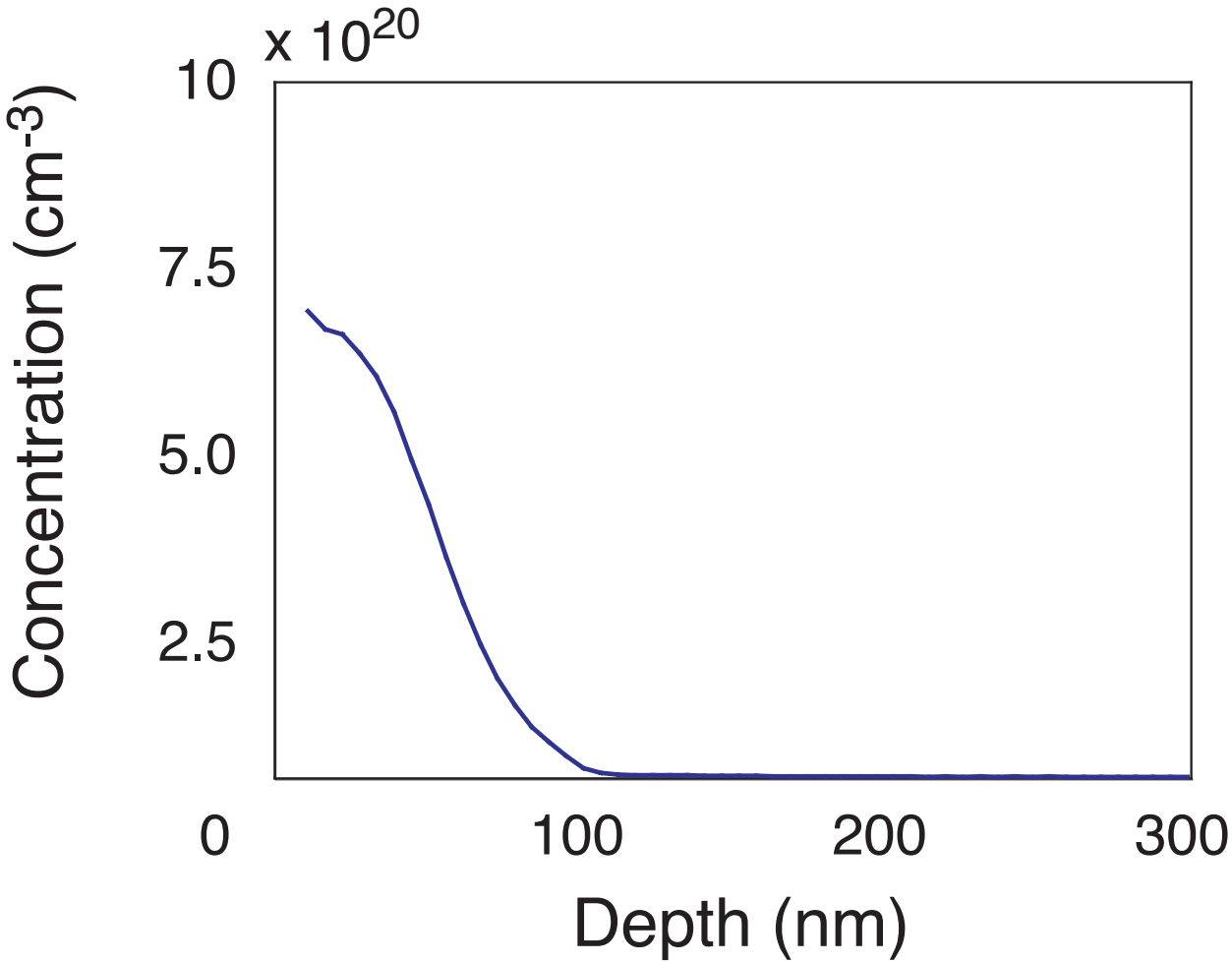
ZEISS


epoxy (used for sample preparation)
laser affected region
substrate
100 nm


Normalized Absorptance
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
500
1000
1500
2000
Flat doped silicon
Unstructured silicon

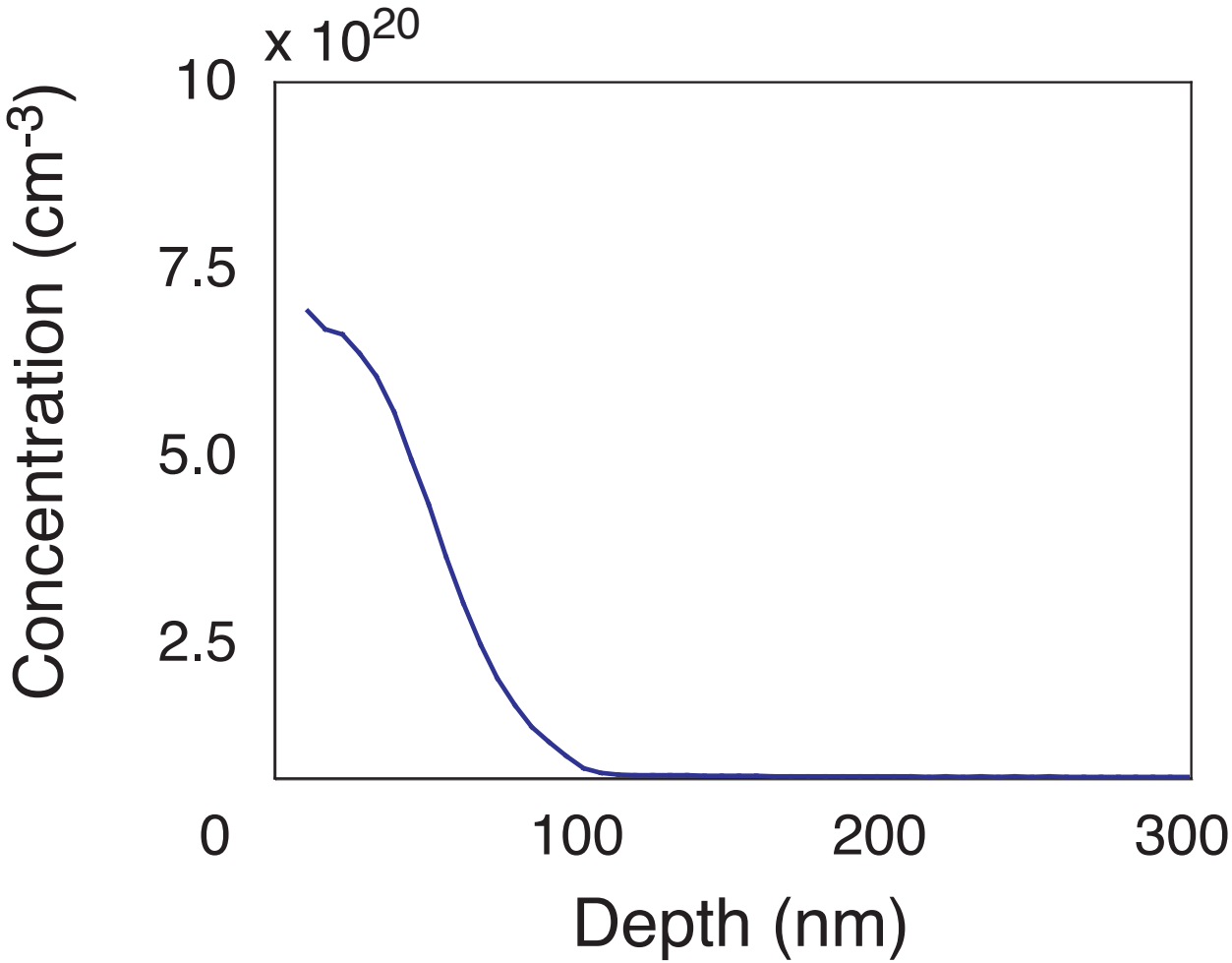
New characterization techniques

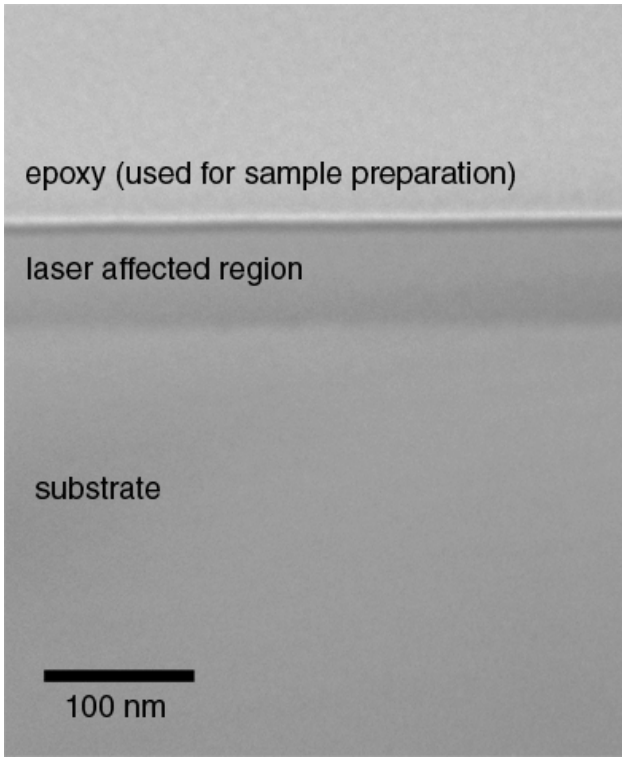
secondary ion mass spectroscopy (SIMS)

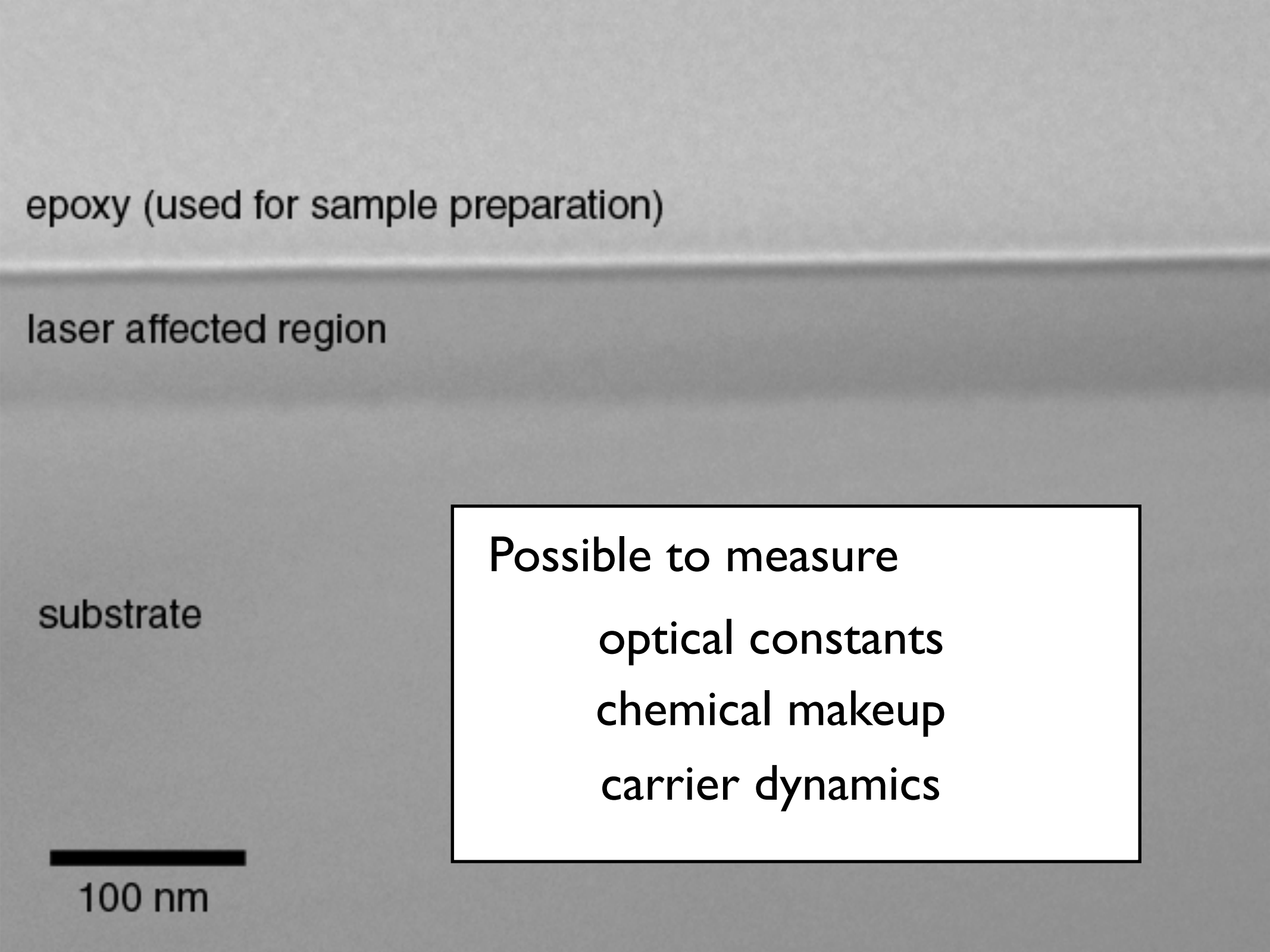


New characterization techniques

secondary ion mass spectroscopy (SIMS)







Possible to measure

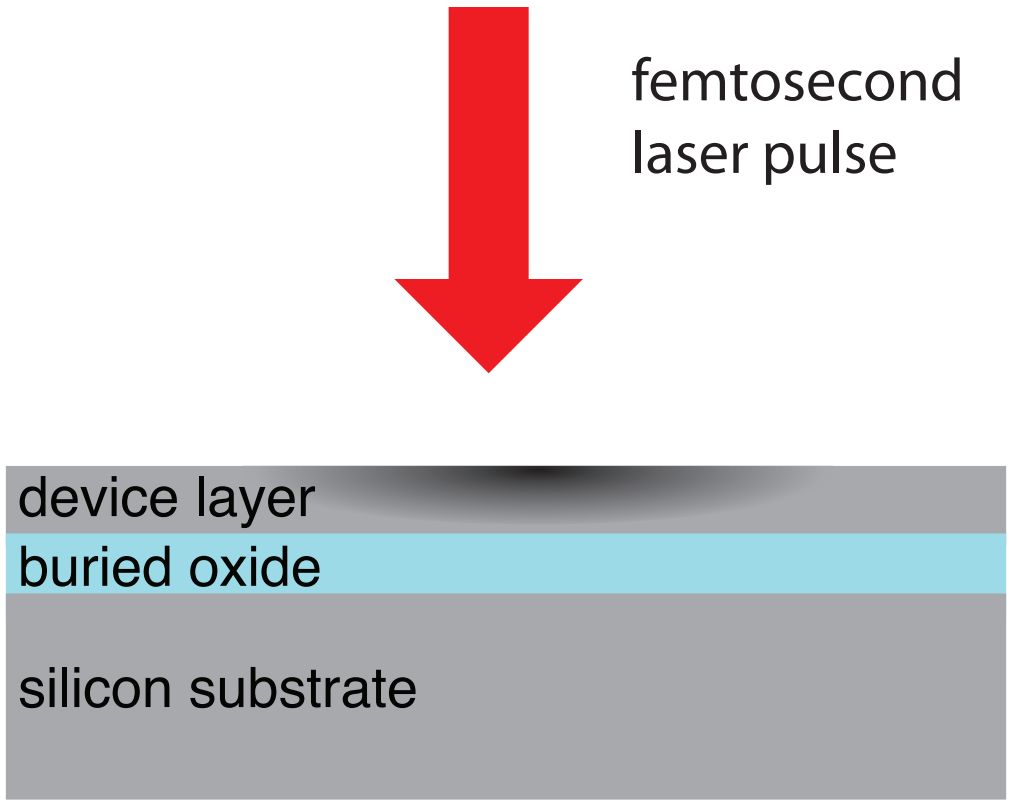
optical constants

chemical makeup

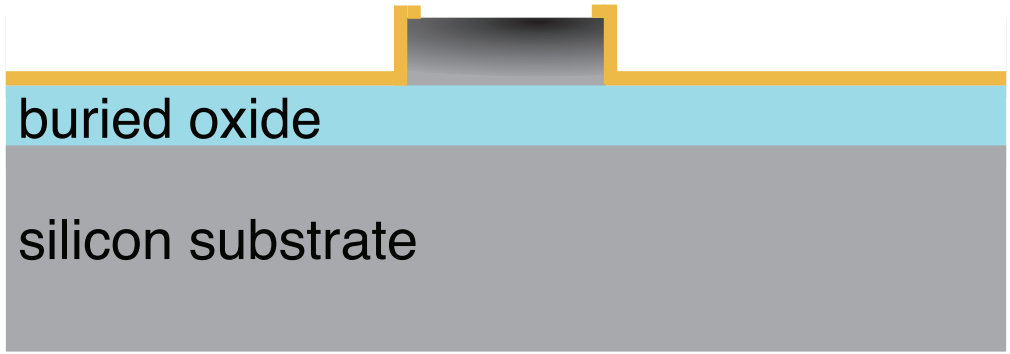
carrier dynamics

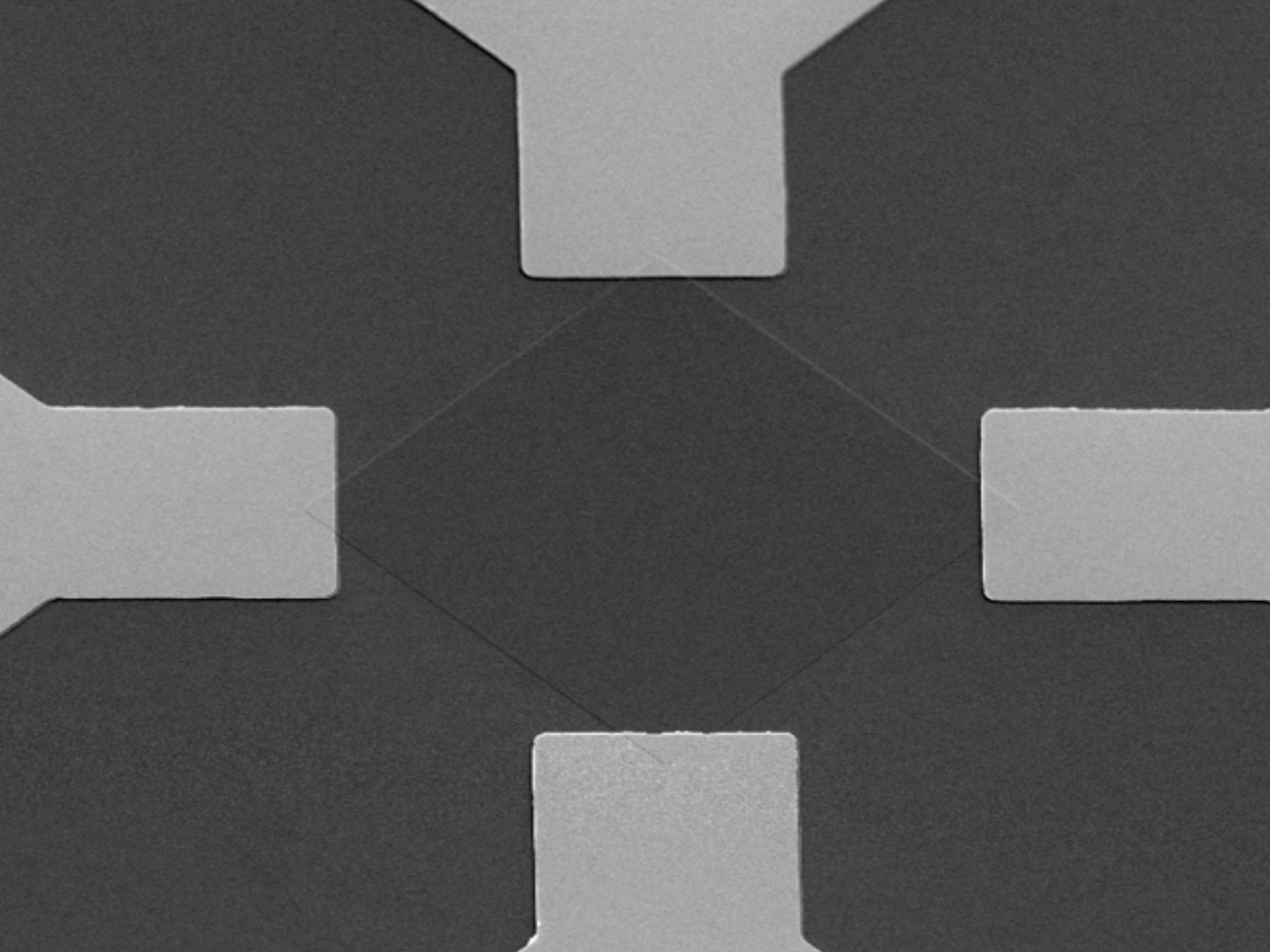
Isolate surface properties

Isolate surface properties



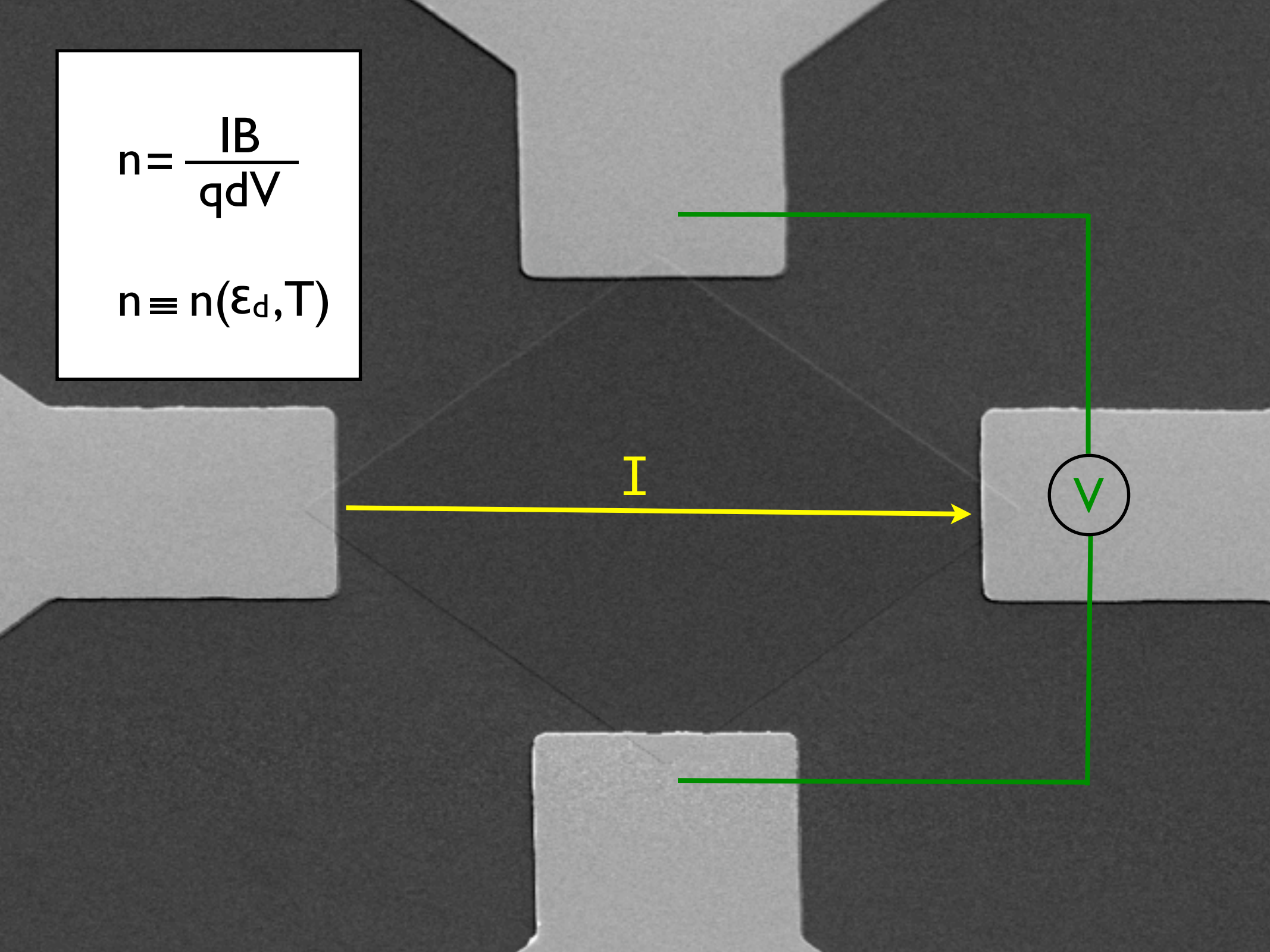
Isolate surface properties



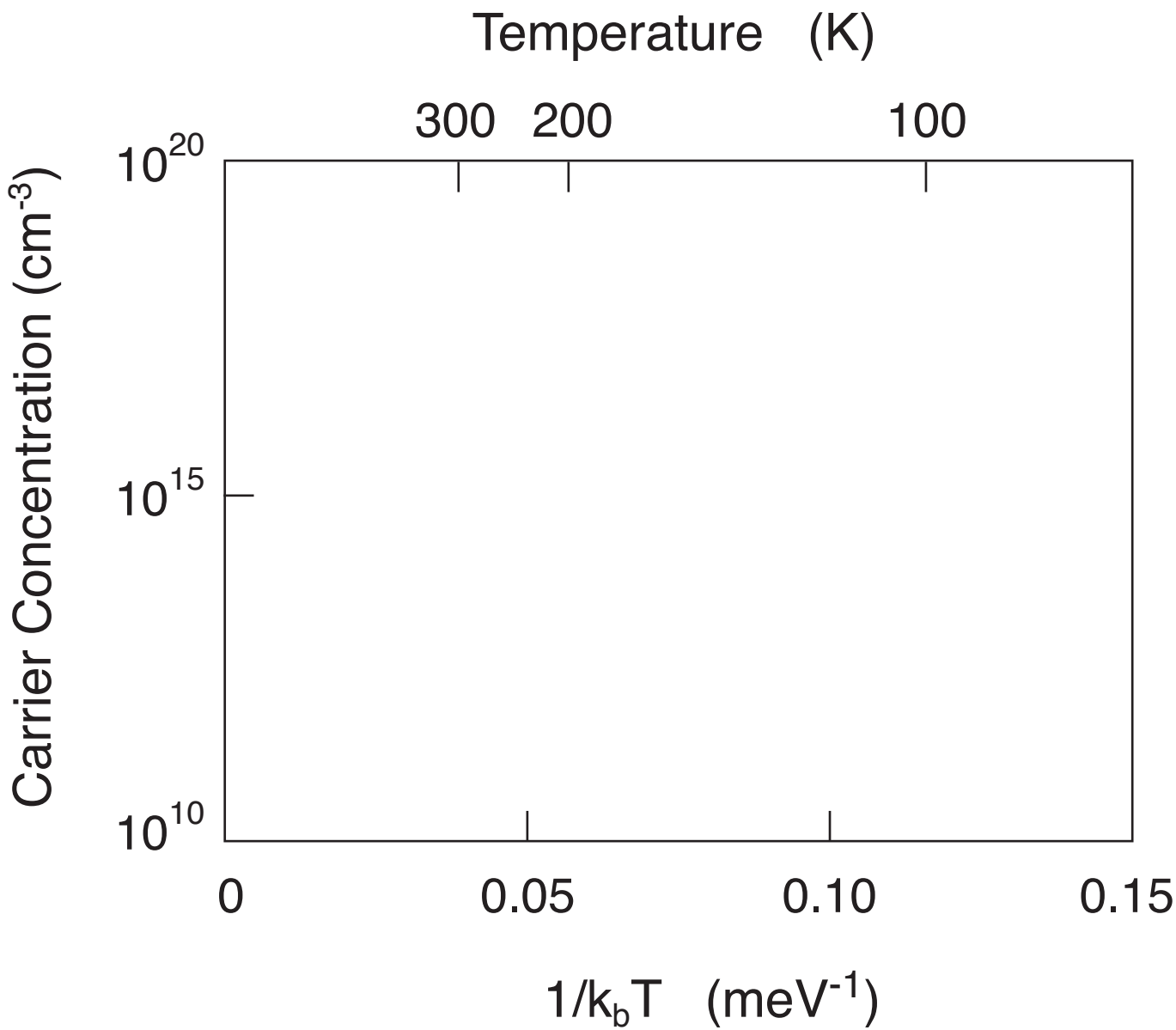


$$n = \frac{IB}{qdV}$$

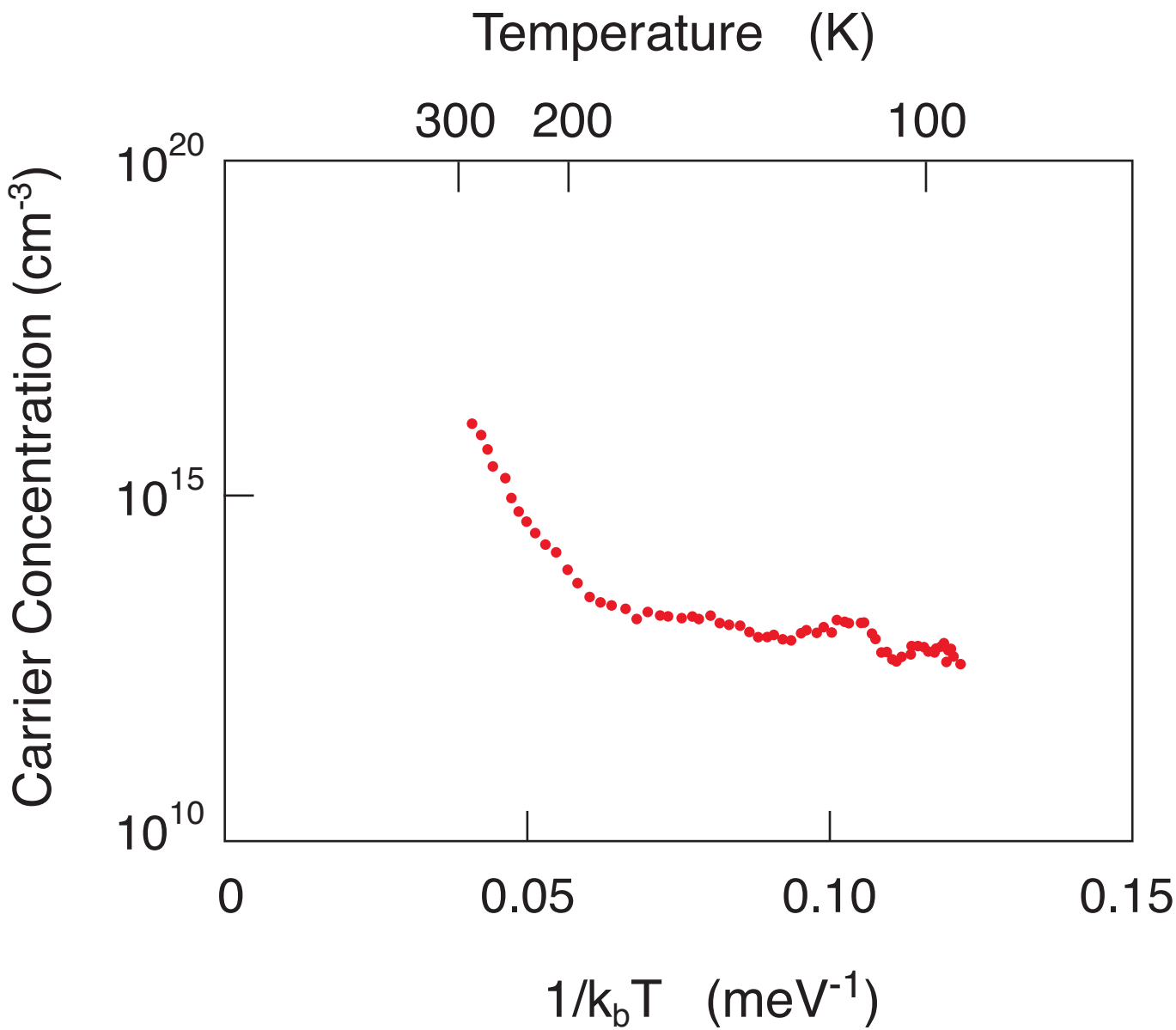
$$n \equiv n(\varepsilon_d, T)$$



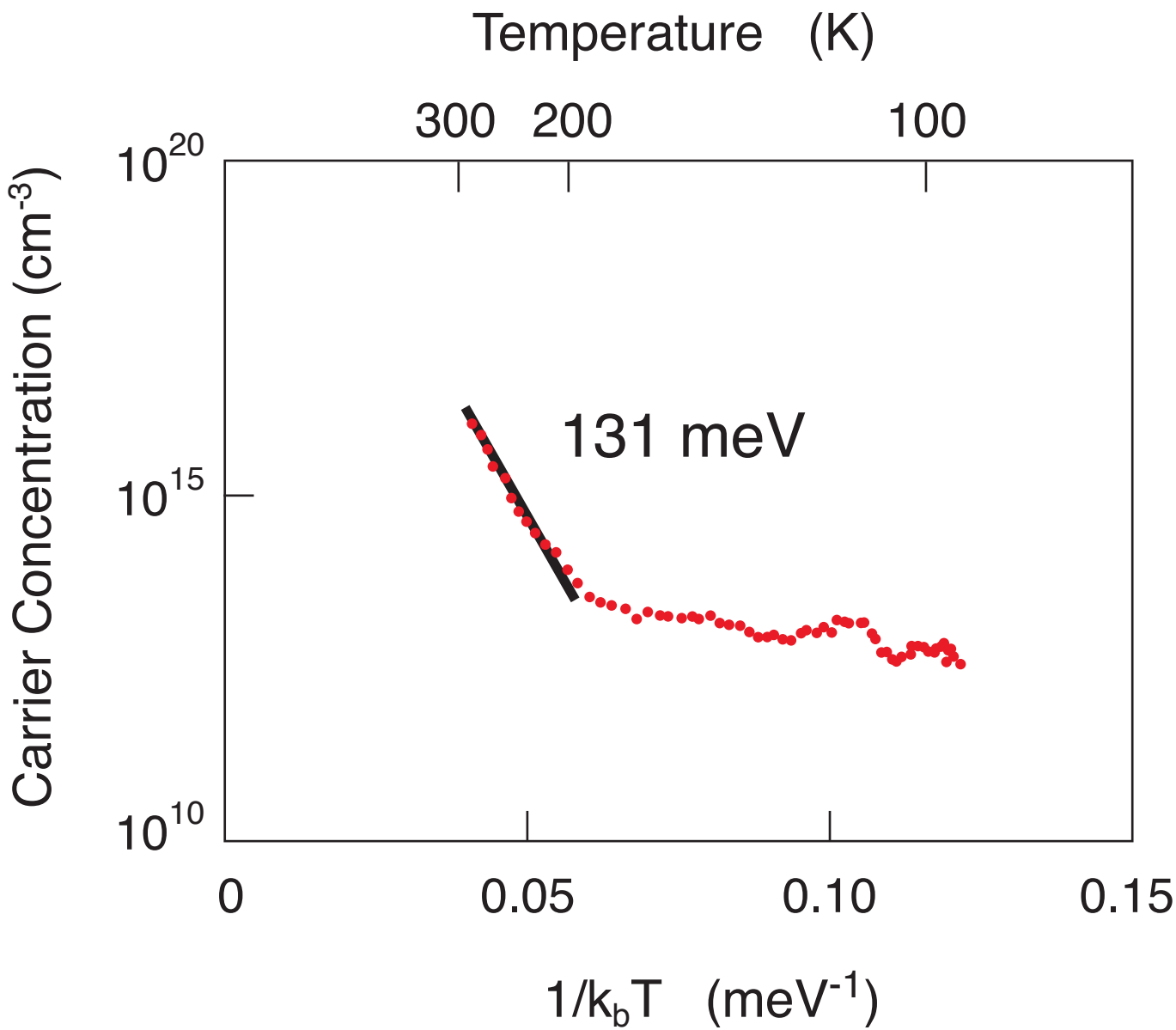
Dopant levels from Hall measurements



Dopant levels from Hall measurements



Dopant levels from Hall measurements



Conclusions

- specular laser-doped materials
- new techniques to characterize laser doped materials
- 130-meV activation energy

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Mike Aziz, Brion Bob

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Thanks! Questions?

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http://mazur-www.harvard.edu