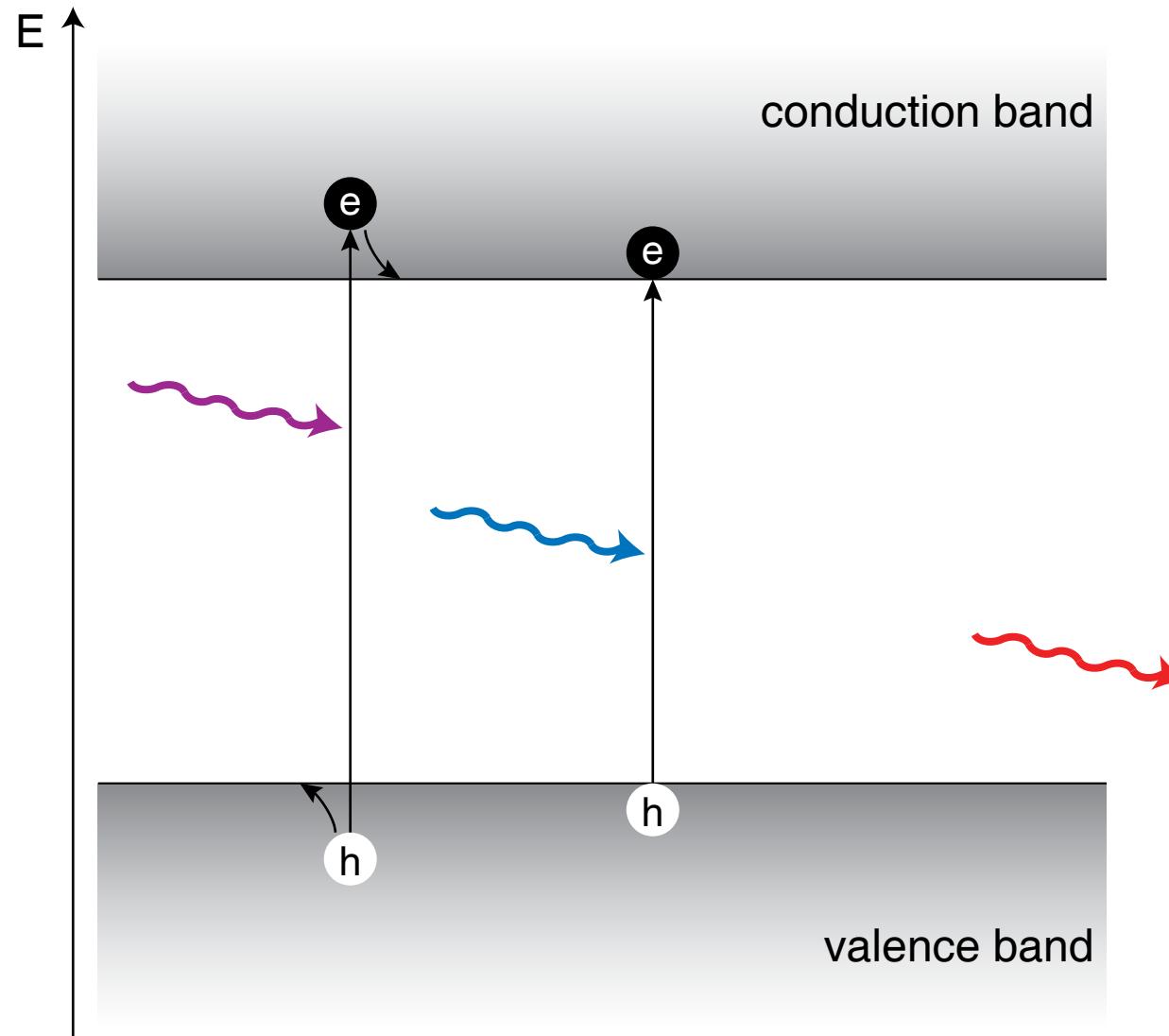


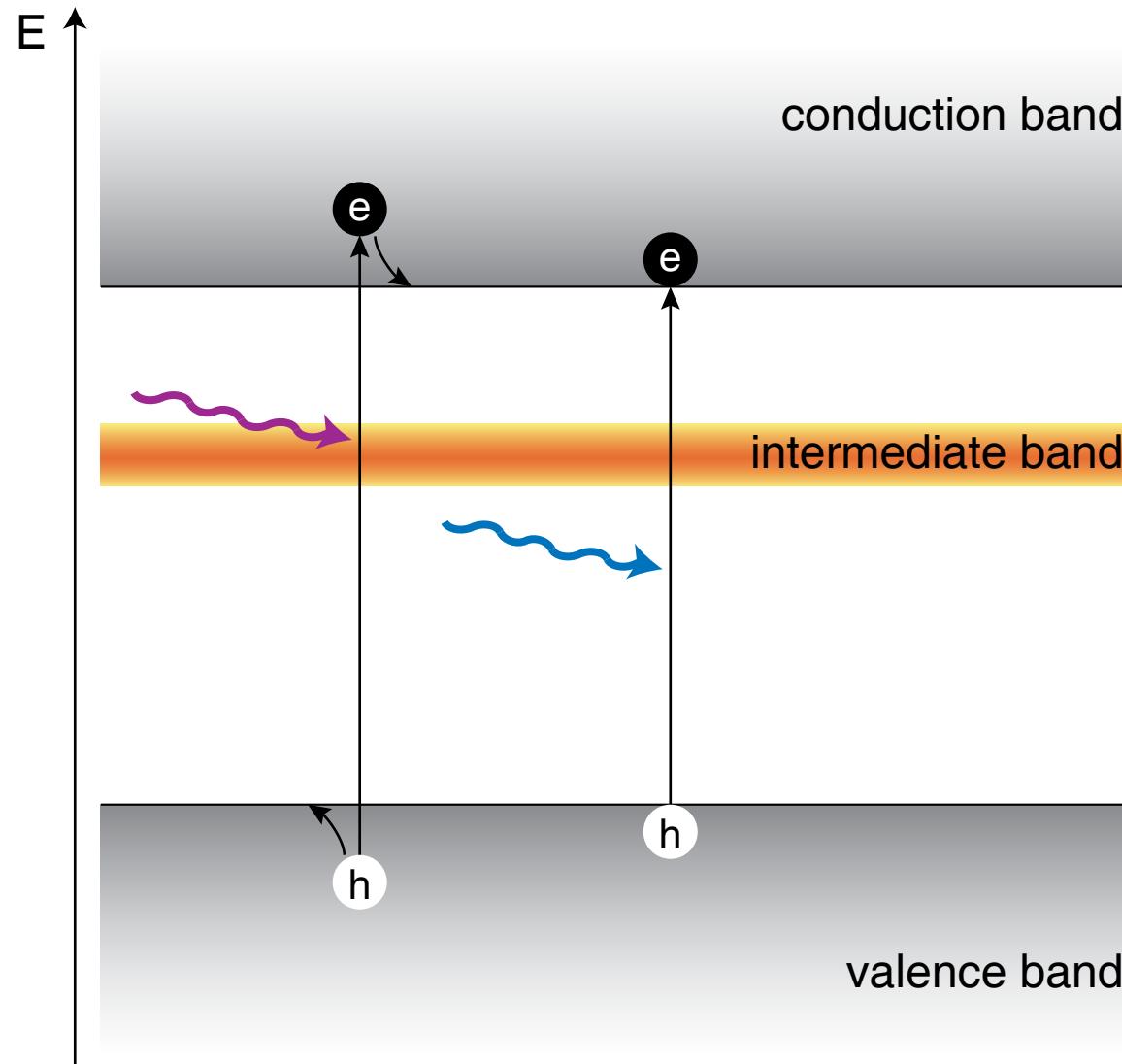
# **Femtosecond laser doped silicon for photovoltaic applications**

**Meng-Ju Sher, Mark T. Winkler, Yu-Ting Lin and Eric Mazur**  
**Harvard University**  
**Photonics West, CA**  
**2011/01/27**

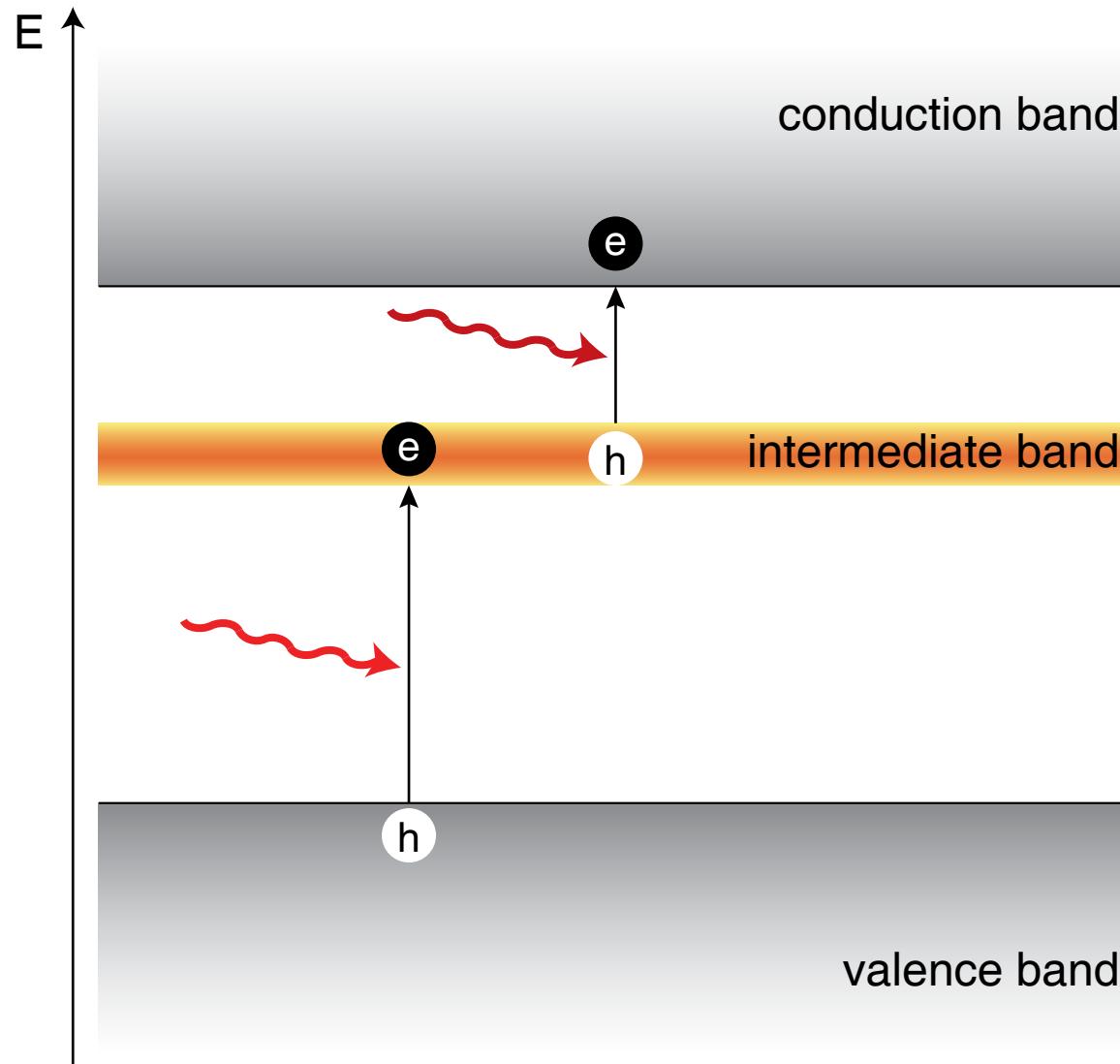
# Intermediate-band photovoltaics



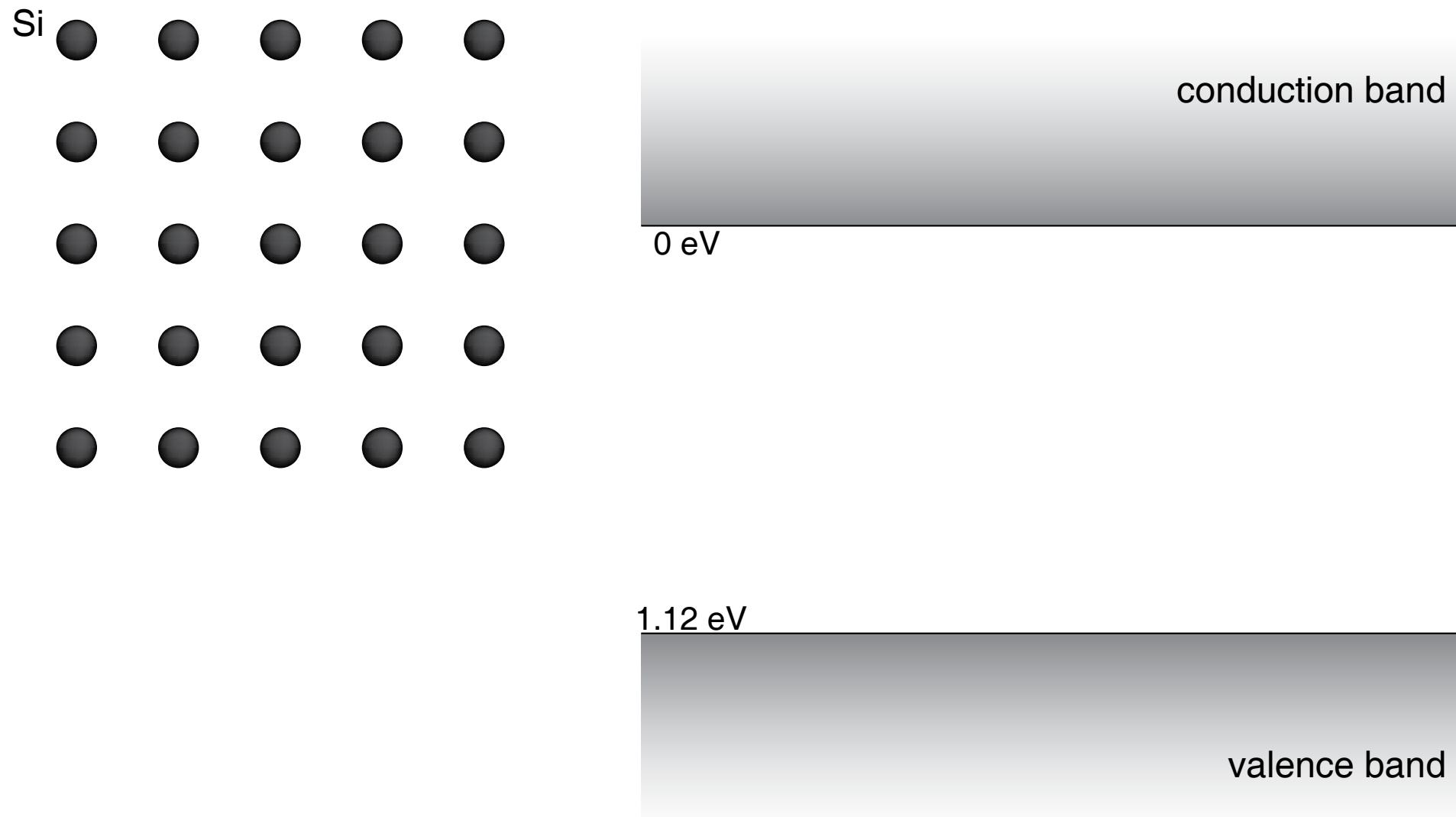
# Intermediate-band photovoltaics



# Intermediate-band photovoltaics

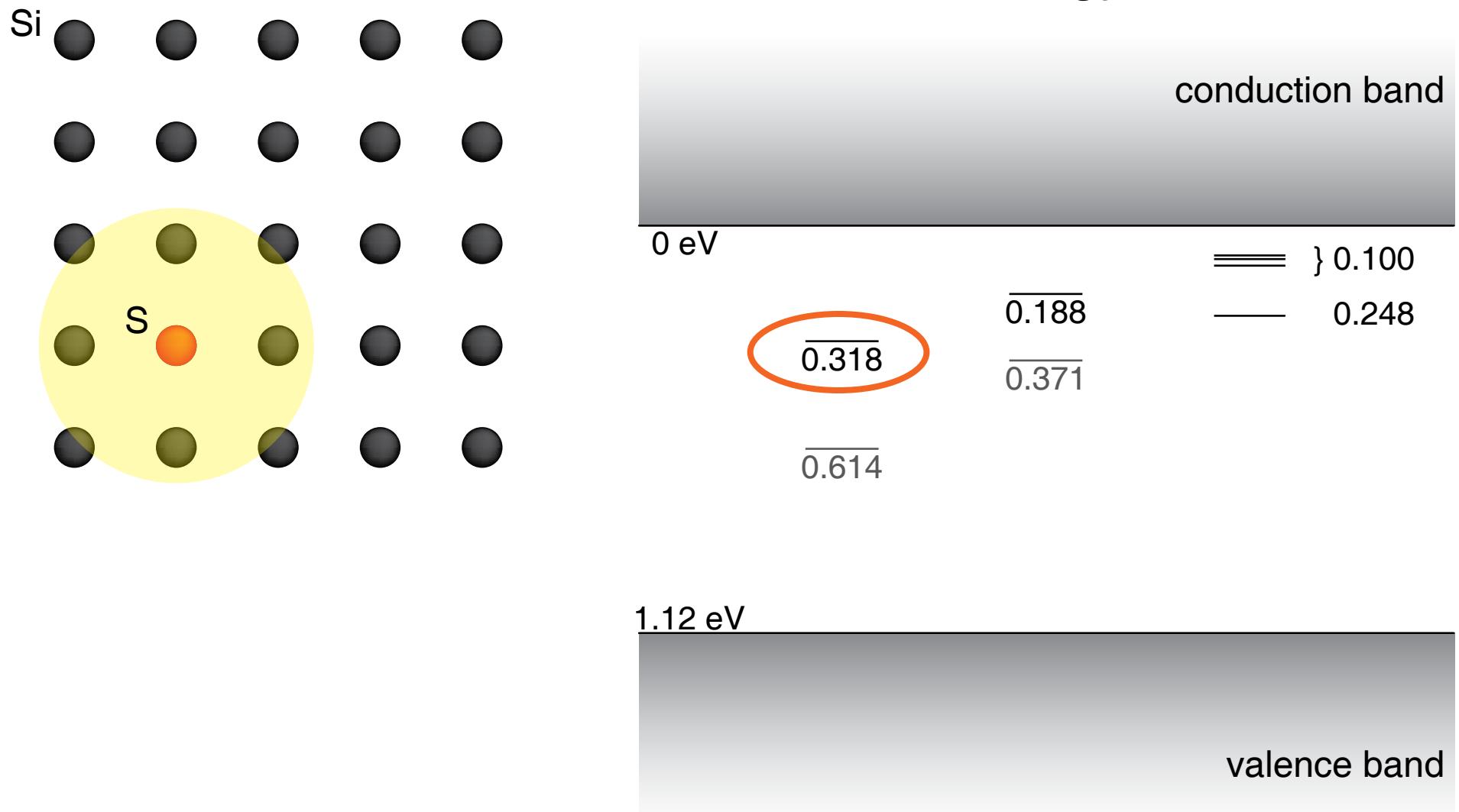


# Intermediate-band photovoltaics



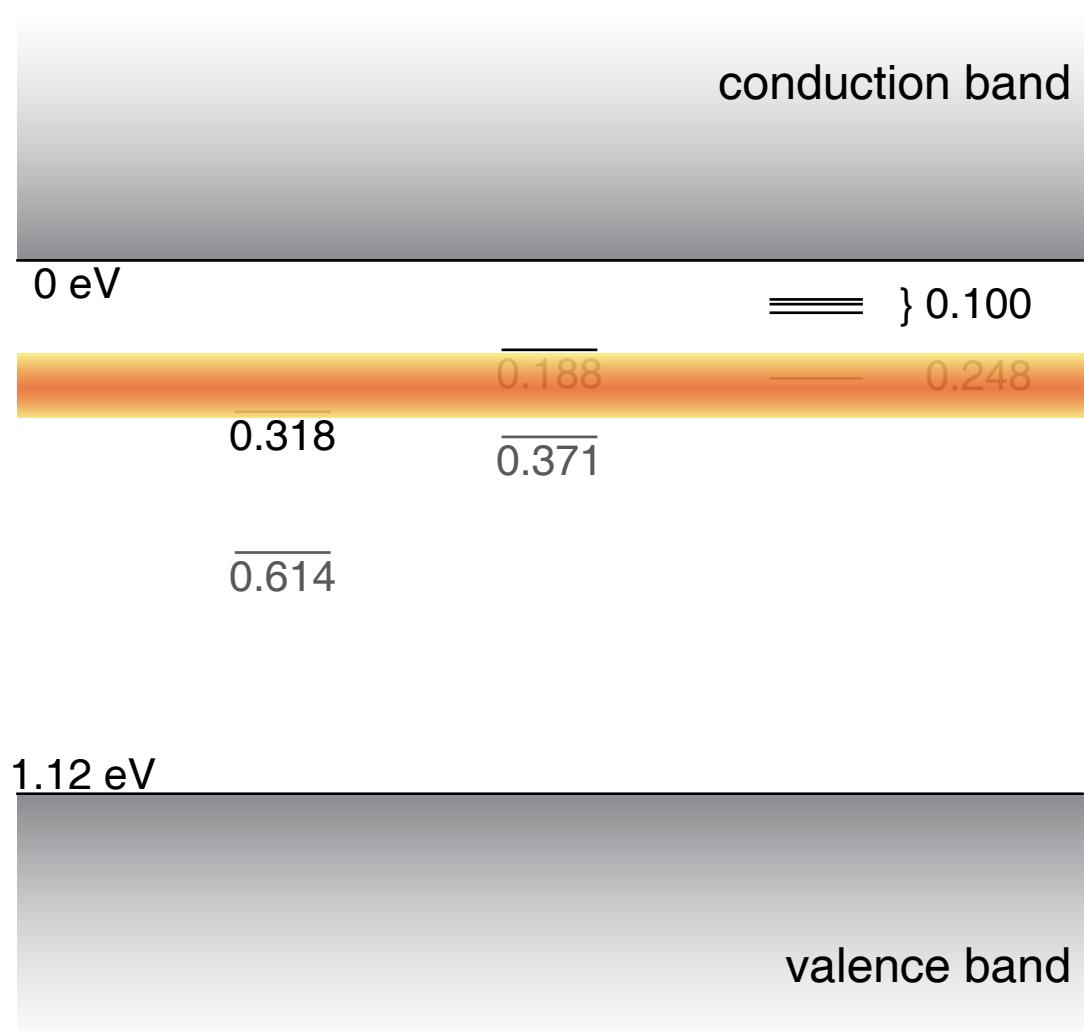
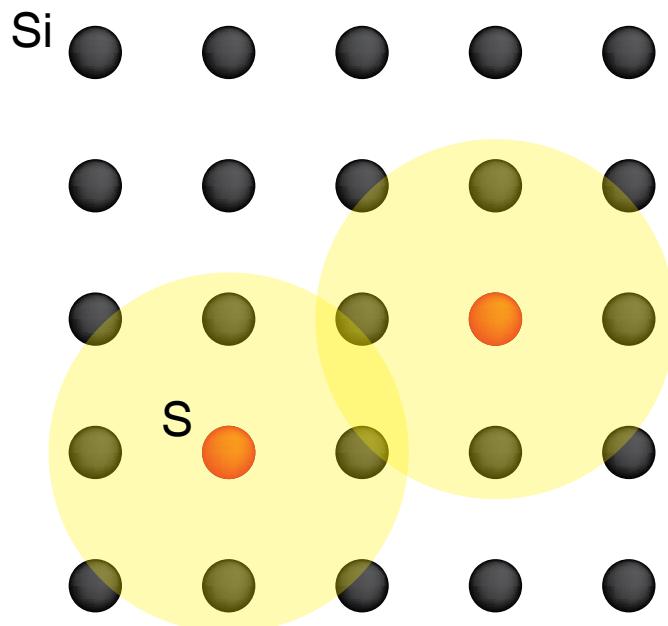
# Intermediate-band photovoltaics

sulfur energy levels



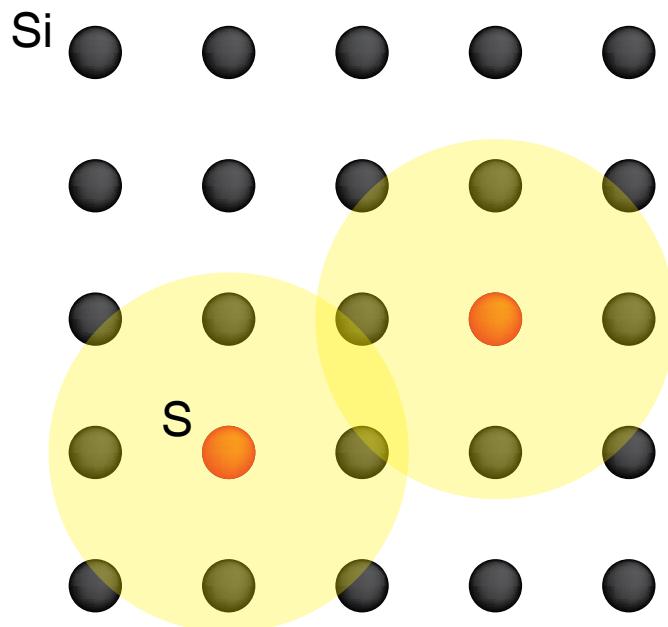
# Intermediate-band photovoltaics

metal-insulator transition

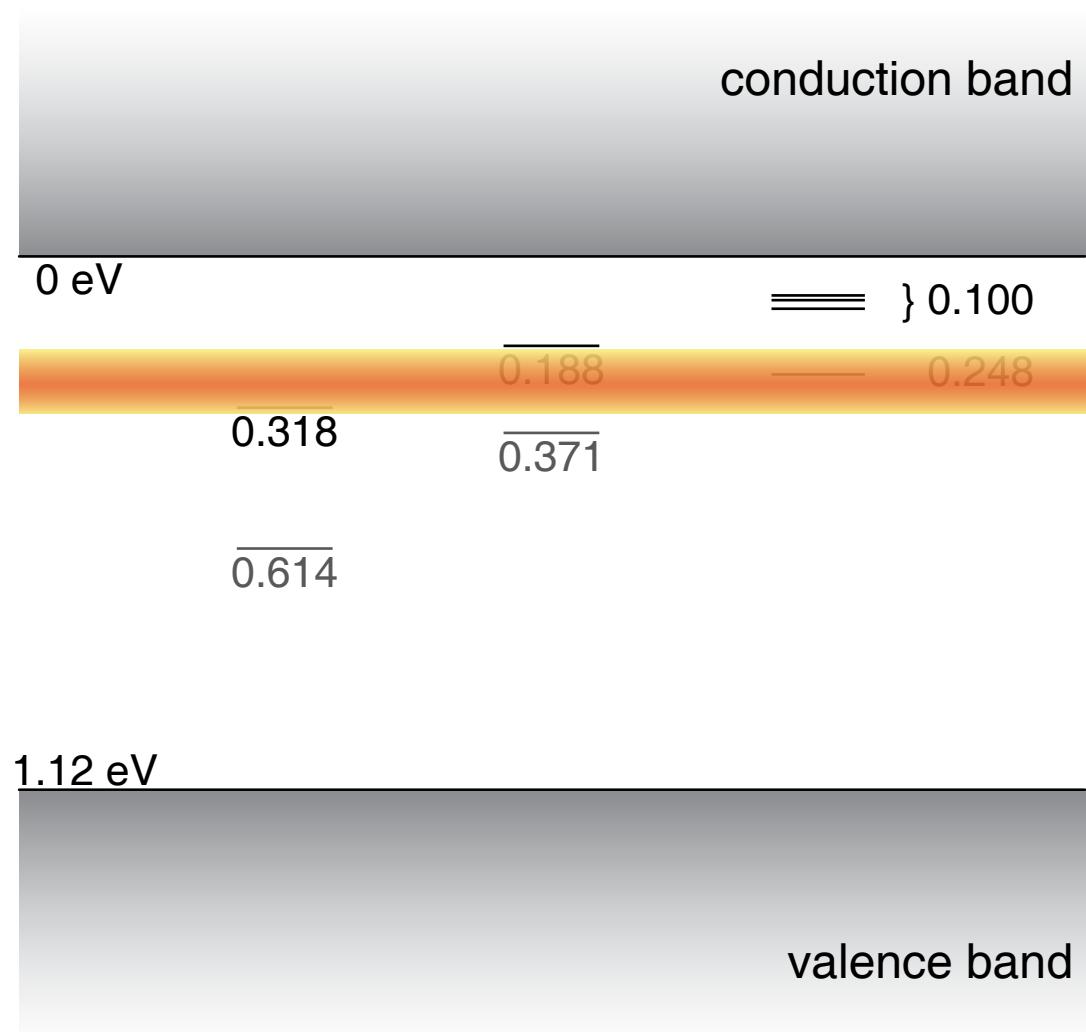


# Intermediate-band photovoltaics

metal-insulator transition

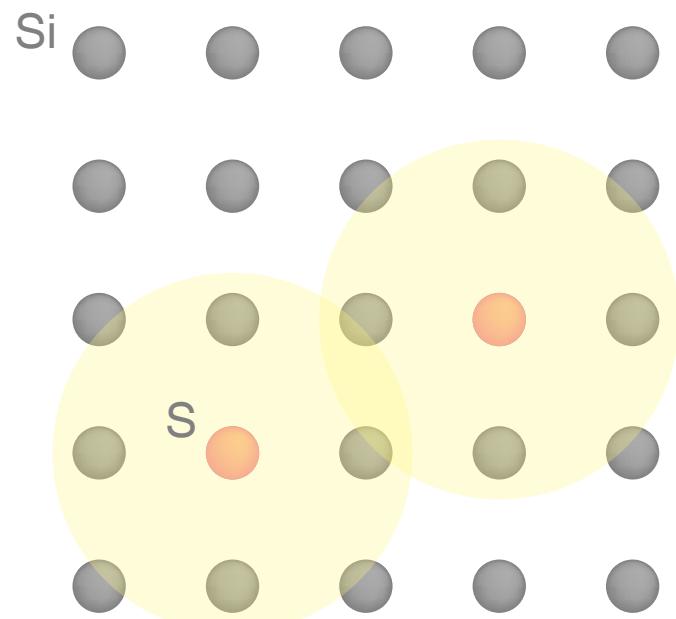


deep level  
high concentration

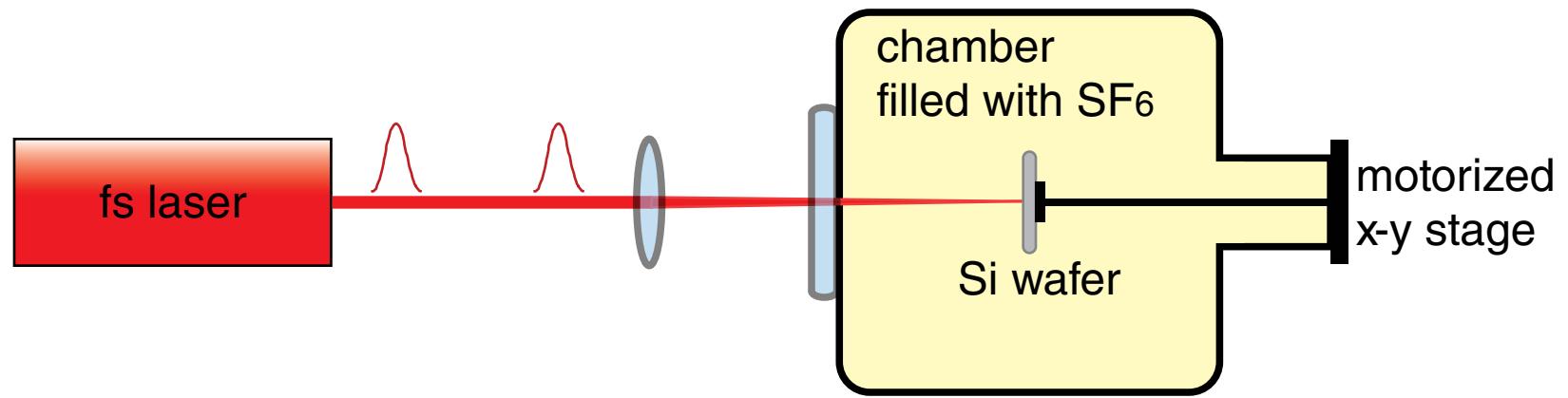


# Outline

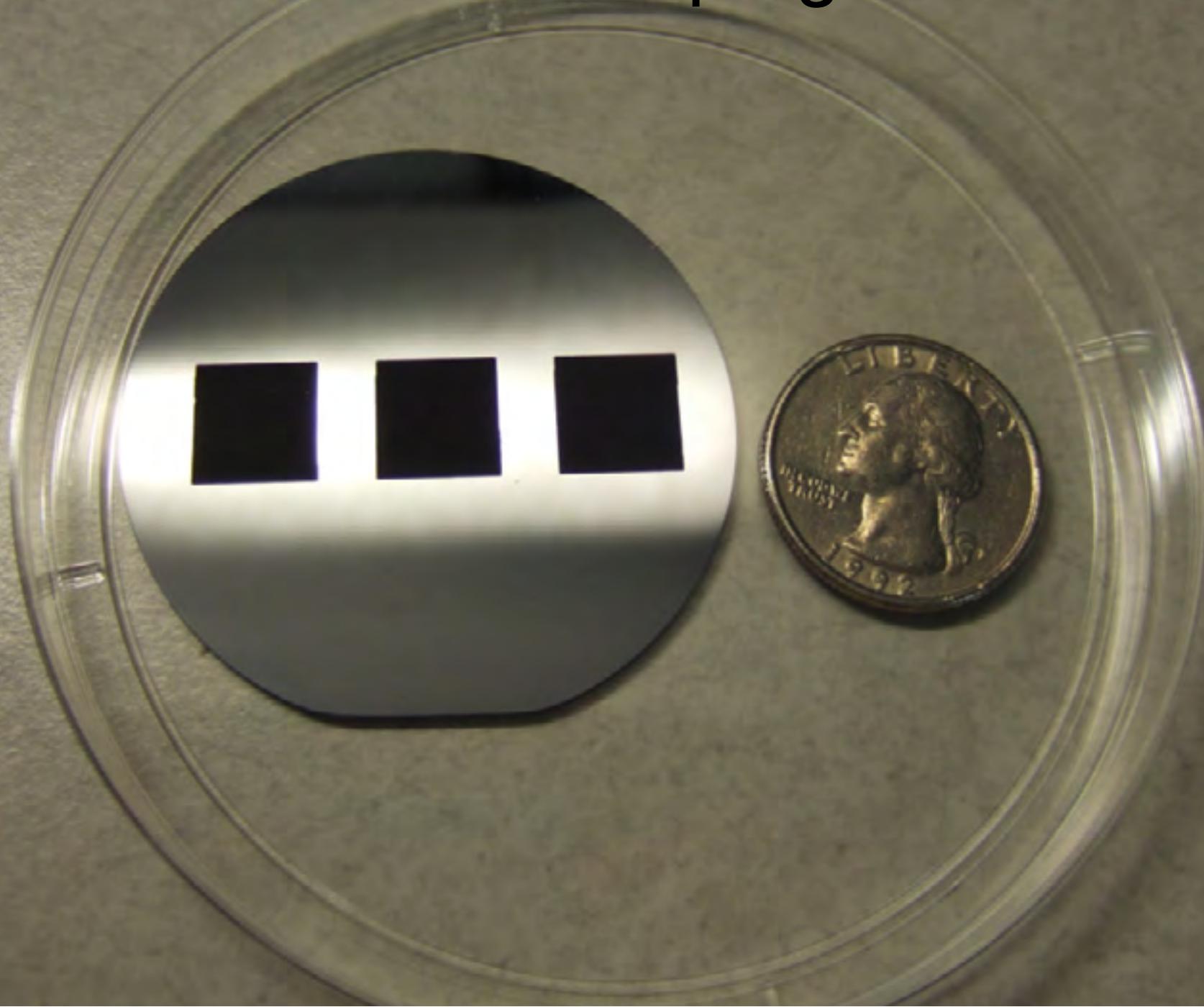
- fs-laser doping
- non-equilibrium dopant concentrations
- optical and electronic properties



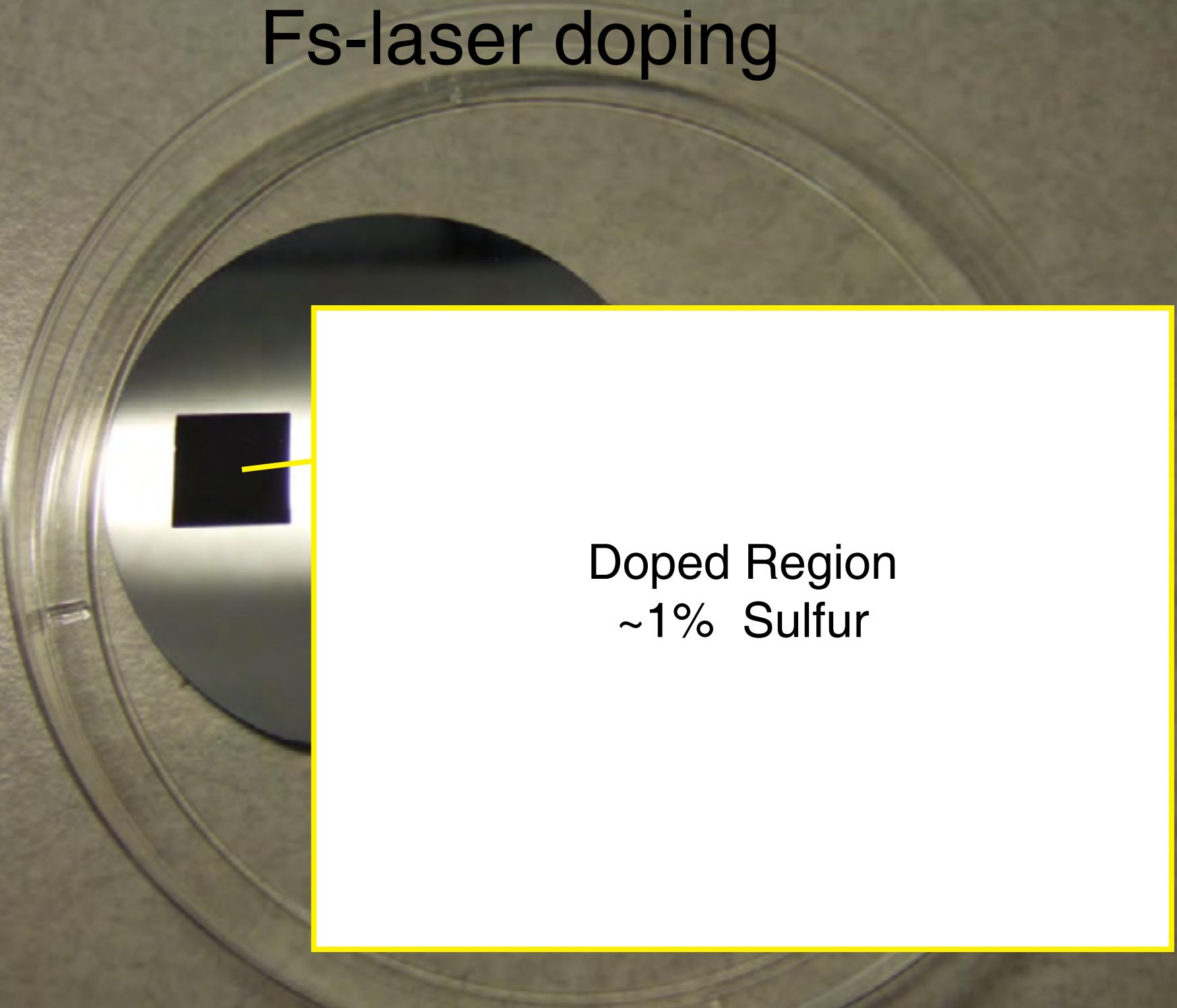
# Fs-laser doping



# Fs-laser doping

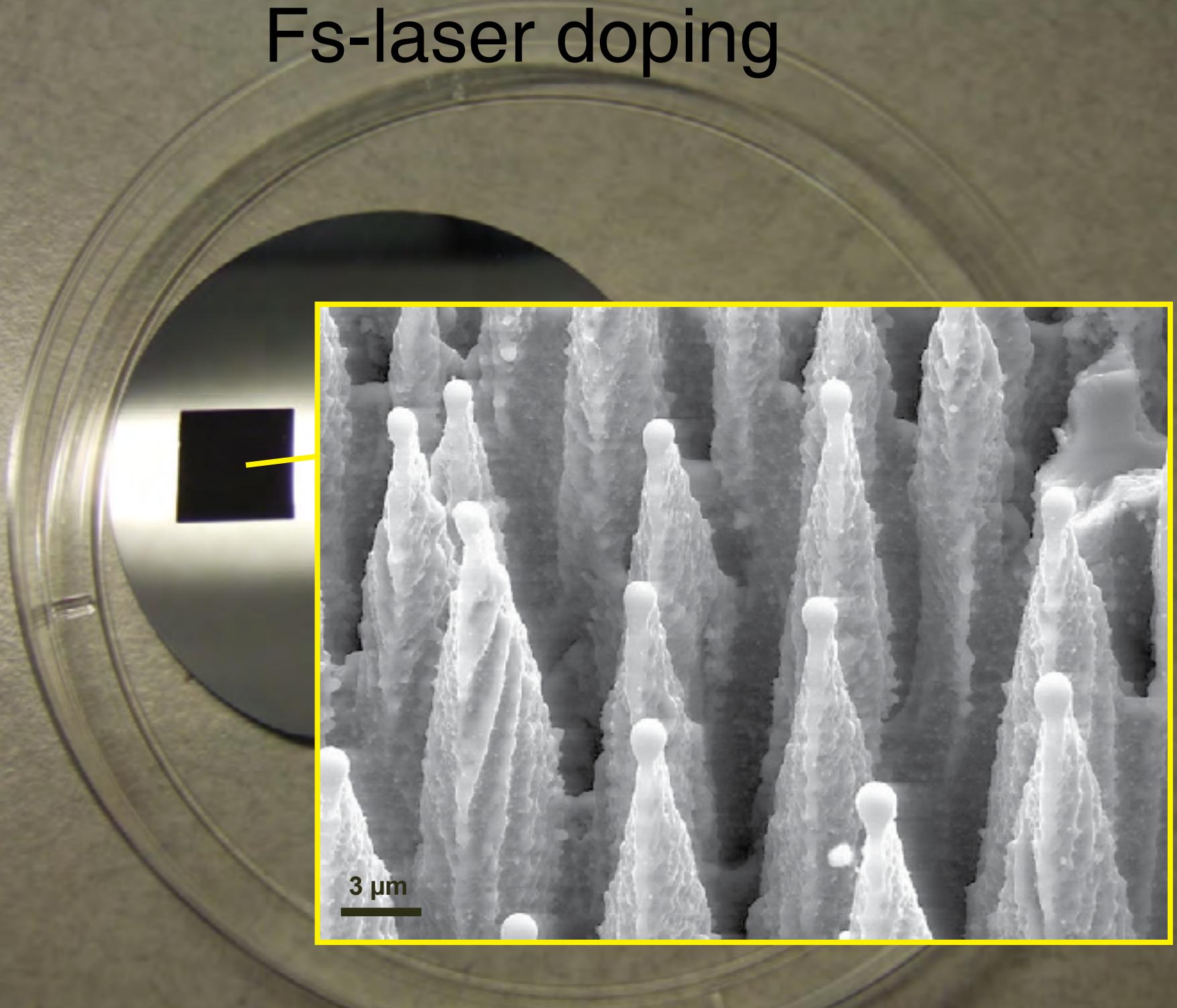


# Fs-laser doping

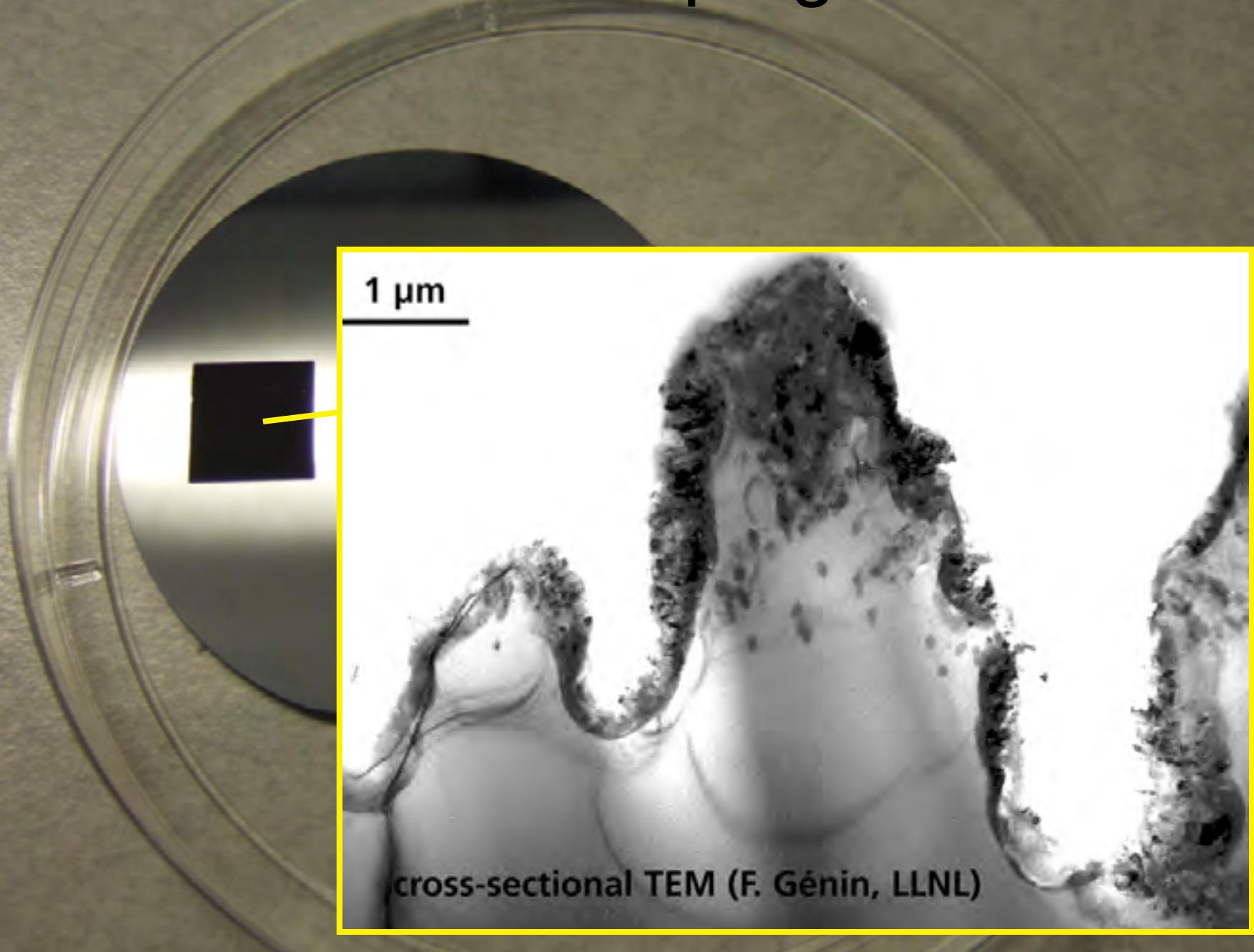


Doped Region  
~1% Sulfur

# Fs-laser doping

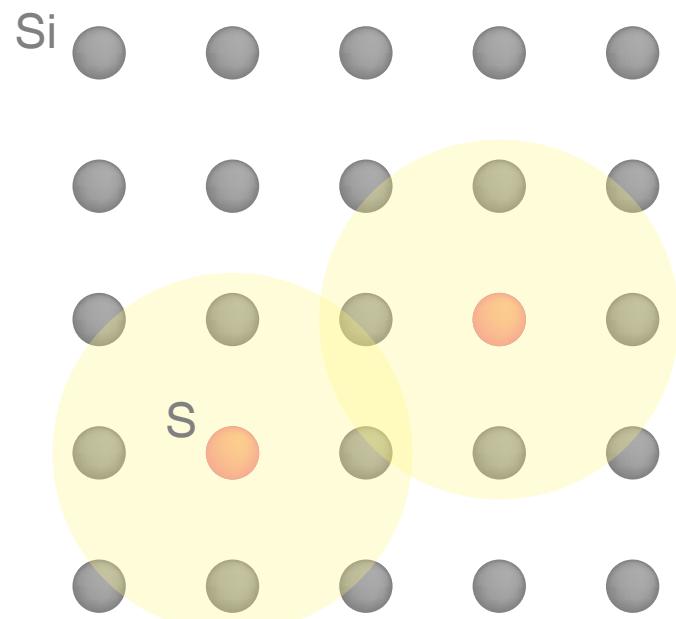


# Fs-laser doping



# Outline

- fs-laser doping
- non-equilibrium dopant concentrations
- optical and electronic properties



# Non-equilibrium dopant concentrations

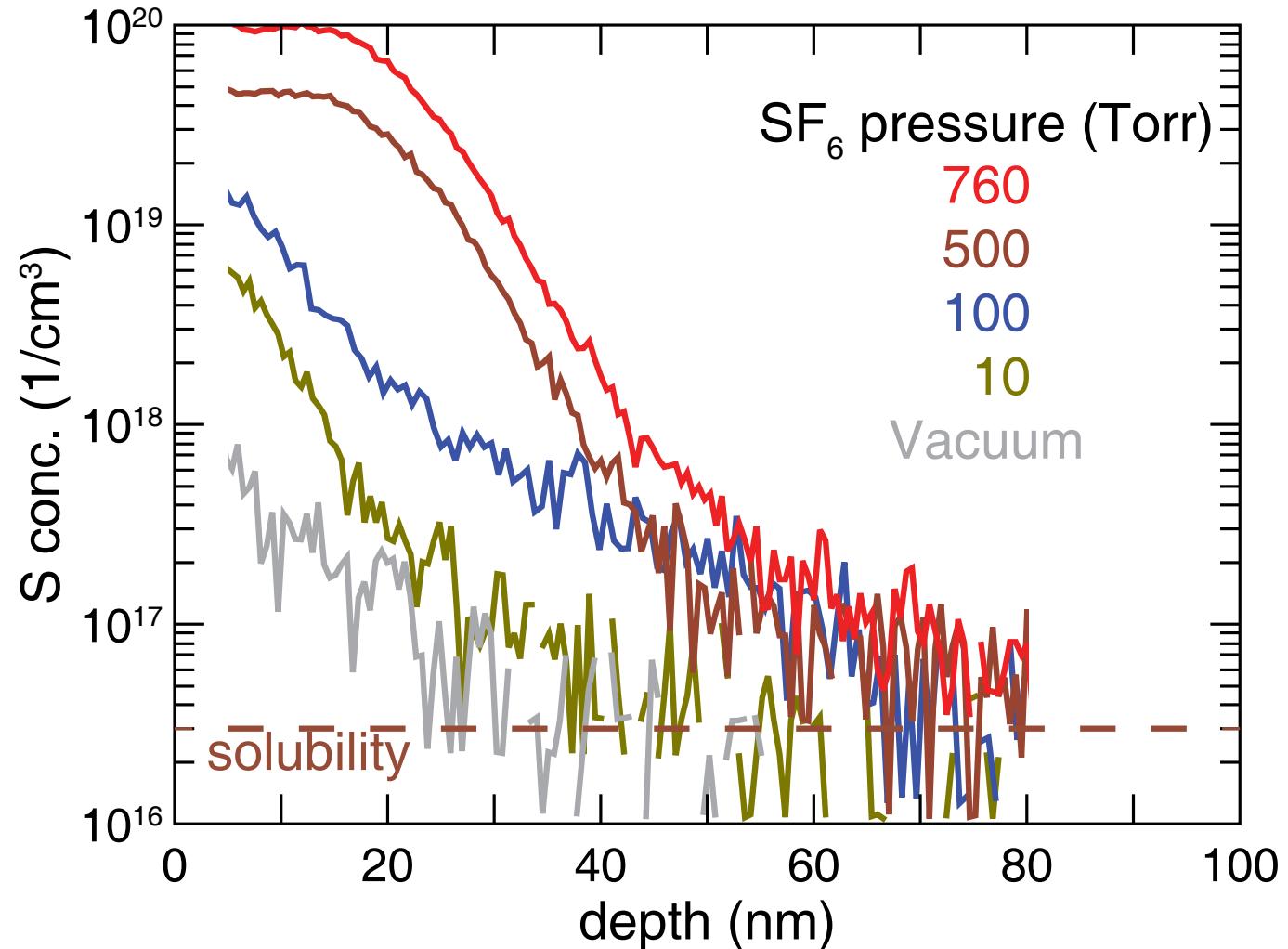
Si substrate

1 fs-laser pulse (800 nm, 80 fs, 6 kJ/m<sup>2</sup>)  
varying SF<sub>6</sub> pressure

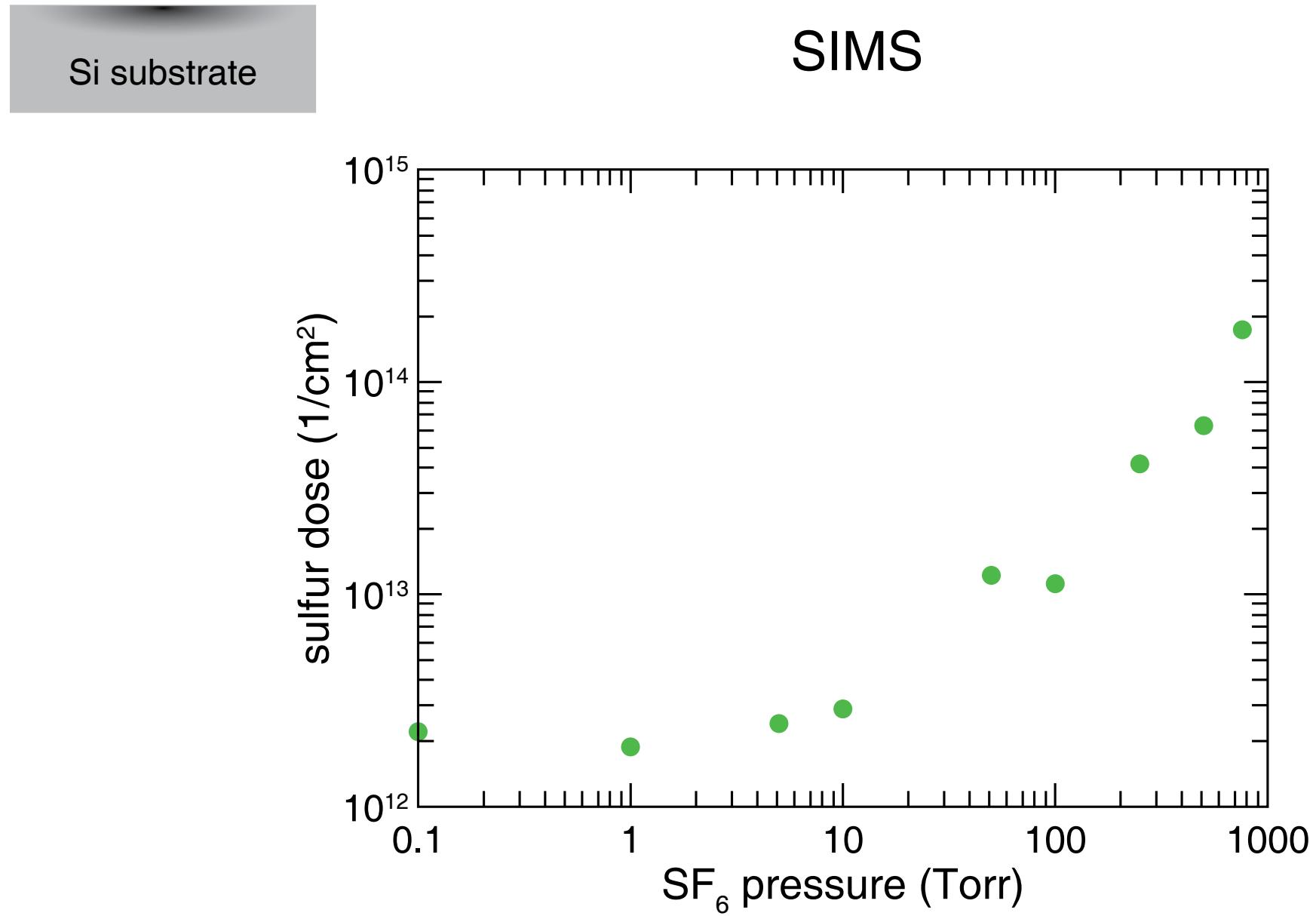
# Non-equilibrium dopant concentrations

Si substrate

SIMS

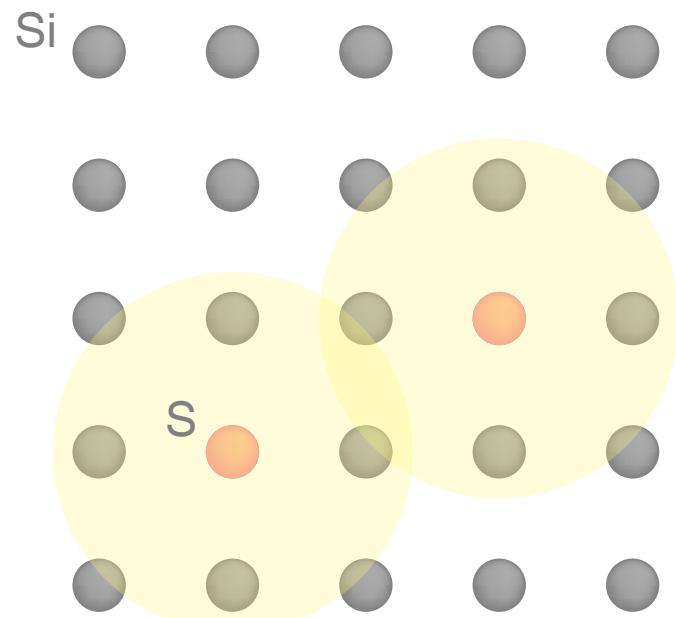


# Non-equilibrium dopant concentrations

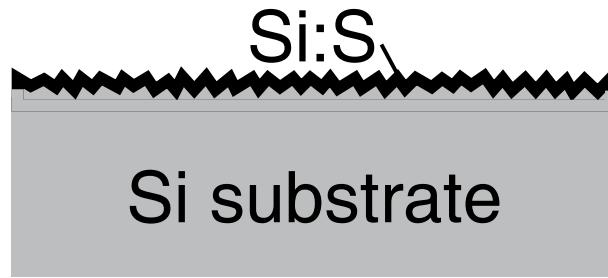


# Outline

- fs-laser doping
- non-equilibrium dopant concentrations
- optical and electronic properties

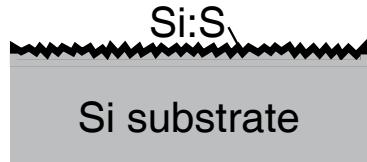


# Optical and electronic properties



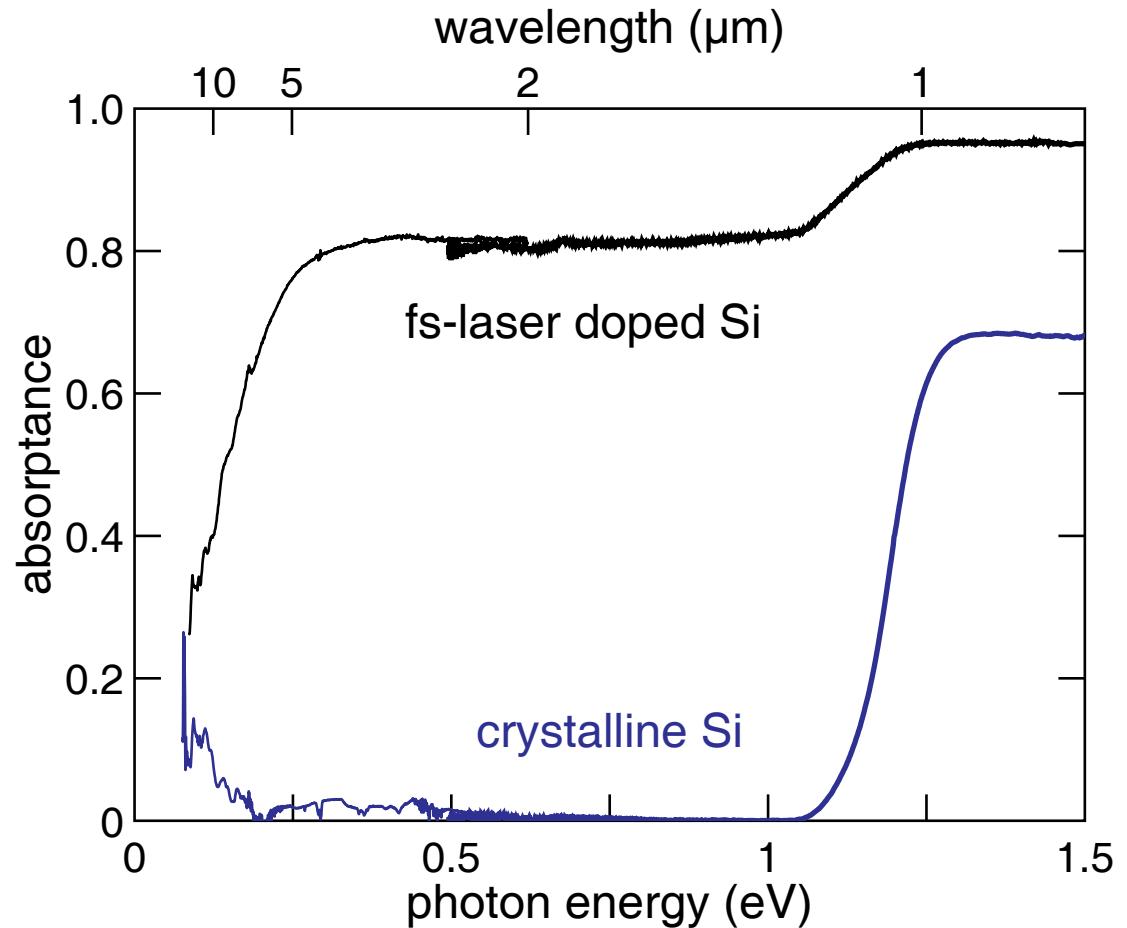
50 fs-laser pulses  
 $\text{SF}_6$  500 Torr

# Optical and electronic properties

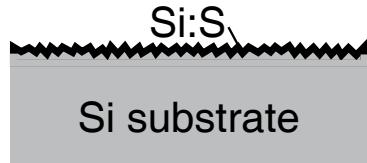


$$A = 1 - T_{int} - R_{int}$$

SF<sub>6</sub> 500 Torr

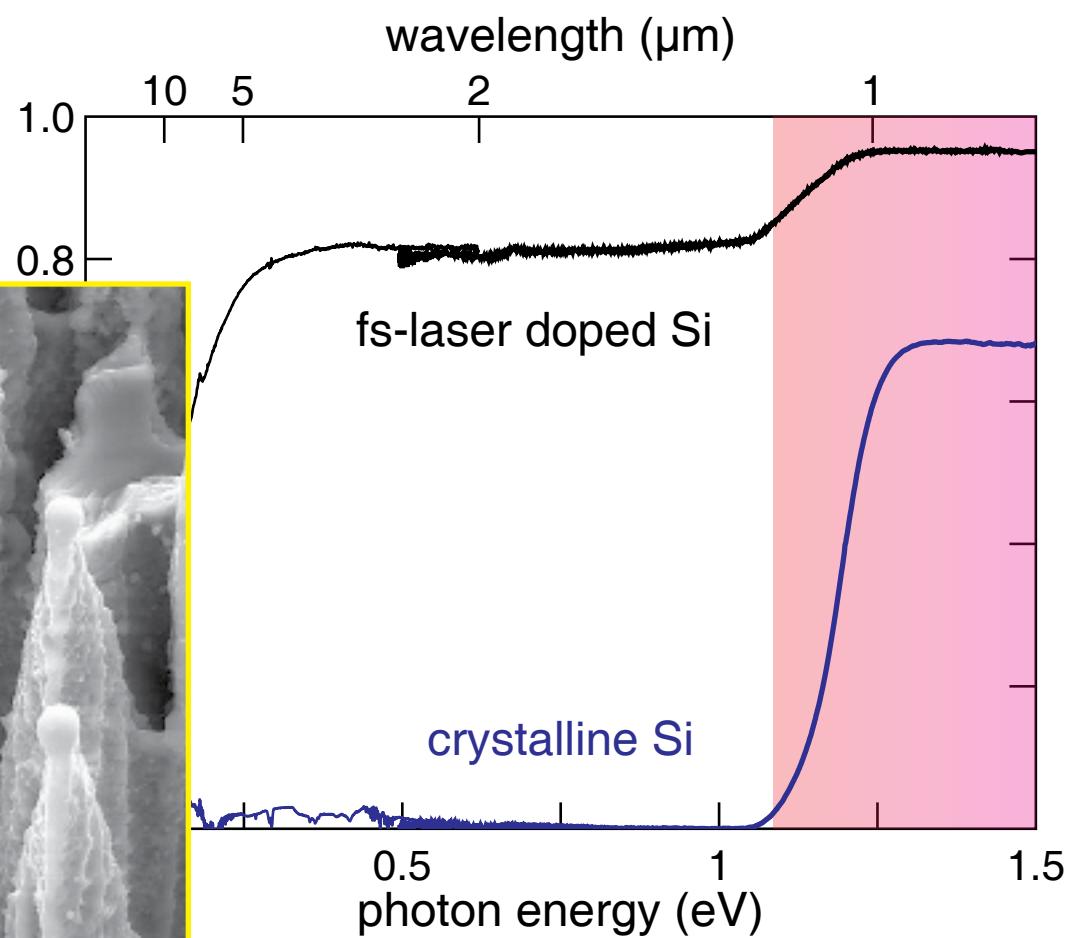
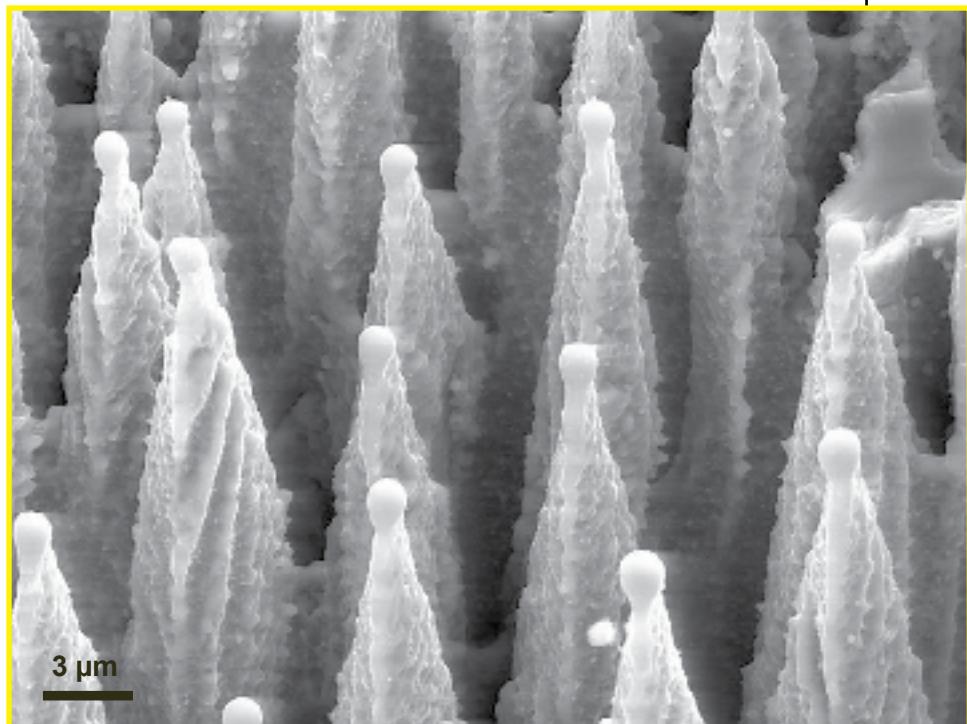


# Optical and electronic properties

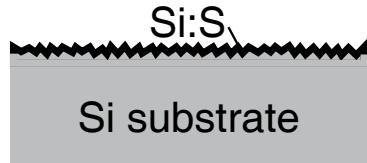


$$A = 1 - T_{int} - R_{int}$$

SF<sub>6</sub> 500 Torr

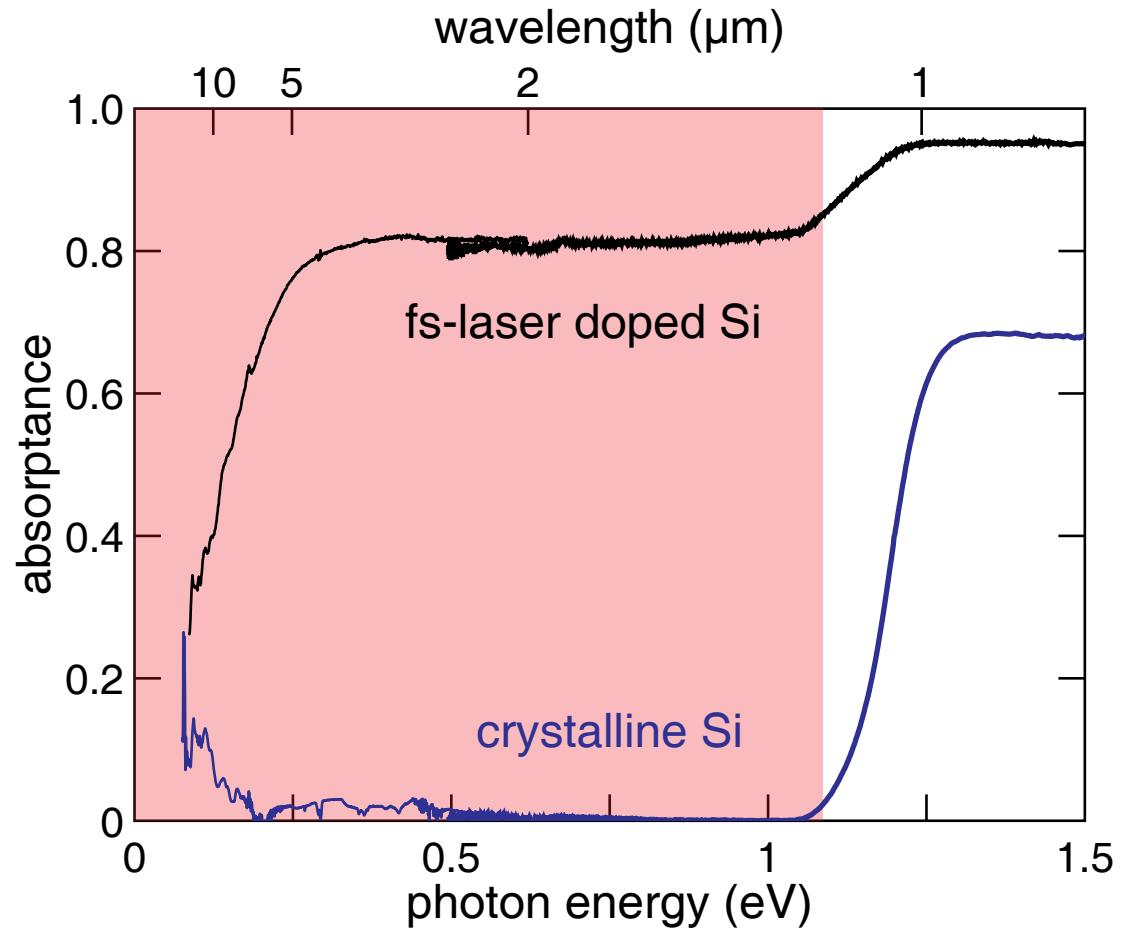


# Optical and electronic properties

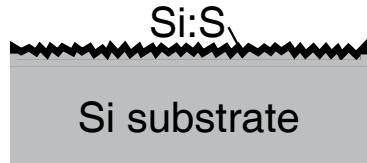


$$A = 1 - T_{int} - R_{int}$$

SF<sub>6</sub> 500 Torr



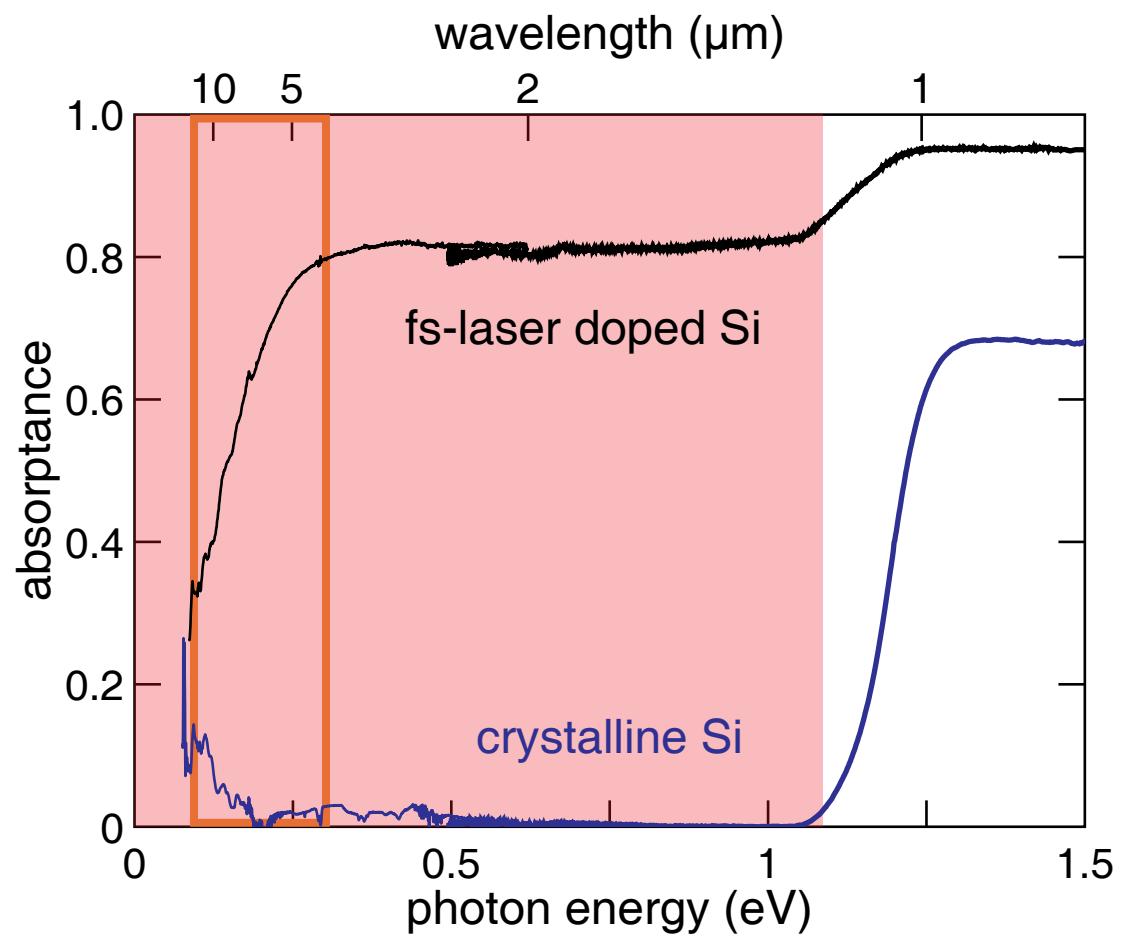
# Optical and electronic properties



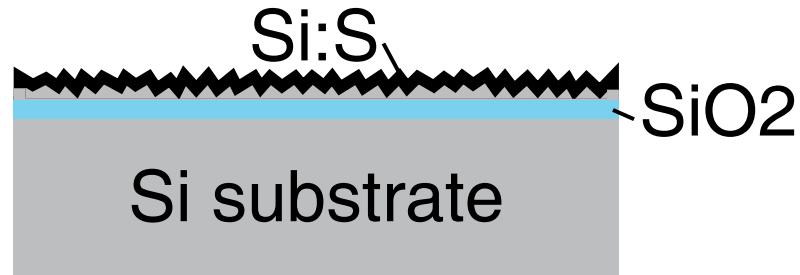
$$A = 1 - T_{int} - R_{int}$$

SF<sub>6</sub> 500 Torr

dopant energy  
level ~ 0.2 eV

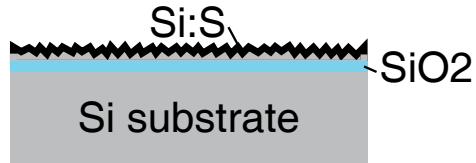


# Optical and electronic properties

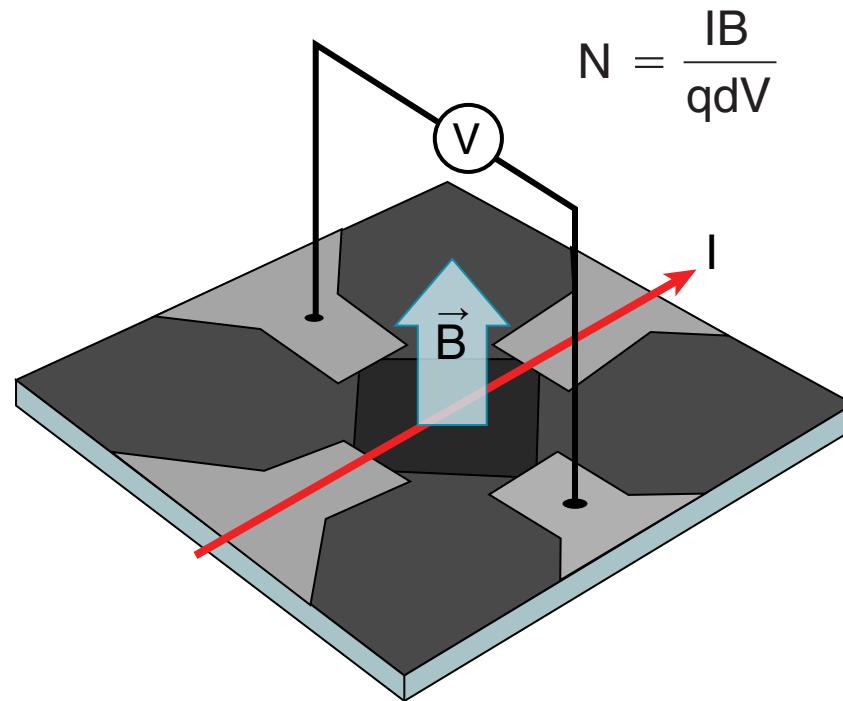


50 fs-laser pulses  
 $SF_6$  500 Torr

# Optical and electronic properties



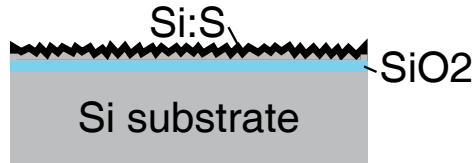
SF<sub>6</sub> 500 Torr



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

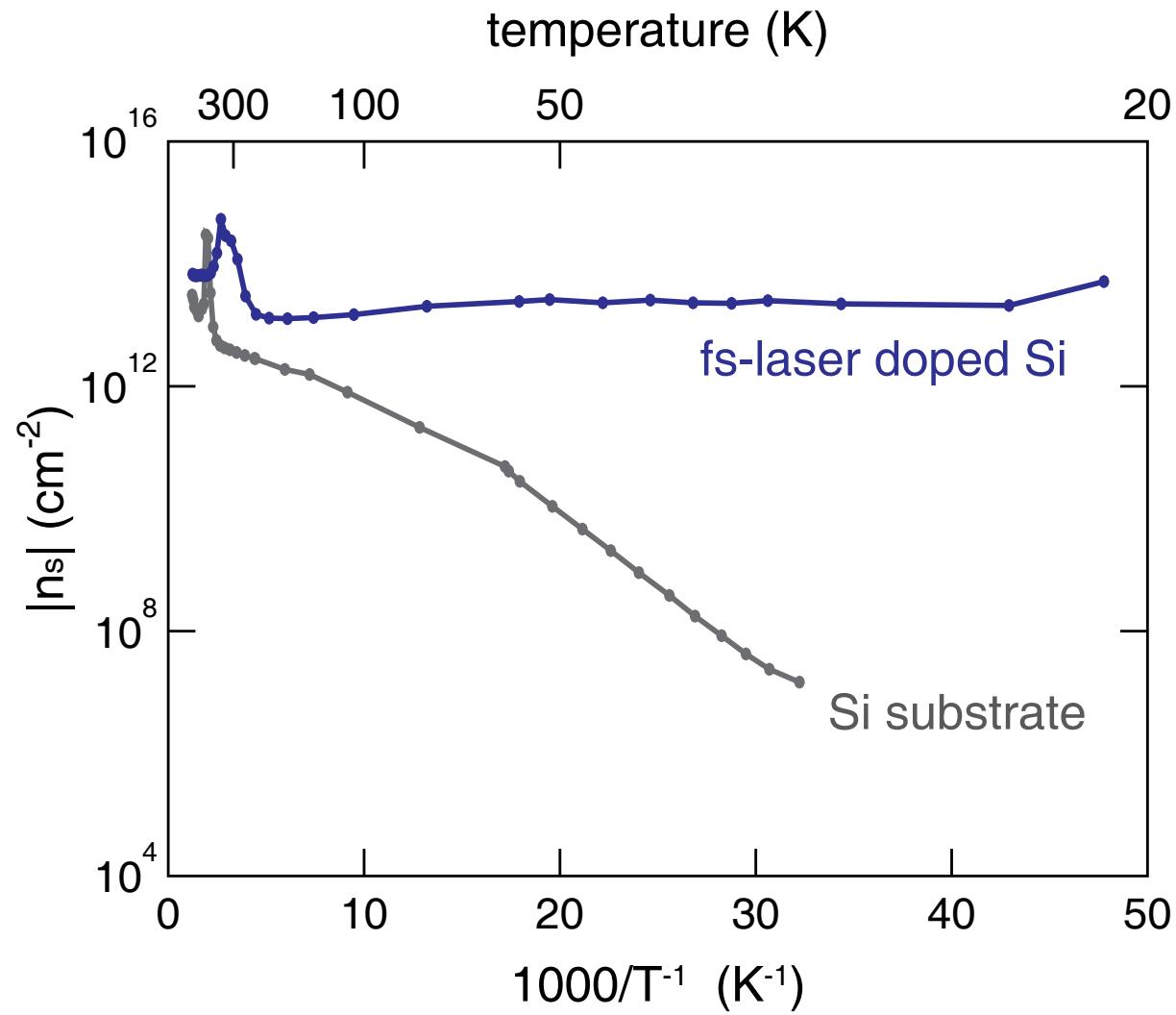
Hall measurements

# Optical and electronic properties

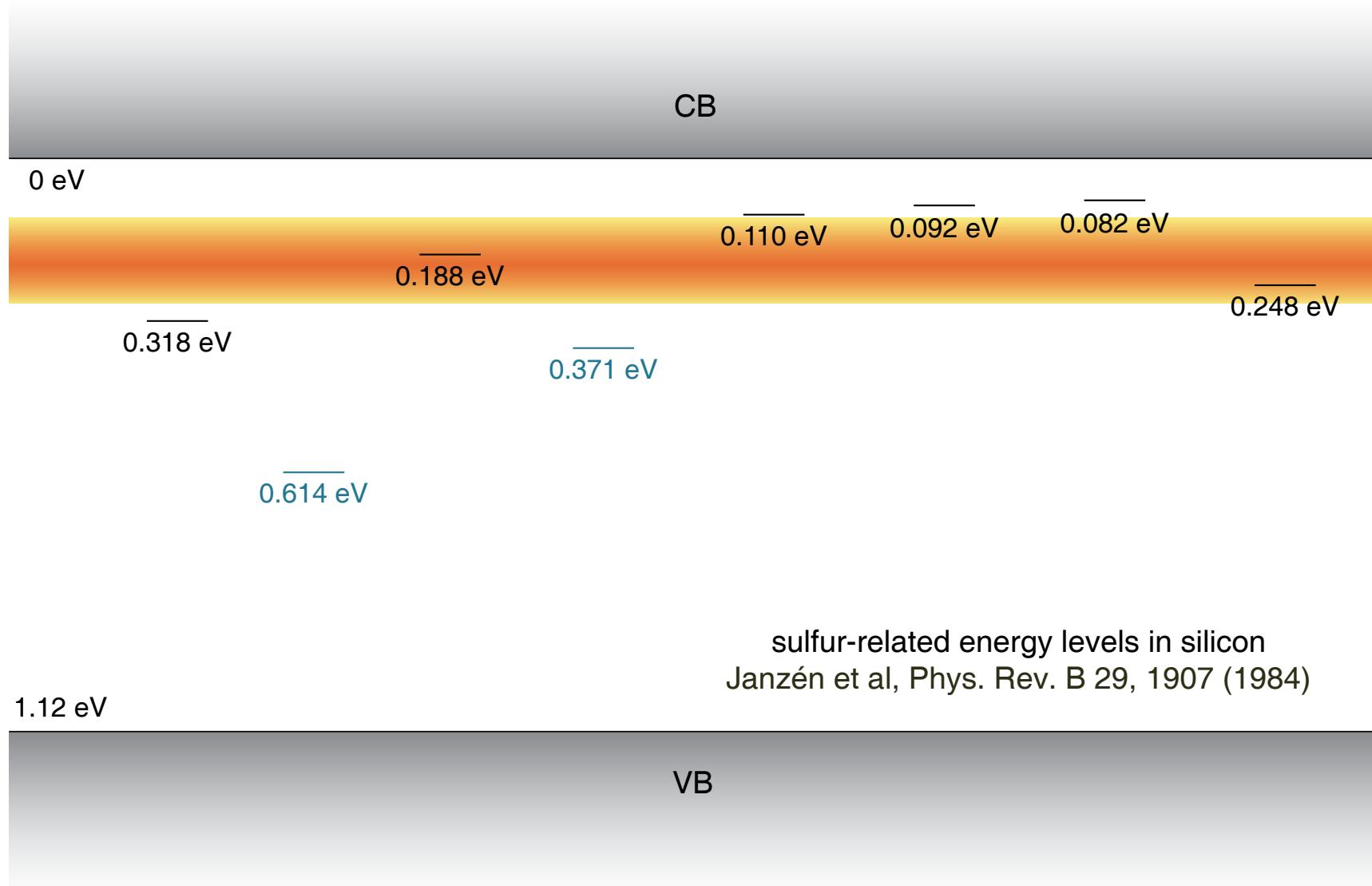


T-Hall

SF<sub>6</sub> 500 Torr

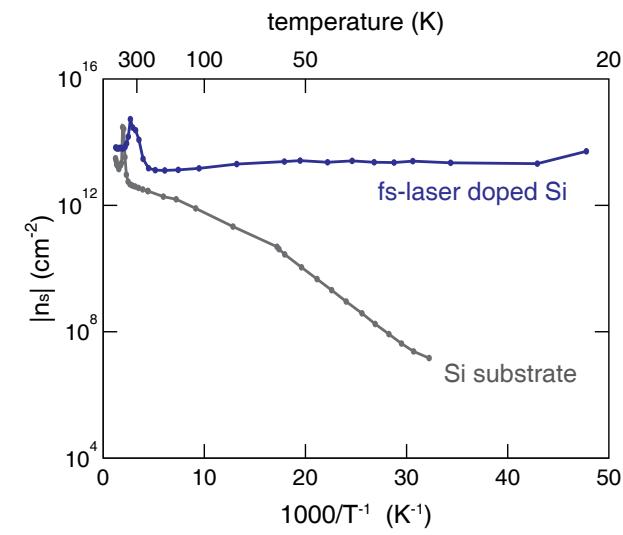
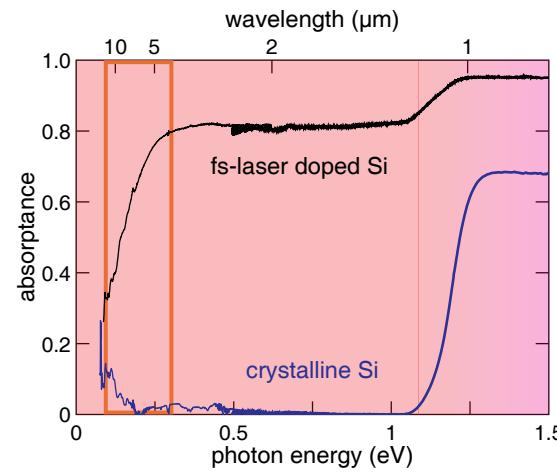
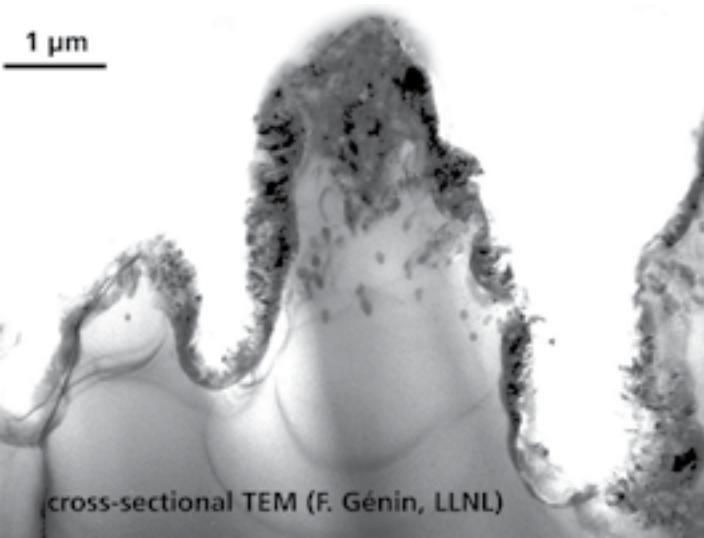


# Optical and electronic properties



# Conclusions

- Fs-laser doping
  - light trapping microstructures
  - non-equilibrium concentrations of S in Si
- IR absorption and T-Hall measurements
  - absorption to  $\lambda \approx 8 \mu\text{m}$
  - $n_s(T=300\text{K}) \approx n_s(T=21\text{K})$
- evidence of intermediate band formation

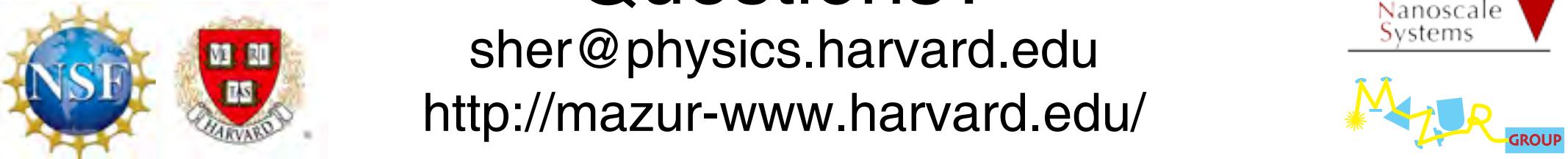


# Thanks!



## Questions?

sher@physics.harvard.edu  
<http://mazur-www.harvard.edu/>



Harvard University  
Center for  
Nanoscale  
Systems