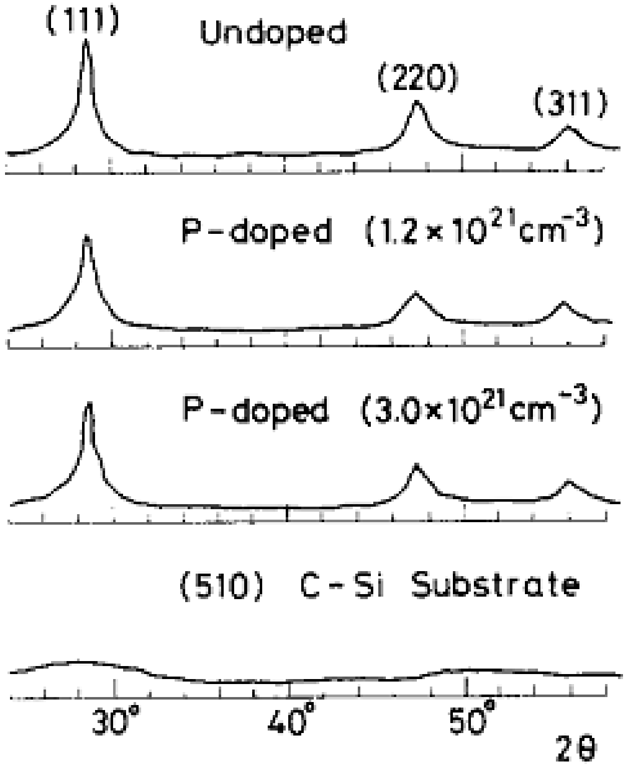
Microcrystalline silicon

µc-Si: a new form of TF-Si

- Discovered for “rather high deposition powers”

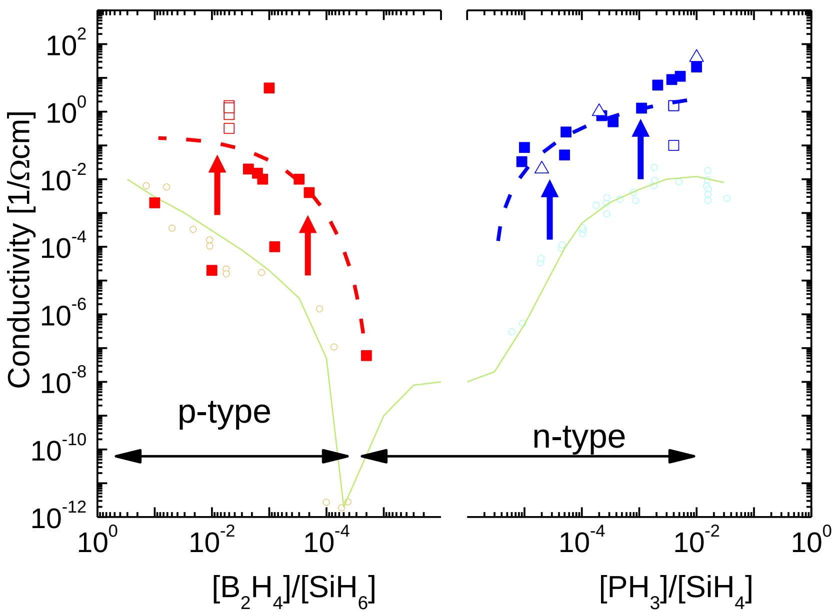
- Different from a-Si because:
  - high conductivity (0.01 … 0.1 Ωcm)
  - doping yields low E_{act} (0.02 … 0.05 eV)
  - diffraction peaks in XRD

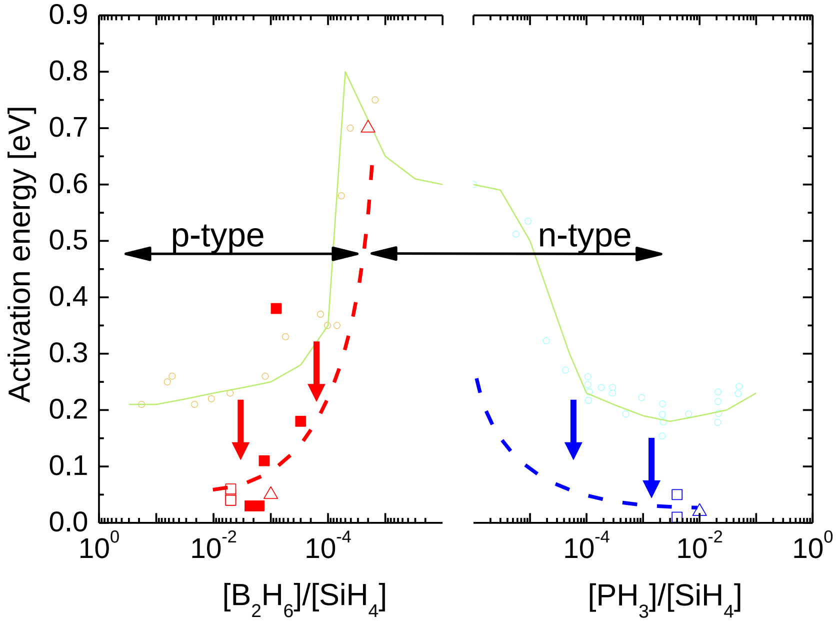
- Later also found for:
  - high hydrogen dilution
  - high deposition temperature
  - “depleted” plasma conditions



Usui, JNCS (1979)
Matsuda, JJAP (1980)

Conductivity vs. doping





conductivity ca. 10 - 100x higher than a-Si:H,
naturally n-type (similar to a-Si)
here: oxygen impurity

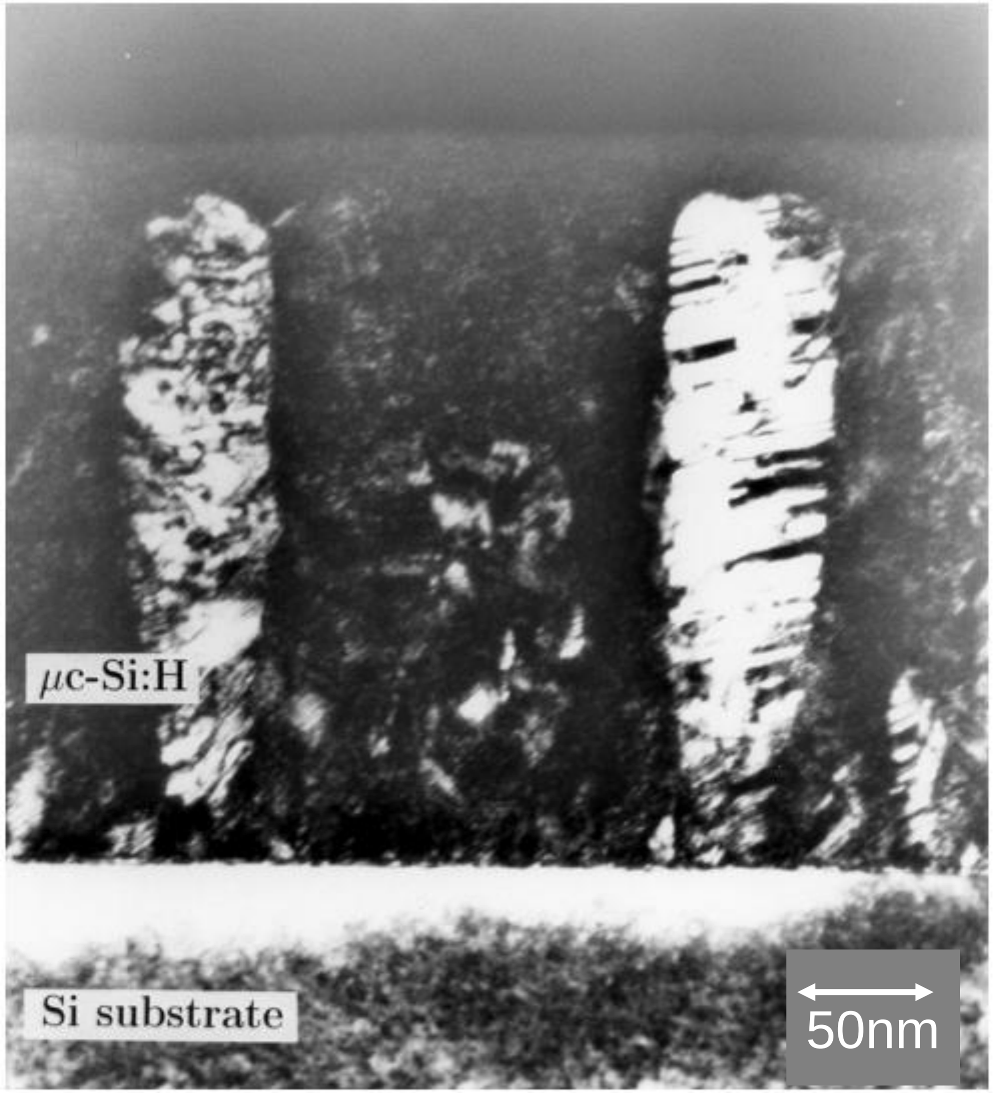
activation energy 10x lower than a-Si:H, typically 20 to 50 meV

Wang, IEEE PVSC (1990)
Spear, J. Phys. C (1981)
Alpuim, JAP (1999)

Structure of μc-Si

Large columnar structures, conglomerates of crystallites (grains) with similar orientation

=> should be called nanocrystalline (nc-Si) because of grain size

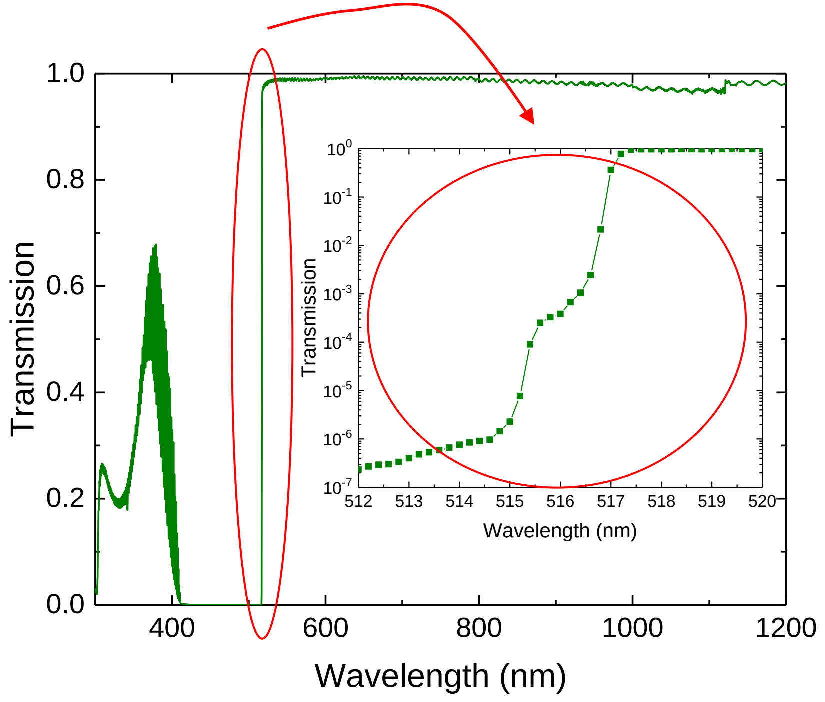


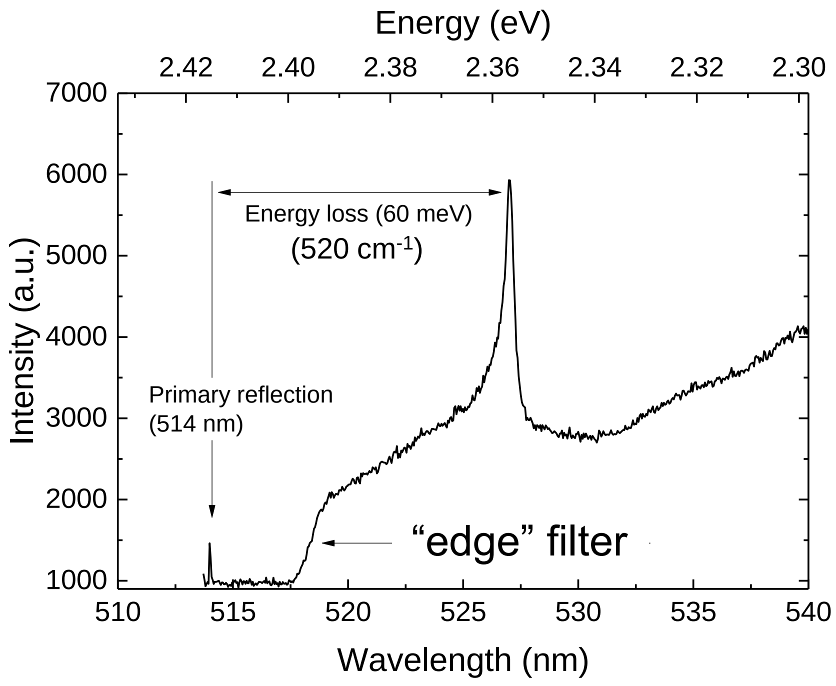
Structural characterization: Raman effect

F.-J. Haug

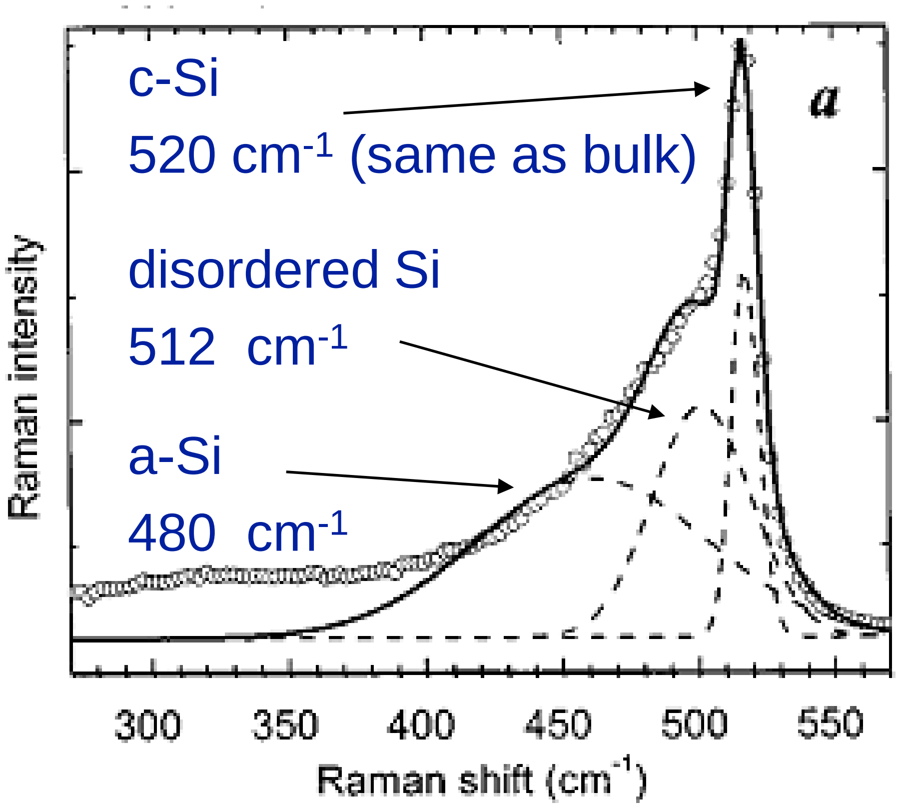
Principle: Energy loss spectroscopy

- illuminate with laser (e.g 514 nm)
- excite vibrations (loss of phonon energy)
- measure reflected spectrum (sharp filter to suppress direct reflection)





Raman signature of µc-Si



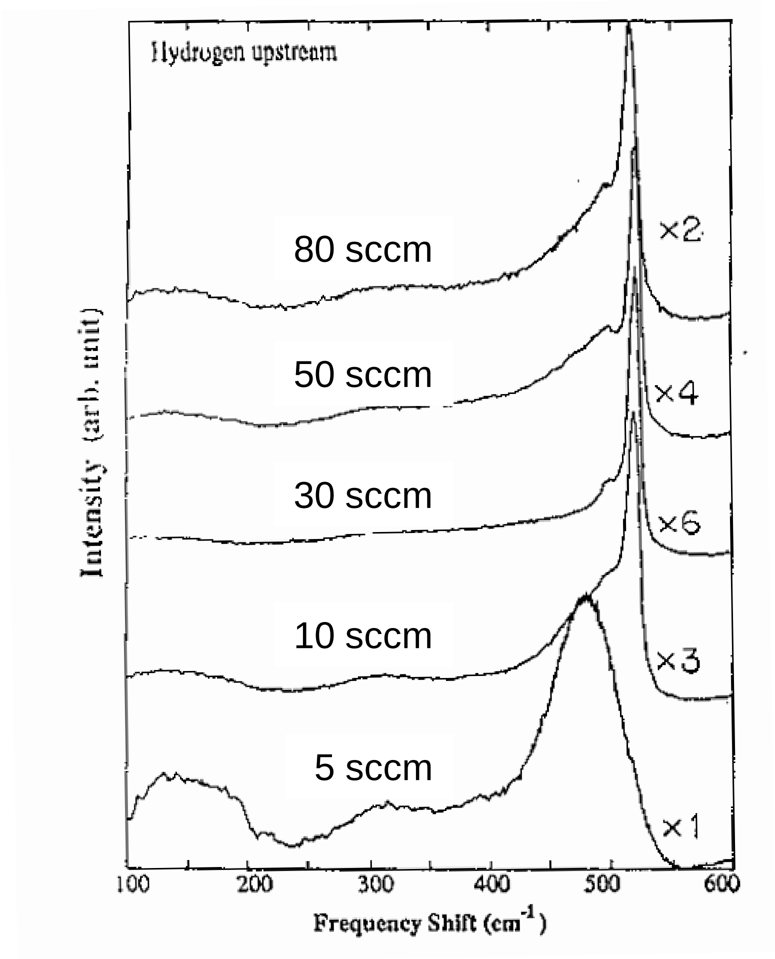
Mixture of amorphous, disordered and crystalline Si

Crystalline Volume fraction:

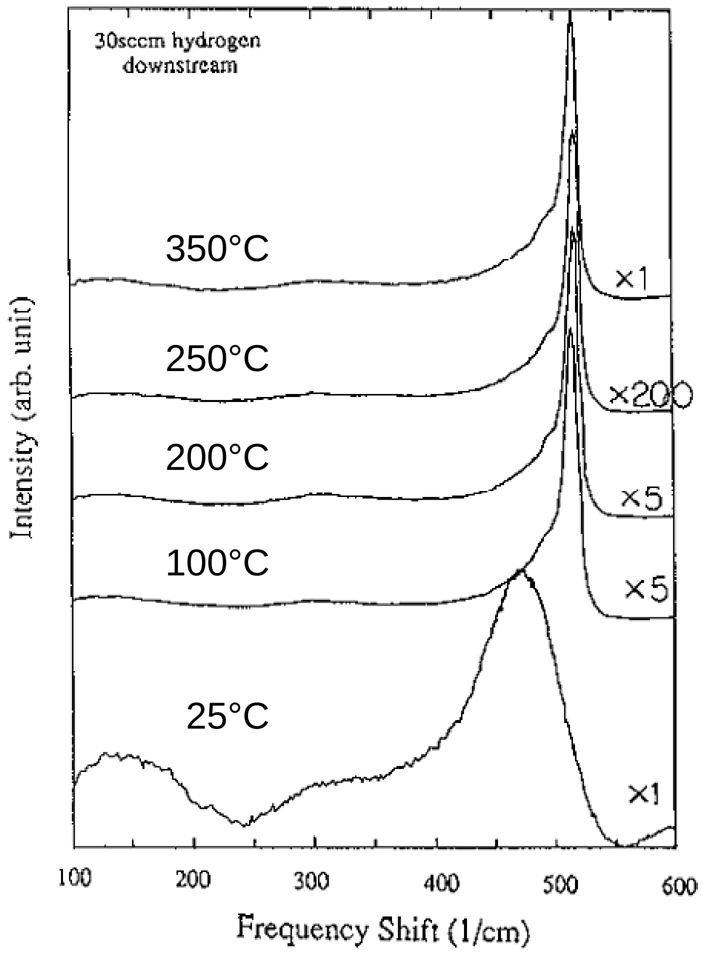
$$CVF = \frac{I(512) + I(520)}{I(480) + I(512) + I(520)}$$

Smit, JAP (2003)

Deposition conditions



Transition with H dilution

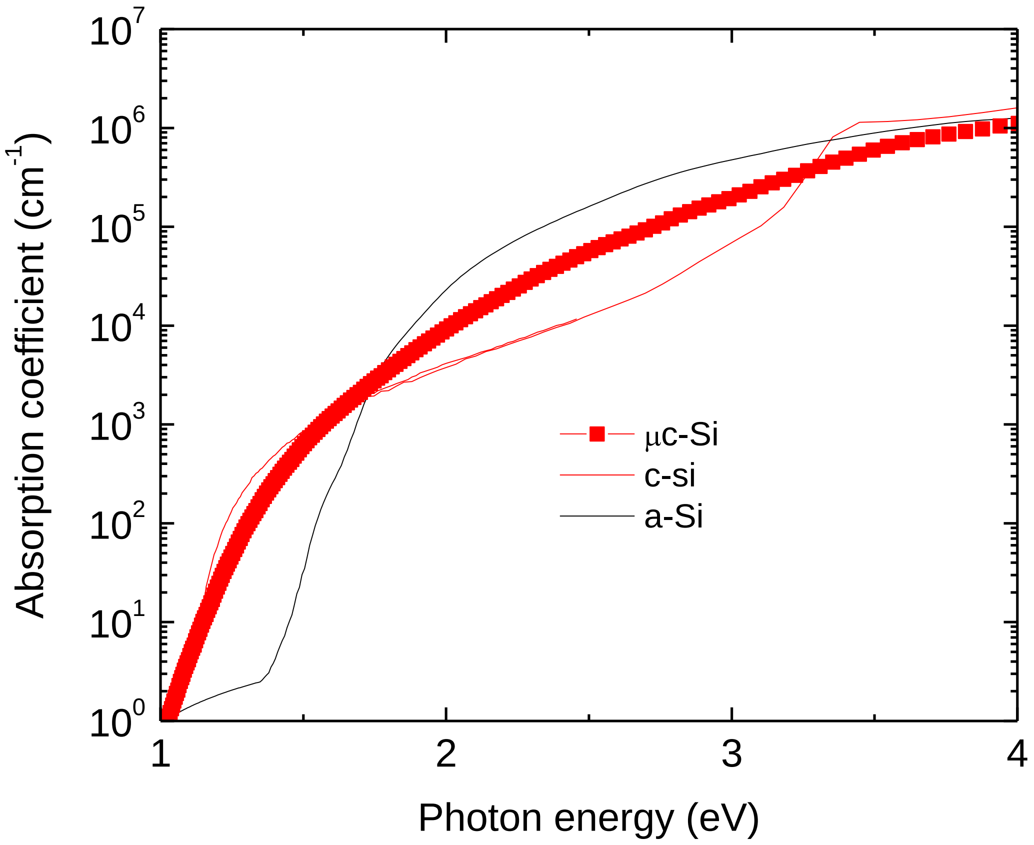


Transition with dep. temperature

- Hydrogen etching model:
  a-Si etched more easily by H-plasma than c-Si
  => occasionally a grain nucleates, survives, and grows
- Nucleation preferably on H-free sites:
  => lower H-coverage at high T

Wang, IEEE PVSC (1990)

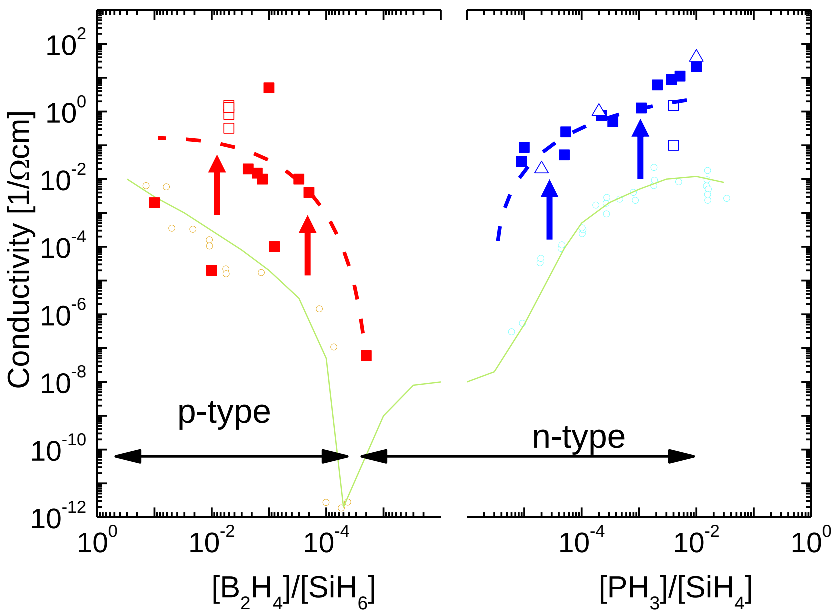
Absorption coefficient

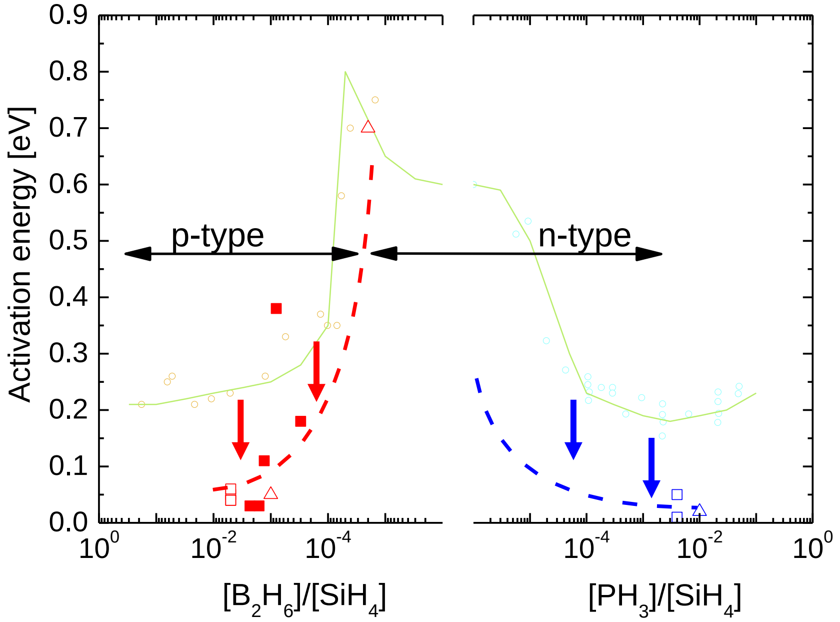


Vis: behaves like mix of amorphous and c-Si

NIR: very similar to c-Si

Conductivity vs. doping





high conductivity
(10 - 100x higher than a-Si:H)
naturally n-type (similar to a-Si)
here: oxygen impurity

activation energy typically 20 to 50 meV
(10x lower than a-Si:H)

Wang, IEEE PVSC (1990)
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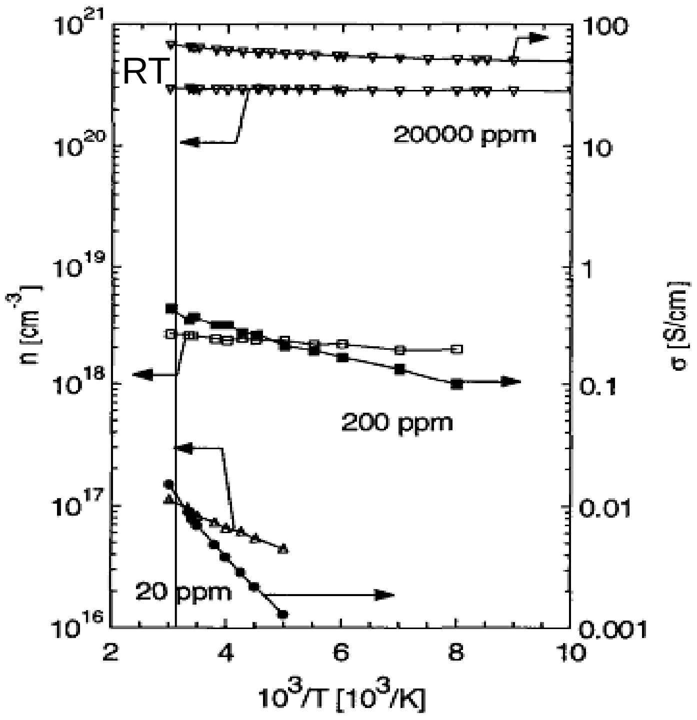
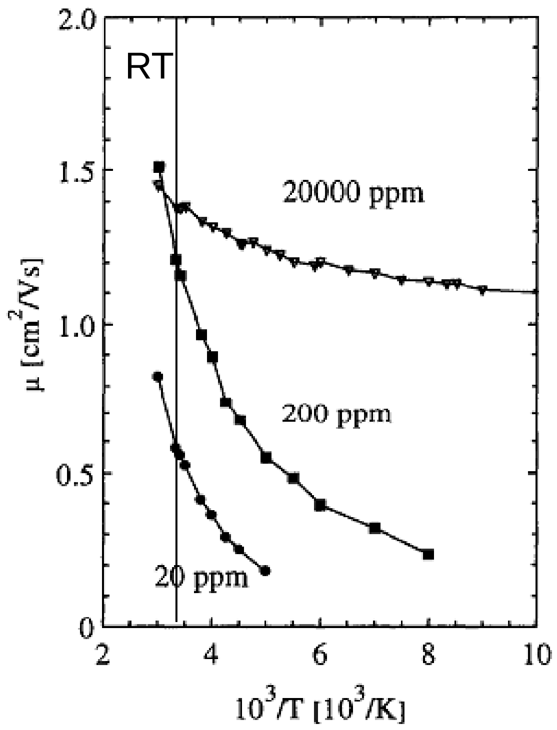
Hall effect





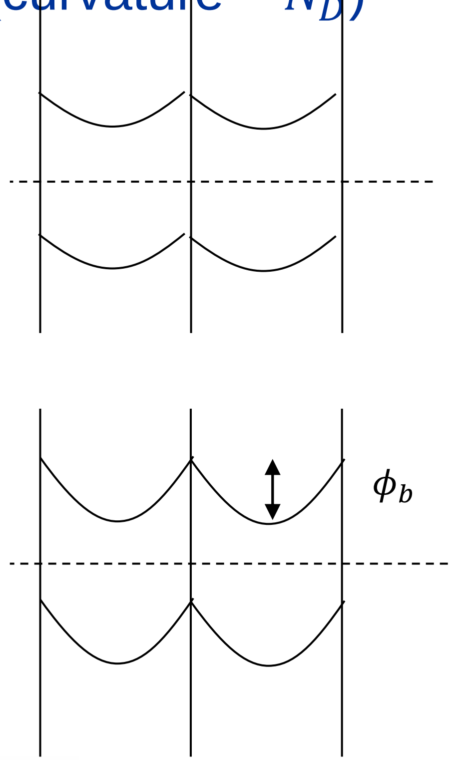
High carrier density w/o compensation, thermally activated (not same as std. semiconductors)

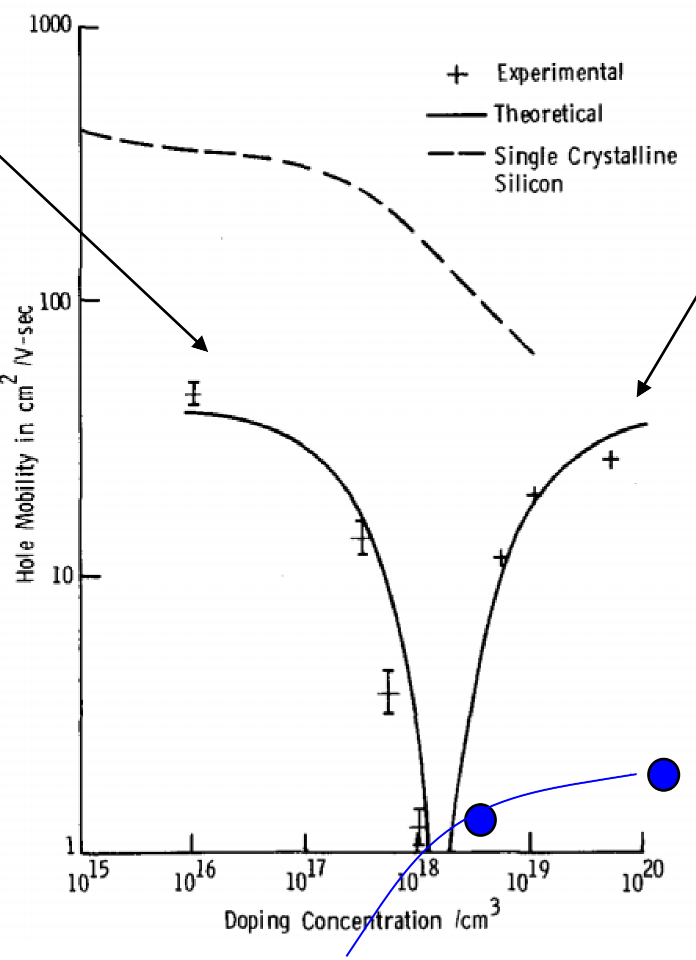
Higher mobility for higher doping indicative of GB transport

Bronger, TSF (2007)
Backhausen, MRS Proc (1996)

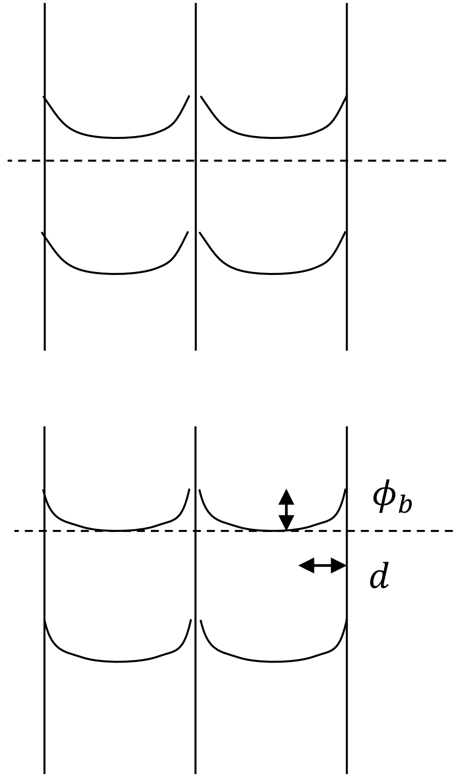
GB transport (polycrystalline Si e.g. n-type)

grains fully depleted
(all carriers in GB traps)
inc. doping => inc. ϕ_b
(curvature ~ N_D)





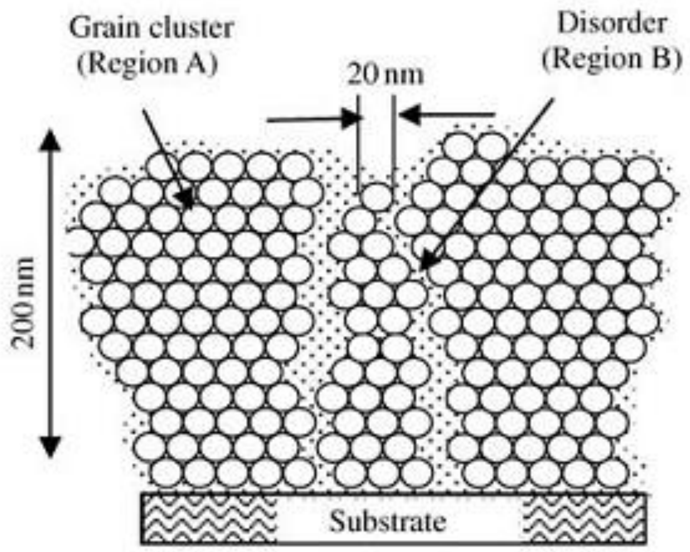
grains partially depleted
inc. doping => dec. ϕ_b
(eventually tunnelling)

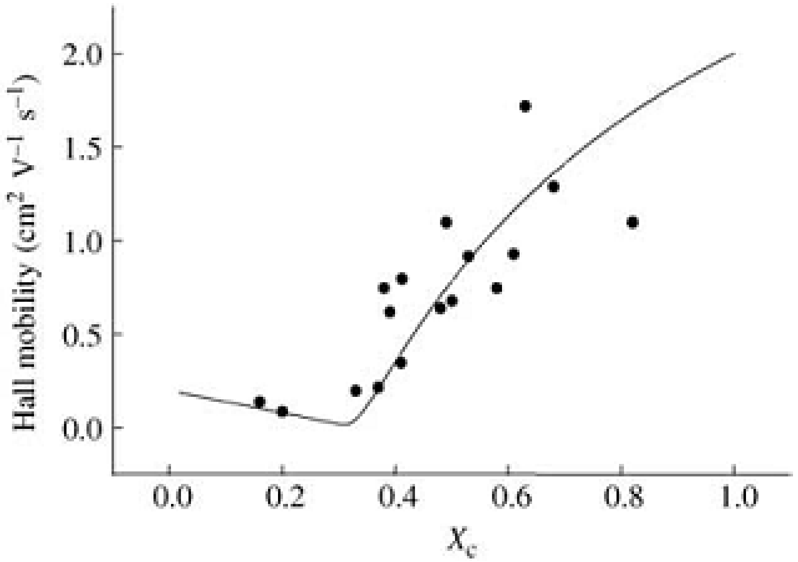


Seto, JAP (1975)

shift due to smaller grain size

Percolation transport



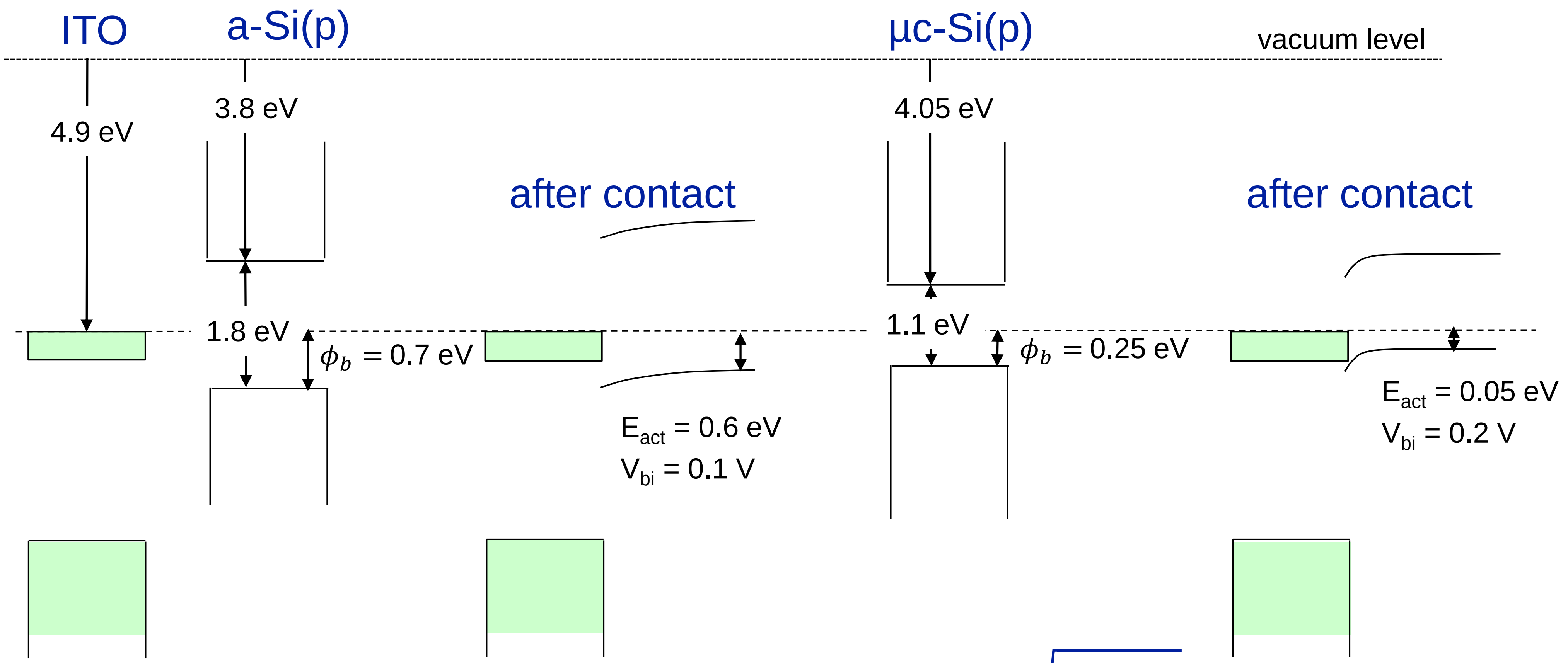


Schematic arrangement of grains (3-5 nm) into clusters => a-Si tissue between grains

Transport by percolation if CVF > 40%

Shimakawa, J. Mat. Sci. (2004)

Excursion: contact formation (idealized)

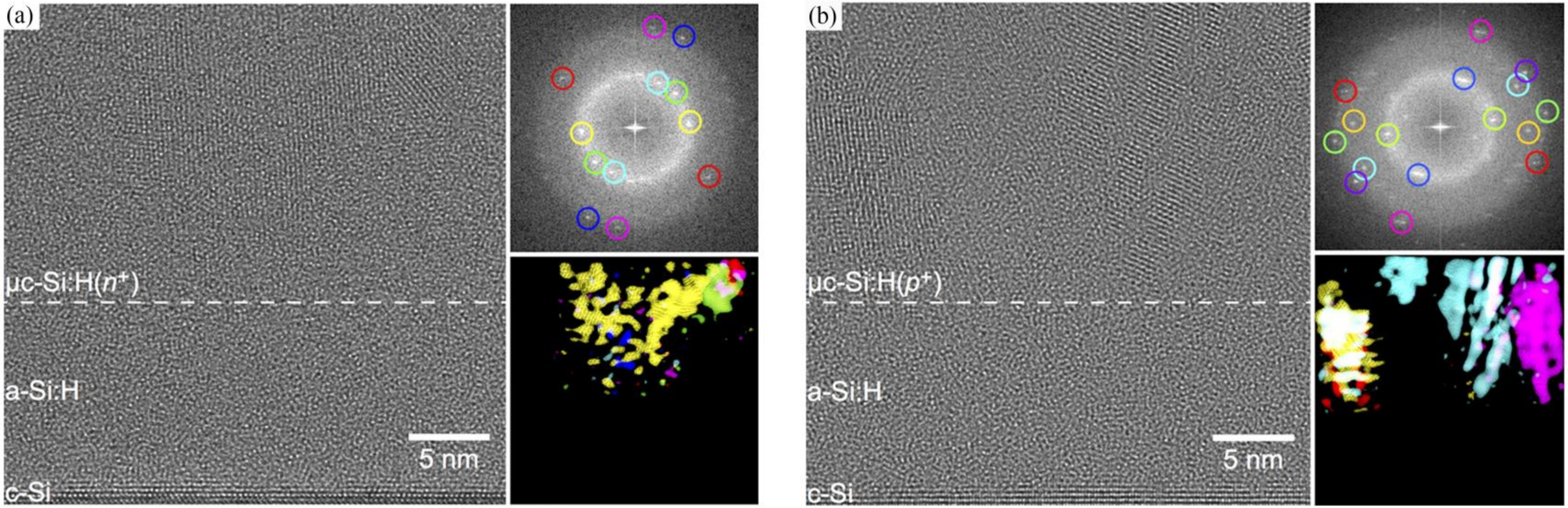


similar V_{bi}, but $d = \sqrt{\frac{2\epsilon\epsilon_0}{N_A} V_{bi}}$

Low active doping density
wide depletion region
=> thermionic field emission

High doping density
narrow depletion region
=> tunnelling becomes likely

Excursion: contact resistivity of HIT solar cells



Cell requires intrinsic buffer layer for passivation (material with low defect density)

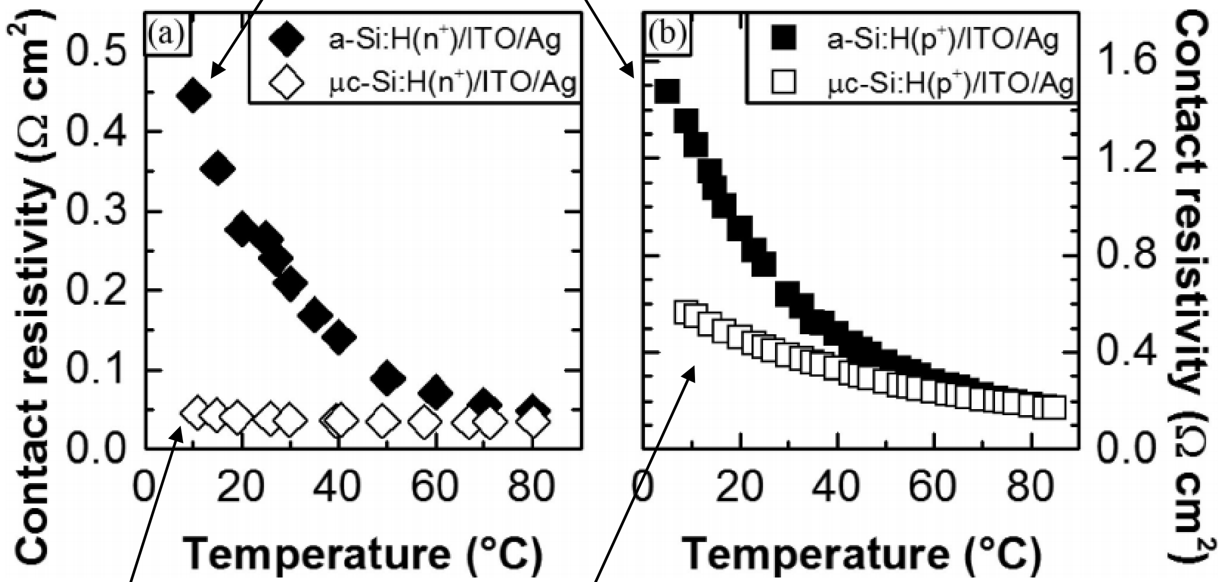
Doped μc-Si: formation of small columnar grains, size between 3 and 5 nm

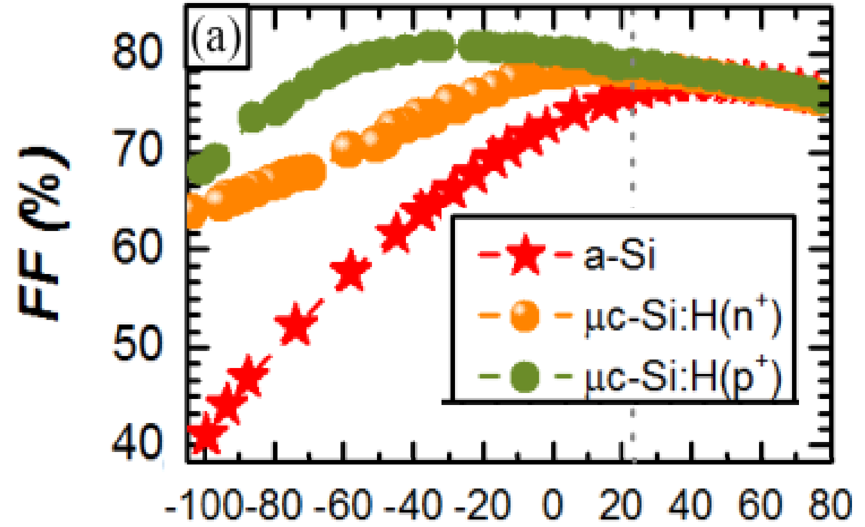
Nogay, JPV (2016)

Excursion: contact resistivity of HIT solar cells

F.-J. Haug

Large temperature dependence: close to thermionic emission





Nogay, JPV (2016)

Intermediate temperature dependence: thermionic field emission

No temperature dependence: tunnelling transport (field emission)

On transport processes and contact resistivity: Padonvani SSE (1966), Yu SSE (1970)

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