Silicon Nanowire Solar Cells

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Solar Cells for Energy Harvesting

Energy supply for low power sensors, …

Thin film cells preferred to wafer cells

- a-Si: low efficiency (6% typically)
- c-Si suffers from low absorption
- CdTe: toxic material
- CIGS Cu(In,Ga)Se_2: rare materials

Alternative: Silicon nanowire solar cells

- High quality material
  - →Potential for high efficiency
- On thin films possible

Basics of Nanowire Solar Cells

Why silicon nanowire cells?

Perfect light trapping

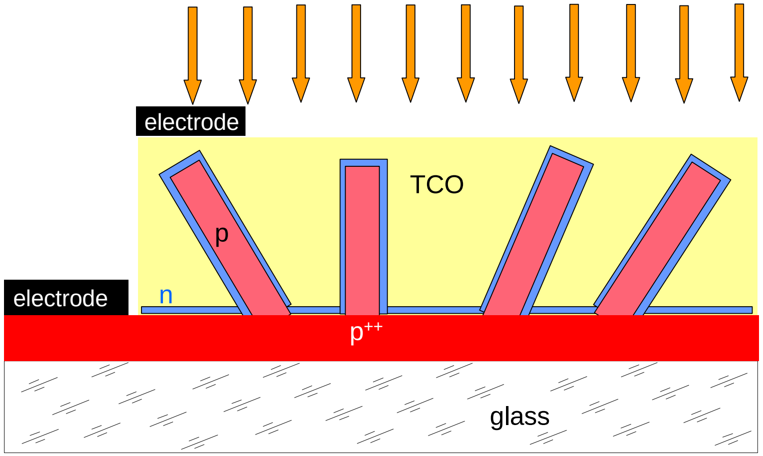
Single crystalline material

Glass as a substrate possible (low cost material!)

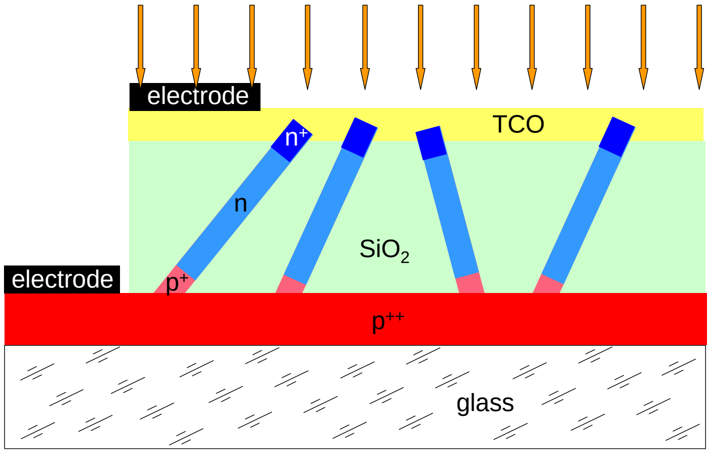
for development: wafers as substrate

Two concepts of nanowire cells under discussion

radial pn-junction



axial pn-junction

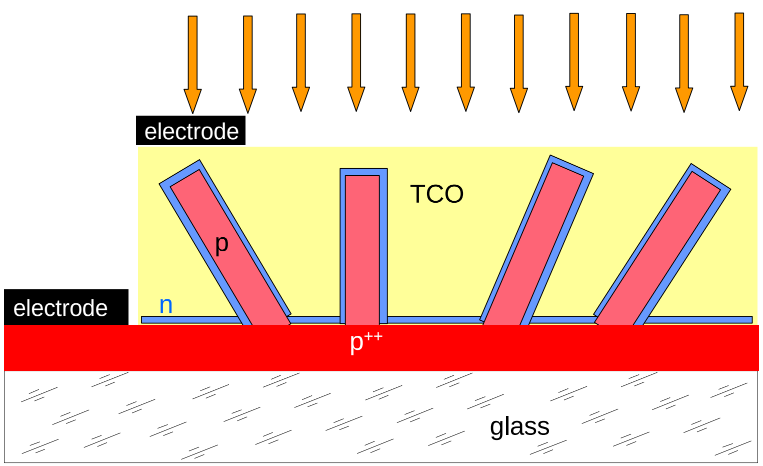


Basics of Nanowire Solar Cells

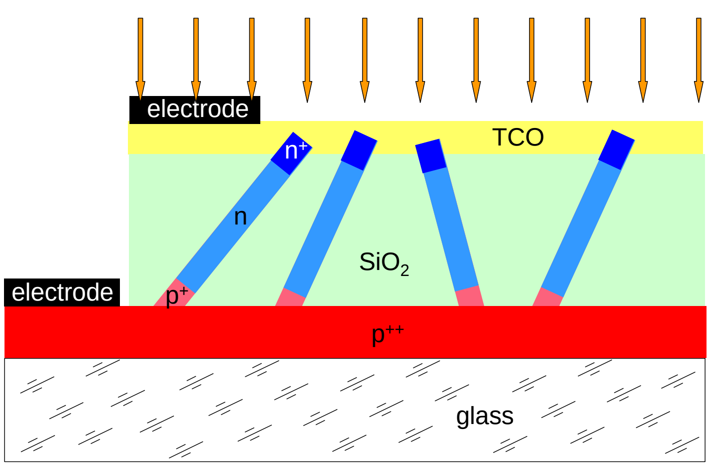
Advantages/disadvantages of radial or axial p-n-junction

Radial case:
Huge area of p-n-junction
→ low photo-current density
→ lower V_{oc}
Short distance between generation of charges and p-n-junction
→ higher V_{oc} and j_{sc}

Axial case:
Low area of p-n-junction
→ high photo-current density
→ higher V_{oc}
Large outer surface area
→ high surface recombination
→ lower V_{oc}



radial pn-junction



axial pn-junction

Preparation of Silicon Nanowires

Two preparation methods

Bottom up:
Growth on substrate
VLS growth (vapor liquid solid)
Wagner&Ellis 1964

Top down:
Etching into bulk
Self organized etching
by HF + $AgNO_3$

Both preparation methods
- work on wafers
- work on Si thin films
- give single crystalline wires

Preparation of Silicon Nanowires

Bottom up: Growth on silicon substrate

VLS growth

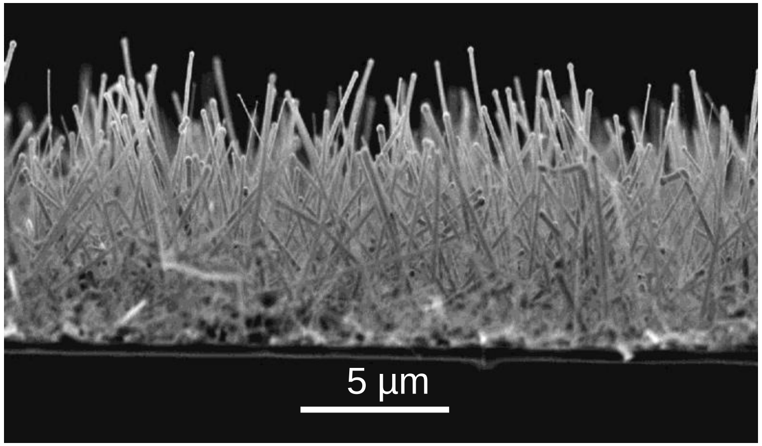
Au nanodots as template

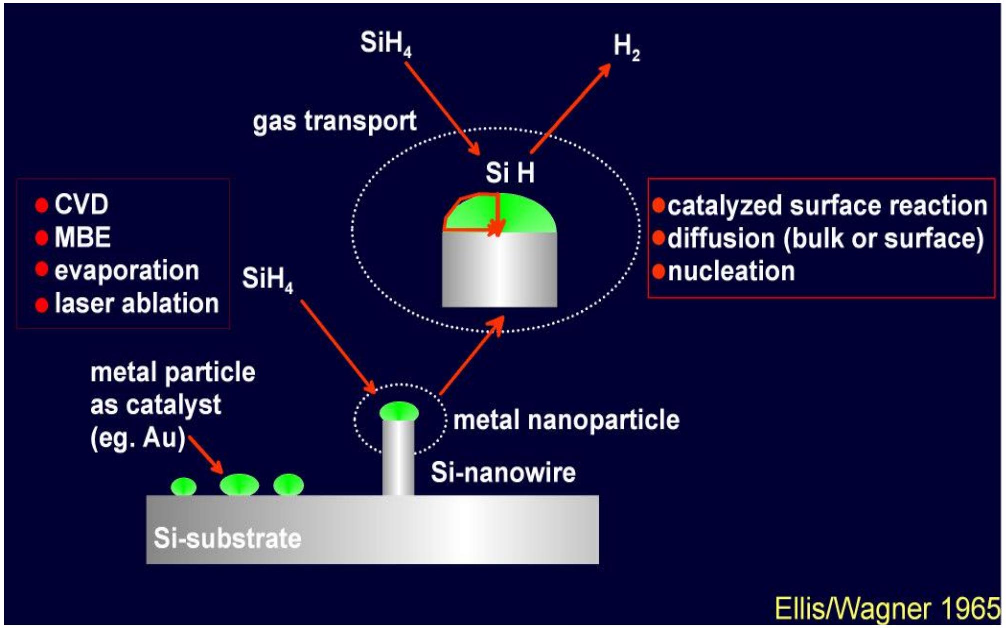
- Deposition of Au nanoclusters or
- 1 nm Au film heated to above eutectic temperature of 370°C

Thermal CVD from silane at 500°C: Au acts as catalyst for SiH_4 decomposition

Doping by adding B_2H_6 or PH_3

Axial pn-junction: Doping can be changed during growth





Preparation of Silicon Nanowires

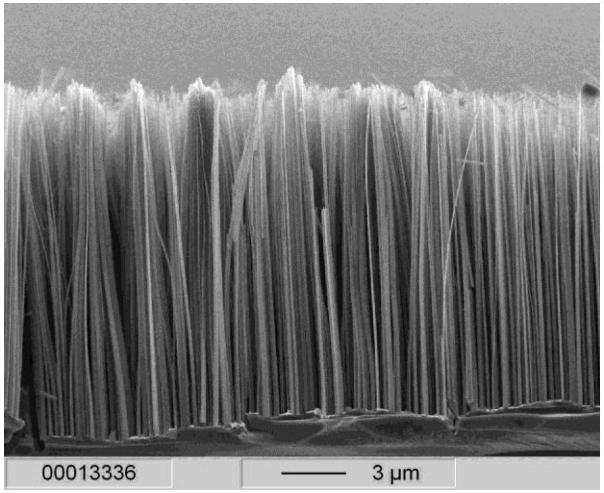
Top down: Etching into bulk

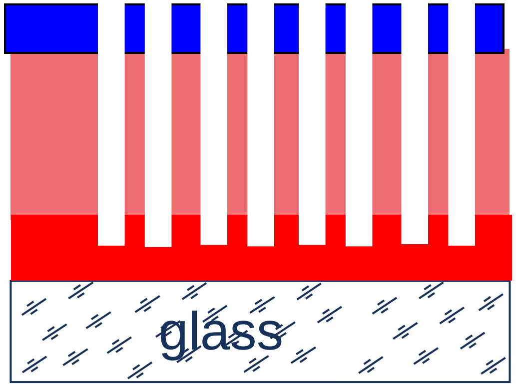
Si wafer or c-Si thin film

Self organized etching

- HF 5m, $AgNO_3$ 0.02m 1:1, 10…30 min at RT
- Ag nanoparticles form and act as catalysts for etching

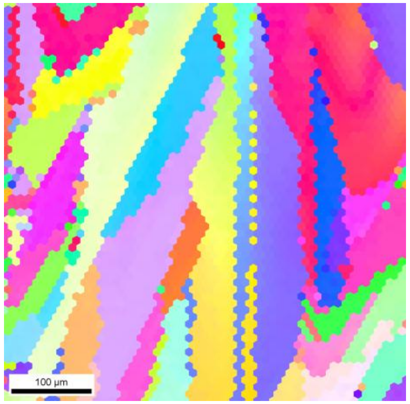
Axial pn-junction: already in substrate





Preparation of Nanowires on Si Films on Glass

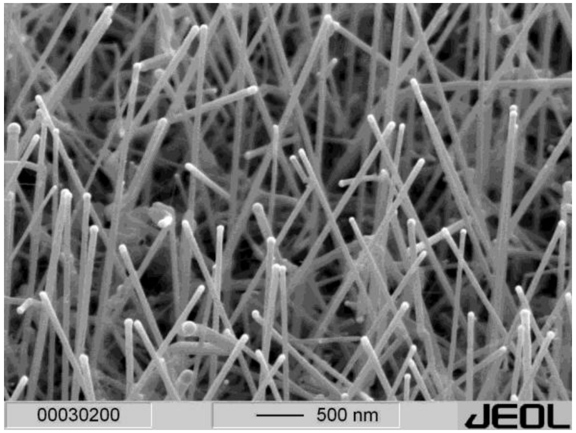
Multicrystalline Si films produced by laser crystallization of a-Si on glass



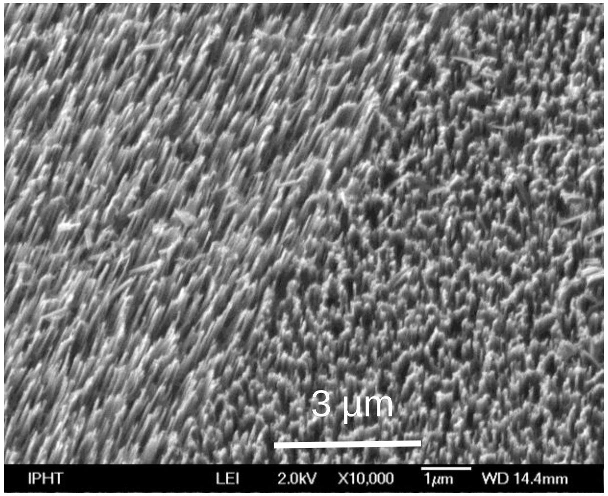
EBSD map
of Si substrate layer:
100 µm grains

0.5 mm

VLS grown nanowires



Etched nanowires
different morphologies
on different grain orientations



Preparation of Solar Cells

Radial hetero-junction

Substrate:

- Si wafer or laser crystallized multicrystalline silicon film on glass
- n-doped, acting as back contact

Etching of nanowires by HF + $AgNO_3$

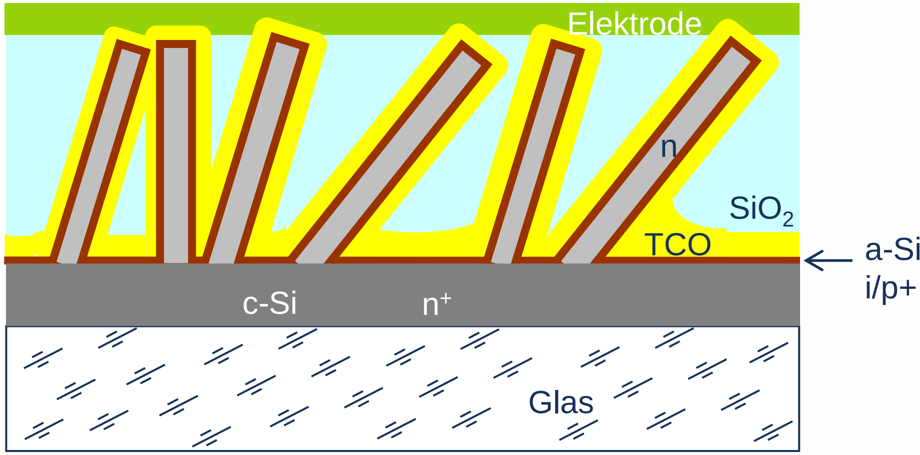
Carefully removing Ag nanoparticles

Depositing a-Si:H by PECVD to cover nanowires by shell

- Layer sequence intrinsic 2 nm + p-doped 4 nm

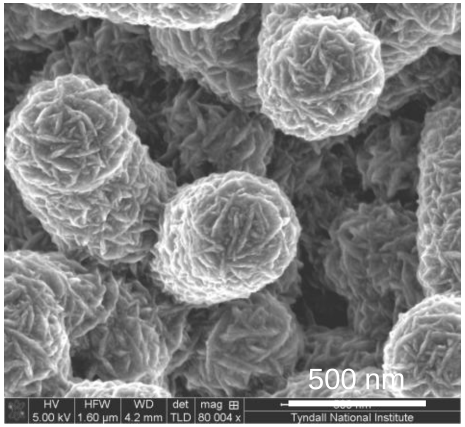
Filling space between nanowires by TCO

- ZnO:Al by ALD or sputtering
- Front contact

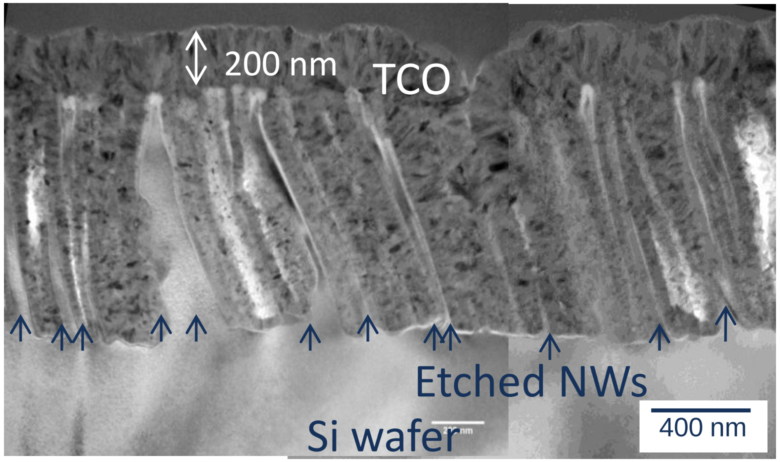


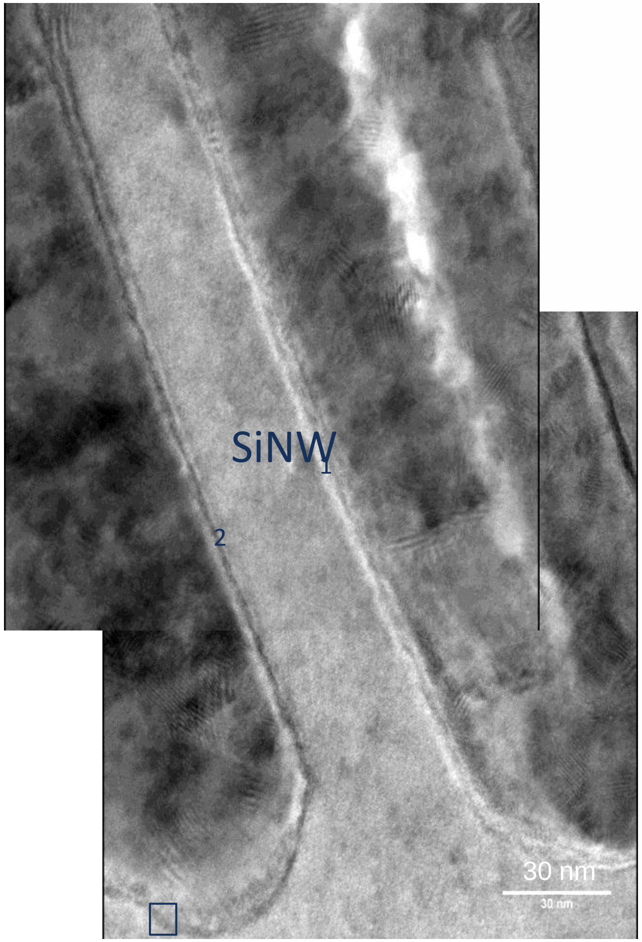
Preparation of Solar Cells

Radial hetero-junction



TEM Investigations
by N. Petkov,
Tyndall, Cork, Ireland





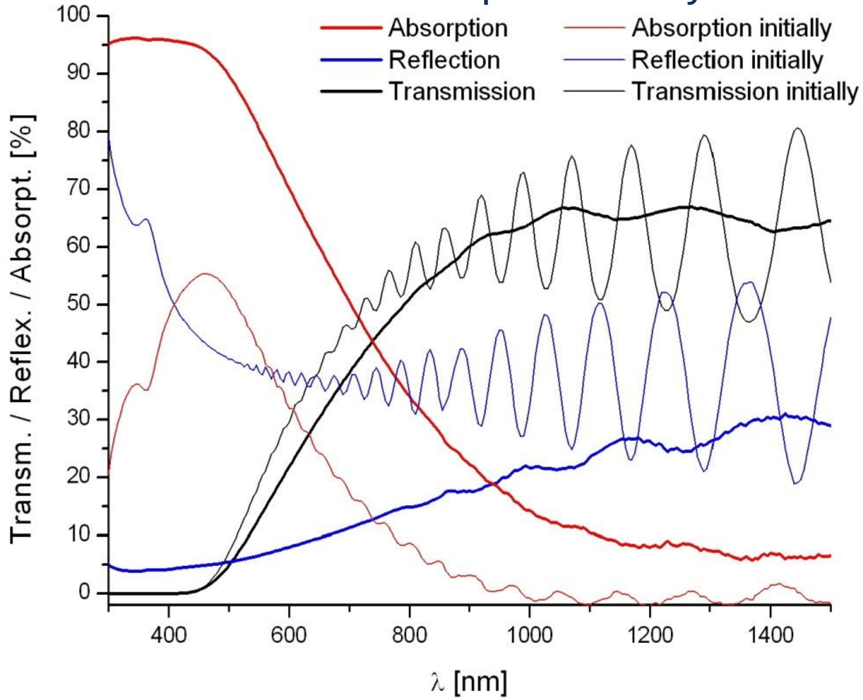
Results: Optical Properties of Nanowire Carpets

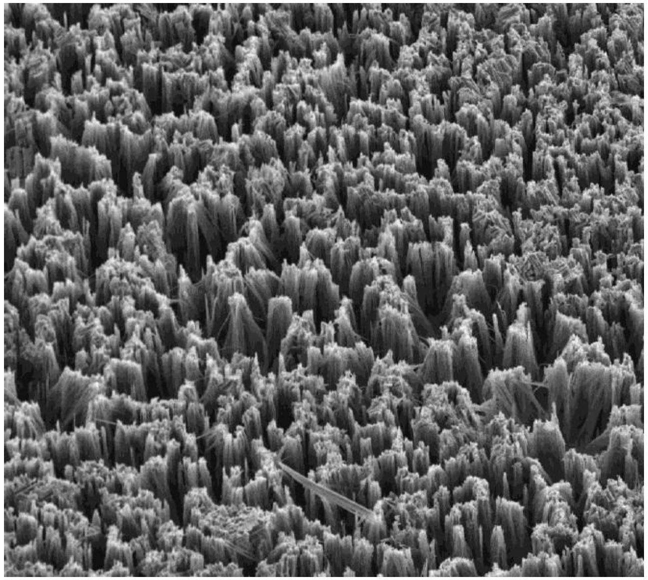
Improved absorption of visible light

- Nanowires etched into Si thin films
- Similar result for grown nanowires

Instrinsic light trapping

1.5 µm thick layer

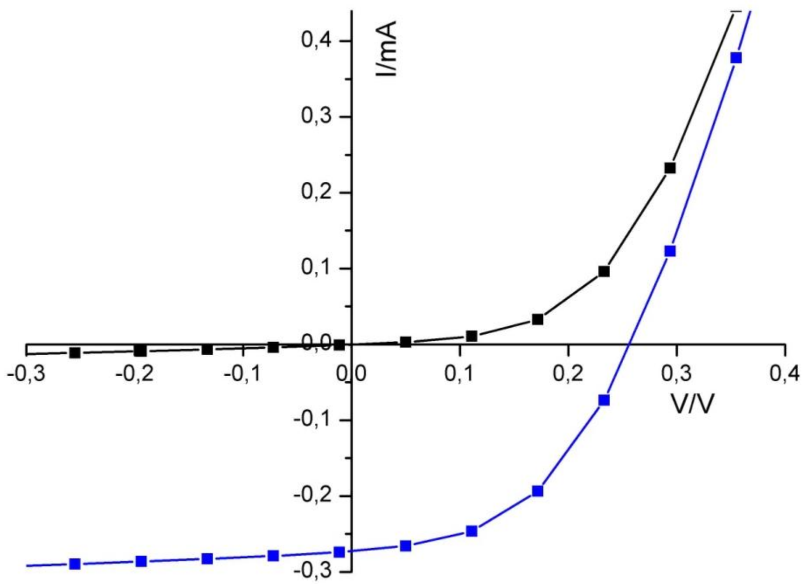




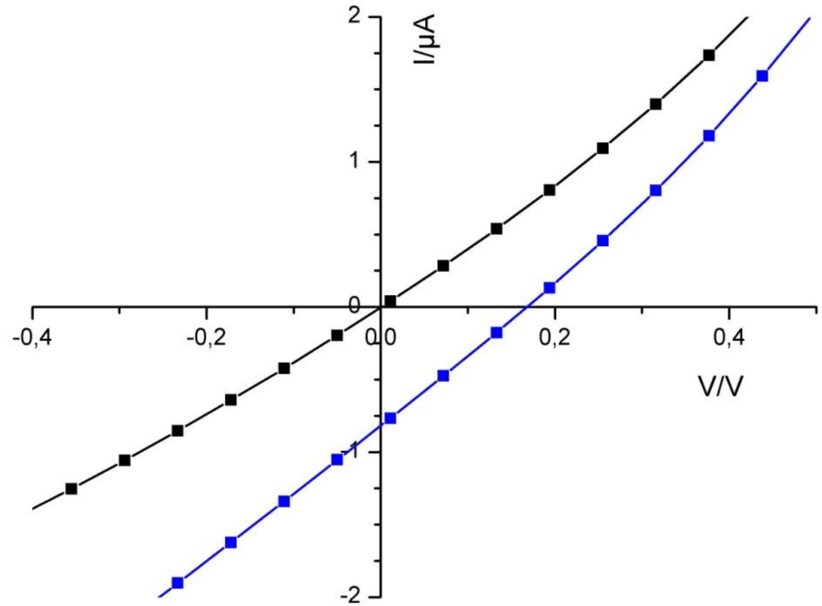
Optical properties measured in integrating sphere

Results: Cells from VLS Grown Nanowires

Axial p-n-junction



n-doped nanowires on p-doped wafer
V_{oc} 260 mV



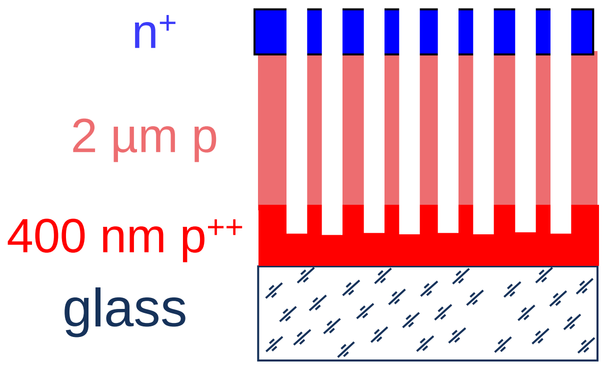
n-doped nanowires on
p-doped silicon thin film on glass
shunting!

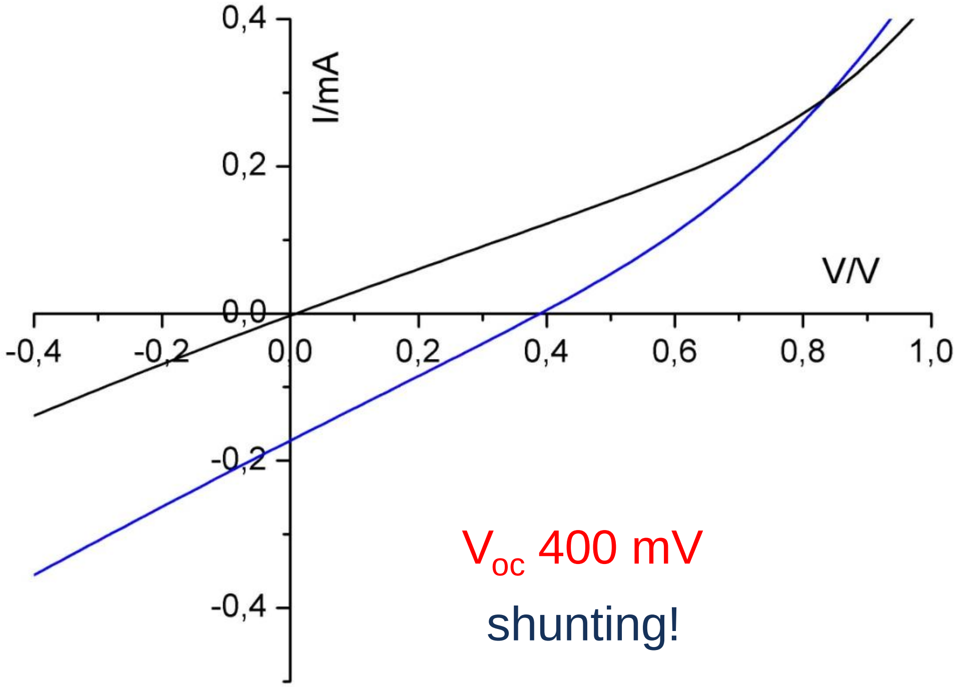
On highly doped substrates:
Dopant deployment: No photovoltaic behavior of wires

Results: Cells from Nanowires Etched into Thin Films

Crystalline Si films produced by Layered Laser Crystallization on glass
Axial p-n-junction

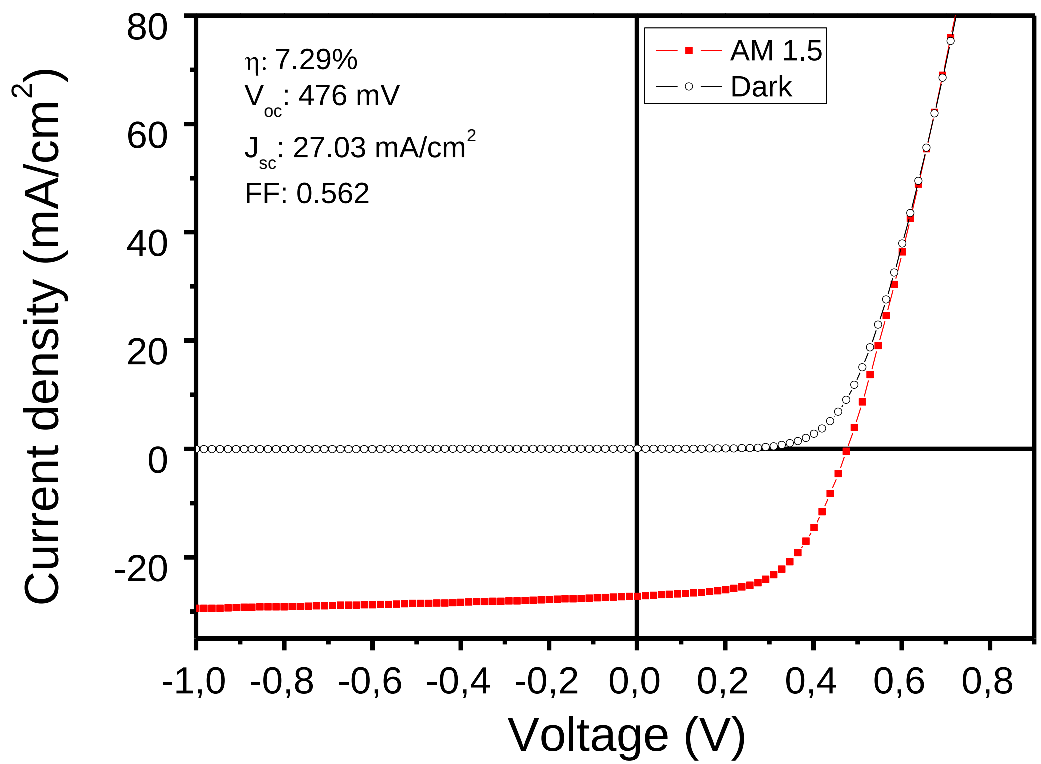
I-V curve measured using metal tips
dark and AM 1.5





Results: Cells from Nanowires Etched into Wafer

Radial a-Si hetero-junction



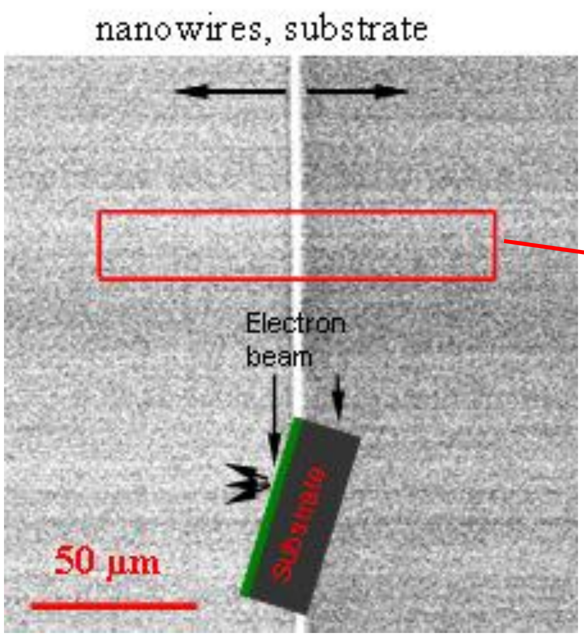
7.3 % efficiency

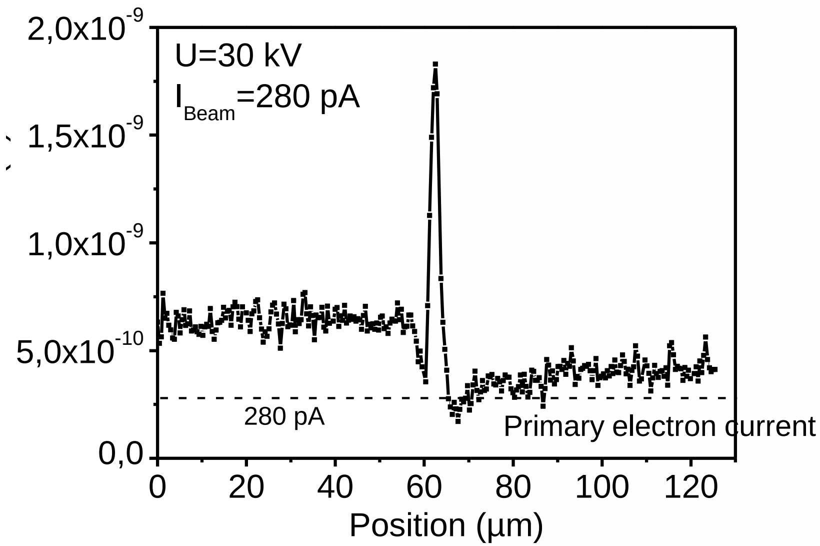
V_{oc} 476 mV

Results: Does PV come from Nanowires or from Substrate

Strong suspicion that in many cases current comes
from wafer substrate and not from nanowires
Nanowires just act as antireflection layer

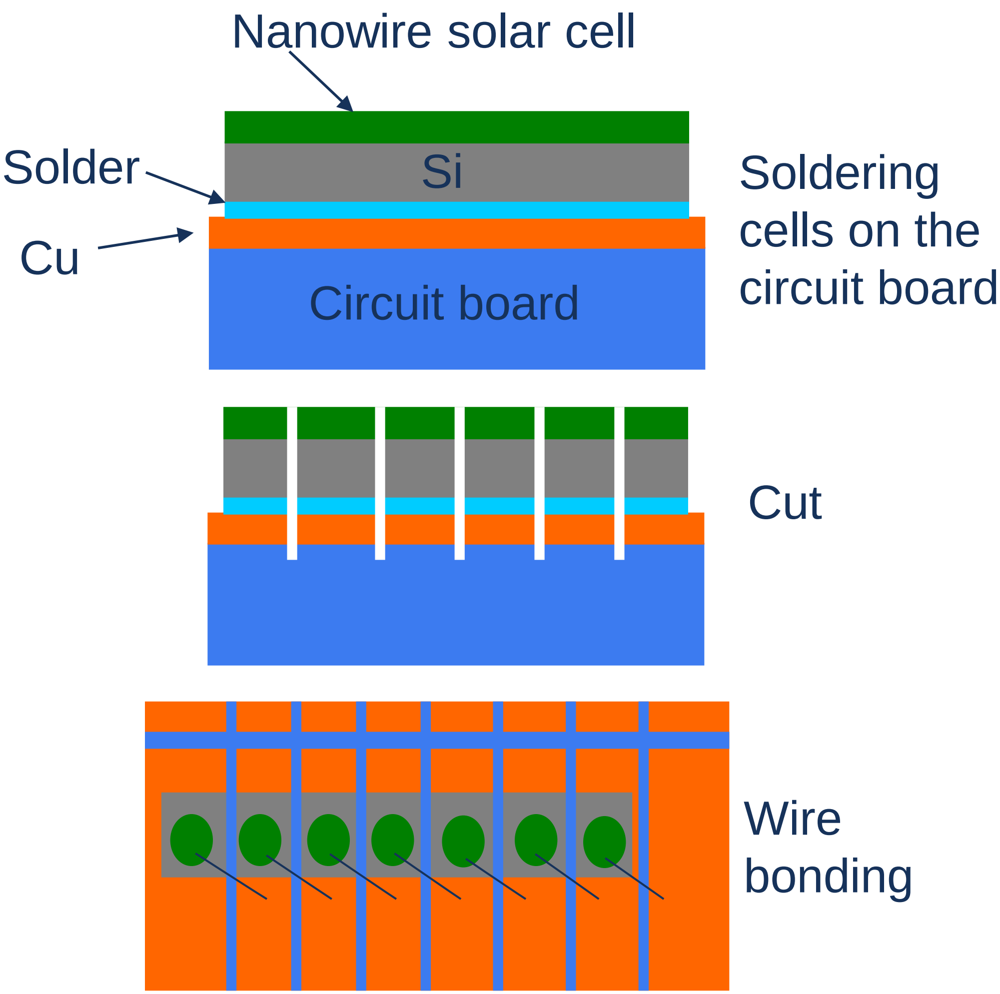
EBIC results confirm PV activity of nanowires in our case

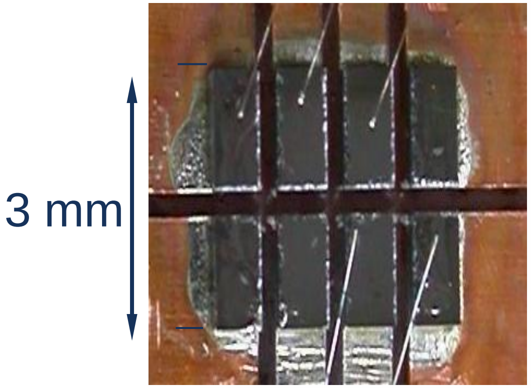




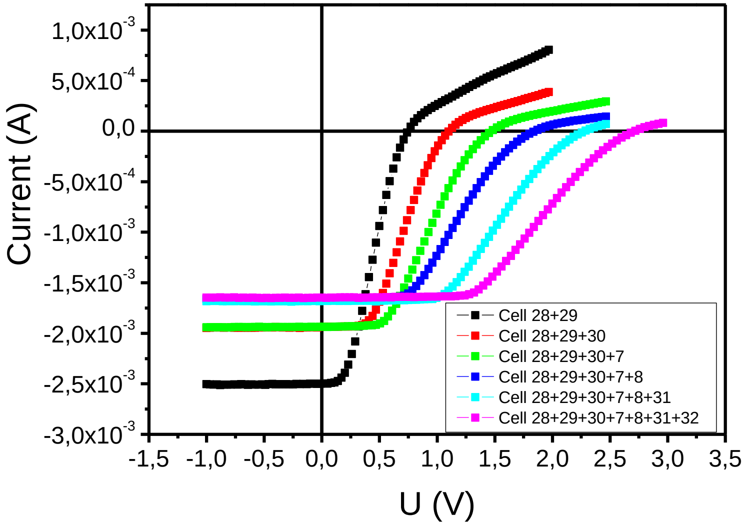
EBIC done at Joint Lab IHP/BTU Cottbus

Results: Minimodule from Nanowires Etched into Wafer





I-V for module with different number of cells



Open Questions

Optimal diameter and orientation of wires

Doping during VLS growth

Influence of Au in VLS grown wires

Reason for shunting and how to avoid it

Removing metal particles from holes between nanowires
    Ag for etched nanowires

Surface passivation

Contacting cells

Summary

Silicon nanowire solar cells were prepared

- with axial or radial pn-junction
- on glass

- grown by VLS from Au templates on c-Si thin films: axial
- etched into wafers or into c-Si thin films with doping profile: axial
- radial a-Si heteroemitter

- perfect light trapping in nanowire carpet

- V_{oc} 260 mV: VLS grown nanowire cell on wafer, axial p-n-junction
- V_{oc} 476 mV, 7.3% efficiency:

  Nanowires etched into wafer, radial a-Si heteroemitter, AZO contact

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TEM investigations

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EBIC measurements

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