Nanomaker

Lab #11: Silicon Photovoltaics (PV)

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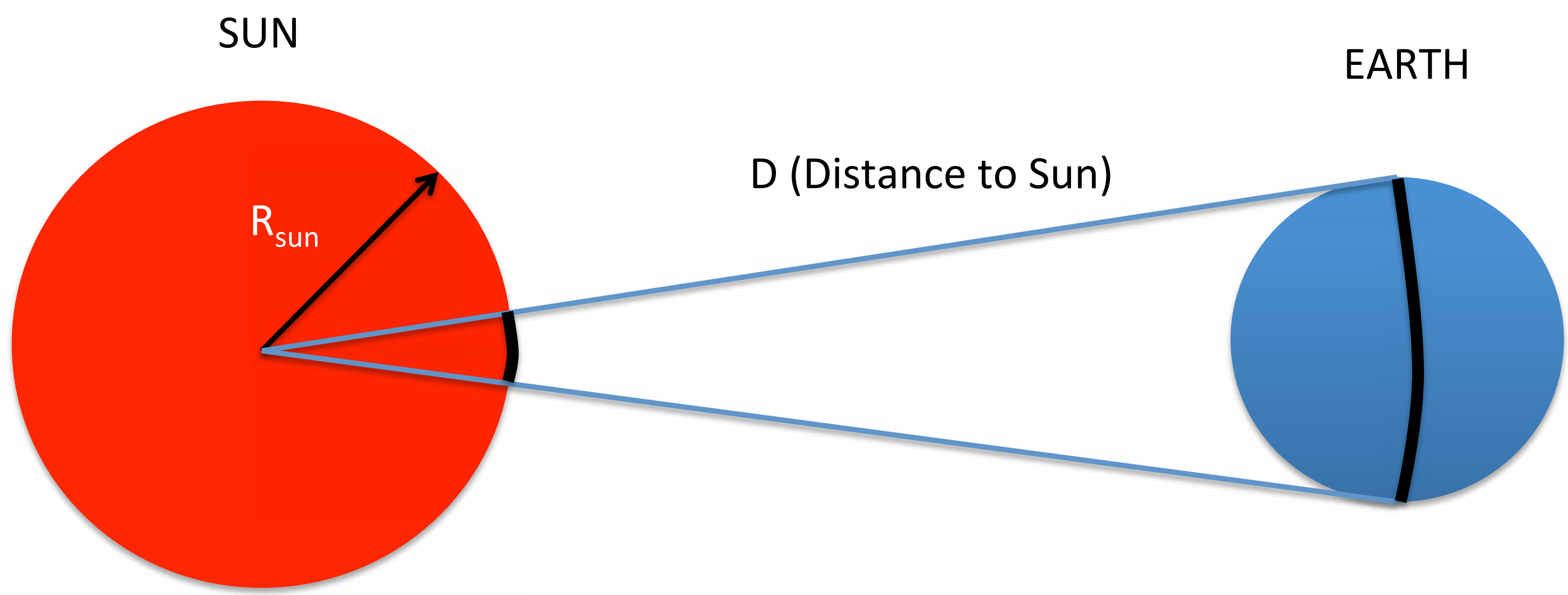
Solar Energy

Fabrication

Material Defect

Efficiency

Solar Energy



Total radiative power of sun
(Stefan-Boltzmann law, T=5762±50K)

$$P_{sun} = \frac{\sigma T^4}{4\pi R_{sun}^2}$$

Radiative power of sun per unit area (5.961×10^7 W/m^2)

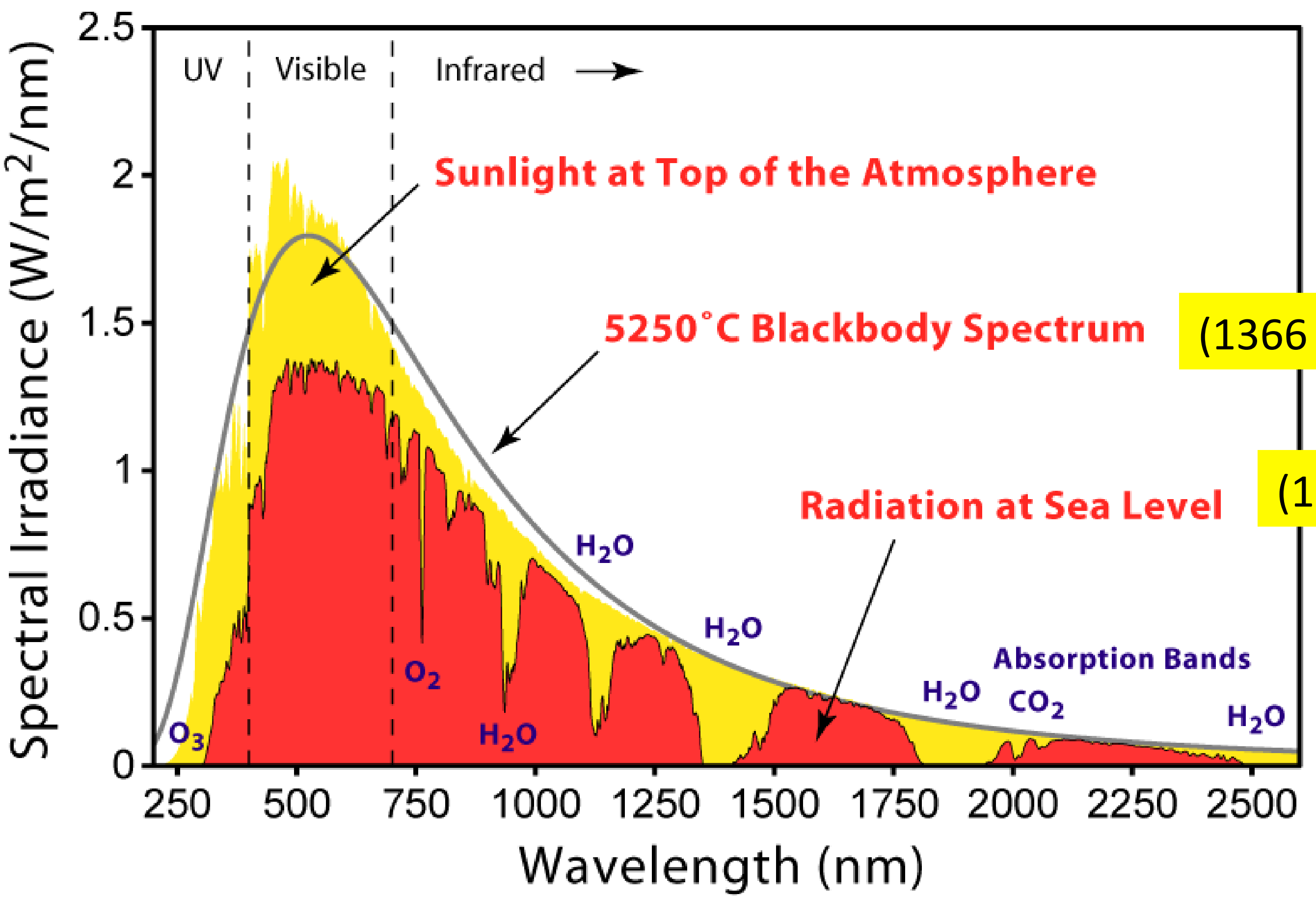
Surface area of Sun

Ratio of surface area

$$P_{earth} = \frac{R_{sun}^2}{D^2} P_{sun}$$

Average power (1366 W/m^2)

Solar Spectrum



(1366 W/m2)

(1000 W/m2)

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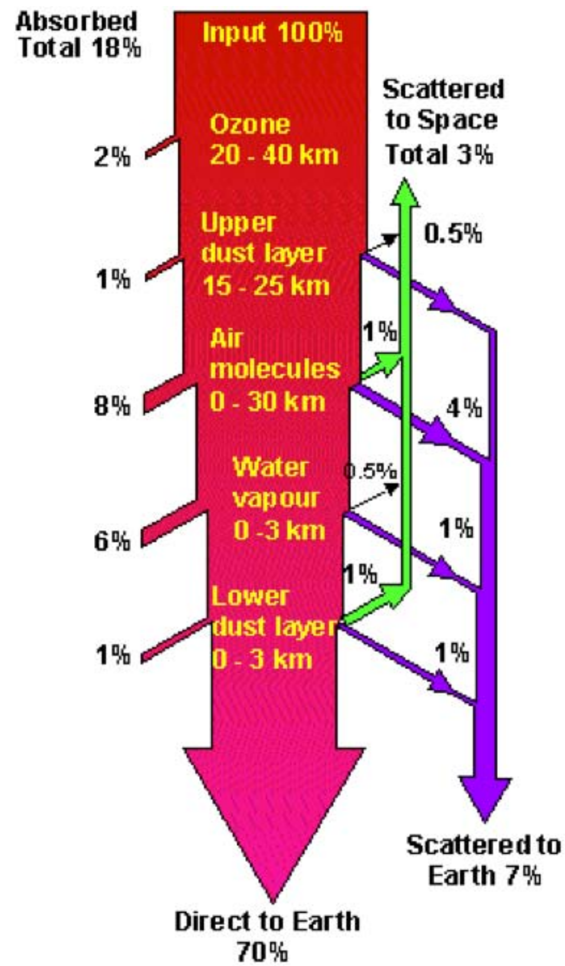
Nearly ~50% of the solar irradiance is in the visible spectrum

Lots of solar power is in the form of IR light

Atmospheric Effects

Atmospheric effects have several impacts on the solar radiation at the Earth's surface. The major effects for photovoltaic applications are:

- A reduction in the power of the solar radiation due to absorption, scattering and reflection in the atmosphere;
- A change in the spectral content of the solar radiation due to greater absorption or scattering of some wavelengths;
- The introduction of a diffuse or indirect component into the solar radiation; and
- Local variations in the atmosphere(such as water vapor, clouds and pollution) which have additional effects on the incident power, spectrum and directionality



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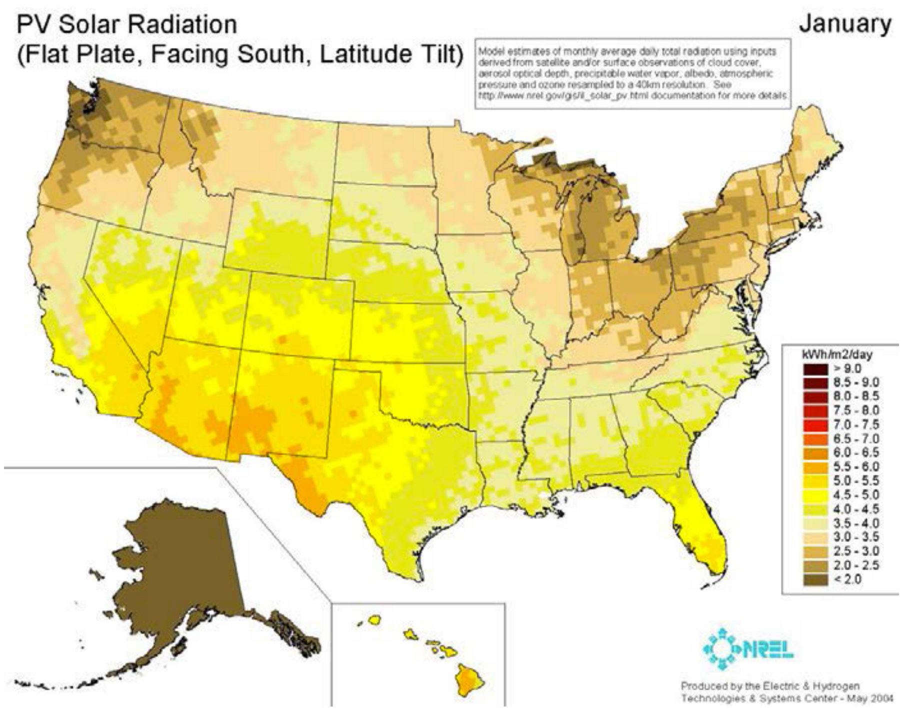
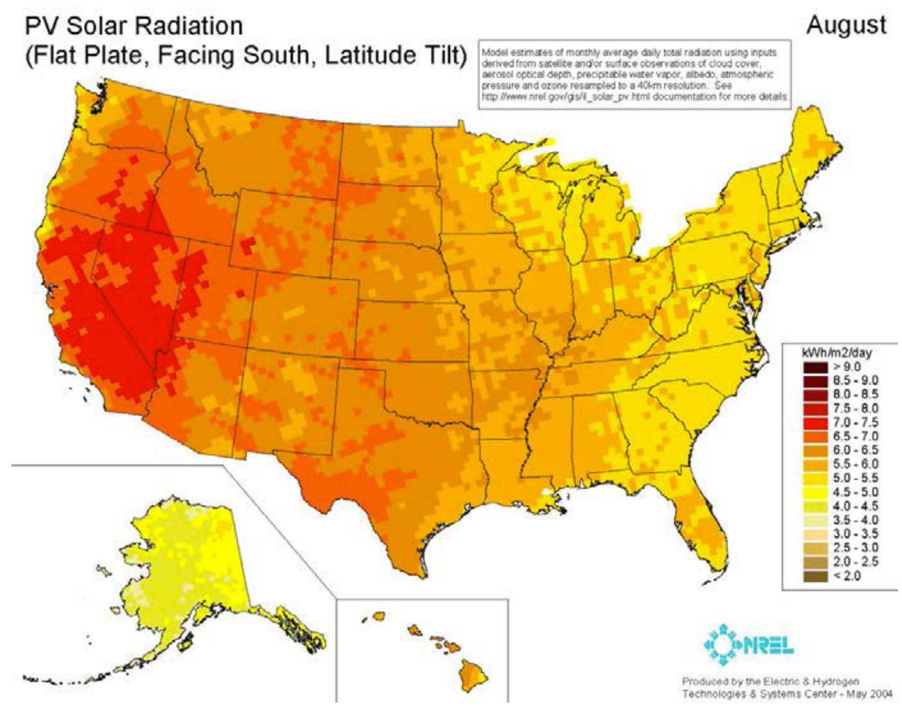
Insolation

Insolation: <u>In</u>coming <u>Sol</u>ar Radi<u>ation</u>

Energy per Unit Area per Unit Time **(kWh/m2/day)**





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Silicon Crystal Growth

Single Crystal Si Boule

Silicon Wafers

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Polycrystalline Silicon Solar Cell

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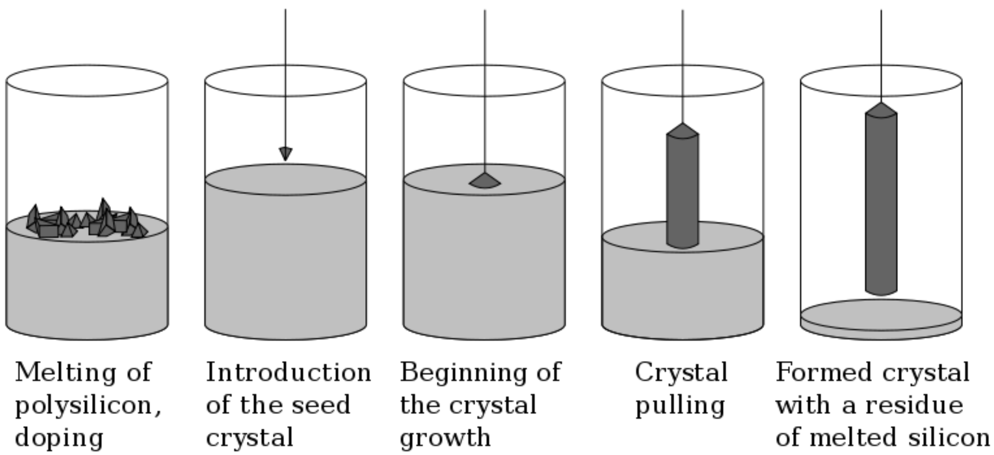

Czochralski growth

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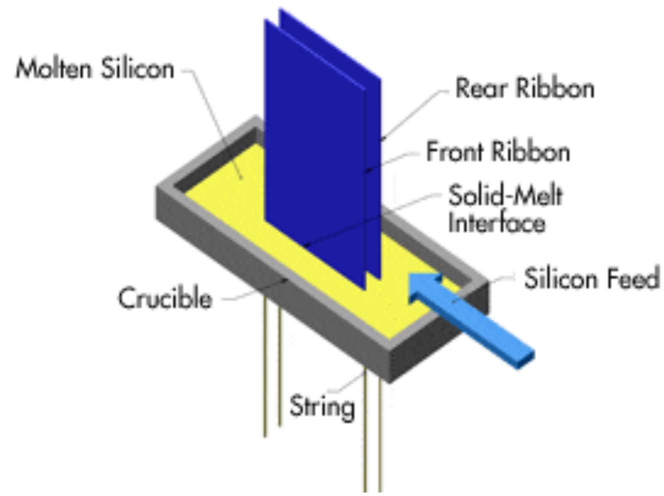
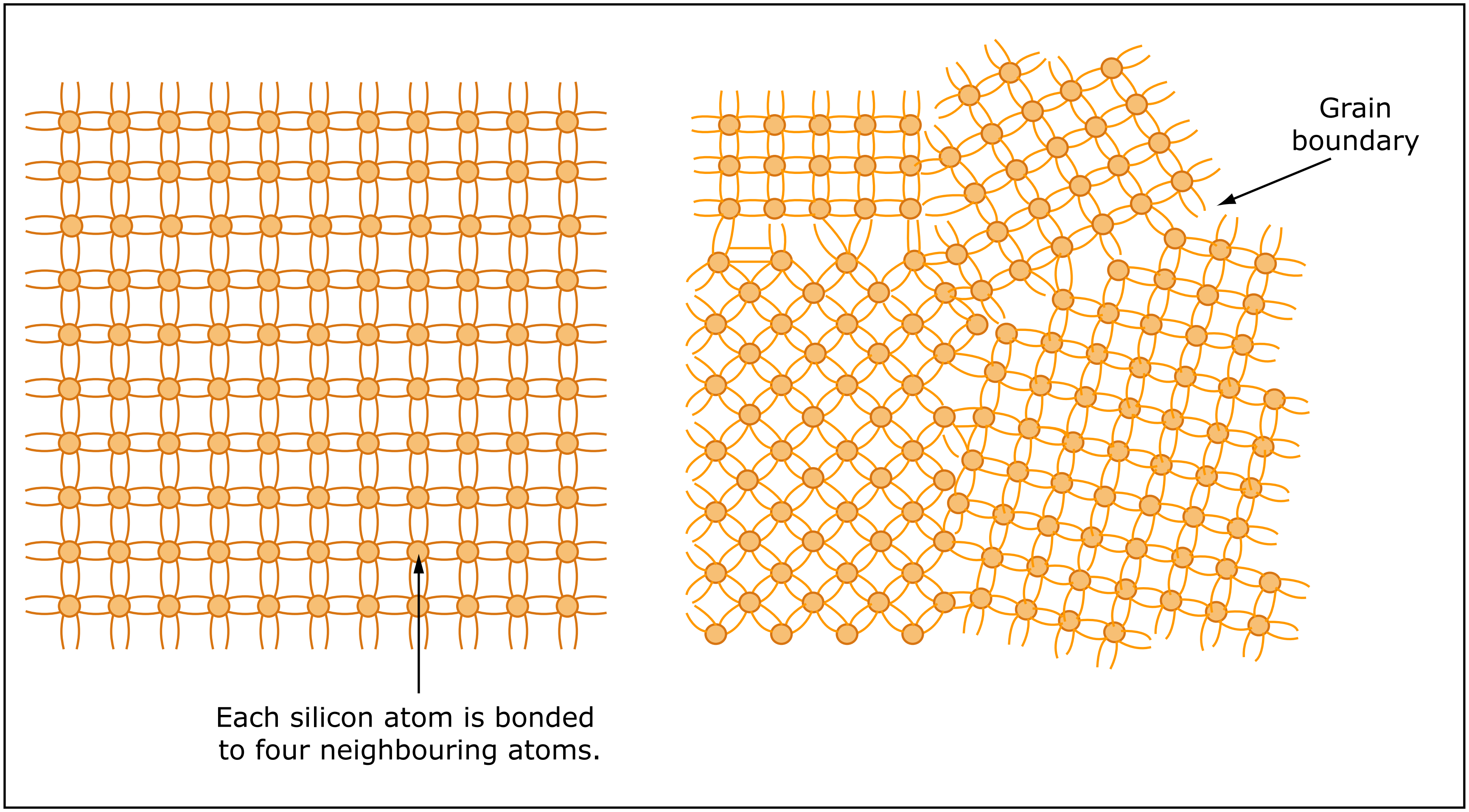


Ribbon growth

Silicon Crystal



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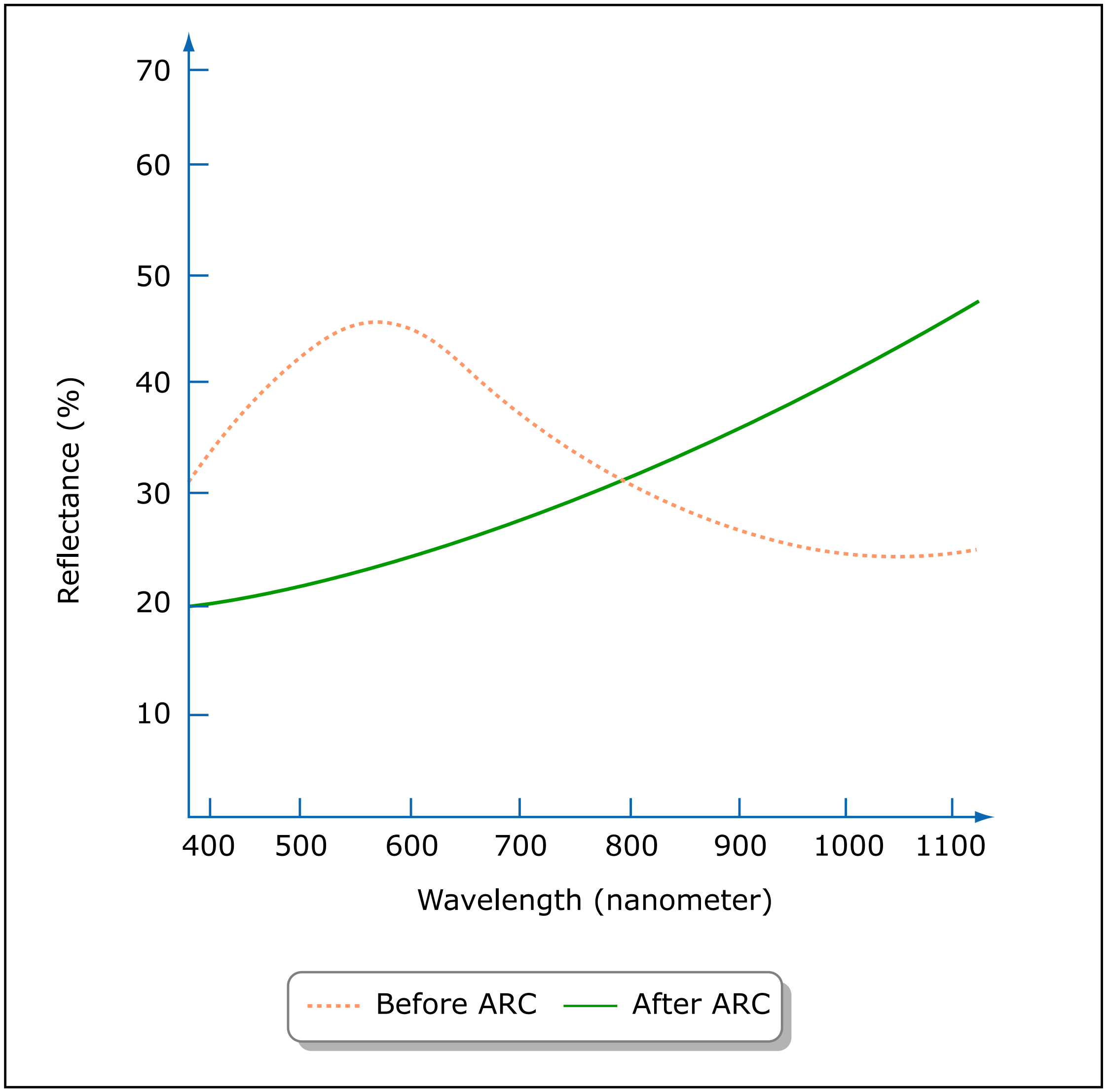
	Width (cm)	Growth rate (mm/min)	Throughput (m2/day)	Energy use (kWh/m2)	Best efficiency
Czochralski	15	0.6 - 1.2	30	21 - 48	20%
Ribbon Silicon	8-80	15 - 20	20	20	18%

Why Purple?



Reflectance curve of a polycrystallinesilicon solar cells before and after silicon nitride coating

Low-Cost: Roll-to-Roll Vacuum Coating

UNI-SOLAR
United Solar Ovonic

Photographs of the vaccuum coating process removed due to copyright restrictions.

Amorphous Silicon Solar Cell
Nine miles of solar cells in three days

Photo courtesy of US Army Africa on Flickr.

Solar Energy

Fabrication

Material Defect

Efficiency

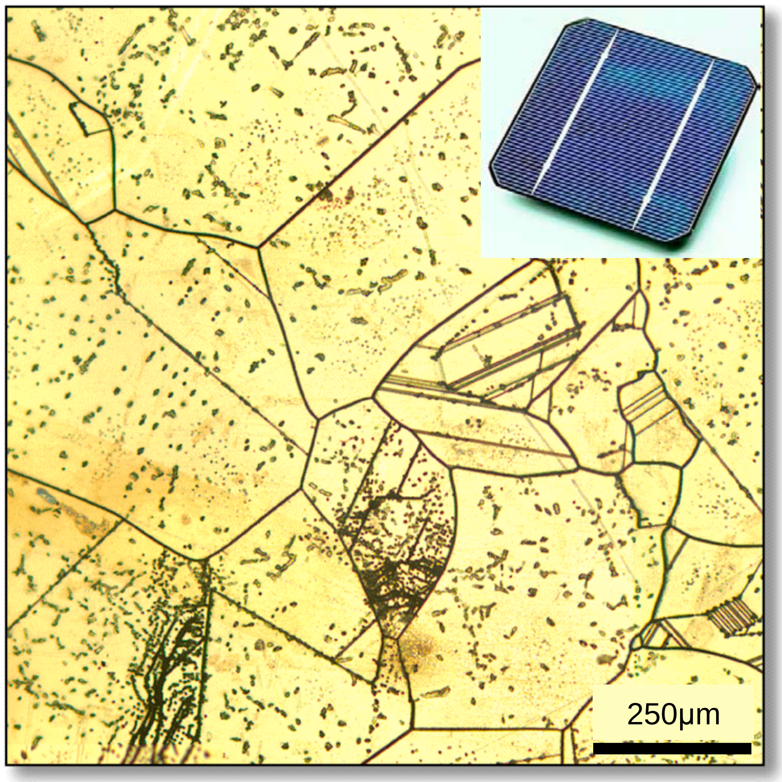
Polycrystalline Silicon

Metal Impurities

Iron, Titanium, Nickel, Chromium, Copper

Non-Metal Impurities

Oxygen, Nitrogen Carbon



Dislocations

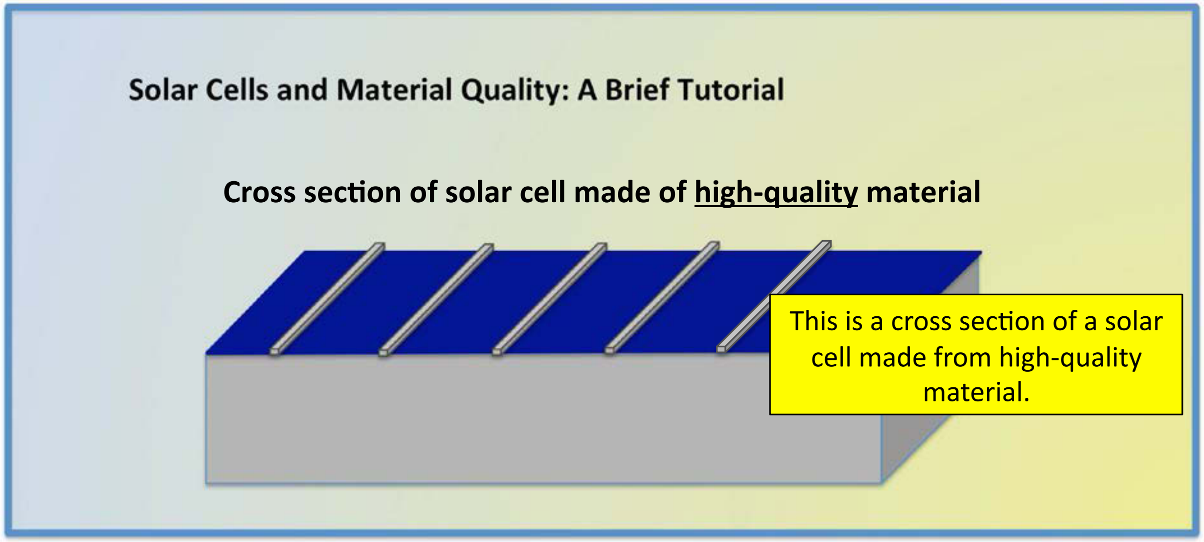
Edge, Screw, Mixed, Loops

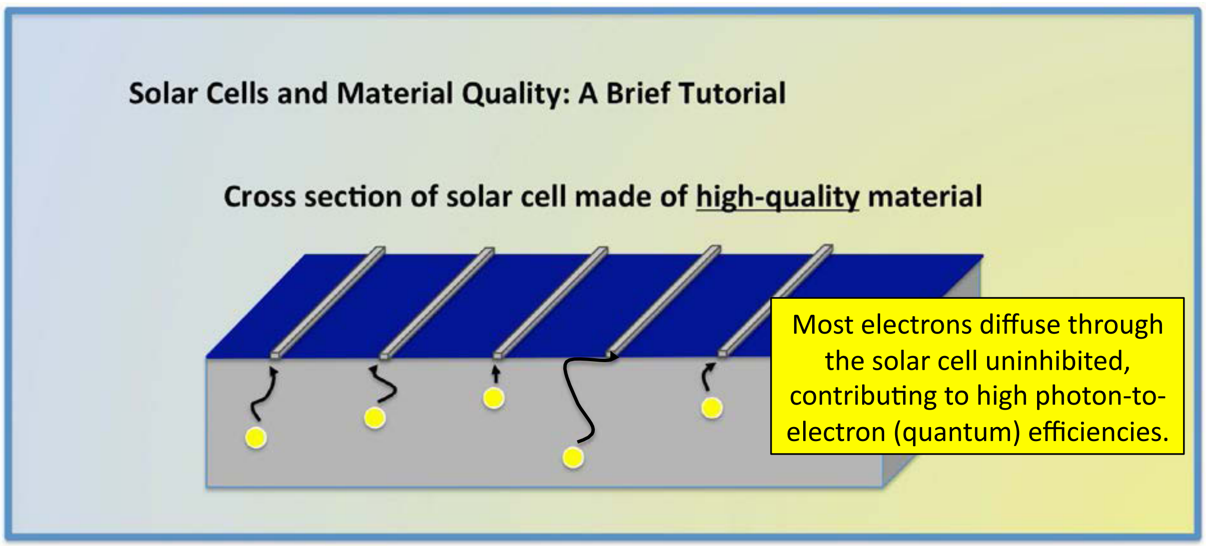
Grain boundaries

Small-angle, Large-angle

Adopted from Prof. Buonassisi

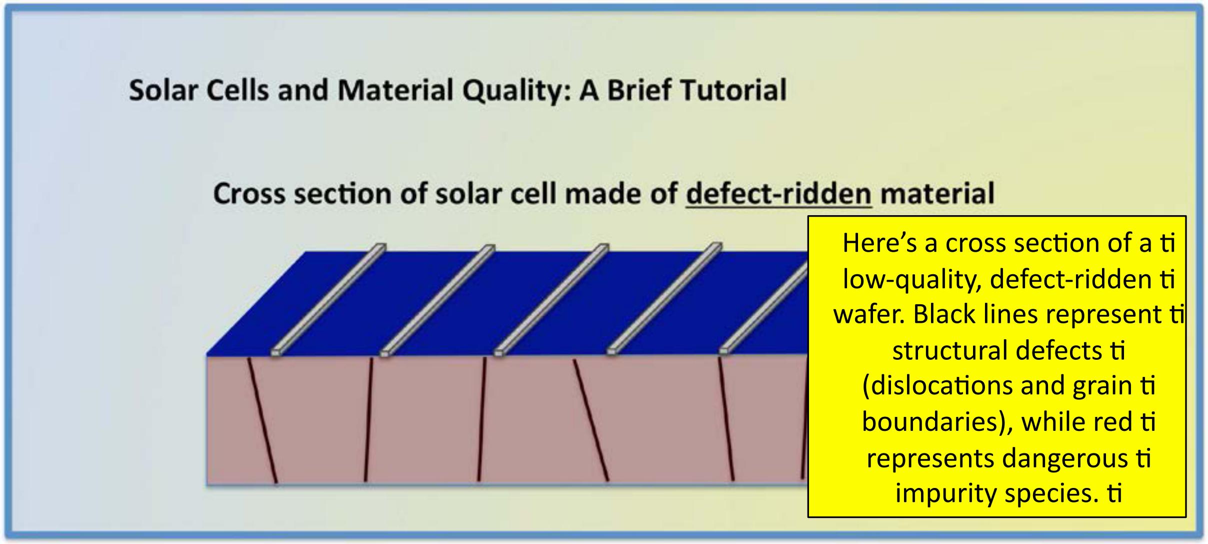
High Quality Materials

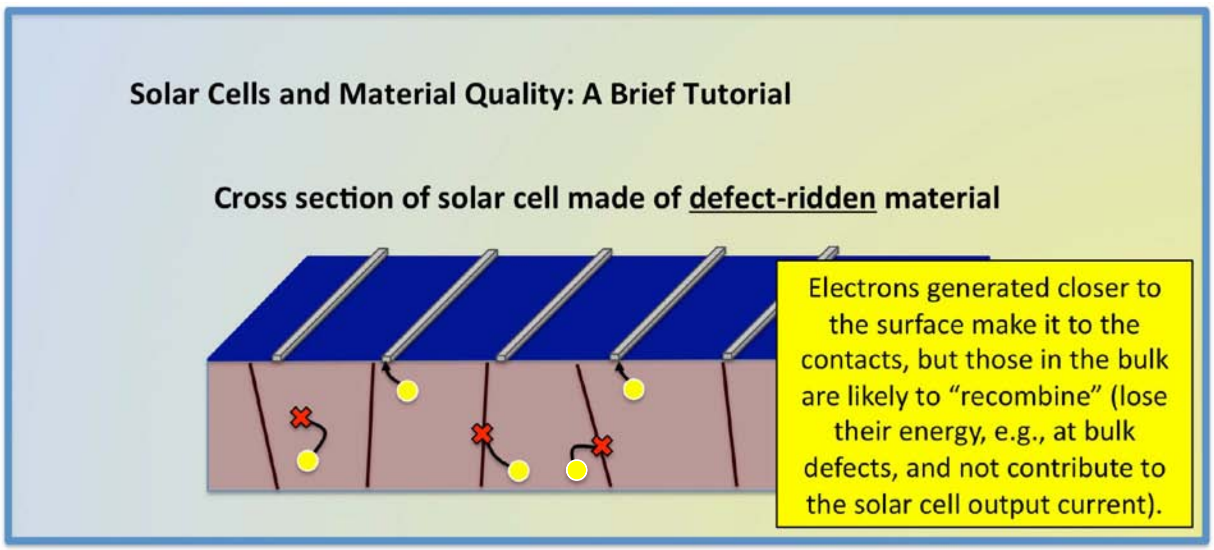




Adopted from Prof. Buonassisi

Low Quality Materials





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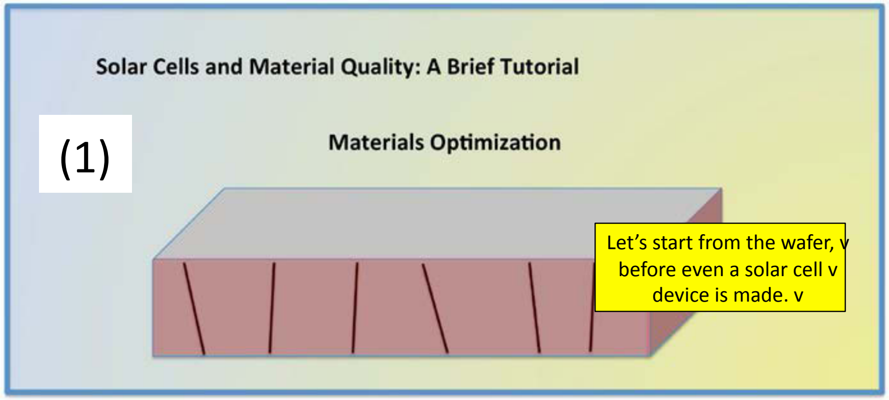

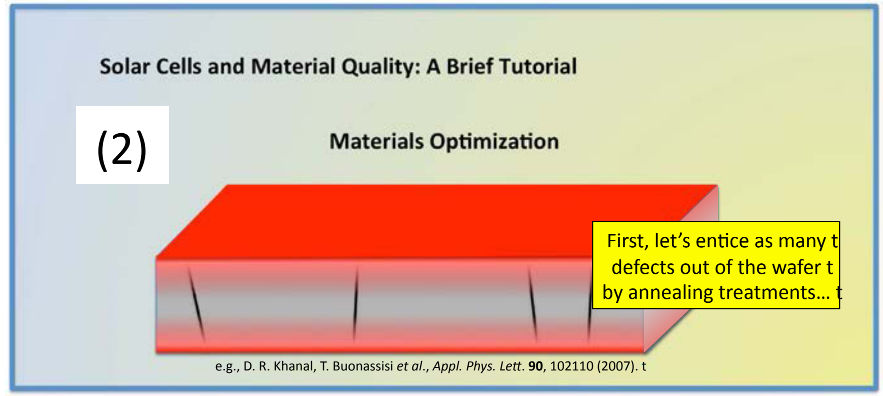

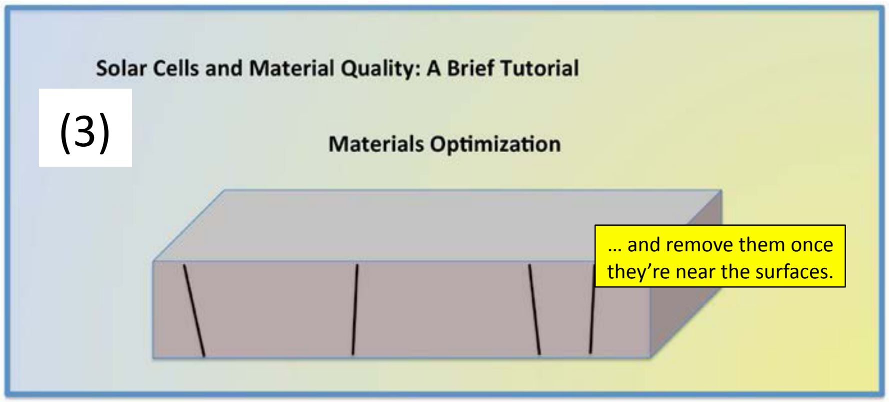

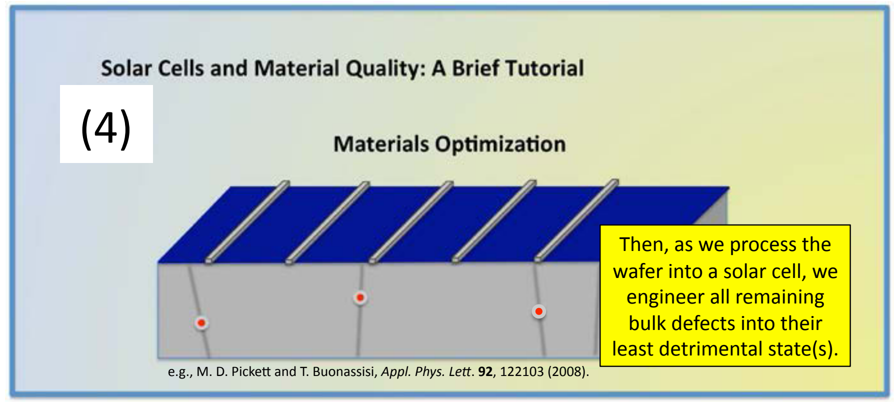

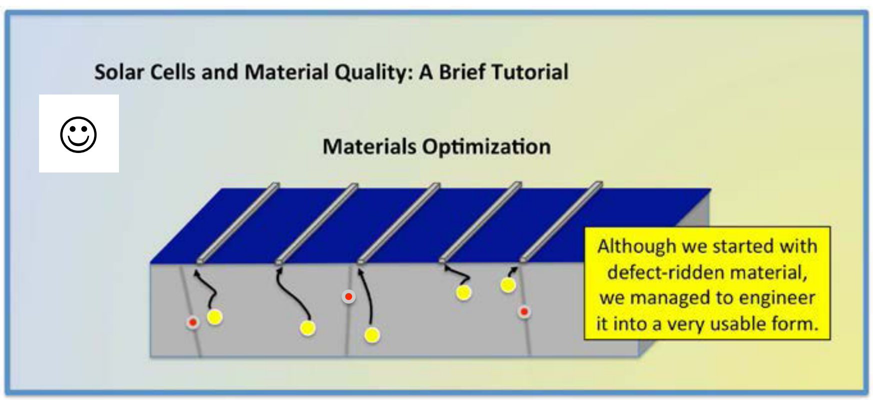

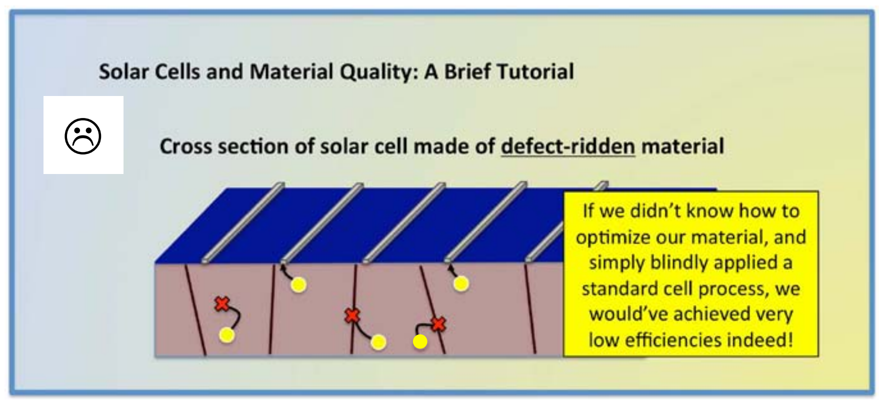

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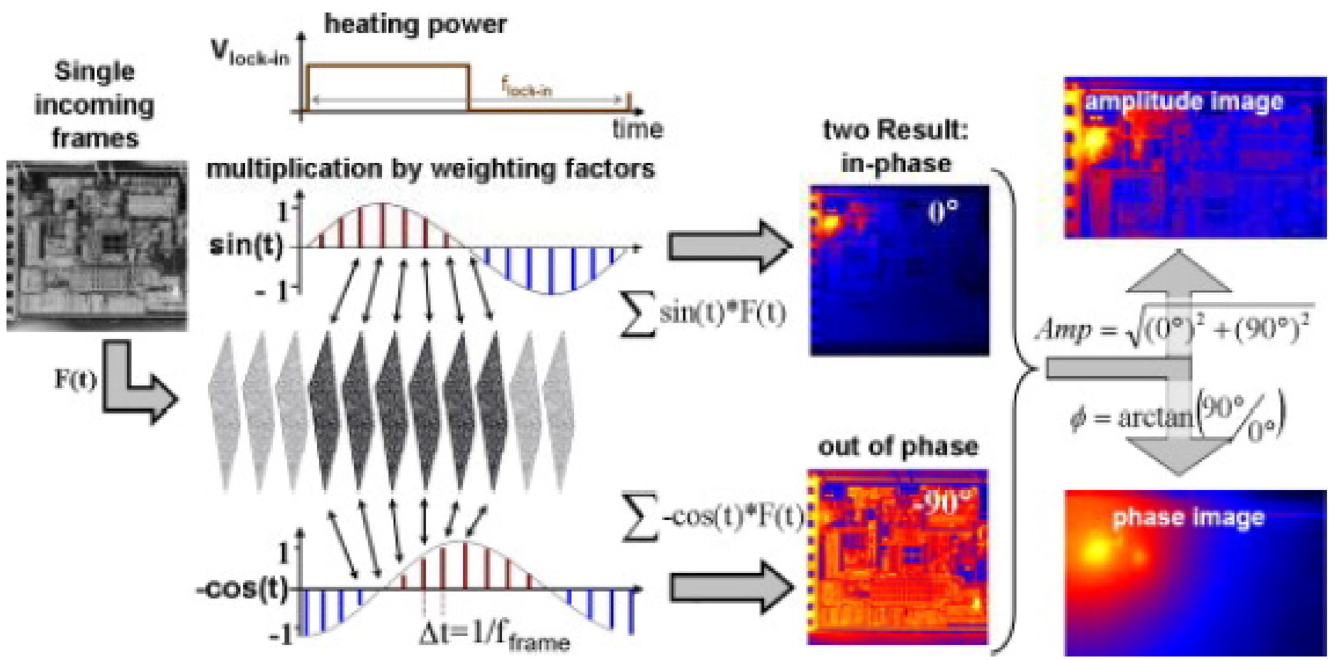
Lock-in Thermography



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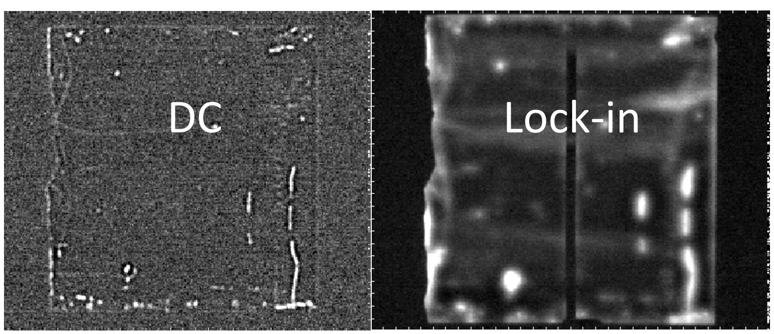

- Ribbon-Si Device
- 100 Hz lock-in frequency
- 0.6 V bias

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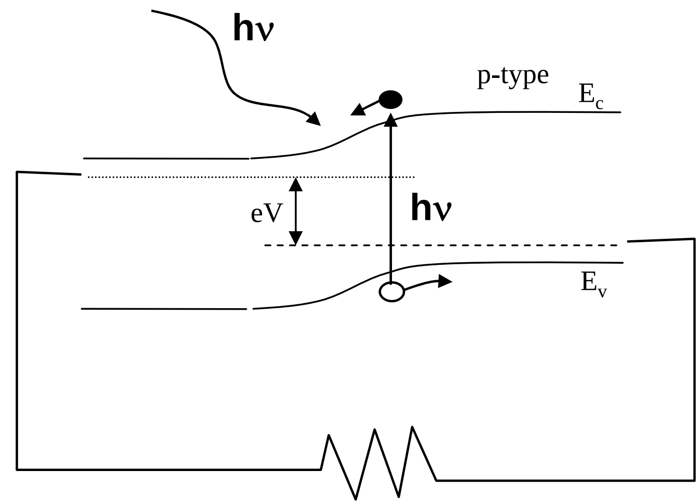
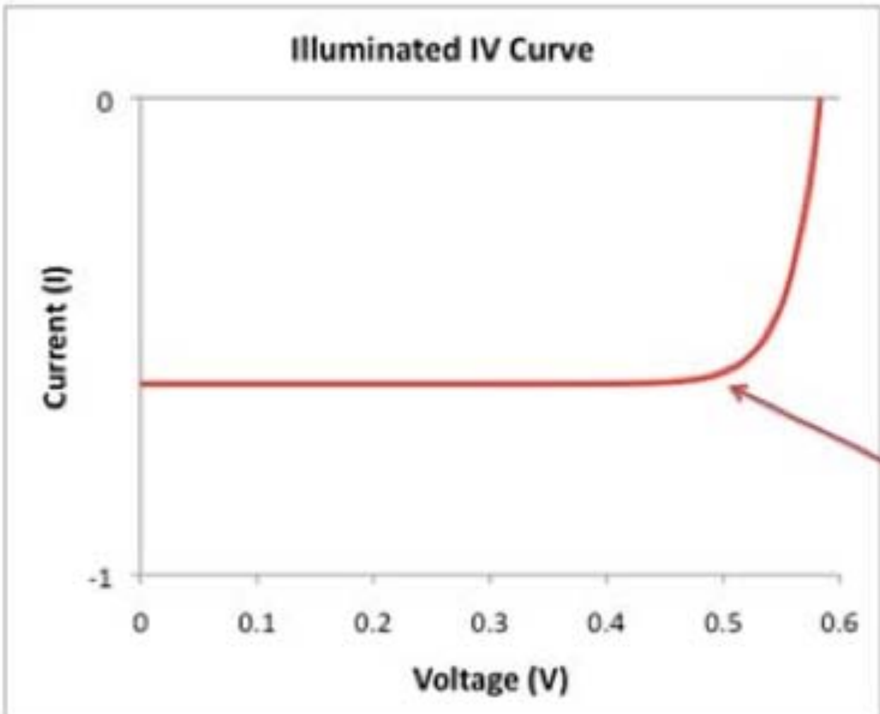
IV Characterization





$$I = I_o\left(e^{qV/kT} - 1\right) - I_L$$

I_L: excitation due to photon short circuit current

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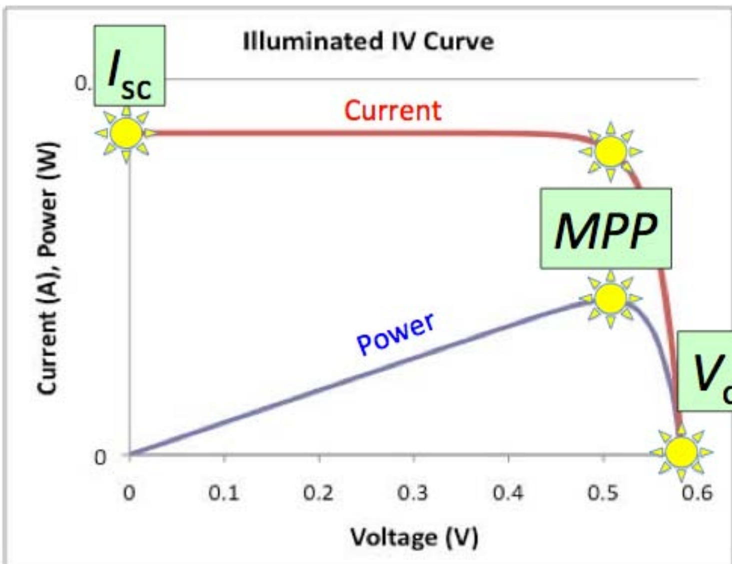
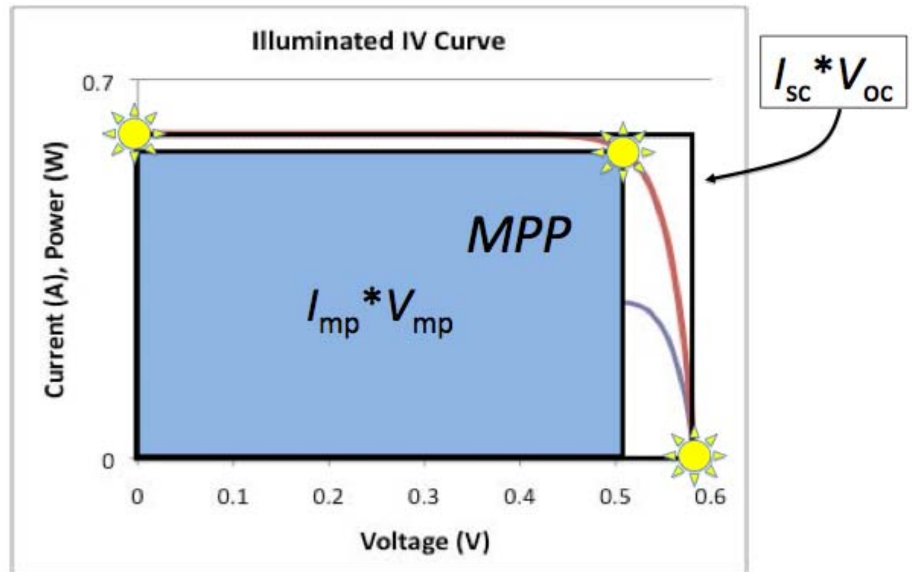
Efficiency

MPP: Maximum Power Point



$$\text{Efficiency} \equiv \eta = \frac{\text{Power Out}}{\text{Power In}} = \frac{V_{mp} \cdot I_{mp}}{\Phi}$$

Quadrant flipped!



$$\text{Fill Factor} \equiv FF = \frac{V_{mp} \cdot I_{mp}}{V_{oc} \cdot I_{sc}}$$

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$$\text{Efficiency} \equiv \eta = \frac{\text{Power Out}}{\text{Power In}} = \frac{V_{\text{mp}} \cdot I_{\text{mp}}}{\Phi}$$

$$\text{Fill Factor} \equiv FF = \frac{V_{\text{mp}} \cdot I_{\text{mp}}}{V_{\text{oc}} \cdot I_{\text{sc}}}$$

$$\text{Efficiency} \equiv \eta = \frac{\text{Power Out}}{\text{Power In}} = \frac{V_{\text{mp}} \cdot I_{\text{mp}}}{\Phi} = \frac{FF \cdot V_{\text{oc}} \cdot I_{\text{sc}}}{\Phi}$$

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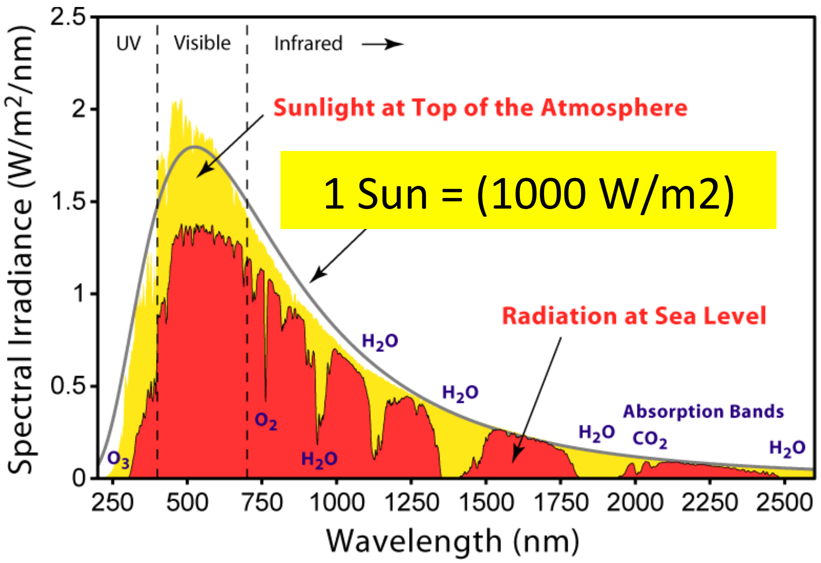
Conclusions



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Single Crystal

Polycrystalline Crystal

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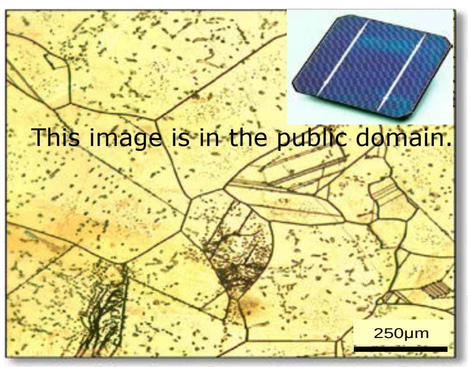
<u>Metal Impurities</u>
Iron, Titanium, Nickel
Chromium, Copper

<u>Non-Metal Impurities</u>
Oxygen, Nitrogen
Carbon



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<u>Dislocations</u>
Edge, Screw, Mixed, Loops

<u>Grain boundaries</u>
Small-angle, Large-angle

$$\text{Efficiency} \equiv \eta = \frac{\text{Power Out}}{\text{Power In}}$$

$$= \frac{V_{mp} \cdot I_{mp}}{\Phi} = \frac{FF \cdot V_{oc} \cdot I_{sc}}{\Phi}$$

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