PV Technology

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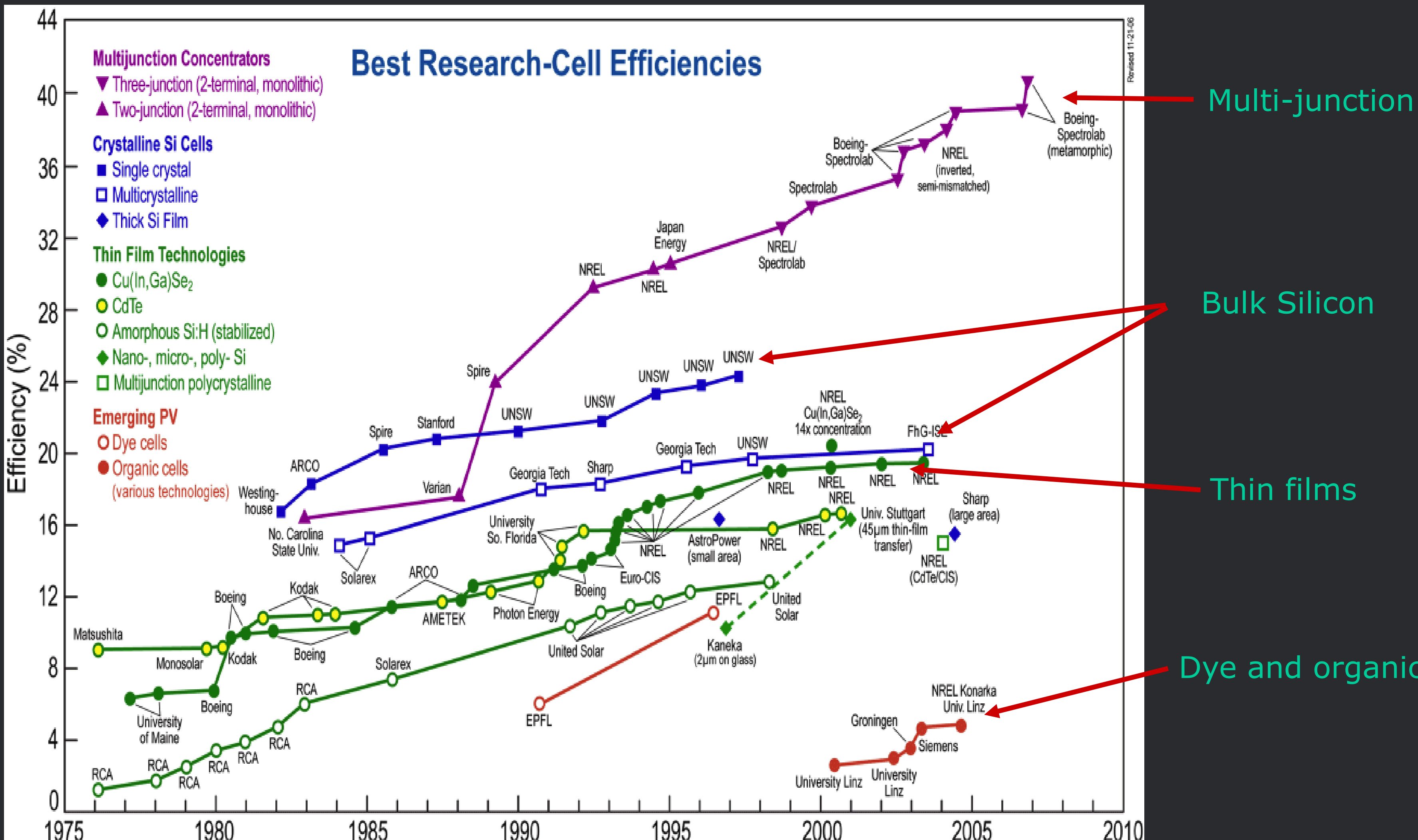
Visão da I&D no fotovoltaico



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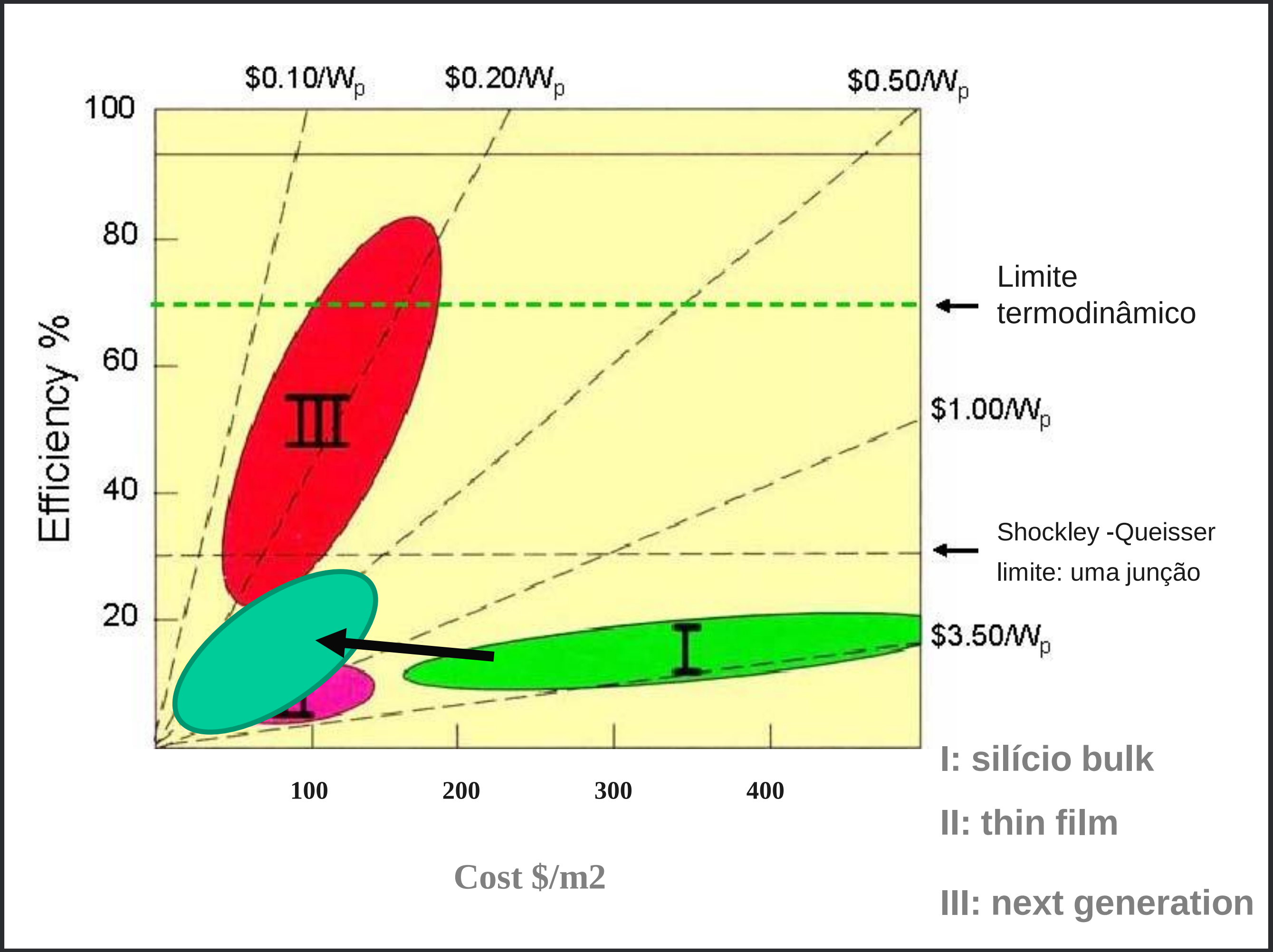
Visão da I&D no fotovoltaico



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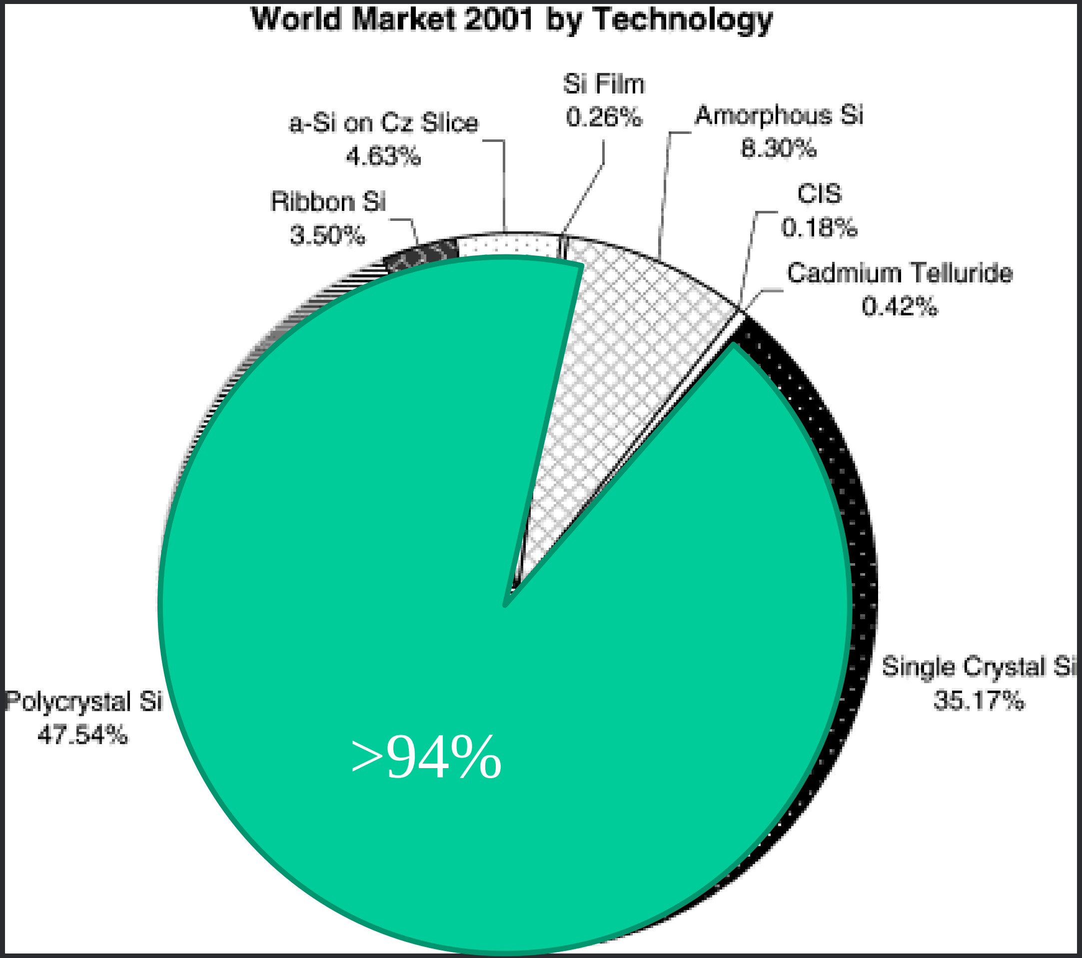
Visão da I&D no fotovoltaico



SOURCE: A. Goetzberger et al. / Materials Science and Engineering R 40 (2003)

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Silicon PV flowchart

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First generation

- Single layer of *p-n* diode
- One excitation per photon
- Mostly made of silicon wafers
- 95 % of solar cell market
- Life expectancy of >30 years
- Energy payback in 2-5 years (positive)

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Second generation

– “Thin-film” solar cells
– Mix of glass and ceramic with very little active semiconductor material
– Inexpensive but lower efficiency

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Third generation

- No *p-n* junction
- Organic polymer cells or nanocrystal cells
- Perovskites

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- Production of Si
- Wafer based Si solar cells
- Thin-film solar cells
- Other concepts

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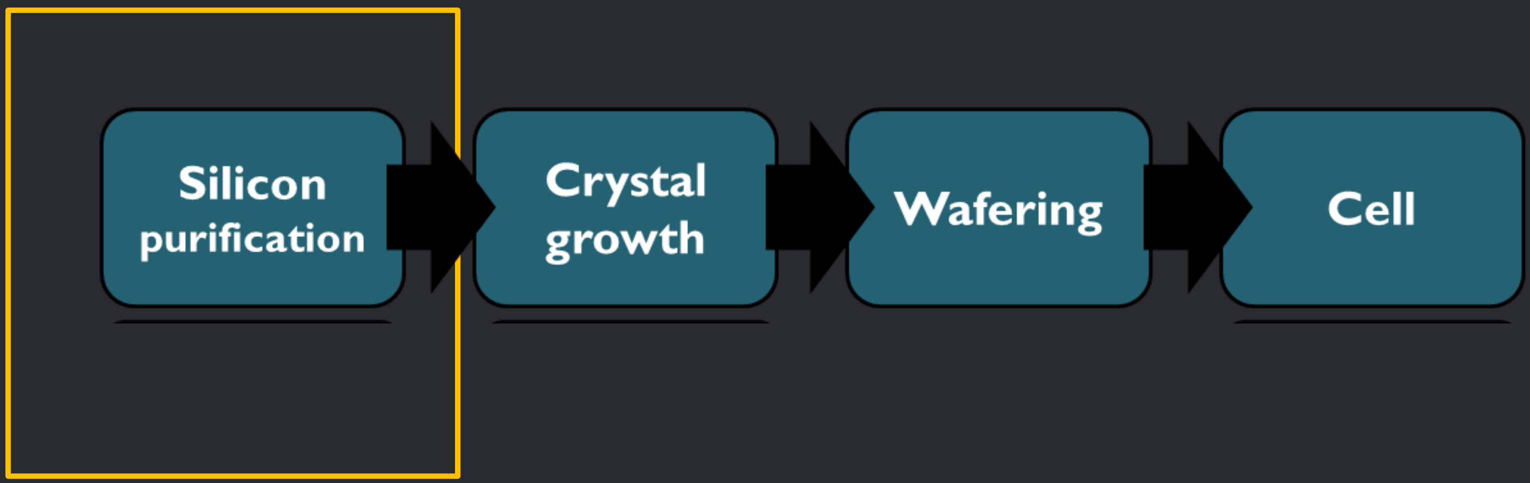
Silicon PV flowchart



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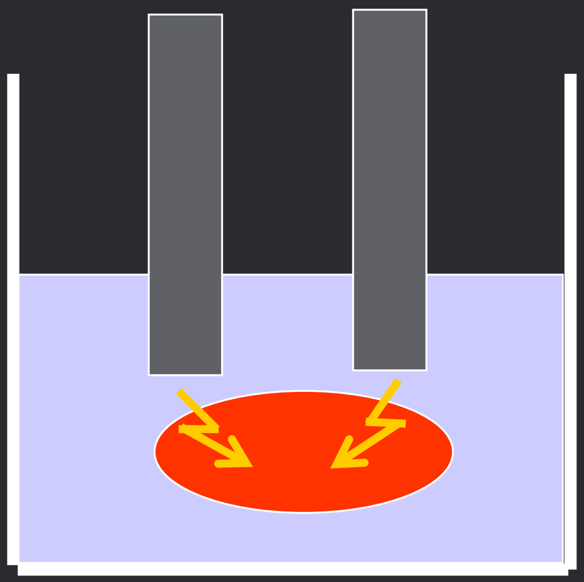
MG silicon



Arc furnace

MG-Si is produced by reduction of SiO_2 with C in arc furnace at 1800 C

$$\mathbf{SiO_2 + C \rightarrow Si + CO_2}$$

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MG silicon

- MG-Si is material with 98-99% purity,
- Produced in about 1 Million tons per year
- Produced in countries which cheap electricity and quartz deposits (USA, Europe, Brazil, Australia, Norway)

- Average price is 2 to 4 $/kg (electronic grade Si is 30-45 $/kg)

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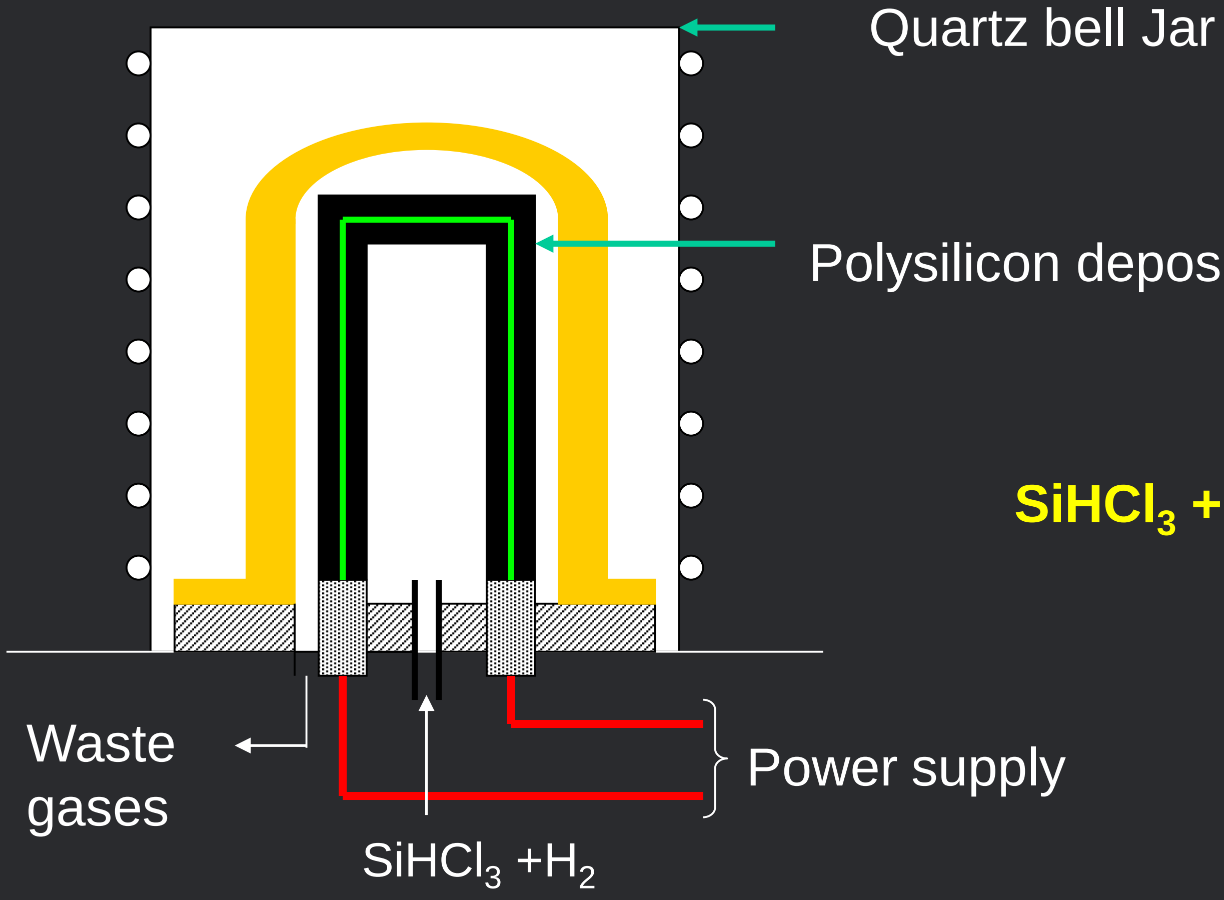
EG silicon



Siemens process

$SiHCl_3 + H_2 \rightarrow Si + 3HCl$

Deposition process is slow

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EG silicon

Feedstock: obtaining hyperpure silicon from gas phase

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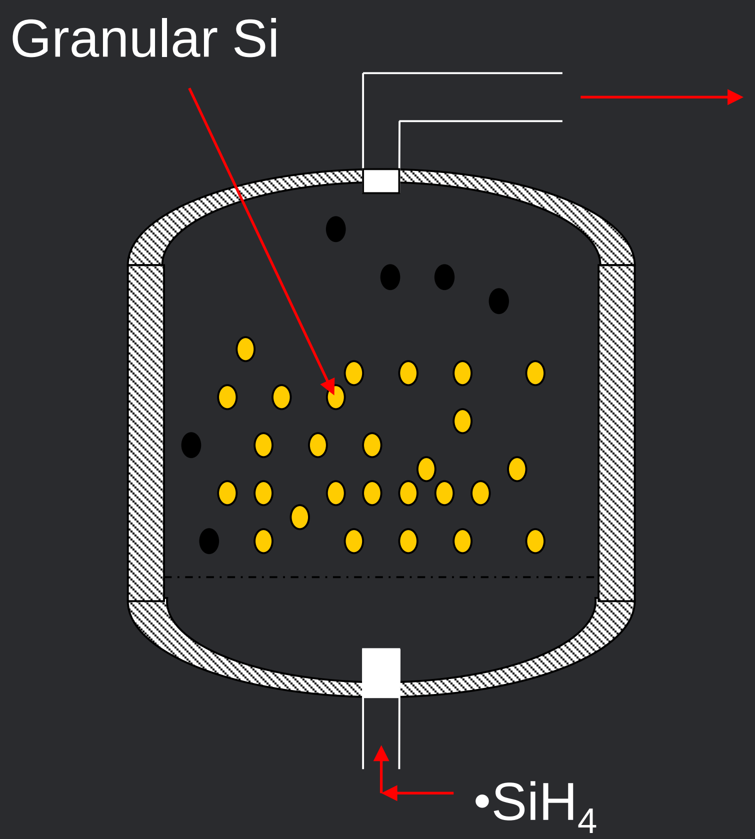
EG silicon



Fluidized bed reactor (FBR)

- Silicon seed particles are held in suspension by a gas mixture (H_2 and SiH_4)
- At 600° C gas phase decomposition takes place, causing the seed particles to grow up to 2 mm in size
- Big particles falls due to weight
- Si is collected from the bottom of the jar

Continuous process

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EG silicon

Crystalline silicon may be crystallized in PV in different forms:

Descriptor	Symbol	Grain Size	Common Growth Techniques
Single crystal	sc-Si	>10cm	Czochralski (CZ) float zone (FZ)
Multicrystalline	mc-Si	1mm-10cm	Cast, sheet, ribbon
Polycrystalline	pc-Si	1µm-1mm	Chemical-vapour deposition
Microcrystalline	µc-Si	<1µm	Plasma deposition

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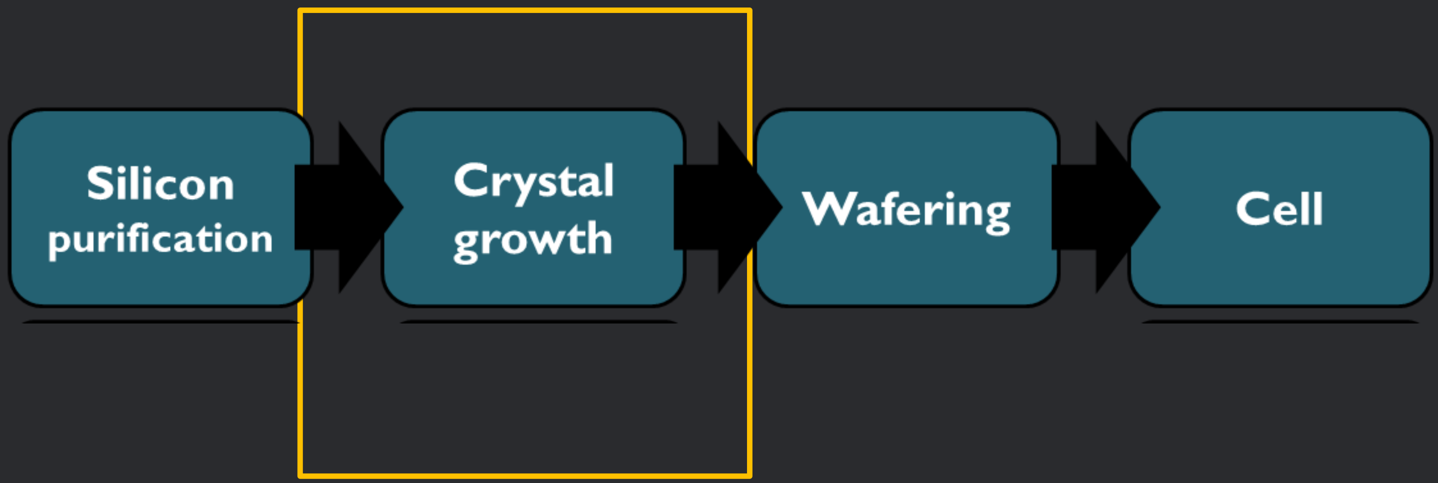
Silicon PV flowchart



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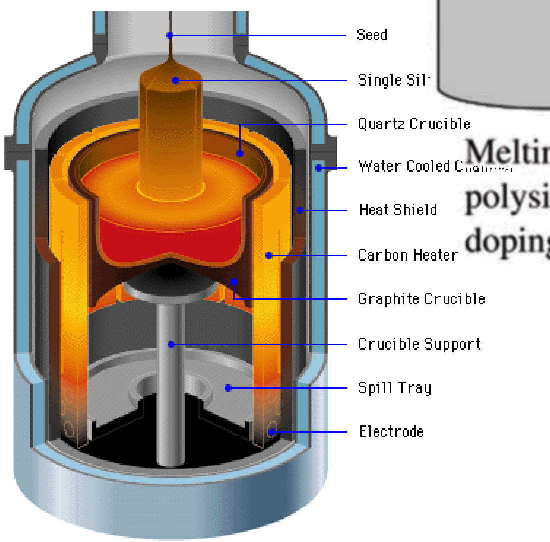
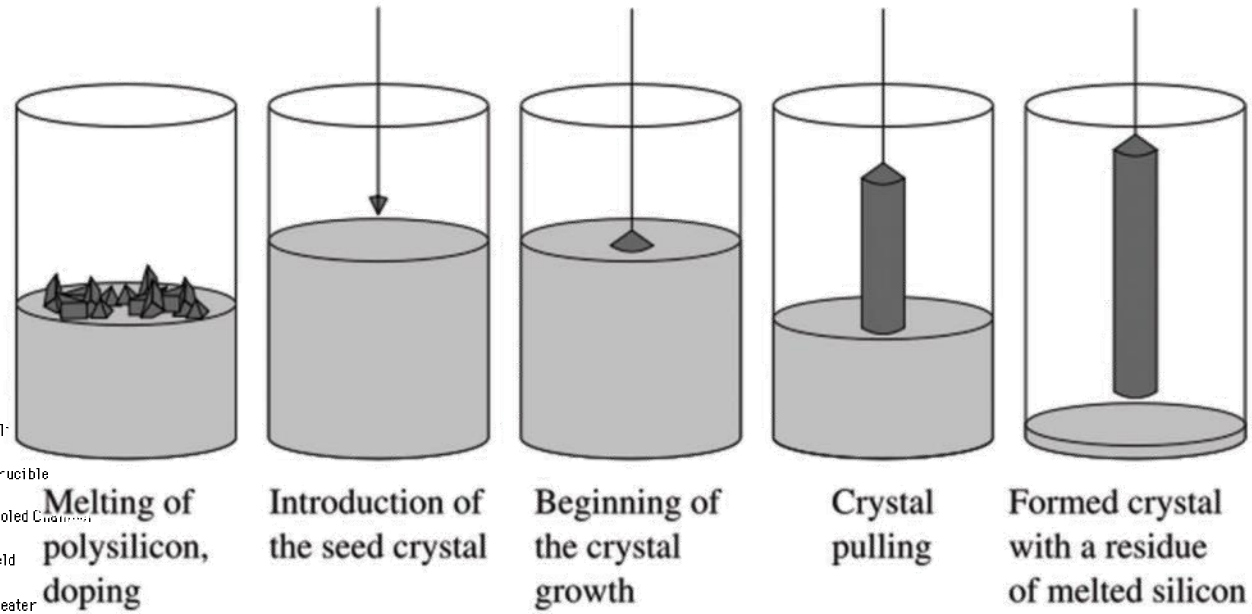
Single crystal growth





Czochralski method

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Single crystal growth

Advantages

Good crystal quality

No induced thermal stresses

Disadvantages

High oxygen content

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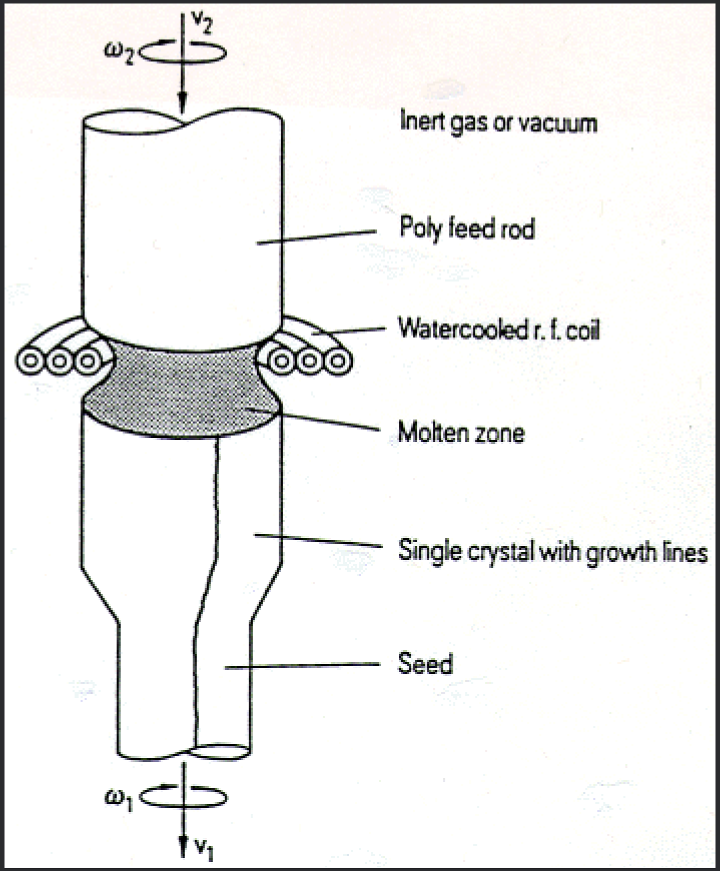
Single crystal growth



Float zone method

Advantages

Good crystal quality

No induced thermal stresses

No contamination

Disadvantages

More expensive

Record efficiency solar cells have been manufactured with float zone

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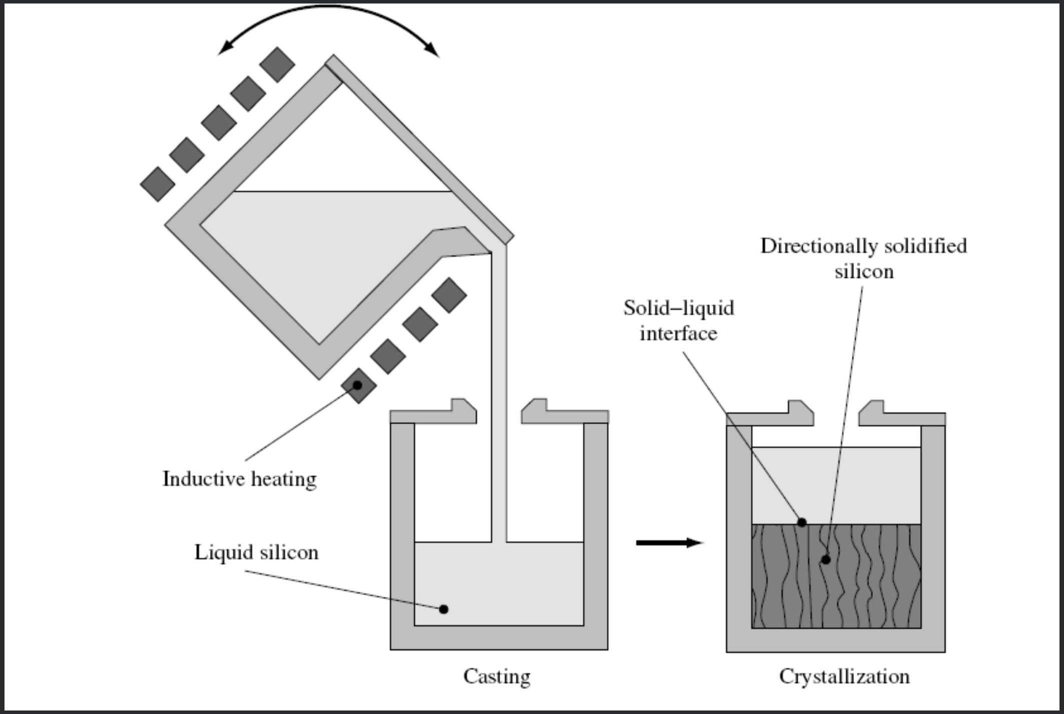
Multicrystalline silicon



Advantages

Large volumes

Simple

Disadvantages

Multicrystalline

Impurity contamination

Crucible costs

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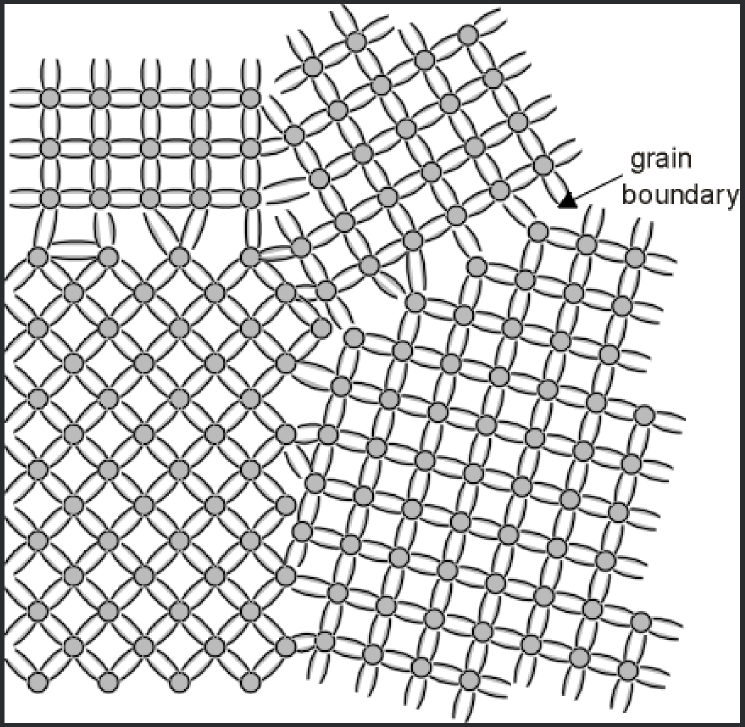
Mc silicon

Multicrystalline silicon offers acceptable quality but at lower cost



Typical casting:
240kg/56 hours

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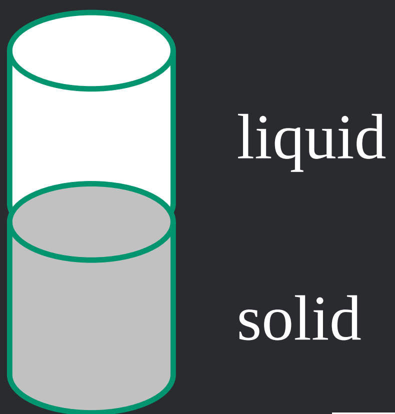
Bulk doping



$$k_0 = \frac{C_s}{C_l},$$

TABLE 1 EQUILIBRIUM SEGREGATION COEFFICIENTS FOR DOPANTS IN SI

Dopant	k_0	Type	Dopant	k_0	Type
B	8×10^{-1}	*p*	As	3.0×10^{-1}	*n*
Al	2×10^{-3}	*p*	Sb	2.3×10^{-2}	*n*
Ga	8×10^{-3}	*p*	Te	2.0×10^{-4}	*n*
In	4×10^{-4}	*p*	Li	1.0×10^{-2}	*n*
O	1.25	*n*	Cu	4.0×10^{-4}	—[a]
C	7×10^{-2}	*n*	Au	2.5×10^{-5}	—[a]
P	0.35	*n*			

[a]Deep-lying impurity level.

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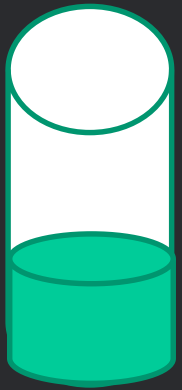
Bulk doping

Mo- initial weight of liquid with dopant concentration C0

S – dopant concentration in the melt



M-Mo

dM

$$-dS = C_s\,dM.$$

$$C_l = \frac{S}{M_0 - M}.$$

$$k_0 = \frac{C_s}{C_l},$$

$$\frac{dS}{S} = -k_0\left(\frac{dM}{M_0 - M}\right).$$

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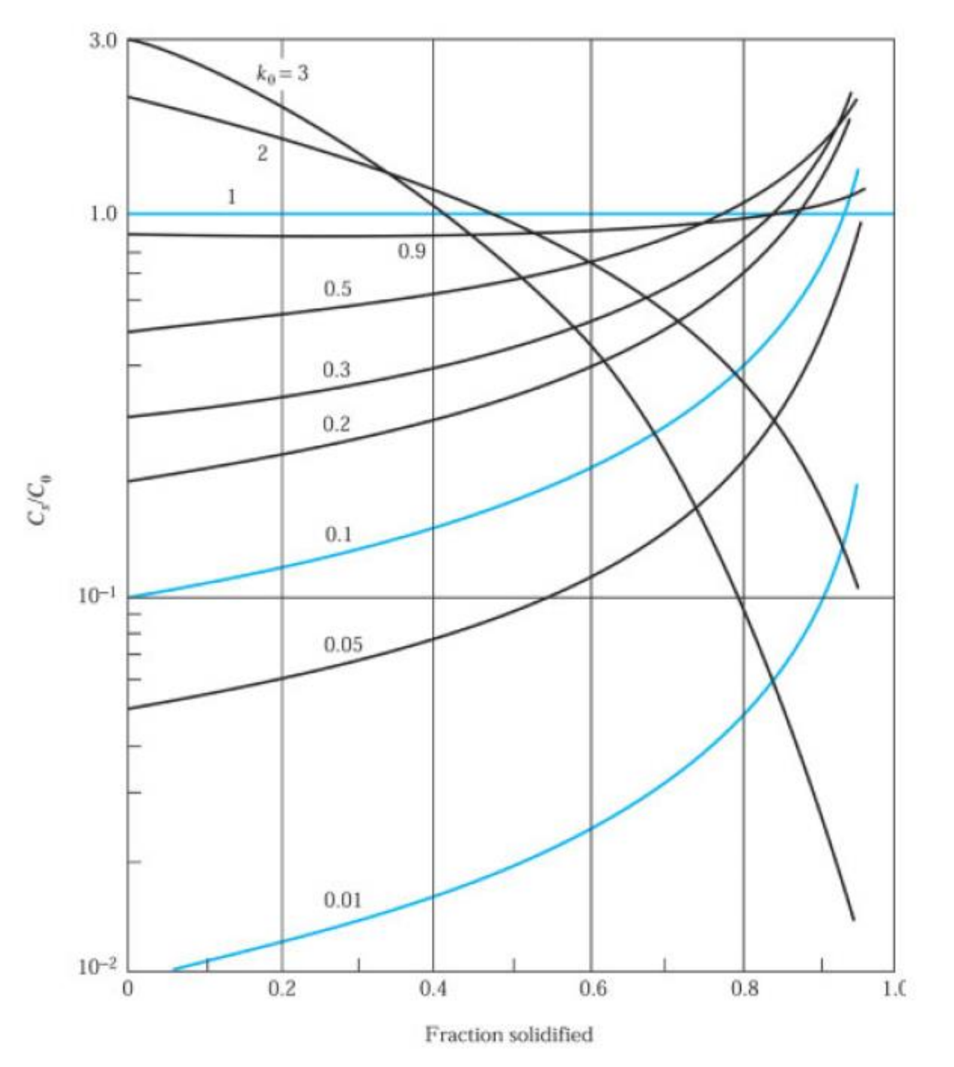
Bulk doping

$$C_s = k_0 C_0 \left(1 - \frac{M}{M_0}\right)^{k_0 - 1}$$



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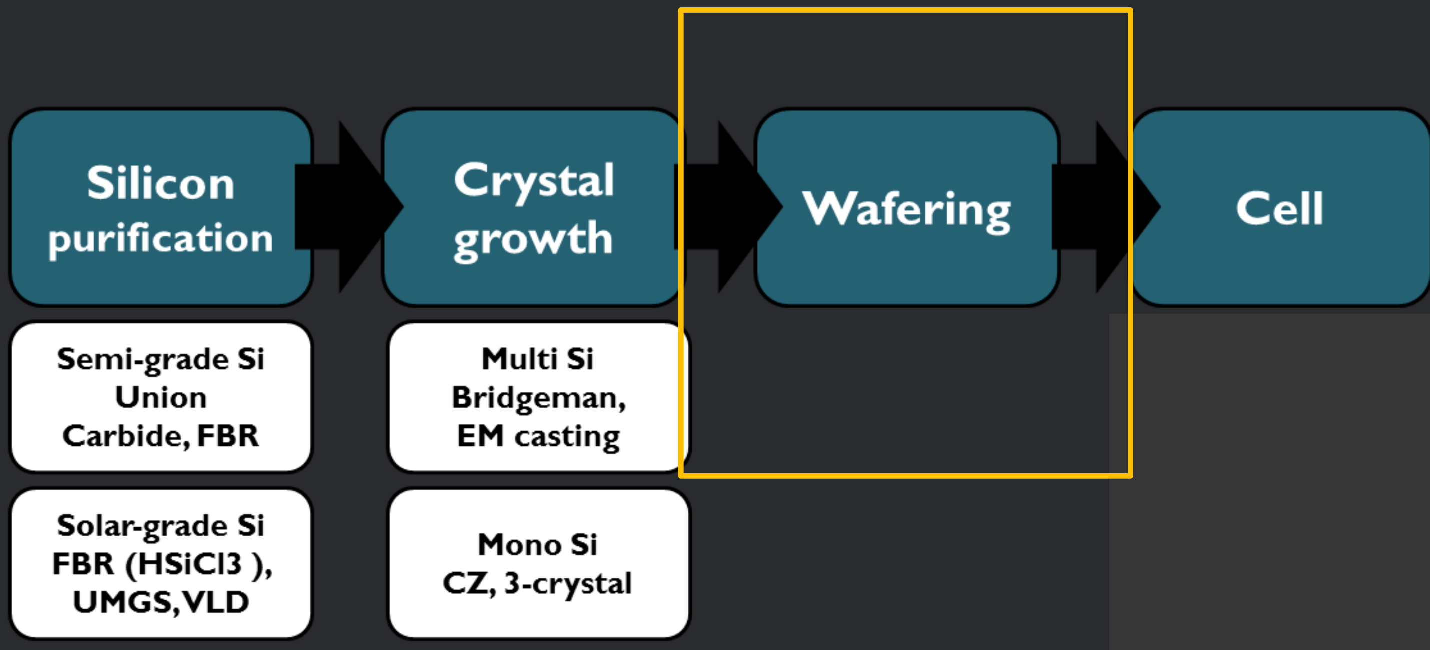
Silicon PV flowchart



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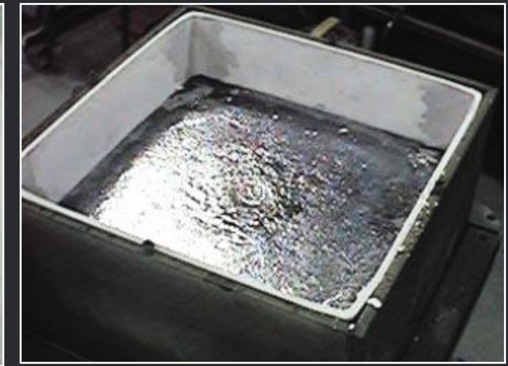
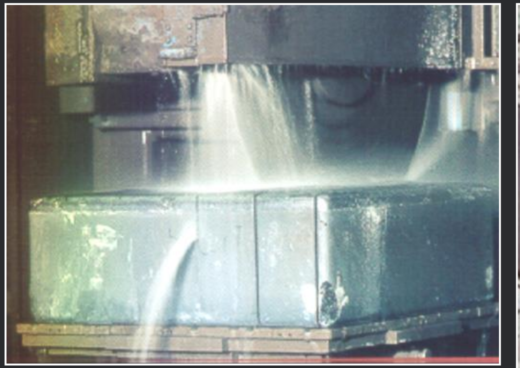
Mc silicon





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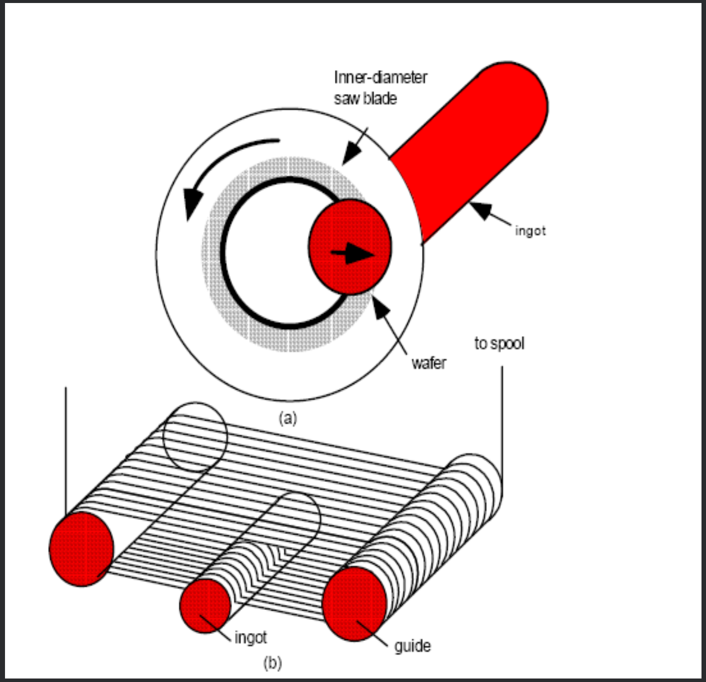
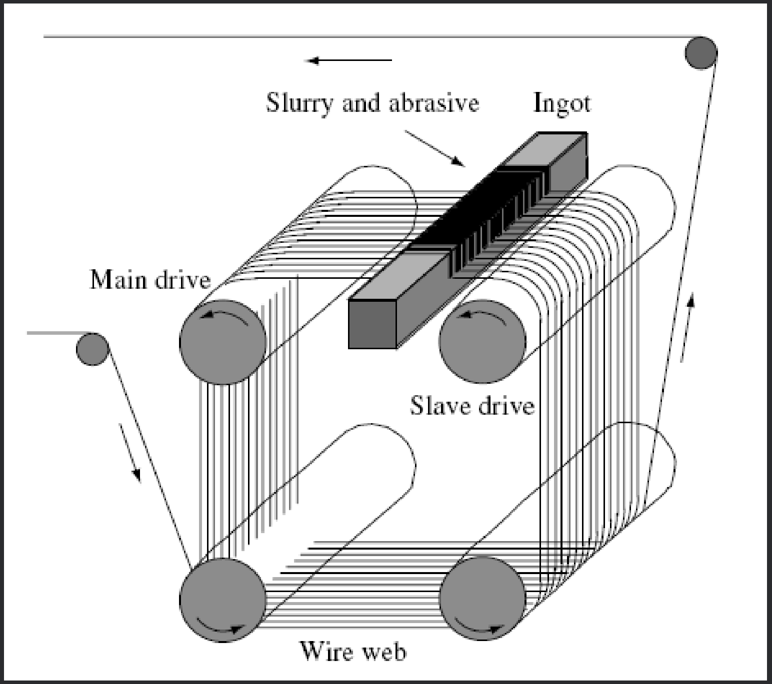
Wafering





Inner diameter sawing

Multi-wire sawing

Disadvantages

Expensive

High kerf loss

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Ribbon technology

Wafering is expensive!

Reducing material consumption by:

Producing thinner wafers

Reducing kerf loss

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Ribbon technology

Multicrystalline wafers may be grown directly in sheet or ribbon form.

- Edge defined film fed growth (EFG)
- String ribbon (SR)
- Ribbon growth on substrate (RGS)
- Dendritic web
- Sheet silicon
- …

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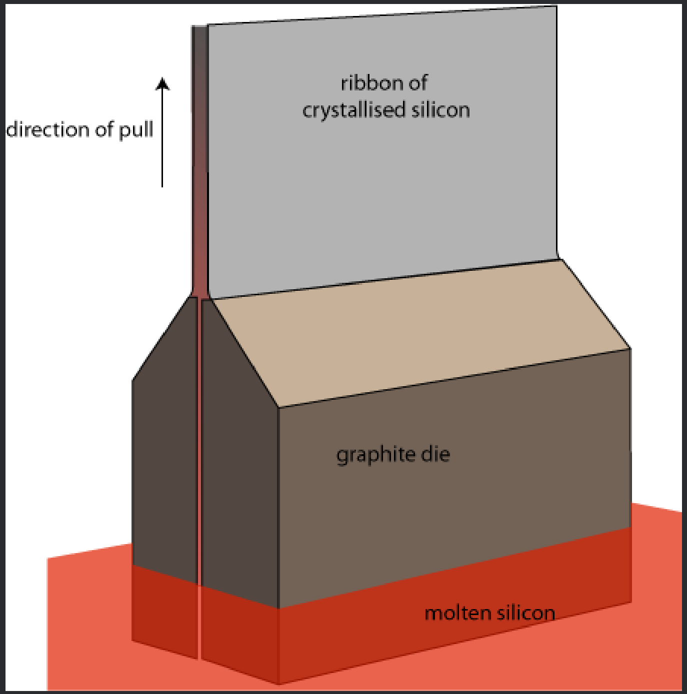
Ribbon technology



EFG

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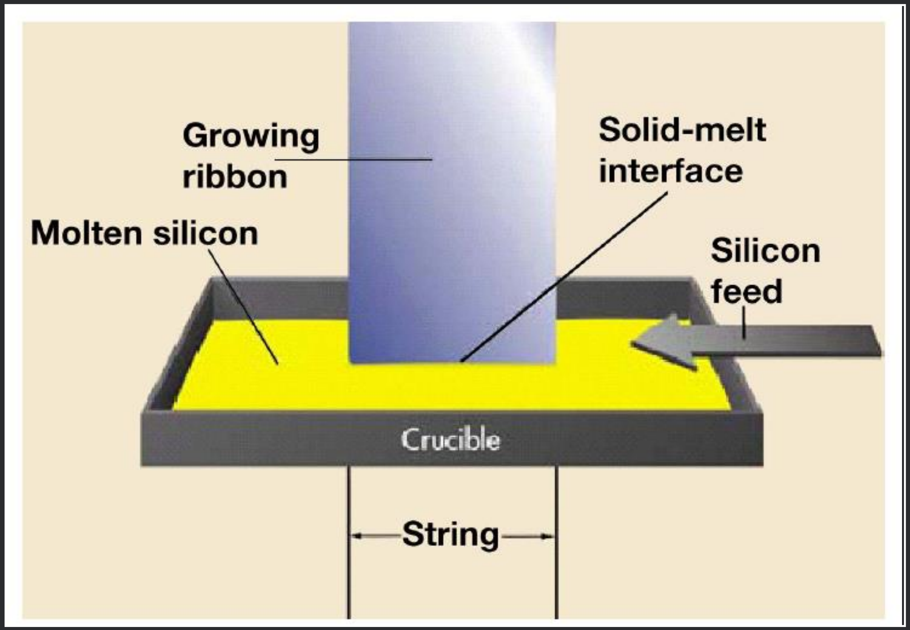
Ribbon technology



String ribbon

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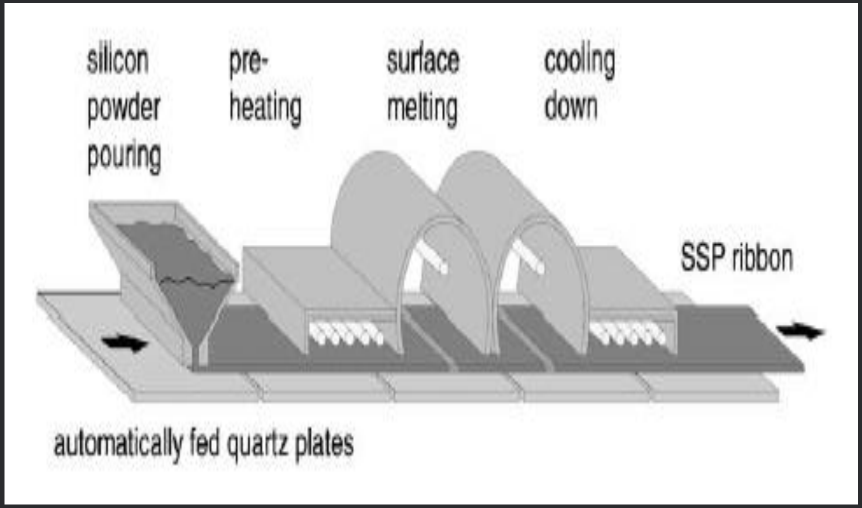
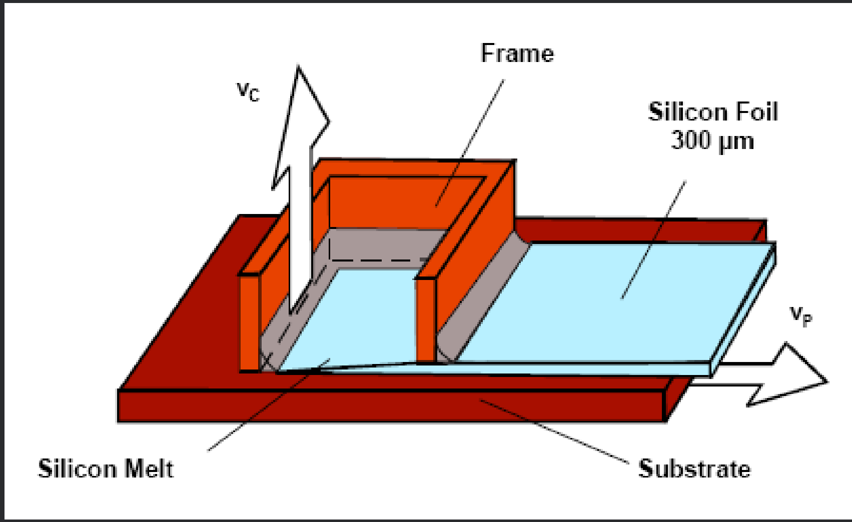
Ribbon technology



SSP



RGS

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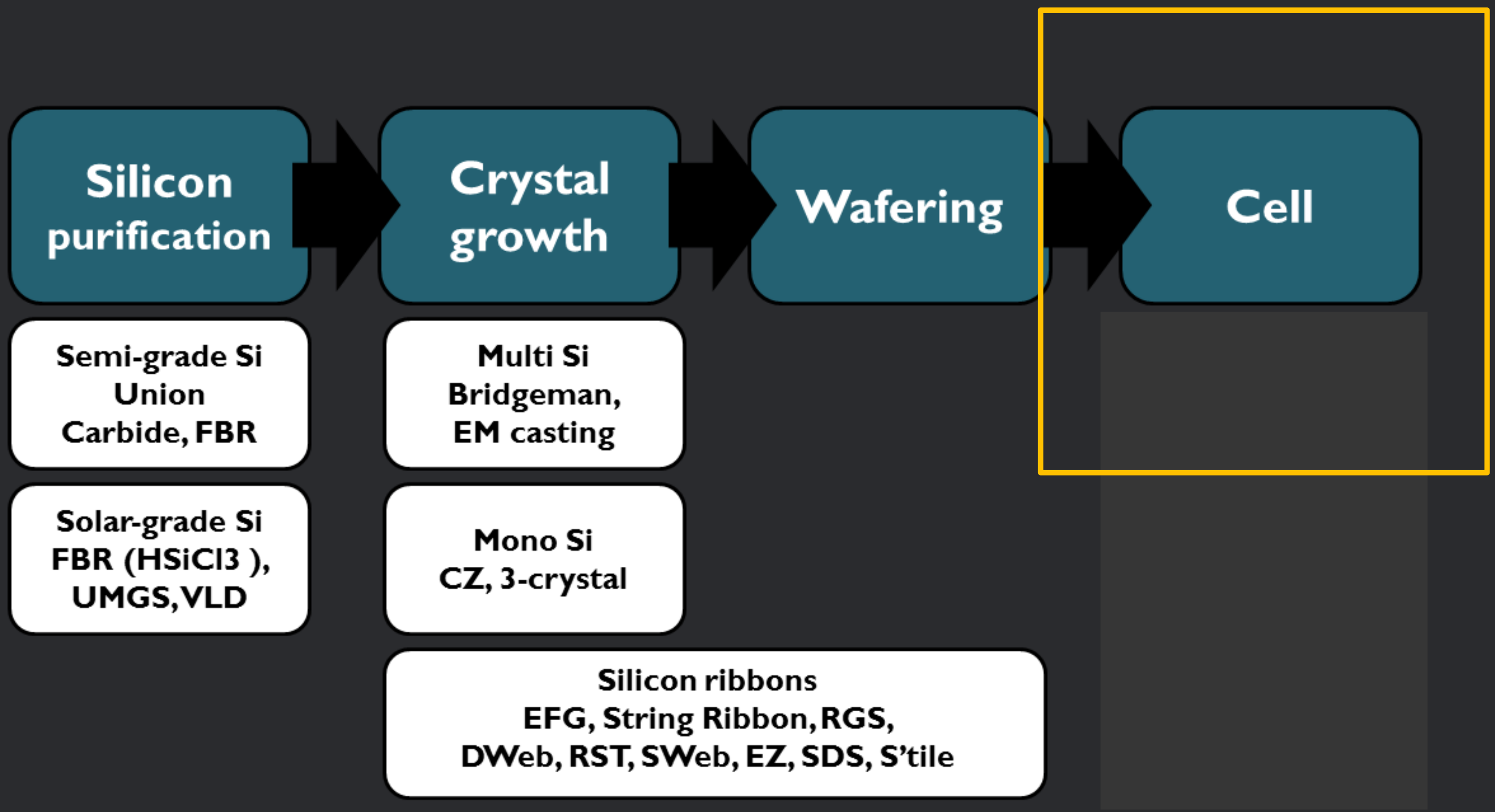
Technology overview



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Technology overview

Next: Cell manufacturing