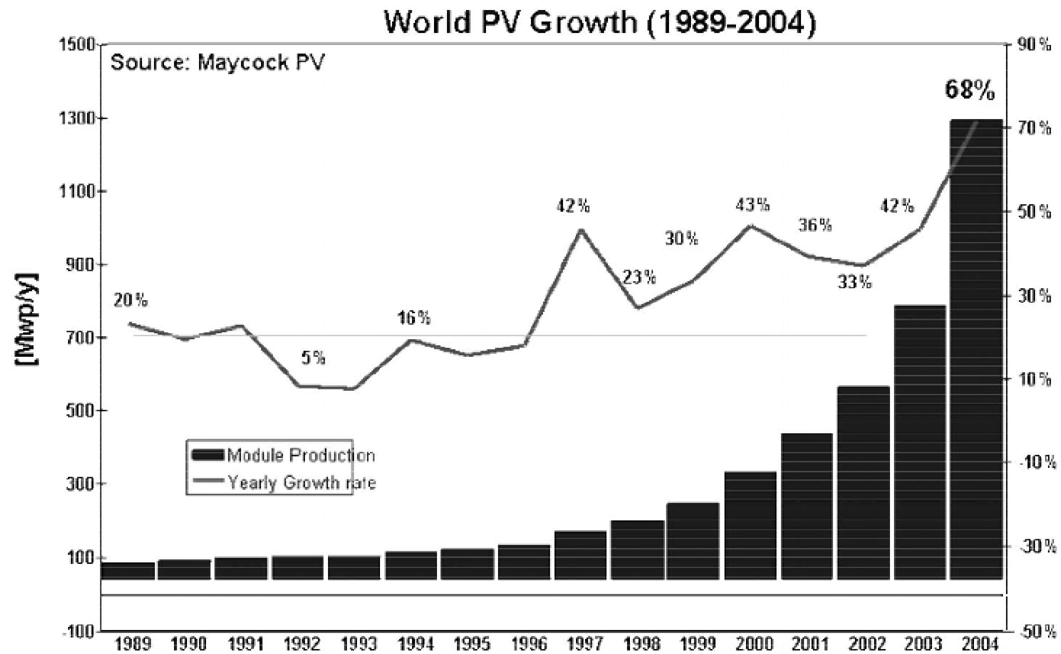
Mass Production Methods of Low Cost Silicon Thin Film Solar Cells

Epitaxial Thin Film Crystalline Silicon Solar Cells on Low Cost Silicon Carriers

Figure from: http://www.allamericanpatriots.com/48744851_record-makes-thin-film-solar-cell-competitive-sili

Status of Photovoltaic Industry and the Role of Thin Film Solar Cells

Industry conditions:
Photovoltaic panel production has been growing with an average annual rate of 48%, making it the fastest growing energy sector.
-In the USA, main driving force for the increase in demand is government incentives(California-70% of the installations)



Why thin film solar cells?
-Cost: *Greatest contribution to cost in module level is the silicon wafer used for fabrication (more than 50%) .*
-Payback Time: *Defined as the time required for electric energy used for production of a panel to equal the energy produced by the same panel (Multicrystalline Si Modules: 2 years, Thin Film Modules: 1year).*

Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Thin Film: Definition and Technologies

"Created by the random nucleation and growth processes of individually condensing/reacting atomic/ionic/molecular species on a substrate."

Thin Film Solar Cell Technologies:

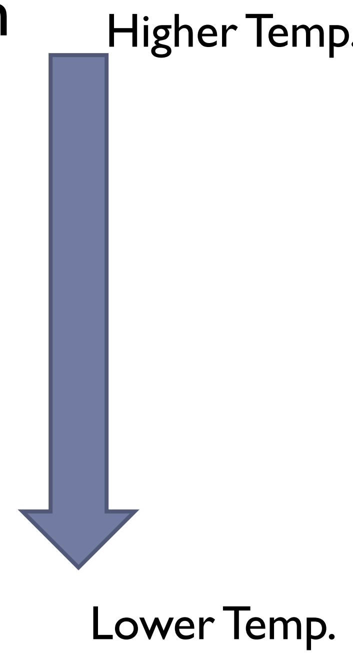
- *Crystalline silicon thin film solar cells*
- *Amorphous and microcrystalline silicon thin film solar cells*
- *Copper indium gallium selenide and cadmium telluride solar cell structures*
- *Thin film organic solar cells*

Epitaxial Thin Film Crystalline Silicon Solar Cells on Low Cost Silicon Carriers

- Decrease cost: How?
  - Decrease the consumption of pure Silicon: *acts more as a mechanical carrier; most absorption in upper 30µm through the device*
  - Optical refinement: *decrease most of the absorption region to upper 0.5µm*
  - Additional concerns about the process yield for Si-wafer thickness smaller than 200 µm: *special substrates (tri-crystalline Si material and thin edge film growth (EFG) ribbons) to prevent crack propagation*
  - Growth of thin active Silicon layer on a cheaper carrier: *Silicon micro or poli- crystalline. Grain size determined by:*
    - *Growth temperature*
    - *Supersaturation conditions during deposition*

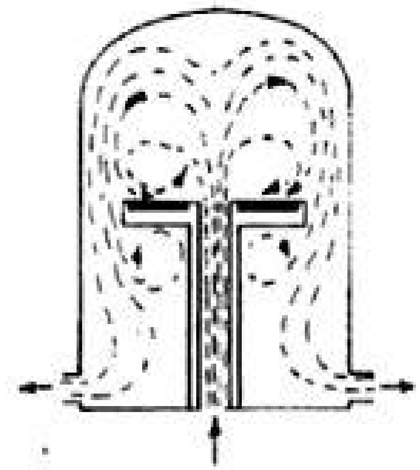
Main Deposition Methods

- Thermally assisted chemical vapor deposition
- Liquid phase epitaxy – electrodeposition
- Close space vapor transport technique
- Ion assisted deposition

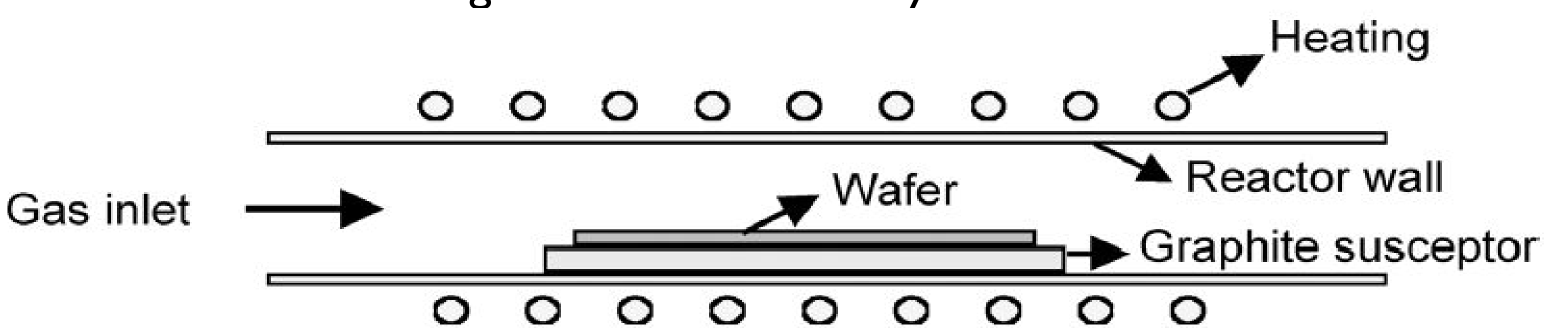


Thermally assisted chemical vapor deposition (TA - CVD)

- Most common thin film production technique in Europe and Japan
- Reactor types:
  - Batch Type:
    - Pancake (figure a) ,Barrel and Low Pressure CVD Reactors
  - Single Wafer Systems:
    - Wafer on graphite susceptor (figure b)
    - Thermally isolated wafer, heated through radiation: extremely fast change in temperature (RT-CVD: rapid thermal CVD); no deposition on the inner surface of funnel and heating of the substrate only



a)



b)

Figure a from: Crystal Growth: Principles and Progress (1987)
Figure b from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Liquid phase epitaxy – electrodeposition

- Similar deposition principles applied in liquid phase
- Growth through a molten metal solution (Sn, In) saturated with Silicon
- Silicon deposited to the substrate in high temperatures (700-900 °C) using the process of heterogeneous nucleation.
- Unique considerations:
  - Melt silicon atoms with high diffusion velocity
  - Growth systems close to thermal equilibrium

They provide an increase in crystallographic quality. But the latter introduces some problems.

LPE (cont.)

- When grown on a non-silicon substrate or defective regions of the silicon substrate, the deposition becomes harder through enhanced shunting risk regions. This disturbs the uniform deposition and decreases the crystallographic quality.
- How to overcome this problem?
  - Faster cooling rates
  - Deposition of initial Si layer through another deposition technique. (Works for non-silicon substrates)

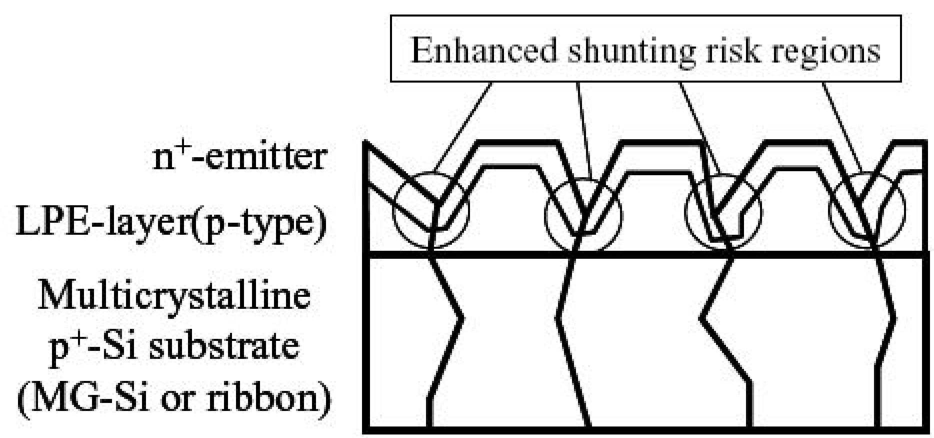
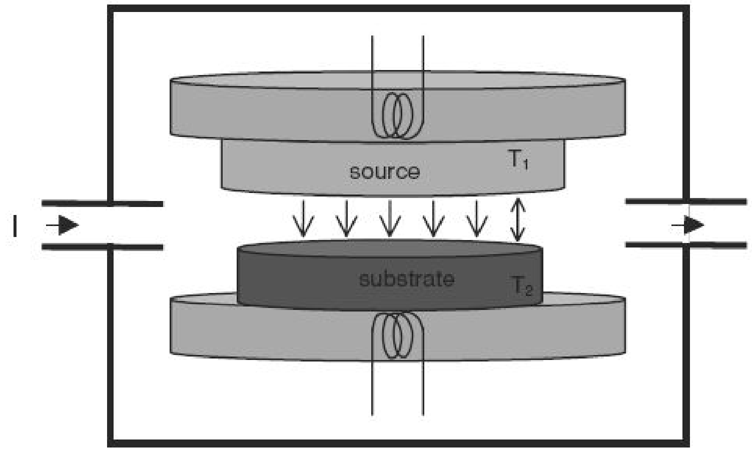


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Close space vapor transport technique

- The deposition using only the temperature difference between source and substrate.
- High transfer efficiency: close source and substrates, thus *very small loss of Si to the surrounding*
- Unlike other techniques, the correlation between temperature and growth rate is rather small, calculated with the equation to right. The growth rate is relatively stable in the order of 1-3µm/min.



$$R \propto (T - T_{\text{source}})\left(T_{\text{source}}^2 - T^2\right)\exp\left(\frac{-Q}{kT}\right)$$

Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Ion assisted deposition

- Deposition through beam shot by electro-guns.
- The change in potential accelerates silicon ions towards the substrates.
  - Also: Increases the surface adatom mobility, allowing epitaxial growth at lower temperatures.

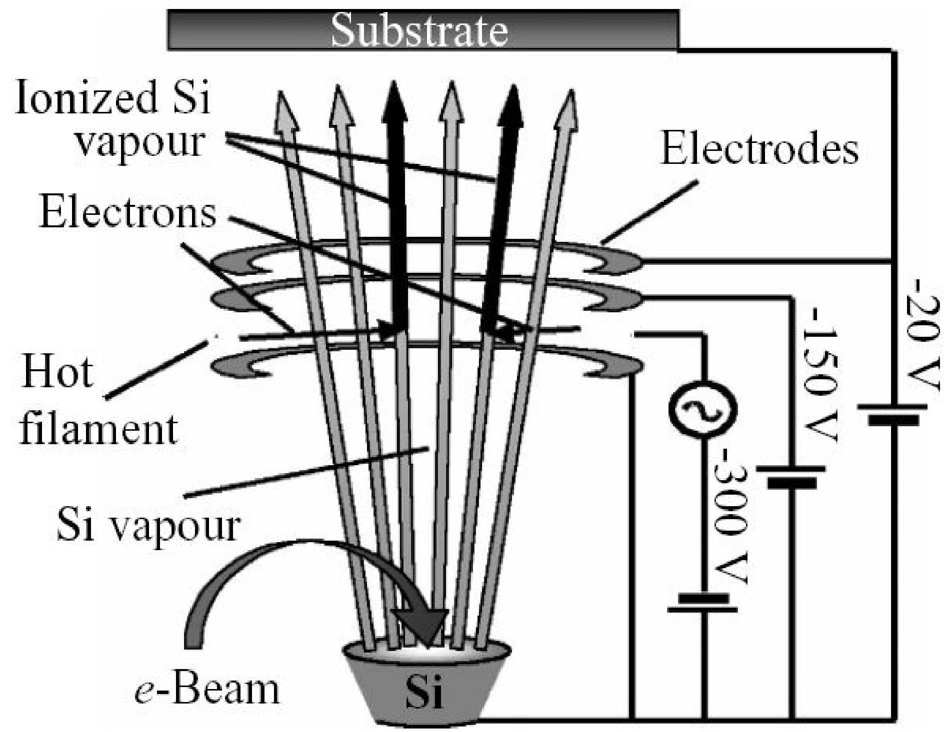


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

High Throughput Silicon Deposition

- Upscaling the introduced deposition procedures

Chemical vapor deposition reactor upscaling

- Tube in tube principle
- Outer tube filled with H_2 or inert gas, and the inner tube filled with a mixture of reactive gasses (SiHCl3 (TCS) and H_2) to allow deposition
- Two rows of substrates moving continuously
- Uniformity in deposition possible: *all substrates go through the same deposition profile in the reaction chamber*
- Overpressure between the inner and outer tube to prevent or reduce the escape of reactive gasses

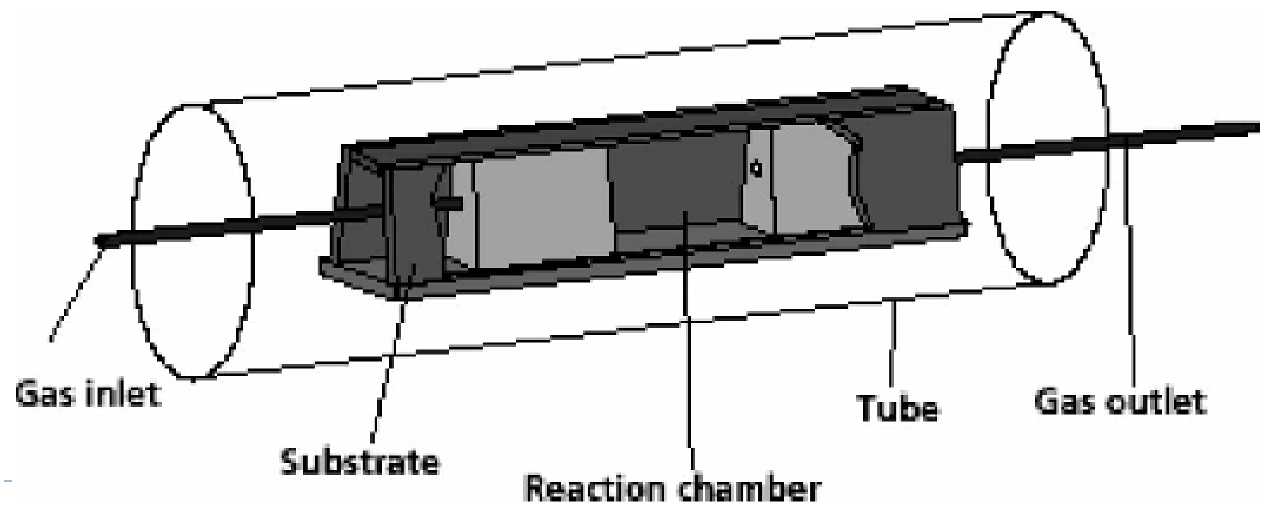


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Chemical vapor deposition reactor upscaling: Gas Curtain System

- A gas curtain system is utilized to separate the gasses in reaction chamber and factory.
- Principle: *diffusion of gas against the flow of another gas*

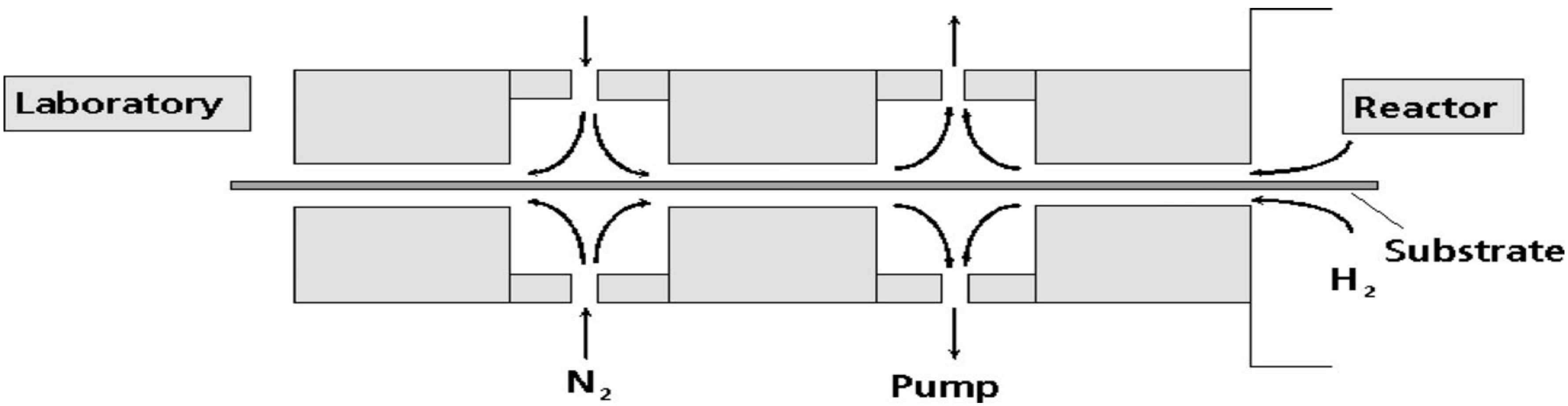
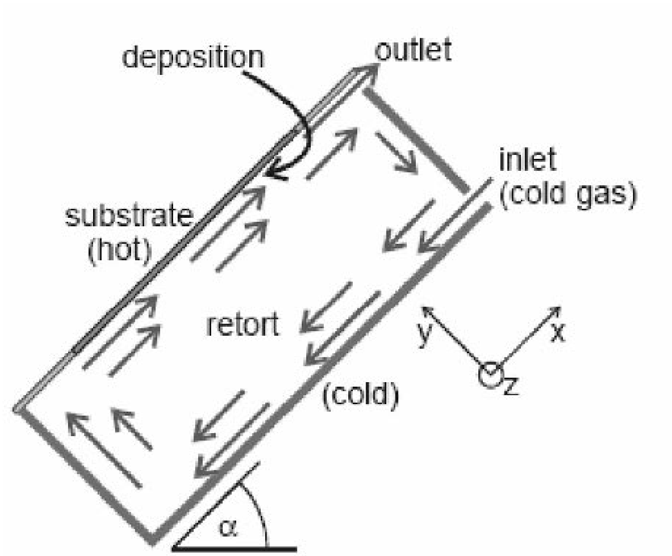


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Convection assisted chemical vapor deposition

- Cold gas flows downward alongside the cold wall
- After reaching the hot substrate, the gas movement is enhanced by convection, forcing it to move up and implement deposition
- Some of the gas flows out through outlet, whereas the rest joins cold gas from the inlet for another retour.
- The inclination angle α governs the convection process.



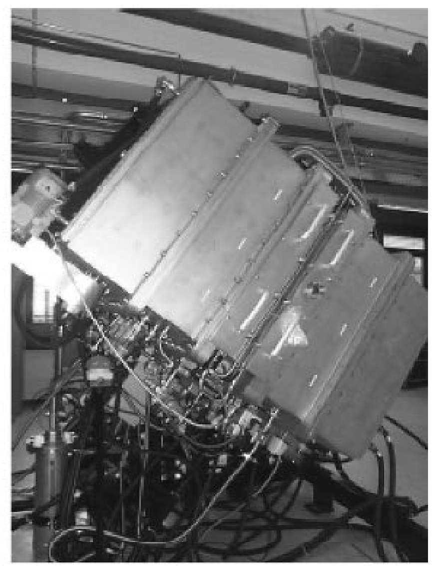


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Why Batch Type Deposition?

- There are still some serious concerns about the reliability and safety of the continuous processes

Batch type epitaxial reactors

- Resistively heated quartz system, with quartz tube for injection and exhaust connected at one side, and a quartz door closed at the other side
- Deposition on quartz walls prevented by quartz insert
- Several configurations are possible

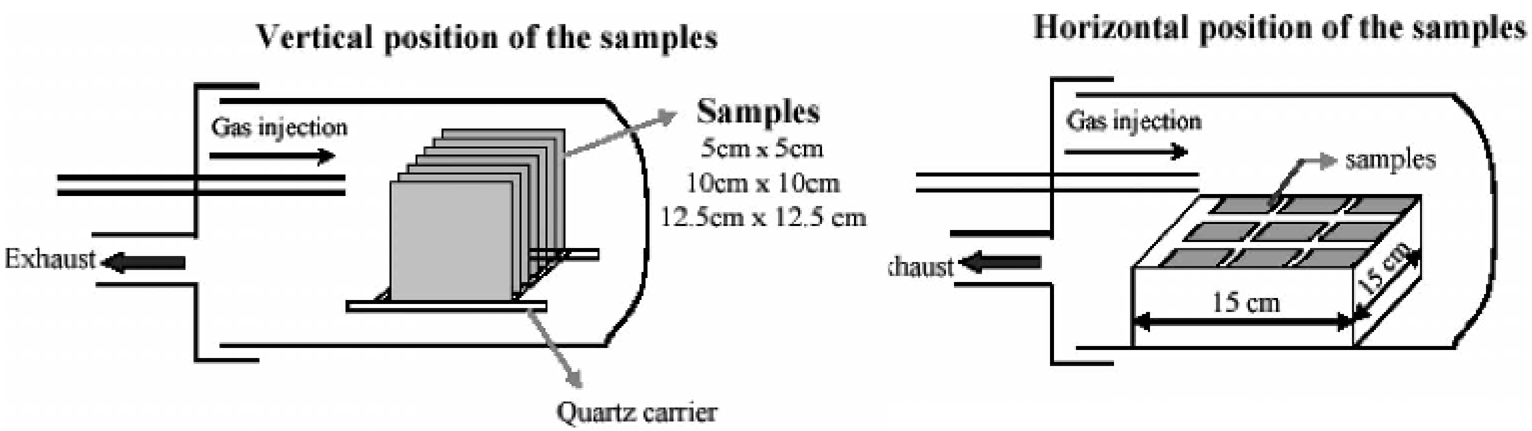


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Batch type epitaxial reactors (cont.)

- The growth rate can be increased by rise in the total gas flow. However this also increases the defect density.

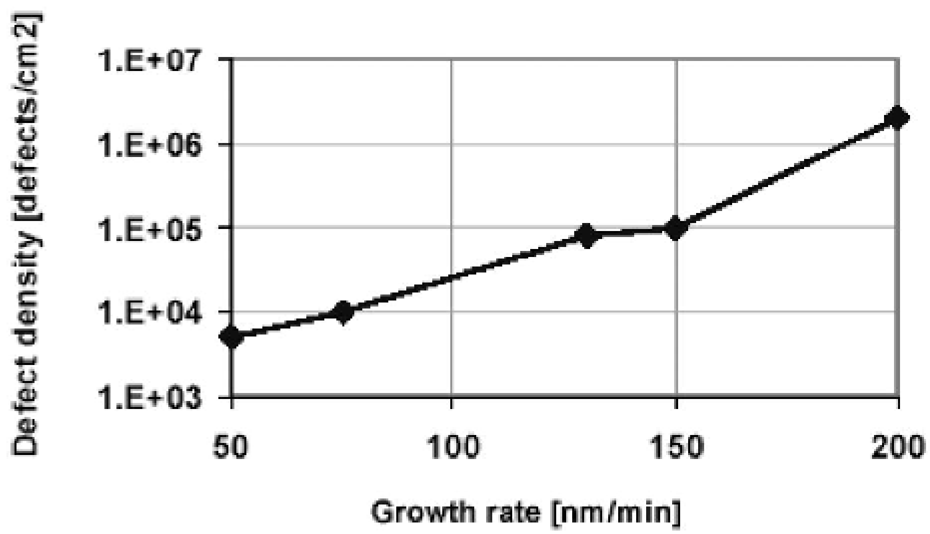


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Batch type epitaxial reactors (cont.)

- A similar approach is used for stacked epitaxial reactor
- Densely packet resistively heated graphite susceptors
- Hydrogen recycling is needed for economically feasible operation

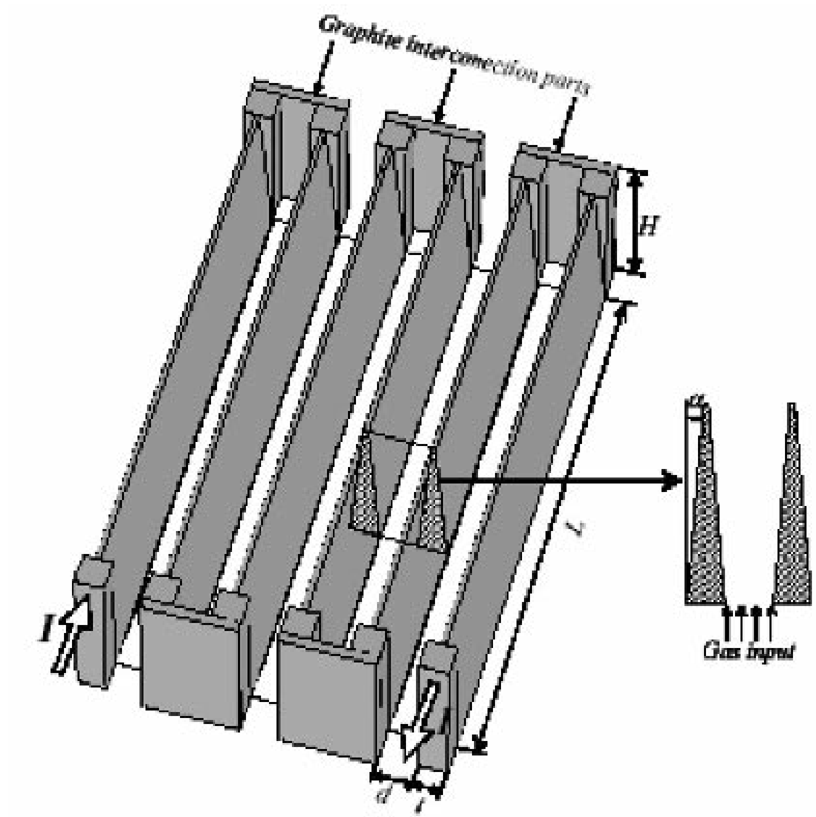


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Liquid phase epitaxy reactor upscaling

- The manufacturing has not reached the same maturity and reliability levels as the chemical vapor deposition procedures

- Two types:
  - **Temperature difference method**
  - **Batch type multiwafer liquid phase epitaxy system using melt-back**

Temperature Difference Method

- Temperature gradient stimulates the deposition of silicon onto the substrate at the bottom, by creating a stable concentration gradient
- Temperature gradient stays the same during the growth process: *temperature dependent solubility does not change the layer composition*
- The process is not fully established

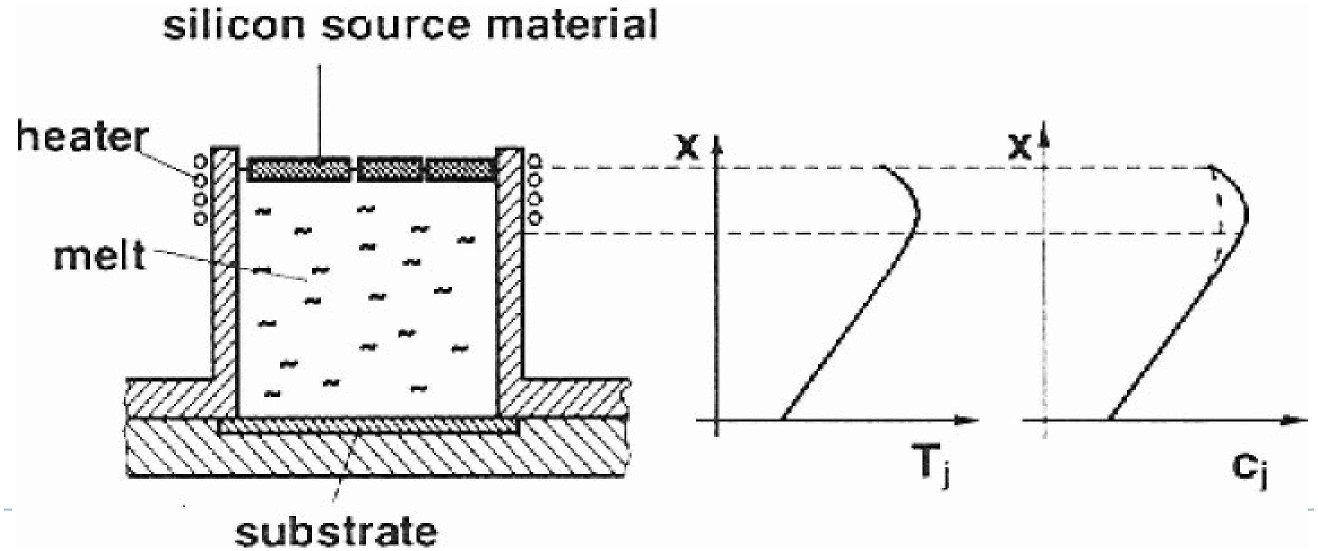


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Batch type multiwafer liquid phase epitaxy system using melt-back

- Still a work in progress
- Traditional models are capable of handling 16 substrates at a time: *however the melt can not be reused since it loses most of its silicon in the deposition process*
- "Sliding boat approach" where the silicon is melt back from UMG-Si, as opposed to adding silicon to the melt after every batch

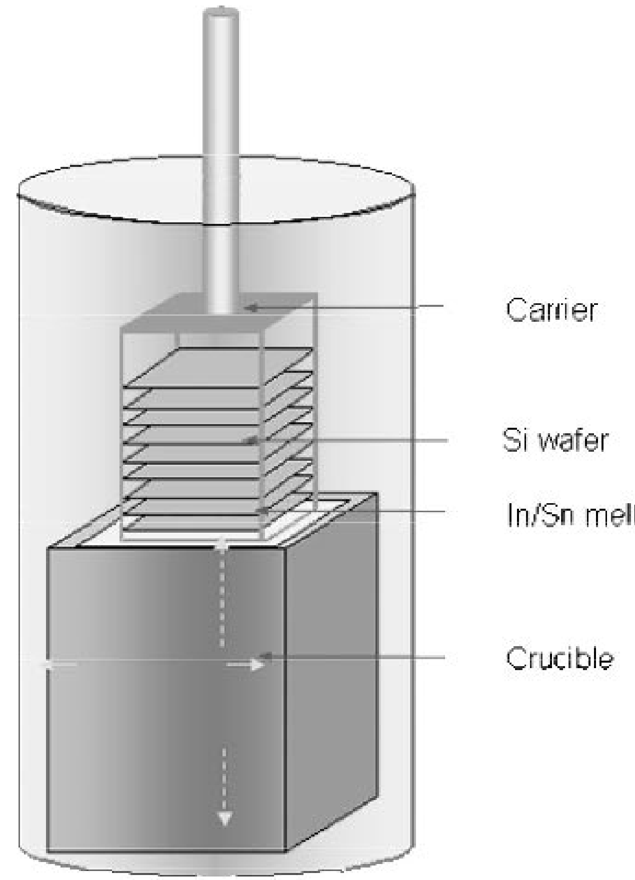


Figure from: Thin Film Solar Cells Fabrication, Characterization and Applications (2006)

Conclusion:

- Chemical vapor deposition procedures are well established, and easy to upscale for industrial production. Other methods do not have a reliable system for mass manufacture.

- Thin film panel structures for increased absorbance are highly complex but also vital in terms of device performance and economic feasibility of mass production.

- Epitaxial thin film solar cell technology follows a very similar production procedure to the mainstream silicon solar cell technology. A change from the traditional crystalline silicon solar cells to thin film solar panel production requires only one high throughput epitaxial silicon deposition chamber added to the beginning of the production line.

Any Questions?

Figure from: http://www.greentechhistory.com/2009/06/techmix-solar-panel-hut/

References:

- Jef Poortmans and Vladimir Arkhipov, Thin Film Solar Cells Fabrication, Characterization and Applications (2006)
- A. W. Vere, Crystal Growth: Principles and Progress (1987)
- http://www.socialfunds.com/news/article.cgi/2639.html
- http://en.wikipedia.org/wiki/Thin_film_solar_cell