2.6 Summary

2.6.1 Summary to: 2. Semiconductor Materials and Products

- Structure and size matter!
  - Mostly we need single crystals, as perfect (and as large) as possible
  - Either in bulk, or thin films
  - If thin film, substrates matter.

Typical Si wafer:	**300 mm** diameter, **850 µm** thick, perfect single crystal
Solar cell: Si	• Single crystalline, bulk. • Poly crystalline, large grain, bulk. • Polycrystalline, micro grain, "thick" film • Polycrystalline, nano grain, thin film. • Amorphous (plus **H**), thin film

- For some applications (solar cell , **LCD**, ...) polycrystalline or amorphous semiconductors are used
  - "**CIGS**" or **CdTe** for solar cells.
  - Amorphous or poly-**Si** for **LCD** transistor matrix

- Important *elemental* semiconductors are **Si** and marginally **Ge**
  - Forget **Se**, **C**, **P**, **As** and b

- Compound semiconductors are important
  - Group **IV** and compounds: SiGe, SiC

  III-V compounds (Al, Ga, In) **-** (N, P , As, Sb). Important GaAs, $Ga_xAl_{1-x}As$, GaP, InP, ..

  Chalkogenides $A_xB_y(S, Se, Te)_2$. Important "CIGS" = $CuIn_xGa_{1-x}Se_2$

  "**Newcomers**" like organic semiconductors, Metal oxides (e.g. TiO_2)

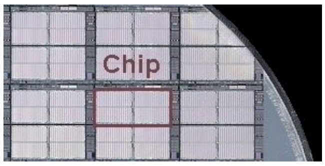
- Properties matter! Some properties are rather independent of the structure (= defects), others can be structure sensitive

Some important **Properties**	**Remarks**
Lattice type, lattice constant	**Structure independent**
Melting point, diffusion constants	
Bandgap type and energy	
Dielectric constant	
Thermal expansion coefficient	
Doping range	**Structure dependent**
Transport of electron / holes (mobility, life time, diffusion length, ..	
Unwanted levels in bandgap	

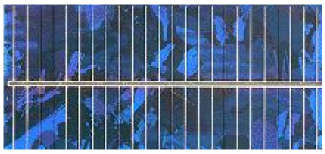
- What counts in the end are products that sell and make a profit!
  - Besides the direct semiconductor products, there are also products that contain semiconductors (PC's, Cars, TV's, any modern machine,...) and products that are needed to make semiconductor products (crystal growers, ovens, ion implanters, ..).

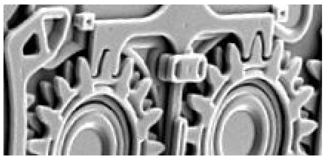
Integrated circuits, Solar cells, Liquid crystal displays, Micro electronic and mechanical systems, Light emitting diodes, (Diode) Lasers, Sensors, ...

- Silicon, and *only* **Si**, enables integrated circuits of amazing complexity, with billions of transistor on one chip
  - Two kinds of integrated transistors exist.
    - **MOS -** the absolute majority
    - bipolar - if speed counts
  - Wafers diameter are up to **300 mm** (2007), smallest (lateral) structures on a wafer are in or below the **100 nm** range.
  - Integrated circuits are packaged chips with some connections to the outside world



- Besides integrated circuits, Si is increasingly used for other semiconductor products:
  - Solar cells based on **Si** consume more Si than IC's, and demand rapidly increasing Si production. The key point of Si solar cell technology is to have high efficiencies η at low prices.
  - Microelectronic and micro-mechanic (and micro-optics and micro-fluidic and...) = **MEMS** systems find increasing uses for many tasks.

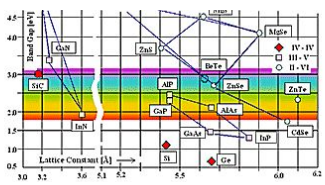




- III-V semicondurcrors combine the group III elements Al, Ga, In) with the group V elements N, P , As, Sb; giving **12** possible combinations.
  - The most important ones are probably **GaAs**, **InP** **GaP** and **GaN**
  - Band gap energies and types vyr,; lattice are wurtzite or zincblende (= fcc) and sphalerite (= hex)

Properties	**Si**	**GaAs**	**InP**	**GaP**	**GaN**	**$In_{0,53}Ga_{0,47}As$**
Band gap [eV]	1,12	1,42	1,35	2,26	3.39	0,75
Type	Indirect	Direct	Direct	Indirect	Direct	Direct
Lattice	fcc	fcc	fcc	fcc	hex	fcc

- Ternary and quaternary (**$III_xIII_{1-x}V_yV_{1-y}$**) compounds are relatively easy to make.
  - Properties like band gap, lattice constant, refractive index then adjustable to some extent.
  - Main materials for optoelectronic products. Some high-speed and sensor applications.
  - "Master diagram" = bandgap vs. lattice constant: of elementary importance for semiconductor technology.



- Germanium (**Ge**) and **SiC**
  - Germanium was almost "useless" but is experiencing some comeback now (2007) in conjunction with **Si** technology.
  - **SiC** is very difficult to obtain as a good single crystal (many polytypes) but has some desirable properties for high speed or high power devices
- **II-VI** semiconductors are objects of heavy research but hardly used for products at present.
  - The "hot" contenders **CdTe** used for solar cells and actually on the market, and, maybe **ZnO** in the near future.
- "Chalcogenides", meaning compounds with "Chalcogens", i.e. **S**, **Se**, and **Te** as major elements are often semiconductors
  - Oxygen, in the same **IIa** group, forms "oxides"!
  - The most prominent representative of chalcogenides is "**CIS**" ($CuInSe_2$) or better "**CIGS**" ($CuIn_xGa_{1-x}Se_2$) used for solar cells and actually on the market.
- Organic semiconductors. A relatively recent addition to the club, organic semiconductors seem to have a bright future in optoelectronics
  - **OLED**'s are on the market, in particular as part of a flat panel display; the first **OLED** based **TV** screen has been announced for **2008**.
  - The big problem of **OLED's** is their sensitivity to oxygen.

Exercise 2.6-1
All Questions to 2.