# 2. Semiconductor Materials and Products

## 2.1 General Chemistry and Structure

### 2.1.1 General Considerations and Elemental Semiconductors

**Some General Statements**

- All semiconductors come in a certain structural form. We will look at the possibilities by just comparing extremes:
- *Large* in three dimensions or *Small* in at least one dimension?
  - *Large:* Can you see *it* and only it (i.e. not its substrate) with the naked eye? Touch it, hold it, break it?
    *Examples:*
    - Single crystals of e.g. **Si** (**300 mm** diameter, **1 m** long!), **GaAs**, **InP**, **GaP**, **SiC**, ....
    - **Si** wafers (up to **450 mm** diameter, about **1 mm** thick), **GaAs**, etc.
  - *Small:*, at least in one dimension. Can you see it with the naked eye? But, maybe, not hold it?
    *Examples:*
    - Small in *one* dimension: All **thin films**; always on a substrate. This contains most **optoelectronic** and all "thin film" **solar cell** uses. Many usable semiconductors exist *only* as thin films!
    - Small in two dimensions: **Micro-** or **Nanowires**. A big research field right now (2007) and in use as connections on **IC**s.
    - Small in three dimensions: **Micro**- or **Nanoparticles**. Semiconducting micro- or nanoparticles are not yet part of products coming out of semiconductor technology (unless you count an integrated transistor as a microparticle which we do not), but a big research item, e.g. for "Nano" solar cells
- *Crystalline* or *Amorphous*?
  - So you need a (thin film) semiconductor on a really large area - for a **flat panel display**, for example. Or a solar cell module made from "one piece". There is no single crystal big enough for that and it would be prohibitively expensive to make on (provided you could).
  - You then must try live with a poly-crystalline thin film or, maybe with an amorphous one. Be prepared to spend some **10.000** man-hours in getting it to work.
    **Class Exercise:** *Ponder the history of "**LCD**" flat panel displays.*
- Here are some alternatives:

| **Mono Crystalline** | *or* | **Poly Crystalline** |
|---|---|---|
| Contains dislocations and other defects *or* is (almost) perfect? | | Large Grains *or* Small Grains? |
| Electronic parameters are adjustable *or* Fermi level pinning is observed? | | Grain boundaries problematic *or* tolerable? |

- By now you get the drift: This may turn out to be quite complicated. Thank God, there are some specialists who have to know all this stuff; the rest of us can forget about it and just be good consumers.
  - Right. Those specialists, by the way, are called **Materials Scientists and Engineers**. Sorry. But it will be up to you (and a few others) to **save the world** - your world.
  - **Class Exercise:** *Why does the world need saving? How shall it be done?*

# Elemental Semiconductors

- There isn't much. All we need to do is to look at a rather small part of the periodic table:
  - Here is a part of the complete periodic table accessible by the link. Semiconductor are outlined a reddish background and big letters. The redder, the better!

| IIA | The Rest | | IIIA | IVA | VA | VIA | VIIA | VIII |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | He |
| Be | | | **B** | **C** | N | O | F | Ne |
| Mg | | | Al | **Si** | **P** | S | Cl | Ar |
| Ca | | | Ga | **Ge** | **As** | **Se** | Br | Kr |
| Sr | | | In | **Sn** | Sb | **Te** | J | Xe |
| Ba | | | Tl | Pb | Bi | Po | At | Rn |

- What we have, in (subjective) order of importance, are
  - **Silicon (Si)**
    It's so obviously of top importance that we are not going to say anything more to it at this point.
  - **Germanium (Ge)**
    A true fine semiconductor. Good single crystal can be grown, doping etc. is easily possible, but the band gap is a bit too small for most applications. Far worse: There is no "good" Germanium Oxide (**$GeO_2$**)
    The first semiconductor put to commercial use in the early sixties - and then phased out almost completely.
    In the last few years **Ge** experiences a kind of "come back"; we take that as a reason to start an "advanced" page at some point.
  - **Selenium (Se)**
    An often overlooked semiconductor. Historically of some interest, and in particular because it made "Xeroxing", i.e. photo copying possible. We take that as a reason to start an "advanced" page at some point.
  - **Diamond (C)**; **metastable fcc form**
    There are some technical uses (besides the obvious non-technical ones in (hetero) human relations, but nothing we have to concern ourselves with at present.
  - **Tin (Sn)**; **$\alpha$ - Sn (below 13 $^oC$)**
    *Forget it!*
  - **Boron (B)**
    *Forget it!*
  - **Phosphorous (P)**;
    *Forget it!*
  - **Arsenic (As)**
    *Forget it!*

- Are we going for ***Crystalline*** or ***Amorphous***?
  - To make it short: In case of doubt we use crystals, preferably single crystals, preferably "perfect" single crystals.
    **Class Exercise:** *Why?*
  - Applications on large areas, however, use amorphous thin films or poly crystals for obvious *(???)* reasons.

# Chemical Element - Technical Semiconductor

We finally must concern ourselves a little with what exactly it is we are looking for when we consider semiconductor technology. To a small extend, we have already discussed some points of interest above.

- To make the issue clear, consider that you can buy a **kg** of e.g. "Silicon" from a chemical company like Merck. What you will get is a bottle full of a greyish powder, which will be of no use whatsoever for semiconductor technology. We are obviously looking for more than just the **element**.
- Let's look at some material parameters that are of interest to us when we want to make a product or component by doing some semiconductor technology. Here we just list key words (hoping that they will strike a chord). In the next sub-chapter we will take a closer look:

| **Properties** | **Remarks** |
|---|---|
| **Crystal** | |
| Crystal structure | **fcc**, **bcc**, **hex**,.. |
| Lattice constant | *Will turn out to be very important* |
| General structure | single-, poly-crystal, thin layer, .. |
| Defect densities | dislocation density, impurity concentration, .. |
| Defect properties | Formation-, migration enthalpies of point defects, .. |
| Unit weight [mol], Density [g/cm$^3$] | |
| Mechanical properties | Yield strength (as **f(*T*)**), fracture strength, surface energies, ... |
| **Electronic Properties** | |
| Band gap **[eV]** | *Gives $n_i$(**T**)* |
| Type | direct, indirect, dispersion function |
| Effective mass of electrons and holes **[m*/m]** | *Important, but beyond the scope here.* |
| $N_{eff}$ in ***C*** and ***V***; $n_i$ | *Needed for calculating **n(T)*** |
| Mobility (undoped) | *Very important for speed* |
| Lifetime; Diffusion coefficient of electrons and holes; Diffusion length | *Appear in any equation!* |
| Mechanism of luminescence | *Important, but beyond the scope here.* |
| Deep levels of impurities and defects | *Important if you can't be perfect* |
| **Dielectric properties** | |
| Dielectric constant | *Appears in most equations!* |
| Break through field strength | *Obviously important* |
| Specific intrinsic resistance | *Not so important* |
| Electron affinity | |
| **Thermal Properties** | |
| Therm. expansion coefficient | *Very important in many cases* |
| Therm. conductivity, Specific heat, Melting point | *of some interest, important in power applications* |

| Economical / Ecological Propertiess | |
|---|---|
| Supply / Price | *Potentially important; depends on product.* |
| Poisonous / polluting; directly or indirectly | ***Si*** *you can eat;* ***GaAs*** *is poisonous!* |

- **Class Exercise:** *Supply examples for critical parameter - component couplings*