2.1.3 Non-Metalic Conductors

We will just give a brief look at some especially important or useful **non-metallic conductors**:

Conducting Polymers

That polymers, usually associated with insulators, can be very good conductors was a quite unexpected discovery some **20** years ago (Noble prize **2001**). They always need some "**doping**" with ionic components, however.

- The resistivity can be ***exceedingly*** low. e.g. for *Iodine (I) doped poly-acethylene* ***(pAc)*** we may have.
  $\rho \leq$ **6,7** **µΩcm**.
- Or in other words: If you divide by the density for some figure of merit, it beats everything else, since **{ρ/density} (pAc) > {ρ/density} (Na)**!
- More typical, however, are resistivities around (**10 .... 1000) µΩcm**.

The conduction mechanism is along **–C=C–C=C–C=** chains, it is not yet totally clear. In fact, the first question is why this kind of chain is *not* generally highly conducting. Use the link for the answer.

- The conductivity is strongly dependent on "doping" (in the **%** range!) with ions, and on many other parameters, the link gives an example.
- So do not confuse this with the doping of semiconductors, where we typically add far less than **1 %** of a dopant!

A new object of hot contemporary research are now ***semi*conducting polymers** which have been discovered about **10** years ago.

Transparent conductors

Indium Tin Oxide (*ITO*) (including some variations) is the only really usable *transparent* conductor with reasonable conductivity (around **1 Ωcm**)! It consists of SnO_2 doped with In_2O_3.

- **ITO** is technically *very important*, especially for:
  - flat panel displays, e.g. ***LCD***s .
  - solar cells.
  - research (e.g. for the electrical measurements of light-induced phenomena).
- **ITO** is one example of conducting oxides, others are **TiO**, **NiO**, or **ZnO**. The field is growing rapidly and known as " ***TCO***" = Transparent Conducting Oxides

If you can find a transparent conductor much better than **ITO** (which leaves a lot to be desired), you may not get the Nobel prize, but you will become a rich person rather quickly.

- Since **In** is rare, and the demand is exploding since the advent of **LCD**s, you also would be a rich person of you invested in **In** some years ago.

Ionic conductors

Solid *Ionic conductors* are the materials behind " **Ionics**", including key technologies and products like

- Primary batteries.
- Rechargeable (secondary) batteries.
- Fuel cells.
- Sensors.
- High temperature processes, especially smelting, refining, reduction of raw materials (e.g. **Al**-production).

- There is an extra module devoted to the **Li** ion battery. This is important for you if you are interested in driving an affordable a car in **20** years or so.
- They are also on occasion the unwanted materials causing problems, e.g. in corrosion or in the degradation of dielectrics.
- See Chapter 2.4 for some details about ionic conductors.

Specialities : Intermetallics, Silicides, Nitrides etc.

- **Silicides**, i.e. metal - silicon compounds, are important for microelectronics (***ME***) technology, but also in some more mundane applications, e.g. in heating elements. Some resistivity examples for silicides:

Silicide	$MoSi_2$	$TaSi_2$	$TiSi_2$	$CoSi_2$	$NiSi_2$	PtSi	Pd_2Si
ρ (μΩcm)	40 ...100	38...50	13..16	10...18	≈ 50	28...35	30...35

  - It looks like the winner is **$CoSi_2$**. Yes, but it is difficult to handle and was only introduced more recently, like **$NiSi_2$**. In the earlier days (and at present) the other silicides given above were (and still are) used.

- Some more examples of **special conductors** which find uses out there:

Material	HfN	TiN	TiC	TiB_2	C (Graphite)
ρ (μΩcm)	30...100	40...150	ca. 100	6 ...10	1000

Superconductors

- Superconductors are in a class of their own. All kinds of materials may become superconducting at low temperatures, and there are neither general rules telling you *if* a material will become superconducting, nor at which *temperature*.
  - There will be an advanced module some time in the future.

- *Why do we need those "exotic" materials?*. There are two general reasons:
  - **1.** Because, if just *one* specific requirement exists for your application that is not met by common materials, you simply have *no choice*. For example, if you need a conductor usable at **3000 K** - you take *graphite*. No other choice. It's as simple as that.
  - **2.** Because *many* requirements must be met *simultaneously*. Consider e.g. **Al** for integrated circuits - there are plenty of important requirements; **see the link**. Since *no* material meets *all* of many requirements, an optimization process for finding an optimum material is needed.
  - **Al** won the race for chip metallization for many years, but now is crowded out by **Cu**, because in some figure of merit the importance of low resistivity in the list of requirements is much larger now than it was in the past. It essentially overwhelms *almost* all other concerns (if there would not be an almost, we would have **Ag**!).

Questionaire
Multiple Choice questions to 2.1.3