

2.2.3 Non-Metallic 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-acetylene (pAc)* we may have.
 $\rho \leq 6,7 \mu\Omega\text{cm}$.

- Or in other words: If you divide by the density for some [figure of merit](#), it beats everything else, since $\{\rho/\text{density}\} (\text{pAc}) > \{\rho/\text{density}\} (\text{Na})!$

- More typical, however, are resistivities around **(10 ... 1000) $\mu\Omega\text{cm}$** .

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 **semiconducting 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 **SnO₂** doped with **In₂O₃**.

- ITO** is technically **very important**, especially for:

- flat panel displays, e.g. **LCDs**.
- 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 **LCDs**, you also would be a rich person if 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 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 ₂ Si
ρ ($\mu\Omega\text{cm}$)	40 ...100	38...50	13..16	10...18	\approx 50	28...35	30...35

It looks like the winner is **CoSi₂**. Yes, but it is difficult to handle and was only introduced more recently, like **NiSi₂**. 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 ($\mu\Omega\text{cm}$)	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**!).

Questionnaire

Multiple Choice questions to 2.1.3