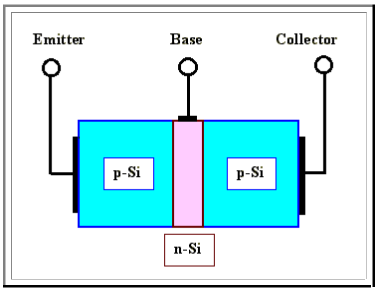
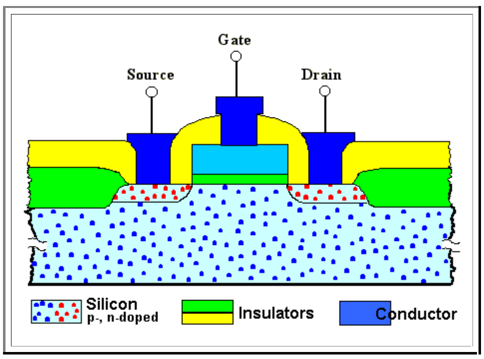
5.1 Basic Considerations for Process Integration

5.1.1 What is Integration?

- The key element of electric engineering, computer engineering, or pretty much everything else that is remotely "technical" in the last thirty years of the **2nd** millennium, is the **integrated transistor** in a **Silicon crystal** - everything else comes in second - at best.
  - *Integrated* means that there is more than one transistor on the same piece of **Si** crystal and thus in the same package. And "*more than one*" means at the present stage of technology some *10^7 transistors per* ***cm^2*** of Silicon.
  - *Silicon crystal* means that we use huge, extremely perfect single crystals of **Si** to do the job. Why **Si** and not. for example**Ge**, **GaAs** or **SiC**? Because if you look at the sum total of the most important properties you are asking for (crystal size and perfection, bandgap, extremely good and process compatible dielectric, ...) **Si** and its oxide, **SiO_2** are so vastly superior to any possible contender that there is simply no other semiconductor that could be used for complex integrated circuitry.
- The lowly **integrated circuit** (***IC***), mostly selling for a few Dollars, is the most marvelous achievement of Materials Science in the second half of the **20th** century. Few people have an idea of the tremendous amount of science and engineering that was (and still is) needed to produce a state-of-the art **chip**, the little piece of **Si** crystal with some other materials in precise arrangements, that already starts to rival the complexity of the brains of lower animals and might at some day in the not so distant future even rival ours.
- If we want to make a *circuit* out of many transistors (some of which we use as resistors) and maybe some capacitors, we need *three basic ingredients* - no matter if we do this in an integrated fashion or by soldering the components together - and on occasion some "spices", some special additions:
- **1. Ingredient:** *Transistors.* "Big" and "small" ones (with respect to the current they can switch), for low or high voltage, fast or not so fast - the whole lot. We have two basic types to chose from:
  - **Bipolar transistors** (the hopefully familiar **pnp**- or **npn**-structures) *are usually drawn as follows*



  - Note right here that no real transistor looks even remotely like this structure! It's only and purely a schematic drawing to show essentials and and has nothing whatsoever to do with a real transistor.
  - The name *bipolar* comes from the fact that *two* kinds of carriers, the negatively charged electrons and the positively charged holes, are necessary for its function.
  - ***MOS*** **Transistors** or **unipolar Transistors**, more or less only exist in integrated form and usually are drawn as follows:



- **2. Ingredient:** *Insulation.* Always needed between transistors and the other electrically active parts of the circuit.
  - In contrast to circuits soldered together where you simply use air for insulation, it does not come "for free" in **ICs** but has to be made in an increasingly complex way.
- **3. Ingredient:** *Interconnections* between the various transistors or other electronic elements - the wires in the discrete circuit.
  - The way you connect the transistors will determine the function of the device. With a large bunch of transistors you can make everything - a microprocessor, a memory, anything - only the interconnections must change!

- Then we may have *special elements*
  - These might be capacitors, resistors or diodes on your chip. Technically, those elements are more or less subgroups of transistors (i.e. if you can make a transistor, you can also make these (simpler) elements), so we will not consider them by themselves.
- If you did the required reading, you should be familiar with the basic physics of the two transistor types; *otherwise do it now!!!*
  - **Basic bipolar transistor**
  - **Basic MOS transistor**
- The list of necessary ingredients given above automatically implies that we have to use several different materials. At the very minimum we need a *semiconductor* (which is practically always Silicon; only **GaAs** has a tiny share of the **IC** market, too), an *insulator* and a *conductor*. As we will see, we need many more materials than just those three basic types, because one kind of material cannot meet all the requirements emerging from advanced **Si** technology.
  - Since this lecture course is about *electronic materials* , it may appear that all we need now is a kind of list of suitable materials for making integrated circuits. But that would be far too short sighted. In **IC** technology, *materials and processes* must be seen as a unit - one cannot exist without the other.
  - We therefore have to look at both, materials with their specific properties and their integration into a **process flow**.
- Todays integrated circuits contain mostly **MOS** transistors, but we will start with considering the integration of bipolar transistors first. That is not only because historically bipolar transistors were the first ones to be integrated, but because the basic concepts are easier to understand.

Questionnaire
Multiple Choice questions to 5.1.1