1 Deposition

1.1 Plasma, the fourth aggregation state of a material

1.1.1 Plasma state

In many semiconductor manufacturing processes, a plasma is used, e.g. in sputtering, deposition or in dry etch prcesses. An important point here is that the plasma is not heated. Therefore wafers, which were already metallized, can be processed in plasma processes.

Plasma is also called the fourth state of matter or fourth aggregate state. An aggregate state is a qualitative condition of materials, which depends on the temperature and pressure. The three states solid, liquid and gaseous one encounters in everyday's life. If temperature is low, every atom in a solid is fixed at one point. Attractive forces prevent them from moving. At absolute zero (-273.15 °C) substances enter into no reaction. With increasing temperature, the particles start to oscillate, and the bonds of the atoms are unstable. If the melting point is reached, a substance transforms from the first to the second aggregate state: ice (solid) is transformed into water (liquid).

The gravitational forces in liquids are still present, but the particles are able to move and have no fixed places like in solid state, the particles are adapted for example to a predetermined shape. If the temperature increases further, the bonds are completely broken, the particles move independently of one another. At the boiling point of a substance it transforms from second to third state: water (liquid) turns into water vapor (gaseous).

While the volume of solids and liquids is constant, gaseous substances take the existing space completely, the particles are distributed evenly throughout the room.

Each substance has a specific melting and boiling point. Silicon melts at 1414 °C and passes into gaseous state at about 2900 °C. If one introduces even more energy to a substance, the collisions between the particles will strike out electrons from the outermost electron shells. Now there are free electrons and positively charged ions: the plasma state is reached.

1.1.2 Plasma generation

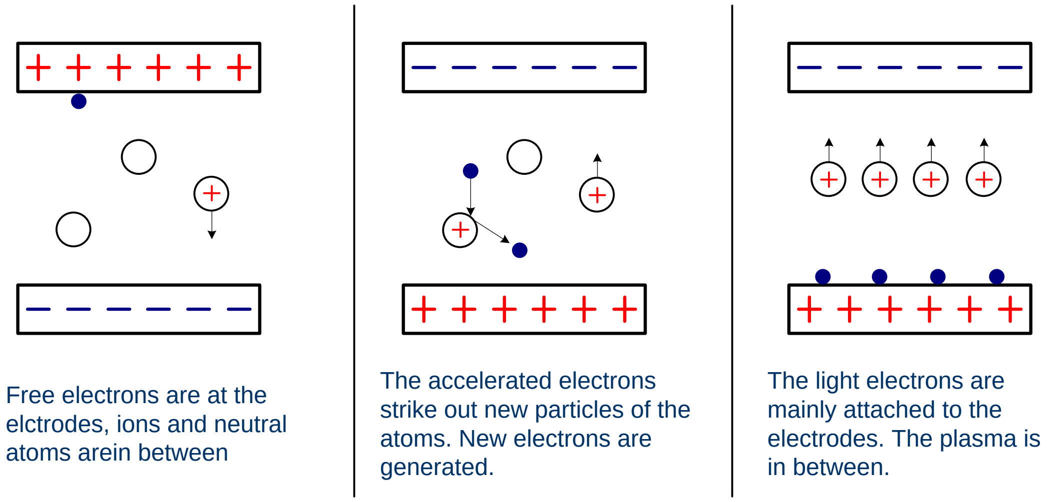
A plasma in semiconductor technology is usually generated by high frequency voltage, for example, argon serves as a gas. The gas is located in a high-frequency field between two charged plates (electrodes) and here it is ionized. Electrons are necessary to strike out electrons from the argon atom's outer shells. These initial electrons can be generated in different ways:

- Electrons are emitted from a thermionic cathode
- By a very high voltage electrons can be pulled out from the negative electrode
- In each gas there always are temporarily free electrons by collisions of the particles

Since the electrons are much lighter than the ions, they are immediately attracted to the positively charged electrode, and the heavy ions moving slowly to the negative electrode. Before they will achieve it, however, the polarity of the electrodes is reversed, the electrons are drawn to the other electrode and on their trajectory they will strike out more electrons from the atoms due to collisions. Typical frequencies for the plasma generation process is 13.56 megahertz and 2.45 gigahertz, so the voltage across the electrodes will be reversed 13.56 million or 2.45 billion times per second.

The electrons are located mainly on the electrodes, while in between the positively charged ions, the plasma, oscillate back and forth, because they can not follow the rapid voltage changes.

The plasma production takes place under vacuum, the produced plasma is not heated, which is important for many processes. The plasma can be used in deposition, sputtering, etching or ion implantation. Due to the rapid oscillations of the positive ions in the high-frequency field they are very energetic. There are not only positive ions and free electrons in the plasma, as other particles are created by collisions: the condition of the plasma changes constantly. Electrons are captured by the ions partially and ejected again, these additional particles, however, do not play a matter in the further use of the plasma. The degree of ionization is 0.001-10 %, depending on the particle density



Free electrons are at the elctrodes, ions and neutral atoms arein between

The accelerated electrons strike out new particles of the atoms. New electrons are generated.

The light electrons are mainly attached to the electrodes. The plasma is in between.

Fig. 1.1: Illustration of plasma generation

in the process chamber ($10^8 - 10^{12}$ particles per cm^3); so the majority of the particles is unloaded.