Training center for Microtechnology and Nanotechnology

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Module Start:

Indroduction to Microtechnology

- **What is microsystemtechnology?**
- **Exercises**

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Micro

What is there behind the term ***Micro***? In order to answer this question let us have a look at the following table. It can be found in books for technicians and scientists. Find the term Micro in the table and write the further information given in its line on a piece of paper.

Prefix	**Abbreviation**	**Factor**	**Abbreviation Power**
Tera	T	1 000 000 000 000	10^{12}
Giga	G	1 000 000 000	10^{9}
Mega	M	1 000 000	10^{6}
Kilo	k	1 000	10^{3}
Hekto	h	100	10^{2}
Deka	da	10	10^{1}
Dezi	d	0.1	10^{-1}
Zenti	c	0.01	10^{-2}
Milli	m	0.001	10^{-3}
Mikro	µ	0.000 001	10^{-6}
Nano	n	0.000 000 001	10^{-9}
Pico	p	0.000 000 000 001	10^{-12}

Table 1: Prefixes, terms and abbreviations

In this table we find prefixes and their terms in short and long forms. What does it mean?

Prefixes had been invented pretty early in time as human beings are idle by nature and thus try to arrange things as simple as possible. For example, they didn't always want to write 1000 or more grams for larger weights, but were looking for an abbreviation. This abbreviation relates to the number of zeros behind the number 1.

Three zeros for example were then abbreviated with the term Kilo. The terms mostly come from the Greek or Latin language.
However, to substitute the zeros wasn't enough. They looked to make writing numbers easier, too. In the number 1000 for example they looked how many times 10 is found in 1000.

$$1000 = 10 \times 10 \times 10$$

However, you can't write that 1000 is 3 x 10 as it isn't correct from a matehmatical point of view, since 3 x 10 is 300. So they wrote $10 \times 10 \times 10 = 10^3$, in words 10 to the power of 3. The upper number is called power, that's why calculating with them is called calculation with powers. The power shows how many times a number is multiplied with itself. Now they could write shortly: 1000 grams = 10^3 grams = 1 kilogram. As you can see it's quite simple with 10, the number of zeros behind the number 1 relates to the power of 10.
Up to this point all were satisfied and happy, especially the businessmen, as you don't need more for weights. However, the technicians and scientists soon came into trouble with lengths, areas and space. The length was measured in metres, areas weren't hard to handle, they just wrote length x width or metre x metre or metre^2, space wasn't hard either, length x width x height or metre x metre x metre or metre^3. But as well as people travelled larger distances they invented instruments to observe and measure smaller objects. Many objects were smaller than 1 m from the start. In order to write them down a metre was divided in 100 similar parts. This smaller measure was called centimetre from Latin cent = one hundred. 1 metre was then 100 divided by 100 or 100 / 100 metre. 1 centimetre was then 1/100 metre or 0.01 metre. So we don't put zeros behind a 1 anymore but we always take one zero away instead. It looks as if the 1 moves more and more to the right side of the point, one place at a time. The zero which has disappeared occurs at the place between the 1 and the point.

Of course it was too complicated to write this down. Again they used the powers, moving in the opposite direction. For 1 divided by 10 or 1/10 or 0.1 they wrote 10^{-1}. So the negative power shows the place of the number 1 after the point.

Another explanation:

Imagine you want to go swimming with your friends on a hot summer day. Everyone's waiting for you but you are still at home as you can't open the lock of your bike. Your husband or wife has played a trick with you and changed the combination. Now you must find the new one as good-looking madams or sirs are waiting. You must take the chance. You find out that the lock has two setting notches and you can only set the numbers 1 and 2.

<u>Problem:</u>

How many possible combinations are there?

<u>Answer:</u>

The lock has two setting notches: 2

You can only set the numbers 1 and 2: 2 (= amount of numbers)

Possibilities: 2 x 2 = 4 combinations.

In order to make it simple powers had been invented::

$2 \times 2 = 2^2 = 4$.

So powers show that a number is multiplied with itself, and the number written at the right side above the according number is how many times the number is multiplied with itself.

Examples:

$1 \times 1 = 1^2 = 1$

$3 \times 3 \times 3 = 3^3 = 27$

$4 \times 4 \times 4 \times 4 = 4^4 = 256$.

Of course mathematicians invented special terms again:

Number which is multiplied = basis,

Number which is written up at the right side, or how often it is multiplied = exponent.

The number 10 is of special interest. The number written up at he right side of the number 10, or how often the number 10 is multiplied with itself, relates to the number of zeros after the number 1.

Thus:

$10 \times 10 = 10^2 = 100$

$10 \times 10 \times 10 = 10^3 = 1,000$

$10 \times 10 \times 10 \times 10 \times 10 \times 10 = 10^6 = 1,000,000$.

You can count in the other direction, after the point:

$1/10^2 = 1/10 \times 10 = 1/100 = 0,01$.

In order not to handle fraction bars you write: $1/10^2 = 10^{-2}$.

The number written up at the right side oft he number 10 is the place after the point where the number 1 appears:

$10^{-2} = 0,01$

$10^{-3} = 0,001$

$10^{-4} = 0,0001$.

Exercise:

1. Write a short report with the title: What are powers?
2. What is the meaning behind the following numbers? (Ex.: $2^2 = 2 \times 2 = 4$, $3^3 = 3 \times 3 \times 3 = 27$): 10^2, 10^4, 10^9, 10^{-2}, 10^{-9}

With this knowledge we can now explain what is meant by Micro.

The following figure shows a standard ruler.

Figure 1: Ruler

This ruler shows 100 centimetres or 1 metre. We can easily find 1 centimetre. 1 centimetre is 10^{-2} metres. When we move to the left of this one centimetre up to the point where we find the last bar of the whole ruler we reach one millimetre. 1 millimetre is 1 metre divided by 1000, a thousandth of a metre. Milli means Mille, the Latin word for one thousand (compare to millennium for a century). We can see this point and have reached 10^{-3} or 0.001 metres. Now we go on and divide this 1 millimetre by 1000 again. So we have a thousandth of a millimeter. Three zeros are added after the point, we have reached 0.000 001 metres. The number 1 moves to the sixth decimal place after the point, we write 10^{-6}. Now the table from above is of great help. The factor 10^{-6} gets the term micro. 10^{-6} metres are 1 micrometre. That's where the term ***Micro*** in Microtechnology, Microsystem Technology etc. comes from. In a simple way: because in this technology structures and devices are formed which have lengths, widths and heights in the micrometer area.

The term ***Micro*** means structures and devices are formed in the **area of micrometres**.

1 micrometer = 10^{-6} metres

The term ***Micro*** has another meaning in the production of small labs. Here you don't just talk about micrometres but also of chemicals moved in liquid and gaseous states by microlitres.

A little more of Physics

While looking at the term ***Micro*** we already worked with other terms such as metre and gram or centimetre and kilogram. Later on you will deal with many different properties and dimensions in the field of electronics and sensorics. Each of the physical properties and dimensions were given special terms in the run of time, again to make things easier. You all know the metre for length or the kilogram for the mass of a body (because of special reasons, only of interest for physicists, the term weight is only used for certain physical states).Later on you will deal with the Ampere for current and the Ohm for voltage.

In some fields there is a vast number of terms for one dimension all over the world. The experts of American Football know what I mean. There the players run for yards and inches and not for metres like football players from the Star of Sahel.

One time in the 19th century scientists thought they couldn't talk to each other properly with all these different terms. They held a conference and invented a basic system of seven units which form all the others or the others could be calculated by them. Before we deal with this system we shortly explain all terms.

Physical dimensions are terms of properties of objects, states and processes. It is important that physical dimensions can be measured. A distance for example has the physical dimension *length*. It can be measured. To make things easier physical dimensions are abbreviated. The length for example is written as *l.*

Since physical dimensions must be measurable they have values. For example, in case we measure 10 times a length then l = 10. Now you also have to write that you don't mean 10 apples or pears but ten ***units*** of length. In former times people chose something which could be measured by our body, for example 1yard according the size of a standard male foot. Nowadays the standard unit for length is 1 *metre*. Units are abbreviated as well. 1 metre is 1m.

The metre is one of the standard units invented in the 19th century. It belongs to one of seven basic dimensions in the International System of Units.

Physical dimension	Abbreviation	Unit	Abbreviation
Length	l	Metre	m
Mass	m	Kilogram	kg
Amount of substance	n	Mol	mol
Time	t	Second	s
Temperature	T	Kelvin	K
Current	I	Ampere	A
Luminosity	I_V	Candela	cd

Table 2: SI Basic dimensions und units

SI means Systeme International d'Unités, French for International System of Units. The measure of each basic unit is standardized. In former times prototypes were used, such as the original metre in Paris. Today the standards are set more precisely by new techniques and instruments, for example the metre is nowadays defined as the distance light passes in vacuum in a period of 1/299 792 458 seconds. Later on you will know what vacuum is, here you only need to know that it is space without air.

All other dimensions and units can be derived from the SI system.

Example 1:

Area, termed A

Area is length times width, l x w, with the according units metre times metre l x w = m x m = m^2. So the unit for area is 1 m^2 or 1 squaremetre (x to the power of 2 is said to be x squared).

Example 2:

Density, termed ρ

Density is mass per volume, m/V, with the according units kg/m^3. Thus the unit of density is 1 kg/m^3 or 1 kilogram per cubicmetre (x to the power of 3 is said to be cubic).

Example 3:

Force, termed F

Force is a mass accelerated along a distance, mass times distance per time squared, with the according units $kg \times m/s^2$. Thus the unit of Force is 1 $kg \times m/s^2$. As this is too complicated again the unit 1 Newton, 1 N, was chosen.

A little more Mathematics

Later on you will have the task to give the thickness of thin films in micrometres and then in nanometres and vice versa. So we must juggle with the powers of ten. That's why we must take a look at how to calculate with powers. It is sufficient when the number beneath the power remains the same.

Rule 1:

Powers are multiplied by keeping the basis and adding the powers.

$10^2 \times 10^3 = 10^{2+3} = 10^5$

Rule 2:

Powers are divided by keeping the basis and subtracting the powers.

$10^3/10^2 = 10^{3-2} = 10^1$

Now it gets more interesting since we also have negative powers:

$$10^3 \times 10^{-2} = 10^{3+(-2)} = 10^{3-2} = 10^1$$

$$10^3/10^{-2} = 10^{3-(-2)} = 10^{3+2} = 10^5$$

Rule 3:

You can calculate powers of powers, too. The new power is calculated by multiplying the two former powers.

$(10^2)^3 = 10^{2 \times 3} = 10^6$

Now it is easier for us to convert units.

Example 1:

Give the distance $l = 3 \times 10^{-4}$ m in µm.

Step 1:

Look at Table 1 (with the prefixes).

Step 2:

You find:

1 µm = 10^{-6} m

1 m = 10^6 µm

Step 3:

You apply tot he given information above:

$l = 3 \times 10^{-4}$ m $= 3 \times 10^{-4} \times 10^6$ µm $= 3 \times 10^{-4+6} = 3 \times 10^2$ µm = 300 µm.

Example 2:

Give the mass m = 0,004 kg in mg.

Step 1:

We have a look at Table 1 again.

Step 2:

We find:

1 kg = 10^3 g

1 g = 10^3 mg

Step 3:

We apply:

m = 0,004 kg = 0,004 x 10^3 g = 0,004 x 10^3 x 10^3 mg = 0,004 x 10^{3+3} mg = 0,004 x 10^6 mg = 4 x 10^{-3} x 10^6 mg = 4 x 10^{-3+6} mg = 4 x 10^3 mg = 4000 mg.

Example 3:

Give the area A = 600 cm^2 in m^2.

Step 1:

We have a look at Table 1 again.

Step 2:

We find:

1 cm = 10^{-2} m

Step 3:

We apply:

A = 600 cm^2 = 600 x $(10^{-2}$ m$)^2$ = 600 x $10^{(-2)x2}$ m^2 = 600 x 10^{-4} m^2 = 0,06 m^2

Exercise

1. Fill in: 1 micrometre = 1 ?m = $10^?$ m = 1/$10^?$ m = 0,(how many zeros are to be here?)1 m.
2. Show on your ruler: 1 m, 1m/1000 = 1 xm, 1 xm/1000 = 1 ym, 1ym/1000 = 1 zm. x = ?, y = ?, z = ?. Are there any problems in doing this?
3. Another new technology is Nanotechnology. How many metres are a nanometre? Fill in: 1 __m = 10^x m = 0,__________1 m = 1/10^y = 1/1______ m

Microthis and Microthat – some definitions

Now you know the general definition of the term ***Micro.*** In technology, however, the term is used along with many others. We give a short overview here.

Miniaturization

This term describes the act of making devices and structures smaller in general. ***Micro*** describes the dimensions oft he devices. The opposite of ***Micro*** is ***Macro***.

Microtechnology

The term ***Microtechnology*** describes all the techniques and processes used to produce microstructures and microdevices from an industrial point of view.

Microsystemtechnology, Microsystems

As the devices are built in to larger systems, such as a microchip in a sensor, they are called ***Microsystems***. The production of Microsystems with all its techniques and processes is called ***Microsystem Technology***

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Microelectronics, Semiconductors, Microchip, Integrated Circuit

Microelectronics was the first field in the 1960ies where devices and structures were miniaturized. The use of certain materials, so-called semiconductors, made it possible to build electronic devices on the microscale. The circuit consisting of several of these devices is called an ***integrated circuit***. It is nothing else than a ***Microchip***. As mainly semiconductors are used as materials Microelectronics is also called ***Semiconductor Technolog***.

In case specific optical devices are combined with electronic ones one speaks of ***Optoelectronics***.

Micro Optics

Micro Optics deals with the design and production of optical devices such as micromirrors, microlenses and optical measuring instruments with dimensions on the microscale.

Micro Mechanics

In ***Micro Mechanics*** motors and other movable mechanical devices are designed and produced on the microscale. Since these devices are movable, doing something by themselves, they are called ***Actuators.*** They are active. The opposite are ***Sensors***, which are passive. Something happens to them as they measure physical dimensions.

Micro Fluidics

Micro Fluidics deals with the design and production of devices and structures which can move liquids and gases on the microscale. Examples are microchannels, micropumps and microvalves. The term ***Micro*** doesn't signify the dimensions here but the transported amount.

Main target in ***Micro Fluidics*** ist he production of complete labs or lab parts on chip-like devices. That's why these devices are called ***Lab-on-a-Chip-Devices***. They are used in Chemistry and Biochemistry, such as microreactors and detection chips for proteins and DNA.

What will I do in my job? – Overview to the production of microdevices using the example of a microchip

In the production of microdevices specific techniques and process are necessary. The site of production plays a vital role, too. Your training and education will be to get used to every single technique. It follows a short overview to the process run of ***Microchips***. At some points additions and differences in the production of ***Lab-on-a-Chip-devices*** will be shown.

The processes are run in a cleanroom since any contamination affects the function of a microchip.

Step 1:

Design of a ***microchip***

Before it comes to production engineers create a layout of the **integrated circuit** based on the task demanded by the customer or an idea for a new patent. This layout is the blueprint for the whole process run. The design of a microchip is not part of your training and education.

Step 2:

Material choice

In order to show the correct function according to their application microchips are made of semiconductors, mainly silicon. It must be extremely pure and is processed as discs, the so-called wafers. The fabs don’t produce these wafers themselves, they are supplied by specialized fabs. Your task in the fab is to mark the incoming wafers for the process via laser. However, you are to achieve knowledge about the properties and the production of the materials used in microtechnology.

In the production of lab-on-a-chip-devices polymers are used as material.

Several different processes are run in order to produce microstructures and devices which can be separated into different areas. The origin is always a film consisting of a specific material. The material must then be

- ✓ deposited at first;

- ✓ then changed in order to achieve specific material properties such as resistivity in the case of microchips;
- ✓ the structure must then be transferred to this film, for example the appropriate conducting paths of the circuit in microchips;
- ✓ and finally the remaining material, which is not of use anymore, must be removed.

Step 3:

Formation of films

In order to deposit single films on a wafer different deposition techniques are used. They run with gases created by high pressure (vacuum), high temperatures and plasma. With gases a material can be deposited uniformly, which is a very important issue on the microscale. The question why we need a gas can be answered by the fact that it is impossible to deposit a fine and homogeneous film on a silicon wafer with a cube made of aluminium.

Step 4:

Modification of films

The deposited film is then to be modified according to the specific application. For example, In case you want to change resistivity more electric charges are to be inserted into the film. This can be done slow or fast. In the first case higher temperatures are sufficient in order to make other materials diffuse into the film, in the second case atoms are accelerate by high energy, in way shot into the film. Here gases are used, too.

In case non-conducting films are to be formed the substrate is oxidized.

This process step is not run in the production of lab-on-a-chip-devices as they don’t use electrical effects.

Step 5:

Patterning of films

After the film is prepared according to its function the according structure must be transferred, such as the area of the according electronic device or the conducting paths. The processes run are lithography, an exposure technique similar to photography, and etching techniques. Either acids or bases, wet chemical etch, or physical techniques such as plasma are used to etch.

The following comparison shows the difference between chemical and physical.

Imagine you go to the department of Physics of the nearby university. You are introduced to the new medical CT-device. It works with beams, definitely a physical technique. You are pushed into the tube and exposed to the beams for several minutes. Then you are pulled out again and you can see that nothing has changed on you. So:

In physical processes a material doesn't change, only its state.

After a short break you go to the department of Chemistry. A professor shows you the mixture of sulfuric and hydrofluoric acid, definitely a chemical mixture. You are immersed in the bath and remain there for several minutes. Then you are taken out again, only to see that nothing is left of you. The sulfuric acid reacts with your body, the hydrofluoric acid with your bones. So:

A material is transformed to a new material in a chemical reaction.

In the production of lab-on-a-chip-devices laser-beams are used to pattern films, with micromechanical devices mechanical techniques such as milling.

Step 6:

Removal of films

After the pattern has been formed the residuals, which are of no use anymore, must be removed as they disturb the function of the device. Here cleaning processes are used, working with acids or bases or physical etch techniques.

The steps 3 to 6 are run not only once but several times. A modern fabrication process of microchips consists of up to 400 process steps and lasts for about six to eight weeks.

Step 7:

Assembly and Packaging

After the fabrication process the microchips are built in the according microsystems such as sensors. Here specific techniques are used such as bonding.
While you have to avoid electric disturbances in the fabrication of sensors, the contamination with bacteria must be avoided in lab-on-a-chip-devices as they are used in medical applications.

The fabrication process is run in a cleanroom, called ***Frontend***, assembly and packaging is run in the ***Backend***.

<u>Exercise</u>

1. Read the attached contents of education and training for Microtechnologists.
    a) Can you identify your operations at work?
    b) What are important contents for your job?
2. Read the attached file about microchip manufacturing. Sketch the fabrication run in a diagramme (with arrows) and use notes to describe.