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TECHNOLOGICAL ASPECTS REGARDING THE USE OF PHOTOLITOGRAPHY IN OBTAINING MICRO-ELECTRO-MECHANICAL SYSTEMS (MEMS)

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ABSTRACT: Micro-electro-mechanical systems (MEMS) include a vast area corresponding to the technological development in the last decades. MEMS are included in a multitude of areas, almost in everything that surrounds us. This aids of small dimensions and high tech are increasingly present in our daily life. The paper presents one of the most popular ways to obtain such a system, wich is the photolithography. The block diagram of the photolithography process is presented and further, the main lithographycal operations are defined and described as they are achieved at IMT Bucharest. Both the used equipment and the main technological guidance specific to each stage are highlighted.
KEYWORDS: lithography, photolithography, mask, wafer, deposit, exposure

1. INTRODUCTION

Invented in 1796 by Aloys Senefelder, **lithography** has come to represent the most used method of patterning. In the microelectronic field, it is defined as being the transfer process of the design (reasons) from a template (physical or virtual mask) on a wafer [1].

Photolithography is the most common form of lithography. If in the past this was a specific technique exclusively attributed to microelectronics, today it has become a technique used in processing the micro-electro-mechanical systems (MEMS) as for the microfluidic systems.
Micro-electro-mechanical systems (MEMS) are used as accelerometers, pressure sensors, optical devices, microfluidic devices and others.
The size of the MEMS devices varies from a few millimeters to less than a micrometer, and their functions may vary from simple static structures to complex systems with moving elements [2].
When the template image transfer on the wafer occurs through light the process is called photolithography [3].
The performances of the photolitography have rapidly developed, and the ability to make transfers for the smallest components is in a constant development [1].
Resolution, the minimum feature size that can be transferred, the accuracy with which the masks are aligned and the number of items that can be transferred in one hour (in a certain period) are some of the photolitography key elements. Two types of conventional photolithography are known: etching and liftoff [4].
The liftoff process used in the microstructures technology represents a method to create structures of a target material on the surface of a substrate using a sacrifice material (e.g. photoresist).
If the photolithography is liftoff type, the photoresist is spread, exposed to the light through photolithographic mask, and it is developed before the deposition of the paterning material. The material to be shaped is deposited both in the developed areas where it is anchored to the substrate as well as over the undeveloped photoresist. At photoresist removal, the material of the undeveloped regions is also removed, leaving the wafer only in the areas in which it has been anchored to the substrate.
Photolithography is performed using photosensitive polymers called photoresists and also UV exposure equipments in perfect delimited areas on the photolithographic masks [5].
With the help of photolithography, some areas on which the evaporation of other materials is not desired can be protected or, some areas on which the material has already been evaporated and on which, it is not necessary to be removed by etching may be protected with photoresist.

2. PHOTOLITOGRAPHY TECHNIQUE

The steps of the photolithography process presented in figure 1 are:
1. the design of the photolithographic mask that can be accomplished with the Clewin software in our case;
2. writing the mask, using as example the DWL 66-fs laser in this case;
3. the growth of a SiO_2 silicon oxide layer of 1.7μm on the silicon wafer;

4. cleaning and degreasing the substrate/wafer (with organic solvents); washing the wafers is made several times in order to remove all the impurities, followed by the degreasing with organic solvents (trichlorethylene, carbon trichloride, etc.), washing with acetone, alcohol and in the last phase with deionized water in abundance;
5. dehydrating the wafer in an oven at 100°C for 30 minutes;
6. obtaining the next layer which is the positive photoresist (applied by rotation movement with a speed of 3000 rotations/min) and a thickness of 1,7 µm deposited on the surface of the wafer oxidized in advance;
7. drying the photoresist on the wafer for 45 seconds;
8. the positioning of the photopattern and the photoresist exposure for 10 seconds under UV light (460 nm wavelength, 7mJ / cm2);
9. development and thermal drying of the photoresist;
10. the chemical etching of the oxide layer (SiO_2) through the windows made in the photoresist;
11. removing the photoresist.

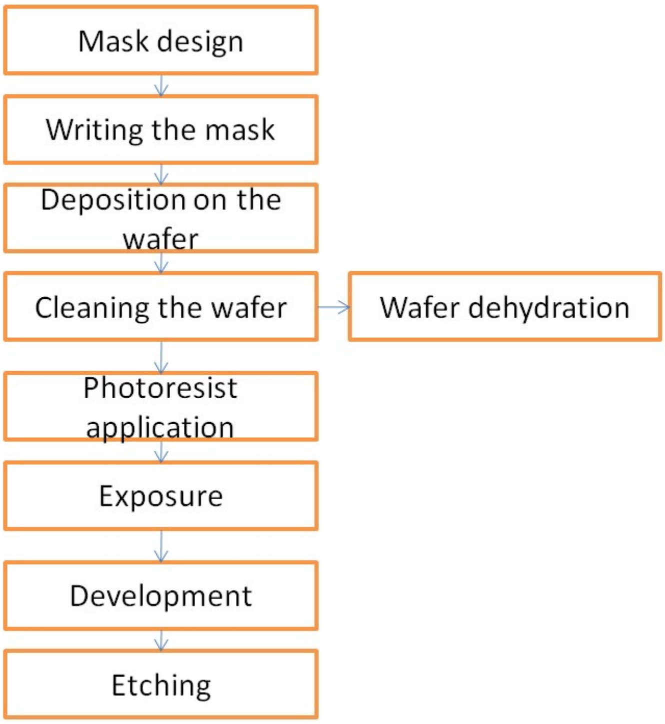

Figure 1. The steps of the photolithography process

All the lithography processes take place inside a very clean room (the white room). This room is built so that inside it, temperature, air pressure, humidity, vibration and light can be controlled [1].

3. THE PROCESS OF IMPLEMENTING THE MASKS

The masks are physical supports on which the model is achieved to be transferred on the substrate of semiconductor material. The material and the building method of the templates are chosen based on the features of the radiation used for the transfer.

The photomask is made of a special flat glass plate on which the desired pattern is drawn with chromium or gelatin. The mask is used to transpose the model by transparency on the surface of the wafer of semiconductor material [4].

There are two types of photomask resist: positive and negative. On the positive ones, the drawings are represented by opaque regions to the active radiation on a transparent background, and for the negative ones the configuration of the forms is made of transparent regions on an opaque background.

3.1 Aspects regarding the design and making the masks

The virtual masks represent the result of some specialized softwares for computer aided design. The graphical image can be transferred from the computer memory to the scanning device (line by line) of the system [4].

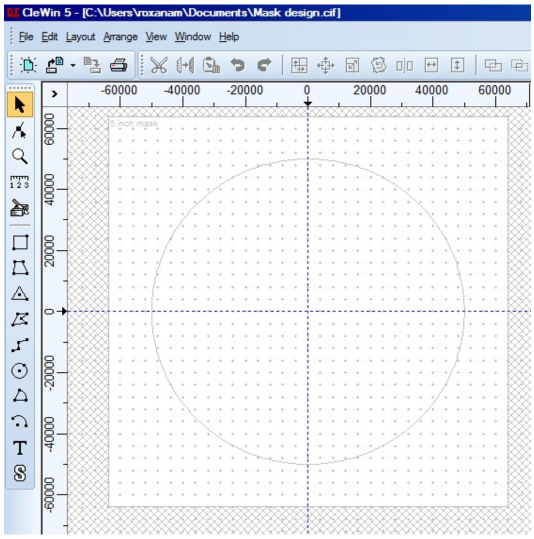

Figure 2a. Apects of geometry creation by Clewin

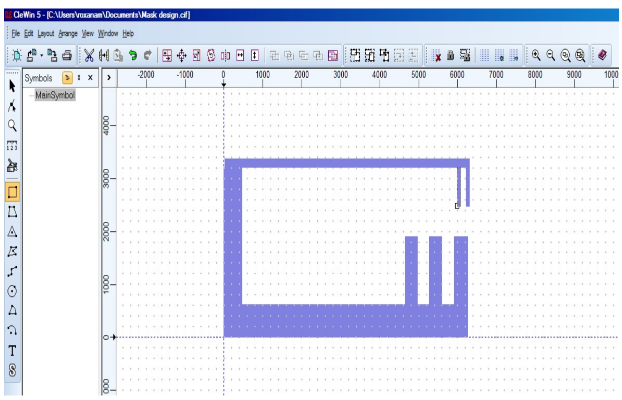

Figure 2b. Wafer sizing

With the help of CLEWIN software (figure 2a) the mask can be designed, choosing both the size for it as for the wafer (figure 2b).

The substrate is represented by a single crystal silicon wafer with a diameter of 4 inches (100 mm). Accordingly, the designed mask will be projected 5-inch size because it must be bigger than the wafer, to ensure that all the items are properly framed.

If in the same process are used multiple masks, they must be aligned, and in this case, alignment marks are put on the masks.

3.2. Writing the masks

This process is made using sthe DWL 66 Laser (figure 3.)

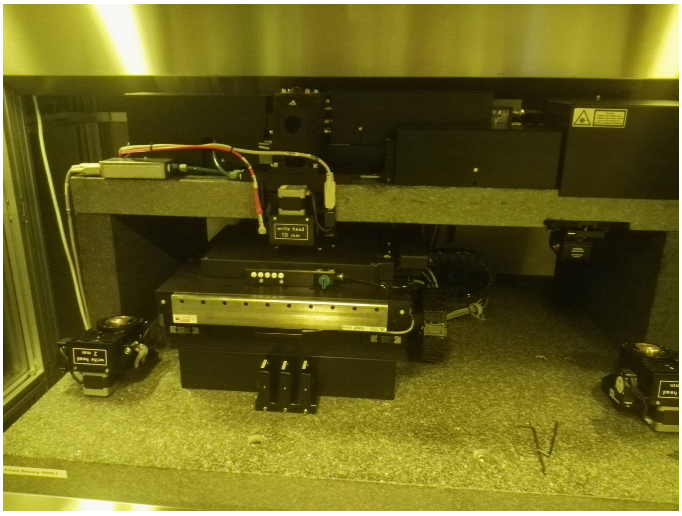

Figure 3. DWL 66-fs Laser equipment from IMT

The mask designed in CLEWIN was transposed on "Lime Soda" glass coated with chrome. The automated DWL 66-fs system achieves printing the designed geometries using a laser beam directly on a thin layer of photoresist deposited on the photolithographic mask. The chrome is etched in wet solution through printed photoresist layer. The laser DWL 66 fs lithography is a system with laser diodes with a wavelength of 405 nm.

The device is equipped with two writing heads of 2 μm with maximum resolution of 0,6 μm, respectively 10 μm with 3 μm maximum resolution. Depending on the desired resolution, writing a mask can vary from a few hours – for the write head of 10 μm – and a couple of days for the 2 μm one .

Using this equipment, both masks are exposed as wafers with sizes ranging between 2,5 inches and 6 inches.

It should be mentioned that the mask design can be accomplished in any editing program as long as it uses one of the following formats: CIF, DXF, HPGL, GDSII or Gerber.

The chemical processing consists of the following steps: developing, etching and photoresist removal (figure 4).

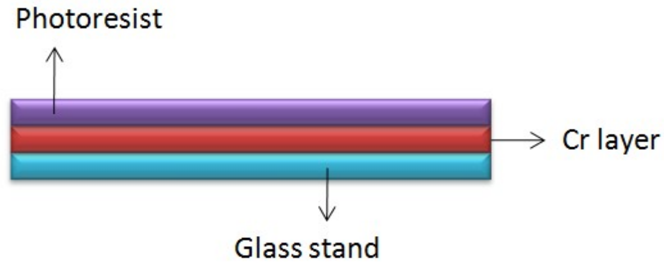

Figure 4. Chemical processing slements

4. WAFER PREPARATION PROCESS

In order to go through the preparation process of the wafer, some steps will be considered:

➢ **Checking the thickness of the deposited layer**

On the desired wafer - in many cases - SiO_2 is deposited. After deposition, the thickness is checked with the Nanocalc-XR system (figure 5).

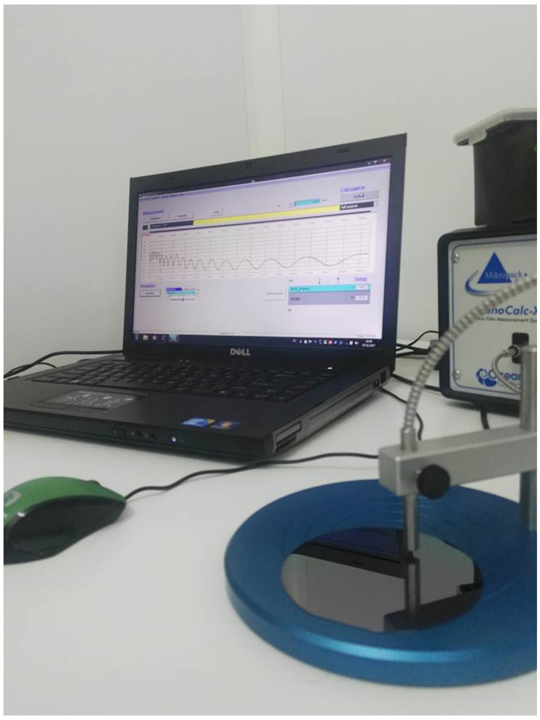

Figure 5. Equipment for checking the deposited layer thickness from IMT

This control system is used to study small-scale thickness for different materials, as well as for measurements of transmission and reflection of the anti-reflective coating and of hardness.

➢ **Cleaning the wafer**

Before begining the conversion process from the mask on the wafer, it must be washed and dried very well.

The washing can be done with a solution known as "piranha", which contains 3 : 1 = sulfuric acid (H_2SO_4) : hydrogen peroxide (H_2O_2). Sulfuric acid mixed with hydrogen peroxide removes and dissolves photoresin and the large organic contaminations.

In this process, the acid is heated for about 10-15 minutes until it will reach +50^{0}C; hydrogen peroxide is poured over the acid and the reaction may reach temperatures over 120^{0}C; using the platform made of quartz on which the wafer has been placed, it is slowly introduced into this mixture (to prevent breaking it at a sudden change of temperature) - and is hold there for about 15 minutes; further, other 10-15 minutes are necessary for washing/cooling in the cascade of water; then it is placed in the spin for drying (about 3minutes) (figure 6).

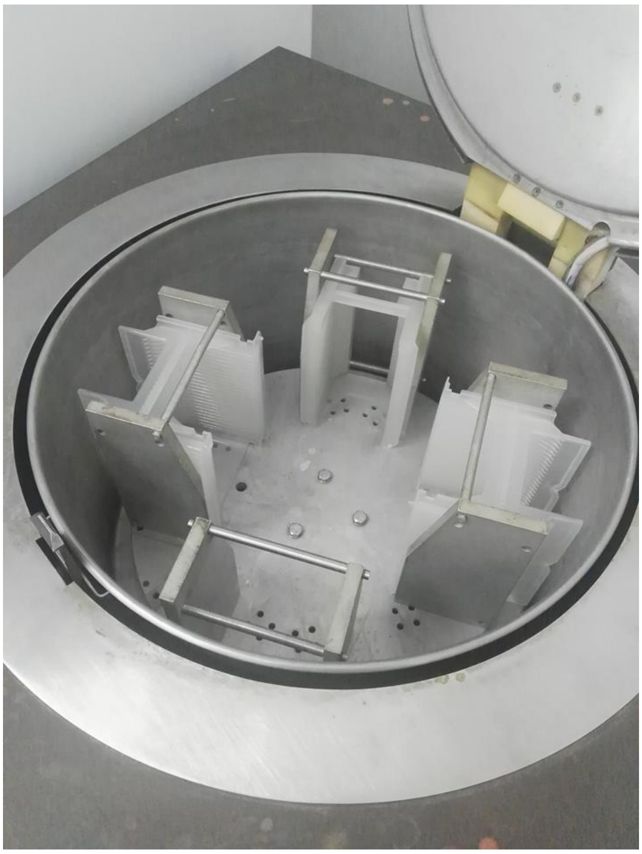

Figure 6. Spin for drying (IMT)

➢ **Dehydration wafer**

It takes place in an oven at a temperature of 100^{0}C for about 30 minutes -1 hour.

5. APPLICATION OF PHOTORESIST

Positive photoresist was used, which was deposited at 3000 rotations / min, with a thickness of 1.7μm. The photosensitive material (**photoresist** or **resist**) when is exposed to a radiation it changes its chemical resistance towards the developed solution.

Depending on how the development is made, two categories of lithographed layers may result: positive layers that preserve the film template configuration and negative layers when the areas affected by the radiation are more resistant to the developing substance (figure 7).

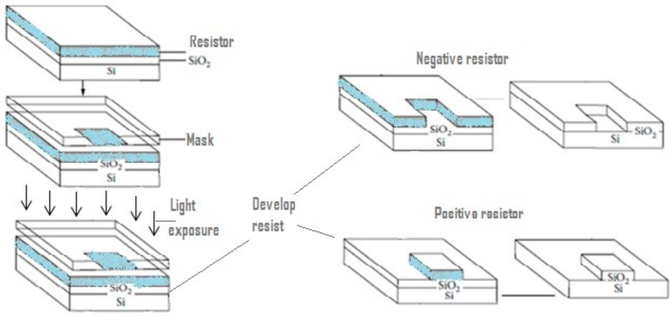

Figure 7. Photoresist layers

The photoresist has three components:
- **the resin,** that ensures the structural stability and etching resistance,
- **the photosenzitive part** (named as well photoactive part);
- **the solvent**, which transforms the photoresist from solid to liquid.

The photoresist layer deposition is made by spinning – a process in which the film thickness is in reverse with the angular velocity of spinning. For this procedure the equipment shown in figure 8 was used.

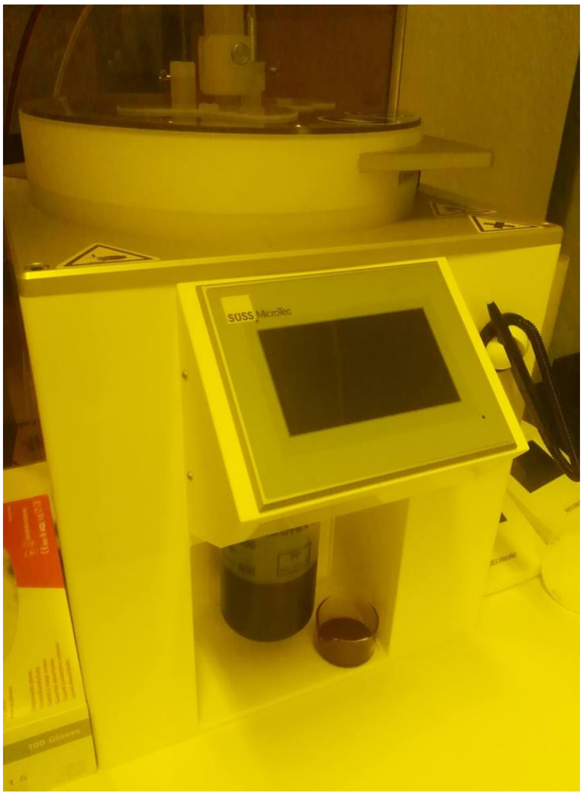

Figure 8. Equipment for photoresist deposition (IMT)

The resin is leveled (extended) on the wafer by using a rotating disc after the wafer has been attached to it by aspiration-vacuum (figure 9). By adjusting the the acceleration and the rotation speed, an uniform spread of the resin is obtained on the wafer [4].

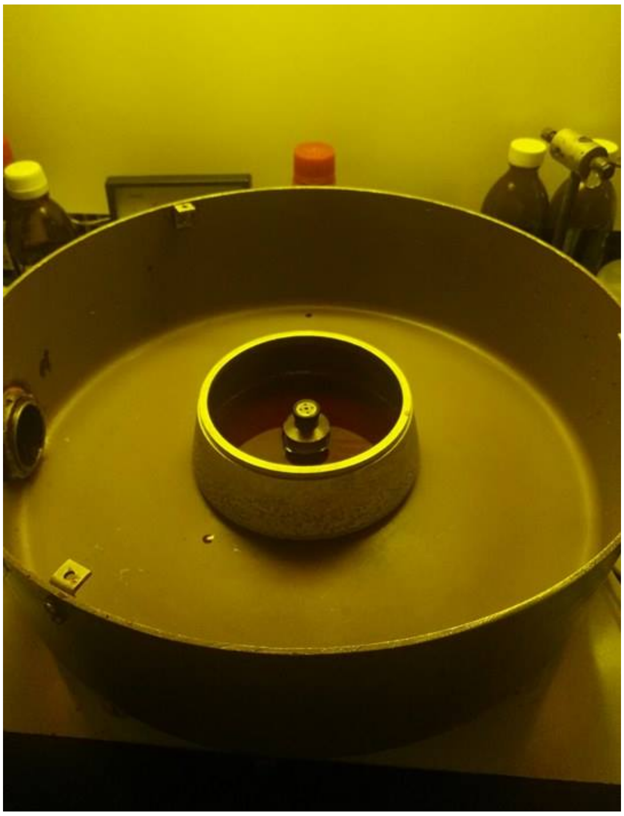

Figure 9. The disk on which the wafer is placed (IMT)

After the photoresist has been deposited, the wafer is put on the stove to dry for 45 seconds. By drying, the resin hardens in order to resist the subsequent chemical challenge with hydrofluoric acid.

6. EXPOSURE OF THE MASK ON THE WAFER

For the achievement of this process the Double Side Mask Aligner - MA6/BA 6 (Suss MicroTec) type equipment can be used (figure 10).

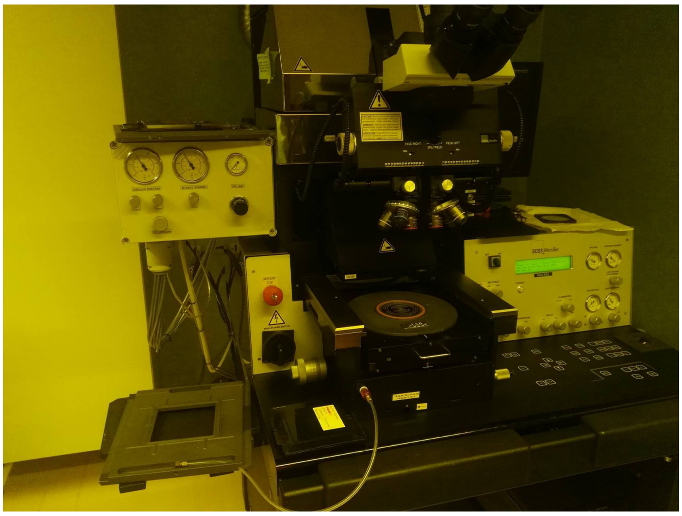

Figure 10. Double Side Mask Aligner – MA6/BA 6 Equipment (IMT)

The mask is fixed in the equipment for vacuum ultraviolet exposure, positioning the wafer under the mask for subsequently alignment (figure 11).

After setting the time and the exposure type (with the mask at a certain distance or welded) the conversion using ultraviolet light is done.

In the areas where the resin was exposed, its chemical bonds will be changed.

The exposure time is chosen depending on the thickness of the photoresist.

Exposure through contact ensures, in theory, the best definition of the drawing, but also leads to the progressive deterioration of the mask after each masking operation (because of rubbing on the wafer) [4].

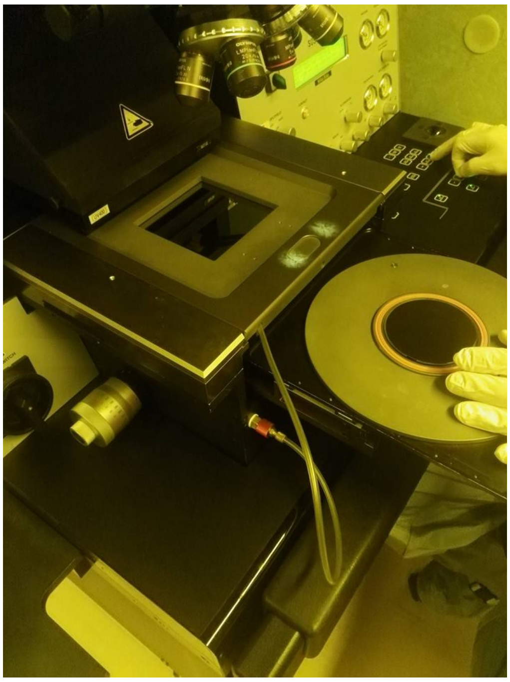

Figure 11. Wafer alignment (IMT)

The photoresist exposed to proper light becomes more or less acidic (positive or negative), making it important to ensure that the exposed areas are the right ones. The correct time of exposure is also equally important. If it is exposed too little, the photoresist will not be enough acidic, and there will remain some resist traces after the development.

There may be problems as well if the exposure time is too big, when the diffraction and the „focusing resolution" can make the protected areas to be exposed. These effects are present all the time, but at short exposures, the effect is very small [6].

After executing the exposure, the film development will be made and the wafer will be ready for etching.

The development represents the process in which the acid components of the photoresist will be removed.

This is done using an alkaline solution optimized for the used photoresist. The development time is very important [6]. The development is performed using a buffer solution (6:1 - hydrofluoric acid:ammonium fluoride), with a temperature of 24^0C (figure 12). It is left for 17 minutes, removed from the solution, washed, dried and checked under a microscope if the etching was made (figure 13).

Figure 12. Buffer solution (IMT)

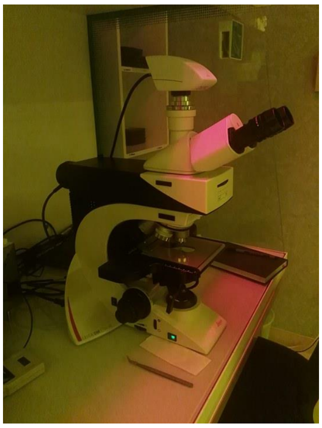
Figure 13. Microscope checking (IMT)

This check under a microscope represents the final step from the photolithography process. After this, the wafer will be used for other processes or other deposits.

7. CONCLUSIONS

An example of photolithography process is described, which covers several specific stages. The high qualification of specialized staff and the corresponding know-how are critical in order to achieve the prescribed parameters.

8. REFERENCES

1. Madou, M. J., Fundamentals of Microfabrication and nanotechnology, Manufacturing Techniques for Microfabrication and Nanotechnology, volume II, CRC Press, 2011
2. Specialized Materials Meet Critical Packaging Needs in MEMS Devices, Master Bond Tech Spotlight, white paper, 2008
3. Gardner, J. W., Microsensors – Principles and Applications, Ed.Wiley, (1996)
4. Oltean, I.D., Electronic Technology, Technology of Semiconductor Devices and Integrated Circuits, Ed. MatrixRom, Bucharest, (2004)
5. Mack C. A., The Litography Tutor (Winter 1994), Positive Photoresists - Exposure, FINLE Technologies, Austin, Texas
6. Torstensson, M., „Photolithography" (http://fy.chalmers.se/~yurgens/FKA196/lab%20exercises/photolithography.pdf)
7. Benilov, A., Skryshevsky,V., Robach,Y., Cabrera,M., Micro and nano electrical discharge machining in microfluidics and micro nanotechnology, International Journal of Material Forming, April, Vol.1, Issue 1, pp,1315-1318, 2008
8. Campbell, S.A., The science and Engineering of Microelectronic Fabrication, Oxford University Press, 2001
9. Gardner, J. W., Microsensors – Principles and Applications, Ed.Wiley, (1996)
10. Ghiculescu, D. - Unconventional processing, Ed. Printech, Bucharest 2004
11. Jackson M.J., Microfabrication and Nanomanufacturing, CRC Press - Taylor & Francis Group, LLC, 2006,
12. Mack C., Fundamental Principles of Optical Lithography: The Science of Microfabrication. John Wiley & Sons, Ltd. ISBN: 978-0-470-01893-4, 2007
13. Marinescu, N.I., Ghiculescu,D., Popa,L., Lacatus,E., Banu,A., Nanu,S. - T Concentrated Energy Technologies for Micro and Nanostraturi, Ed. Printech 2008
14. Madou, M.J., Fundamentals of Microfabrication and NanotechnologySolid-State Physics, Fluidics and Analytical Techniques in Micro- and Nanotechnology, volume I, CRC Press, 2011
15. Madou, M.J., Fundamentals of Microfabrication and Nanotechnology, From MEMS to Bio-NEMS, volume III, CRC Press, 2011
16. The Royal Society & The Royal Academy of Engineering, Nanoscience and nanotechnologies: opportunities and uncertainities, 2004
17. Vijay, K., Vinoy,K.J., Gopalakrishnan,S. - Smart Material Systems and MEMS:Design and Development Methodologies, John Wiley & Sons Ltd, 2006.
18. Vijay, K., Vinoy,K.J., Gopalakrishnan,S. - Smart Material Systems and MEMS:Design and Development Methodologies, John Wiley & Sons Ltd, 2006.
19. Weiping Zhou, Denzel Bridges, Ruozhou Li, Shi Bai, Ying Ma, Tingxiu Hou, Anming Hu,– Recent progress of laser micro- and nano manufacturing –
20. Colin Webb, Julian Jones, „Handbook of Laser Technology and Applications" , Volume III: Applications, Institute of Physics Publishing, 2004