

# Tool Package Training – Mask Design (v1)

## Exercises

### Exercise1: Getting started

Follow the instruction

[http://labadviser.danchip.dtu.dk/index.php/Specific\\_Process\\_Knowledge/Pattern\\_Design](http://labadviser.danchip.dtu.dk/index.php/Specific_Process_Knowledge/Pattern_Design) in order to download and install Clewin on your laptop.

You can find more information about mask design in the official manual [CleWin 5 User Guide](#) and in [Beginner guide to mask design using Clewin](#)

Watch the introduction videos:

Clewin: [https://www.youtube.com/watch?v=2EzB3RSOW80&list=PLgxlvEm0RUtfr\\_hTfjUHTNrIAnxph3hDn](https://www.youtube.com/watch?v=2EzB3RSOW80&list=PLgxlvEm0RUtfr_hTfjUHTNrIAnxph3hDn)

**Exercise guidance.** Small exercises to ensure that you come around the basics of drawing in Clewin/L-edit.

1. First thing to do is to define mask and wafer size if not already visible: Go to View\Background\Background settings and set the mask size and the wafer size. Remember to check out the box “Show mask dimension in background” and “Show wafer dimension”. Chose a 4” wafer and a 5” mask.
2. Make a rectangle that is 50  $\mu\text{m}$  wide and 35  $\mu\text{m}$  high in layer 0. Place the rectangle such that the lower left corner is in the coordinates (-100, 0). Make a copy of the rectangle and place it such that the center is in the coordinate (-125,-25). Enlarge the rectangle with 50 % such that the upper right corner stays in the coordinates (-100,-7.5) and rotate it counterclockwise 45 degrees around the upper right corner. Make a shape that connects the two lower corners of the smaller rectangle with the two upper corners of the rotated rectangle (You probably need to zoom to highest level to ensure no gap is present and that the corners actually overlap). Merge all three shapes into one shape (this act cannot be reversed). How many nodes does the shape consist of and how large is the area? (Answer: 8 nodes and  $\sim 6942 \mu\text{m}^2$ .)
3. Define another layer named *Layer 1* and change the color to your favorite color in this layer.
4. Make a rectangle that is 50  $\mu\text{m}$  wide and 35  $\mu\text{m}$  high in layer 1. Place the rectangle such that the lower left corner is in the coordinates (0, 0). Make another rectangle 10  $\mu\text{m}$  smaller on all edges and place it next to the first rectangle you made separated 20  $\mu\text{m}$  and aligned to the top. Combine the two rectangles in a symbol named *Rectangles*. Now a hierarchy is shown to the left where the *Rectangles* are below the *MainSymbol*.
5. Create a circle in the *MainSymbol* with a diameter of 200  $\mu\text{m}$  with a square hole in the center with an edge length of 80  $\mu\text{m}$ . Center the structure in (100,-200). How do you make the figure?
6. By the way the circle should have been drawn in layer 2.

7. Create a new symbol called *Shapes* (in the Main Menu Bar click Arrange and then Create empty symbol) Open the created symbol. You will find it by clicking on the list view icon next to Symbols in the symbol tree view.
8. By using the shaping tool create the 4 figures shown below in the symbol *Shapes*. The 1<sup>st</sup> shape from the left is roughly 150  $\mu\text{m}$  wide and 200  $\mu\text{m}$  high, the 2<sup>nd</sup> is 270  $\mu\text{m}$  wide, the 3<sup>rd</sup> is 200  $\mu\text{m}$  high and the outermost to the right is 200  $\mu\text{m}$  high and 250  $\mu\text{m}$  wide:



Describe in words how you made the 4 shapes. List from left to right.

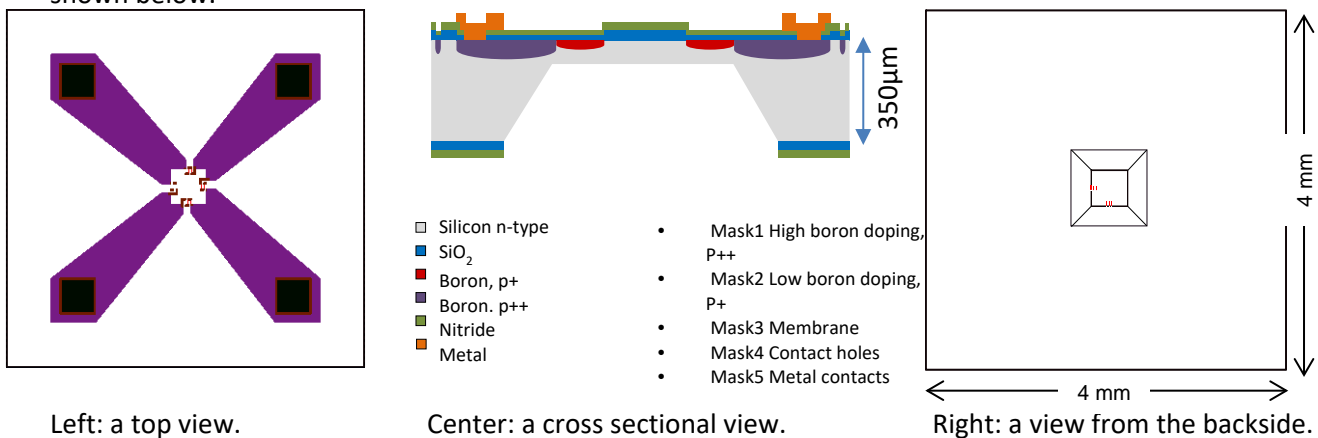
9. Click on the *MainSymbol* and drag the symbol *Shapes* into the *MainSymbol* and place it next to the circle with the square hole. If you click on the tree view icon in the symbol tree view, the hierarchy of your design will appear in the pane:

You should now see two symbols (*Rectangles* and *Shapes*) at the same hierarchy level under the *MainSymbol*.

10. To make an array of the smaller rectangle in the symbol *Rectangles* open the symbol *Rectangles* either by clicking on the symbol in the pane or by double-click in the layout and make a new symbol of the smaller rectangle, named *Rectangle\_small*. While staying in the symbol *Rectangles* duplicate the smaller rectangle in an array of 100 rows and 80 columns separated with a 20  $\mu\text{m}$  space in both directions. What happens in the array if you open the symbol *Rectangle\_small* and change the size of the small rectangle by double clicking and change size?
11. What happens if you open the symbol *Rectangles* and make the array larger by double clicking on the array? And if you use the scaling tool from the tool bar?
12. Create an empty symbol and name it *Squares*. Make a square 500x500  $\mu\text{m}$  in the empty symbol with origin in (0,0) in *Layer1*. Make a smaller square (400 x 400  $\mu\text{m}$ ) on top of the first square in *Layer0*. Open *MainSymbol* and instance the symbol *Square* here and place it in the coordinate (0,-1000).
13. Save the layout with a new name as a cif file as well as a gds file. It is important in the gds file to give every single layer a unique gds number, this is done by clicking each layer one by one and in the layer properties pop up window choose advanced and give the gds layer a number.
14. Send the files to [kabi@dtu.dk](mailto:kabi@dtu.dk) and you can move on to Exercise 2 and 3 (see below).

## Exercise 2: Design making

In this step you are going to make a mask layout for a pressure sensor. An example of a pressure sensor is shown below.



Left: a top view.

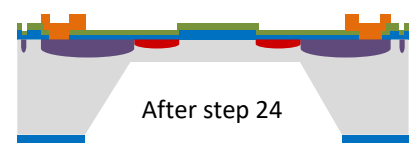
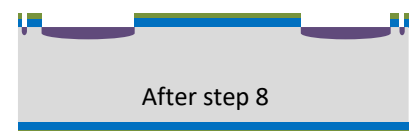
Center: a cross sectional view.

Right: a view from the backside.

It will take 5 different masks (i.e. 5 different layers in the design file) to make the shown design; one for the interconnections, high boron doped; one for the piezo-resistors, low boron doped; one for the pressure membrane and finally one for the metal contacts. In the layout we have made the first 2 masks. Your task will be to complete the layout with 3 more masks; the membrane, contact holes and contact metal.

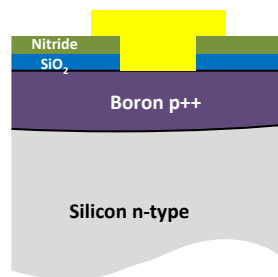
A simplified process flow for the pressure sensor could be:

1. RCA Clean wafers
2. Thermal oxidation of wafers
3. LPCVD nitride deposition
4. Photolithography on front side.
  - Mask 1: open holes in nitride and oxide for high boron doping
5. Etch nitride and oxide on front side
6. Resist strip
7. RCA Clean wafers
8. Boron doping p++
9. Photolithography on front side.
  - Mask 2: open holes for low boron doping
10. Etch nitride and oxide on front side.
11. Resist strip
12. RCA Clean wafers
13. Boron doping p+, the p++ area will also be p+ doped in this step
14. Thermal drive in and oxidation
15. LPCVD Nitride deposition
16. Photolithography on back side.
  - Mask 3: open hole on back side for membrane etching
17. Etch nitride and oxide on back side only
18. Resist strip
19. KOH etch of Silicon
20. Photolithography on front side.
  - Mask 4: open contact holes
21. Etch nitride and oxide on front side
22. Photolithography on front side. Negative tone resist.
  - Mask 5: define metal contacts
23. Evaporate metal
24. Lift-off process



**Exercise guidance.** Getting started with the pressure sensor design:

1. Start to open the file Exercise pressure sensor.cif in [http://labadviser.nanolab.dtu.dk/index.php/LabAdviser/Courses/Mask\\_Design](http://labadviser.nanolab.dtu.dk/index.php/LabAdviser/Courses/Mask_Design). Under symbols to the left you will see *MainSymbol* which is empty. If you click on the list icon in the pane a list with symbols will show in alphabetic order, you will not be able to see which symbols are instanced where. Hence, you cannot see the hierarchy of the layout. Now click on *MainSymbol* while you are in the list and drag the symbol *SensorDie* to the drawing field. Then click on the *tree* icon in the pane and the full hierarchy will show.
2. Define a layer in which the membrane should be made and draw the membrane in an appropriate symbol. The opening for the membrane has to be larger than the final membrane size, due to the nature of the used etch (KOH) and it should be centered such that the strain gauges are close to the edge of the membrane still allowing for a possible misalignment of 5-10  $\mu\text{m}$ . (A membrane opening of  $850\mu\text{m} \times 850\mu\text{m}$  will result in a membrane size of  $410\mu\text{m} \times 410\mu\text{m}$  in a  $311\mu\text{m}$  deep KOH etch).
3. Define layers for the masks forming the contacts of the pressure sensor. The metal contacts should be  $500\mu\text{m} \times 500\mu\text{m}$  and the contact hole should be somewhat smaller to ensure fully coverage of the hole with metal in case of misalignment. The contacts should be placed close to the die edge on top of the Boron p++ layer in order to ease the interconnection with gold wires to a substrate for electrical measurement. A cross sectional drawing of a contact is shown below:



4. The *SensorDie* should be duplicated such that approximately 400 dies is centered on the wafer. The die size should be  $4 \times 4\text{ mm}$ . Remember to make space for the dicing lane, which will require  $100\mu\text{m}$  between each die.

## Exercise 3: Wafer layout

### Mask definitions

Before making the alignment marks it is a good idea to consider the mask definitions first. An example of a set of mask definitions is shown below. All layers are made as 5" masks (for 4" wafers). The masks are made of Soda-lime glass with a dark periphery. The periphery and the design patterns are defined in Chromium. Each layer then has its own set of definitions: Chrome Up (CU) or Chrome Down (CD), Right Reading (RR) or Wrong Reading (WR), Bright Field (BF) or Dark Field (DF). In the example below all three layers are defined with the chromium downwards (CD):

#### All Layers:

5" chromium mask  
fracture limits ((-50000, -50000),(50000, 50000))  
Soda-lime Glass  
Dark periphery  
Chromium Down

**Filename:** write the name of the cif or gds file with the design (eq. Microneedles\_v1.gds)

**Top cell:** state the mask level that you want to fabricate (usually Wafer or MainSymbol)

**For each layer (mask) in the design one must specify:**

#### Layer:

unique name or number for each layer in the design (for GDS files, one must specify a unique GDS number for each layer in the design file as well)

#### Mask Type:

state which polarity - **Dark or Clear** - the mask should have:

Digitised data = clear – means that closed polygons in the design will be transparent/glass.

Digitised data = dark – means that closed polygons in the design will be in Cr

State the orientation - **Right reading / Wrong reading** - the mask should have with chromium down.

**Text:** write a text of max 30 characters for identifying the mask. The text could for instance be: init-2019-Nitride-etch

**Template files for 5" and 7" mask specifications can be found on Labadviser**

[http://labadviser.danchip.dtu.dk/index.php/Mask\\_spec.](http://labadviser.danchip.dtu.dk/index.php/Mask_spec.)

Each mask layer in the file has to be addressed. The text is an identifier that will be written in the edge of the mask for your information only and will hence not appear on the wafers. Notice that the definitions are made for all layers with Chromium Down. Then right reading masks are for one side of the wafer while wrong reading masks are for the other side of the wafer.

### Alignment

All the individual layers in the design need to be aligned to each other in the order they are processed. It can be a good idea to define all alignment marks in the 1<sup>st</sup> mask, such that all forthcoming masks can be aligned with the same accuracy to the first mask. However, sometimes it can be convenient that for instance the 4<sup>th</sup> mask is aligned more precisely say to the 2<sup>nd</sup> mask than to the 1<sup>st</sup>. In that case a new mark can be defined on the 2<sup>nd</sup> mask such that aligning the 4<sup>th</sup> mask is independent of the misalignment of the 2<sup>nd</sup> mask to the 1<sup>st</sup> mask.

It cannot be recommended to have only one single mark for all masks to be aligned to, because it can be quite difficult to preserve the mark during processing, especially in deep etches. You can find design rules for the alignment marks in [Beginner guide to mask design using Clewin](#)

### Monitor structures

It is wise to incorporate monitor structures on a mask design for the individual processing steps.

If you save the file "Alignment and test structures" from [http://labadviser.nanolab.dtu.dk/index.php/LabAdviser/Courses/Mask\\_Design](http://labadviser.nanolab.dtu.dk/index.php/LabAdviser/Courses/Mask_Design) you can open it as a library under File-> Open Library... in CleWin. You will see a list of files containing different patterns like alignment marks, flat alignment marks and monitor structures and test dies for electrical measurements. You are free to use these in your layout or you can make your own.

### Exercise 3 - Making the overall wafer layout

1. Make and place monitor dies at strategic positions in the mask design. Argue why they are placed as it is.
2. Incorporate guiding marks for the dicing in an appropriate layer.
3. Make flat alignment mark in your mask design, this should be on the first mask to be processed.
4. Make alignment marks for each layer in the mask design. You want to align with high accuracy (1-3  $\mu\text{m}$ ). Remember that the polarity of the mask influence the way they are made, since you need to be able to see what is on the wafer beneath the mask you are going to align to. Also remember that the field in an aligner typically is 300  $\mu\text{m}$  x 300  $\mu\text{m}$ .
5. Where there is room you can place your name and other fun stuff as Global ID's
6. By the way it has been decided that the contact holes on all sensor dies should be circular with at diameter of 400  $\mu\text{m}$ , while the metal contact should remain as a square.
7. We also need to know the fraction of the surface of a 4" wafer (diameter 10 cm) that is covered with metal in the design. Clewin has an area calculator, choose **Layout->Special->Area calculator** in the menu bar. You should be aware that the calculated fraction (percentage) is with respect to a defined rectangle and not a disc like a wafer. Do the calculation with respect to a 4" wafer. You can ignore the wafer flats in the calculation.
8. Save the file as a cif file as well as a gds file. When saving as a gds file it is important that all layers in the layout have unique gds-II-numbers. You can check that out by for each layer double click on the layer, click advanced and write an unique number in the field "Datatype value (only used in GDS-II files)".

Finally you are ready to make a mask order.

- Write a text file with the mask specifications as shown in the example. A negative tone photoresist is used for the mask defining the metal pads followed by a lift off (the areas that are exposed to light will be the area with metal after the lift off). The other masks are to be used with a positive tone photoresist (the areas that are exposed to light will be openings in the resist).

- Send a mail with the text file with the mask definition together with a cif- or gds-file with your layout attached to [Mask@nanolab.dtu.dk](mailto:Mask@nanolab.dtu.dk). In the subject field of the mail you write **“TPT Course: maskorder”**.