CleWin 5

CAD tool for mask designs – beginners guide

Version 1.31

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1 Introduction

This beginner's guide for the photolithographic mask design by CleWin 5 is based on the almost identical guide about the program L-Edit from Tanner research (USA) which was initially written for use in the course *"Micro and nano fabrication"* at MIC in the fall semester of 2003. Due to restrictions for the L-Edit license for commercial usage, Danchip instead license CleWin 5 to be used on the DTU terminal servers free to use for all with a DTU login. The guide is intended to give the reader a basic understanding of photolithographic mask designs and of how to use the CleWin 5 program. To really be proficient in the use of any computer program practice is needed and the reader is strongly recommended to do so.

The Introduction has been revised with a couple of sections added for the fall semester of 2004. Most noticeably are the sections concerning insertion of text and the exercises.

Minor corrections in the 2005 revision, parts of the exercises removed.

CleWin 5 version fall 2013 with all figures replaced by corresponding CleWin 5 figures,.

This note is intended as an educational aid, any feedback is highly appreciated.

2 General considerations for mask designs

Before delving into the actual design of a mask set with CleWin it may be worthwhile to clarify a few issues, such as what is a photolithographic mask set and why should you learn to use a computer aided design (CAD) tool and in particular why CleWin?

2.1 What is a photolithographic mask set?

A photolithographic mask set is a series of photo masks containing patterns for all the masking steps needed to realize a particular component. The number of masks in a MEMS mask set can vary from one to about fifteen.

In general it is advantageous to keep the number of photo masks low, since the whole photolithographic cycle is both time consuming and expensive. On the other hand, sometimes more masks should be used simply because it will make processing a lot easier.

2.1.1 Photo masks

A photolithographic mask is normally a glass plate with chromium patterns. The chromium patterns serve as areas where light cannot pass through. A mask can be fabricated in several ways. One cost effective approach is to use laser writing, this limits the linewidth to about 1.5 µm and the price is about 400 € per 125 mm mask, usually a delivery time of 1-3 weeks can be expected. If a finer linewidth is needed electron beam written masks can be used. These have a linewidth of approximately 200 nm however the price increases up to about 3000 € per 125 mm mask with an expected delivery of several months. Further reductions in linewidth require different masking techniques usually only employed by the microelectronics industry; these techniques are very expensive and complex usually requiring steppers or even direct e-beam writing. Cheaper and simpler solutions also exist; transparencies for overhead projectors are often used for simple and crude structures. A laser printer with a 600dpi resolution creates dots of approximately 40 µm and a 4800dpi printer will give dots of 6 µm. Two to three dots are required to have a reasonable pattern so these systems can be used to give linewidths of 120 µm and 20 µm

respectively. The price for such masks is a couple of euro for the 600dpi version and some 50 € for the 4800dpi version. Masks based on transparencies suffer from a couple of drawbacks: they are very hard to clean and their dimensional stability is poor, due to warping of the flexible transparency. The problem with dimensional stability has considerable impact on the alignment precision. Alignment of transparency masks becomes very hard if the precision needed is better than ~200 μm (on a 100 mm wafer). The drawbacks of masks based on transparencies can be overcome by transferring the pattern from an overhead mask to a glass substrate covered with chromium and photoresist. When developed and the chromium is etched the formed mask can be used just like a laser written or e-beam mask, and also cleaned using the same cleaning methods.

2.2 Hierarchy layout

Good mask design practice involves creating mask set which are as simple as possible to understand. This is both from the mask file point of view as well as understanding the wafer development during processing. When designing masks it is important to understand that the final result of the mask designing process is a series of physical masks. This is usually implemented as layers in the design program. Each layer can then be used to fabricate one mask. In the program the layers usually have different colors, however, even if two layers have the same color the patterns will end up on two different masks. This point is also important when considering the result of overlapping structures. If two structures on different layers overlap the individual patterns will end up on individual masks. This means that overlapping does not shade structures from each other.

The layout program handles a lot of information and helps organize very complicated structures through the use of cells and instances. A "cell" is a pattern, which can contain patterns on some or all of the layers in the design. The pattern described in the cell can be of any size. The cell can then be instanced (inserted) several places in the design, but still only be defined once. Cells are used to keep the design consistent, making it easy to update and keep the file size down.

Consider for example a structure where the chip size is 10 mm by 20 mm (Figure 1) on a 100 mm wafer there could be 21 chips. On this chip, there are four fluidic access points called vias. When using cells the fluidic via can be defined as one cell and then instanced 4 times in another cell containing the chip. Finally, the chip is then instanced 21 times to create the final layout.

Compare this to the situation where the drawn structures are merely copied, it would require the information for drawing the chip 21 times with the fluidic via being drawn 84 times. Imagine for these two situations that the pattern for the fluidic via had to be changed. Using the cell approach, the change could be made in the cell and then automatically updated throughout the layout. If the design had been copied 84 times instead, these copies of the old fluidic via has to be deleted and then the new pattern should be copied again. If in doubt whether or not to define a cell for a structure, you should definitely make a cell.

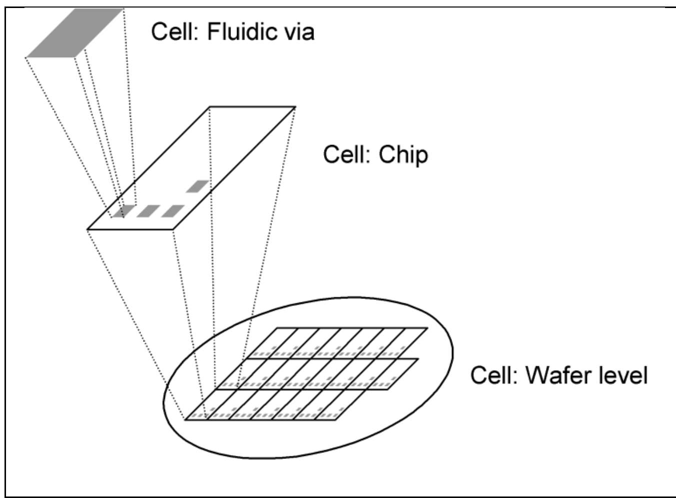


Figure 1: The figure shows the concept of hierarchy in a mask design.

2.3 Why use a CAD program for mask designs (why CleWin)?

The main requirements for the program used for drawing structures is that it should be able to handle cells and the various length scales involved in mask design. On the macroscopic end of the length scale there is the complete mask, which usually covers a 100 by 100 mm area, you should be able to see this.

On the microscopic end of the length scale there is the need to draw structures of 1 μm or even less. This means that the zoom range should be something like 10^4 to 10^5. For non-CAD drawing programs such high zoom ranges are cumbersome at best and impossible at worst. A further difference is that when designing masks there will often be an overlap of structures on the different mask layers. These overlaps are usually important and therefore the structures on one layer should not overwrite the other structure. For mask making CAD programs, this is handled by assigning a different color to overlap regions to make it clearer.

CleWin is a quite simple mask layout-program without some of the advanced features for electronic chip layout. It is however quite easy to learn and is in most cases quite capable for the designs used at Danchip. Also it has some scripting capabilities which can be good. The most important aspects of CleWin is the approach to handling cells and instances of cells. CleWin can also transform (read/save) between some of the most used chip layout file-formats like CIF, GDSII and DXF. CleWin is the preferred mask design software at Danchip.

3 Use of CleWin

There are two ways of using Clewin at DTU. Installing the program on your own computer and working on it locally or connecting to a remote DTU server and running it using a remote desktop. The next sections describe how it is done in more details. Find updates to this installation procedure here: http://labadviser.danchip.dtu.dk/index.php/Specific_Process_Knowledge/Lithography/Pattern_Design_and_Mask_Fabrication/CleWin

3.1 CleWin 5 - local installation

CodeMeter and CleWin 5 install

1. Install Clewin 5
    1. Copy this link to Windows Explorer:

       \\dtu-storage.win.dtu.dk\AIT-software\Institut\SoftwarePackages\CleWin\Clewin 5.2.4\Win\

    2. Copy the complete Dist directory to your own computer
    3. Run the installation program **PhoeniXSoftware.msi** (be patient).
2. Install Codemeter
    1. Go to the web-site of Wibu systems: Codemeter Download
    2. Download and install Codemeter (be patient).
3. Note: You need to install *both* the **Codemeter** and the **CleWin 5** software!
4. You may have to restart your computer for changes to take effect.
5. Start **CleWin 5** from the link on your desktop.
6. A window showing *"Licenses error"* pops up.
7. replace "localhost" with "clewin.ait.dtu.dk"
8. Click OK (also to the info window) and
9. start **CleWin 5** again.
10. If everything is correct no *"Licenses error"* window should show and you should be able to use **CleWin 5**.

3.2 CleWin 5 - without installation

Because CleWin is hosted on the DTU terminal server no installation is required. This is just a guide on how to login on the terminal server and start the program.

- Open "Remote Desktop Connection"
- Click "Show Options"
- Type the computer name: "ait-terminal.win.dtu.dk"
- Type your DTU login name preceeded by "win\"
- Click "Save as" and save your connection setup for later use
- Click now on "Connect"
- Check your login username and type your password.

- Press ”OK” to log on the server.
- When logged in click on the Windows button in the left corner and write CleWin in the search field. Under programs choose CleWin5.

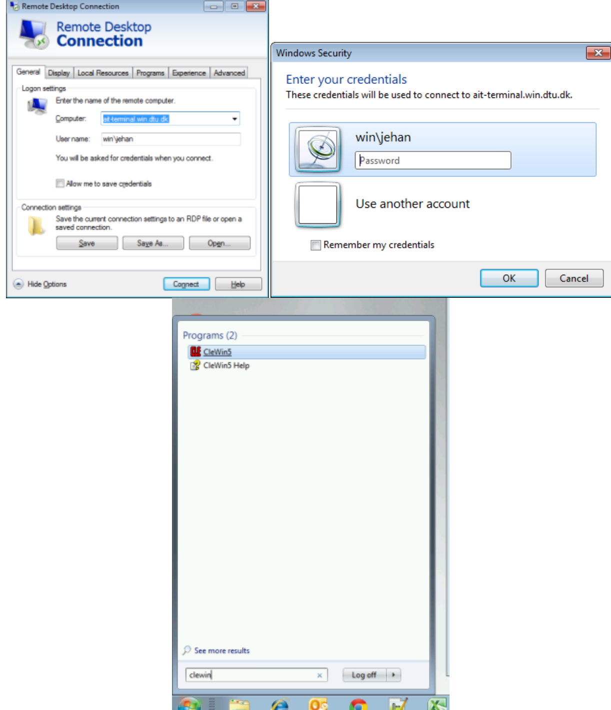


Figure 2: Pop-up windows shown when connecting to the AIT-terminal server and locating CleWin 5.

4 Fundamentals of the CleWin user interface

When starting CleWin 5 a start-up screen pops up (Figure 3). Click on the icon in the top left corner to create a new (empty) drawing. Now a central drawing area used for drawing the figures takes up the major part, this is surrounded by a host of menus, icons and information areas. The most important are shown in Figure 4. Please refer to the “CleWin 5 - User Guide” for a comprehensive guide to all the commands and features available in CleWin.

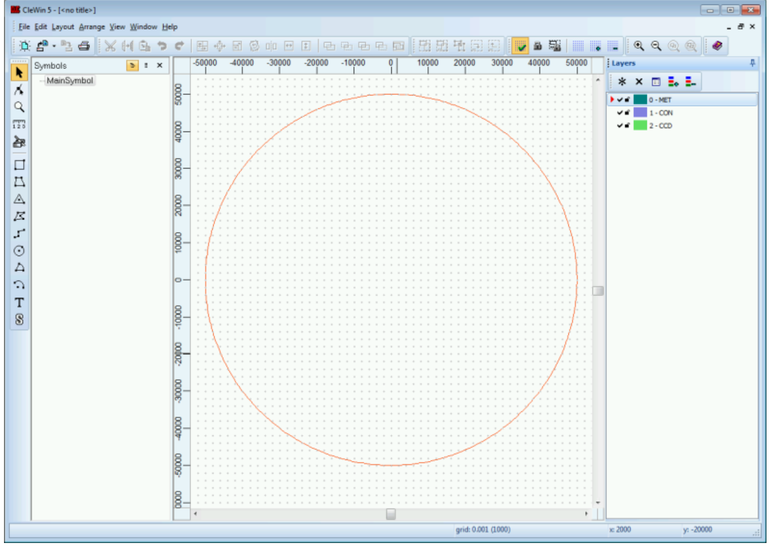


Figure 3: The CleWin 5 start-up screen (after new drawing is created).

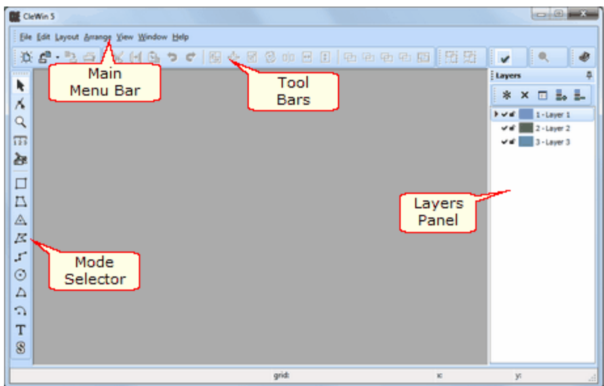


Figure 4: Location of various palettes and menus on the CleWin user interface.

5 Mask design specifics

To make a good mask design there are a couple of points, which should be incorporated or at least consciously ignored. This section deals with issues such as identifiers and test structures. As a running example a set of 3 masks for fabrication of solar cells (Figure 5) is used.

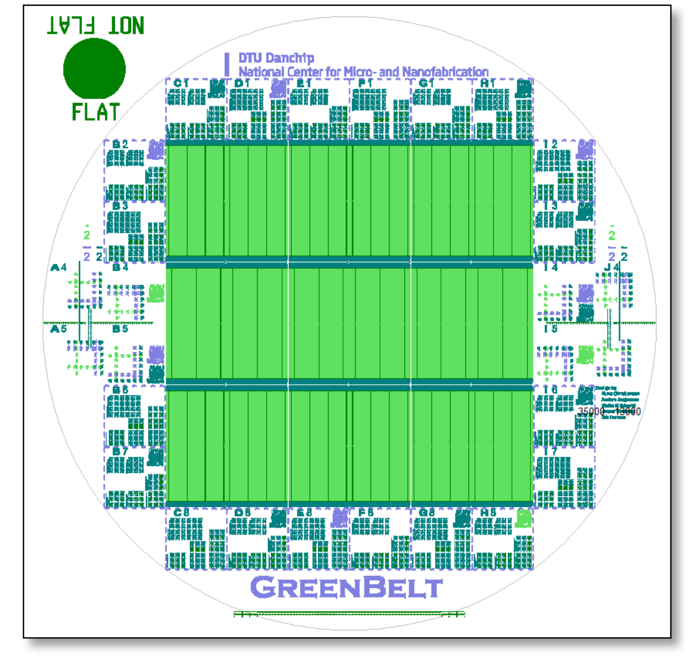


Figure 5: A plot of a front-side mask design. Details from this design are used as examples throughout this section.

5.1 Global identifiers

A global identifier is a large structure, which is used to make processing and handling of the wafers easier. With a global identifier it is easy to figure out how the masks should be turned and whether the mask and wafer correspond to each other. The use of a version number in the global identifier makes it easy to change one mask and still keep track of which mask has been applied. In the example, there are several global identifiers, one of them is the project name GREENBELT (Figure 7)

Another global identifier, which can be very useful, is to include the names of the designers. This means that wafers are less likely to get lost during fabrication.

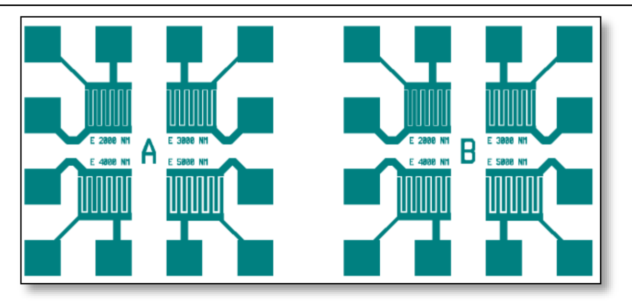
Figure 6: The global identifier from the mask shown in Figure 5.

5.2 Local identifiers

A local identifier is a structure, which identifies a chip or a substructure. It can either be on micro-scale, for instance giving information about dimensions of a particular structure, or it can be on macro-scale, being readable by the naked eye. Structures on micro-scale can have any size that can be resolved by the lithography and subsequent processing. Macro-scale letters should not be much less than 1 mm high.

To make systematic text identifiers, i.e. labeling of a row and column position, the script function of CleWin 5 can advantageously be used.

Figure 7: Local identifiers on some structures from the mask shown in Figure 5.



5.3 Alignment marks

In some cases, it can be a great advantage to use a mask to define some alignment marks for the following masks. This can for instance be the case if the alignment mark mask allows more freedom in the order of the following masks. It may also be the case that the subsequent masks cannot hold alignment structures because the processing of these layers will destroy any fine marking (for instance deep isotropic etches). When you design alignment marks it should be stressed that they should be easy to find, easy to use, hard to misinterpret and not vulnerable to processing. Two sets of alignment marks are used, one on the left-hand side of the design and another on the right-hand side. For highest precision the distance between alignment marks should be as large as practically possible.

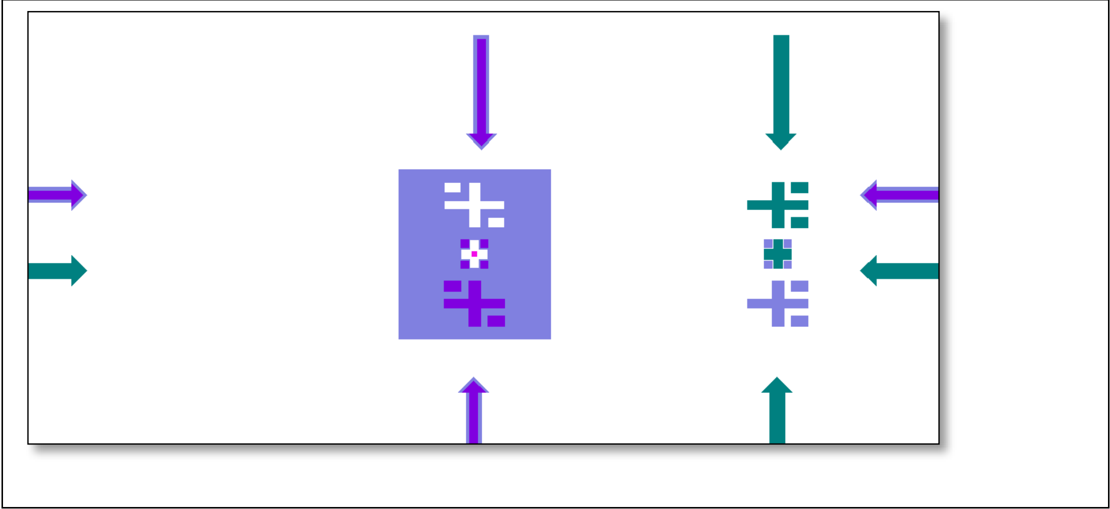


Figure 8: A part of an alignment structure for 3 masks (purple, blue, green). The green arrows are 20μm wide.

On some aligners the field of view may be as little as 200 μm square so to assure that alignment marks are easy to find, it is necessary to have distinct helping structures to guide the aligner-operator to the alignment marks, such as arrows and pointers (see Figure 8). Designing alignment marks for ease of use is a matter of experience and also personal preference. An example is shown of a reasonably easy to use structure. The alignment structure is for 3 masks (purple, blue, green). The left structures are for aligning the blue pattern to the purple. The mask for the blue pattern are reversed (dark field) so the box defines the clear part of the mask and provides the view field for the alignment. The right structures are for aligning the green pattern to the blue. The pattern shown is the left-hand side structure; a mirrored version is placed on the right-hand side. The configuration with mirrored versions and two unequal-squares as the alignment object means that it is immediately obvious if the wrong mark is used or if the mask/wafer is placed upside down in the aligner. Preventing such simple handling mistakes is quite simple if done in the design phase but a lot harder to do later on.

Design rules for making alignment marks:

1. **Place the alignment marks in an appropriate position on the wafer.**
   It depends on aligner and wafer/mask size. It is always important to investigate the rules for the specific aligner that is intended to be used for the specific set of masks.
   At Danchip the coordinate of the alignment marks in the mask design for a 4 inch process is:

   For Back Side Alignment (BSA): alignment marks must be located between -1 and +1 mm in vertical location from mask center (y=0±1mm) and exactly at 45mm in left and right in horizontal location (x=±45mm).

   For Top Side Alignment (TSA): alignment marks must be located within 35-45 mm in left and right in horizontal location and between -2 and +2 mm in vertical location (y=0±2mm).

   For a 6” process both BSA and TSA must be located between -2,5 and +2,5 mm in vertical location from mask center and 60 mm in left and right in horizontal location.

2. **Make sure that the marks are preserved during processing**
   Especially when etching you risk destroying or totally etch the marks away. It is important to protect the marks in your design.

3. **Consider polarity of the masks when designing the alignment marks.**
   Make the design of the alignment marks such that the wafer is visible looking through the mask. Then it is easier to align the mask to an existing pattern on the wafer. Remember that the polarity of the mask influence the way the marks 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 microscope typically is 200 µm x 300 µm.

   There are however two exceptions regarding the polarity dependence:
   a. The first mask is independent on polarity since nothing has to be aligned to it.
   b. Back to front side alignment is independent of mask polarity, since in this case you grab an image of the marks on the mask and then align the wafer to the image.

4. **Include clear and visible arrows pointing towards the alignment marks – then they are easy to find in the aligner.**
   Alignment marks is typically less than 100x 100 $µm^2$. The field in an aligner microscope is typically 200 µm x 300 µm. So it is like finding the famous needle in a haystack looking for the alignment marks through the microscope searching on a 100 mm wafer. Long arrays of arrows can ease the search.

   Further one must be aware that KOH etching will attack convex corners, so normal looking arrows will appear strange looking after a long etch.

5. **Include vertical/horizontal lines for easy rotational aligning.**
   When aligning it is easiest to do the rotational alignment first and then the x,y alignment. Visually, the rotational aligning is easiest to do having some longer vertical/horizontal lines included in the design.

6. **Make sure that the marks are unique such that no mistakes can be made if rotating the mask, placing it up-side down or translate it by mistake.**
   This is best avoided by making the marks asymmetrical by adding structures, number or letters indicating how the marks should fit to each other.

7. **Consider if flat-alignment is crucial.**
   It is always a good idea to include flat-alignment in order to see how well aligned the mask is to the crystal orientation of the wafer. Especially, when KOH etching is a part of the process flat aligning is very important and should be done with the first mask.

   A flat is typically approximately 35 mm long and normally orientated in the bottom of the wafer in the layout.

5.4 Test structures

Test structures are structures on your mask, which are not part of the components or of the embellishments. There are two different types of test structures: Process monitors and experimental test structures. A process monitor is a structure, which you can use to check the processing. It is a structure where you know what shape it should end up with after processing. These structures can be very simple lines (see Figure 9) or highly complex patterns, the design depends strongly on the lab practice and the amount of time used on developing good process monitors.

Experimental test structures are structures placed on the mask because they will provide some useful information for future work. This could for instance be a series of corner compensation structures for KOH etching. If the mask is going to be etched in KOH the corner compensation structures can be analyzed to reveal the optimum structure. In this way you do not have to order a specific mask for the test purpose. This saves both time and money, because you will be processing the wafers the same way as before but now you get additional information without getting a new mask or doing a specific process aimed at realizing the test structures.

You should include test structures. They will almost always be worth the effort put into them.

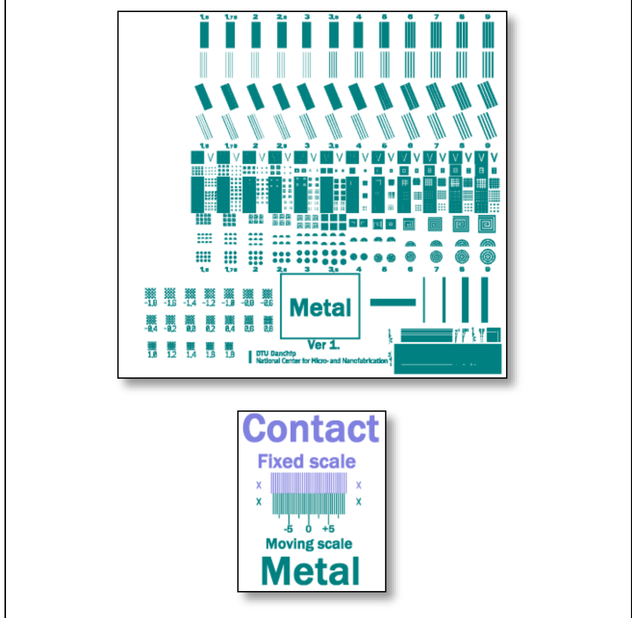


Figure 9: Some of the test structures on Figure 5. These are process monitors used to check the influence of linewidth on dry etching characteristics. The Contact/Metal structure is a Vernier scale to better estimate the alignment accuracy between the two mask patterns on the wafer.

5.5 Embellishments

Embellishments are structures that only have decorative purposes. They do not serve to help the navigation of the layout, nor are they actual components or test structures. These structures are obviously not necessary for the design to work, however, there are a couple of reasons why you might want to include such structures anyway. One thing is to make sure that when pictures are made of the chip, your name or institution will show up. This is actually a quite important point since it is essentially free advertising should you make nice designs and pictures. Embellishments are also very good at demonstrating joint efforts. In the example (Figure 10) the embellishments demonstrate that this chip has some connection to DTU Danchip.

Figure 10: One of the embellishments from the mask shown in Figure 5.

The final point of embellishments is the pure excitement of making very small pictures. I can't explain it but small pictures are fun. Check out the web for small pictures on chips and check out what Motorola and Intel have snuck unto chips (http://micro.magnet.fsu.edu/creatures/).

5.6 Choice of chip size

A chip is a part of the wafer, which can be used without the rest of the wafer. In many cases the desired components are quite small and so several can fit on a wafer. When the chips are separated from each other it is usually done either by dicing (with a saw) or cleaving along weak crystallographic directions. This means that the cuts will extend all the way across the wafer (see Figure 11). In most cases the best (easiest) shape is rectangular with one side parallel to the flat of the wafer.

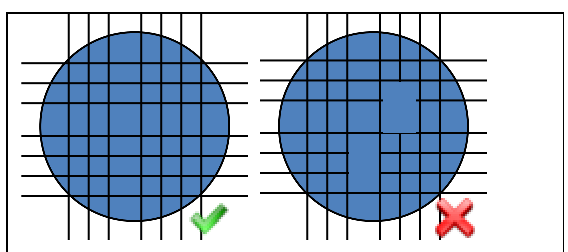


Figure 11: How to and not to arrange chips for easy dicing.

5.6.1 Monitor chips

Sometimes it is worthwhile to reduce the number of component chips and instead add specific chips with a large number of test structures. This should especially be considered if the chip-size is very small (meaning the chip-count is high) or if the design is used in the beginning of a process development. Since the monitor chip can replace a component chip completely it is simple to place it at various distances from the center of the wafer so as to be able to check the uniformity of processing. The use of well-designed and placed monitor chips means that the quality of processing can easier be checked from fabrication run to fabrication run.

6 Mask polarity and orientation

When ordering masks the polarity and orientation must be specified. In some cases the location of chromium is also indicated (Figure 12). The description of how the mask should be fabricated is important because in some cases of dual-sided designs, the pattern must be drawn mirrored to make sense.

When ordering masks and determining polarity it is important to find out if the polarity in the mask manufacturer jargon refers to the drawn structure (Compugraphics) or the field i.e. surroundings of the drawn structures (Delta Mask).

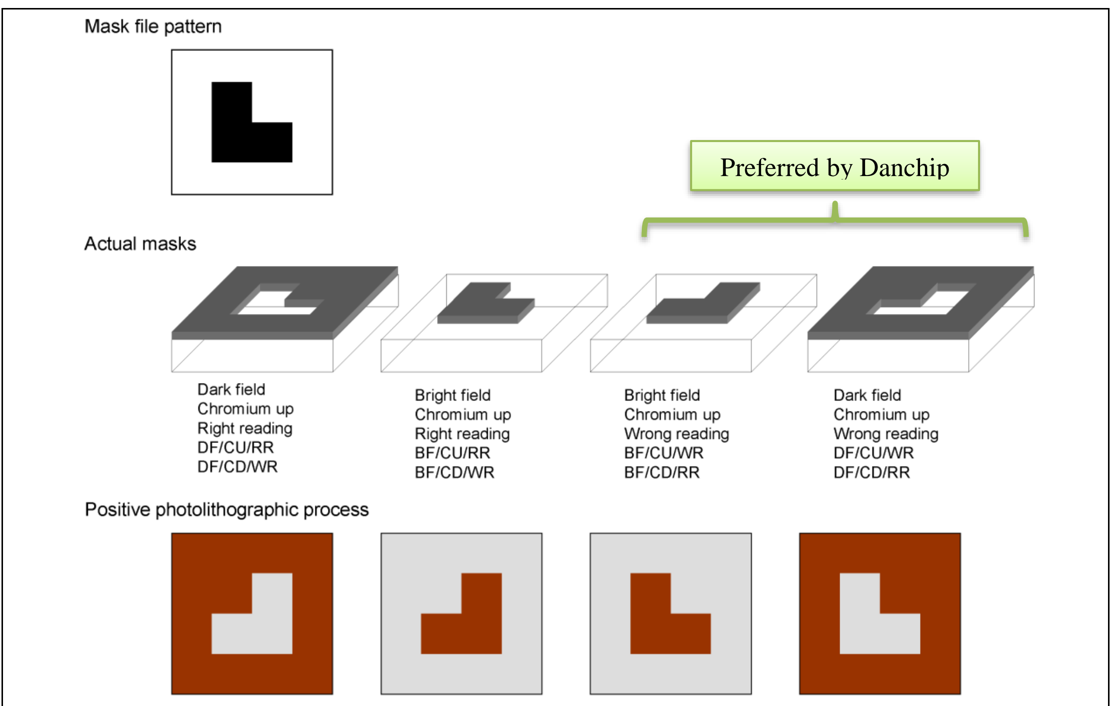


Figure 12: Explanation of the mask polarity and orientation attributes for mask ordering. The mask file pattern is drawn in CleWin and depending on the polarity (bright or dark) and the orientation ("right reading" or "wrong reading"). The short form of the ordering information is also shown for each mask. Note that CU/RR is the same as CD/WR and can be used depending on what is most convenient.

To visualize why the orientation is a useful tool; take a look at Figure 13. Here is shown a simplistic design where one mask is supposed to be used on the back side and the other on the front (a). In figure (b) the masks are shown as one would like them (notice that the reading is different). In (c) both masks are shown with the same reading. It is obvious that this choice of orientation does not produce the desired structure. The alternative is to draw one of the masks mirrored, but that is very tiresome and prone to generate errors.

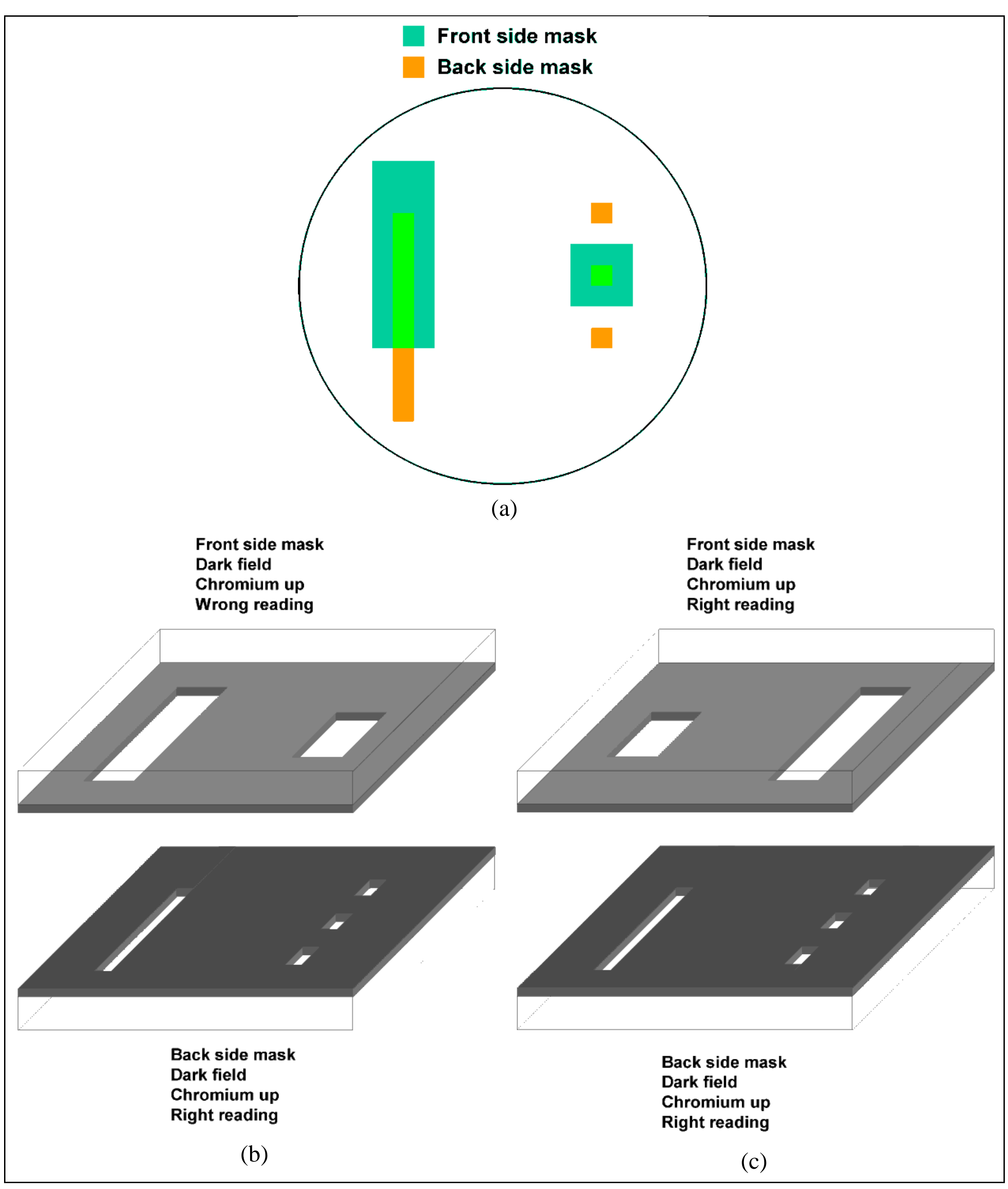


Figure 13: Why reading becomes important for dual sided mask sets. A simplified mask set is shown in (a). Here there is a front side and a back side mask, which each has their own color, with the overlapping structures having a third color. One correct way of reproducing this mask set as photomasks is shown in (b). A wrong way of doing it is shown in (c) where the same set of orientation is chosen for both the front and the back side mask.

7 “End of chapter” questions and exercises

The first part of these questions deal with theoretical considerations when designing masks. The second part is a series of hands-on CleWin exercises.

A. This exercise focus on the design of alignment marks and the considerations needed for designing good alignment marks. In the table there are two pictures of alignment marks on each row. The first structure is on the wafer and the second is on the mask. This mask is supposed to be aligned to the structure in the first picture. The mask contains the drawn objects in the mask layout program (black means “drawn in program”, for a clear field mask the black structures would be chromium). Then further along the row is a description of the polarity of the mask.

   1. Does it matter if the pattern on the wafer is dark or bright where the structures are shown as black?
   2. For each row please describe if this is a useable set of alignment marks, for each mark also indicate if it is a good mark if the polarity of the mask is changed.

Number	Pattern on wafer	Pattern on design	Mask polarity	Ok + Bad -	Fixed by changing polarity	Needs more help
1			Dark field			
2			Dark field			
3			Clear field			
4			Dark field			
5			Clear field			
6			Dark field			

7			Clear field			
8			Clear field			
9			Clear field			
10			Clear field			
11			Dark field			
12			Clear field			
13			Dark field			

B. Consider that you are designing a mask set for an aligner with two microscopes which each has a field of view of 200 µm width and 300 µm height:

   1. How large a fraction of the wafer surface of a 100 mm diameter wafer can then be seen in the microscopes?
   2. Would you expect an alignment mark filling the field of view to be easy to find?
   3. In an aligner the mask can be manipulated in the x- and y- direction independently of each other. Can you suggest some structures, which can be added to the alignment mark to make it easier to find? Please be precise with respect to dimensions and location.

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