

L-Edit (11.01)

CAD tool for mask designs – beginners guide

Version 1.4

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1 Introduction

This beginners guide for the photolithographic mask design program L-Edit from Tanner research (USA) was initially written for use in the course “*Micro and nano fabrication*” at MIC in the fall semester of 2003. The guide is intended to give the reader a basic understanding of photolithographic mask designs and of how to use the L-Edit 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.

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 L-Edit 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 L-Edit?

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 200 € 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 laserprinter 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 $\sim 200 \mu\text{m}$ (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.

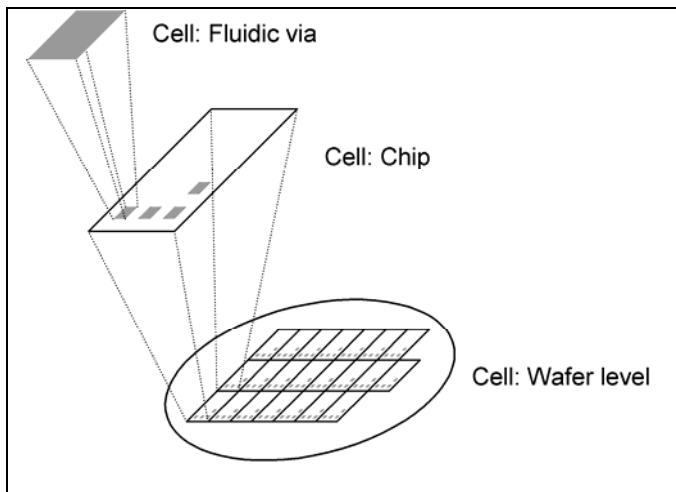


Figure 1: The figure shows the concept of hierarchy in a mask design.

2.3 Why use a CAD program for mask designs (why L-Edit)?

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.

L-Edit is a very powerful program and generally, MEMS and BioMEMS designs only use a fraction of the capabilities. The most important aspects of L-Edit is the substantial expertise developed for using it and the approach to handling cells and instances of cells. L-Edit is the preferred mask design software at MIC.

3 Installation of L-Edit

When making complex mask designs using L-Edit, most personal computers are pushed to their performance limit. Due to the graphical nature of L-Edit it is mainly the video card, which is the bottleneck in most configurations.

The operating system should be Microsoft Windows 2000 or XP. If Windows 2000 is used make sure a service pack later than SP2 is installed (this is due to a bug). Computers on the MIC local area network can install the latest version of L-Edit from the server "micdat2".

L-Edit mainly puts a strain on the graphics capabilities of the computer. The better a 2D graphics adapter the easier it is to work with. Make sure the computer you are using has the latest graphics driver installed and at least 2D hardware accelerator enabled. The computer I used for designing masks was quite reasonable, although not fantastic:

- Pentium III, 833 MHz
- 256 Mb RAM
- 1024x768 monitor @ 85 Hz refresh, 17" CRT
- Onboard Graphics adapter Intel 82815, 4 Mb RAM
- Logitech MX500 optical mouse

The graphics adapter was really not up to the job and that is why the monitor was only operated at 1024x768 mode. If you have a higher resolution monitor/adaptor system, it is much easier to navigate the designs.

I have now changed to another computer (Compaq NX7000), which is very good for mask designing:

- Intel Centrino 1.5 GHz
- 512 Mb Ram
- 1680 x1050 pixels (flat screen)
- Mobility Radeon 9200 graphics adapter, 64 Mb ram
- Logitech MX500 optical mouse

3.1 How to avoid injury when using a computer mouse

A computer mouse is a nice tool and for mask design; and it is the most often used drawing device. However, extended use of a computer mouse is not healthy. Often people will place themselves in a position where their mouse arm is not relaxed, this forces the shoulder to lift the arm all the time. Typically, the symptoms of this are shoulder ache or pain in the upper arm. Another common problem is the small and very precise movement of the fingers and wrist this will tire the wrist and result in constant pain and feeling of numbness in the hand, this condition is called carpal tunnel syndrome (CTS). Trust me on this one; I have already been on medication once to get rid of CTS. At Cornell University they have done research into the subject (<http://ergo.human.cornell.edu/cumousetips.html>) and have come up with 10 recommendations:

1. **Mouse Grip** - don't throttle your mouse (it's already dead)! Hold the mouse gently to move it over a mousing surface.
2. **Mouse from the Elbow** - don't skate or flick the mouse with your wrist. Make controlled mouse movements using your elbow as the pivot point and keep your wrist straight and neutral.
3. **Optimal Mouse position**- sit back in your chair, relax your arms then lift your mousing hand up, pivoting at the elbow, until your hand is just above elbow level. Your mouse should be positioned somewhere around this point. Don't use a mouse by stretching to the desk or out to the side of a keyboard. With a **flat mouse platform**, position this 2-6 cm above the keyboard

and over the numeric keypad if you are right handed - you can easily move it out of the way if you need to access these keys. With a **downward sloping mouse platform**, position this close to the side of the keyboard so that you can use the mouse in a neutral wrist position. Position adjustable mouse platforms are commercially available (e.g. [Humanscale](#), [Proformix](#), [Flexrest](#), [3M](#) etc.)

4. **Protect your wrist** - if you look at the anatomy of the wrist it is curved away from any contact surface (you can easily see this by resting your hand/arm on a flat surface - you'll see light under the wrist and can probably even pass a thin pen under this). The forearm is shaped liked this for the wrist to remain free of surface pressure contact.
5. **Avoid restricting circulation** - For many people there are exposed blood vessels near the skin at the wrist, which is where the pulse is often taken. Any pressure in this region will disrupt circulation into the hand and this will increase the risks of injury.
6. **Don't use a Wrist Rest** - research has shown that using a wrist rest doubles the pressure inside the carpal tunnel, because the floor of the tunnel is a more flexible ligament that transmits external pressure changes directly into the carpal tunnel (the roof of the tunnel is bone so the pressure doesn't get transmitted on through the hand). Indeed, one test for carpal tunnel syndrome (CTS), know as Tinel's sign, simply involves tapping on the palmar surface of the wrist, which is enough to cause tingling and numbness in someone developing CTS.
7. **Avoid Restricting Arm Movement** - with a softly padded wrist rest, especially one that is rounded, or a soft chair arm rest the forearm becomes "locked" into position and this encourages people to make mouse movements by flicking the wrist, which also increases intracarpal pressure.
8. **Keep the Mouse Free Moving** - The base of the palm of the hand is the part of the body designed to support the hand when resting on a surface. For keyboard use a broad palm support is best. However, mouse use is different to keyboard use. With a keyboard the best posture is for users to float their hands over the keyboard when typing and then to rest on the palm support in microbreaks between typing bursts. You can use rest-breaking software (e.g. [Magnitude ErgoManager](#), [Break reminder](#) etc) to help track and advise on your mouse use. With mousing this doesn't happen. A mouse is used by moving it's location over a surface, and resting usually occurs when mouse movements stop but with the mouse still being held in the hand. Mouse movements should be made using the elbow as the pivot point, not the wrist. Anything that impairs free movement of the forearm/hand and mouse will increase injury risks.
9. **Mouse shape** - choose a mouse design that fits your hand but is as flat as possible to reduce wrist extension. Don't use a curved mouse. Use a symmetrically shaped mouse. Consider a larger mouse, such as the [Whale mouse](#) or the [Perfit mouse](#), that encourage arm rather than wrist movements.
10. **Load sharing** - if you want to load share between your right and left hands, that is using the mouse for some of the time with each hand. For this you need to choose a mouse platform that can easily be configured to the left or/and right, and a symmetrical shaped mouse that can be used by either hand.

Priority of mouse arrangements

- **Best** arrangement for a mouse is a platform over the number keypad and just above the keyboard.
- **Good** arrangement is a pad on an angled platform to the side of the keyboard.
- **Poor** arrangement is a flat surface to the side of the keyboard
- **Worst** arrangement is on the desk out to the side of the keyboard.

4 Fundamentals of the L-Edit user interface

When starting L-Edit 10.12 a start-up screen pops up (Figure 2). A central drawing area used for drawing the figures takes up the major part, this is surrounded by a host of menus and information areas. The most important of these (Figure 3) are described in more detail in the following. The individual menus and palettes can be switched on or off by right clicking the mouse while the pointer is

in the menu area. Start by right clicking and remove the tickmark next to *Command Line* and *Verification* those menus will not be needed for now.

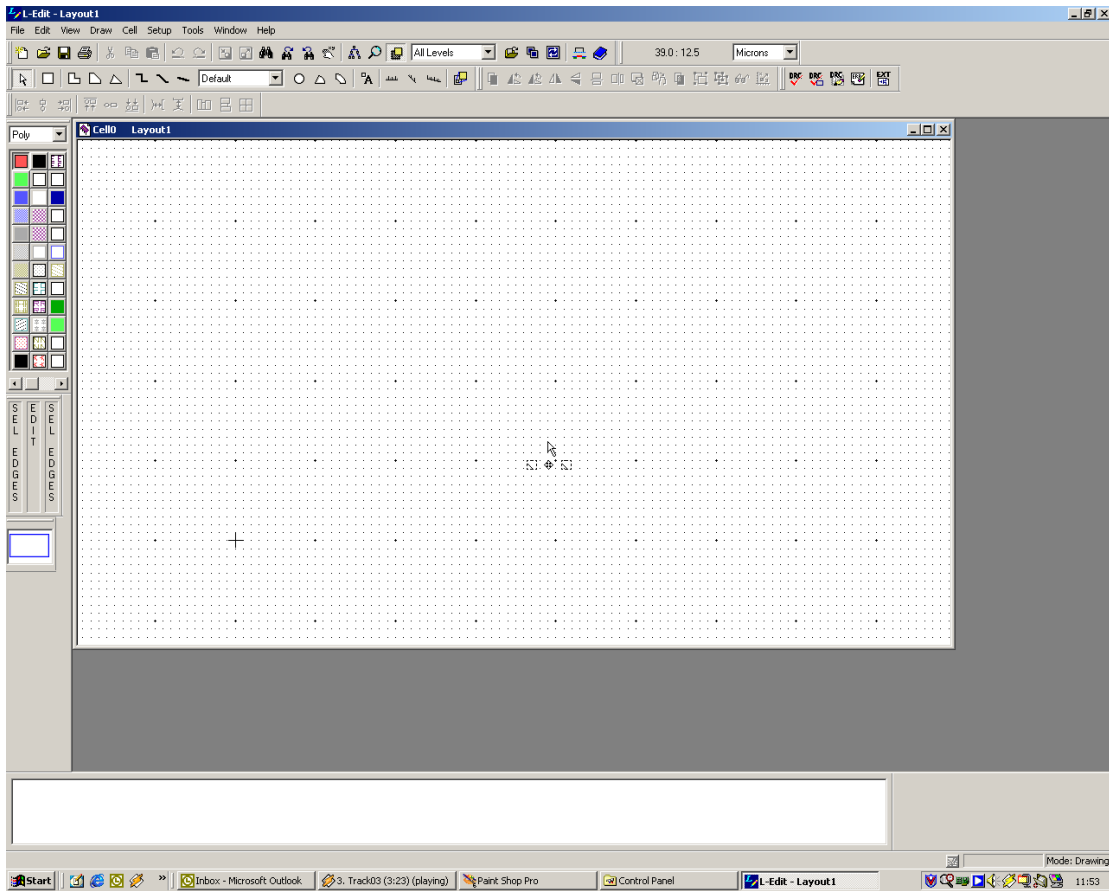


Figure 2: The start-up screen when L-Edit 11 is first run.

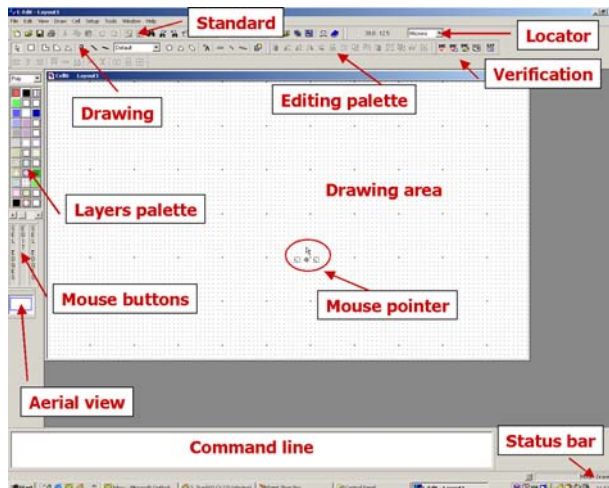


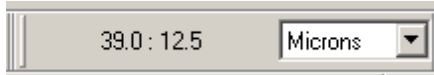
Figure 3: Location of various palettes and menus on the L-Edit user interface.

4.1.1 Standard toolbar



The standard toolbar is very much like in most windows program. There are a few more menu points such as the hierarchy view but these need not be used initially.

4.1.2 Locator toolbar



The locator toolbar gives information of the mouse pointer position relative to origin. Clicking the unit dropdown menu can change the unit. Usually microns or mm are the most useful units. The zero on the numerical keyboard can be used to set a new origin, but should only be used with care since it influences how cells are instanced. The key “q” can be used to reset the locator and allows for definition of a new temporary origin without changing the actual origin. This may then be used for measuring distances between a given point and the mouse pointer.

4.1.3 Drawing toolbar



The drawing toolbar includes the drawing primitives. The first selection “the pointer” is used for selection purposes, and is the default for cell manipulation etc.

The next selection “the rectangle” is used for drawing rectangles. The next three selections represent polygons with varying freedom in shapes. The first one only allows for 90° geometry (Manhattan), the second one allows for 45° angle geometry and the final one is completely free with regards to the angles. All polygons must be closed and not intersect itself. For examples of the rectangle and the three polygon types, see the first row of Figure 4.

Next follows selections for wires, which are much like lines in regular drawing programs, avoid using wires if possible, since there is a problem with the definition of the ends.

Following the lines are three selections for drawing arced structures, first is the disc, then a pie slice and finally a torus. Ignore the next 4 selections.

The final possibility is the *instance* function, this is used to place one cell in another, this will be used often, it also has a shortcut key “i”.

4.1.4 Editing palette



The editing palette is only available when some objects are selected, the first 5 are simple duplicate, rotate, mirror buttons common for most drawing programs.

The next four are for cutting parts of the structures. I find these four to be a bit hard to use. Try them out at some point and see if they suit your style of designing.

Then comes the grouping function (two squares and four black corners). This can be used to place different structures (including cells) in a new cell. It should be noted that the structures are placed in the cell so that origin of the new cell and the original cell coincide. This only matters on occasion (like when rotating) but then it is quite annoying.

The ungroup function (two squares and 8 black corners) is used to remove the hierarchy information of a cell. Be careful when using this function, since sometimes a cell on a too high level in the hierarchy is chosen and thus the structure of the design may be damaged by flattening the cell (plus the filesize may increase significantly).

The glasses activate the Edit Object(s) function, which is also available with ctrl-e or through the menu bar: Edit->Edit Object(s).

The move function (x and y plot and a vector) can be used for moving a selection a precise distance. This function is really simple but also highly useful when making sure that structures are exactly where wanted.

4.1.5 Verification Palette

Remove it for now.

4.1.6 Layers palette



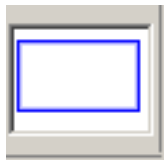
The layer palette displays the various layers, which are available. Each layer can be turned into a mask but it need not. This means that some layers are used for the actual design, while others help the layout, the displayed grid, the origin cross and the drag boxes are drawn on specific layers. If more layers are needed they can be created and also the rendering of existing layers can be manipulated.

4.1.7 Mouse buttons



L-Edit operates best with a three-button mouse. The “mouse buttons” palette informs you what the mouse buttons will do. The behavior of the mouse changes depending on what different kind of control buttons are pressed, ctrl, alt, shift, z. This definitely takes some practice, and notice that L-Edit is designed for right-handed people, there appears to be no good way around using the mouse with the right hand and operate the control keys with the left hand.

4.1.8 Aerial view



The aerial view shows you where the visible screen is compared to the rest of the layout, this is great if you have zoomed in too close or too far out.

4.2 Drawing structures in L-Edit

Structures in L-Edit are made up of drawing primitives. The drawing primitives represent fundamental figures such as squares, polygons, lines and circles (Figure 4). The actual process of drawing is by using point-and-click, in many ways resembling any drawing program for windows. One critical point is that all corners of figures correspond to grid points. The grid can be very fine, but each point is always on a grid point.

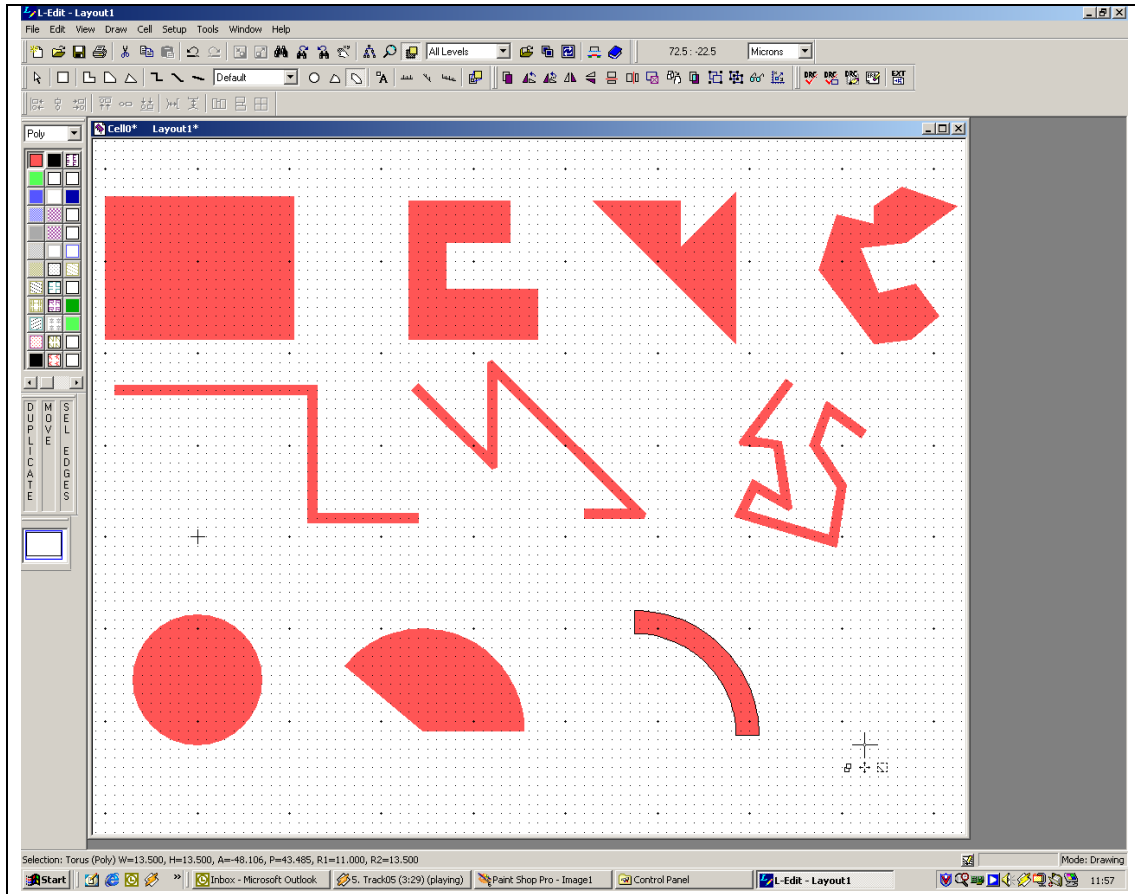


Figure 4: A collection of different structures with various complexities.

4.2.1 Adding text to a design

It is often desirable to have some text, especially for global and local identifiers. L-Edit has a built in tool to create text. The font is ugly but gives access to text in a simple manner. By choosing Draw->Layout Text generator it is possible to enter the desired text in the field: "Layout text string". It is possible to choose, which layer the text should be placed on and also name the new cell, which will contain the text. Don't be fooled by the scaling boxes or the other checkboxes they do not all work intuitively, and I suggest not using them.

After having chosen "ok" you will be asked to click a "Center point". Just click anywhere because you probably need to work on the alignment anyway. Now you have a cell with the desired text. You can open this and make sure the text is located correctly with regards to origin (I usually have lines of text aligned to origin, and single letters and numbers offset slightly from origin to make it easier to construct series with a decent spacing later). With the text correctly aligned the text cell can be placed at the desired location and resized (ctrl-e) to the size needed.

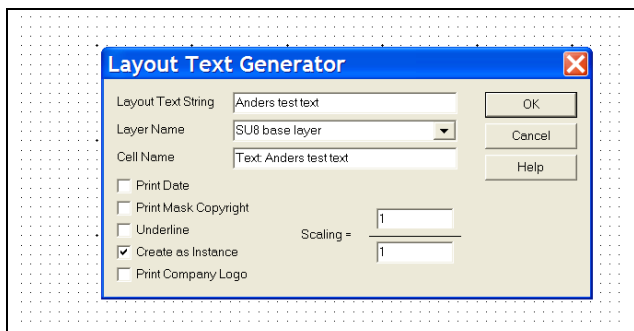


Figure 5: Dialog box for inserting simple text in a layout. The box is opened by choosing: Draw->Layout Text Generator...

Hint.

I use a naming convention for my text in files. The first word of the cell name describes what kind of text I am dealing with. I use the following:

- “Letter:” for cells containing only a single letter
- “Number:” for cells containing only numbers (may be more than single digit)
- “Name:” for cells with words used as local identifiers
- “Text:” for cells with words or text more than 1 letter long
- “Symbol:” for cells with symbols such as: *, °, μ, λ.

Then I name the cell after what it contains and finally if the layout uses more than a single masking layer I include the layer name in parenthesis. A cell could for instance be called: “Name: Channel length (Front etch)”

4.2.2 Manhattan geometry

The simplest geometry possible for mask designs are the so-called 90° geometry. When drawing designs using 90°-geometry there can be no structures with angles other than 90°. This geometry is often referred to as Manhattan geometry due to the way the streets are placed on Manhattan.

4.2.3 Curves and “Why can’t I draw circles”

For most microsystem designs it is vital to be able to draw structures having any angle and not be restricted to Manhattan or 45° geometry. Sometimes the circle symbol etc will be missing from the “Drawing toolbar” (section 4.1.3). Then it is necessary to change the drawing mode. This is done by selecting “Setup->Application...” in this menu on the “General” tab is the “Drawing mode” located under “Toolbars”. The drawing mode can also be accessed by right-clicking with the mouse pointer located on the “Drawing toolbar”.

5 Navigating L-Edit

5.1 Layers

Each layer contains structures, which will be placed on the same photomask. Structures drawn on different layers do not automatically have any relation to each other (derived layers are an exception). This lack of relationship between structures on various layers is one of the reasons why there is no “Flood fill” function in L-Edit. Some of the layers in L-Edit are special layers, which are used for various purposes these layers are never turned into photomasks. The most important special layers are the “Origin”, “Grid” and “Drag Box” layers. The origin layer contains a cross indicating the coordinate $(x,y) = (0,0)$, and that’s it. The “Grid” layer contains dots indicating the drawing grid. The grid settings can be changed using the menu Setup->Design->Grid.

5.1.1 Copying a structure from one layer to another

Sometimes it is desirable to copy a structure (or number of structures) from one layer to another. It is done like this:

1. select all the structures which should be copied
2. click “Edit->Copy” or ctrl-c
3. make the target layer the active layer (click it in the layers palette)
4. choose alt-v (yes alt not ctrl)
5. copies of the structures is then inserted on the active layers and are automatically selected.

5.1.2 Changing colors of layers

In principle it is straightforward to change the colors of the layers in L-Edit, however in practice it is often a bit challenging to get good results, this is an advanced subject.

5.2 Cells

A cell is a collection of drawn structures. The structures in a cell can be on any or all of the available layers. Empty cells can also be created but they generally lead to confusion and so should be avoided. Cells can be placed within other cells as shown previously (Figure 1). This creates a hierarchy among cells, which means that some cells may not be inserted in others. If for example the cell “Small 10 micron Resistor” is inserted in the cell “Wheatstone” then “Wheatstone” may not be inserted into “Small 10 micron Resistor”. L-Edit handles this automatically and will not allow descendant cells to be inserted into ancestor cells. The example above was quite obvious but sometime the designer may be surprised that a particular cell may not be instanced into another, most likely it is because the designer tries to instance a descendant into an ancestor.

The cells drawn are placed in the database file (*.TDB) but not all cells in the file are turned into masks. Only cells placed on the so-called “Fabrication cell” and their ancestors are turned into useful mask data. This is due to the database structure of the file format: Unless it is clearly defined what is to be turned into a mask and how everything relates to it, garbage would be the result. On the other hand the database can also be used for drawing cells and then later instancing them. The database format gives a lot of flexibility for the added trouble of having to define a “Fabrication cell”. The fabrication cell is the one lowest in the hierarchy (cell: Wafer level in FIG), it is defined by choosing “Cells->Fabrication Cell” and then selecting the desired cell. The fabrication cell is indicated in the cells menu with a purple script F.

5.2.1 Instance – I or Ins

When one cell is placed into another cell it is done by “instancing” it. Instancing can be done by either choosing the i-key, insert-key, the instance button on the drawing toolbar or “Cell->Instance”. The instance command is the backbone of structured design and that is reflected in the many possible ways of choosing this command.

5.2.2 Edit object(s) – Ctrl-e

The command “Edit->Edit object(s)...” opens to a very important menu. With this details of each object can be modified. This can for instance be the exact position of an object or the size and shape of it. The same command is used for all objects but it opens up to several different sub menus depending on the object.

Arrays of cells can be placed in a cell using this command, an instance of the desired cell is chosen and then the number of times it should be repeated in each direction is entered in the submenu. Also in the “Edit object(s): Instance” submenu are controls for defining rotation or scaling of the instance. The scaling requires a bit of explanation: The menu point holds two values, one on top of the other, between the two is a line. This line should be interpreted as a division line where the upper value is the numerator and the bottom value is the denominator. This means that entering the numbers 6/1 will make the instance six times larger in all directions whereas 6/6 will make the instance have the same size as the original cell (in effect doing nothing).

5.2.3 Other useful cell commands

A number of different other ways to manipulate cells also exists, these are accessed from the menu “Cells”, these include “Rename”, “Deleting”, “Flatten” and “Fabrication Cell”

5.3 Setup

5.3.1 Scale

Each drawing window can be magnified and demagnified. The “+” and “-“ keys on the numeric keyboard can be used for changing magnification. The mouse can also be used if “z” is pressed first and the pointer is used to create a dragbox, the area in the dragbox will then be magnified to fill the screen. To get a global view of a cell the key “Home” will make the whole cell fit into the window. The ability to fit the whole cell onto the screen can be very useful to find errors in the design, such as structures drawn far away from the actual important structures.

Zoom range is a property of each open window. This means that the same cell can be open in two windows at different zoom range. This is very useful since otherwise even more zooming operations would have to be performed.

6 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 is used a simple mask for etching a microfluidic channel structure (Figure 6).

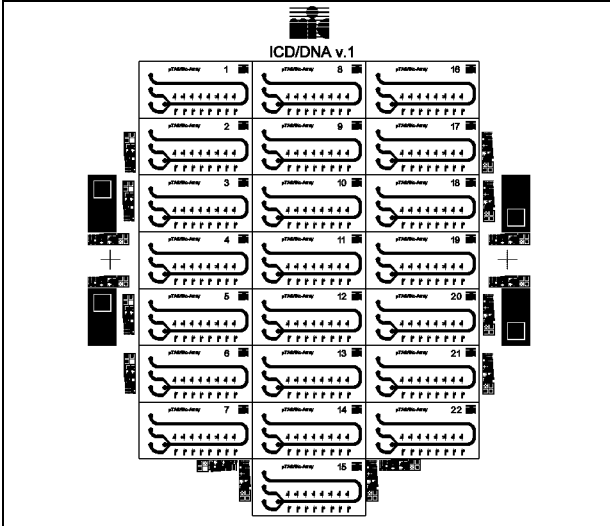


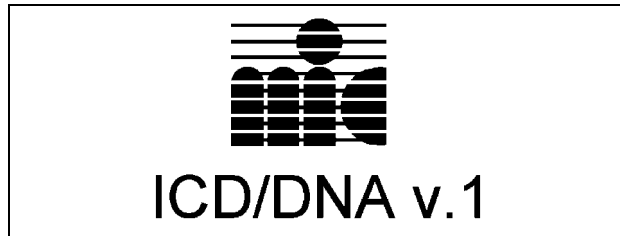
Figure 6: A plot of a front-side mask. Details from this mask are used as examples throughout this section.

6.1 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 (Figure 7), the logo “MIC” and the mask set name and version number.

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 7: The global identifiers from the mask shown in Figure 6.



6.2 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.

6.3 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 where 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 designing the 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.

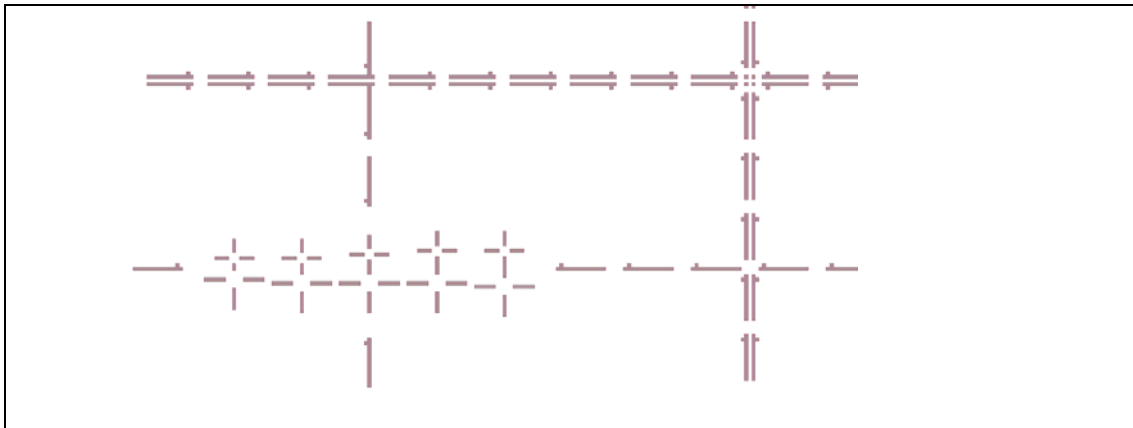


Figure 8: A part of an alignment structure. On the left-hand side is shown 5 structures for aligning other masks to this one. On the right-hand side is shown a structure for aligning the front-side to the back-side. The width of each line is 10 μm .

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 (\circ). 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. Each of the five alignment structures consists of seven bars surrounding two squares of unequal size. The bars are on the alignment mask and the squares are on the mask to be aligned to the alignment mask. The five structures are different in that the central bar has a different length from its neighbors. 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.

6.4 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.

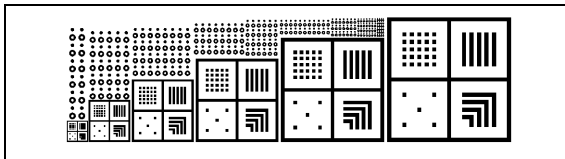


Figure 9: Some of the test structures on Figure 6. These are process monitors used to check the influence of linewidth on dry etching characteristics.

6.5 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 MIC and that it was created as part of a co-operation between μ TAS and Bio-Array.

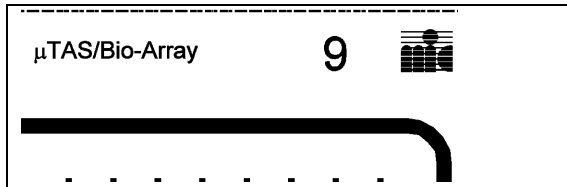


Figure 10: Some of the embellishments from chip 9 of the mask shown in Figure 6.

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 onto chips (<http://micro.magnet.fsu.edu/creatures/>).

6.6 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. In most cases the best (easiest) shape is rectangular with one side parallel to the flat of the wafer.

6.6.1 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.

7 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 11). 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).

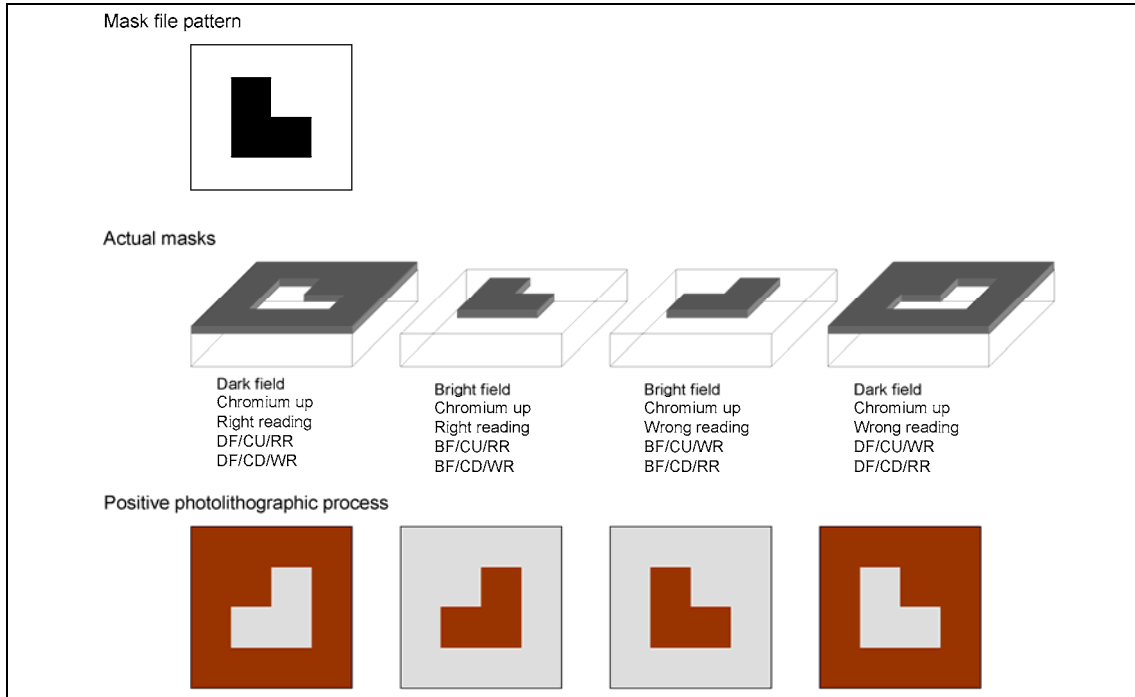


Figure 11: Explanation of the mask polarity and orientation attributes for mask ordering. The mask file pattern is drawn in L-Edit and depending on the polarity (bright or dark) and the orientation (“right reading” or “wrong reading”). The short form of the ordering information is also shown for each 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 12. 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.

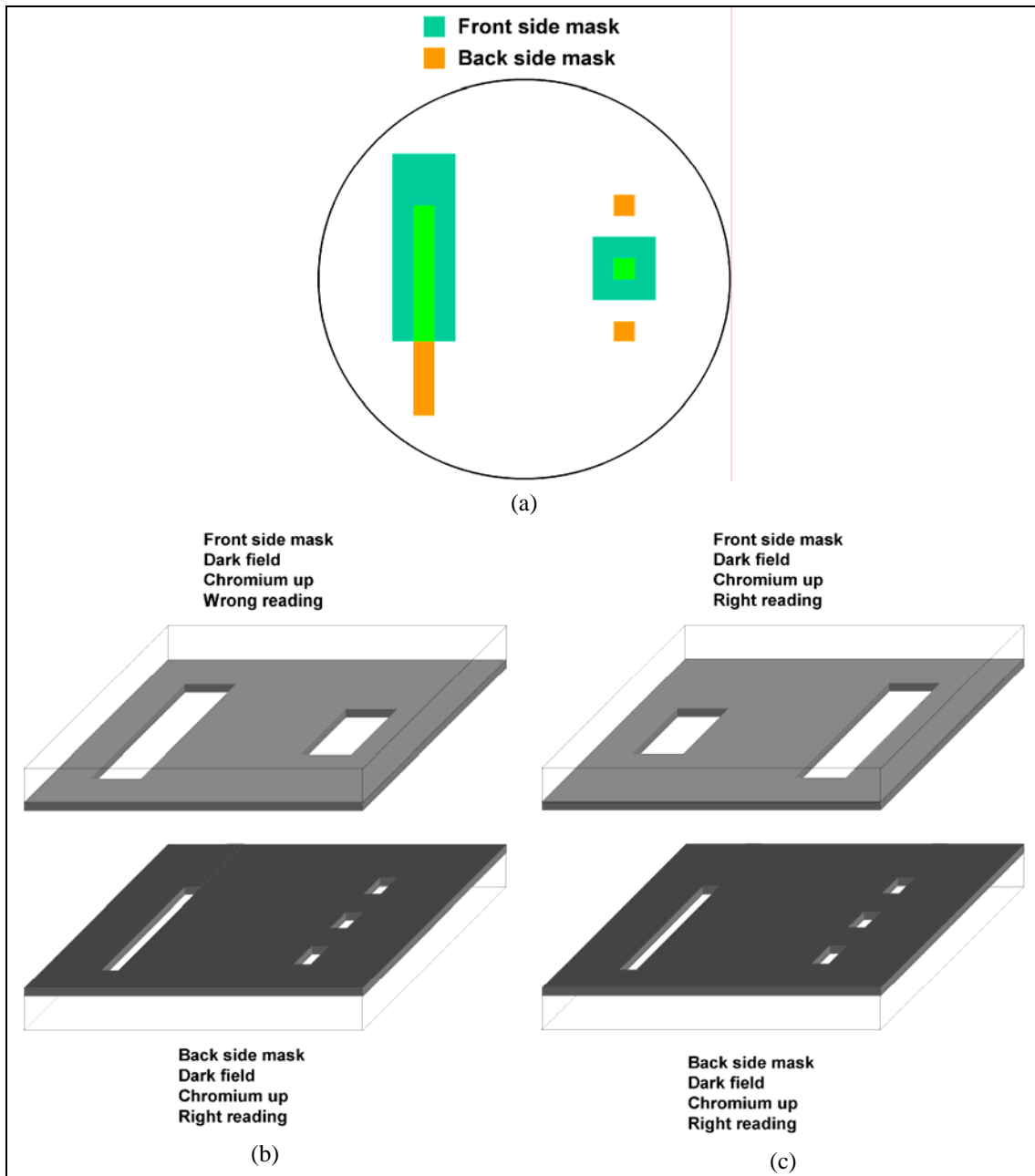


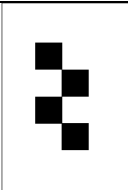
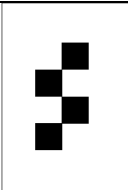
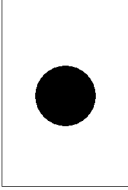
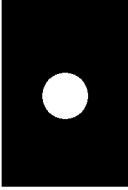
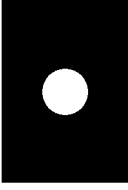
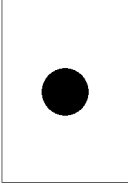
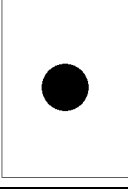
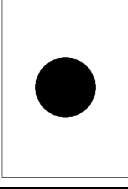
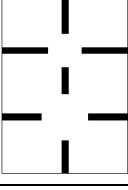
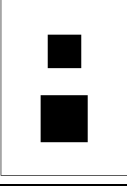
Figure 12: Why reading becomes important for dual sided mask sets. A simplified mask set is shown in (a). Here there is a front side and a back side mask, which each has their own color, with the overlapping structures having a third color. One correct way of reproducing this mask set as photomasks is 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.

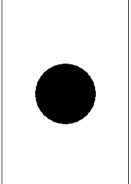
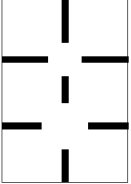




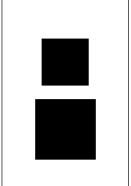
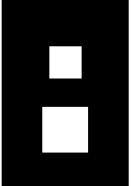
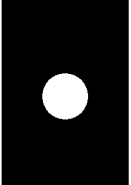
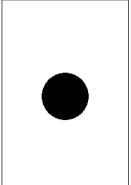
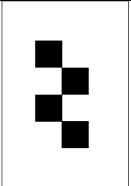
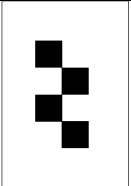
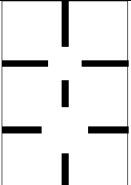
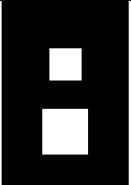
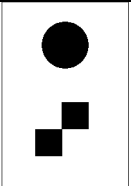
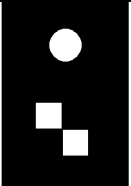
8 "End of chapter" questions and exercises

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