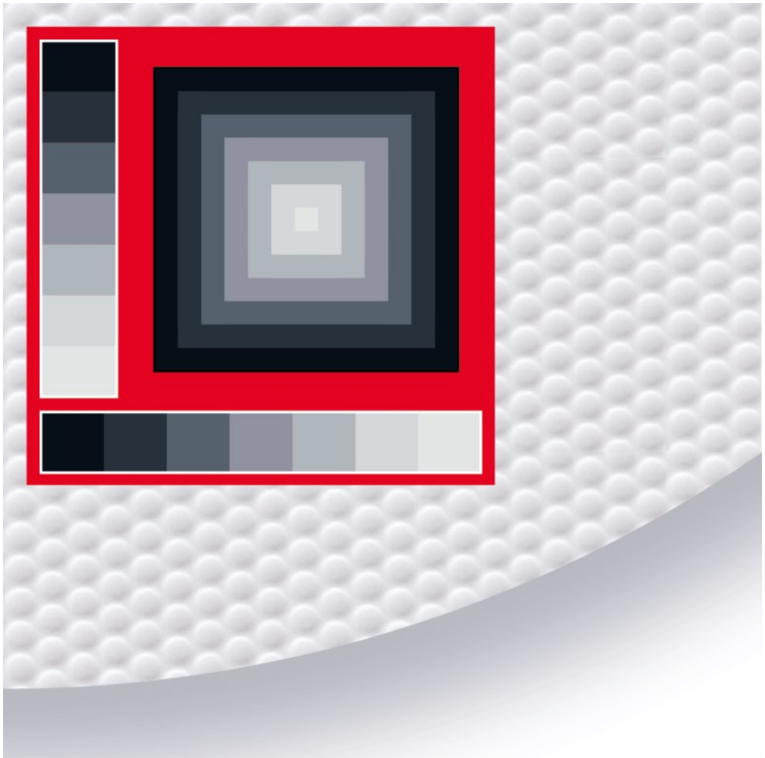
HEIDELBERG INSTRUMENTS

Grayscale Guide



MLA 150

Disclaimer

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Doc. No.: DWL-HI-**01416-UG11**
Revision: 1 (January 2022)
Software Version: APP **1.2**

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1 Introduction

Grayscale lithography is a way to expose different amounts of photoresist in a single exposure by varying the intensity of the base exposure dose. The gray value determines the amount of photoresist that will be exposed, and unlike traditional lithography practices, allows for three-dimensional structures within the photoresist. Since photoresists and substrates have many different properties, it is important to establish a workflow or process to optimize the photoresist to the desired shapes and profiles. The gray values that correspond to the desired shape under one condition may not be the same in different conditions, so having workflows for modification and optimization are important.

Traditional binary lithography processes leave the photoresist exposed or not exposed. With grayscale lithography, the photoresist can be exposed with a precise amount of energy known as a dose. Different doses in different locations mean that three-dimensional structures can be created within the photoresist.

The system tools use a process called 8-bit grayscale. The design is exposed to the photoresist eight times with eight different intensities where the smallest bit is worth 0.39 % of the base dose. The next bit is worth double the bit to its right until the 8th bit, which itself is worth 50 % of the base dose.

The table below shows the percentage of the base dose for the bits:

Bit	**Base dose**
8^{th}	50 %
7^{th}	25 %
6^{th}	12.5 %
5^{th}	6.25 %
4^{th}	3.125 %
3^{rd}	1.5625 %
2^{nd}	0.78125 %
1^{st}	0.390625 %

Tab. 1: 8-bit grayscale

This allows 255 different gray values with 11111111 representing the full dose and a gray value of 255. The gray values determine the bits to be turned on or off, which is physically done using mirrors within the system. It is possible to achieve smooth and precise profiles using the system and some post-development processes.

1.1 About this guide

This guide describes a grayscale lithography workflow for the MLA150. To become familiar with the concept of grayscale lithography, there is an explanatory section preceding the workflow description.

The main part of the guide describes a possible workflow, which consists of the following steps:

- Design creation for grayscale applications
- Conversion of the design using the MLA150 conversion software
- Exposure process with the MLA150 control software
- Possibilities for optimization of specific shapes and profiles within the photoresist

1.2 Related documentation

Heidelberg Instruments offers several additional manuals related to the machine and its operation. If you did not get one of these or need an update, please contact Heidelberg Instruments, Germany.

Pre-installation guide

This guide contains detailed information about the system requirements. Also, this guide provides information about the sizes and weights of the components as well as other information relevant for installing the system.

Safety guide

This guide contains information about potential hazards (health, physical, and environmental) of the system. This guide provides you with the information necessary to safely move in, install, operate, and maintain the system.

System guide part I: Operator’s guide

This guide contains a general description of the system. Also, this guide contains step-by-step instructions about how to use the system and how to execute standard operations.

Maintenance Guide

This guide provides information about regular maintenance tasks that must be performed on the system.

Conversion software guide

Manual for the HIMT conversion software used for data preparation and fractioning

Design creation guide

This guide contains general rules, specific restrictions, and best-practice recommendations for creating designs. Also, this guide lists the supported design formats.

Technical datasheet

This sheet contains the system specifications and summarizes the performance and other characteristics of the system. Also, this sheet lists the technical requirements of the system.

1.3 Design rules

In order to design a grayscale pattern, use your design software to make a dxf grayscale file (alternatively use a bitmap) containing layers that correspond to different gray values. The gray values should be optimized to reach the desired photoresist height at certain positions in order to match your target profile of the shape.

When making a grayscale design, each layer corresponds to a different gray value. The conversion software will take the number within the name of the layer and assign it as the gray value. These gray values can be altered using a gray value table or editing them within the conversion software (see "3.3 DXF Grayscale conversion", page 17). Below you find an example of a drawing that uses all 255 layers:

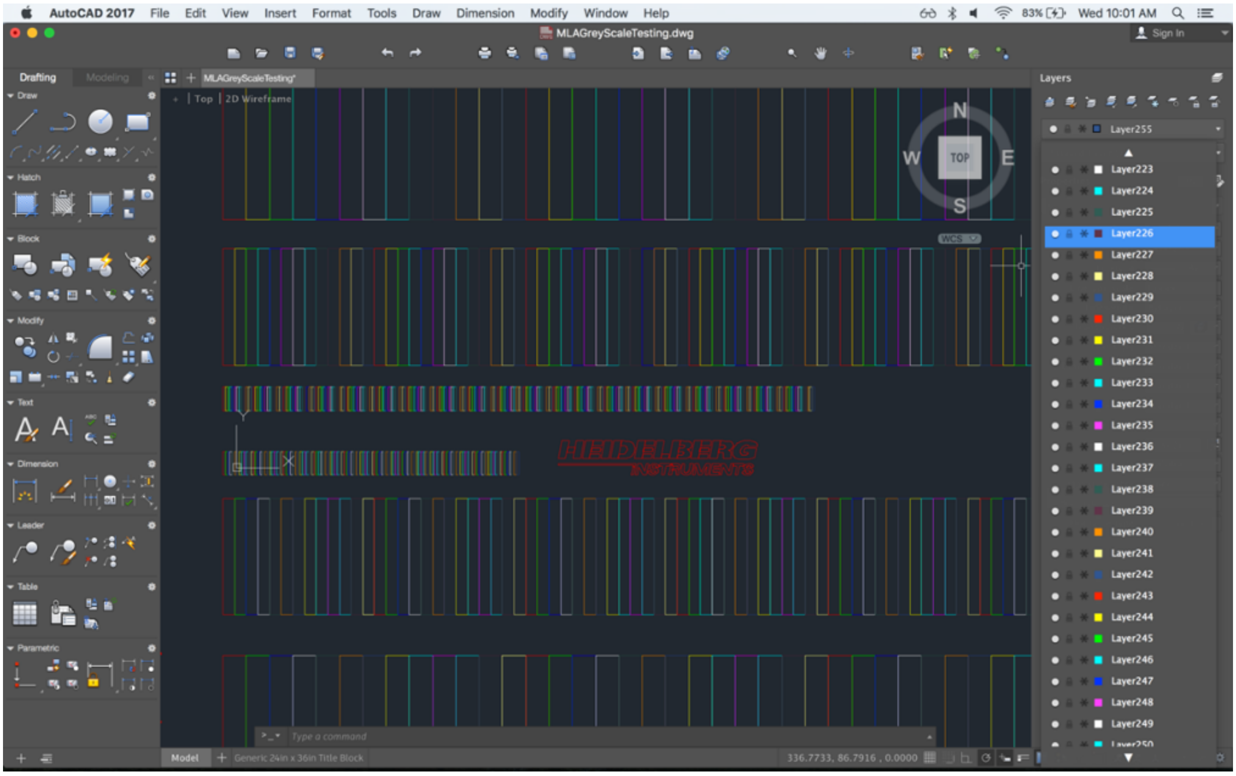

Fig. 1: Grayscale design using all 255 layers

The figure shows a grayscale design that uses every single gray value that the MLA150 is capable of producing. Each rectangle is a polyline drawn in a different layer between layer 1 and layer 255. The layer names are displayed on the right side of the figure, and the numbers inside each layer name will be the default gray values unless they are changed during the conversion. Below you find some important rules when designing a grayscale drawing.

1.4 General structure rules

NAMING

- Do not use special characters (punctuation marks, umlauts, etc.) or spaces in the design name.
- Do not use `main` or any combination of `main` as the name for a layer, cell, or any structure. It does not make any difference if `main` is written in lowercase or uppercase letters or a combination of both.

TEXT

Text is only supported for DXF format and ODB.

GENERAL SIZE LIMITS

Size limits can be given by hardware-specific restrictions such as the available memory space of the RAM or CPU.

AREAS

Use only polygons/closed polylines and circles to define exposure areas. Lines cannot be used to define an area; only the outlines will be exposed.

COMBINATION OF STRUCTURES

Some of the design formats that can be converted to LIC are layer-based (DXF, GDSII). Also, structures can overlap within a design. In both cases, the treatment of overlapping structures must be defined, sometimes by the user, sometimes by the software.

The following logical commands are available:

- **OR**: Results in a true merging of the structures. Any structures that lie completely within bigger structures are covered by these.
- **CUT**: Subtracts a layer from the previous layer
- **XOR**: Leads to a cutting only in the overlap region, while elsewhere both structures remain intact.

So **OR** and **XOR** are applied for overlapping structures within a layer/design. **OR** and **CUT** are used for merging layers.

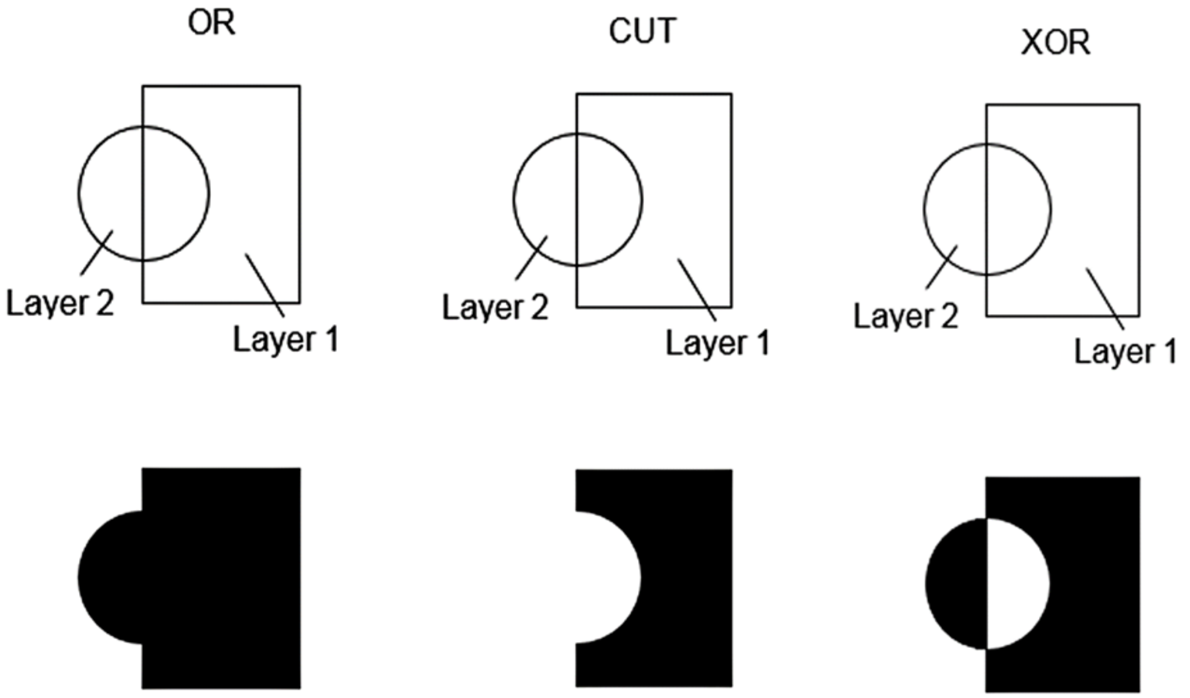

Fig. 2: Combination of structures

In designs with multiple layers, different operations can be chosen for each layer combination. Operations are executed layer-by-layer from the top of the list to the bottom. There is no way of enclosing sets of operations in brackets, not even by merging merged files.

NOTE

If several layers are merged, the result of each **CUT** operation depends on the order of operations.

WIDE LINES

- Lines have to be defined with a fixed positive line width.
- Lines with width zero are ignored, as well as any line width changes within a line (tapered lines).

LINES

- Single lines without width are ignored.

POLYGONS/POLYLINES: VECTOR COORDINATES THAT DEFINE CLOSED LINES

- Areas surrounded by a polyline are filled. Some data formats allow the automatic closing of polylines. Always use this option if available. Otherwise, polylines are closed automatically.
- Do not cross polylines. Crossed polylines create ambiguities that can lead to data errors.

- Do not create double vertices. Double vertices are successive points with identical coordinates. These lead to data errors.

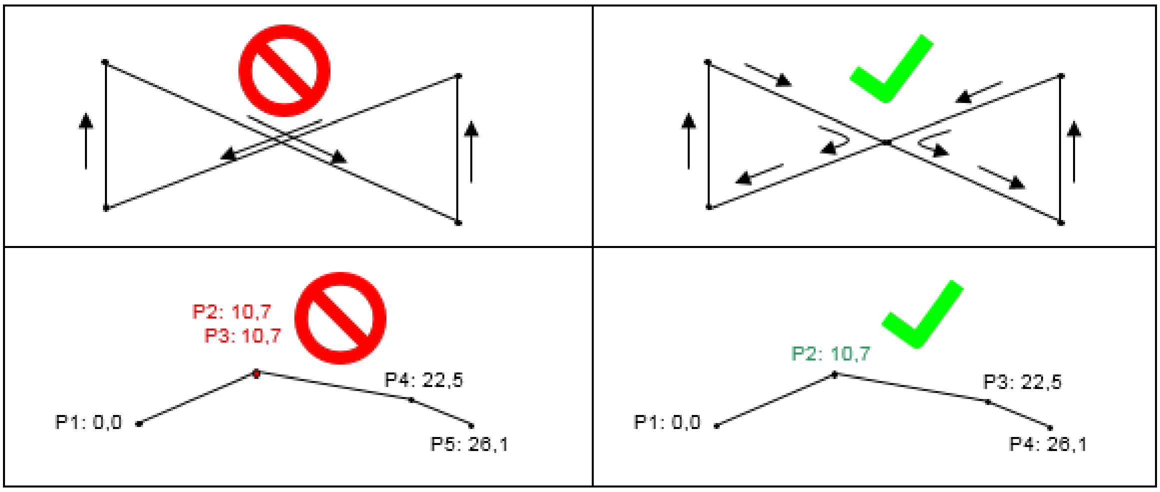

Fig. 3: Polygon/polyline drawing rules

1.5 Structure rules for grayscale design drawing

1.5.1 DXF/GRAYSCALE DXF DESIGN RULES

DXF is a common graphics design format, used by the well-known *AutoCAD* software. There is also other design software available that can export into DXF format, and software that can translate between different design formats (e.g., *LinkCAD*).

Regardless of the design software you use, make sure the resulting file format is 100% AutoCAD R12 compatible.

Create designs according to the software manufacturer's instructions, taking into account the general plus the following additional rules.

UNITS

Use the metric system when designing (mm as basic unit recommended).

ENTITIES

- Polyline/LW Polyline
- Circle
- Solid
- **Text:** Only one text font is provided (Courier-like typewriter font). This will replace any other font used in the design creation. The only supported text attributes are: rotated, mirrored, scaled

NOTE

Avoid placing structures in layer 0!

NOT SUPPORTED

- **Entities**: Line, Arc

BLOCKS:

- When inserting blocks, the same scaling has to be used for x and y.
- External blocks are not supported

DXF TRANSLATOR TOOL

Although our DXF translator supports newer DXF releases, we recommend using *Release 12*.

In addition to the standard DXF rules, the following rules apply:

- Structures on different layers may not overlap; each layer may only contain those areas that are to be exposed with the relevant gray value.
- With complex structures, file sizes might increase above the limit by available hardware. Try to keep structures as simple as possible.

1.5.2 BITMAP RULES

3D exposures require a file format where for each pixel within the design area, a depth can be defined in the form of a grayscale value. This is given in the bitmap format. The system offers 256 different intensity levels that can be addressed by the grayscale values 0 to 255 in an 8-bit grayscale format. The bitmap format also has some specific rules that have to be taken into account in addition to the general ones when setting up a design.

- Grayscale format: For grayscale exposures, use 1-bit, 4-bit, 8-bit, and 24-bit grayscale format. For designs that require only 16 or fewer gray values, also 4-bit grayscale can be used. This has the advantage that a bigger area can be covered, as the file size is smaller (see below).
- File size: The official Microsoft possible image file size in BMP is 4 GB, but the software can ignore these limitations. In the above-recommended setting for designs (8-bit grayscale), this corresponds to 4 billion pixels, or a size of e.g., 63000 × 63000 pixels. The physical size of such a design depends on the configuration of the system.

2 Basics

2.1 Standard lithography vs. grayscale lithography

Grayscale lithography is a versatile technique for the creation of three-dimensional microstructures in a photoresist. By exposing thick layers of low-contrast positive photoresists with spatially modulated light intensities, which means that the intensity is varying along the exposed area, the exposure depth can be precisely controlled. That way, intensity gradients are converted into resist topographies and allows for three-dimensional structures within the photoresist.

In contrast to grayscale lithography, standard lithography is characterized by the binary exposure of photoresist which means that some areas are exposed while others remain unexposed resulting in steep sidewalls in the developed structure. As mentioned above, grayscale lithography aims to expose gradients of the exposure dose to the photoresist resulting in a certain topography, which makes grayscale exposures more complicated compared to their binary counterpart.

The following illustration shows this difference:

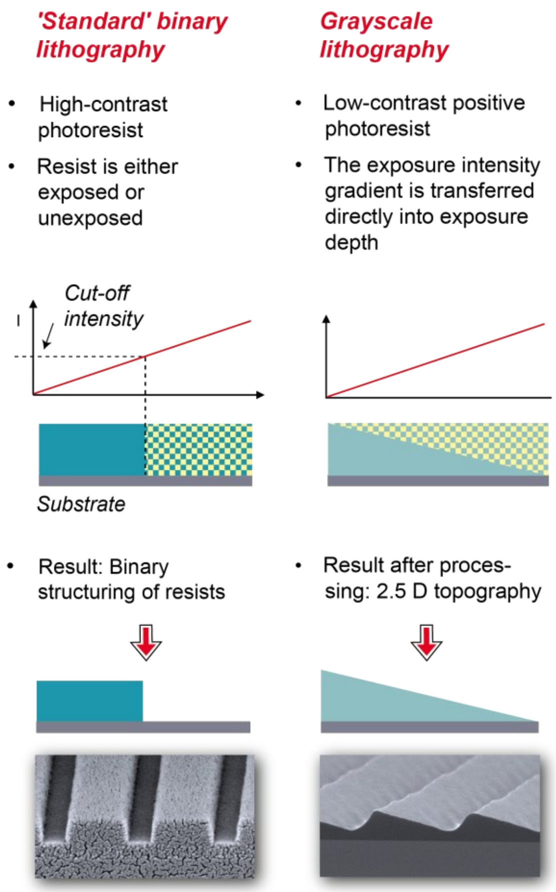

Fig. 4: Standard vs. grayscale lithography

2.2 Applications for grayscale lithography

DIFFRACTIVE OPTIC ELEMENTS (DOE)

Multi-level DOEs are valuable devices commonly used for light modulation. By changing the phase profile of a laser beam, DOEs can split and shape the beam in a well-defined way, thereby enabling the efficient generation of beam arrays or complex light patterns. Fields of application range from laser material processing, medical applications, optical sensors, spectroscopy, and lithography to optical communication.

Fig. 5: Diffractive optic element

BLAZED GRATINGS

Blazed gratings are diffraction gratings with an optimized efficiency at a given wavelength and diffraction order. The optimization is achieved by precisely tuning both the angle of their sawtooth-like profile as well as the groove spacing to match the desired application. Blazed gratings are key components in several optical instruments, such as monochromators and spectrometers, which in turn are important tools for many fields of science, sensors, and communication systems.

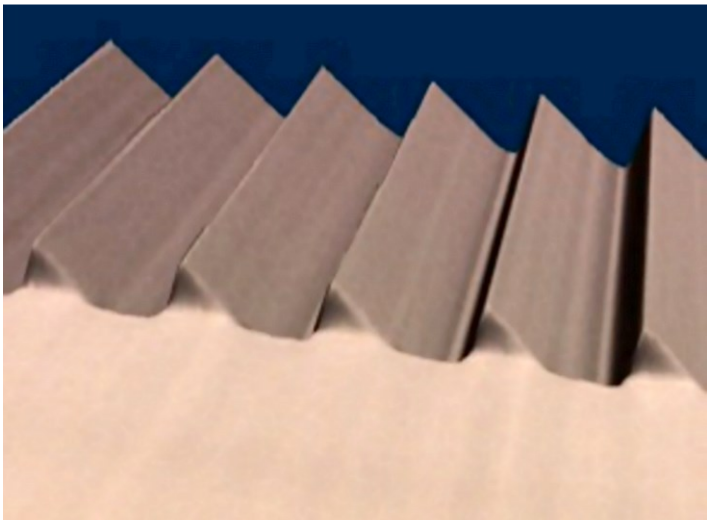

Fig. 6: Blazed grating

FRESNEL LENSES

This compact lens design consists of several concentric circles. Originally invented to reduce the mass and volume of lenses used in lighthouses, it is still a crucial component in today’s (micro-)optics and optoelectronics. Fabricated on a microscale, Fresnel lenses have great potential for applications in, for example, mobile devices, allowing us to carry powerful camera systems in our pockets.

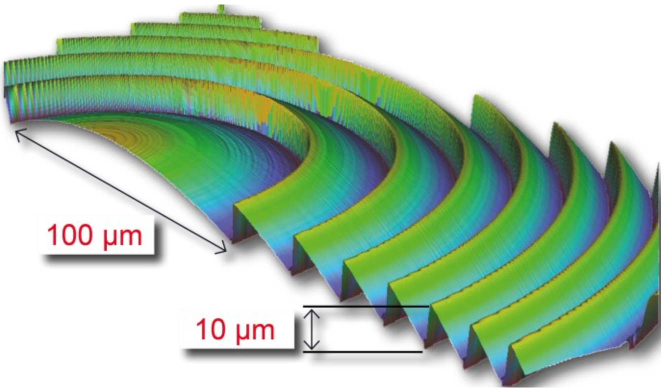

Fig. 7: Fresnel lens

MICROLENSES, MICROLENS ARRAYS

Like Fresnel lenses and blazed gratings, microlenses and microlens arrays are key components in modern-day micro-optics. They are used in wavefront sensors, fiber coupling, or homogenizing light sources. With grayscale lithography, the customization of microlens arrays in terms of geometrical density, shape, and radius of curvature is quickly and easily accomplished.

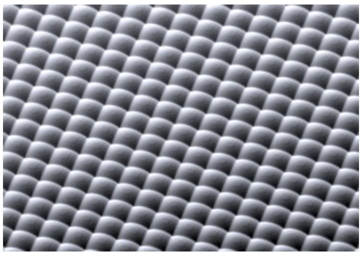

Fig. 8: Microlens array

Another application for grayscale lithography is the creation of diffusers and reflectors where targeted 3D micro structuring leads to controlled reflection or diffusion of light, which is applicable for example in light sources and illumination, like backlight units in LCDs. In the manufacturing of MEMS and MOEMS, lithography is used to create parts of the 3D topography which is necessary for certain parts of MEMS devices. MEMS devices are used in optical switches, optical modulators, interconnects, and a lot of others.

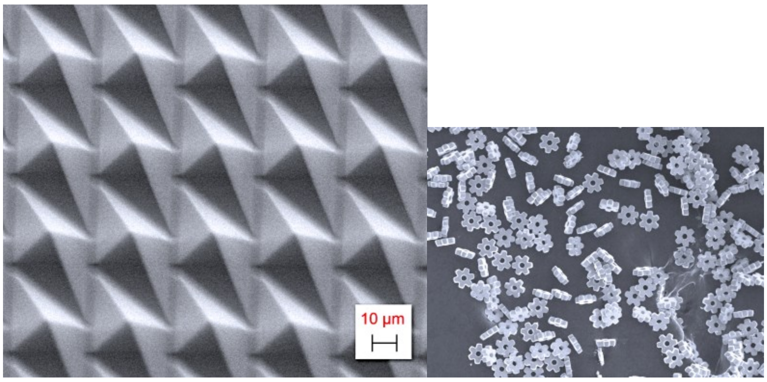

Fig. 9: Retro-reflector design (courtesy of karmic.ch); GS application in MEMS/MOEMS

In the field of microfluidics, for example for the creation of formed channels with specific flow properties and in textured surfaces for tailor-made surface properties such as hydrophobicity, friction, haptics, and adhesion used in touch panels and automotive applications grayscale lithography is applied.

2.3 The 3D-writing concept

All Heidelberg Instruments systems share a common concept: Light from a laser source is imaged onto the substrate by a static optical setup, while the substrate is placed on an interferometer-controlled high-precision moving stage. The individual gray values, that is, the intensity levels for the grayscale exposure, are created by modulating a laser beam with a spatial light modulator (SLM). The SLM is the centerpiece of the optical system. It addresses each position on the lateral grid, i.e. each pixel, with the correct light intensity on the substrate. The SLM creates a fast light modulation for multiple pixels over a specific, limited area (either a pixel line or a pixel array). The SLM itself is fed with design data by software which pixelates the input design and converts the design gray values to the appropriate SLM signals. The modulated laser beam is then imaged onto the substrate and exposes the resist at the current stage position with the desired intensity. Based on the design data and the stage position in a given moment, the SLM lets the beam pass, blocks it entirely, or attenuates it to one of up to 1000 intensity levels in between. The output of the SLM is not necessarily only a single pixel, because depending on the SLM used, a whole line of several hundred pixels or even a 2D array of pixels is written at a time.

The stage travels in a vertical direction underneath the standing laser beam, exposing a single stripe. After a stripe has been exposed, the stage is stepped by one stripe width along the horizontal direction and places the next stripe directly next to the previous one.

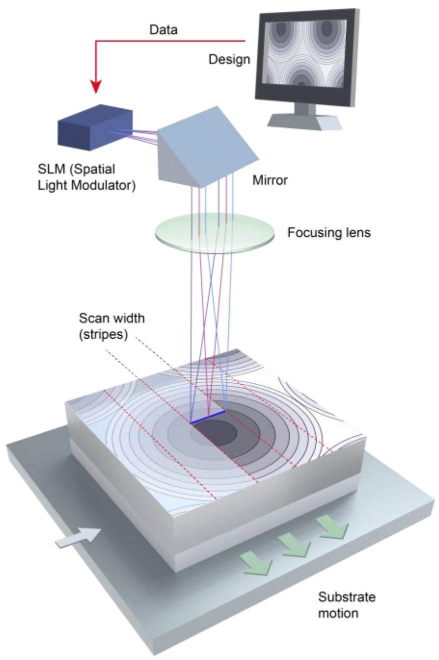

Fig. 10: Main 3D writing strategy (combination of SLM, focusing optics, and an x/y-stage)

2.4 Advice on design creation

The following section shows recommendations concerning the rule stated above.

- Set a unique name for each layer.

  For conversion of the design, the layer names must be clear, so gray values can be assigned to the proper layers.

- Use polylines and make sure the shapes are closed.

  If the polyline does not connect back to close itself, the conversion software will ignore it. For more information, see "1.4 General structure rules", page 5.

  Check if the designs are closed polylines. The following illustration shows a comparison of open and closed polylines.

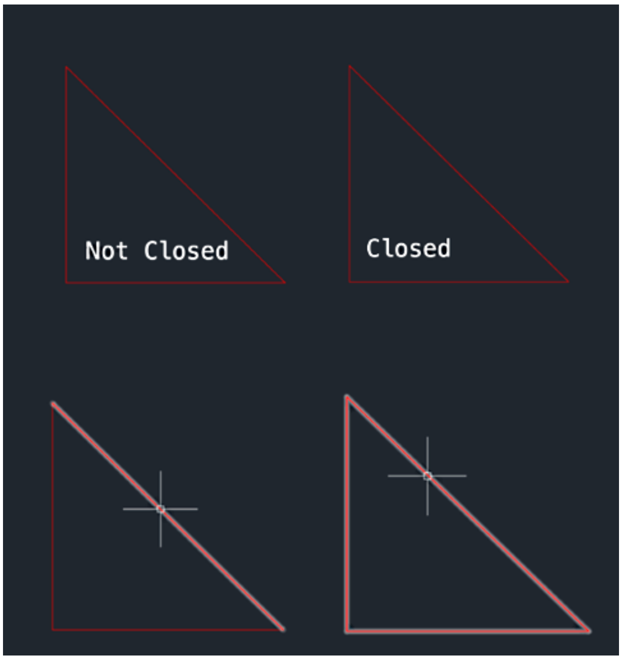

Fig. 11: Open and closed polylines

  Find out, how to check this with your design software. It might be possible to check the designs, e.g., by hovering over the structures. If the whole structure is not highlighted as shown in the closed polyline, the design will not be converted or exposed.

  Also, the design may not be exposed if the structures are regions instead of polylines. If a structure is a region, it will appear the same way a closed polyline appears in the drawing and needs to be checked carefully.

  To make sure that all of the structures in a drawing are closed polylines, select the entire drawing and join the structures with a respective command which should be available in your design software. This should convert all the regions into polylines and close all of the open polylines. If a structure is still displayed as in the illustration above, a part of the structure is not connected to itself, so it will have to be redrawn.

- If there is an area not being exposed within a larger area that is being exposed, break the structure up into multiple parts.

For example, if a donut were being drawn, do not draw one circle inside another circle and subtract the inner region from the outer region. This creates a donut region rather than a polyline. If this structure is exploded and joined together then the entire outer circle will be exposed.

The following illustration shows how to split up a structure into multiple parts:

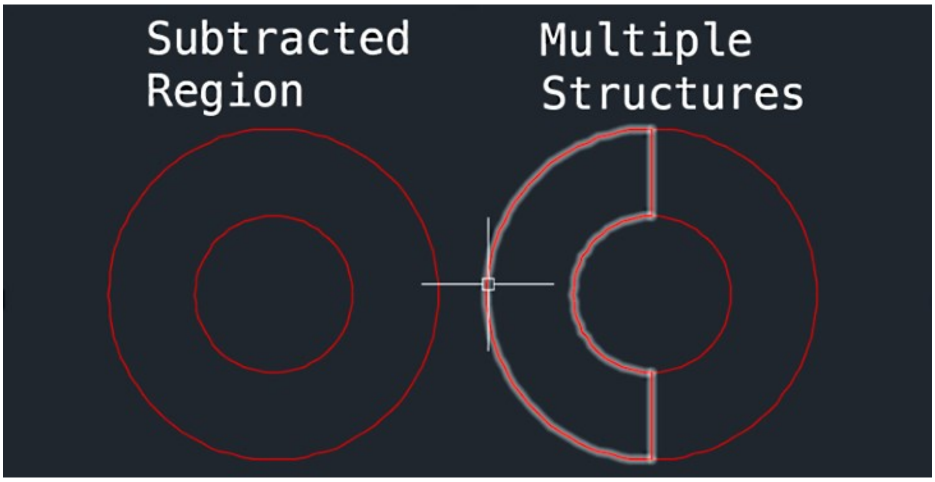

Fig. 12: Drawing subtracted regions with multiple structures

The conversion software would not convert the structure that is shown at the left in the illustration above correctly either because it is a region or a closed polyline with overlapping structures. However, the multiple closed polyline structures as shown at the right of the illustration above will be converted and exposed.

An easy way to draw multiple structures is to draw half and then mirror it.

- Do not include overlapping structures of different layers.

  The gray values will be altered and the depth will be different than expected.

- Make yourself familiar with the following functions and commands of the design software:
  - How to select structures, how to snap to the grid, and how to draw horizontally or vertically.
  - How to copy and rotate.
  - How to make one structure into a group of structures.
  - How to join lines and polylines and close together polylines.
  - How to group again into polylines, and break them and regions into lines again.
  - How to flip the structure.
  - How to trim away extra lengths, when joining polylines that intersect, but do not meet at the same point.

3 Conversion

Unlike binary lithography using the MLA, setting up a grayscale exposure requires a few extra steps that assign each layer to a gray value. Although, it is possible to manually input each gray value to the corresponding layer, gray value tables or charts that match gray values to target photoresist thicknesses are used to speed up the optimization process.

3.1 Setting up gray value table files in advance

For assigning the gray values to the layers, it is possible to set up a file in advance that can be loaded for the conversion process. The gray values must be written underneath each other in a column and assigned to the corresponding layers, which are also written in a column. Writing down the values in one column while leaving out the layer column does also work.

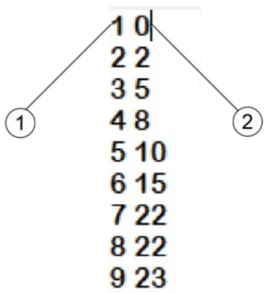

Fig. 13: Values assigned to layers in a text editor

After having finished listing the gray values, save the file using the extension `.gvt` for the DXF grayscale format or `.map` for the BMP format into the corresponding folder. This file can then be loaded during the conversion setup.

3.2 Start the software

The first few actions for converting a grayscale file are like converting a normal binary file. For more information, see the *Operator's Guide*.

1. Select the correct substrate size, the laser wavelength, and double-click the **Design** column.

   You see the following screen:

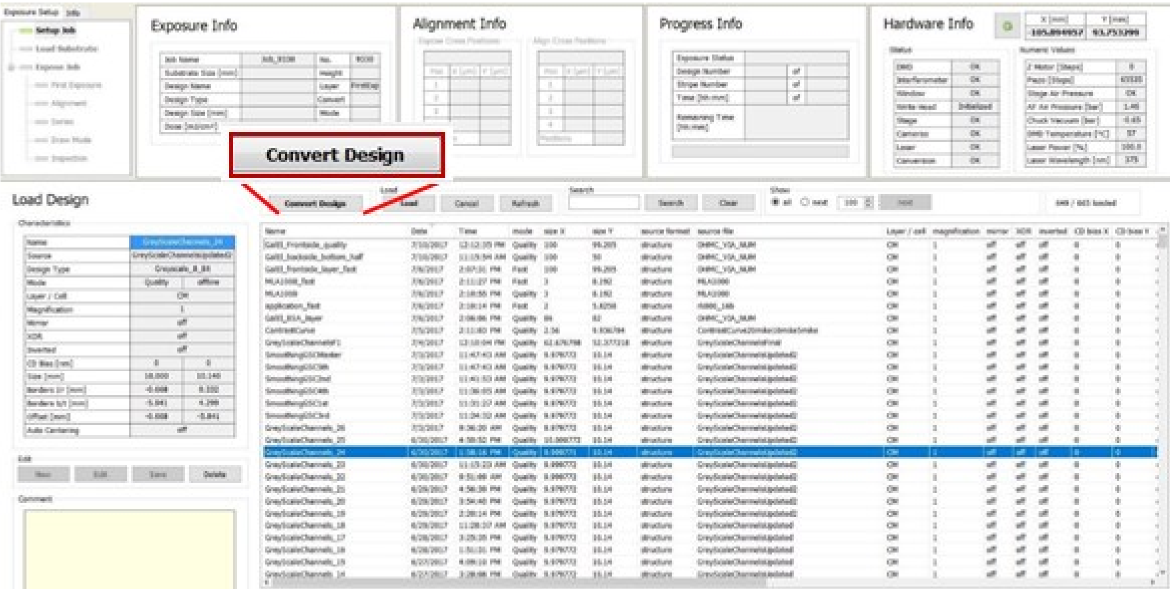

Fig. 14: Converting the design

2. After the screen loaded, click **Convert Design** to open the conversion software.

✓ The conversion software opens in the top left corner as shown in the following screenshot.

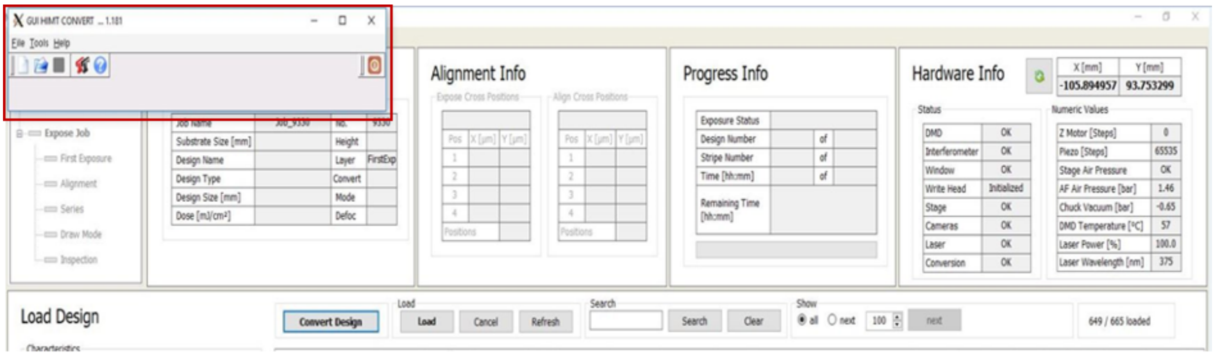

Fig. 15: Opening the conversion software

3. Click the paper icon in the top left of the conversion software and enter a job name to start converting the grayscale file. Save it.

✓ A window opens.

✓ You see the conversion software GUI.

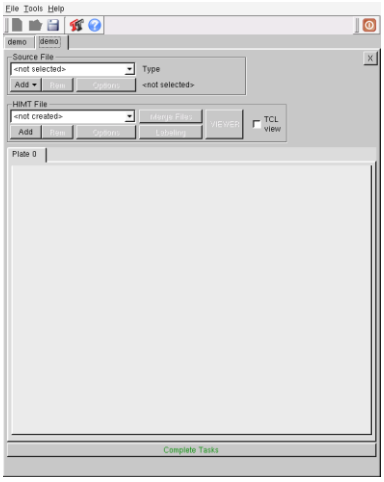

Fig. 16: Conversion GUI

3.3 DXF Grayscale conversion

NOTE

Gray value table files for DXF Grayscale-format prepared in advance must have the extension . gvt , so they can be loaded for conversion job setup. For more information, see "3.1 Setting up gray value table files in advance", page 15.

1. In the *Source File* frame, click **Add**.

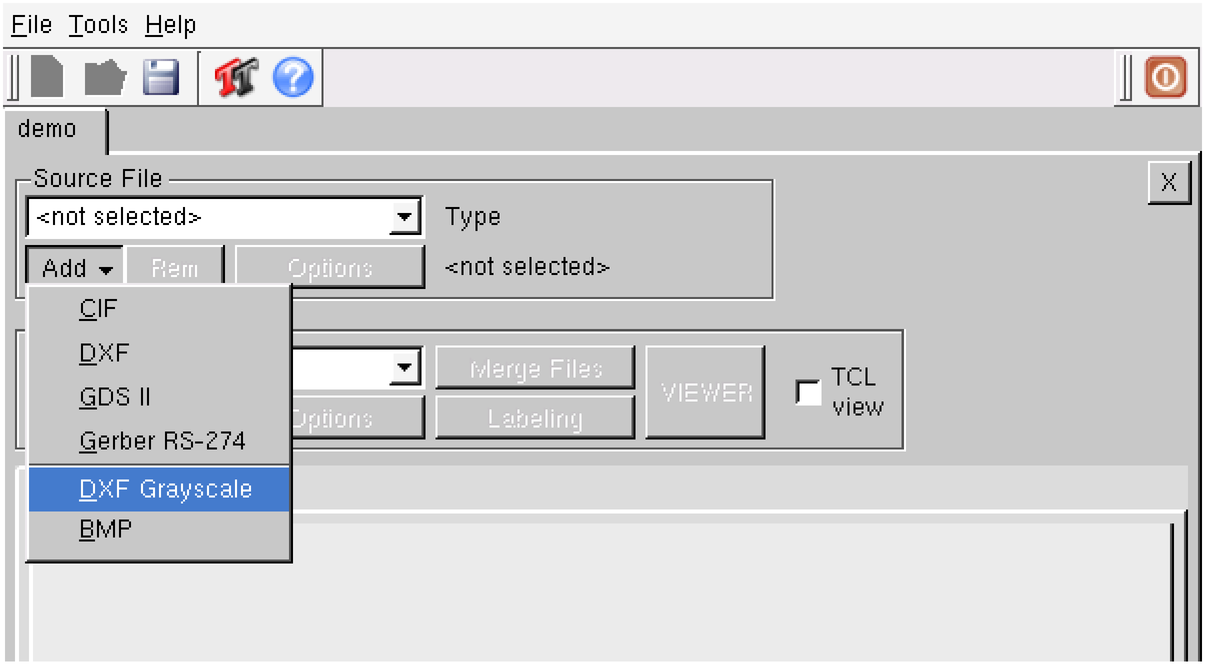

Fig. 17: Conversion window – DXF selection

2. From the drop-down list, select **DXF Grayscale** (not DXF).
3. From the directory, select the correct design file.

NOTE

If the file does not show up, check if you have stored it in the correct location `HIMT/Designs/DXF`.

✓ The following screenshot shows the *DXF Grayscale Options* panel. Here, you can assign the layers to certain gray values and set the design size.

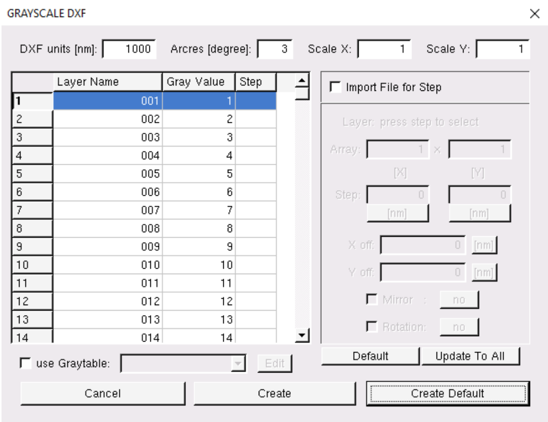

Fig. 18: DXF Grayscale Options to assign gray values

It is possible to assign each layer to a certain gray value by hand. This is workable and makes sense if there are not many layers in a design. When having more than 100 different layers in a design, setting the gray values by hand becomes time-consuming and labor-intensive. It is recommended to use a gray value table:

4. To use the gray value table, select the **use Graytable** checkbox at the bottom of the panel.

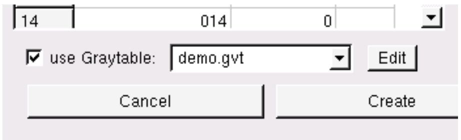

Fig. 19: use Graytable checkbox / Edit button

In the drop-down list next to the checkbox, you find preloaded gray value tables. If the file you are looking for is not in the drop-down list, click **Edit** next to the drop-down list. The *Transforming GrayValues* window pops up.

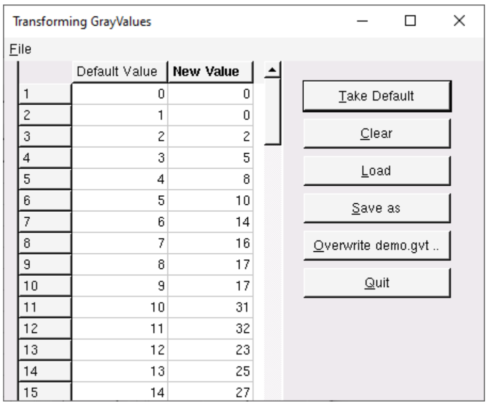

Fig. 20: Transforming GrayValues window

5. To load a different file, in the *Transforming GrayValues* window, click **Load**. The *Load GrayValueTable* file manager opens.

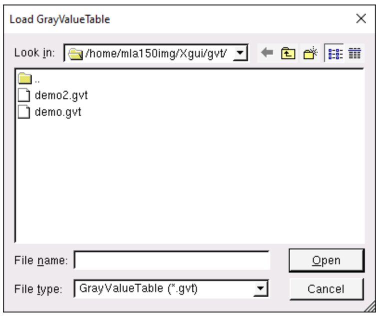

Fig. 21: Load GrayValueTable file manager

6. Select the correct GVT file.
7. Once the correct GVT file is opened, go to the *Transforming GrayValues* window and click **Quit**.

NOTE

If the .gvt file does not show up, make sure that it has been saved to the correct location.

8. Check that the gray values are aligned with the correct layers and make sure that the size of the design is set to the correct value.

   The following screenshot shows an example of a completed gray value conversion using the gray value table. In the design, one unit was a micron, which is why the DXF units are set to 1000 nanometers.

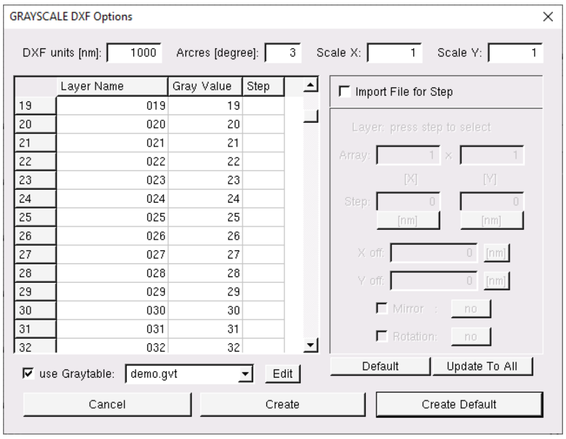

Fig. 22: Completed grayscale conversion

9. When the gray values and the size are satisfactory, click **Create Default**.

✓ Now, the design can be viewed through the viewer. From this point onwards, setting up the exposure is the same as setting up exposures for designs with binary lithography. For more information, see the *Conversion Guide*.

NOTE

Activate the **Color** checkbox in the *View Options* docking window of the *HIMT Viewer*. The layers are displayed differently colored.

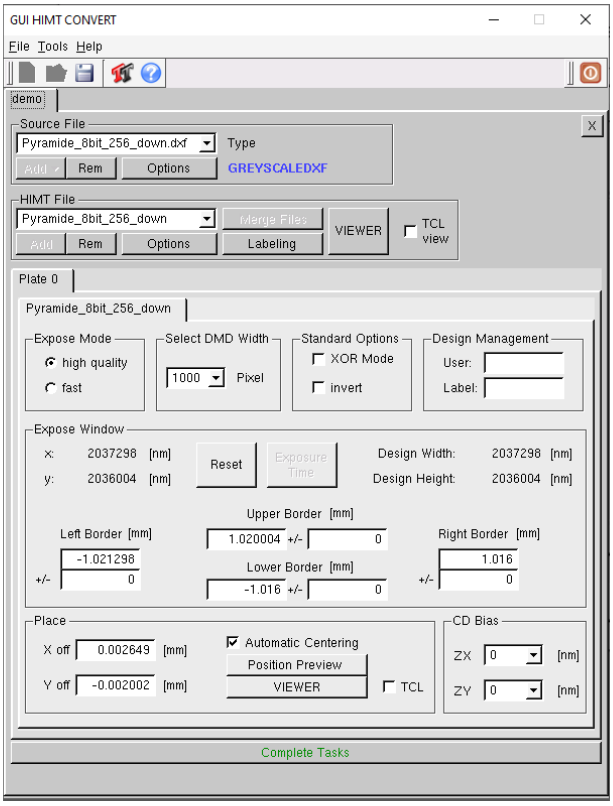

Fig. 23: Finishing the conversion setup

10. Check the design in the Viewer. If it is not centered in the drawing, it may be useful to activate the **Automatic Centering** checkbox.
11. To confirm and save the task, click **Complete Tasks**.

12. In the prompting window, enter in a name for the conversion process.

✓ The conversion process starts. The time required to complete the process depends on the complexity and size of the design.

After completion of the conversion process, the file can be loaded in the Setup panel like any other design file. For more information about how to load designs and set up exposures, see *Operators Guide*.