Helpful hints for grayscale lithography on the Heidelberg MLA 150

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When using the grayscale capability of the Heidelberg MLA 150, there are a few quirks that may slow down your progress. This document exists to provide warning of these roadblocks and provides helpful tips to overcome them. Primarily, we focus on limitations of grayscale mode, file preparation and conversion, dose considerations, and the development and etching of grayscale features.

Limitations of grayscale mode

The Heidelberg converts dose using an 8-bit format, which is outlined in the manual. Converting 1's and 0's into dose can be a bit daunting, but this formula can be used instead:

$$Dose = layer * 0.0039 * MaxDose$$

Where the layer is assigned during pattern conversion and the maximum dose is determined during exposure. **The minimum value that can be set for the maximum dose is 510 mJ/cm^2, meaning the lowest dose at which a feature can be exposed (corresponding to a layer value of 1) is ~2 mJ/cm^2.** This also implies that **the minimum step size in dose is also 2 mJ/cm^2.** As the maximum dose increases, the step size also increases. This 2 mJ/cm^2 is the limiting number for grayscale dosing, but with sufficiently thick resist, one can increase the maximum dose and pattern several hundreds of dose values for a single design.

File preparation and conversion

The primary difference between the standard operation of the Heidelberg and operation in grayscale mode is the input pattern file and its conversion. To ensure compatibility, **create a .dxf pattern preferably using an Autodesk product (e.g. AutoCAD).** As of this writing, there is an AutoCAD license on one of the shared SNF computers, and Autodesk currently provides free student licenses. We recommend using your own license since the configuration for AutoCAD on the shared computer may be nonstandard given that other users may move features to their preferred window setup. The key to making .dxf files that will can be converted to grayscale patterns is in assigning layers, so keeping the layer properties window open will be helpful. In addition, start off your design by deleting all layers except for the default layer 0. Then, create each drawing in a new layer knowing that a different dose requires a different layer.

Not all patterns that successfully convert in the Heidelberg software will actually pattern in grayscale mode. Uniquely, we found that any designs with arcs did not pattern in grayscale mode, even though they patterned in standard operation. Therefore, circles should be represented as many-sided polygons. And as noted in the manual, all patterns must be closed polygons, meaning a donut-type pattern is not allowed (see the manual for an example).

Finally, it is important to observe the command line when converting the file. After loading your file, choosing your settings, and selecting to convert your file, the operation may read "success" even if it failed. The command line, however, will read a failure, and you will know that your pattern did not successfully convert. Often, closing the file conversion window and trying again will resolve this issue. If not, be sure to view the pattern before converting to ensure that your expected drawing is displayed.

Dose considerations

Dose is arguably the most important consideration when moving to grayscale mode, therefore it is helpful to have an accurate contrast curve specifically for the resist you are using. This contrast curve will vary depending on the resist type, deposition conditions, thickness, and even feature size. **Note that smaller features will require larger doses to reach dose-to-clear.** Dose curves can be quickly obtained by using the Dose and Defocus mode in the Heidelberg software, patterning a geometry representative of your intended design (e.g. 5 um diameter circle, 10 um width line, etc.).

The Nanospec is a quick tool to obtain film thickness measurements after development and therefore obtained contrast curves, although the S-neox interferometry objectives may also be useful for imaging exposure variations over larger areas or complex geometries. If using the S-neox to measure resist thickness, be sure to correct for stigmation. Alternatively, AFM, profilometry, and ellipsometry may be appropriate depending on the resist and feature geometry.

Developing and etching grayscale features

In order to preserve the "gray-ness" of grayscale features, post-development baking should avoid reflow beyond the step size of the features and etching should be performed with minimal selectivity to the substrate (i.e. 1:1). For low-dose areas, significant abnormalities may present themselves after development or after etching, especially for features <10 um. To avoid this, traditional descum prior to etching and a longer post-development bake may be helpful. However, both of these steps have the potential to smooth out the grayscale features you want to retain, therefore the post-development bake should be performed in an oven at reasonable temperatures (110 C for 3612) rather than extending the hotplate bake time or increasing its temperature.

If the dose is below the dose-to-clear value (as necessitated in grayscale lithography), the sidewalls of the resist will exhibit a slope that will transfer into your pattern after etching, although this may only be significant for features <10 um. For example, a 2 um pattern that is under-exposed may etch into a 3 um hole due to a gaussian-type energy deposition profile. **Therefore, if working near the resolution limit of the Heidelberg in grayscale, design dimensions may need to be scaled to account for sidewall abnormalities.**

Good luck!

The Heidelberg MLA 150 is a powerful tool, and its grayscale capability is relatively straight-forward to operate. Considering these few tricks, operation should be a simple and quick as using the tool in its standard mode of operation. Good luck!