OPERATING PROCEDURE

Title: BUILDING 518 HEIDELBERG DWL 66FS LASER MASK WRITER

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Document Release or Change History:

Issue	Date
A	05/17/2010

Review period for this ES&H OP is: Five Years

Approved by:
David Sandison
Center 1100 Director
Original Signature on file in Center 1100 offices.

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OPERATING PROCEDURE FOR USE OF THE BUILDING 518 HEIDELBERG DWL 66FS LASER MASK WRITER

1.0 PURPOSE, SCOPE, AND OWNERSHIP

1.1 Purpose

This activity-specific Operating Procedure (OP) documents the safe usage and handling of the Heidelberg DWL 66fs laser mask writer.

1.2 Scope

This document applies to the fabrication of masks using the Heidelberg DWL 66fs laser mask writer for use at the Center for Integrated Nanotechnologies (CINT) Integration Laboratory (IL). All personnel using the laser mask writer shall be required to familiarize themselves with this OP and adhere to the defined guidelines.

1.3 Ownership

Center 1100 is responsible for this document. Any recommendations for improving this document should be directed to the author.

2.0 RESPONSIBILITIES

2.1 Manager

The manager shall define the qualifications and training required for authorized users and provides oversight to ensure equipment is maintained, and safely used as required in the Pressure Safety Manual, MN471000, and other reference documents listed in Sec. 10 of this OP.

2.2 Key Operator

The Key Operator shall adhere to the requirements set forth in this document. Each Key Operator must sign the Authorized Users list to acknowledge they have read and understood the general requirements of this OP and will comply with its guidelines and restrictions. Additional duties include:

- Selecting authorized users
- Maintaining the equipment in consultation with the Field Service Engineer.
- Adhering to the requirements set forth in the Pressure Safety Manual, MN471000.
- Adhering to the requirements set forth in the Environment, Safety and Health Manual, MN471001.
- Adhering to the requirements set forth in ES&H SOP SP471409, Class 3B and Class 4 Laser Systems Operations in Research.
- Notifying the Manager and the Center ES&H Coordinator in the event of an accident involving this equipment.

2.3 Authorized User

The Authorized User shall adhere to the requirements set forth in this document. Each user must sign the Authorized Users list to acknowledge they have read and understood the general requirements of this OP and will comply with its guidelines and restrictions. Additional duties include:

- In exchange for independent access, the Authorized User must be willing to fabricate masks for general lab users on an occasional basis.
- Follow the requirements set forth in the Pressure Safety Manual, MN471000.
- Observe the requirements set forth in the Environment, Safety and Health Manual, MN471001.
- Observe the requirements set forth in ES&H SOP SP471409, Class 3B and Class 4 Laser Systems Operations in Research.
- Notify the Manager and the Center ES&H Coordinator in the event of an accident involving this equipment.

3.0 JOB QUALIFICATIONS

All personnel shall complete the following training when they are required to work with this equipment. After reading and signing all applicable OP's, completing applicable training, and receiving consent of the Integration Lab Manager, the Authorized User will be issued an Integration Lab badge indicating that they have been trained to use the Integration Lab and specified equipment. A user must have their badge above the waist outside their clean room suit at all times when in the Integration Lab. Note that the Integration Lab badge is not a substitute for the DOE issued badge. The DOE badge must also be worn at all times while in the CINT facility.

3.1 Corporate Training

All personnel shall complete the following Sandia National Laboratories corporate training:

- LAB100, Laboratory Standard Information and Training
- PRS150, Basic Pressure Safety.

3.2 Site Specific Training

- Site specific training for un-escorted access to the Integration Laboratory
- Site specific training for personal protective equipment (PPE)
- Site specific training for demonstration of operating the laser mask writer

4.0 DEFINITIONS

The following definitions, as they apply to this document, were obtained from the Sandia ES&H Manual and the other reference documents listed in Section 10.

4.1 Asphyxiation

Asphyxiation results from a lack of oxygen, which can result in loss of consciousness or death.

4.2 Authorized User

An Authorized User is an individual who, with the required training and qualification from the Key Operator, is approved by the Manager to operate the laser mask writer. An Authorized User is distinct from a general lab user, who may be authorized to use other Integration Lab equipment, but is not authorized to operate the laser mask writer.

4.3 ES&H Officer

The ES&H Officer fulfills environmental safety and health, safeguards and security, and quality assurance tasks for the Integration Laboratory.

4.4 Laser

A laser is a device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally or spatially or both. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.

4.5 Key Operator

Key Operators are qualified to perform maintenance of the tool and train Authorized Users.

4.6 MSDS

Material Safety Data Sheet.

4.7 Pressure System

A pressure system is any system which is capable of maintaining a system pressure that is different from the ambient atmospheric pressure.

4.8 Shall

“Shall” indicates a mandatory requirement.

4.9 Should

“Should” indicates a provision which is not required, but which is recommended as good

4.10 Visitor

Visitors are trained in general clean room safety and gowning procedures, but are not authorized to operate equipment.

5.0 HAZARDS IDENTIFICATION

This section describes hazards associated with operating the DWL 66fs laser mask writer. Authorized users and service personnel must be aware of these hazards and trained to manage them by applying the hazard identification, work plans, and controls specified by the Sandia Integrated Laboratory Management System (ILMS). See https://my.sandia.gov/authsec/portal/ilms/ for complete details.

5.1 Asphyxiation Hazards

The pressure system that actuates the sliding door that separates the nominal hazard zone (NHZ) work space and the operator is supplied by house nitrogen. Nitrogen is a simple asphyxiant and, in the event of a pressure system leak, can displace the oxygen in the room. The asphyxiation risk is low, however, due to the constant circulation of clean room air. In their site specific training, all personnel shall be aware of the location and the visual and audible alerts associated with oxygen monitors and Toxic Gas Monitoring System (TGMS) light towers in the Integration Laboratory.

5.2 Electrical Hazards

The DWL 66fs is fed by a 240 VAC utility. The potential for lethal electric shock exists when users are exposed to energized circuits within the mask writer's power sub-systems. Key Operators and service personnel who must perform maintenance on energized circuits must obtain a Hot Work Permit and apply Lock-Out-Tag-Out (LOTO) controls.

5.3 Laser Hazards

The DWL 66fs includes a semiconductor laser operating at 405 nm which can cause serious eye injuries. In normal operation, the laser beam is enclosed in a Class 1 (no hazard) condition. The NHZ, defined by the volume within the mask writer enclosure, is covered by a sliding door that prevents viewing injury. No user shall remove laser beam covers or defeat the enclosure door interlock during normal operation. Laser eye wear that is compatible with the laser wave length and of appropriate optical density must be worn during maintenance where the beam is exposed. Contact the Deputy Laser Safety Officer (DLSO) for laser eye wear support.

5.4 Pressure Hazards

A pressure system is used to actuate the vacuum chuck and the mask writer enclosure door. Dangerous pressures may exist and maintenance may only be performed by a qualified Pressure System Installer or field service technician.

5.5 Mechanical Hazards

Mask writer elements, such as the stage and the sliding enclosure door, contain moving parts that may start or stop unexpectedly. The potential for pinching or crushing injuries exists. Authorized Users and Key Operators must be familiar with the location and operation of the emergency cut-off switches (EMO's) on the machine, and must take care to keep their bodies clear of moving parts.

6.0 EQUIPMENT AND MATERIALS

6.1 Equipment

The DWL 66fs shown in Figure 1 consists of the mask writer apparatus with supporting

Figure 1. Heidelberg DWL 66fs, front view

equipment rack, and laser power supply (not shown). Two personal computers (not shown) support mask writing operations. A Linux-based machine is used for mask file conversions, while a Windows XP machine is used to process exposure maps.

6.2 Materials

The DWL 66fs may expose photo resist on soda lime or similar glass plates, or write directly on semiconductor process substrates. Glass plates must be stored in the Integration Laboratory refrigerator to preserve the photo resist prior to use. The chilled plates must warm to room temperature for at least thirty minutes prior to exposure.

7.0 OPERATING PROCEDURE

7.1 Scheduling

Scheduling of the DWL 66fs is controlled by an online calendar. Open the calendar by the following steps. Navigate to www.google.com. Enter "/calendar" in the search window. Select Google Calendar. Enter the following username and password at the Google Calendar login page: username: “cintdwl,” pass word: “cintDWL 66FS.” Click on the time slot of your choice to create a new event and follow the instructions in the pop-up menu.

7.2 Start Up

Start the DWL 66fs by the following steps:

- Verify that the red EMO switch on the front of the machine is not depressed (see Figure 1). If it is, it must be reset.
- Verify the main breaker on the on the front of the electronics rack is on.
- Press the green ON-button located on the front panel (see Figure 1).
- Activate the laser by turning the key switch on the power supply behind the machine. **The laser requires 30 minutes to stabilize prior to exposure operations. Enter the laser warm-up start time in the Operation Log Book.** Remove mask substrates from the refrigerator and begin warming to room temperature at this time.
- **If laser is turned off for any reason, you must wait at least one hour before powering it up again.**
- Switch on the Linux Conversion PC and the Windows XP User PC.
- Enter the User PC password provided by the Key Operator.
- On the User PC, click on the appropriate icon to open the DWL 66 user menu.
- Click on the appropriate icon to open the Tera Term. **(This is only necessary if communication has been interrupted).**
- Pres Enter for the login prompt. Login by entering “dwl” for both the user name and password.
- Close the terminal by again clicking on the icon or the X in the upper right corner of the Tera Term window. A window will open showing the system settings of the current configuration. Confirm by clicking OK. The communication port is now available to process commands.

7.3 Mask File Conversion

Mask files that are created using CAD software such as L-Edit, AutoCAD or DWL2000 must be converted from cif, dxf, or gdsii format to that used by the DWL 66fs. File conversions are performed on the Conversion PC running the Linux OS. All commands in Linux are single click on mouse.

7.3.1 Load Mask File

- Insert a USB drive or CD-ROM into the Conversion PC and open the home directory by clicking on the "little house" icon at the bottom of the screen.
- Copy the file to be converted to the appropriate directory (cif, gdsii, or dxf) on the desktop, and remove the storage media.
- Start the conversion software by clicking on the large red **X** (XConvert) icon near the center of the screen.
- Open a new conversion job by clicking File-New Job. Select a conversion job name according to the conversion file naming convention listed in the mask writer log book and enter the name in the log book. Alternatively, select File-load job if an existing conversion job is being resumed. Select the file type that matches your mask file. This action will open the Options window where conversion settings will be selected.

7.3.2 Select Conversion Options

Figure 2 depicts the Convert and Options windows. The following steps review conversion options.

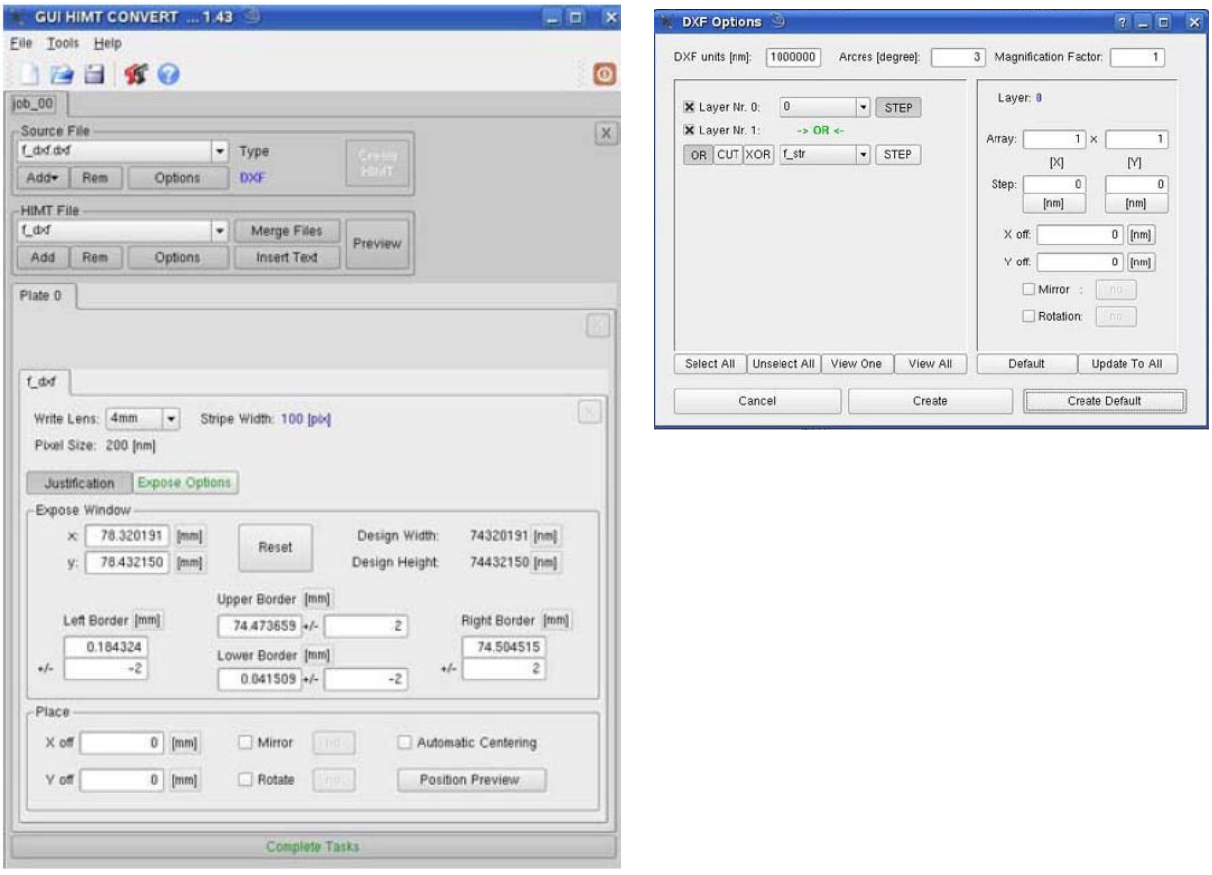

Figure 2. Convert and Options windows (Princeton University)

- In the Options window, select all layers that are to be converted. Individual layers may be joined by Boolean operations as shown in Figure 3.

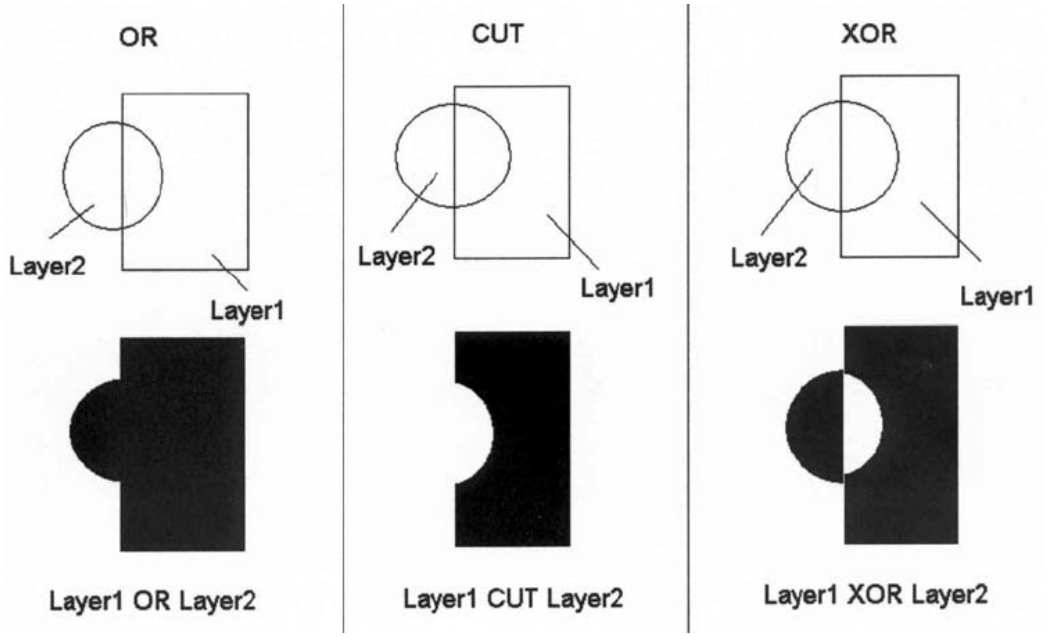

Figure 3. Boolean layer operations (Princeton University)

- Select STEP at the left of the Options window (see Figure 2). In the Array fields enter the integer number of patterns to be repeated in the X and Y directions. In the Step fields, enter the step size for each pattern (this number should reflect the pitch of the array, or the sum of the pattern total length and the space between patterns). Enter the X and Y offsets in nanometers (if desired) in the X off and Y off fields.
- Mirror and Rotation options are available if changing rotational orientation of a pattern or mirroring a pattern is desired. Rotation is discussed here. Figure 4 illustrates proper rotation for an array of parallel lines. The DWL 66fs exposes

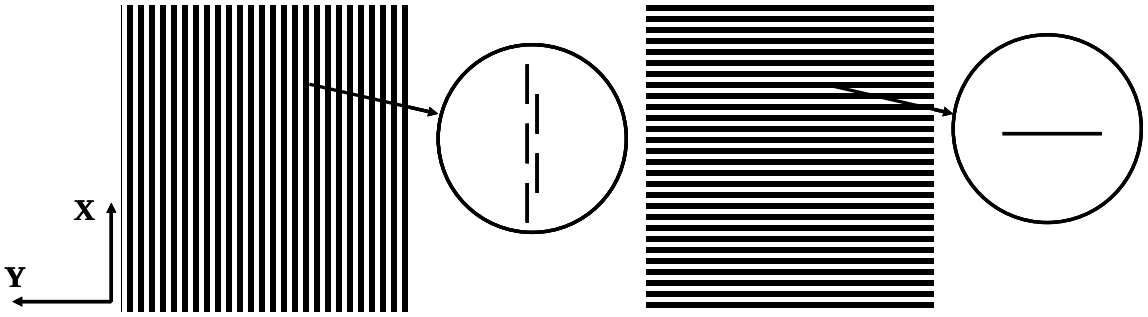

Figure 4. Array of parallel lines indicating proper alignment with the machine axes

features continuously (referred to as “writing stripes”) in the Y direction, and steps in the X direction. In the left of Figure 4, lines are oriented parallel to the X axis. The result is individual lines that have a piece-wise stitched appearance due to stepping in the X direction. The proper array alignment is depicted at the right, where lines are oriented parallel to the Y axis and are exposed in a continuous fashion. Select the Rotation feature to orient the pattern such that long, continuous features are aligned parallel to the Y axis as shown.

- When converting DXF files, enter the units conversion in the DXF units field.
- The Arcres feature defines the resolution of arcs in degrees. A smaller resolution will increase the conversion run time.
- Select Magnification Factor greater than the default (1) if magnification of the pattern is desired.
- Click Create Default at the lower right of the Options window to complete the conversion set-up.
- Look for and heed warnings in the status window.

7.3.3 **Preview**

To preview the mask prior to conversion, click Preview in the Convert window. The following is a summary of the most useful preview modes. Click the mouse wheel to exit from each mode.

- Clicking Fill will show the black regions that will be exposed by the laser in a non-inverted pattern. Clicking Polarity will depict the inverted image.
- Click All to zoom out to the complete pattern.
- Click Left, Right, Up, or Down to pan (move left or right).
- Click Snapshot to capture a JPEG image of the pattern. The image will be stored to the home\convert directory.
- Return to the Options window to make changes. Click Redraw in the Preview window when finished.
- Click Measure to determine dimensions of the pattern in millimeters. Record for later use.
- Click File/Exit to close viewer when previewing is complete.

7.3.4 **Select Justification Options**

Figure 2 depicts the Convert window with the Justification tab selected. In selecting justification options, the Expose Window is for information purposes and need not be edited. It should, however, reflect a reasonably sized drawing. In the Place window, select the Automatic Centering option. This will center the pattern with the measured center of the mask. Automatic Centering is not selected in the case of aligning a pattern to a previously-exposed reference. Other options in the Place window are redundant with the conversion options and may remain at the default settings. If Boolean operations were not used, or a one layer drawing is to be converted, mirror and rotation functions should be selected now, in the Place window.

7.3.5 **Select Exposure Options**

Figure 5 illustrates the Convert window with the Expose Options tab selected. The four

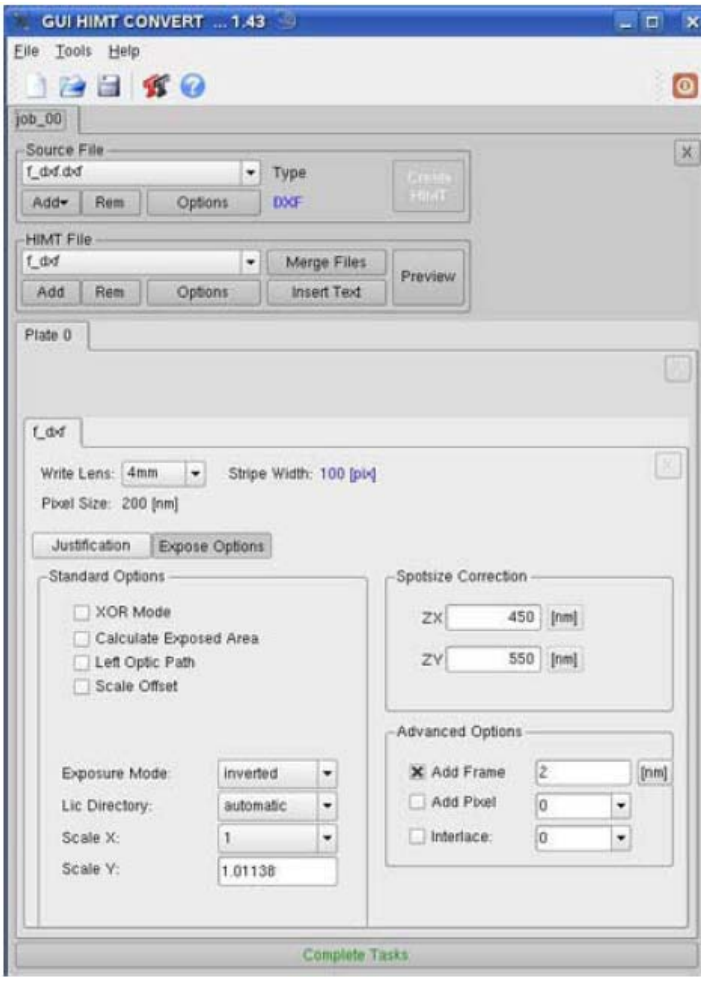

Figure 5. Convert window with Expose Options tab selected (Princeton University)

options at the top of the Standard Options section may be left un-selected. Choose the desired exposure mode: non-inverted (Dark Field) or inverted (Clear Field). Figure 6 illustrates the concept. A

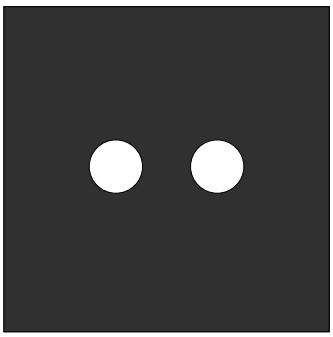

Figure 6. Non-inverted mask

non-inverted (Dark Field) mask will have an opaque, dark field. The exposed circular features will be clear and will transmit light. In the non-inverted mode, the Add Frame field value in the Advanced Options section must be zero. In the inverted (Clear Field) mode, the laser is exposing the field, so an appropriate frame (a border where the laser will not write) size must be selected as shown in Figure 5. Note: **A 2mm border should be added to expose window borders under the Justification tab to account for this frame.** Accept the default values for the Lic Directory and Scale options. Contact the Key Operator for spot size correction data from the mask writer calibration text file. Otherwise, accept the default values in the Spot Size Correction section. In the Advanced Options section, accept the default value for the Interface option. Some pattern designs will require an extra pixel at the end of each line. Figure 7 illustrates the case when adding a pixel is necessary. In this case, the long lines were

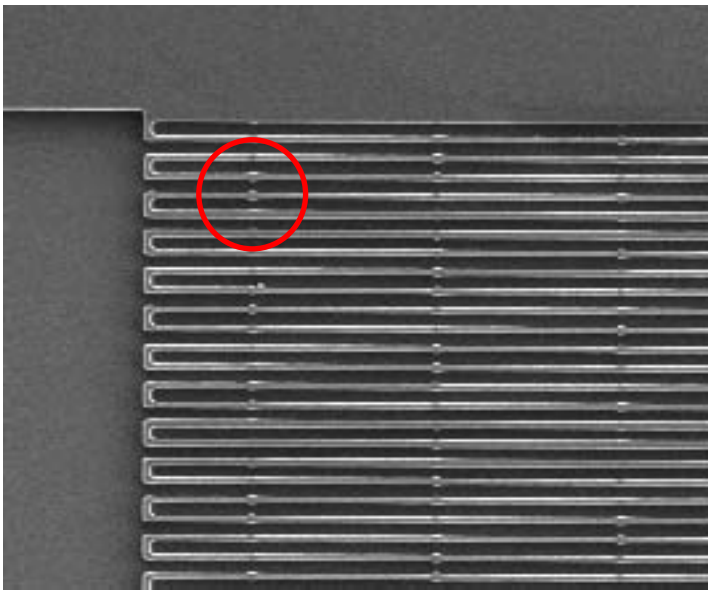

Figure 7. Pattern defect that is remedied by adding a pixel

oriented with the X-axis in the mask design as shown in Figure 4. The resulting stitching errors left a gap at the junctions of the line segments. When the process substrate is etched following lithography with this mask, the result is an array of lines with periodic bulges as shown. Adding one extra pixel (enter a value of 1 in the Add Pixel field) at the end of each line OR orienting the line segments with the Y-axis as suggested in Figure 4 eliminates the defect. **Note: the manufacturer recommends adding at least one pixel to all conversions that use the 10mm or larger write lens.**

7.3.6 Convert

This section lists the steps for completing the mask file conversion.

- Verify the correct files in the Source File and HIMT file windows. Text can be added to the mask by selecting the Insert Text button in the HIMT File section. In

non-inverted exposure mode, the text will be clear. Other options in these fields are not discussed here.

- Select the desired write lens in the pull-down menu (the procedure for changing the write lens is included in the following section). Note the stripe width and pixel size.
- Click on the Complete Tasks bar at the bottom of the Convert window. The Conversion Progress window will appear. Click "ok" when the conversion is complete.
- Click on the Finish button. The Transfer Lic Files window will appear.
- Click Save and Transfer to move the converted mask file to the User PC. Once transferred, mask files are stored in the /h1 directory on the User PC.
- Exit the conversion software.

7.4 Mask Exposure

Follow the steps in this section to fabricate masks. To get started, open the DWL 66 software by clicking the smiley face icon on the User PC desktop. Click "ok" in the DWL Menu window and the DWL 66 menu and toolbar appears (see figure, below).

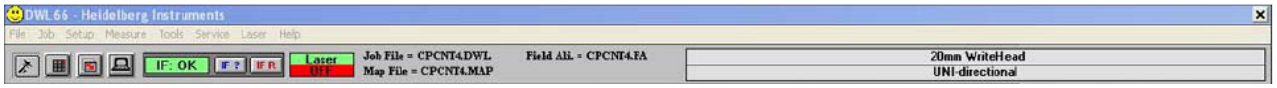

Figure 8. DWL 66 menu and tool bar (Princeton University)

From left to right, the icons in the toolbar open the DWL Control Panel, open the Exposure Map, start the manual plate alignment sequence, and open the Mini-Terminal, respectively.

7.4.1 Configure the Write Lens

Each write lens corresponds to a minimum pixel size. For example, the 4-mm write lens produces an 800-nm minimum pixel size. If the current write lens is not desired, a new one must be installed.

- Open the Control Panel menu by clicking the appropriate icon shown in Figure 8, above. Figure 9 is a screen capture of the Control Panel menu.

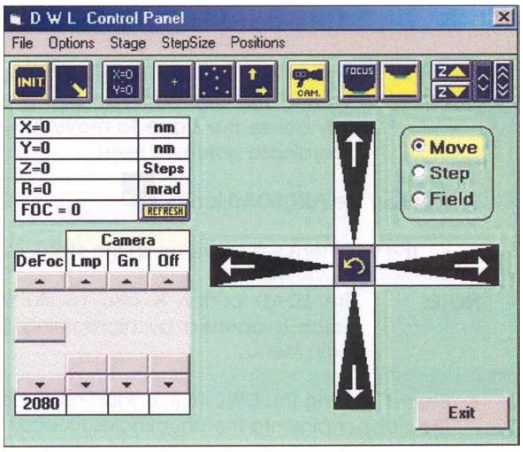

Figure 9. Control Panel menu (Princeton University)

- Before initializing the positioning system, check the interferometer status icon in the DWL 66 menu (see Figure 8). The icon should read "IF: OK" against a green background. In the event the icon reads "IF ???," click the "IF ?" button. If the status icon reads "IF: FAIL," reset the interferometer by clicking the "IF R" button and check the status icon once again. In the rare case where the "IF: FAIL" status persists, verify the interferometer beam path is clear of obstructions. **When checking the interferometer beam path, take care not to touch the interferometer mirrors. Any contact may cause permanent damage and interferometer failure.**
- Select the INIT icon to initialize the positioning system. Stage will not move if door is open.
- Click the Load icon directly adjacent to the INIT icon to move the stage to the load position. More importantly, the write lens assembly will move up to facilitate removal.
- **When executing the following steps, take care not to touch the interferometer mirrors.** Note the location of the mirrors relative to the write lens assembly.
- Carefully unplug the motor and piezo cables attached to the write lens assembly as shown below.
- With a #3 metric Allen wrench, loosen the four fasteners on top of the write lens.
- While supporting the write lens assembly with one hand, loosen and remove the fasteners. Do not allow the write lens to fall. Upon removing the fasteners, gently lower the write lens and remove it.

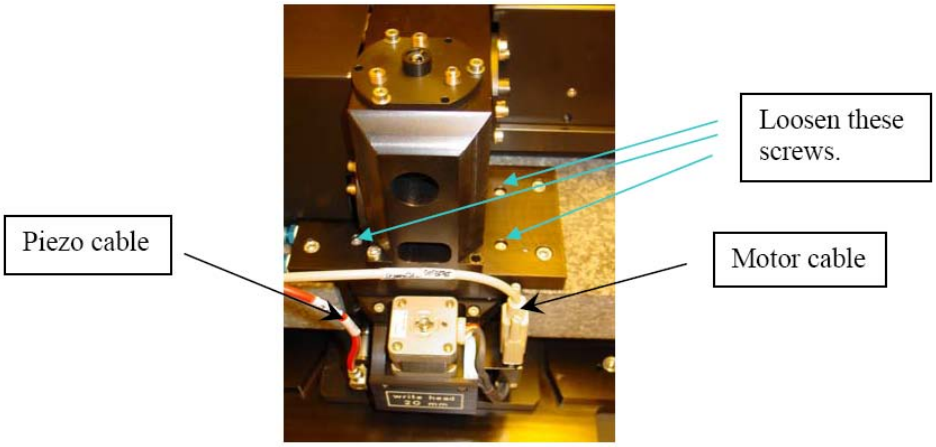

Figure 10. Write lens assembly (Princeton University)

- Insert the new write lens assembly into the mount gently until it stops. Install the fasteners and tighten in a cross pattern. Do not over-torque the fasteners.
- Attach the motor and piezo cables.
- Double click on the write lens fields in the DWL 66 toolbar (at right in Figure 8).

- Select the write lens that was installed and the writing mode: UNI-directional (4mm lens only), binary exposure mode, or gray scale. Click on “Load it!” when finished.

7.4.2 Load Substrate and Focus

Perform the following steps to load a resist-coated glass plate for exposure. Direct writing on process substrates is discussed in a later section.

- Click the Load icon directly adjacent to the INIT icon once again to move the stage to the load position.
- Inspect the substrate platen (chuck or plate) attached to the stage. The continuous platen with small vacuum holes is commonly used for front-side mask exposures. If back-side alignment is desired, replace the platen with one with a port for viewing the substrate with the under-side camera. Be careful not to disturb the platen o-ring or damage the write head when changing the platen. The following steps apply to the continuous platen.
- Install the alignment pins into the holes in the platen for easy mask alignment. When loading an unexposed mask plate covered with resist, verify the yellow light is activated in the room and within the machine enclosure before opening the mask container. • If computer monitors are positioned close to the machine, verify the brightness is set to a minimum.
- Remove the mask plate from its container and verify the resist-covered side of the plate is facing up. **Do not touch the resist. If resist becomes damaged, replace the mask plate.** To facilitate repeat registering of the mask plate on the chuck, consider adding a small scribe mark in one corner, away from the exposed area.
- Mount the mask plate on the platen. Tilt the mask plate slightly until it contacts the alignment pins. Set the mask plate down carefully.
- Switch on the vacuum with the lever at the front of the platen as shown below.

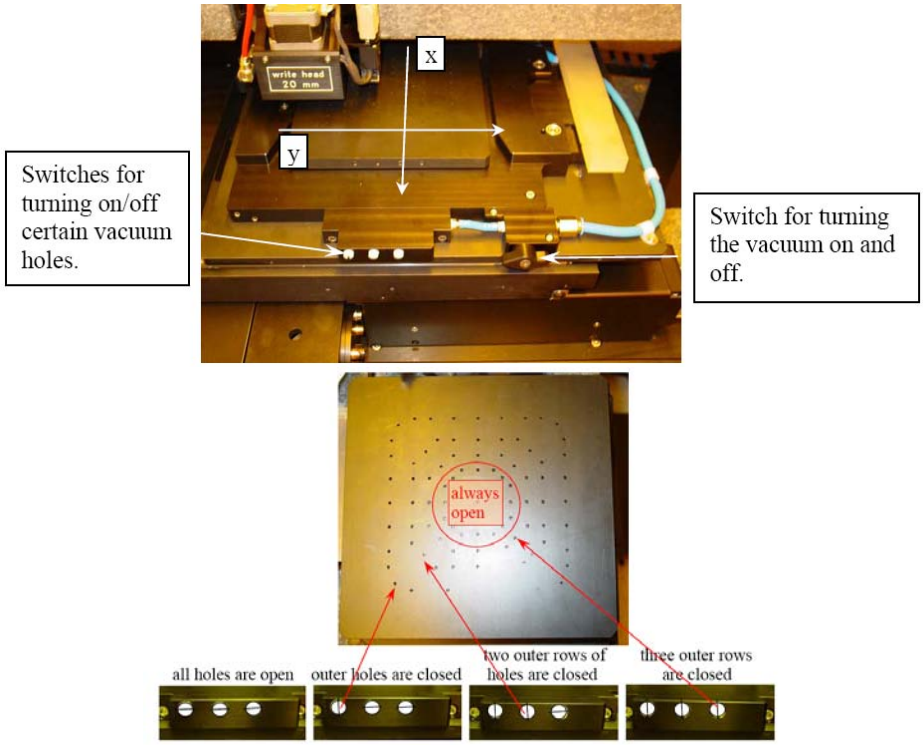

Figure 11. Vacuum controls (Princeton University)

- The four white screws at the front of the platen open and close different rows of vacuum holes. Adjust as indicated. The central locus of holes is always open. In the case where the mask plate is smaller than the smallest vacuum area, use a thick foil to cover the open vacuum holes. Once the mask plate is mounted vacuum is activated, verify the vacuum by pushing laterally on the mask plate. If the plate can be moved easily, there is a vacuum leak. Attempt to improve the holding force by pressing the plate down carefully against the platen. If this is not successful, check the surface of the mask plate for abrasion or foreign objects. Replace the mask plate if necessary.
- Following successful loading of the mask plate, click on the INIT button to center the stage. **Verify that the mask plate is approximately centered under the write head and that the nitrogen feed to the machine is on. Failure to do so may cause the write head to crash during the subsequent focus operation.**
- Click on the Focus button and accept the default defocus (DeFoc) value.
- Find the center of the mask plate by doing the following. In the Control Panel, select Stage and Find Plate Center then click the Start button when the prompt appears. Click "Yes" when the center seeking operation completes (set plate center to 0,0).

7.4.3 **Build the Exposure Map**

Building the Exposure Map relies on map, dwl, and other job files transferred to the User PC as a product of conversion. With these files, execute the following steps.

- In the DWL 66 menu, choose Setup and New. The New Exposure Map window will appear. In the directory menu, \vbmenu\wafer should already be selected. If not, open these folders before proceeding.
- Click on Create Map and input a file name according to the exposure map file naming convention listed in the mask writer log book and enter the name in the log book. A project directory is created and three default root files from \vbmenu\windwl are copied into the new directory with the project name and the respective extensions. To load an existing map, click on the Environment folder in the directory menu, then double-click on the map file (<project name>.map) listed to the right. Confirm in dialog box to change to the new project environment.
- To work with the new map, click on Yes to set the environment. In the New Exposure Map window and in the "C:\..\vbmenu\wafer" field, double click on the folder that was just created. Corresponding files will appear in the rightmost window. Double click on the ".map" file and select "Set Environment to" and exit the New Exposure Map window.
- Select Exposure Map located under Setup in the DWL 66 menu. The Exposure Map Design window will appear, showing the current settings. See figure, below. Edit exposure map design settings according to the rules listed below. The design rules are illustrated in Figure 13.

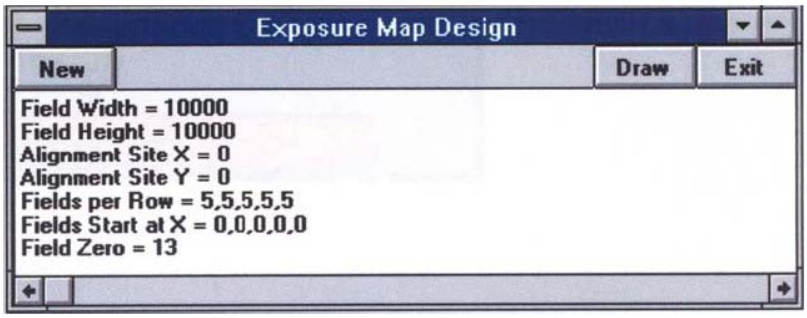

Figure 12. Exposure Map Design window (Princeton University)

Field Width, Field Height is the width and height dimensions of each field or die site on the mask in micrometers. The value must be large enough to accommodate thee extents of the pattern.

Alignment Site X / Y denotes the coordinates of any alignment marks or reticles to the origin of the local coordinate system (typically the lower left corner of each field). Up to four alignment sites can be entered, separated by commas.

Fields per Row indicates the number of fields or dies in each row of the mask delimited by a comma. As many rows will be created as there are numbers in the entry. In the example shown in Figure 12, there will be five rows, the first row has five elements, as does the second, third, and so on.

Fields Start at X indicates the X-axis coordinate position in micrometers of the start of each row of fields with respect to the global (mask) coordinate system. In Figure 12, each row begins at X = 0.

Field Zero is the numerical identification number of the field that corresponds to the origin of the mask substrate. The center of this field is the zero point for the exposure and it must match the coordinate origin set previously in the Control Panel. The Field Zero will be represented in the exposure map with an "X."

- Click on the Draw button when design edits are complete. The Map corresponding to the latest entries will be displayed in the Map window (see figure below).
- Close Exposure Map Design window and save the exposure map by clicking the Exit button.

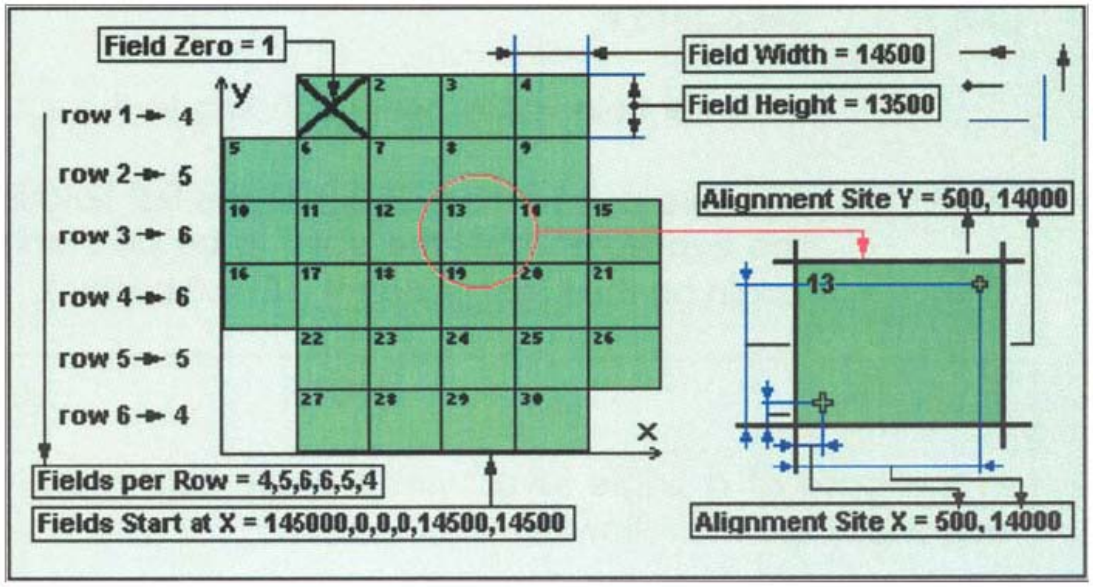

Figure 13. Exposure Map (Princeton University)

7.4.4 Edit and Run the Job

This section discusses the Make Job utility in the Job menu. The Edit Job worksheet allows the user to select exposure or measurement parameters.

- Select Job and Make Job in the DWL 66 menu. The Edit Job worksheet appears as shown below. Open the File menu. Select New to open a blank worksheet with rows corresponding to the rows in the current exposure map. Select an existing job file from the \VBMENU\WAFER\ directory, if available. Be sure to load the map file corresponding to the existing job. Modify the worksheet by the following steps.

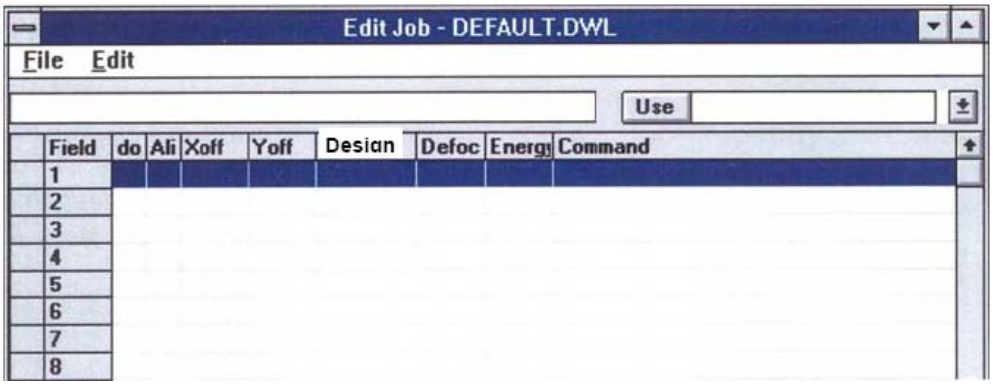

Figure 14. Edit Job Worksheet (Princeton University)

- Click on the "do" field for Row (Field) 1. Enter **-1** if the field is to be exposed and **0** if it is to be skipped. Repeat for all rows in the worksheet.
- If the pattern is to be actively aligned to the mask substrate, click on the "Ali" field for Row 1. Enter one of the following values. Otherwise, leave blank.

ALI=1: alignment to a single reticle or alignment feature.
ALI=2: alignment to two reticles.
ALI=3: alignment to three reticles.
ALI=4: alignment to four reticles.
Verify the reticles were entered previously in the Exposure Map Design window (see Figure 12). Repeat for all rows in the worksheet.

- Click on the Xoff field for Row 1 to enter a decimal offset of the pattern in micrometers from the local coordinate system datum (the field that contains the Field Zero, see Figure 13) as calculated by the exposure map. Repeat for the Yoff field. Repeat for all rows in the worksheet.
- Click on the Design field for Row 1. In the DWL 66 menu, select File and Designs. Click Refresh if the file of interest does not appear. Select the converted design file from the "lic" directory and click on To Job. Multiple designs may be exposed in a single field by separating file names with a semicolon. Repeat for all rows in the worksheet.
- Click on the Defoc field for Row 1. Enter a defocus value between the limits of 0 and 4095. 4095 steps equal an (uncalibrated) range of approximately ± 10μm. A value of 2048 is equivalent to the nominal focus with no defocus component. If no value is entered, the system defaults to the value of the previous job. When exposing substrates with thick resists, vary the defocus value over several fields to determine the best focus. Note that defocus has the greatest impact when working with the two and four-millimeter write lenses which have a very small depth of focus. Conversely, defocus will be ineffective with the larger write lenses such as the 40-mm. Repeat for all rows in the worksheet.
- Click on the Energy field for Row 1. Enter the optimized laser energy in increments of 10 from 10 to 100. The optimized energy for each write lens is listed in the current parameter calibration text file. Repeat for all rows in the worksheet. Repeat for all rows in the worksheet.
- Click on the Command field for Row 1. Commands may be selected from the menu above the Job table. Click the Use button to accept. Commands to be executed before an exposure or measurement must be preceded by the keyword BEFORE. Commands to be executed after the exposure / measurement are to be preceded by the keyword AFTER. Do not enter BEFORE or AFTER more than once. Multiple commands must be separated by a semicolon. Repeat for all rows in the worksheet.
- Select File and Exit to save the job.
- In the DWL 66 menu, open the Expose window by selecting Job and Run Job.
- Click on Expose. **Be careful not to hit the enter key at this time, as this action will terminate the exposure.** Fields in the exposure map will turn green as they are completed. If any remain red following the exposure sequence, an error has occurred. Click on Edit Report in the Expose window for details.
- Upon completion, click on Unload and remove the mask. Then, click Exit. Click on INIT in the Control Panel menu to home the stage. The mask may now be developed according the recipe provided by the Key Operator.

7.5 Mask Metrology

Measurements can be performed with the DWL 66 metrology tool suite to correct for alignment errors between the mask or substrate and the pattern to be exposed. Metrology is accomplished using the system cameras, which require sharp focus and contrast on the output display. Contrast controls Lmp and Gn are available in the Control Panel menu for this purpose. Basic metrology options include Distance, Positions, and Line Width. The following steps describe a typical distance measurement.

- Load the mask plate or substrate, initialize the system stage, and focus as described above.
- Load the Exposure Map according to instructions in Section 7.4.3.
- In the DWL 66 menu, select Measure and Distance to call the Distance Measurements window.
- In the Distance Measurements window, click on Manual, in the Alignment field.
- Click the Set Up Measurement bar. The Point of 1st Site window appears.
- Move the cursor to the desired feature and click OK.
- Move the stage to the second point using the stage controls in the Control Panel.
- Move the cursor to the desired feature and click OK. Coordinate dimension results are displayed in the Distance Measurements window. The Goto Site buttons automatically translate the stage to either digitized measurement point. Multiple measurements are possible for statistical purposes by setting the Repeat Measurement field in the Distance Measurements window and clicking the Repeat Measurement bar.

7.6 Pattern Alignment for Direct Writing on Process Substrates

In addition to creating masks, the DWL 66 can write features directly in photo resist on process substrates. This section describes useful procedures for aligning patterns to pre-existing reticles when operating in this mode. The first step to successful alignment is to measure and correct the alignment error in the system. The following example is for a 4-mm write lens.

- Open one of the manufacturer's overlay test patterns by clicking File and Designs in the DWL 66 menu. Select "Overlay4_#," where # is the layer number.
- Initialize the stage and load a substrate that is at least 2.5 inches square and scribe a registration mark in one corner. Focus as described above.
- In the DWL 66 menu, select Setup and New. Double click on "C:\..\VBMENU\wafer\align." Double click again on the corresponding map file and select Set Environment To, and Exit.
- In the Control Panel menu, find the center of the substrate by selecting Stage and Find Plate Center.
- Write the first layer in unidirectional standard mode by selecting Job and Make Job in the DWL 66 menu. In the Edit Job work sheet, click the Design field. In the DWL 66 menu, select File, Designs, Overlay4_1, and To Job.
- In the DWL 66 menu, select Job and Run Job. Following exposure, develop as described above.

- After development, re-register the substrate on the machine in the same orientation and focus. Activate the front-side camera and illuminate the substrate with the camera controls in the Control Panel menu.
- In the Control Panel menu, select Stage and Find Plate Center. Select Move and toggle the arrows to center the test pattern alignment feature in the center of the screen. In this case, the test pattern alignment feature is the corner of the pattern boundary.
- Activate the front side micro camera by clicking on FS Macro Cam in the Control Panel.
- In the DWL 66 menu, load the exposure map for the Layer 1 pattern by repeating the Setup, New, and "Set Environment To" commands listed above.
- In the Control Panel menu, select Field. Click the arrows to move to the same location in the uppermost field in the exposure map. Optimize the camera defocus, illumination, and gain using the Control Panel.
- In the DWL 66 menu, select the Manual Align icon, then Align Along Y-Axis. Click and drag in the Point to 1st Site window to align the cursor cross hairs with the edges of the corner feature on the substrate. Arrows provide fine adjustment.
- After clicking OK, Open the Control Panel and select Field once again. Move to the bottommost field in the exposure map. Repeat the previous manual alignment step, this time clicking OK in the Point to 2nd Site window. An angular error value will be displayed. After clicking OK, the system will return to the first site. Repeat the alignment cycle until the error is less than 0.002 mrad. Exit the loop by selecting Cancel in the Point to 2nd Site window.
- Use the Control Panel to return to the center of the substrate. In the field zero pattern, move the substrate such that the large central cross is centered in the display. Click on Set X=0 and Y=0 in the Manual Global Alignment window. Move the cursor cross hairs into alignment with the central cross. Click OK and exit the window.
- In the DWL 66 menu select Job and Make Job. In the exposure map, click on the Design field and select Overlay4_2. Expose only one pattern at field zero to save time.
- Select Job and Run Job in the DWL 66 menu, followed by Expose and Yes. Following exposure, remove the substrate and repeat the development step.
- After development, load the substrate, focus, and use the Control Panel arrows to move to a site that contains an overlay box-within-a-box feature. If the system was perfectly aligned, the inner box would be centered within the outer box. Execute the procedure in Section 7.5 Mask Metrology to measure the distance from each edge of the inner box to the edge of the outer box. Use simple math to calculate the X and Y components of the centration error of the inner box.
- In the DWL 66 menu, select Service and Edit Configuration File. Add the absolute value of the respective centration error components to the XBEAM# and YBEAM# values if beam deflection in the positive direction is required (see Figure 4). Subtract if deflection in the negative direction is necessary. Once the edits are complete, click OK. Click on the write lens field in the DWL 66 menu and select "Load it!"

7.6.1 **Front-Side Overlay**

With the system aligned, accurate front-side overlays are possible. After developing a base layer, load the substrate and follow the following steps to align and expose a subsequent layer.

- Move to the center of the plate by selecting Stage and Find Plate Center in the Control Panel. Click the Start button when the prompt appears. Click "Yes" when the center seeking operation completes.
- Use the Control Panel arrows to move the stage to the desired reticles or alignment features. Note the coordinates of the reticles.
- Select Job and Make Job in the DWL 66 menu. In the Exposure Map Design window, enter the X coordinates of all the reticles, separated by commas, in the Alignment Site X field. Enter Y coordinates in the Alignment Site Y field.
- In the Edit Job work sheet, enter the number of reticles in the "Ali" field for each row. See Figure 14.
- Complete the exposure as described above.

7.6.2 **Back Side Exposure**

To perform back side alignment and exposure, a substrate platen with a port for viewing with the bottom camera is necessary. Assuming that reticles were previously added to the bottom side of the substrate, activate the bottom camera by selecting BS Check in the Control Panel menu. Click on the Focus icon to focus the bottom camera. Use the bottom camera to determine the coordinates of the bottom reticles and align the top surface pattern to the bottom reticles using the procedure described in Section 7.6.1 Front-Side Overlay.

7.7 **Grayscale Exposure**

The DWL 66 can produce grayscale exposures with up to 32 levels. In other words, the resist can be exposed to varying depth. Sample patterns named "Pyra.." and Grey.." are available by typing File and Designs in the DWL 66 menu.

- Follow the design conversion procedure listed above using a native design file in dxf format with discrete layers corresponding to the grayscale levels.
- In the Edit Job work sheet, enter "g" in the Energy field.
- Run the exposure job as usual and develop. Expect a significantly longer exposure time relative to non-grayscale exposures.

7.8 **Shut Down**

At the end of the session, shut down the system according to the following steps.

- Switch off the laser power supply at the rear of the machine using the key switch.
- Exit DWL 66 menu by highlighting Exit under the File submenu.
- Confirm menu shut down in the dialog box.
- Shut down Windows XP by choosing Shutdown from the Start menu.
- Switch off the User PC and monitor (if not done automatically).
- Press the red OFF-button located on the front panel of the DWL 66fs.

- For a complete shutdown, switch off the red main breaker at the front of the electronics rack.

8.0 EMERGENCY PROCEDURES

All users shall evacuate the Integration Laboratory according to their IL site-specific training in the event of a toxic gas or fire alarm. Do not attempt to secure the DWL 66. Evacuate immediately. In other emergency situations, call "**911**" (844-0911) from the nearest telephone. If unsure if an actual emergency exists, call **"911."** The Manager and Center ES&H Coordinator shall be notified, as soon as possible, after the occurrence of any emergency within the laboratory. In the case of a non-emergency incident, personnel shall notify the Manager and Center ES&H Coordinator (if not available, notify another member of management team). The manager/supervisor shall **call "311"** (844-0311) to report the non-emergency; a trained individual (OOPS Trained Points of Contact*) assigned to CINT will respond and assist in identifying the appropriate reporting process(es) and follow-on steps. If no member of the management team is available, other personnel shall call "311".

9.0 WASTE DISPOSAL

Normal DWL 66 operations produce little waste. Dispose of damaged resist-coated mask substrates as hazardous solvent waste.

10.0 ES&H REPORTING AND DOCUMENTATION REQUIREMENTS

Authorized Users and Key Operators shall read and sign this procedure. A copy with the signed Authorized Users List shall be filed in the Mask Writer LAN (Laboratory ES&H Assurance Notebook).

11.0 TROUBLE SHOOTING

This section is a guide to solving common problems associated with mask writer operations. File conversion is the first operation to check and/or repeat if a problem arises. A high number of stripes in file conversion are a reliable indication that something is wrong. Practical trouble shooting and diagnostic procedures are discussed below.

11.1 Trouble Shooting Common Problems

11.1.1 Exposure Job Will Not Run

- Verify that the AC power cord is plugged into the wall outlet and that the outlet is energized.
- Verify that the machine enclosure window is completely closed.
- Re-boot the OS9 (DWL 66 internal) system and the User PC.

11.1.2 System Shuts Down During Exposure

- The accessed file is too big or the lic buffer is too small. Try splitting the lic file.
- The system reached a limit switch, because the imaging area was set incorrectly during conversion or in the exposure map.
- The accessed file has the wrong format

- The data file is too complex, which causes the MBCIII to be selected without being ready. Try a slower writing speed or a smaller stripe width.
- The interferometer head is broken.

11.1.3 Mask Plate Is Unexposed After Running a Job

- The substrate or resist is incompatible for the laser type.
- The beam path is obstructed.

11.1.4 Mask Is Partially Exposed

- An incorrect write lens is installed.
- Wrong write lens configuration was chosen in the DWL 66 menu.

11.1.5 Overflow Error

Overflow errors will result if the memory in the DWL 66 OS9 processor becomes full. In the event of an overflow, old files must be deleted to free space in memory.

- If not performed previously, click on the appropriate icon on the User PC to open the Tera Term.
- Pres Enter for the login prompt. Login by entering “dwl” for both the user name and password.
- Navigate to the /h1 directory using the chd /h1 command.
- List the contents of the /h1 directory with the dir -e command.
- Use deldir <file name> to delete old files.

11.2 Parameter Calibration

Parameter calibrations are to be conducted by Key Operators only. Calibration procedures for laser energy, digital ramp, and initial position of the AOD (defocus) motor are listed below.

11.2.1 Laser Energy

Laser energy must be gradually increased as it approaches the end of its useful life. An exposure test provides a means of calibrating laser energy for each write lens. It is also necessary when introducing new photo resists.

- Follow the procedures listed above to convert the appropriate test pattern pfm##mm (where ## represents the write lens's focal length) in the home\convert\ root directory (from the DWL 66 menu, select File and Designs).
- Install the desired write lens and mask substrate.
- Focus as directed and set up the exposure map such that several patterns are run at various laser energies. Note that for the two and four-millimeter write lenses, the defocus test will also need to be run. See Section **7.4.4 Edit and Run the Job** for complete details. Run the exposure job.
- Following development, inspect the region of the “pfm” test pattern that includes a series of closely-spaced rectangles under 50X magnification. At appropriate energy levels, the rectangles at the end of the pattern should appear to be very nearly merged as shown below. If there is a noticeable gap, the laser energy is too low. Repeat the

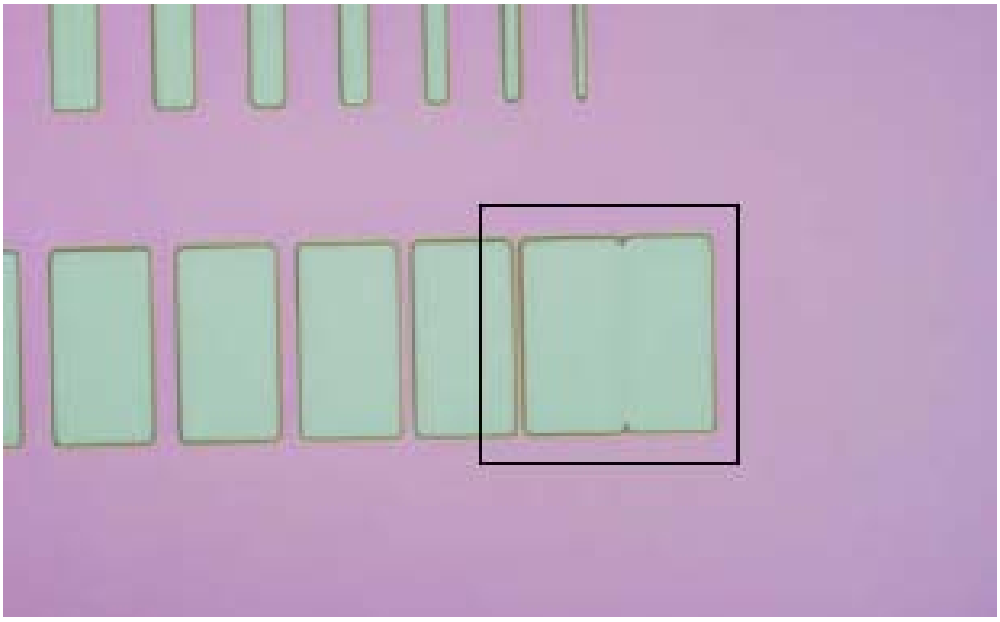

Figure 15. Test pattern for exposure test (Princeton University)

visual inspection to identify the appropriate energy level. Update the mask writer calibration text file accordingly.

11.2.2 **Digital Ramp, DFT (Kris Barraca, Heidelberg Instruments)**

The digital ramp of the DWL 66 controls the spacing between the 'stitches' that make up the image that the system prints out. When the digital ramp is too 'short' for a given write lens, the image appears to have gaps in it. In particular, lines and other structures appear to be incomplete. A digital ramp that is too 'long', on the other hand, appears as a slight bump/bulge in the line itself. A digital ramp that needs to be adjusted can be seen, in general, as deformations within the pattern printed by the system. To find a good value of digital ramp (where a good value is one that creates an image which both looks complete, and has no deformations), test patterns will have to be printed for the user to examine. These test patterns will have differing values of digital ramp. To create the patterns, the user will first have to create a series of files that will change the digital ramp that has been set in the configuration. After a good ramp value has been found, the configuration itself will need to be changed so that the new ramp value will be loaded for future mask writing. Additional detail for each of these steps follows.

Step 1: Preparing the system for change in digital ramp

The system does not recognize changes in command for the digital ramp in the Make Job menu. Instead, for each exposure in the Make Job menu, a new digital ramp configuration file must be loaded. To accomplish this, configuration files for digital ramp values must be created for the system. These files are stored in the sys/dgr directory in OS9 system memory. These can be viewed by the following steps.

- Open Tera Term by double clicking on the icon, then pressing OK to connect. Once in Tera Term, go to the Dgr folder by typing chd sys, then chd dgr after which, you may choose to view the folder's contents by typing dir –e. Typing in dir alone will display the contents of the folder. Typing in dir -e shows the contents in an organized list. The files in this folder are different sets of configuration files for the different write lenses present with the system. Other files which correspond to other values of digital ramp may be present. These files are denoted as dgr_#.####.cfg, where each # represents a number. These files are previous digital ramp configurations that may have been used to test the system at its origin point. Should you choose to test some of these older values, go to the next step.
- To create new files for digital ramp configurations, type umacs dgr_#.####.cfg where the number represented by the # symbols is the actual value for digital ramp that you would like to test. Typing in this command will bring up the umacs editor which is blank, provided that the file did not yet exist. Into the blank area, type dfT=#.#### where the # represents the same value you used for the filename, and the value that you're interested in testing. Once the above line has been entered, you can save the file by pressing Ctrl-x, then s. Afterwards, exit the editor by pressing Ctrl-x, Ctrl-c. Repeat this process for the different values of Digital Ramp which you wish to test.

Step 2: Preparing the Digital Ramp Test

The next step to finding a good value of digital ramp is to prepare the test patterns for examination. This is done by printing the same image with different values of digital ramp.

- Close the Tera Term window and open the DWL 66 menu, choose the correct write lens configuration for the write lens that you have loaded, and prepare the exposure map according to the procedure.
- Open the Make Job menu. Select which fields that you wish to expose, and mark them as usual. Select the pfm##mm as the design for exposure. To change the value of digital ramp in each field, select the command box on the right side of the field that you wish to change. After selecting the appropriate field, use the drop down menu in the upper right hand of the window to select OS9 Command. Press the Use button. In the pop-up box that appears, input the command dg_ramp -f=dgr_#.####.cfg where dgr_#.####.cfg is the name of the file which you have chosen for its digital ramp value. After inputting a different chosen ramp value for each field, expose and develop/etch as usual.
- Examine the plate and find the field with the best image. Note the digital ramp value of that field.

Step 3: Entering the New Digital Ramp Value

- Once the exposure has been finished and the mask analyzed, close the menu and reconnect to Tera Term as in Step 1. Go to the Dgr folder by typing chd sys and then chd dgr. Type in the command dir –e to bring up the directory listing and confirm that there exists a configuration for the write lens with which you are working. Enter the command umacs dgr##mm.cfg to open the umacs editor for the appropriate write lens. You should see "dfT=#.####" and "ft0=####."
- Replace the dfT value with the digital ramp value that you found to have the best image. Save your changes by pressing Ctrl-x, S and exit the editor by pressing Ctrl-x, Ctrl-C.
- Close the Tera Term window, and open the DWL 66 menu. Reload the configuration for the appropriate write lens, and the system is ready for use.

11.2.3 **AOD Initial Position, AOD0 (Kris Barraca, Heidelberg Instruments)**

A bad AOD0 value is characterized by tilts within the lines of an image (along scan axis, typically the Y axis). This causes straight lines in the image to display a periodic misalignment, as shown below. Changing the AOD0 changes the way the line appears. The following instructions allow you to create a mask that contains images with different values of AOD0 for your write lens. Initially, the system is prepared for changes to the value of AOD0. This is accomplished by changing settings in the configuration file. Next, a test pattern will need to be printed. Finally, the new settings will be input to the system configuration.

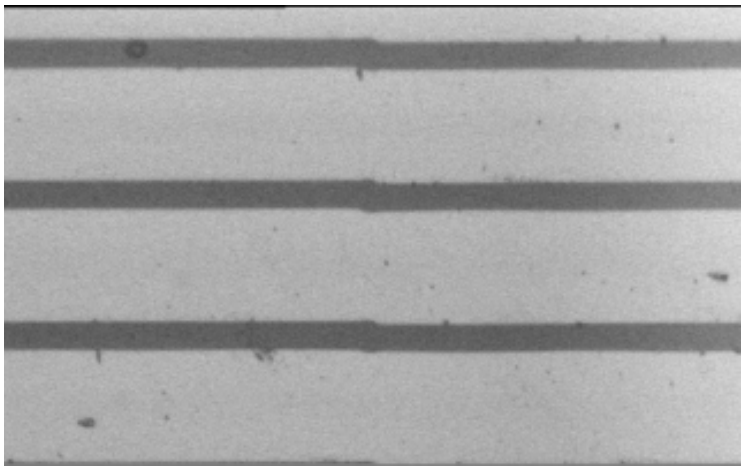

Figure 16. Stitching error due to incorrect AOD0 value

Step 1: Disabling the Default AOD0 Value

The first step towards AOD0 correction involves disabling the default AOD0 value for your write lens in the DWL configuration file. This step is vital; as the system will always disregard any user defined AOD value and load the default value.

- Login to Tera Term by double clicking the Tera Term icon and then type chd sys. This will bring you into the SYS directory, in which there will be a file called "dwl.cfg." Type dir. This will list the objects in the directory. Once you've confirmed the presence of the dwl.cfg file, type umacs dwl.cfg. This will enable the umacs editor, which allows you to edit files contained on the DWL hard disk. You will see a list of what is in the file; it should contain a list of configurations for each write lens.
- Find the listing for the write lens for which you wish to change the AOD0. Under the heading for that write lens, there is a value: "DefDPos = -#.###", where each # represents a number. Place an asterisk (*) at the beginning of this line so that the line reads: "*DefDPos=-####." This will disable the default AOD0 value for the write lens, and will allow you to use other AOD0 values for exposure. To save the change, press Ctrl-X, then S. To exit: Ctrl-x, Ctrl-C (NOTE: make sure that the asterisk addition is the only change that you have made!).

Step 2: Positioning the AOD Motor

This step sets the AOD at the initial position for creating the test pattern.

- At the DWL prompt type "HW Movd+20000." You should get a message stating: Upper End switch reached. This moves the AOD to the upper position, so that you can place it in the range in which you wish to test. Next type: "hw movd-####," where, #### represents the beginning of the range that you wish to test. I recommend testing around the original value of your AOD0. So if your AOD0 is -1500, start the test around -1450 or -1400. After typing the command above, you should get a response from the system that D= the inputted value. At this point, close Tera Term and open the DWL menu. Once the menu opens, reload the configuration for the write lens for which you want to check the values of AOD0.

Step 3: Exposing the Test Pattern and Restoring the Configuration File

This step outlines how to prepare the mask, as well as how to reconfigure the system configuration files.

- Load a new mask plate, center the mask, and prepare the exposure map for exposure. Once that has been done, go to the Make Job Menu. In the Make Job menu, use the pfm##mm Design, where the ## represents the write lens's focal length. Select the box in the Commands column for the first field in which you want to change the AOD0. In the upper right hand corner of the menu there is a drop down menu with a Use button. Click on the drop down menu and select OS9 Command. Press the use button. In the pop up window that appears, type in the command "hw movd-##," where ## represents the amount that you wish the AOD value to change. For example, starting the AOD at -1500, using HW movd-20 will set the AOD at -1520. Pressing OK will place the command in the Commands box in the make Job menu. Copy this command to subsequent boxes, until you have covered the range that you feel is necessary.

- Expose the plate and develop and etch it as usual.
- Examine that plate and find the field with the straightest lines. Use the Make Job menu and your known starting AOD0 value to find the AOD0 value for that field.
- Close the DWL Menu and Open up Tera Term. Return to the dwl.cfg file, as shown above and type umacs dwl.cfg. In the write lens listings, remove the asterisk that was placed earlier, and replace the DefDPos Value with the new value that you've obtained through testing. Save the changes as above and exit Tera Term. Reopen the menu and reload the configuration. The system is ready for use.

12.0 REFERENCES

Sandia National Laboratories Environment, Safety, and Health Manual, MN471001.

Sandia National Laboratories Pressure Safety Manual, MN471000.

ES&H Standard Operating Procedure, Class 3B and Class 4 Laser Systems Operations in Research, SP471409.

DWL 66 Operating Instructions, Princeton University, 2010.

13.0 APPENDIX A: AUTHORIZED USERS LIST

OPERATING PROCEDURE FOR USE OF THE BUILDING 518 HEIDELBERG DWL 66FS LASER MASK WRITER

The personnel whose signatures appear below affirm that they have read and understand this OP and agree to operate within its constraints and meet all requirements specified within it.

Acknowledged by:

Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date
Print Name	Signature	Date