Resist Characterization

GOAL

To achieve high resolution and adequate throughput, a photoresist must possess relatively high contrast and sensitivity to exposing radiation. The objective of the experiment is to determine the responses of lithographic sensitivity, contrast, and thickness loss of positive photoresist as a function of the input process parameters.

INTRODUCTION

Photolithography is the production of a three dimensional relief image based on the exposure with light and subsequent development of a light sensitive polymer called a photoresist. Microlithography is the lithography technique used to print ultra-small patterns, used primarily in the semiconductor industry. The types of radiation, materials, and tools used are important factors for any microlithography process.

To characterize a microlithography process the basic steps are generally the same as those for conventional optical lithography. A radiation sensitive polymer material, called a photoresist, is applied as a thin film to a substrate. Image-wise exposure is then given to the photoresist, usually through a mask of clear and opaque areas on a quartz substrate. Clear areas within the mask allow exposure of the photoresist material, which photochemically alters its composition. Depending on the photoresist type, exposure will either increase or decrease solubility of the exposed areas in suitable solvents, or developer. A positive photoresist material will become more soluble in exposed regions, while a negative photoresist will become less soluble in exposed regions. This solubility differential of exposed to unexposed areas in a resist allows reproduction of the mask image into the photoresist. Regions of the substrate (usually Si or SiO2) are no longer covered by the photoresist film after development. Further subtractive or additive processing can now be performed by either etching unprotected areas or depositing layers over exposed areas of the substrate. The photoresist must be capable of reproducing desired pattern images and provide protection, or resistance, for the substrate for subsequent processes.

Photoresists are generally organic materials polymeric in nature, with properties tailored to specific performance criteria. Resists may be classified either as positive or negative, depending on response to exposure. In two component systems, the resist is formulated from a base matrix resin, which serves as a binder for the material, and a sensitizer, which provides appropriate exposure sensitivity. In addition to these components is a casting solvent that keeps the resist in a liquid state until application, along with dyes, plasticizers, surfactants, or other additives to tailor resist performances. Positive photoresist accomplishes an image-wise solubility differential upon exposure through changes produced in its sensitizer component.
The effectiveness of a photoresist for microelectronic fabrication depends on a number of factors. Not only must a material possess proper sensitivity and resistance properties, it must be suited to the remainder of the fabrication process.

The resolution and contrast of a resist material is important. The term resolution is used to specify the consistent ability to print minimum size images under conditions of reasonable manufacturing variation. Contrast of a resist directly influences resolution, resist profiles, and linewidth control. Contrast is measured in terms of Gamma (γ), and is related to the rate of polymer chain scission and changes in solubility. Resists with higher contrasts result in better resolution than those with low contrast. If a resist had infinite contrast, vertical resist profiles would result independent of image contrast. Calculation of contrast for a typical positive resist is shown in Figure 1.

![Figure 1. A characteristic curve for a positive photoresist.](image)

For a positive resist, increases in exposure cause decrease in film thickness until complete removal of the resist is achieved. The corresponding exposure dose to clear is referred to as $E_0$. To experimentally calculate contrast, photoresist films are given known amounts of exposure and resultant thickness after development is measured. Contrast is determined from the extrapolated slope of the linear portion of the response curve.
Laboratory Procedure **g-line stepper**

1. Obtain bare **six inch Si wafers**.
2. Coat wafers with HPR 504 positive resist. Use SVG track spin speed. Note recipe parameters in lab notebook.
3. Using the NanoSpec tool measure resist thickness of each sample at several points on the wafer to obtain mean thickness and uniformity.
4. Using the GCA 6700 stepper, run an exposure step series on each wafer. An Exposure Test Mask reticle will be used for all exposures. Using the job "MCEE205" and the "EXPO" command, perform an exposure array on each wafer. The "ARRAY" option should be used to increment successive exposures (row 2 to 9 and column 2 to 9) with one focus value.
5. Develop each wafer using the SVG track recipe. Note recipe parameters in lab notebook.
6. Measure film thickness after development in large exposed areas on each sample, for each exposure dose. Use this information to create normalized film thickness after development vs. natural log dose curves.
7. Calculate sensitivity (E_0), film loss (t_i), and contrast (γ) for each sample.

Laboratory Procedure **i-line stepper**

1. Obtain **bare 6" silicon wafer** substrates for each group.
3. Using the NanoSpec tool measure resist thickness of each sample at several points on the wafer to obtain mean thickness and uniformity.
4. Expose using the ASML (i-line) with the following conditions:
   A. Loading Wafers
4.1.1. Lift the cover to the loader (input) and place the cassette of wafers on the stage. Make sure that the cassette is properly seated.

4.1.2. Place an empty cassette on the receiver (output). All 4 stations should have a cassette.

B. Dose to Clear Test (Exposure Matrix)

4.2.1. This test is done with or without a mask and the full field is exposed. No mask will be used for this experiment.

4.2.2. From the Main Menu select 6-Test Manager.

4.2.3. Select 1-Run Test.

4.2.4. Move to the top of the directory by clicking Up.

4.2.5. Select Illumination System.

4.2.6. Select Performance Tests.

4.2.7. Select Resist Uniformity.

4.2.8. Select Accept at the top of the screen.

4.2.9. Input the Nominal Energy, the Energy Increment and the Window Size. Be sure to hit return after each entry. The minimum exposure dose for ASML stepper is 40mJ/cm\(^2\). Select the inputs accordingly. See Figure 2.

4.2.10. Select Accept.

4.2.11. One wafer will be exposed with the nominal exposure in the center of the wafer. The remaining exposures will be divided up above and below this. When the wafer is finished, a report will come up and show the exposure pattern.

4.2.12. When finished, select Exit twice to return to the Main Menu.

4.2.13. A dose to clear test can also be done in the screen used to define a batch.

C. Unloading Wafers

4.3.1. Lift the cover on the output cassette and remove the wafers. Do not remove a carrier that is not fully raised.

4.3.2. Place the empty cassette back on the tool. All 4 stations should have a cassette.
5. Develop each wafer using the SSI track recipe. Note recipe parameters in lab notebook.

6. Measure film thickness after development in large exposed areas on each sample, for each exposure dose. Use this information to create normalized film thickness after development vs. natural log dose curves.

7. Calculate sensitivity ($E_0$), film loss ($t_l$), and contrast ($\gamma$) for each sample.

Figure 2: Resist Uniformity Screen on ASML.