Resist Sensitivity, Contrast and Swing Curves

This lab is an introduction to photoresist coating and exposure on a stepper as related to use in imaging and manufacturing of IC semiconductors.

To achieve the goal of 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.


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 line width control. Contrast is measured in terms of gamma (\( \gamma \)), and is related to the rate of 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 gamma for a typical positive resist is shown in Figure 1.

**Figure 1.** A characteristic curve for a positive photoresist.

For a positive resist, increases in exposure cause decrease in film thickness until complete removal of the resist is achieved. The 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 **i-line stepper**

1. Each group is to obtain 2-3 x 6” wafers, process only one at a time.
2. Coat wafers on the SSI track with OiR 620 photoresist. The class will share data so that each group has all of the information. Each group will coat their wafer at different spin speeds, making sure to use the following speeds: 2900, 3020, 3140, 3260, 3380, 3500, 3620, 3740, and 3860.
3. Using the NanoSpec tool measure resist thickness of each sample at several different radial points on the wafer to obtain mean thickness and uniformity.
4. Plot film thickness vs. spin speed for all wafers.
5. Expose using the ASML (i-line) with the following conditions:
6. Using the ASML stepper, run an energy meander on each wafer. Load a reticle (Material Handler). In the ASML’s main menu, choose Batch Control. 1-Define Batch. Enter a batch ID and select job FEM (5x5 array). Layer ID is FEM. Choose W(wafer) for control mode and number of wafers is 1. Batch type is E(energy meander). Choose your reticle. Enter a starting dose of 40 mJ/cm² and choose an energy step of xx mJ/cm². Apply all data then click Run.
7. Develop on SSI track, program Develop.
8. Using the Nanospec, measure the film thickness in large areas on each sample (die) for each exposure dose, for each wafer.
9. Using the data, create normalized film thickness after development vs. natural log dose curves.
10. Using the above curves, calculate dose to clear($E_0$), film loss($z_l$), and contrast($\gamma$) for each of your wafers and share $E_0$ data with classmates. Determine relationship between spin speed and film thickness.
11. Plot dose to clear($E_0$) vs film thickness.
12. Plot film loss($z_l$) vs film thickness.
13. Plot contrast($\gamma$) vs film thickness.
14. Comment on results.