Dose-to-Clear Swing Curves for Process Optimization

Microlithography Materials and Processes Laboratory (EMCR 676 / 721)
Microelectronic Engineering Department
Rochester Institute of Technology

1. OBJECTIVE

The objective of this experiment is to characterize the resist system swing curve response as it relates to the resist, substrate, and the microlithography exposure system (stepper). The E_o swing curve will be evaluated by varying the control inputs of resist thickness and exposure. The experimental results will then be compared to simulation predictions from Prolith.

2. INTRODUCTION

The objective of the photolithography process is to transfer a binary pattern, which is defined on a quartz mask, to a photoresist-coated substrate while minimizing any disparity in critical dimensions. It is expected that the photoresist will exhibit only two states of spatial variation upon exposure, either the resist thickness will be comparable to the original thickness when coated or it will all be gone. The sidewalls of the photoresist will be vertical if there is no spatial variation as a function of photoresist thickness. Vertical sidewalls would be an ideal result of lithography, however the reality of the materials involved makes this a difficult goal to achieve.

Spatial variation can be introduced to the lithography process by altering the propagation of light through the photoresist during exposure. Since light is absorbed as it travels down through the photoresist, the top of the photoresist will receive a higher dose than the bottom. This leads to wider resist profiles at the bottom for positive photoresist. Light is also reflected off the substrate back toward the top of the photoresist, which can lead to standing waves and possibly swing curves.

The properties of the light that is reflected at the interface between the substrate and the photoresist is defined in simple terms by the amplitude of the reflectance at normal incidence, where the refractive indices involved are complex and the complex part is associated with the absorption of the photoresist:

$$R = \left| \frac{n_{resist} - n_{substrate}}{n_{resist} + n_{substrate}} \right|^2$$

Upon reflection at the photoresist/substrate interface a phase shift occurs in the light reflected back toward the photoresist surface. The path length that the light travels through the resist determines its phase and whether the interference will be constructive or destructive. Interference between the outgoing and incoming light waves due to a phase difference between them will result in a swing curve. The swing curve is a sinusoidal variation in the E_o, or dose-to-clear due to changes in the phase difference between incoming and outgoing radiation induced by varying resist thickness. The dose-to-clear is a parameter of the photoresist that defines the amount of energy required to induce a sufficient change in the resist chemical properties so that all of the resist will develop away.

Resist thickness optimization can be performed using swing curves.

3. SWING CURVE PROCEDURE

1. Obtain ten bare 100mm or 150mm silicon wafer substrates per group.
2. Ensure that the surfaces of the silicon wafers are clean.
3. Use the manufacturer's data sheets and Prolith simulation to estimate spin speed and dose ranges; you want to plot an entire period of the swing.
4. Use appropriate track recipes or for hand coating; dehydrate bake at 100°C for 60 seconds, coat photoresist at different spin speeds to achieve photoresist thickness variation, and soft-bake at appropriate temperature for 60 seconds. Measure thickness on the Nanospec at 5 radial locations on the wafer. Record the average thickness as t_o.
    a. Do not let the 150mm wafers exceed 4000 RPM, or the 100mm wafers exceed 5000 RPM.
5. Expose using the proper stepper procedure.
6. Develop the wafers on the appropriate track or by hand using appropriate PEB.
7. Examine the exposed wafers to determine the dose-to-clear, or E_o, for each initial resist thickness.
8. Try to localize the data-points around the swing curve's min's and max's. Generating a spin speed curve will help you to set the proper casting spin speed to target these thicknesses.
9. Generate a swing curve by plotting photoresist thickness versus E_o (dose-to-clear) [mJ/cm^2].
10. Repeat steps 1-9 above and add steps to coat optimized BARC before resist coating.

3.1 ASML i-line procedure

Follow instructions in ASML user manual for Dose to Clear Test (Exposure Matrix).

3.2 GCA 6700 procedure

Use the ETM reticle.

1. Make sure that the switch below the keyboard is in the "Time Mode" position.
2. Load the blank mask and first wafer.
3. EXPO EMCR221A
4. PASS: 1

At the time of this writing, the first die in a 9x9 array lies off the wafer's edge. Doing an 8x8 array starting at the second position avoids the resulting auto-focus error.

5. STARTING ROW: 2
6. ENDING ROW: 9
7. STARTING COLUMN: 2
8. ENDING COLUMN: 9
9. OVER: E
10. Input the desired starting exposure time
11. Input the desired increment value
12. Use the most up-to-date focus setting (it should be written near the screen)
13. FOCUS INCREMENT: 0
14. Do not run an open frame test
15. RETICLE BAR CODE: NONE (just hit "ENTER")
16. FLOOR #: enter the appropriate value.
17. ALIGNMENT MARK PHASE (P/N/X): X
18. Hit the [RES] key and wait for the laser sensor lights (near the loading boat) to illuminate.
19. Hit the [1st L] key, and then the [S/C] key

4. DATA ANALYSIS

Analyze the E_0 data graphically; evaluate the process window as a function of latitude for exposure and latitude for resist thickness, that is, which target photoresist thicknesses provide the most tolerance for thickness variation?

Empirically fit a sinusoidal function, superimposed upon a linear function, to the data. Use the frequency to calculate the radiation's wavelength in the photoresist, and the photoresist's index of refraction.

Compare and contrast the experimental and Prolith results for process with and without BARC.

Swing Curve Data Sheet

(Use appropriate units)

Spin Speed [RPM]										
Resist Thickness [Å] **(5 radial locations)**										
Average Thickness [Å]										
Dose-to-Clear [mJ/cm^2]										