Critical Dimension Enhancement for DUV Photolithography on the ASML 5500/300

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***Abstract* — The smallest feature resolved with the ASML 5500/300 has been reduced to 150 nm. The new photoresist, UV210-0.3, allowed a thinner coat to be spun. Using varied exposure doses and focus offsets, we have created focus-exposure matrices and Bossung and exposure latitude plots. These plots helped to determine ideal exposure conditions to create 150 nm isolated lines. Furthermore, the use of annular illumination improved the exposure by increasing the exposure latitude. From the test runs it was shown that the exposure latitude was much smaller when using annular illumination. Our results show that 150 nm isolated features can be reliably patterned on SiO2 coated wafers by using a dose of 16 mJ/cm2, focus of -0.23 um, numerical aperture of 0.6, and sigma values of either 0.855 and 0.550 or 0.755 and 0.450 for outer and inner, respectively.**

I. INTRODUCTION

The manual made by the Marvell Nanofabrication Laboratory states that the minimum feature that the ASML 5500/300 can resolve is 250 nm. Other labs using similar systems have reported isolated features down to 200 nm. The goal set by this project was to investigate the smallest feature size that can be resolved in the ASML. Of all the photomasks at the NanoLab, the smallest feature available for testing was 150 nm. The machines used include svgcoat3 for an approximately 600 Å thick bottom anti-reflective coat, svgcoat6 for the approximately 3800 Å UV210-0.3 photoresist coat, ASML 5500/300 to expose the wafer, svgdev6 to develop the wafer, and axcelis or uvbake to UV stabilize the photoresist on the wafer.

II. EXPERIMENTAL

The first accomplishment in this project was the spin speed curve (Figure 1). By coating many wafers at different spin speeds we validated the information from the vendor data sheet. Next, we created a process specification (Table 1) to show the final process that would be used for resolving the smallest features possible. We used a 600 Å layer of bottom anti-reflective coat on top of a 5000 Å layer of SiO2 with a 3800 Å layer of UV210-0.3 photoresist as shown in Figure 2. We achieved the 3,800 Å coat of photoresist with a 1,800 RPM spin speed. Then, we created many Bossung and exposure latitude plots with information from focus exposure matrices. In the Bossung plots we looked for lines that were closest to the target. In the exposure latitude plots we looked for tight bunching of lines at the exposure dose decided upon. When there is tight bunching and a small slope, there can be more variation in the exposure and focus while still staying on target. From these observations, it was obvious that critical dimension enhancement techniques would benefit the exposure. We ran two different annular illumination tests. The small ring had a outer sigma value of 0.755 and an inner sigma value of 0.450. The large ring had 0.855 and 0.550 values for the outer and inner sigma values, respectively. Both annular imaging modes used a numerical aperture of 0.6. After fully analyzing the Bossung and exposure latitude plots we patterned whole wafers to test the repeatability of the results.

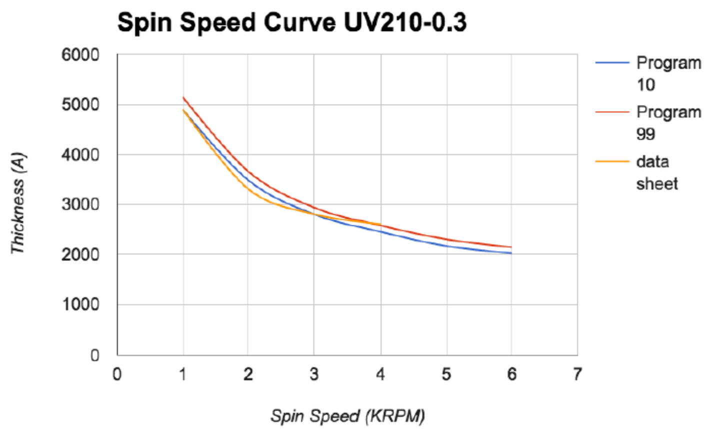

Figure 1 - Spin Speed Curve

Table 1 - Tool Specifications		
Step	Tool	Settings
Prime	(svgcoat6)	Program (1)
Coat	(svgcoat6)	Programs (9,7modified,1) No prime, coat at 1800 rpm for 30 sec. 130 C proximity softbake for 60 sec.
Expose	(asml300)	Run stepper job CMOS200 located in Clarkson folder. Set exposure and focus offset to 14 mJ/cm2 and -0.23 microns respectively. Set alignment type to None.
Develop	(svgdev6)	Programs (1,1,9) Contact post exposure bake at 130 C for 60 sec, puddle develop in MF-26A for 60 sec., no hard bake
UV Stabilize	(axcelis)	Program U

Figure 2 - Wafer Set-Up

III. RESULTS

To compare the performance for the various annular illumination modes, Bossung and exposure latitude plots were created for conventional, large annular, and smaller annular rings. There was a large difference seen when comparing conventional and annular modes and a minor difference observed between the large and small annular modes. The plots in Figure 3 are from a wafer using conventional imaging (no resolution enhancement techniques). At the desired dose of 13 mJ/cm2 you can see that the focus lines are not very tight about the target value of 150 nm. The latitude value in this case is 69 nm. Figure 4 shows plots from the larger annular illumination mode of 0.855 and 0.550. The latitude was brought down to 9.5 nm at a dose of 16 mJ/cm2. A higher dose value is required when using annular illumination because the ring shape blocks some of the light. Plots made from the smaller annular illumination mode of 0.755 and 0.450 are shown in Figure 5. The latitude was slightly smaller at 3.5 nm. Our observations suggest the small ring might be slightly better. These results greatly surpasses that of the wafers with no annular illumination (conventional). Table 2 shows three separate wafers and the results after taking 21 measurements that represent the population of die on the entire wafer. The averages were 142.4 nm and 150.3 nm for the large ring and small rings respectively. The standard deviations were between 10.5 and 13.3 nm.

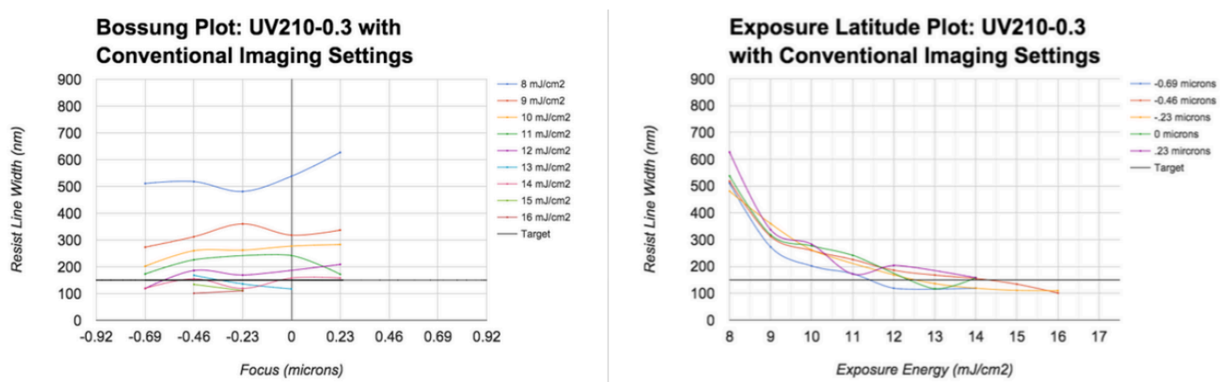

Figure 3 - Bossung and Exposure Latitude Plots with conventional (no annular) illumination

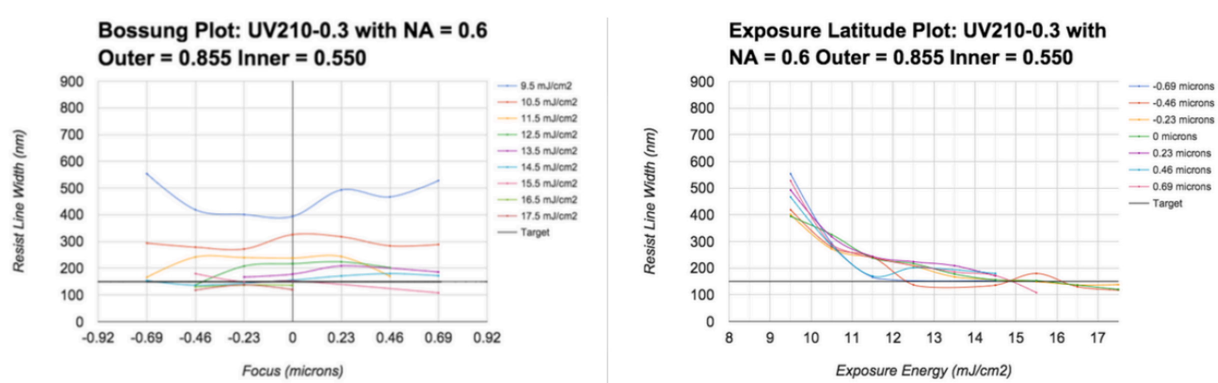

Figure 4 - Bossung and Exposure Latitude Plots for the large annular illumination mode

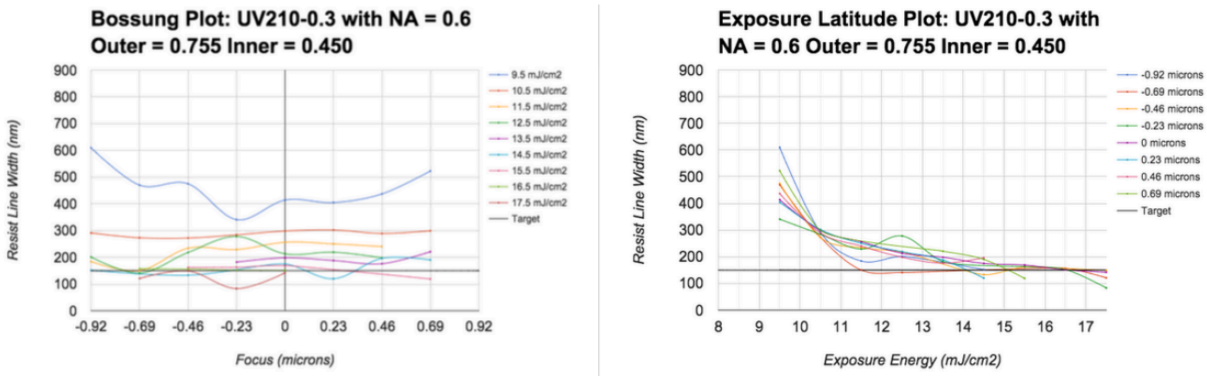

Figure 5 - Bossung and Exposure Latitude Plots for the small annular illumination mode

Table 2 - Wafer Results					
8/5/2015		8/6/2015		8/11/2015	
IF51		IF61		IF64	
16 mJ/cm^2		16 mJ/cm^2		16 mJ/cm^2	
-0.23 µm		-0.23 µm		-0.23 µm	
0.6		0.6		0.6	
0.855		0.855		0.755	
0.55		0.55		0.45	
position	(nm)	position	(nm)	position	(nm)
avg:	142.4	avg:	142.4	avg:	150.3
Std Dev:	13.3	Std Dev:	10.5	Std Dev:	10.9
range:	50.0	range:	32.0	range:	39.0
yield:	90.5%	yield:	52.4%	yield:	90.5%

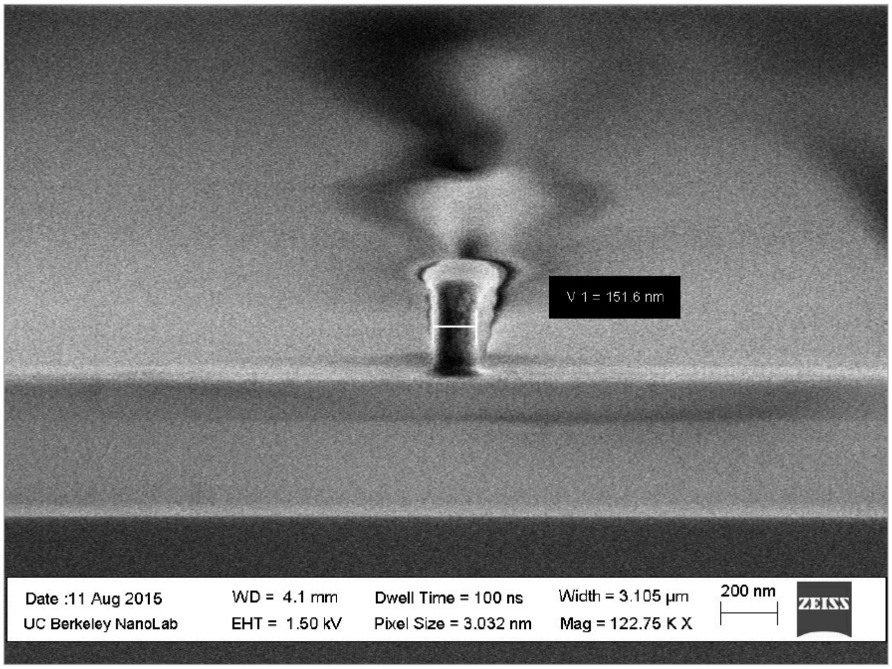

Figure 8 shows the cross-sectional SEM image of an optically lithographed isolated line targeting 150 nm. This line was imaged using 16 mJ/cm^2, a focus of -0.23 µm , NA of 0.6, sigma inner of 0.550, and a sigma outer of 0.855.

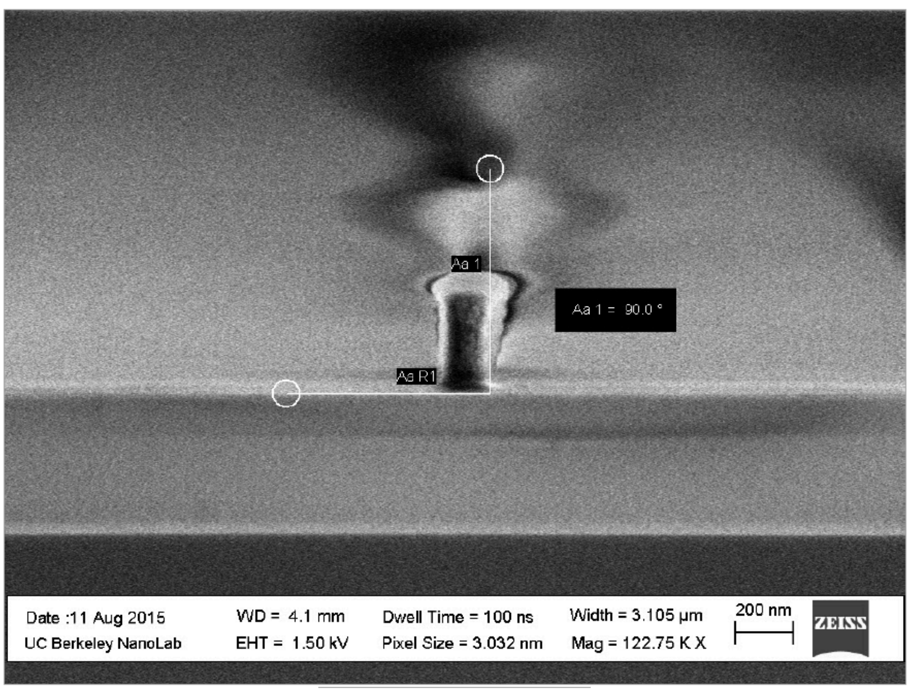

Figure 9 - 90° Sidewalls of the same feature shown in Figure 8. This line exhibits an aspect ratio of ~ 2.5:1 and has smooth vertical sidewalls.

IV. CONCLUSION

The ASML 5500/300 is capable of printing 150 nm lines. Annular illumination was used as a critical dimension enhancement technique which resulted in a repeatable and uniform process from wafer-to-wafer and across wafers. The standard deviation for a CD target of 150 nm was as low as 10.5 nm. Furthermore, the aspect of printed features was kept high at 2.5:1 (H:W) and this will be beneficial for subsequent etching processes.

ACKNOWLEDGMENTS

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