Characterization of e-beam induced resist slimming using etched feature measurements.

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ABSTRACT

ArF resist is critical in the production of today's state-of-the-art lithography. It is well documented[2,3] that process control measurements via CD-SEM at landing energies greater than 200 eV significantly slims the ArF resist, leading to inaccurate measurements and changes in the final geometries of the feature measured in-circuit. Resist slimming is most frequently quantified as the difference between consecutive measurements of the same feature. This study uses an alternative method to measure the slimming caused by a single measurement on a resist feature. Measurements were taken of etched features that had been exposed on a CD-SEM to various beam conditions prior to etch. The slimming was calculated by measuring the delta between the exposed portion of the line and the adjacent un-exposed portion of the same line. Previous work [1] and the results of this current work show that the slimming of the ArF resist carries over through the etch process and measurably altered the final CD. In this work a systematic study of various image acquisition conditions shows that the choice of landing energy dominates all other factors affecting the amount of slimming, with near zero slimming measured for the 100 eV landing energy.

Keywords: low voltage, resist slimming, metrology, CD-SEM, 193 nm resist

1. INTRODUCTION

Recent studies have described the phenomenon of e-beam induced resist slimming. This is a source of uncertainty in the process control data because the critical CD is changed by the act of measuring that CD. In addition to this aspect of resist slimming, the final CD of the etched line is also affected, and a reduction in the final CD is observed. One method that is used to quantify the amount of slimming is to report the difference between two consecutive measurements of the same resist line. The ability to quantify the resist slimming caused by the measurement of a feature is limited by the lack of a pre-measurement reference or knowledge of the feature size prior to slimming. Consequently, this method is not able to determine the amount of slimming caused by the exposure during the first measurement of the feature. The purpose of this study is to examine the amount of slimming that is measured on the etched line as a function of CD-SEM parameters that include landing energy, beam current, and image integration frames.

2. METHODOLOGY

The sample consisted of an array of 130nm 1:1.2 resist lines printed using 193 nm resist (Fig. 1). A one micron square portion of each set of lines was exposed to an image acquisition condition (Fig. 3). The rest of the line remained unexposed (Fig. 2). In choosing the experimental conditions, consideration was given to the typical beam conditions that are used for a CD-SEM measurement. In order to study the affect that total energy dose has on the final CD, these typical conditions were varied through a range of values. By utilizing the Ultra Low Voltage^{tm} capability of the Soluris Inc Yosemite CD-SEM, five beam landing energies were studied, namely 100eV, 200eV, 300eV, 500eV, and 800eV. Beam currents of 20pA and 40pA were used with each of the five landing energies. Exposures were also varied by changing the number of frames used for image integration. The number of frames was chosen as an experimental variable because this parameter is often adjusted as a way of minimizing resist slimming while maintaining an acceptable signal level in the CD-SEM measurement image. Integration frame quantities of 48, 64, 96, 128, and 256 were used for each combination of landing energy and beam current. Care was taken to ensure that the exposed portion of the line was separated from the measurement site of the unexposed portion of the line by 3 microns. This was done to minimize the possibility of the unexposed part of the line undergoing beam-induced slimming due to proximity effects such as the CD-SEM raster over-scan and heat transfer from the exposed portion of the line.

Each exposure condition was used on four different die. After exposure, the wafer was etched. The slimming was computed as the width of the unexposed portion of the line minus the width of the exposed portion of the line. The data from all four die for each condition were averaged to yield a single value for the slimming. All post-etch measurements were made using a single image acquisition condition of 500 eV landing energy, 20 pA beam current, and 64 image integration frames.

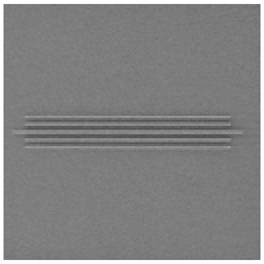

Figure 1: 10 micron FOV
Example line

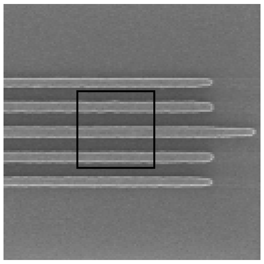

Figure 2: 3 micron FOV
Measured line

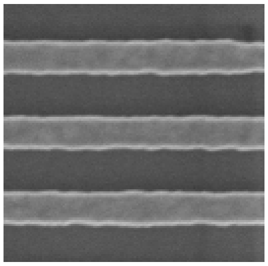

Figure 3: 1 micron FOV
Center line was measured

3. DATA

A number of lines were measured after etch which had not been exposed to e-beam before etch. These measurements were taken to provide a control group for the experiment. The mean delta of the control group (-0.75 nm) was used to normalize the data before the ANOVA analysis was performed. The experimental data for the 20 pA case are presented in Table 1 and Figure 4, and the experimental data for the 40 pA case are presented in Table 2 and Figure 5. The control group data is presented in Fig 6.

	Mean Delta in nm, by number of frames, 20 pA				
Frames	100V20pA	200V20pA	300V20pA	500V20pA	800V20pA
48	0.35	-0.50	-2.21	-2.97	-4.20
64	-1.90	-1.86	-1.66	-3.52	-6.40
96	-0.82	-1.42	-2.44	-4.78	-7.45
128	-1.47	-1.40	-0.96	-4.85	-2.87
192	-1.75	-3.00	-3.67	-5.03	-6.89
256	0.03	-2.49	-4.66	-4.01	-6.74
Mean	-0.93	-1.78	-2.60	-4.19	-5.76

Table 1: 20 pA data

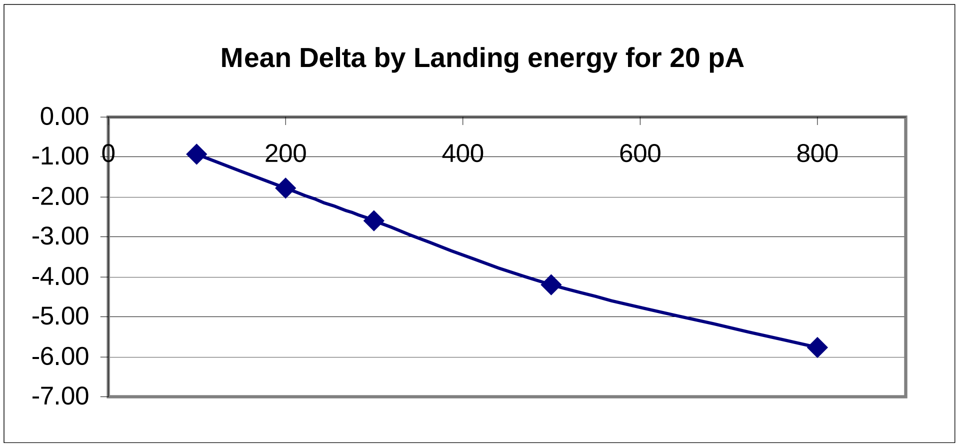

Fig. 4: Chart of delta vs landing energy, 20 pA

	Mean Delta in nm, by number of frames, 40 pA			
Frames	100V40pA	200V40pA	300V40pA	500V40pA
48	-1.62	-1.84	-3.16	-5.33
64	-2.60	-2.20	-2.71	-4.76
96	-1.42	-1.32	-3.45	-7.05
128	-1.58	-2.69	-2.24	-7.41
192	-2.39	-1.67	-3.27	-7.19
256	-1.66	-1.76	-3.87	-6.07
Mean	-1.88	-1.91	-3.12	-6.30

Table 2: 40 pA data

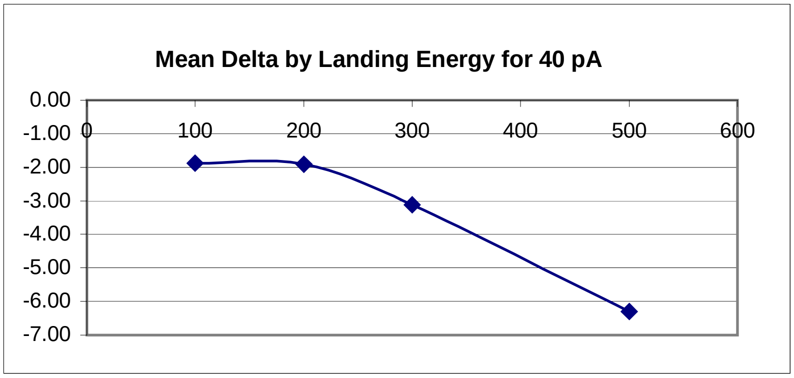

Fig. 5: Chart of delta vs landing energy, 40 pA

Control Data	
Site Number	Delta (nm)
1	2.8
2	3.1
3	-0.2
4	2.9
5	-4.1
6	1.6
7	-3.0
8	-5.6
9	-0.9
10	2.6
11	4.0
12	-0.1
13	-0.6
14	2.6
15	1.1
16	1.3
17	2.9
18	2.7
19	1.2
Mean	0.75

Table 6: Control Data

4. RESULTS

The experimental data was subjected to ANOVA methods to identify the contribution to line slimming for each of the experimental parameters. In each case the deltas were normalized using the mean control delta before the ANOVA. Figures 6, 7, and 8 show that the landing energy is the dominant effect in amount of line slimming that was measured on the etched wafer. Figure 9 is included to summarize all of the currents and frame exposures to show the dominance of the landing energy effect.

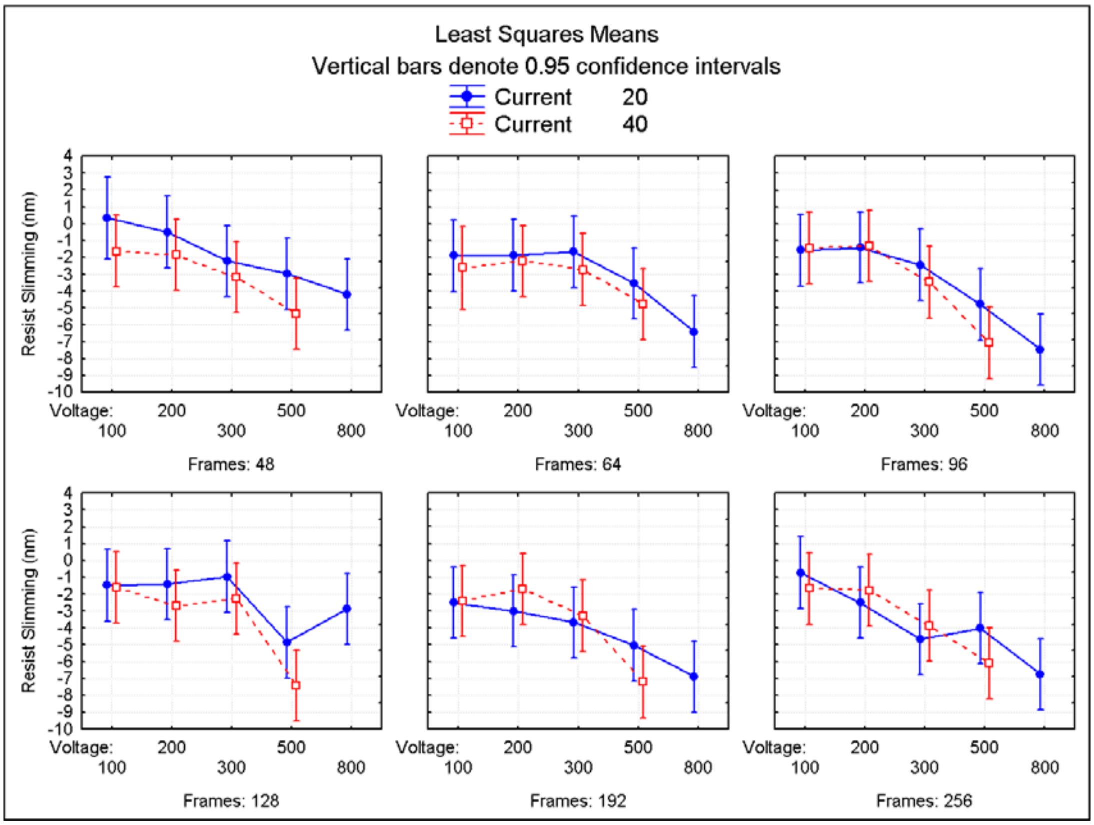

Figure 6: ANOVA results for Landing Energy

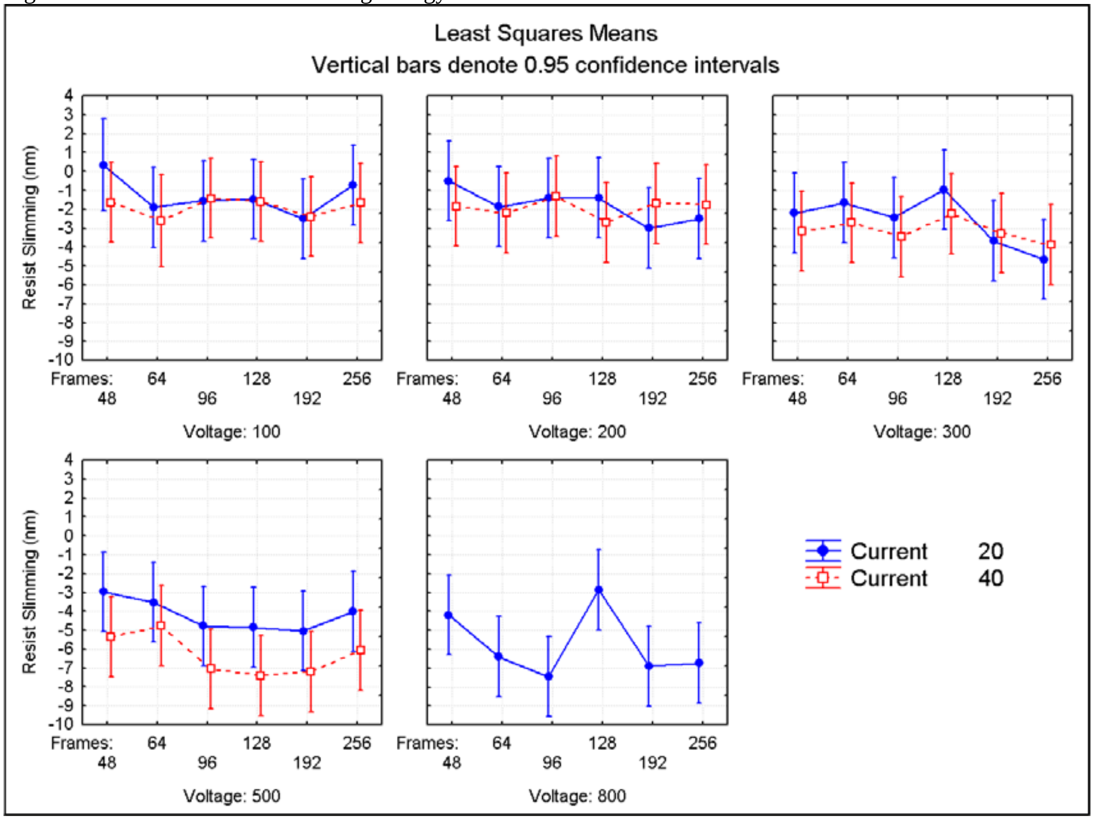

Figure: 7: ANOVA for the number of image integration frames

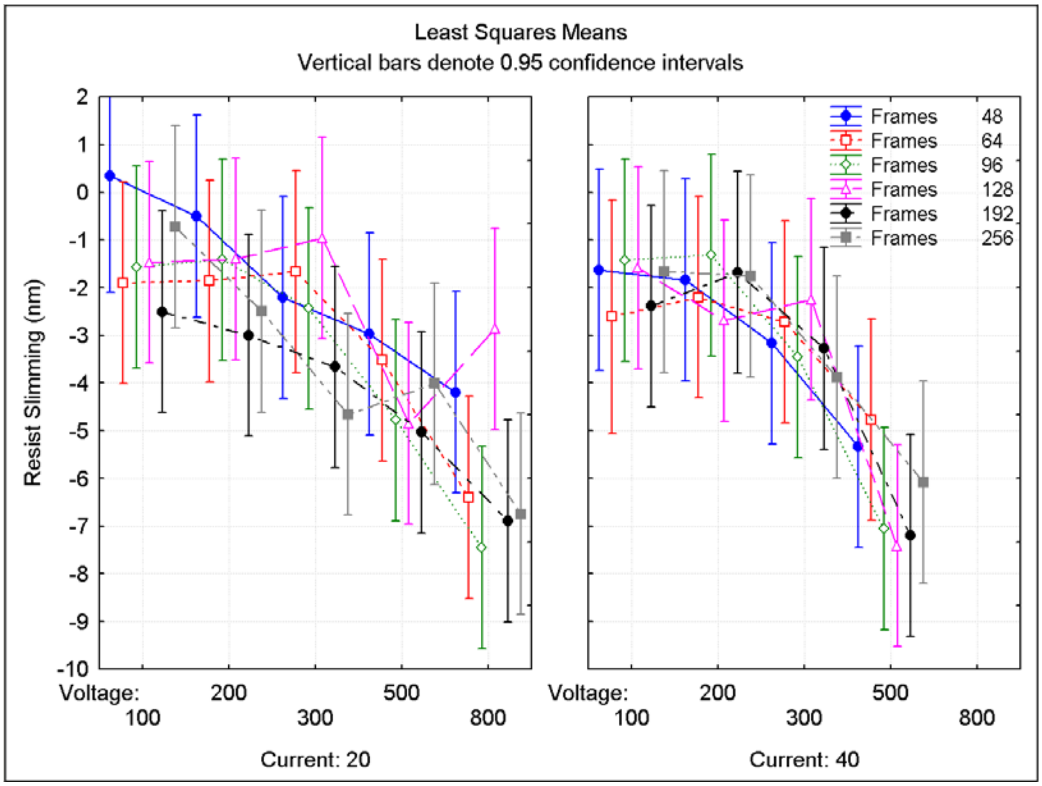

Figure 8: ANOVA results for the electron probe current

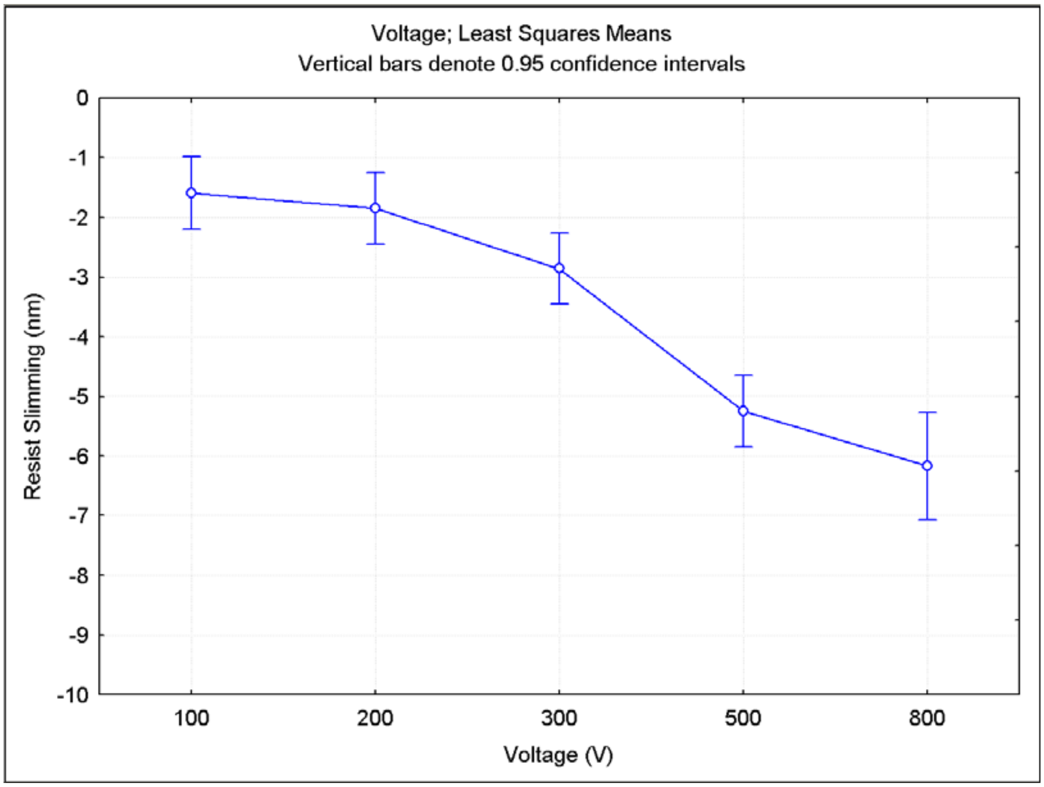

Figure 9: Resist slimming pooled for all currents and numbers of frames.

5. CONCLUSIONS

This experiment has demonstrated the desirability of Ultra Low Voltage CD-SEM for reducing resist slimming during in-circuit metrology at the 130 nm process node with a reduction in after etch slimming of as much as 5nm. The 100 eV landing energy measurement condition resulted in ~1 nm of slimming in the etched line. This landing energy needs to be further investigated in regards to precision, accuracy and throughput. Future work along these lines is planned. In addition, the beam interaction volumes for each edge of the lines that were studied here were assumed to be independent of each other. As smaller process geometries come into production, this will no longer be an acceptable assumption as the edges will begin to interact with each other in under the e-beam probe. Additional studies to characterize the nature of the edge to edge interactions will be necessary to ensure the correct approach to the process metrology of these smaller geometries.

6. REFERENCES

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7. ACKNOWLEDGEMENT

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