Three dimensional aspects of the shrinking phenomenon of ArF resist

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ABSTRACT

Previous studies of the interaction of electron beams with different types of ArF resists have shown the undesired phenomenon of the resist shrinkage. The lateral component of this shrinkage has been detected and quantified easily by SEM CD measurements. However, the vertical extent of this phenomenon has to date remained unknown.

In this work we present measurements of the changes in height and sidewall angles of an ArF line by using a new e-beam tilting ability of the Vera SEM 3D.

The 3D measurement results show that the height of the line shrinks in similar proportions to the top and bottom CDs, with a difference in the magnitude. Due to higher penetration depth of the e-beam on the top of the line than on the sidewall, the vertical shrinkage reaches steady state more rapidly than the lateral shrinkage. We also found a slight reduction in sidewall angle, which is less than one degree even under high e-beam exposure.

Keywords: ArF resist, Resist shrinkage, 3D SEM-metrology

1. INTRODUCTION

Resists for the 193 nm scanners are candidates for the 130 and 100 nm lithography nodes and have increasing importance in manufacturing [1-5]. Experiments and studies have been performed to improve the important characteristics of the resists, such as: light absorption, etch resistance, adhesion, mechanical strength and resolution etc. [1-2]. However, disadvantages in the form of the resist collapse and stability still remain. Additionally, when exposed to electron beam, these resist types tend to shrink.

Studies have been performed in order to find out the source of this undesired phenomenon. It has been suggested that structural changes due to alteration of the polymeric structures were the origin of the shrinkage. Both polymer chain cleavage [3] and polymer cross-linking [4] were proposed.

Shrinkage rate and amplitude are subject to the 193 nm resist type, pattern density, e-beam energy and exposure factors [3-5]. It is common to detect the shrinkage of the resist by performing consecutive CD measurements on the same location on a resist line. The results of this experiment will typically exhibit the following behavior: the difference value between 1st and 2nd CD is the largest and may be up to few nanometers. Thereafter, differences between two consecutive measurements decrease with the measurement number, until a steady state is achieved.

The typical behavior of the resist type used in this study, under the conditions specified in the next section, is shown in Figure 3.

In previous studies concerning the ArF resist feature deformation under e-beam, it was found that the volume of the shrinkage is independent of the initial CD target: “Shrink amplitude stays roughly constant whatever the initial CD pattern. Only the edge of the resist is affected by the e-beam.” [3]. Therefore the resist is not deteriorated in its depth.

Vertical shrinkage was observed [1,2] and it was found that top CD shrinks and reaches steady state faster than the bottom, due to the top’s higher exposure [1].

The pattern density influence is inconclusive. Reference [3] indicates increases in the shrink amplitude and kinetics on dense lines when compared to isolated lines. Reference [4] observed the opposite behavior when experimenting with a 193 nm resist based on a Hyundai platform. Additionally no differences were observed on another two resist kinds that included a new formulation of Clariant and an Acrylate based resist.

In this study we used the Vera SEM 3D to investigate the 3D behavior of ArF resist shrinkage. We will show that the vertical shrinkage can be correlated to the lateral and thus determine the ratio between the decrease in CD values and the decreases in height.

2. EXPERIMENTAL

This study was performed on the ArF resist, SUMITOMO PAR 700, with film thickness of 300nm. Measurements were made on an isolated line in order to avoid the undesired effect of electrons emitting from neighboring sidewalls [1-3].
A new design of the Vera SEM 3D was used for the metrology this provided the ability to tilt the electron beam through 10 degrees. This is key to providing an accurate method of measuring the height and sidewall angle of any feature of interest. In addition to the top down e-beam used for line top and bottom CD measurements, two sets of measurements from e-beams tilted by about 3 degrees (low tilt) and over 10 degrees (high tilt) were used for the profile reconstruction, using the profile reconstruction utility (PAU).
For the purposes of this work, measurement parameters were set specifically to amplify the shrinkage behavior. It is important to note that these are not the recommended values for inspection of 193 nm resist type and included an acceleration voltage of 500V.
Exposure doses were set differently than for CD and 3D measurements. In order to amplify the shrinkage volume in the vertical dimension, the 3D exposure parameters were set higher than those of the CD measurements. The exposure dose mentioned for the 3D measurements is per measurement, i.e. the exposure ratio refers to the sum of the low and high tilt exposures. Typical low and high tilt images are presented in Figure 1 and 2, respectively. All measurement data presented in this study are the average value of five iterations.

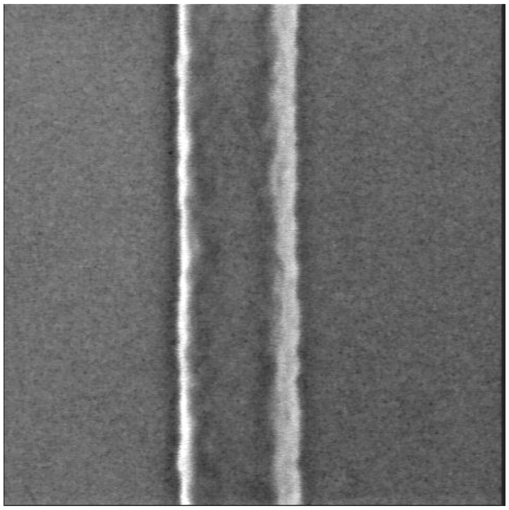


Figure 1: Low tilt view of the line

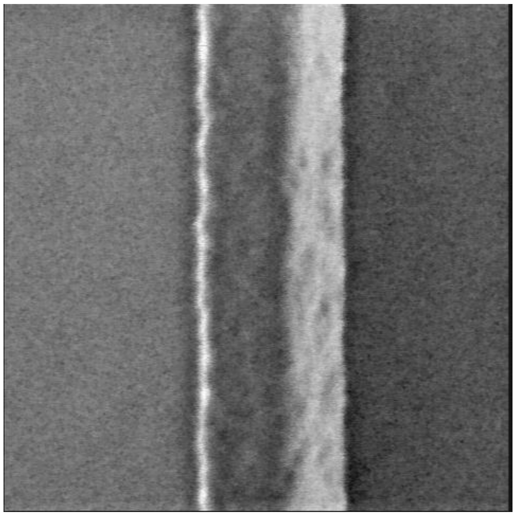
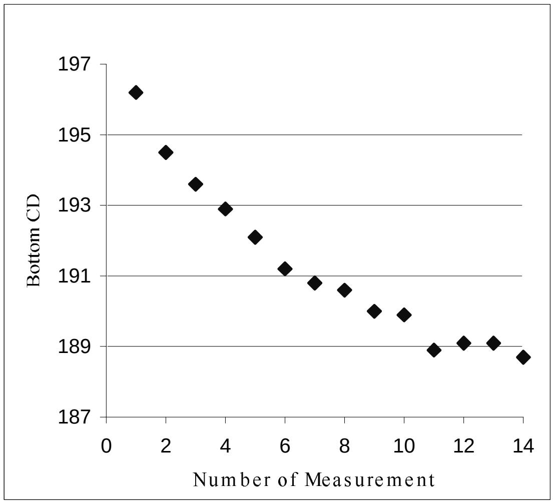


Figure 2: High tilt view of the line

3. RESULTS & DISSCUSION

3.1. CD results

Top and bottom CD measurements as a function of number of measurement are shown in Figure 3 and 4. Figure 3 presents the typical ArF shrinking behavior with decreasing difference between every two consecutive measurements. From Figure 4 it is clear that for the top CD results, steady state is reached by the 5th measurement since the CD ceased to decrease in spite of the ripple.
Table 1 compares the differences between consecutive measurements of top CD and bottom CD (Deltas). When comparing the first four Deltas of the top and bottom CD, rate difference cannot be determined. However from the 5th delta and on the bottom CD's Deltas keep decreasinga tendency whereas the top CD, in average, stabilizes.
The conclusion is that for the first four or five measurements, the rate and amplitude for both top and bottom CD are more or less the same. However, from that point and on the bottom CD shrinks in a decreasing rate and the top remains more or less the same.



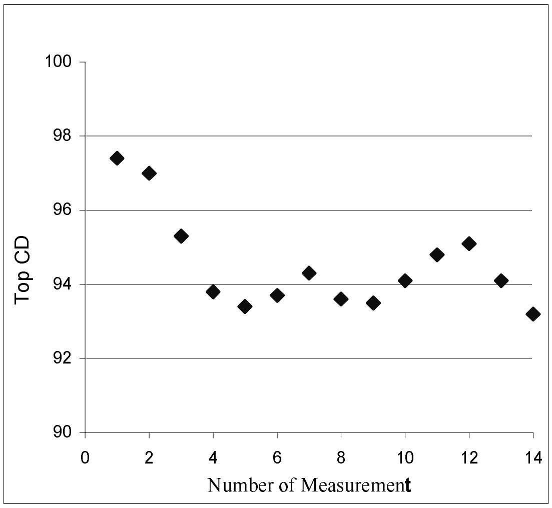


Figure 3: Typical shrinkage behavior – bottom CD results [nm]

Figure 4: Top CD results [nm]

***Parameters were Especially set to increase shrinkage**

#	Δ Bottom CD	Δ Top CD
1	1.7	0.4
2	0.9	1.7
3	0.7	1.5
4	0.8	0.4
5	0.9	-0.3
6	0.4	-0.6
7	0.2	0.7
8	0.6	0.1
9	0.1	-0.6
10	1	-0.7
11	-0.2	-0.3
12	0	1
13	0.4	0.9

Table 1: Comparison of Delta CD between bottom and Top CD

3.2. **3D results**

The Vera SEM 3D has a profile analysis utility (PAU) that performs the full profile reconstruction of a desired feature, including changes in the edge sidewall angle.

A series of results showing the changes in height and sidewall angle as a function of measurement number, are presented in Figure 5 and 6, respectively. It is clear that the line height and sidewall angle are decreasing with the increasing number of measurements. There is a striking similarity in the traces in Figure 5 and 6 and the CD measurements results as presented in Figure 3 and 4.

The ripple in the measurement of the sidewall angle results is ascribed to minute changes in the sidewall angles, which are smaller then 0.4 degrees, this is on the verge of the metrology limits.

The e-beam exposure of the 3D measurements is higher than the exposure of the CD measurements. It was expected that steady state will be reached sooner for the 3D measurement, i.e. reduction in the measurement value should have ceased after the 2nd or 3rd measurement. However, vertical steady state begins only at the 10th measurement this can be seen on the accompanying graphs where the plateau behavior only occurs at the 10th measurement.

The above observation adds weight to the assumption that the penetration depth on the top of the line is higher than at the line edges. As penetration depth is higher, the volume in which shrinkage occurs is extended and more exposure is needed in order to reach steady state. This also explains the strong dependence of the shrinkage on voltage of acceleration [V_{acc}] since the mean electron path is higher thus increasing the volume.

These findings support the conclusion presented in reference [3], that the resist is not deteriorated in its depth.

The penetration depth concept is illustrated in Figure 7.

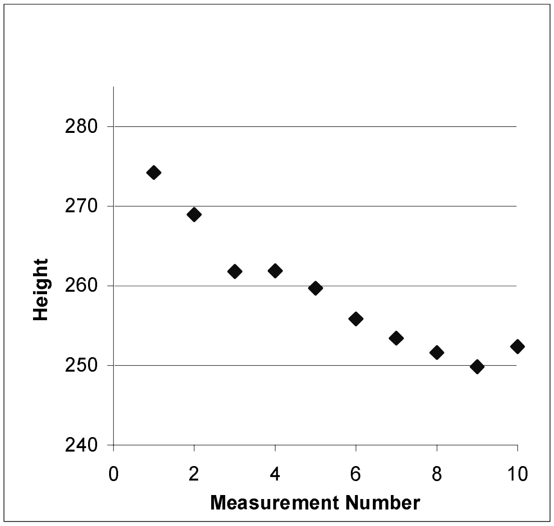


Figure 5: Height [nm] changes as a function of measurement number

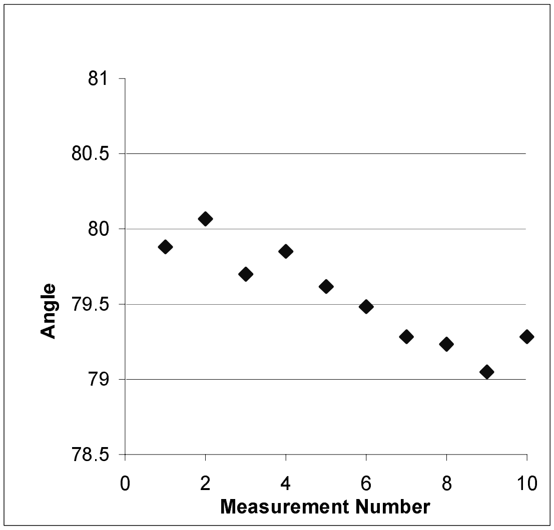


Figure 6: Sidewall angle [degrees] changes as a function of measurement number

*** Parameters were especially set to increase shrinkage**

3.3. Height and sidewall angle influence on top CD:

The sidewall angle of the line under study is about 80 degrees with almost constant value (sidewall angle range is less than 1 degree under relatively high exposure). Therefore, for geometry reasons, decreases in height should widen the top CD. Alternatively, the top of the line is the most exposed to incident electrons hence it should shrink more and reach a steady state faster. These competing effects (also reported in reference 2) give a probable explanation for the noise exhibited in Figure 4.

3.4. The ratio between bottom CD shrinkage to vertical shrinkage

The similar behavior of the CD measurements and 3D measurements presented in section 3.2 were performed using the same acceleration voltage. Therefore, the penetration depth within the top of the line is within the same magnitude in both measurement types. It is acceptable to normalize CD values and 3D values by the e-beam exposure dose. This mathematical manipulation produces the same shrinkage extent for the vertical and lateral components.

The conclusion above is true only for the first few measurements taken on the target location. Because of the differences in the penetration depth, shrinkage in the lateral direction reaches steady state faster than the shrinkage in the vertical direction. Hence the height shrinkage of the line continues after the lateral shrinkage halts.

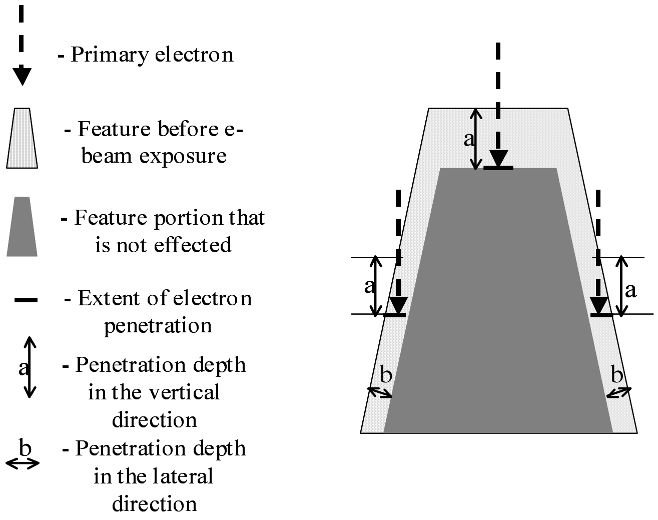


Figure 7: Illustration of the deeper electron penetration into the top of the line compared to the penetration depth into the edge of the line

4. CONCLUSIONS

By using the 3D capability of the Vera SEM 3D we have succeeded in measuring all of the geometrical aspects of a 193 nm resist: Top, bottom, sidewall angel and height.

The ratio between bottom CD shrinkage to line CD shrinkage has been determined. The loss in height is of the same scope as the bottom CD shrinkage. However, when measuring repeatability on the same site, the height continues to shrink even after the bottom CD reaches steady state.

We found that the sidewall angle is hardly affected by the feature deformation. The range of sidewall angle change is less than one degree even for high doses of exposure.

The penetration depth is a crucial factor of the shrinkage potential. As the acceleration voltage determines this property, low acceleration voltage should be used when exposing ArF resist to e-beams.

Using the 3D metrology function and the standard top and bottom CD measurements, we were able to reconstruct a complete shape of a line and analyze the various geometric factors in ArF resist shrink.

ACKNOWLEDGMENTS

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