Characterization of Line-Width Variation on 248 and 193 nm Exposure Tools

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ABSTRACT

The line-width variation of a 193 nm lithographic process utilizing a 0.60 NA scanner and a binary reticle is compared to that of a 248 nm lithographic processes utilizing a 0.68 NA scanner and a variety of reticle technologies. These include binary, attenuated PSM with assist features and alternating PSM reticles. Despite the fact that the 193 nm tool has a lower NA and that the data was generated using a binary reticle, the 193 nm lithographic process allows for the line-width values to be pushed lower than previously achieved with 248 nm lithographic processes. The 3-sigma values from 4000 electrical line-width measurements per wafer (160 measurements per 25*25 mm field, 25 fields per wafer) were calculated for different mask features. The 193 nm process was capable of reaching line-widths needed for future generations of advance logic chips. Compared to the 193 nm process utilizing a binary reticle, only the 248 nm processes utilizing either an attenuated PSM with assist features or an alternating PSM reticle had similarly low line-width variation. The 248 nm processes utilizing a binary reticle had higher line-width variation even at larger poly gate conductor line-widths.

1. INTRODUCTION

Performance of logic chips is not only controlled by the poly gate conductor line-width, but also variation of the poly gate conductor line-width within the logic chip.[1] Three times the standard deviation (3-sigma) of line-widths measured within a logic chip is commonly called across chip line-width variation (ACLV). Decreasing the ACLV allows logic chips to be operated at higher speeds. This means that lithographic techniques need to be chosen that minimize ACLV. Along with ACLV, across wafer line-width variation (AWLV) is another important parameter for logic chips. To accomplish low chip-to-chip performance variation, AWLV needs to be minimized. To effectively study the root causes of ACLV and AWLV a methodology was established by Wong et al.[2] The methodology allowed the separation of intra-field variations (such as those caused by CD errors on the reticle or lens aberrations) from extra-field variation (such as those caused by development and etch).

In this paper, results from a 193 nm process will be discussed in detail and compared to those from a 248 nm process. Using the methodology described by Wong et al.,[2] the line-width variation obtained using several different reticle types and wavelengths was compared. The reticles examined as part of this study included binary, attenuated PSM with sub-resolution assist features (SRAF)[3,4] and alternating PSM. With the 193 nm resist, two thicknesses were examined; one at the Emax and the other at the Emin of the Eo swing curve.

2. EXPERIMENTAL

2.1 Reticle design

Binary, attenuated PSM and alternating PSM reticles were manufactured using a design similar to that described earlier.[2] The binary reticle was used with both 193 nm and 248 nm exposure tools; the PSM reticles were used only with the 248 nm exposure tool. Each reticle consists of a unit cell replicated so that electrical CD values could be measured eight times in the scan direction and twenty times across the slit of an exposure field. The resulting 160 unit cells print in a "chip" 25mm X 25 mm on the wafer. Each of the unit cells includes several electrically testable modules each of which contains a van der Pauw structure for measuring sheet resistance and ten structures for determining line-width. The structures for determining line

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width include those for isolated, semi-dense and dense features in both the x and y directions. On the attenuated PSM reticle the isolated and semi-dense features with and without sub resolution assist features (SRAF) were available for analysis. Lines for cross-sectional SEM analysis were also available to correlate the true physical CD to that measured either electrically or using top-down SEMs.

2.2 Printing, Processing, Electrical Probing and SEM analysis of Wafers

The binary reticle was examined with several different illumination conditions on 248 nm exposure tools and on a 193 nm exposure tool at 0.60 NA and 0.75 sigma. The structures with SRAF were examined on wafers exposed on 248 nm tools with two-thirds annular illumination. The alternating reticle was examined using a 0.68 NA 248 nm exposure tool with a sigma setting of 0.44.

With each reticle and illumination condition studied, wafers were etched using IBM's poly gate stack etch. Each wafer was printed at constant dose and focus in a five by five matrix, i.e. 25 chips per wafer. Thus, each unit cell is replicated 4000 times on a wafer. After exposure the wafers were etched, ion implanted and readied for measurement. For each structure of interest all 4000 unit cells per wafer were measured electrically. Average CD and three sigma values from 4000 electrical line-width measurements per wafer were calculated for different mask features. An Applied Materials VeraSEM was used for top-down SEM measurements and Hitachi SEM for cross-sectional SEM measurements.

3. RESULTS AND DISCUSSION

3.1 193 nm Resist Lithographic and Etch Performance

To determine the effect of operating at an Emax vs. an Emin on line-width variation, the Eo swing curve of the resist was obtained experimentally. Figure 1 shows the Eo swing curve for the 193 nm gate level resist and organic BARC combination used in this study. The Eo swing with this resist is approximately 10%. The resist performance was examined at both the Emax and the Emin. Similar exposure windows and profiles were observed at each thickness. Using the binary reticle, a focus exposure matrix (FEM) was exposed on a 0.60 NA, 193 nm scanner. The FEM was cross-sectioned after being etched with IBM's poly gate etch. The cross-sectional SEM shows a 55 nm isolated poly line with excellent profile (figure 2).

To correlate the true physical CD to that measured by top-down SEM, isolated lines after poly etch, were measured both by top-down and cross-sectional SEM (the cross-sectional SEM measurements are representative of the true physical CD value). Specifically, twenty isolated lines in the center chip, all printed from the same mask CD, were measured by both top-down and cross-sectional SEMs. Table 1 shows that the average physical value of the twenty cleavable lines was 53 nm. Since the average top-down SEM measured value of the same lines was 74 nm, a delta of 21 nm is calculated between top-down SEM and physical CD. After etch, the average CD value from twenty electrically testable isolated lines, determined by top-down SEM, was 69 nm. Thus, the electrically testable lines are estimated to have a physical size of 48 nm.

3.2 Line-widths obtained with the 193 nm resist process

Table 2 summarizes the data from the electrical prober from wafers exposed with two different doses. The data show that the probable isolated lines, printed from the nominal mask CD, in the vertical direction printed at nominal dose have an electrical CD of 22 nm. The same lines were determined to have a physical CD of 48 nm (top-down SEM measured value less the 21 nm bias). Thus, a bias of 26 nm from the physical CD value and electrical CD exists. The CD is maintained at a pitch of 350 nm. However, at a pitch of 300 nm the CD increases substantially due to the poor proximity behavior exhibited by the low NA tool with a binary reticle. Mask and resist linearity appear to be exceptional, at least within the narrow range examined. This is illustrated in Table 2, where increasing the mask CD 30 nm, resulted in poly CDs 27 nm larger on the wafer exposed to a dose lower than nominal and 28 nm larger on the wafer exposed to nominal dose. The fact that the measured CD delta on the wafer is so close to that on the mask is remarkable considering the over-exposure used to achieve these poly gate CDs.

3.3 Line-width variation for 193 nm resist process

The line-width variation calculated from four thousand measurements across the wafer for a variety of features is shown in Table 2. Features ranging in electrical CD from 20 to 60 nm all have 3-sigma variation across the wafer less than 75% of the line-width variation measured for a 100 nm isolated line imaged with a 0.68 NA, 248 nm process using a binary reticle. Just as CD is maintained to a pitch of 350 nm, the low line-width variation is maintained at a pitch of 350 nm

A second set of wafers was printed at both the Emax and the Emin of the gate level resist. Figure 3 shows the raw data from isolated vertical lines printed from the nominal mask CD from these two wafers. For both the Emin and Emax wafers, the 3-

sigma line-width variation across the entire wafer was 69 % of the line-width variation measured for a 100 nm isolated line imaged with a 0.68 NA, 248 nm process using a binary reticle. This indicates that operating at either an Emin or an Emax on the swing curve does not affect line-width variation.

3.4 Line-width variation of the 193 nm lithographic process compared to that of several 248 nm lithographic processes

Figure 4 compares the line-width variation of an isolated line obtained with a 193 nm lithographic process using a binary reticle to what was achieved with 248 nm lithography with and without and reticle enhancements. Even with a low (0.60) NA 193 nm scanner, line-width variation and electrically measured CD are both as low as values obtained using 0.68 NA, 248 nm lithography with reticle enhancements. Using a 0.68 NA, 248 nm scanner with a binary reticle resulted in line-width variations at least 50% higher than those achieved with the 0.60 NA, 193 nm scanner at the same electrical CD. Only by using either attenuated PSM with sub-resolution assist features or alternating PSM were we able to obtain similarly low CDs and line width variations to those obtained with the 0.60 NA 193 nm scanner. We expect that a combination of higher NA 193 nm scanners and reticle enhancements will allow even lower line-width variation to be obtained with 193 nm lithography.

4. SUMMARY

A 193 nm gate level process has been established. This process was found to be capable of fabricating poly gate conductor lines with CDs less than 50 nm and low across-wafer 3-sigma variation. Even though the 193 nm process used a low NA 193 nm tool and binary reticles, the line-width variation achieved was as low as that achieved using higher NA 248 nm processes utilizing a range of reticle enhancement techniques. It is expected that with higher NA 193 nm exposure tools and resolution enhancements the line-widths and tolerances needed for future high performance logic devices will be obtained.

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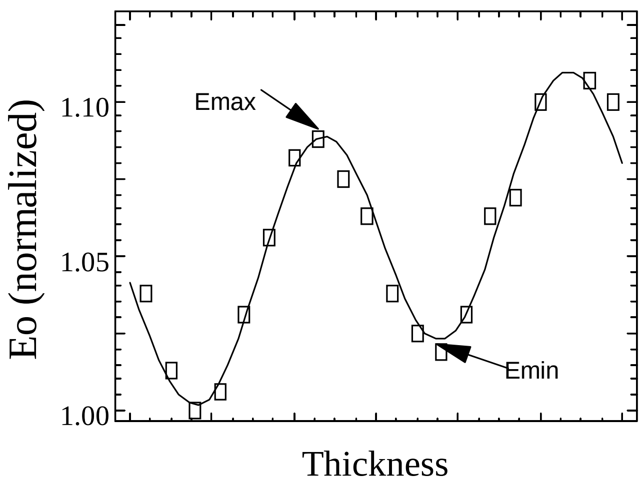

Figure 1. Plot of Eo swing curve for 193 nm gate level resist on top of organic BARC.

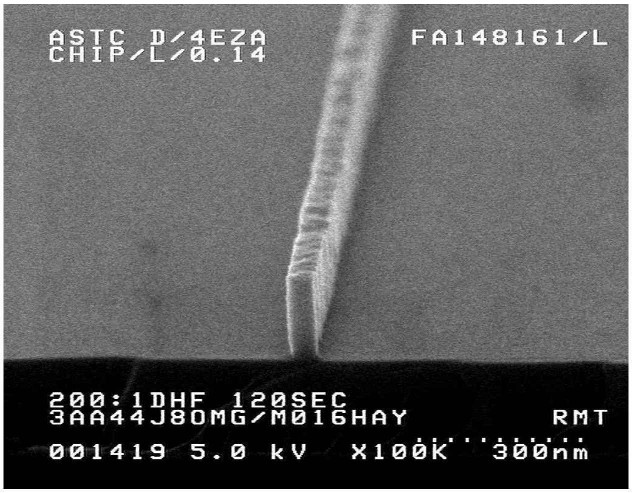

Figure 2. Cross-section of 55 nm poly line after resist strip. The line was imaged using a 0.60 NA 193 nm tool with a sigma setting of 0.75 and then transferred into the polysilicon using IBM's poly gate etch.

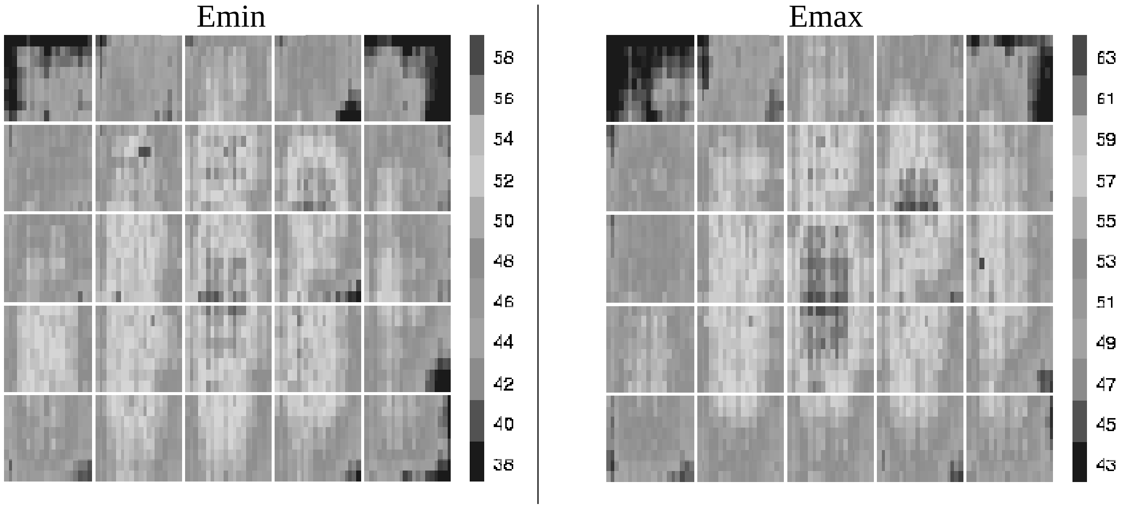

Figure 3. Raw data for the isolated vertical lines with an electrical poly gate conductor CD of 48 nm and 53 nm for the Emin and Emax wafers respectively. The 3 sigma values from 4000 electrical line-width measurements per wafer, for both Emin and Emax, were 69 % of the line-width variation measured for a 100 nm isolated line imaged with a 0.68 NA 248 nm process using a binary reticle.

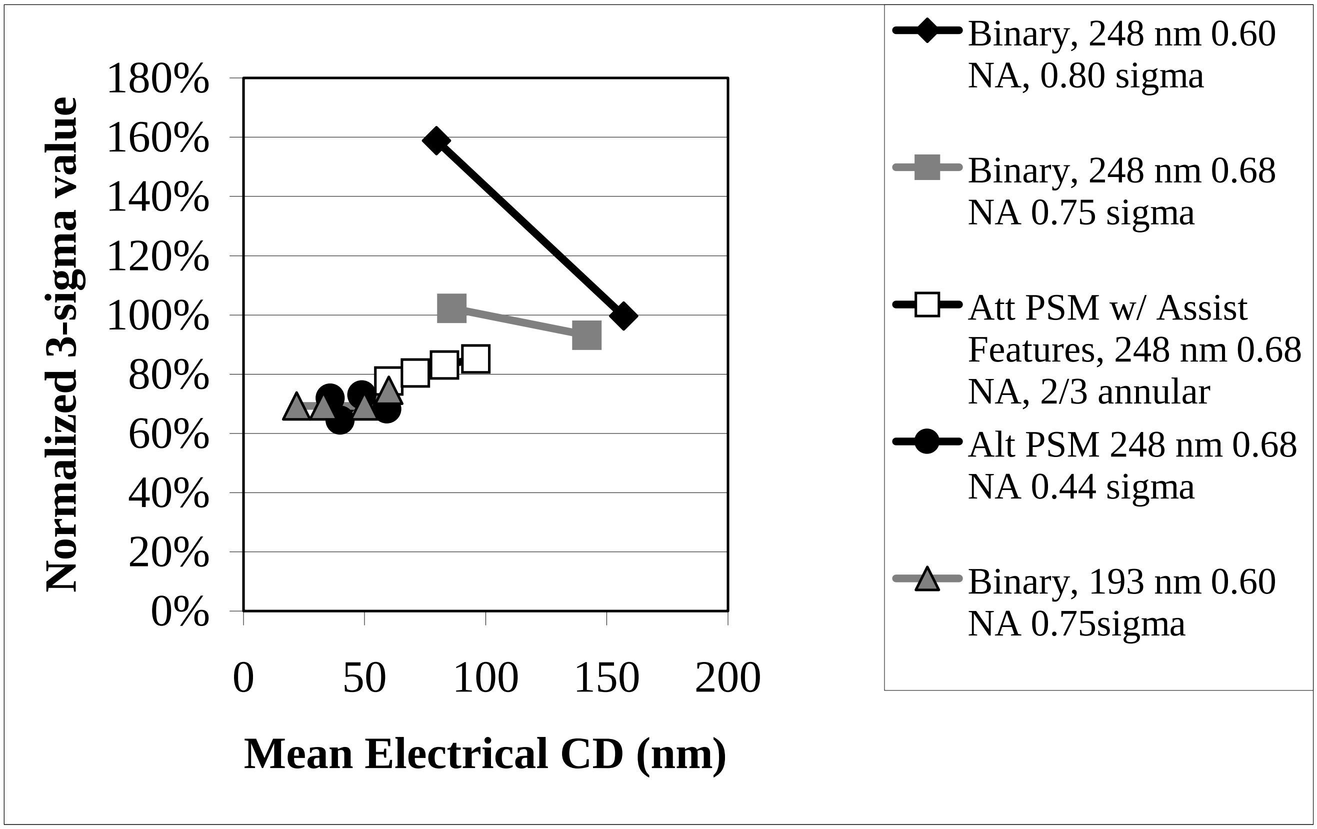

Figure 4. Chart showing relationship between 3 sigma line-width variation and poly gate conductor CD for various wavelength and reticle combinations. Compared to the 193 nm process utilizing a binary reticle, only the 248 nm process utilizing an alternating PSM reticle had similarly low line-width variation. The 3-sigma values are normalized to that obtained for a 100 nm isolated line imaged with a 0.68 NA, 248 nm process using a binary reticle.

Table 1. CD values from twenty probable and twenty cleavable isolated lines after poly etch, from wafer printed with ACLV reticle.

	Average CD (nm)
CD of cleavable lines measured by Top-down SEM	74
CD of cleavable lines measured by cross-sectional SEM	53
Delta between top-down and cross-sectional SEM CDs	21
CD of probeable lines measured by Top-down SEM	69
Predicted physical size of probeable lines	48

Table 2. Poly CDs values from 4000 electrical line-width measurements per wafer (160 measurements per 25*25 mm field, 25 fields per wafer) for different mask features at two doses. The true physical CD can be estimated by adding 26 nm to any of the electrically measured CD values.

Delta from nominal Mask CD	Mask Pitch (nm)	Dose	Orientation	Normalized CD (nm)	3 sigma value for wafer line-width variation (Electrical) (nm)
0	iso	low	Horizontal	31	75%
0	iso	low	Vertical	33	69%
0	350	low	Vertical	31	64%
0	300	low	Vertical	131	155%
+30 nm	iso	low	Vertical	60	75%
0	iso	nominal	Horizontal	20	75%
0	iso	nominal	Vertical	22	69%
0	350	nominal	Vertical	20	59%
0	300	nominal	Vertical	112	192%
+30 nm	iso	nominal	Vertical	50	69%