Efficient large volume data preparation for electron beam lithography for sub-45nm node

[§]Kang-Hoon Choi[a], Manuela Gutsch[a], Martin Freitag[a], Christoph Hohle[a], Luc Martin[b], Sébastien Bayle[b], Serdar Manakli[b] and Patrick Schiavone[b]

[a]Fraunhofer Center Nanoelectronic Technologies, Koenigsbruecker Strasse 180, D-01109 Dresden Germany
[b]Aselta Nanographics, MINATEC-BHT, 7 Parvis Louis Néel, BP50, 38040 Grenoble Cedex, France

ABSTRACT

A new correction approach was developed to improve the process window of electron beam lithography and push its resolution at least one generation further using the same exposure tool. An efficient combination of dose and geometry modulation is implemented in the commercial data preparation software, called Inscale®, from Aselta Nanographics. Furthermore, the electron Resolution Improvement Feature (eRIF) is tested, which is based on the dose modulation and multiple-pass exposure, for not only overcoming the narrow resist process windows and disability of exposure tool but also more accurate correction of exposure data in the application of sub-35nm regime. Firstly, we are demonstrating the newly developed correction method through the comparison of its test exposure and the one with conventional dose modulation method. Secondly, the electron Resolution Improvement Feature is presented with the test application for complementary exposure and with the application of real design, specifically for sub-30nm nodes. Finally, we discuss the requirements of data preparation for the practical applications in e-beam lithography, especially for future technology nodes.

Keywords: electron beam lithography, data preparation, proximity effect correction, dose-geometry modulation, electron Resolution Improvement Feature (eRIF), complementary exposure, requirements for data prep.

1. INTRODUCTION

Electron beam (e-beam) lithography is used in the IC manufacturing industry to sustain optical lithography for prototyping applications, low volume manufacturing and is applied at a larger scale in mask manufacturing. As semiconductor technologies are now moving towards the 32nm node and beyond, the specifications in terms of resolution and process control become tighter for direct write on silicon and mask writing. As the proximity effect correction (PEC) based on dose modulation commonly applied for the standard PECs in the current e-beam lithography shows difficulties to provide the required process window for patterning structures designed below the critical dimensions (CDs) of 45nm[1], it is demanded to develop new types of correction methods for overcoming those difficulties. However, the development of new correction methods in the data preparation (data prep) for e-beam lithography should be reviewed and examined not only in its accuracies but also in various criteria, such as the persistence of correction algorithm, calculation time, correction capabilities according to the data volume, compatibilities according to the hardware, and so on.

Aselta Nanographics developed the new algorithm where dose and geometry modulations are contributing together for PEC. This called dose-geometry modulation, also named as DMG, is integrated into their commercial data prep software, Inscale®. This method is designated not only to overcome the difficulties mentioned above in the data prep

§ kang-hoon.choi@cnt.fraunhofer.de; phone +49 351 2607 3016; fax +49 351 2607 3005; http://www.cnt.fraunhofer.de/

Presented on SPIE 2011 Photomask Technology, 21st Sep. 2011, Monterey, CA/USA.
To be published in Proc. of SPIE, Vol. 8166, 2011.

point of view for the future technology nodes but also to enhance the other details of corrections such as corner rounding, line end shortening (LES)[2] and LER/LWRs. In parallel, a new approach for the PEC and data prep is ongoing, which establishes the combination of dose modulation and multiple pass exposure, called electron Resolution Improvement Feature (eRIF)[3].

In this study, the Fraunhofer Center Nanoelectronic Technologies (CNT) examined and reviewed the three themes. First, the dose-geometry modulated PEC was examined by comparison of dose modulated PEC. This was performed through the exposure of test pattern, which the one that was designed to imitate the several cases of real application and are corrected with each of both modulations. The second theme covers the review of eRIF, which aimed to apply for the complementary exposure and future technology nodes. Together with the test patterns, a real application layout, which comprises sophisticated patterns, is also corrected by eRIF, simulated and exposed for the observation. The evaluations of those new correction methods are not only done with the exposed resist images but also followed taking into account calculation time, applied data volume, continuance of algorithms and hardware compatibilities. Finally, we summarized the requisites of the new algorithms and data prep for the practical applications, specifically for complementary exposure and future technology nodes, in e-beam lithography.

2. EXPERIMENTALS

Three different types of test layouts were prepared and applied for this study. The first test layout, which is called Type 1, consists of the combination of large arrays of line/space patterns, isolated lines, various standard features like cactus, chevrons and bubbles. It is designed to see the correction differences of relaxed design CDs, for example from 200nm till down to 50nm, together with sophisticate combinations of pattern varieties in general. The second one, as named Type 2, is prepared to focus on the critical CDs, not only with the large arrays of line/space patterns and isolated lines but also includes the artificial arrays and imitated cutting lines for the applications of complementary exposures. These are varied with the design CDs of 40, 36 and 28 nm. The last is a designed layout for a real SRAM metal 1 layer, which is shrunk down to the CDs of 25nm, and referred as Type 3. All applied designs are intended to test the correction of large area, complex structures and large volume of data, specifically the latter one, in the newly developed data prep. Table 1 summarized the other details about the test layouts applied in this study.

Table 1. Physical details of test layouts

Layout Type	Data Volume	Layout Size [mm^2]	Exposed Area [mm^2]	Density of Exp. Area [%]
1	145 kB	2.598 × 2.598	~0.622	9.2
2	12.9 MB	0.510 × 0.3	~0.030	19.9
3	1.6 MB	0.04 × 0.04	~0.00057	35.8

The dose-geometry modulated PEC and simulations are carried out using Inscale® (Aselta Nanographics) and the exposure data are prepared using MGS (v7.3, Fraunhofer IPMS) after that. The conventional dose modulated PEC is done by PROXECCO (v6.1, PDF Solution GmbH).

The prepared test patterns are exposed using a Vistec SB3050 50 kV shaped electron beam direct writer, which has as same capabilities as the one in LETI Grenoble/France, on 300mm wafer at the Fraunhofer CNT. Positive and negative chemically amplified resists (CARs) were applied and processed on a CLEAN TRACK ACT-12 resist track (Tokyo Electron Ltd.) for the test exposure and their post-coat resist thickness of negative CAR (nCAR) and positive CAR (pCAR) are 80 nm and 55nm, respectively. The CDs and images of exposed patterns according to the correction methods are obtained using an Applied Materials VeritySEM 4i®.

3. RESULTS AND DISCUSSIONS

3.1 Dose-Geometry Modulation and Conventional Dose Modulation

One of the initiatives for the development of dose-geometry modulation was not only to improve the correction accuracies of CDs but also to enhance the correction capabilities of LES and corner rounding in the e-beam exposed patterns. It is commonly experienced that there are some difficulties to correct those details above with conventional dose modulation, especially when the technology nodes are shrink down to sub-50 nm. Figure 1 shows the comparison of dose-geometry modulation and conventional dose modulation at the cactus-like pattern with the design CDs of 60 and 50nm half pitch. For the direct comparison, the simulation was performed with identical PSF parameters of the nCAR for all cases and the real test exposures.

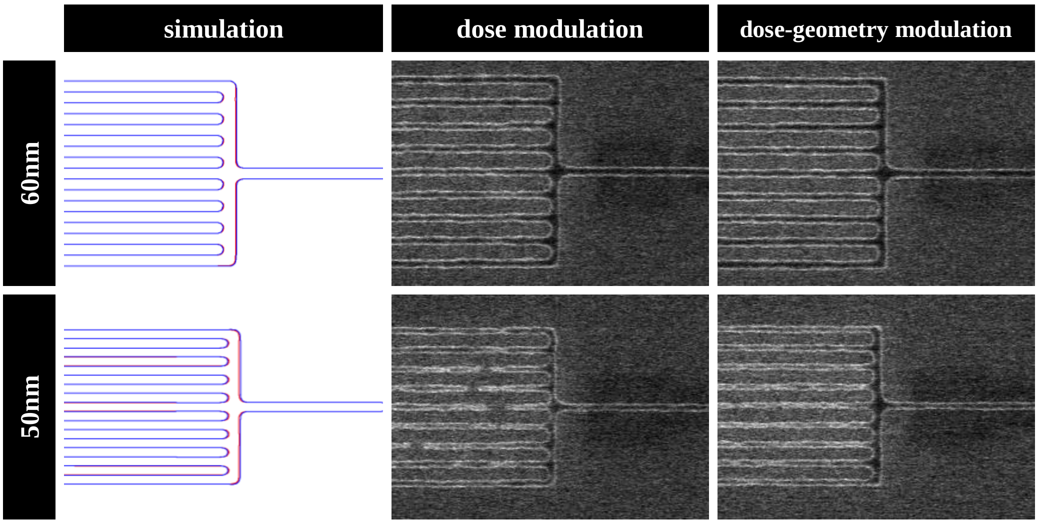


Figure 1. Comparison of the conventional dose modulation and dose-geometry modulation in the real test exposed images along with that of simulation results. The red contour corresponds the result obtained from the dose modulated correction and the blue one depicts the outcome of dose-geometry modulated correction in the simulation. All cases, simulations and test exposures, applied with same PSF parameters of nCAR for the direct comparisons.

On the simulation of figure 1, the thick contour is the result obtained from the dose-geometry modulated correction and the thin outline is the one from the conventional dose modulated correction. It looks that there were not much big differences in the simulation contours between the modulation of dose-geometry and that of dose only. However, the exposed patterns, which is observed through the CD-SEM and appeared in figure 1, shows less corner rounding and better exposure qualities in the dose-geometry modulation than in the conventional dose modulation. These improvements are recognizable when the design CD is decreased from 60nm to 50nm, as it is featured in figure 1. The observation gives us the deductive prospect that the difference between dose-geometry modulation and conventional dose modulation will come more distinctive in the case of sub-45nm designs.

The comparison of exposed images at the sub 45-nm designs that were corrected with the dose-geometry modulation and conventional dose one are demonstrated in figure 2. The CDs are 40, 36 and 28nm as it was designed in second type of test layout. Even the examined cases in figure 2 are simple 1:1 dense line features, it is clear to observe that dose-geometry modulation has better capabilities of correction, specifically in the LES and corner rounding in the simulation. The images of real exposed patterns at the sub 45-nm designs showed evident differences according to the modulations. The exposed patterns of 40nm dense lines with the dose-geometry modulated corrections showed reasonable qualities of images. On the contrary, the same with the dose modulated corrections appeared as underexposed with various broken lines. It is apparent that dose-geometry modulation has better capabilities, not only on the CDs but also on the LES and corner rounding, in PEC than the modulations with dose-only, specifically in sub-45 nm designs. However, it is also possible to notice that even the correction based on dose-geometry modulation was not qualified to correct properly the sub-40 nm designs. In figure 2, the 36nm 1:1 dense lines corrected with dose-geometry modulation are attached and bridged each other like it was starting to overexpose. It is able to speculate that these features are not simply the data prep issues but limited by narrowing of the process windows of the resists. While the patterning of sub-40nm is not simply the consequence of data prep, there is an idea it can either be enhanced through the data prep.

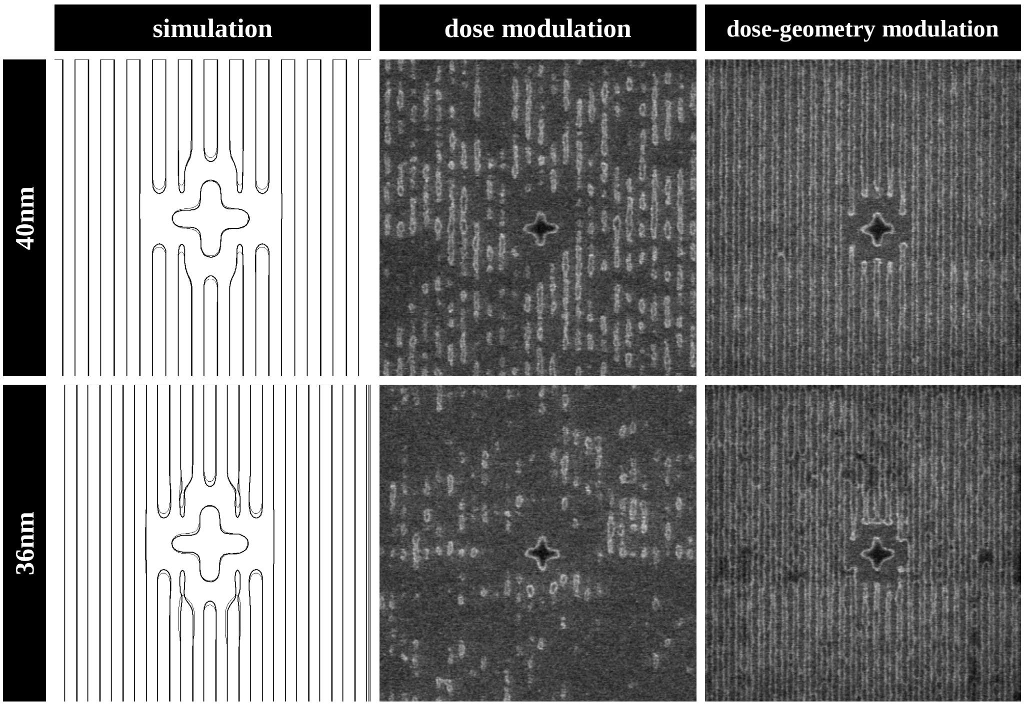


Figure 2. Comparison of the simulations and test exposed images between does modulated correction and dose-geometry modulated correction, based on the 1:1 dense line test designs with the CDs of 40 and 36nm. In the simulation, the thin surroundings are the simulated resist contour obtained from the conventional dose modulated correction and the thick contour is the one from the dose-geometry modulated correction. The same PSF parameters of nCAR were used for all cases for the direct comparisons. The area of simulation is $1\times1\mu m^2$ and that of the examined test exposure is $2\times2\mu m^2$.

3.2 The electron Resolution Improvement Feature (eRIF) and its Applications

Based on the idea above, Aselta Nanographics developed the new type of algorithm called electron Resolution Improvement Features, which bases on the dose modulation and multiple pass exposure. Figure 3 presents the Type 2 test pattern images, exposed and observed at Fraunhofer CNT and corrected with eRIF. The PSF parameters and process conditions of nCAR are same as the previous test exposures, demonstrated in figure 1 and 2, for examining the influence and efficiency of eRIF straightforwardly. With the application of eRIF, test patterns are clearly resolved not only on the dense lines of 40 nm but also on that of down to 36nm. The artificial arrays of 40nm test patterns are also resolved with good qualities. The test artificial array with the design CDs of 36nm are observed as enhanced its quality of exposures but with some glitches. It is considered that these are not just due to the capabilities of data prep but also the susceptibility of process in the applied nCAR is getting to reach its boundary. Though the observation of test exposure that is obtained in the artificial array of 36nm does not seem perfect, the eRIF is able to demonstrate that the data prep can make the exposures possible for a technology node beyond using current exposure tool and its processes.[4]

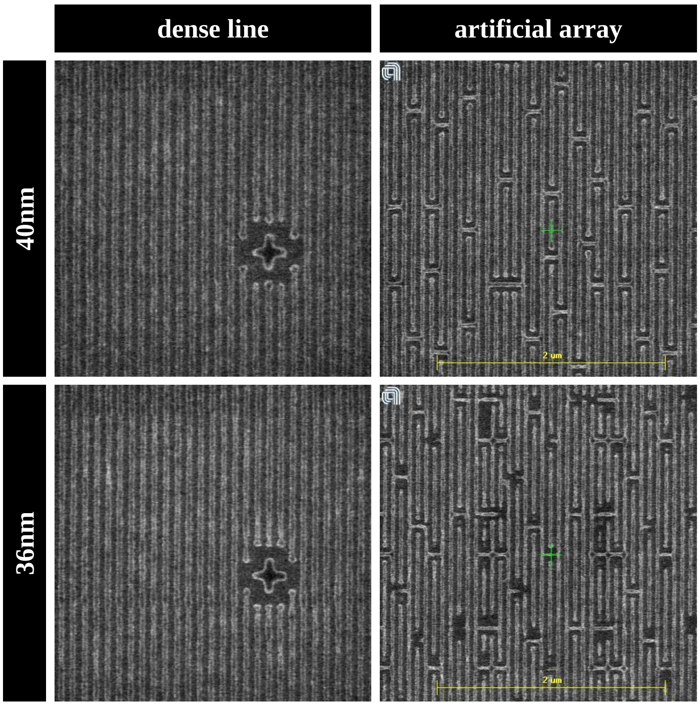


Figure 3. The SEM images of test exposed patterns corrected and prepared with eRIF and Inscale®. The same PSF parameters and process conditions of nCAR as previous test exposures, which appeared in figure 1 and figure 2, were applied. The artificial array is a test pattern that resembles the metal array layer to increase the complexity for the test of data prep and its exposures. The portrayed area in the 1:1 dense line images is $2 \times 2 \mu m^2$ and that in the artificial array is $2.5 \times 2.5 \mu m^2$.

One of the promising candidates for the real application in e-beam lithography in near future is complementary exposure, especially for the high volume manufacturing in logic node[5, 6]. Because of the characteristics of its application, the design consists not simply of the line repetition but of the complicated combination of lines, polygons, elongated holes and holes. To achieve the usable corrections for those, the various correction redundancies, which means not only of CDs but also for corner rounding and LES, are required. This means the correction algorithm itself should be more weighted to 2-dimensions than the 1-dimensional way. It is the reason why the eRIF considered as beneficial to this application. Figure 4 exhibits the images of exposed test patterns Type 2, which are corrected by eRIF, along with the simulated resist contours after the correction. Based on the images presented in figure 4, the patterns corrected using eRIF seems not well defined and clearly resolved. However, those are further enhanced than the images obtained from the patterns that are corrected using dose-geometry modulations, which are not shown in here, when they are cross-examined in comparison.

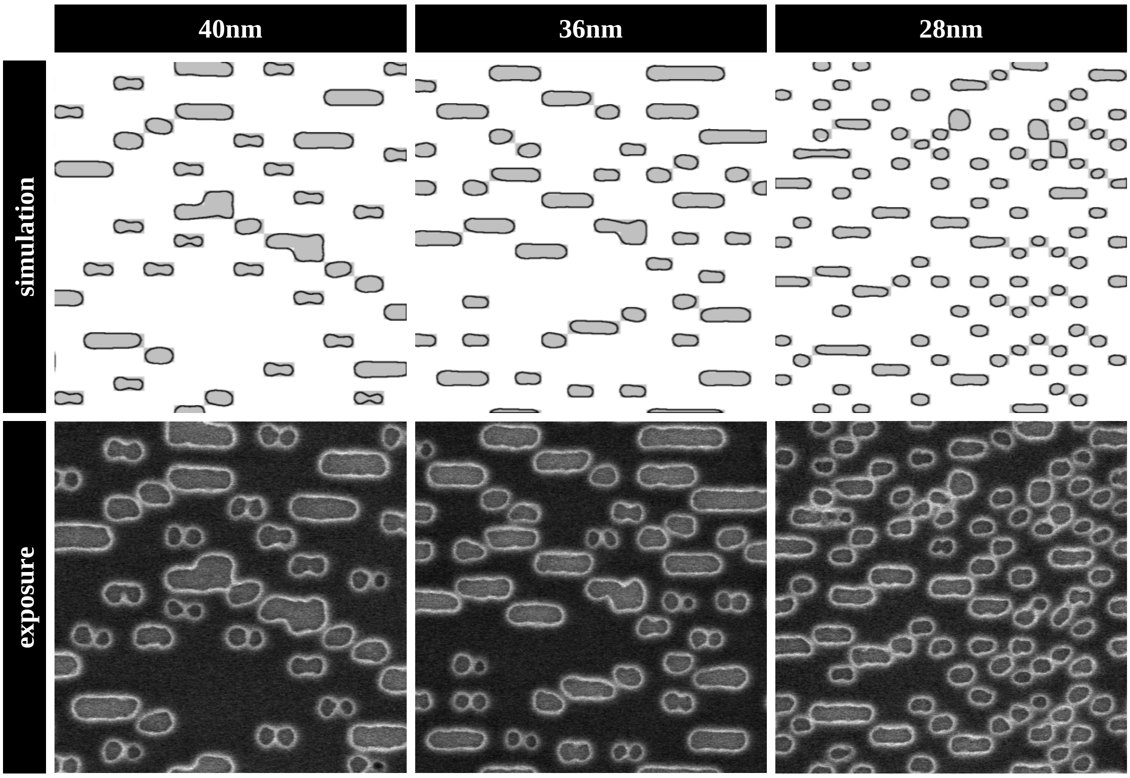


Figure 4. Comparison between simulation and test exposed images of cut-line test pattern for complementary applications. On simulations, the designed layouts with CD variations of 40, 36 and 28nm appeared as light grey rectangle patterns and the thick surroundings depict the resist contours that are obtained from the simulation. The same PSF parameters and process of pCAR were applied in all the cases. The areas of simulation and observed test exposures are same for all CD variations as $1\times1\mu m^2$.

It is also important to examine how the eRIF is working for the real application pattern. For that, the eRIF is applied for the correction of the layout for SRAM metal 1 layer with the designed CD of 25nm, mentioned as Type 3, and compared with the same corrected with dose-geometry modulation. The firsthand comparison of simulation between two corrections in actual design is portrayed in figure 5. In a glance, the correction looks finer and more precise in the eRIF than that in the dose-geometry modulation. However, it is interpretable that still further improvements are possible and needed in eRIF after the closer look. Several advisements are possible for what have attained above, as in figure 4 and 5. First, the process windows and its stabilities are additional considerations in this evaluation. In practice, the process window of current pCAR resist, which is used for cut-line test exposures, is beginning to narrow when the design CDs are smaller than 40~45nm. Under those circumstances, the reproducible and hyperfine results of exposure for sub-40nm in a wide area are tricky and that for even smaller dimensions like sub-30nm is somewhat challenging. Secondly, the eRIF algorithm is still under development now for the full applications. This means that the status of this correction is ‘rule-based’. Its algorithm is not fully automated and generalized yet to apply for all the cases, for example the different CD variations with various complexes shape and feature. The current ‘rule-based’ approach in eRIF for PEC requires careful and sensitive optimization of correction parameters. Nevertheless, it is able to present that the eRIF suggests the new approach for the PEC and it is a promising data prep for the application of electron beam lithography in future technology nodes.

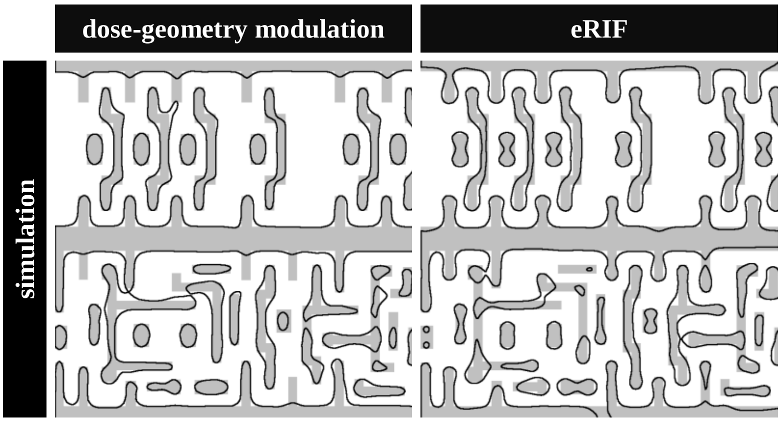
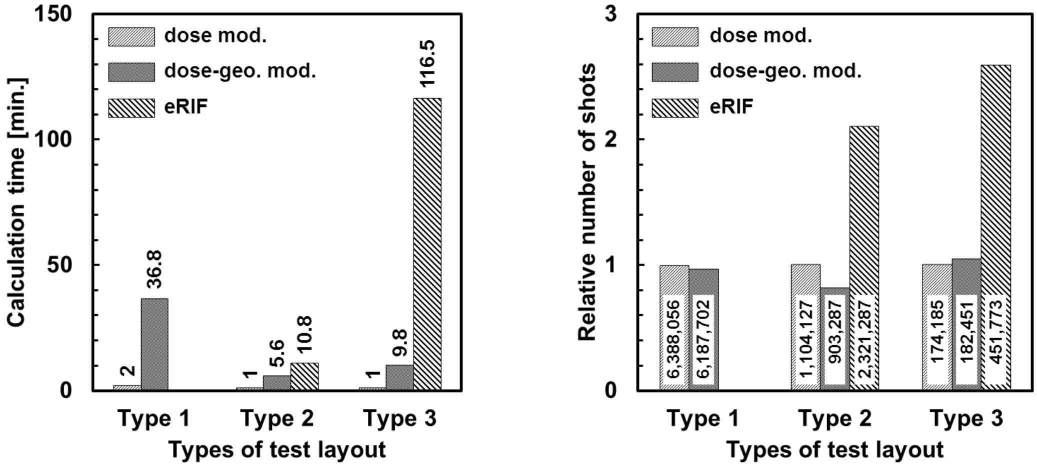


Figure 5. The evaluation of PEC by dose-geometry modulation and eRIF through the simulation of actual SRAM metal 1 layer with the designed CD of 25nm. The identical PSF parameters of nCAR and the area of simulation, $1\times1\mu m^2$, were practiced for both modulations. The light grey areas demonstrate the designed layout and the exposed profile of resist overlapped on top of it as thick contours.

3.3 Calculation time, writing time estimation and other facts

The correction accuracy and its efficiency are not the only concerns for the development of new PEC and data prep, specifically in practice. For the thorough evaluation and review, one also has to take into account is the real case factor, like calculation time, the influence to writing time, applicable data volume, redundancies of algorithm, hardware compatibilities and so on. Figure 6-(a) illustrates the comparison of calculation time for the corrections. It is able to note that the dose-geometry modulation took a bit longer calculation time for corrections in all cases of test patterns. Based on the comparisons according to the types of layout, it is interesting that the calculation time for dose-geometry modulation in Type 1 needs longer than that for same modulation in others. This is because of the complexity and large correction area of the Type 1 pattern. Set aside the pattern complexity and the area of corrections, it is acceptable that the time of correction in dose-geometry modulation takes bit longer than that of dose modulation, especially taking into account its correction capabilities, which are obtained from the dose-geometry modulations. As appeared in figure 6-(a), the calculation time in eRIF increased 2~12 times, specifically for test Type 3 pattern, than that in the dose-geometry modulations. Nevertheless, this substantially longer calculation time in eRIF is also understandable. It is because of those below. First, the eRIF is still under development phase for the complete applications and it is still a rule-based algorithm as mentioned above. Second, the eRIF is intended and developed to aim the specific applications, for example critical correction like sub-40nm or complementary cut-line exposures. This means that final goal for the application of eRIF is not in the entire chip or large area general correction but for the specific critical area and particularized pattern. This is the reason why the Type 1 test layout did not apply to the evaluation of eRIF. However, the shortening of this time in eRIF is one of the important factors to be improved in further development phase now.

In a variable shaped beam tool, as the one that used for testing these algorithms at Fraunhofer CNT, the easiest way to evaluate the writing time is to extract the number of shots from the prepared data for the exposure and compare those. Even if this does not mirror the exact writing time in actual exposures, it can delineate how much the writing time can be influenced according to the different modulations in correction. Figure 6-(b) depicts the number of the exposure shots of the prepared exposure data depending on the each modulation method for PEC along with the respective test layouts. The shot numbers of the prepared patterns are normalized with that of pattern corrected by dose modulation in each test layout types. It draws the attention that the shot numbers of patterns that are corrected with dose-geometry modulation are nearly same as those corrected using simple dose modulation or somewhat reduced, specifically in a case of Type 2 pattern. This means that the dose-geometry modulation developed by Aselta Nanographics does not give any harm or serious differences in the writing time of patterns, especially when comparing it to patterns prepared with conventional dose modulation. The number of shots in patterns prepared by eRIF increased 2~2.6 times than that prepared by dose modulation in PEC. Considering the principle of eRIF, which is based on multiple pass exposure, these considerable larger amount of shot numbers are unavoidable. However, it seems that this will not be an obstacle for the application of eRIF in future because of its specific purpose already discussed.



(a) (b)

Figure 6. (a) The calculation time according to the types of modulation and that of test layouts. As those appeared in graph, the light grey bar represents the calculation time for the correction with conventional dose modulation and the dark grey one presents the same for that with dose-geometry modulation. The time for correction in eRIF is illustrated as the oblique stripe bar. (b) Extracted exposure shot numbers from the prepared exposure patterns, which those are corrected with the different modulations, according to the respective test layouts. The shot numbers of patterns are normalized based on that of the pattern corrected by conventional dose modulation as 1 in each type of test layouts. The actual numbers of shots are stated in the bars of graph.

4. CONCLUSIONS

Fraunhofer CNT tested and evaluated the newly developed modulation algorithms for PEC, called dose-geometry modulation and electronic Resolution Improvement Feature (eRIF), developed by Aselta Nanographics. Simulations and actual test exposures with standard processes in Fraunhofer CNT using test layouts, designed to mimic the actual possible applications, and the design of SRAM metal 1 layer, carried out the evaluation and review.

First, the dose-geometry modulation in PEC proves its enhanced correction capabilities down to the design CDs of 40nm half pitch with a current variable shaped beam tool whereas the conventional dose modulation PEC has reached that of 50nm half pitch with difficulties. The correction through the dose-geometry modulation is not only improved in CD point of view but also regarding better line end shortening and corner rounding. Secondly, the eRIF, a correction algorithm based on the dose modulation and multiple pass exposures, refined the PECs for sub-40nm designs. Furthermore, this method shows a new approach for the correction of peculiar designs for specific applications like complementary exposures, especially in sub-35nm half-pitch designs. Finally, the other real case factors, specifically the calculation time and estimated writing time, are figured that it is not going to be affected by the application of dose-geometry modulation. Correspondingly, the eRIF is considered not to hamper those to take into account of its application on limited area and specific patterns.

In summary, it is able to state that the dose-geometry modulation and eRIF is promising algorithm for the PEC of future multiple beam maskless lithography and mask writing, especially in the EUV mask that requires the rigid accuracy of CD. Fraunhofer CNT and Aselta Nanographics are currently cooperating to complete both new methods and to improve the glitches and the other miscellaneous factors for actual applications, which those found in the review and evaluation processes.

5. ACKNOWLEDGEMENTS

The authors would like to thanks to the help and collaboration of Xaver Thrun at Fraunhofer CNT and Dr. Alexandre Chagoya at Aselta Nanographics.

REFERENCES

[1] L. Martin, S. Manakli, S. Bayle, K.-H. Choi, M. Gutsch and L. Pain, "Data Preparation solution for e-beam multiple pass exposure: Reaching sub-22nm nodes with a tool dedicated to 45nm", Proc. of 23rd Int. Microprocesses and Nanotechnology Conference, Fukuoka/Japan, 9~12th Nov. (2010).

[2] Martin Freitag, Kang-Hoon Choi, Manuela Gutsch and Christoph Hohle, "Line end shortening and application of novel correction algorithms in e-beam direct write", Proc. of SPIE 7985, 79850T (2011).

[3] L. Martin, S. Manakli, B. Icard *et al*., "Multiple pass exposure in e-beam lithography: Application to the sub-22nm nodes", Proc. of SPIE 7637, 76370E (2010).

[4] Luc Martin, Serdar Manakli, Sebastien Bayle *et al*., "Data preparation solution for e-beam multiple pass exposure: Reaching sub-22nm nodes with tool dedicated to 45nm", Proc. of SPIE 7970, 797019 (2011).

[5] Yan Borodovsky, "ArF lithography extension for critical layer patterning", LithoVision 2010, 21st Feb.,San Jose, CA/USA (2010).

[6] David K. Lam, Enden D. Liu, Michael C. Smayling and Ted Prescop, "E-beam to complement optical lithography for 1D layouts", Proc. of SPIE 7970, 797011 (2011).