PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

100 nm half–pitch double exposure KrF lithography using binary masks

Geisler, S., Bauer, J., Haak, U., Stolarek, D., Schulz, K., et al.

S. Geisler, J. Bauer, U. Haak, D. Stolarek, K. Schulz, H. Wolf, W. Meier, M. Trojahn, E. Matthus, "100 nm half–pitch double exposure KrF lithography using binary masks," Proc. SPIE 6924, Optical Microlithography XXI, 69241Z (11 April 2008); doi: 10.1117/12.771333

SPIE.

Event: SPIE Advanced Lithography, 2008, San Jose, California, United States

100 nm Half – Pitch Double Exposure KrF Lithography Using Binary Masks

S. Geisler[a], J. Bauer[a], U. Haak[a], D. Stolarek[b], K. Schulz[a], H. Wolf[c], W. Meier[d], M. Trojahn[e], E. Matthus[a]
[a]IHP, Im Technologiepark 25, D-15236 Frankfurt (Oder), Germany, geisler@ihp-microelectronics.com
[b]University of Applied Sciences Wildau, Faculty Engineering / Industrial Engineering, Physical Engineering, Bahnhofsstr., D-15754 Wildau, Germany
[c]Photonics Inc., Photonics MZD GmbH, Maria-Reiche-Str. 4, D-01109 Dresden, Germany
[d]Nikon Precision Europe GmbH, Paul-Ehrlich-Str. 3-5, D-63225 Langen, Germany
[e]Rohm and Haas Electronic Materials Deutschland GmbH, Limburgerstr. 31, D-73734 Esslingen, Germany

ABSTRACT

In this paper we investigate the process margin for the 100nm half – pitch double exposure KrF lithography using binary masks for different illumination settings.
The application of Double Exposure Lithography (DEL) would enlarge the capability of 248 nm exposure technique to smaller pitch e.g. for the integration of dedicated layers into 0.13 µm BiCMOS with critical dimension (CD) requirements exceeding the standard 248 nm lithography specification. The DEL was carried out with a KrF Scanner (Nikon S207D, NA_{Lens} = 0.82) for a critical dimension (CD) of 100nm half pitch. The chemical amplified positive resists SL4800 or UV2000 (Rohm & Haas) with a thickness of 325nm were coated on a 70 nm AR10L (Rohm & Haas) bottom anti-reflective coating (BARC). With a single exposure and using binary masks it is not possible to resolve 100nm lines with a pitch of 200 nm, due to the refraction and the resolution limit.
First we investigated the effect of focus variation. It is shown that the focus difference of 1st and 2nd exposure is one critical parameter of the DEL. This requires a good focus repeatability of the scanner. The depth of focus (DOF) of 360 nm with the coherence parameter σ = 0.4 was achieved for DEL with SL4800 resist. The influence of the better resist resolution of UV2000 on the process window will be shown (DOF = 460 nm). If we change the focus of one of the exposures the CD and DOF performance of spaces is reduced with simultaneous line position changing.
Second we investigated the effect of different illumination shapes and settings. The results for conventional illumination with different values for σ and annular illumination with σ_{inner} = 0.57 and σ_{outer} = 0.85 will be shown.
In summary, the results show that DEL has the potential to be a practical lithography enhancement method for device fabrication using high NA KrF tool generation.

Keywords: KrF Lithography, Double Exposure Lithography, binary masks

1. INTRODUCTION

The double exposure (DEL) and double patterning lithography (DPL) are two exposure techniques to improve the resolution limit of the exposure tool. Both techniques are widely known and already used in modern lithography /1/ to achieve smaller pitches. Another motivation to develop new techniques for existing exposure tools are the rapidly increasing costs for new lithography equipment. The double exposure and double patterning lithography can enlarge the life-time of the current exposure tools, because it is possible to use them for smaller structures and new applications. The resolution R is defined by the Rayleigh equation (1):

$$R = k_1 \frac{\lambda}{NA_{Lens}} \tag{1}$$

Optical Microlithography XXI, edited by Harry J. Levinson, Mircea V. Dusa,
Proc. of SPIE Vol. 6924, 69241Z, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.771333

Where R is the lowest printable half-pitch, k_1 is a process factor, λ is the wavelength of the exposure tool and NA_{Lens} is the numerical aperture of the projection lens. The principle for the DEL and DPL is to divide the layout in at least two parts to have a more relaxed half-pitch for the photolithography. Due to the layout splitting we are able to reduce the half-pitch with the used exposure tool. The resolution limit for the NIKON NSR207D tool is 130 nm half-pitch using binary masks. This equals a k_1 – factor of 0.43 for λ = 248 nm and a numerical aperture NA = 0.82. With the use of DEL we could print a 100 nm half-pitch grid and lower the k_1 – factor to 0.33.
Several types of DEL and DPL have been developed and investigated. Especially for the DEL several procedures are possible, e.g. one resist spin on, double exposure and one develop step or double exposure with two resist spin on and two develop steps. The DEL and DPL techniques are shown in Fig. 1. Furthermore positive and negative techniques are shown in /1/.

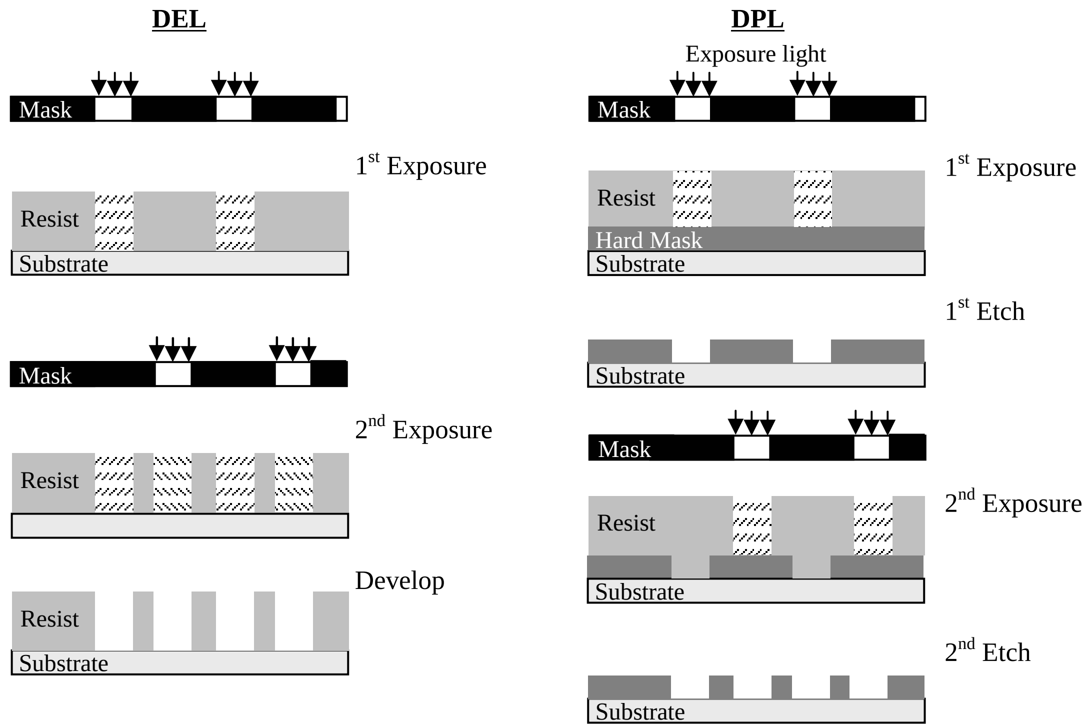

Fig. 1: Process flows for the DEL (left) and DPL (right) technique. For DEL the one spin-on, double exposure and one develop technique is shown. A litho, etch, litho, etch - process is shown for the DPL.

The main difference between the DEL and DPL is that the DEL uses a resist mask for pattern transfer and the DPL uses a hard mask. The resist mask of the DEL is structured in two lithography steps. For the structuring of the hardmask in the DPL two litho – etch steps are necessary. Therefore the DPL needs more process steps and requires a higher wafer alignment of the exposure tool.

2. METHODOLOGY

The experiments were carried out with the NIKON NSR207D exposure tool and TEL ACT 8 wafer track. For all exposures we use the highest aperture of NA_{Lens} = 0.82. We used SL4800 and UV2000 as photoresists. Both resists were coated on a 70 nm ARC (AR10L) layer with a thickness of 325 nm. All three chemicals are from Rohm & Haas. The CD measurements for the process window determination were performed with a KLA-Tencor eCD 2 CD – SEM. We analyze the collected data with PRODATA® by KLA-Tencor /2/ to calculate the process windows for different exposure settings. For the exposure we use a dark field binary mask with a grating (100 nm space / 300 nm line). The process window investigation was carried out by a wafer shift of 200 nm for the 2nd exposure to get a grating with 100 nm half-pitch. The process window determination shows that a focus difference between the 1st and 2nd exposure is a critical

parameter for the DEL. First we investigated the focus difference impact for the 1st and 2nd exposure. Therefore we investigate three possible focus changes.
Second we discuss the process windows for the different illumination settings. In addition, we compare our experiments with simulation results generated with Solid-E® by Sigma-C – Synopsys /3/.

3. RESULTS AND DISCUSSION

3.1 Focus variation between 1st and 2nd exposure step

There can be a focus difference for the 1st and 2nd exposure of DEL. There are several causes for the focus differences. The first cause is the focus repeatability of the exposure tool. The focus repeatability of the used exposure tool is specified to be ≤ 30 nm. Compared to the DOF of single exposure (DOF ~190 nm) the error of the focus repeatability is quite negligible. In Fig. 2 we show that a focus shift of the 2nd exposure for the CD of the lines is negligible, but for the CD of the spaces the focus shift needs to be below 100 nm for 5 % CD tolerance. The space 1 is exposed in 1st exposure and line 1 is on the right side of the space 1.

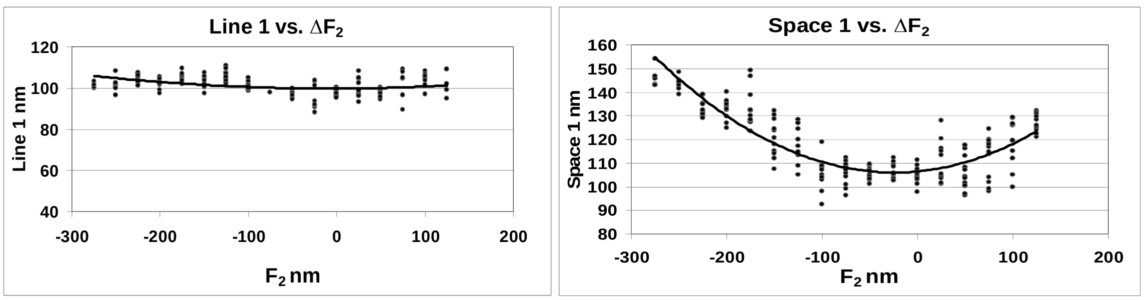

Fig. 2: CD variation for lines and spaces. The focus of 1st exposure is fixed at best focus and the focus for 2nd exposure is the x-axis. /4/

The second and more important cause appears due to the wafer shift for 2nd exposure. We found that this is more critical for application of multi-layer reticles, if the structures for the 2nd exposure are not in the scan direction of the exposure tool. Due to the larger wafer shift with multi-layer reticles, the used focus sensors change and may measure a different value. In comparison to the usage of different focus sensors for 1st and 2nd exposure to the usage of the same sensors, we found a higher CD uniformity (CDU) of 10 nm – 15 nm (3σ). These results are inferior to the case if we use the same sensors for the exposure, where we get a CDU of 6 nm – 7 nm (3σ) for lines and spaces. The usage of fixed focus sensors for the exposure is also possible, but with the wafer shift for the 2nd exposure the focus is measured at a different location, which is critical for wafer topography.
Furthermore the focus differences between the 1st and 2nd affects the process window. In our experiments we investigate three variants of focus differences. First we change the focus for the 1st and 2nd exposure in the same way and get the highest DOF of 360 nm for SL4800 resist. Second the focus for the 2nd exposure is changed in the opposite direction to the focus for the 1st exposure. For this case we found a reduced DOF of 300 nm. For the third variant we fix the 1st exposure focus at best focus and change the focus of the 2nd exposure. This could be a typical case, if we use multi-layer reticles and fixed focus sensors. The measured DOF of 150 nm is slightly lower than the DOF for a single exposure where we found a DOF of 190 nm. An overview for the three cases is given in Fig. 3. On the left side the changing of the focus for 1st and 2nd exposure is given. On the right hand side we show SEM images for best and defocus points. Additionally, we shift the 2nd exposure by 200 nm in y – direction, to identify the 1st and 2nd exposure.

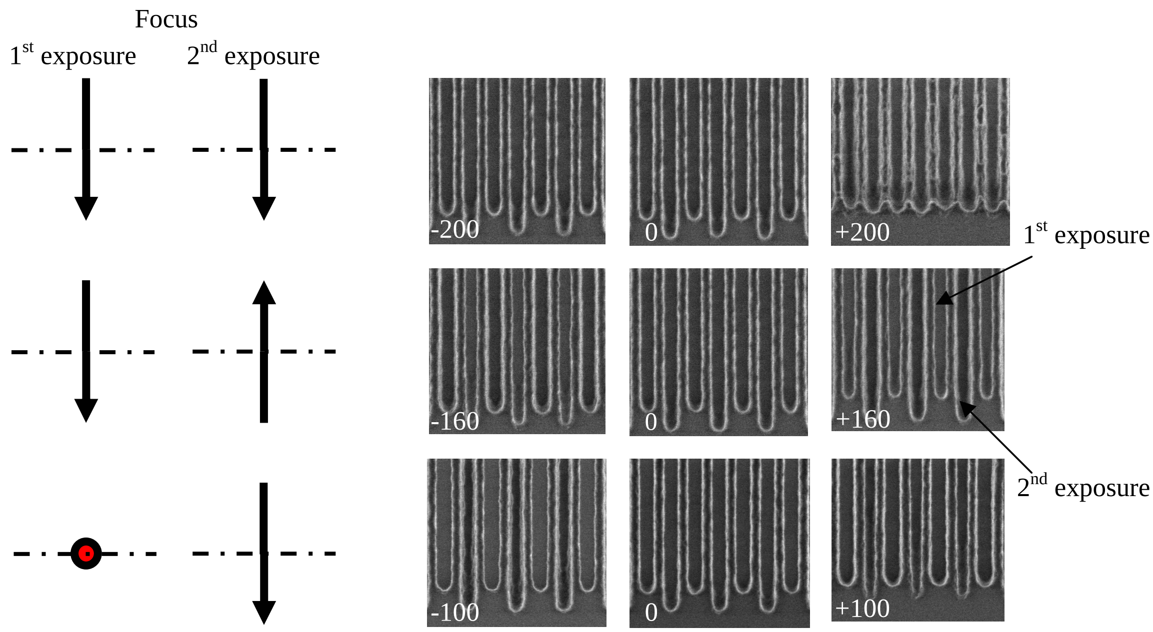

Fig. 3: Overview of focus difference investigation. For the exposure we use the same 1:4 (line/space) grid and pitch doubling by shifting of 200 nm in x – direction for the 2nd exposure. Furthermore we shift the 2nd exposure by 200 nm in y – direction to identify each exposure

A comparison of the experimental values of the focus difference for the 1st and 2nd exposure with simulation shows very good agreement. In Fig. 4 the standardized intensity for each exposure with the superposition and the resist profiles for different focus settings are shown. The corresponding resist structures are shown on the right hand side. The upper picture shows the intensities and resist structures at best focus for 1st and 2nd exposure. In the lower picture the focus for the 2nd exposure is shifted by 150 nm, equals the third focus variant (Fig 3). The superposition of the two exposures shows different intensities for the structures of the 1st and 2nd exposure.

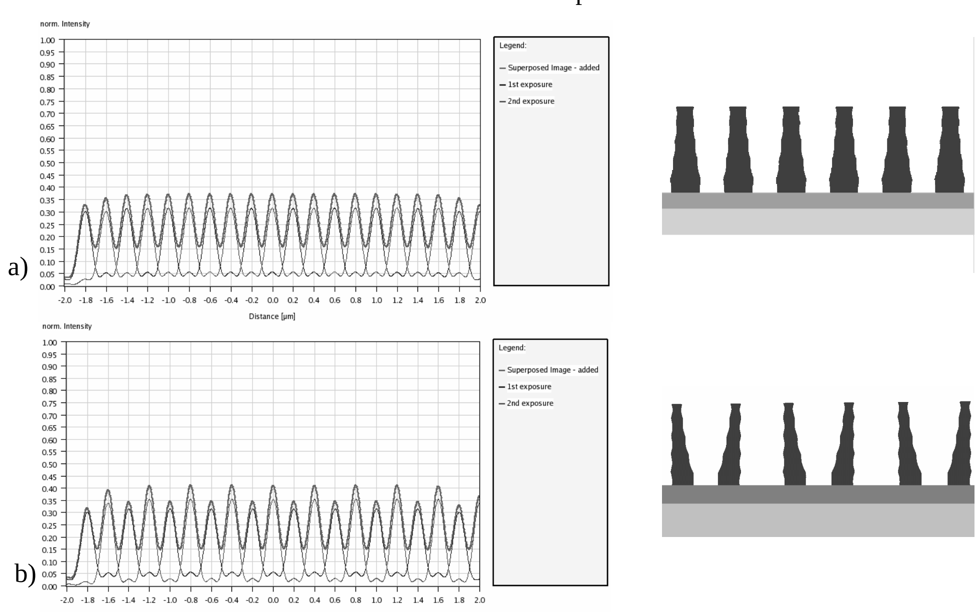

Fig. 4: Standardized intensity and resist profiles for best focus (a) and 150 nm defocus of 2nd exposure (b).

The changes are to be seen on the resist structures on the right side. The DEL of the 100 nm half – pitch grating needs a lower exposure dose than the single exposure of the grating (100 nm space and 300 nm line). The dose difference of ~ 10 mJ/cm² can be explained by the superposition of the intensities for the 1st and 2nd exposure. This superposition of the intensities is causing an increased DOF for DEL in comparison to the single exposure. Additionally, we see a defocus introduced shift of the lines.

3.2 Process windows for different illumination settings

For the process window determination we use the SL 4800. We show the better process window for the UV 2000 resist compared to the SL 4800 with coherence parameter σ = 0.4. We measure the CD of the lines in the middle of the 100 nm half – pitch grating. In addition, we measure the line edge roughness (LER) for the best focus and best dose point. The LER measurement offers a comparable pattern quality parameter. With increasing the coherence parameter σ (NA_{Lens} = const.) the contrast decreases and we see a high resist lost in height due to the superposition of the 1st and 2nd exposure.
For the exposure we use a predefined set of illumination settings. The numerical aperture NA_{Lens} = 0.82 is fixed and the coherence parameter σ is changed. In table 1 we show all illumination settings with NA_{Lens} = 0.82 and the annular setting.

Table 1: Summary of the possible illumination settings with NA_{Lens} = 0.82.

ID	aperture type	NA_{Lens}	coherence parameter σ
1	Conventional	0.82	0.9
2	Conventional	0.82	0.4
4	Annular	0.82	2/3
6	Conventional	0.82	0.55
7	Conventional	0.82	0.2
8	Conventional	0.82	0.85
10	Conventional	0.82	0.7

For all process windows we use 3 % exposure latitude and 100 nm ± 5 % CD variation. In Fig. 5 the measured process window and the exposure latitude (EL) - DOF graph for ID 7 are shown.

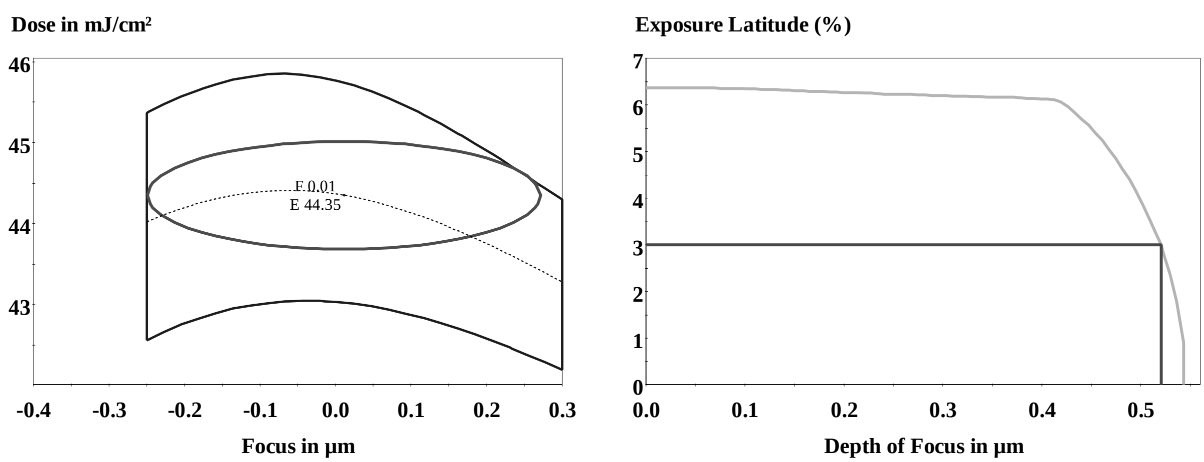

Fig. 5: Process window and exposure latitude for ID 7. DOF = 520 nm with 3 % exposure latitude.

For the smallest coherence parameter σ = 0.2 we measured the highest depth of focus (DOF) = 520 nm with 3 % exposure latitude. The LER for the lines at best focus and exposure is LER = 3.5 nm.

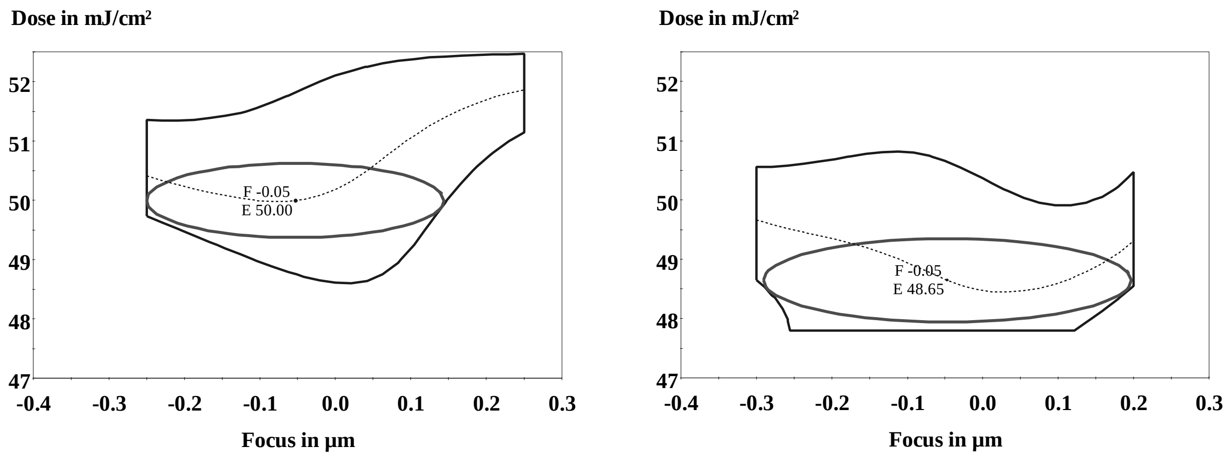

Fig. 6: Process windows for SL4800 (left) and UV200 (right) exposed with ID 2.

The DOF for ID 2 is decreased to 360 nm with SL 4800 (Fig. 6), due to the lower contrast for the increased coherence parameter σ. In addition, the LER = 4.6 nm is higher compared to ID 7. In Fig. 7 we show the EL - DOF graph for the UV 2000 and SL 4800 resist. In comparison of the UV 2000 to the SL 4800 resist the DOF is increased by 100 nm to DOF = 490 nm for the UV 2000. Furthermore, the best dose for the UV 2000 resist is ~ 1 mJ/cm² lower compared to the SL 4800 resist. This shows the better contrast ratio for the UV 2000.

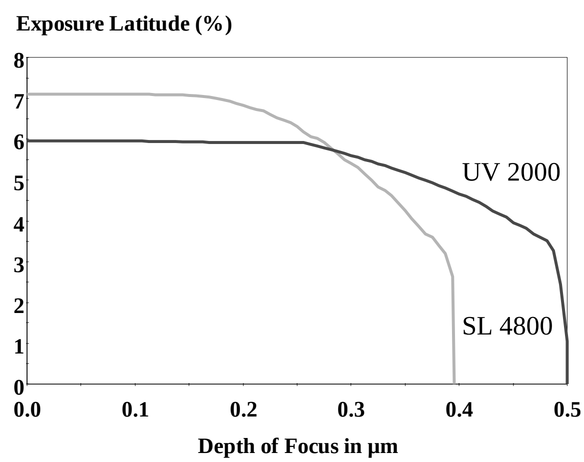

Fig. 7: Exposure latitude for SL 4800 and UV 2000 exposed with ID 2. We measure a DOF = 390 nm for SL 4800 and DOF = 490 nm for UV 2000.

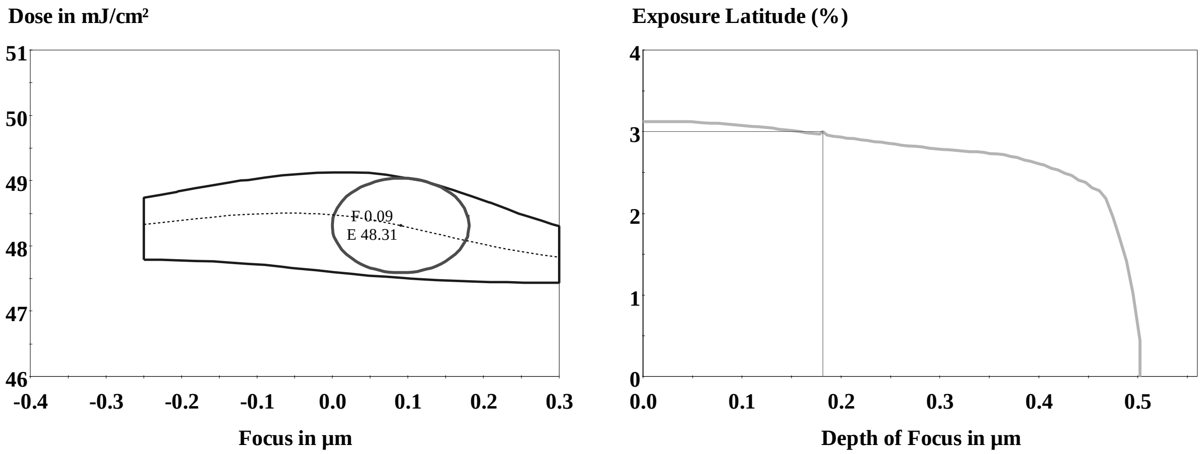

Fig. 8: Process window and exposure latitude for ID 6. DOF = 180 nm with 3 % exposure latitude.

Fig. 8 shows the process window for ID 6. The DOF is decreased to 180 nm and the LER = 6.3 nm is nearly twice as for ID 7. The simulations results are comparable with the experimental wafer printing results. We see the same decreasing DOF for the illumination settings.

In Fig. 9 we simulate the coherence parameter – contrast chart to show the decreasing contrast in dependency to the coherence parameter σ.

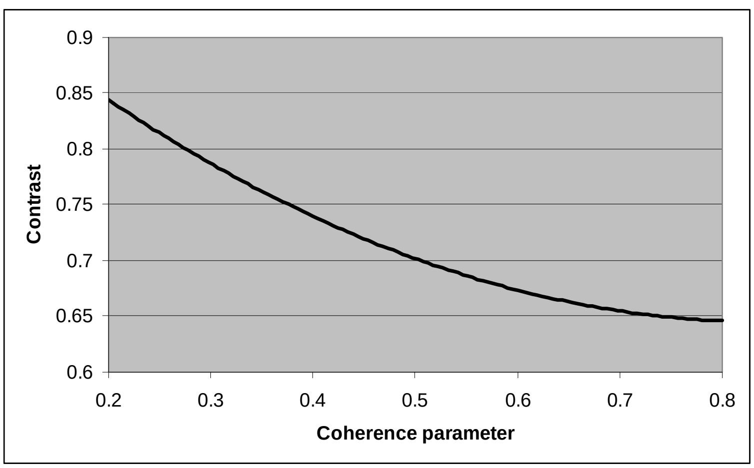

Fig. 9: Coherence parameter – contrast chart for conventional illumination.

For the contrast definition we need to consider both exposures, due to the superposition of the intensities shown in Fig. 4. The contrast is defined by (2):

$$Contrast = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \tag{2}$$

I_{max} and I_{min} are the maximum and minimum intensity for a single exposure. If we consider both exposures the equation change to (3):

$$Contrast = \frac{(I_1 + I_2)_{\max} - (I_1 + I_2)_{\min}}{(I_1 + I_2)_{\max} + (I_1 + I_2)_{\min}} \tag{3}$$

I_1 and I_2 are the intensities for the 1st and 2nd exposure. With the increasing the coherence parameter σ from 0.2 to 0.8 the contrast decreases from ~ 0.85 below 0.65. Due to the superposition of the 1st and 2nd exposure the decreased contrast affects the pattern quality and the process window even more. Exposures with higher coherence parameter than 0.55 show smaller process windows and worse pattern quality with high resist lost.

The annular illumination setting shows very poor results. We could not measure a process window. For a dose = 55 mJ/cm² and a focus = -0.05 we measure structures within the tolerance, but with a LER = 8.6 nm. LER of about 10 % of the pattern width is too high for 100 nm half – pitch structures.

Finally, we compare SEM images for the different illumination settings for the best focus and dose point (Fig. 10).

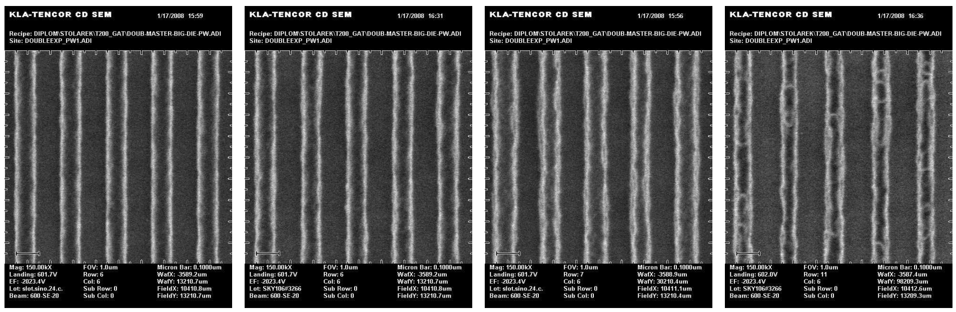

Fig. 10: SEM images for ID 7, ID 2, ID 6 and ID 4 (left to right) with 100 nm half - pitch

The SEM images in Fig. 10 show the resist pattern with 100 nm half – pitch for different illumination settings for DEL. The images for ID 7 and ID 2 are comparable, due to the ~ 1 nm difference in the LER. For ID 6 and ID 4 we see a higher slope of the resist structures and the higher LER is visible.

As already described, there is a superposition of the 1st and 2nd exposure affecting the pattern fidelity. For the outer structures of the grid we see a large distortion due to the missing intensity in comparison to the middle of the grid. This effect is critical for device fabrication and should be noted. There are several possibilities to correct the distortions. One option could be the application of an optical proximity correction, or the application of sub resolution assist features (SRAFs). A second possibility could be a 3rd exposure to expose the borders, comparable to the *CODE* process /5/.

4. CONCLUSION

Our experiments show that the DEL has the potential to be a practical lithography enhancement technology for the KrF Lithography. We investigated several illumination settings to achieve an excellent process window. The best illumination setting with the highest DOF and lowest LER was obtained with a coherence parameter σ = 0.2. Furthermore, we show the effect for a focus difference between the 1st and 2nd exposure and its impact on the process window, especially for the use of multi – layer reticles. The superposition of the two exposures and the distortions on the outer structures should be considered.

REFERENCES

/1/ Gianfranco Capetti, et al, "Sub k1 = 0.25 Lithography with Double Patterning Technique for 45nm Technology Node Flash Memory Devices at λ = 193nm", Proc. of SPIE Vol. 6520, 2007

/2/ www.kla-tencor.com

/3/ www.synopsys.com

/4/ S. Geisler, et al, Double Exposure Technology for KrF Lithography, EMLC 2008

/5/ Y. Trouiller, et al, "Gate imaging for 0.09 µm logic technology of single exposure with assist bars and the CODE approach" Proc. SPIE 5040, 1231 – 1240, 2003