CDP - Application of focus drilling

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ABSTRACT

In this paper, we investigate Nikon's CDP (continuous depth of focus expansion procedure) used for focus drilling. The method is based on tilting the wafer stage along the scanning direction, with the stage moving up- or downwards. This averages the aerial images in the resist and increases the achievable depth of focus. The application of CDP (or tilted stage approach) would enlarge the depth of focus (DOF) for patterning of contact holes, especially in backend of line processes with increased topographical complexity. For CDP to be applied in mass production, it is necessary to understand the relation between CDP values, numerical aperture (NA), the coherence parameter σ and the depth of focus. The influence of CDP on patterning of isolated and dense contact holes needs to be considered. We show that CDP could enlarge the depth of focus and thus improve the process stability for patterning of contact holes.

Keywords: RET (resolution enhancement technology), CDP, tilted stage, binary masks, KrF lithography

INTRODUCTION

The achievement of a depth of focus required for stable process conditions is one of the biggest challenges in modern optical photolithography. There are several ways of improving the depth of focus. For line/space layers, for instance, application of RET (Resolution Enhancement Technology) using scattering bars, phase-shift masks or optimized illumination systems have shown good results. For contact and via layers the depth of focus is limited and critical, due to the structure size of the holes, alternating pattern density and wafer topology. A well known method of improving the depth of focus for contact and via layers is called focus latitude enhancement exposure (FLEX) [1-3]. With FLEX, several focal planes are being exposed, i.e. each during a separate exposure step. The main drawback is low throughput, as the total processing time rises which each additional exposure.

In this paper, we investigate Nikon's CDP (continuous depth of focus expansion procedure) [4]. The CDP option is applicable to modern scanning exposure tools [4-5]. A schematic view of the procedure is shown in Fig. 1. The CDP value or CDP amplitude defines the tilt of the wafer and thus the range of focus in the resist, as the focus plane migrates through the resist during the exposure. The main advantage of CDP, compared to FLEX, is higher throughput, since focal planes are defined within a single exposure. A non-CDP exposure may result in varying aerial images within resist thickness, therefore leading to decreased image contrast within out-of-focus planes. As shown in Fig. 1 the averaged aerial images of a CDP exposure induce better image contrast throughout the resist layer and therefore increase the focus window.

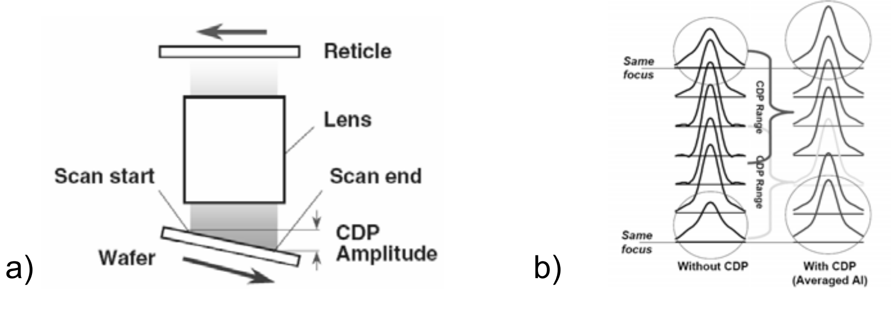


Fig. 1: A schematic view of the CDP technique (a) and the aerial image contrast without and with CDP (b).

We examined the influence of NA, σ and the CDP value on the depth of focus and the process window. In addition, we show patterning of dense, semi-dense and isolated contact holes with different illumination and CDP settings.

METHOLOGY

For our experiments we used the Nikon KrF NSR S207D scanner and the TEL Track ACT 8. The silicon wafers were coated with an UV210 resist (Rohm & Haas) with a thickness of 420 nm and an AR10L (Rohm & Haas) as BARC. The minimum feature sizes were 180 nm for the contact layer and 190 nm for the via layer. We used binary masks for both feature sizes. The CD measurements were carried out using KLA-Tencor SEM eCD 2. Finally, KLA-PRODATA software was used to determine the process windows (Fig. 2). First, we determined the best exposure conditions and process windows for a CDP exposure (Table 1). Subsequently, we checked the influence of CDP exposure on structures with various pitch. We measured CD of test patterns with pitches in the range of 340 nm to 1600 nm for both 180 nm and 190 nm structure sizes (Fig. 3). The CD uniformity (3σ) is a very important aspect and needs to be considered for CDP to be successfully applied. For this investigation we measured an isolated feature over 188 dies for every exposure setting on the same wafer with and without CDP.

Results

In comparison with our standard exposure with NA = 0.75, σ = 0.7 and CDP = 0 µm, the results for NA = 0.82, σ = 0.4 and CDP = 1.125 µm show a ~ 90% increase in DOF. The results also show an increasing DOF for increasing CDP values. In Table 1, a summary of the NA and σ parameters as well as the CDP values with measured CD for isolated and dense contact holes are shown. The last column contains the resulting depth of focus. A comparison of results in Table 1 for NA = 0.75 and NA = 0.82 reveals similar or slightly better results with higher NA.

Process windows for several exposure conditions are shown in Fig. 2. We measured isolated contact holes to determine the process windows. As shown, the DOF increases with increasing CDP value.

The effect of CDP on CD at various pitches is shown in Fig. 3. For pitch smaller than 520 nm, σ = 0.7, and CDP=1µm the CD increases, and σ = 0.4 the CD is decreased. These effects appear for pitches below the design rules only. The spread between isolated and dense pattern shows the limits for the application of CDP procedure for IC layouts.

The results in Fig. 4 show a decrease of the CD uniformity of up to ~250% for CDP = 1 µm.

CD uniformity (3σ) for standard exposure and low wafer surface topography is around 10 nm. For uncorrectable leveling residuals of topography (~ 300 nm) the CD uniformity decreases by 50% for a CDP value of 0.5 µm. For CDP = 1 µm the CD uniformity decreases up to ~ 250%. The cause of worth CD uniformity is the averaging of the aerial images. Due to wafer tilt and scan tilt, the high contrast at best focus is swapped against a lower contrast over a wide range around best focus.

Table 1: Exposure results for 0.19 µm holes on a binary mask for different NA, σ and CDP values.

NA	σ	CDP in µm	CD Iso in µm	CD Dense in µm	DOF in µm
0.75	0.7	0	0.171	0.171	0.19
0.75	0.7	0.5	0.171	0.179	0.22
0.75	0.7	1	0.196	0.217	0.3
0.75	0.7	1.5	0.175	0.283	0.51
0.82	0.4	0.75	0.187	0.162	0.25
0.82	0.4	1	0.183	0.17	0.31
0.82	0.4	1.125	0.171	0.171	0.36
0.82	0.4	1.25	0.167	0.192	0.4
0.82	0.4	1.5	0.175	0.229	0.57
0.82	0.55	1	0.183	0.204	0.3
0.82	0.7	1	0.188	0.22	0.33

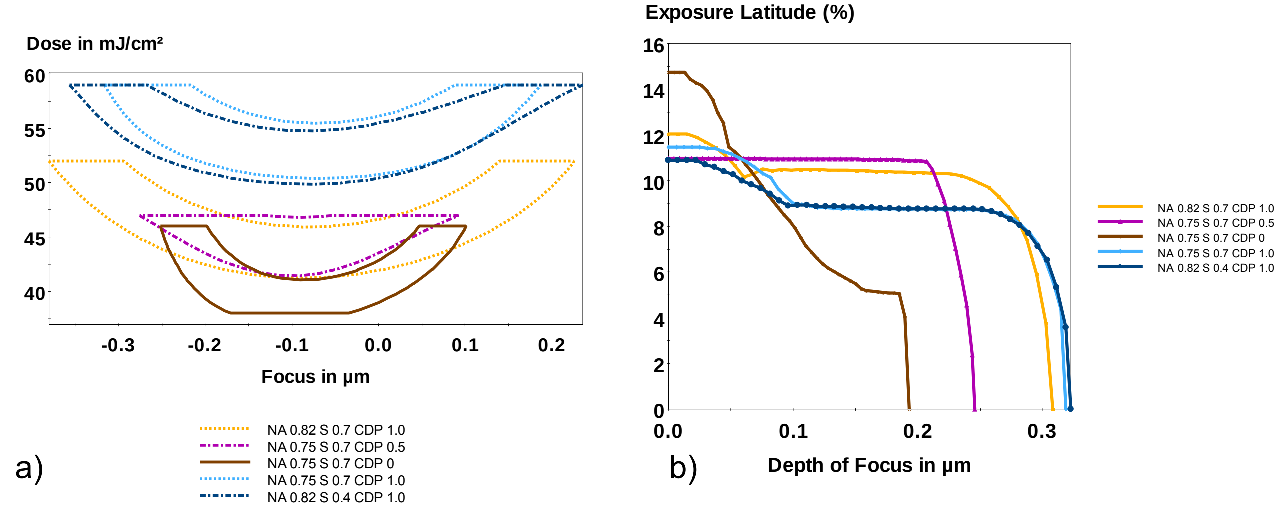


Fig. 2: Process windows for different illumination and CDP settings. a) CD process window, b) exposure latitude process window.

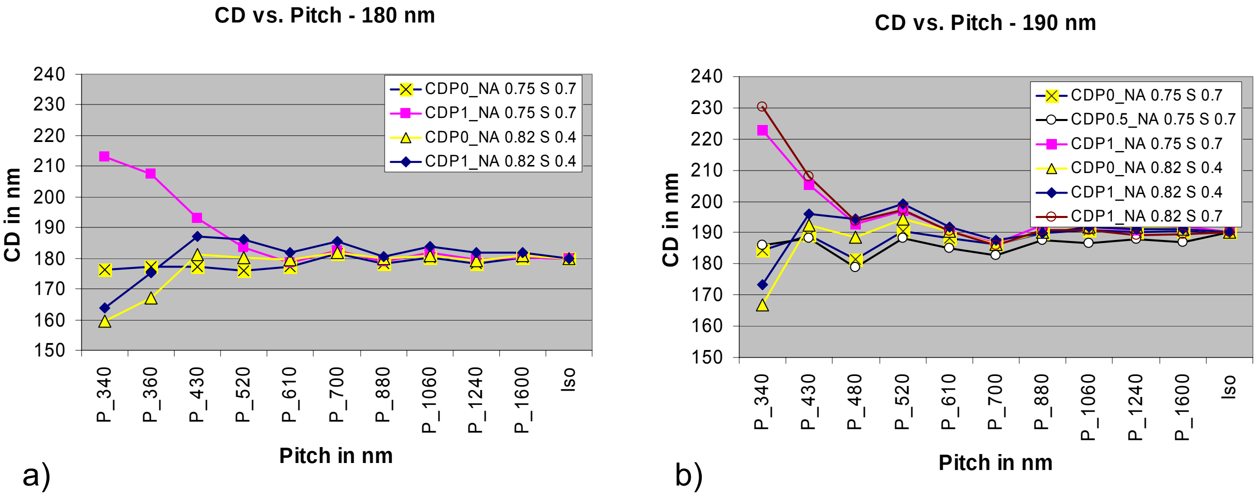


Fig. 3: CD vs. pitch measurements for 180 nm (a) and 190 nm (b) contact holes with different illumination and CDP settings.

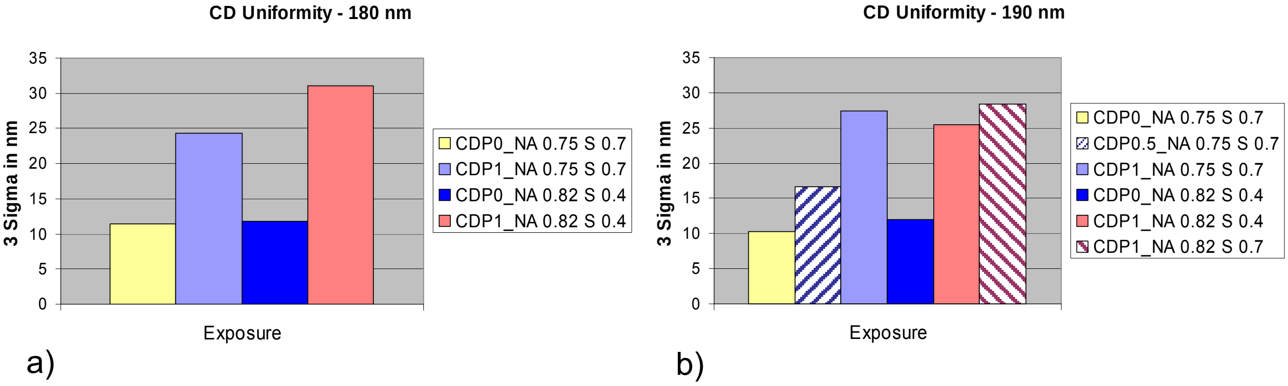
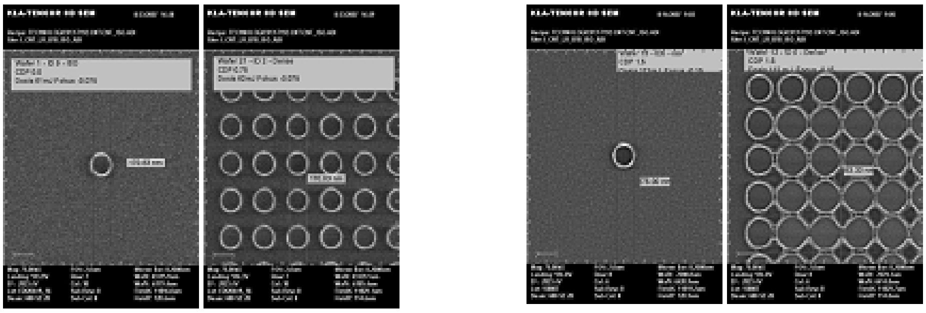


Fig 4: CD uniformity (3σ) for 180 nm (a) and 190 nm (b) isolated structures with different illumination and CDP settings.

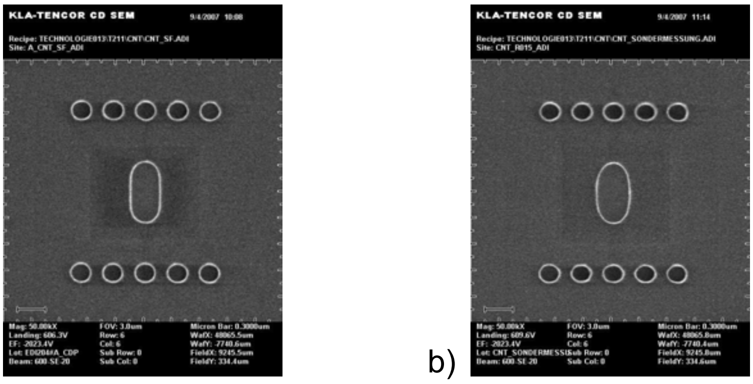


a) b)

Fig. 5: Exposure results (NA = 0.75, σ = 0.7) for a) CDP = 0 µm, and b) CDP = 1.5 µm

Fig. 5 shows exposure results for different CDP. For a high CDP value of 1.5 µm (Fig. 5b) dense features are larger than isolated features and they become bridged. Furthermore a gentler slope at the sidewalls of the features may be observed with CDP exposure. Depending on the pitch and the CDP value bridging might occur and limit the CDP exposure.

Clear bar pattern, in this case pattern which are stretched in x or y direction, are imaged with distortions. This is due to image blur with defocus, caused by tilt. Fig. 6 shows a comparison of exposure with and without CDP. The clear bar pattern in the middle is wider with CDP exposure. Furthermore, neighbouring contact holes become elliptic.



a) b)

Fig. 6: Patterning of contact holes and bars: a) without CDP exposure and b) with CDP = 1 µm.

The influence of CDP exposure on overlay is described in [6]. We tested CDP on product lots with slightly worse overlay results, but the results were within the tolerances.

In addition, we compared the exposure results with simulation results. For the simulation we used the Synopsys Sentaurus® simulator. The simulator cannot simulate CDP exposures. Therefore we used a FLEX approach to simulate CDP exposures with multiple exposures at different vertical stage positions. In Fig. 7 we show simulated results compared with measurements. The experimental results were compared with simulation. The maximum CD deviation between simulation and measurement is 5 nm and could be caused by CD mask tolerances as well.

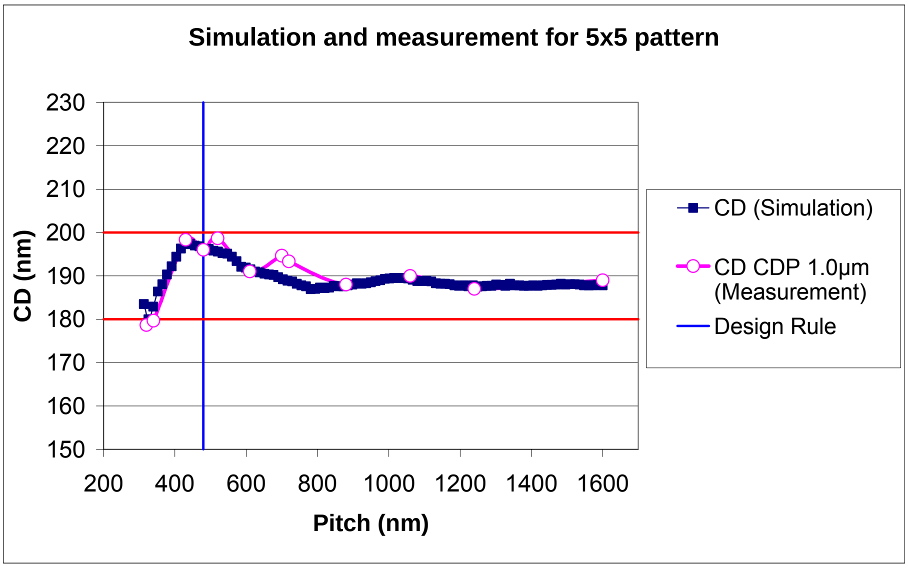


Fig. 7: Simulation and measurement results for a 5x5 contact hole array pattern. CD tolerance ranges between 180 nm and 200 nm.

APPLICATION

CDP exposure could be used for backend of line processes with large variations of metal pattern density. The varying metal density leads to intra field topologies after oxide deposition and CMP (Chemical Mechanical Polishing), mainly due to different polish rates for oxide spikes and flat oxide areas. These effects may become significant for higher layers in backend of line, especially for the lithography of contact holes, due to the limited DOF. According to [7], topology effects can influence the focus scan during exposure. An example of an intra field topology is shown in Fig 8. The local heightening of the layout can not be corrected with exposure tools and requires a large DOF for patterning. In Fig. 9 we show patterning results for the layout (Fig. 8) with and without CDP exposure.

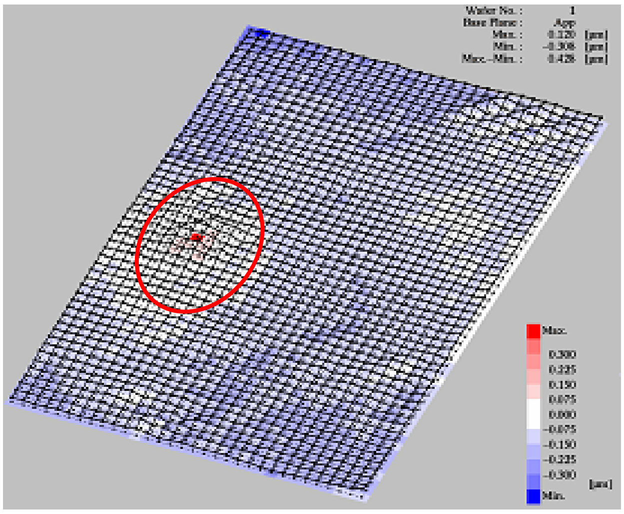


Fig. 8: Measured topology for layout with intra field topology (about 320nm) due to metal density variations.

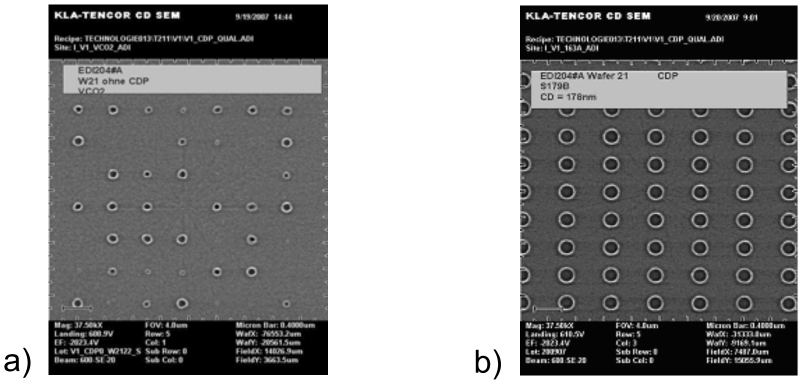


Fig. 9: Patterning comparison a) without CDP and b) with CDP for intra field topology shown in Fig 8

CONCLUSION

In summary, our results show that the Nikon CDP technique is a very useful tool for improvement of the depth of focus for contact hole patterning. For an applicable CDP value of 1 µm the DOF is increased by ~ 50% and the bias between isolated and dense pattern is still within the tolerance without the requirement of using optical proximity correction (biasing). With σ optimization, it is possible to reduce the bias between isolated and dense patterns. A negative impact of higher NA on the DOF is not observed. Our results show the same or slightly higher DOF for higher NA. The main disadvantage of the CDP exposure technique is a decreased CD uniformity. We measured a 2.5 times higher CD variation for exposures with CDP=1 µm in comparison to an exposure with CDP = 0 µm. Nevertheless, the CDP technique is a cost effective and productive lithography to improve yield of ICs with intra field topology.

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