Sub- Resolution Assist Feature Tolerances for Contact Windows Using 193 nm Lithography

A. Kroyan [a, b], G. P. Watson [a], R. A. Cirelli [a], O. Nalamasu [a], A. E. Novembre [a], F. K. Tittel [b]

[a] Bell Labs, Lucent Technologies, 700 Mountain Ave., Murray Hill, NJ 07974
[b] Rice University, 6100 Main, Houston, TX 77005

ABSTRACT

Combining assist features with appropriate off-axis illumination conditions can significantly improve depth of focus and uniformity of critical dimensions of contact windows. It is known that sub-resolution assist features modify the environment of isolated features in a fashion that they appear dense. In recent years the impact of assist features was mostly studied for gate-level lithography. In this paper the placement and dimension control of assist features for contact windows are examined and analyzed using 193 nm lithography in conjunction with a state-of-the-art single layer resist. Our study is primarily done for 160 nm contact windows, and it is based on experimental data obtained from critical dimension measurements with varying focus, exposure dose, and in different environments. Along with optical proximity corrections we use off-axis illumination technique which increases depth of focus of contact windows and improves the overall process latitude.

Specifically for this study we have designed a test photomask with different geometries and pattern densities of contact windows with and without assist features to be used at 193 nm wavelength. To study the proximity effects, different sizes of assist features were used as well as the distances of assists from the main feature were varied.

The results have shown that while increasing the process latitude for the primary feature using assist slots in combination with off-axis illumination, the resist thickness and contrast are limiting the assist feature dimensions that can be used. Assist features appear to significantly increase critical dimension uniformity of the contact windows when using both conventional and off-axis illumination techniques, and they dramatically increase the common exposure dose latitude for contact windows with densities from near-isolated to dense, decreasing the proximity effects. Assist feature technique combined with quadrupole illumination demonstrates about 0.3 micron improvement in depth of focus for every type contact window pattern used.

Keywords: sub-resolution assist features, off-axis illumination, depth of focus

1. INTRODUCTION

In recent years optical proximity correction technology is becoming increasingly important to leading-edge integral circuit manufacturing. Sub-resolution assist feature technique has been shown to be very effective in terms of improvement of depth of focus and overall process latitude of printed features.[1,2,3,4] Since the majority of studies are primarily focused on gate-level lithography, our goal is to investigate the impact and tolerances of sub-resolution assist features on 160 nm contact windows using 193 nm lithography.

Further author information-
A.K.: Email: kxa@rice.edu; Telephone: 713-527-8750 ext. 2209

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The use of sub-resolution assists modifies the isolated and semi-dense (dense only in one direction) environments in a way that they appear dense. This technique becomes especially effective when combined with off-axis illumination. Quadrupole illumination is well known to improve the depth of focus of dense patterns, and using it with sub-resolution assist features improves the depth of focus (DOF) of all of the features.

While the introduction of sub-resolution assist features can be very effective in terms of improvement of the overall process latitude, the contrast and thickness of the resist should be considered when choosing the most effective sub-resolution assist-based proximity correction approach.

2. RETICLE DESIGN AND EVALUATION

We have designed a test reticle which contains contact window arrays with different designs and feature densities to investigate the impact of sub-resolution assist features. Contact window arrays include features ranging from near-isolated to dense with and without sub-resolution assist features. Several arrays were designed to have features with pitches different in X and Y directions. For more precise study of the proximity effects of sub-resolution assist features, our designs include assist slots with different sizes and pitches from the main feature (Figure 1).

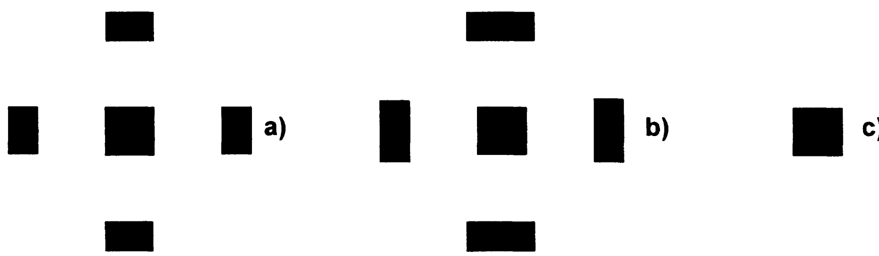
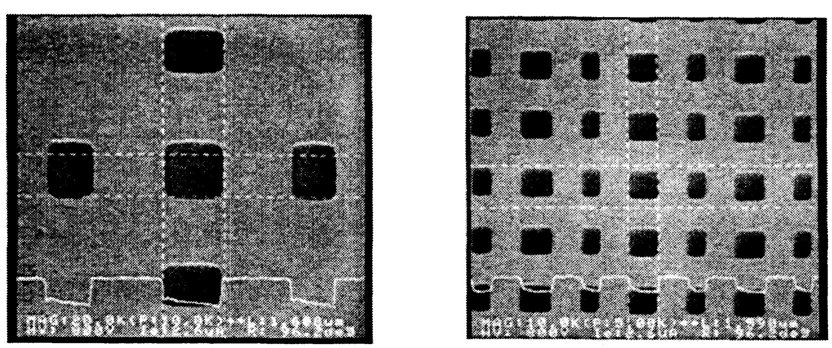


Figure 1. Different designs of isolated contact windows on the mask: **a)** isolated contact window with sub-resolution assist features; **b)** isolated contact window with extended sub-resolution assist features; **c)** isolated contact window.

The test reticle was manufactured to be used in a 10x reduction mode in a 193nm ISI XLS microstepper. Using Hitachi 6000 scanning electron microscope (SEM), different designs of feature arrays on the mask were evaluated and feature dimension measurements were made (Figure 2).



a) b)

Figure 2. SEM images of contact window patterns on the mask: **a)** isolated 160 nm contact window with 120nm sub-resolution assist features; **b)** 160 nm semi-dense contact windows with 100nm sub-resolution assist features.

3. EXPERIMENT

This work is mainly based on the study of the impact of assist slots on depth of focus and critical dimension uniformity of 160 nm contact windows. The primary focus was on the following contact window designs:

Contact Window Design Type	Pitch (nm)		Assist Slot Size (nm)		Assist Pitch (nm)	
	in X	in Y	in X	in Y	in X	in Y
Isolated	2500	2500	-	-	-	-
Isolated with Assists	2500	2500	120(160)	160(120)	320	320
Isolated with Assists	2500	2500	100(160)	160(100)	320	320
Isolated with Extended Assists	2500	2500	120(200)	200(120)	320	320
Semi-Dense	560	320	-	-	-	-
Semi-Dense with Assists	560	320	120	160	280	-
Dense	320	320	-	-	-	-

Using ISI XLS microstepper which operates on 193 nm wavelength, window features were printed on Si wafers with state-of-the-art inorganic bottom anti-reflective coating (BARC) and with thin single-layer resist K111030, which is developed by Olin Microelectronics and Lucent Technologies. The numerical aperture (NA) of the XLS stepper is 0.6.

To be able to eliminate most of the resist process effects and study the impact of the sub-resolution assist features on the aerial image, the target thickness of the single-layer resist was set to be 1800 Å. Nevertheless, the type and contrast of the resist used might have an impact on critical dimensions of the assist slot that can be used without being cleared during the development process.

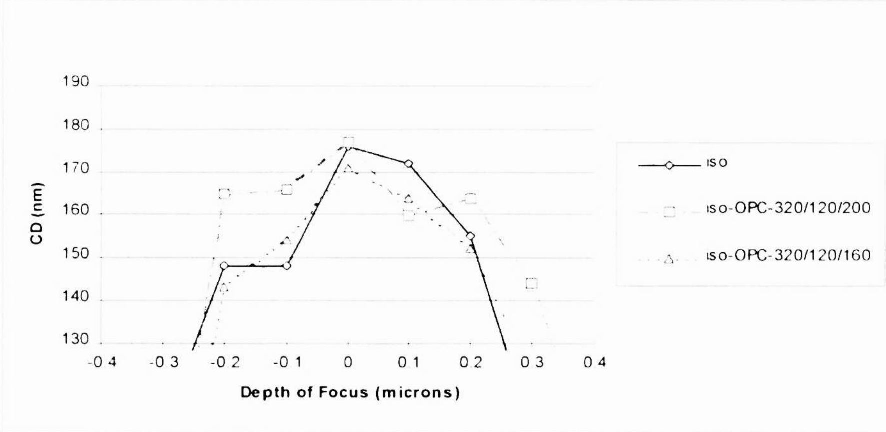
There were three illumination conditions used in our experiment. Along with conventional large partial coherence (σ = 0.7) and conventional small partial coherence (σ = 0.29) illuminations, we have studied off-axis quadrupole illumination, optimized for 160 nm features.

Feature critical dimension measurements were done using KLA 8100 top-down critical dimension (CD) measuring scanning electron microscope. As it was mentioned in the previous section, the CD measurements of the mask features were done on Hitachi 6000 SEM.

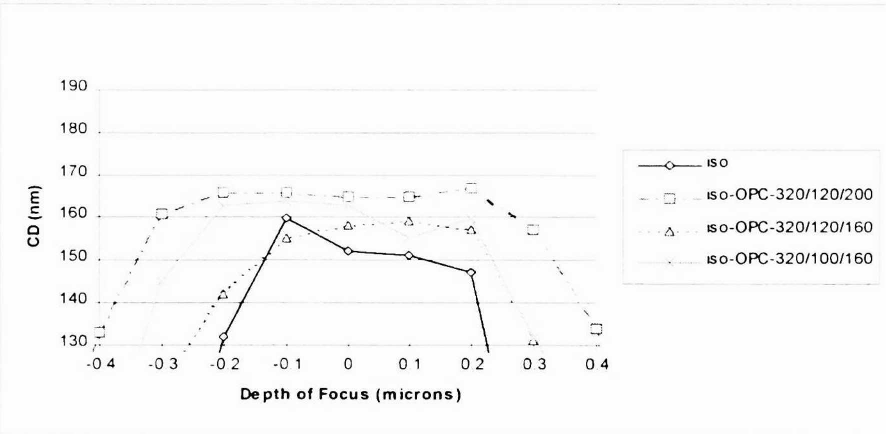
4. RESULTS OBTAINED AND DISCUSSION

The performance of the assists slots with isolated contact windows was measured by observing the depth of focus and CD uniformity of printed features when using different illumination conditions. Figure 3 shows a comparison of results for large partial coherence conventional and quadrupole illumination conditions. Conventional illumination shows only a slight improvement in CD uniformity of printed contact windows with assist slots (Figure 3a). In Figure 3b, however, that assist slots combined with quadrupole illumination have a significant impact on CD uniformity and depth of focus. Measuring the DOF within 10% of target feature CD size, the depth of focus of isolated contact windows is about 0.4 μm using conventional illumination, and we get an improvement of 0.2 to 0.3 μm in DOF when quadrupole illumination and assist feature technique are combined.

As it can be seen on Figure 3b, the overall performance of sub-resolution assist features is not very sensitive to their size variations within a certain range. The results show a clear improvement in uniformity and depth of focus in each case of the assist slot configurations studied over isolated contact windows without assist. Depending on the resist process and illumination condition used, the printability of the assist features depends critically on the assist feature dimensions, as Figure 4 indicates.

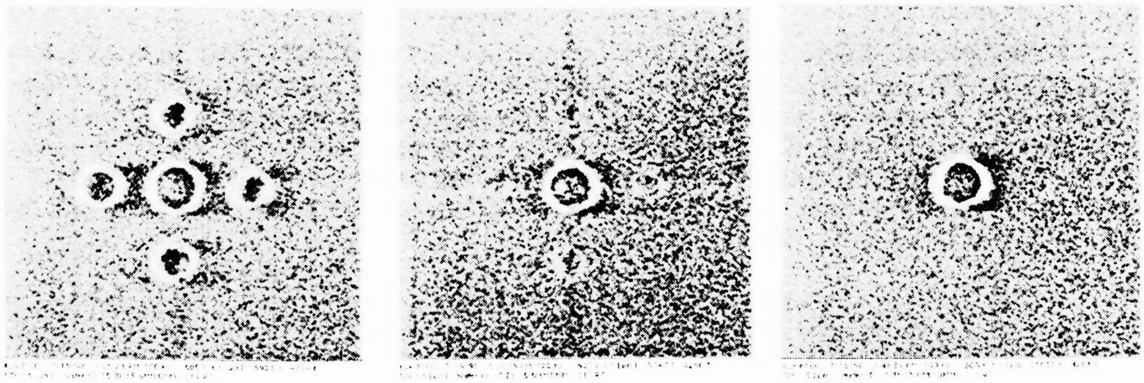


a)



b)

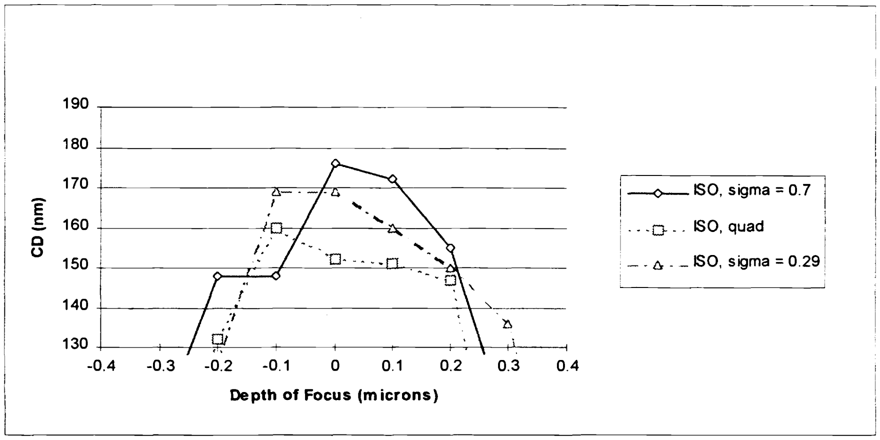
Figure 3. Critical dimensions of 160 nm contact windows through focus using **a)** conventional illumination (σ = 0.7) and **b)** quadrupole illumination. The data label numbers show the pitch, width, and length of the assist slots correspondingly.



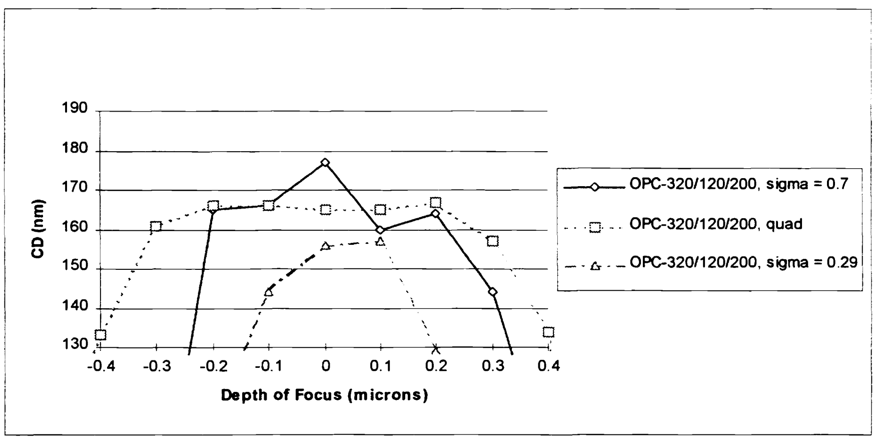
a) **b)** **c)**

Figure 4. Tolerances of the assist slot configurations for 160 nm contact windows in terms of they printability in a common exposure dose using conventional illumination (σ = 0.7). Assist slot pitch/size/extension: **a)** 320/120/200; **b)** 320/120/160; **c)** 320/100/160.

Results presented in Figure 3b clearly show the effectiveness of combination of sub-resolution assist feature technique with quadrupole illumination. Figure 5 illustrates the depth of focus of 160 nm isolated contact windows with and without OPC for each of the three illumination conditions we used in our experiments.



a)

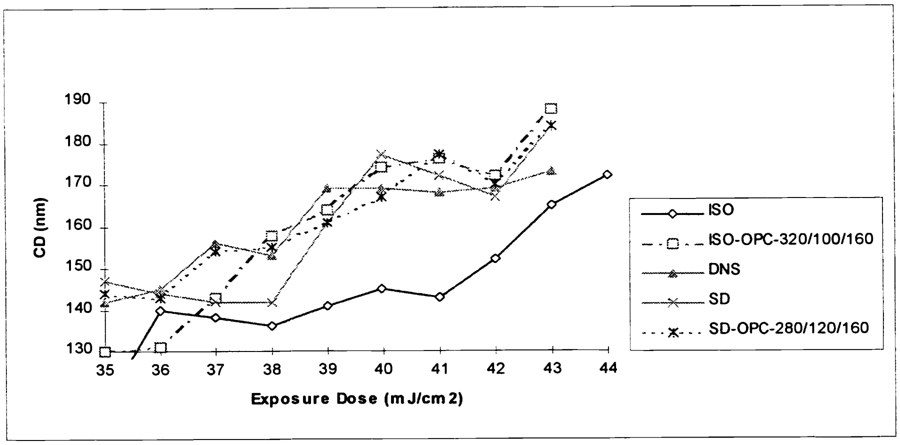


b)

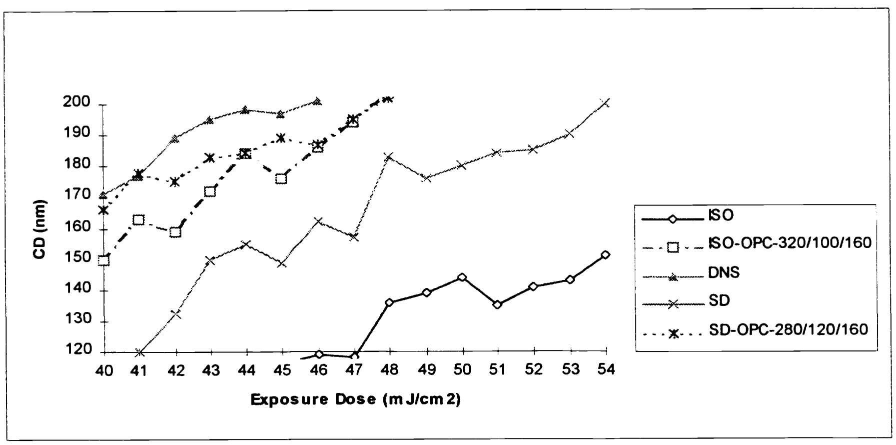
Figure 5. Comparison of CDs of 160 nm isolated contact windows through focus when different illumination conditions are used: **a)** isolated contact windows; **b)** isolated contact windows with assist features.

Comparing critical dimensions of contact windows without assist features and with different pattern densities, we have observed very large proximity effects. In the case of conventional illumination conditions, critical dimensions of semi-dense and dense contact windows measured about 30 nm larger than CDs of isolated features for a common exposure dose. When using quadrupole illumination, along with increased depth of focus we observe even further increase of proximity effects. In this case semi-dense and dense feature patterns printed about 40 and 70 nm larger than the isolated ones.

Introduction of sub-resolution assist feature technique showed that the proximity effects can be significantly reduced and almost eliminated due to the fact that assist features change the nature of isolated patterns making them appear dense. Figure 6 shows critical dimension measurements of 160 nm contact windows with different densities through exposure dose at best focus and the impact of sub-resolution assist slots when conventional and quadrupole illuminations are used. The results show that in the case of conventional illumination condition (Figure 6a), isolated contact windows with assist slots print about 30 nm larger than the ones without assists at the same exposure dose, practically eliminating the proximity effects. Similarly the proximity effects are significantly reduced when quadrupole illumination is used (Figure 6b). Semi-dense and isolated patterns with OPC print about 30 nm and 60 nm larger correspondingly compared to similar patterns without OPC at a common exposure dose.



a)



b)

Figure 6. Impact of sub-resolution assist features on proximity effects of printed 160 nm contact windows at best focus when **a)** conventional (σ = 0.7) and **b)** quadrupole illumination conditions are used.

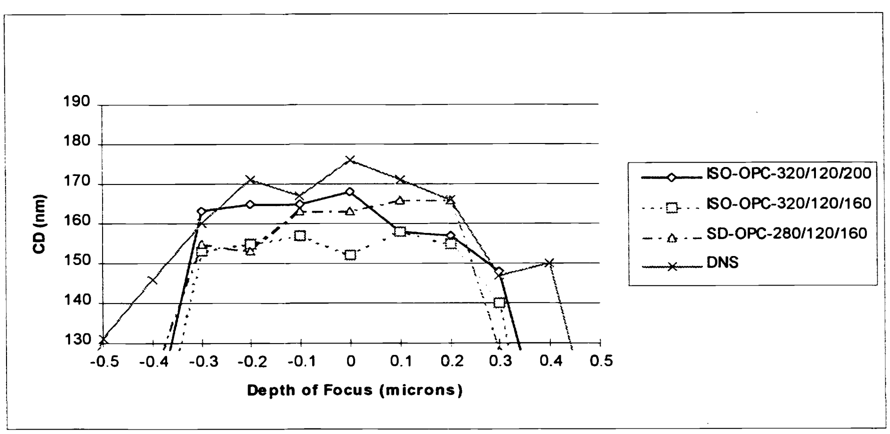
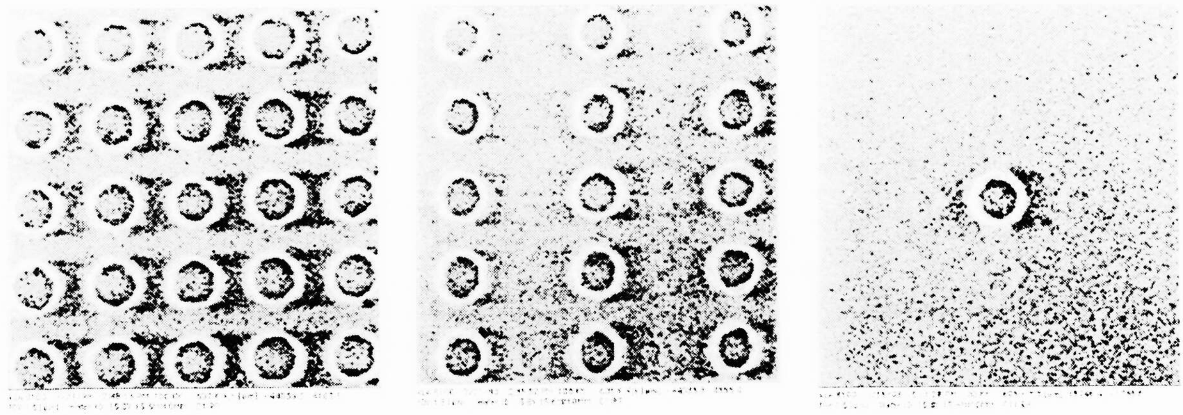


Figure 7. Printability of 160 nm contact windows with different pattern densities through focus at 40 mJ/cm^2 exposure dose. Quadrupole illumination is used, and isolated and semi-dense features have assist slots.

Figure 7 shows that applying sub-resolution assist feature technique in conjunction with quadrupole illumination, the proximity effects are practically eliminated. At a common exposure dose of 40 mJ/cm^2, dense, semi-dense, and isolated contact windows can be printed simultaneously with a least depth of focus of 0.6 to 0.8 microns and a good CD uniformity. SEM images of dense, semi-dense, and isolated patterns printed at an exposure dose of 40 mJ/cm^2 and in best focus are presented in Figure 8:



a) b) c)

Figure 8. Dense **(a)**, semi-dense **(b)**, and isolated **(c)** 160 nm contact windows printed at a common exposure dose of 40 mJ/cm^2 and in best focus using quadrupole illumination. Semi-dense (280/100/160) and isolated (320/120/160) patterns have assist features.

5. SUMMARY AND CONCLUSIONS

The impact of sub-resolution assist features on 160 nm contact windows with different pattern densities was studied and analyzed using 193 nm lithography. A specially designed test reticle, which contains contact windows with a range of assist feature sizes and configurations, was used to thoroughly analyze the tolerances of sub-resolution assist features for contact windows. A 1800 Å single-layer resist on inorganic BARC were used in order to maximally decrease the impact of the resist process and study the impact of the assist features on the aerial image. The experiments were done in three illumination conditions: conventional high partial coherence (σ = 0.7), conventional low partial coherence (σ = 0.29), and quadrupole off-axis.

The results have shown that the sub-resolution assist feature technique improves the overall critical dimension uniformity of contact windows combined with conventional illumination conditions. It works even more effectively in combination with quadrupole illumination improving both CD uniformity and depth of focus of printed features. The average DOF improvement for isolated contact windows with assist slots is in the order of 0.3 microns. It was noticed that assist slots with different sizes performed quite similarly in terms of improvement of the process latitude. This means that there is a certain size range within which the assist feature dimensions can vary without significantly impacting on the process latitude and printed features quality. However, depending on the resist process and illumination type chosen, the critical size of non-printing assist features can vary and should be determined for each new process used.

Sub-resolution assist feature technique demonstrated to be very effective in terms of improving the proximity effects. In both conventional and off-axis illumination conditions used, contact windows with different pattern densities and combined with assist slots printed practically without proximity effects. Using quadrupole illumination, isolated and semi-dense contact windows with assist slots along with dense contact window patterns printed at a common exposure dose level with a large depth of focus and a good critical dimension uniformity.

6. REFERENCES

1. J. F. Chen, T. Laidig, K. E. Wampler, and R. Caldwell, "Practical method for full-chip optical proximity correction", SPIE Proceedings, Vol. 3051, 790-803, 1997.

2. J. Garofalo, C. J. Biddick, R. L. Kostelak, and S. Vaidya, J. Vac. Sci. Technol. B **11**, 2651, 1993.

3. A. Kroyan, M.D. Levenson, F. K. Tittel, "Coping with the impact of lens aberrations in the context of wavefront engineering", SPIE Proceedings, Vol. 3334, 1998.

4. G. P. Watson, R. A. Cirelli, A. G. Timko, and O. Nalamasu, "Sub-resolution assist feature and off-axis illumination optimization for 200 and 240 nm contact windows using 248 nm lithography", SPIE Proceedings, Vol. 3334, 1998.