Pattern Scaling of Holes, Bars, and Trenches with Directed Self-Assembly using Polymer Blend

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The directed self-assembly (DSA) of polymer blends in various types of guiding patterns was investigated. The change in CD and aspect ratio before and after the DSA process as a function of the pitch and aspect ratio of the guiding patterns are reported. The behavior of polymer blend DSA was found to depend on guiding pattern design rather than a simple conformal, spacer-like shrinking. The results achieved from this study provided useful information for guiding pattern design for this specific polymer blend system.

Keyword: blend directed self-assembly, blend DSA, pattern scaling

1. Introduction

The continuous drive for smaller device features necessitates the development of new patterning techniques to accommodate the commensurate scaling of critical dimensions (CDs) and pitches. The aggressive ground rules for the 22 nm node and beyond present great challenges for printing features with adequate resolution and yield using standard immersion lithography tools, whose physical resolution limit has already been reached at the 22nm node. Double patterning, which decomposes one layer of dense patterns into several less dense layers and employs multiple processes to achieve the target patterns, is the interim solution for printing smaller features and tighter pitches beyond the resolution limit. However, further device scaling beyond the 14nm node, especially for contact/via levels, may require triple or quadruple patterning at the expense of significantly increased process complexity and cost of ownership (CoO), since printing hole size less than 50nm at 90nm pitch with sufficient process window remains challenging even with the advent of negative-tone-develop (NTD) process with immersion lithography. Although next-generation EUV lithography is anticipated to alleviate the patterning difficulties, its successful insertion into high-volume semiconductor manufacturing has not yet been demonstrated.

Directed self-assembly (DSA) of block copolymers or polymer blends [1] has the potential to extend the resolution of immersion lithography and double patterning and even complement the future EUV lithography. The attractive properties of DSA, e.g. pattern rectification, density multiplication, process window improvement, and reduced process complexity and cost, have motivated the semiconductor industry to pursue DSA as a means for satisfying the advanced patterning requirements of future nodes [2-5]. Among the major applications of DSA processes, the contact/via shrink process appeals to logic and memory device manufacturers because the existing hole shrink processes are relatively complicated. DSA of polymer blend in photoresist guiding patterns provides a versatile and cost-effective route for contact shrink compared to the existing approach. However, due to the introduction of
local interconnects, [6] contact patterns now require a variety of aspect ratios rather than simple circular holes. The DSA behavior in these guiding patterns needs to be further investigated in order to extract the design rules for DSA guiding patterns. In this work, patterning performance with DSA of polymer blend was evaluated using the following metrics: through-pitch hole printability; printability of bars as a function of varying aspect ratios; and the mask error enhance factors (MEEF) at different feature pitches.

2. Experimental

The guiding pattern (GP) for DSA used in this work is composed of an industry standard tri-layer stack, i.e. a patterned photoresist on top of Si-containing anti-reflective coating (SiARC) and organic planarization layer (OPL). Exposures were performed on a TEL CLEAN TRACK™ LITHIUS Pro™ and NXT: 1950i scanner (ASML.CO. LTD) cluster followed by a negative-tone development process on a TEL CLEAN TRACK™ LITHIUS Pro™ V.

Experimental polymer blend materials and NTD photoresists were synthesized and used as received. The graphoepitaxy DSA process used in this work is illustrated in Fig. 1. The polymer blend was spin-coated onto the guiding pattern at a proper spin speed and followed by a short annealing at 120°C under ambient environment to drive the phase separation of the polymer blend. After the annealing, an organic solvent was used as a developer to remove one of the components in the polymer blend. Critical dimension (CD) was then measured from top-down images using a Hitachi CG4000 scanning electron microscope using a pixel size of ~0.88nm. All the process steps were performed in a clean room environment at Albany NanoTech using 300 mm wafers.

3. Results and Discussion

3.1. DSA behavior in circular guiding patterns with aspect ratio of 1

Top-down SEM images of resist guiding patterns and post-DSA structures at various pitches and exposure doses are illustrated in Fig. 2. Here we define:

\[
\text{DSA CD bias} \equiv CD_{\text{DSA}} - CD_{\text{litho}} \quad \text{Eq. (1)},
\]

\[
\text{Shrink amount} \equiv |\text{DSA CD bias}| \quad \text{Eq. (2)}
\]

The dependency of DSA CD bias on the pitch of GP, ranging from 94nm - 600nm in this work, was investigated. Fig. 3 shows the DSA CD bias decreased from -14nm to -18nm as the pitch increased. Furthermore, the shrink amount did not vary linearly with the pitch of GP but reached a plateau at pitch ~220nm. In addition, as one can see in Fig. 3, the trend of the shrink amount as a function of GP pitch remains the same for different GP sizes, which are created by modulating the exposure dose in this experiment.

![Figure 3. Guiding pattern pitch and exposure dose effect on DSA CD bias.](image)

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Figure 4 further illustrates that for a given GP pitch, the resulting CD after DSA varies linearly...
with the GP CD. One should note that as mentioned earlier, the shrink amount increased as GP pitches increased, i.e. for a given GP CD, larger pitch GP resulted in smaller post-DSA CD. This behavior points out the fundamental difference between the blend DSA used in this work and the BCP DSA reported in the literatures [5].

Mask error enhance factor (MEEF) of the GP and the DSA structures were evaluated using circular GPs. MEEF was found to decrease from 4.67 to 3.99, as shown in Fig. 5.

3.2. DSA behavior in elliptical guiding patterns with aspect ratio between 1 and 5

Representative top-down SEM images of elliptical GPs with aspect ratio (AR) of 2.5 and their corresponding post-DSA structures at various pitch and exposure dose are illustrated in Fig. 6. The DSA CD bias in major and minor axis were measured and are shown in Fig. 7. By comparing Fig. 3 and Fig. 7, one can see that the trend of DSA CD bias in elliptical GPs as a function of GP pitches is similar to that in circular GPs. One should note that for the GPs with this specific AR, the shrink amount in the major axis, ranging from 17nm to 27nm, is always larger than that in the minor axis, ranging from 13nm to 18nm, regardless of pitch and exposure dose. Larger shrink amounts in the major axis than the minor axis indicates that polymer blends have a tendency to segregate at the end of the trench more than the side of the trench. It is believed that this non-conformal segregation behavior depends on the polymer/resist interaction and consequently could be tuned by the choice of the materials and chemistry of the resist and/or the polymer blend.

Figure 4: Post-DSA CD versus guiding pattern CD at different pitches.

Figure 5: The resulting CD of GPs and post-DSA structures as a function of mask size.

Figure 6. Top-down SEM images of resist guiding patterns with aspect ratio of 2.5 and post-DSA structures with (a) various pattern pitch and (b) exposure dose at fixed pitch of 112nm.

Fig. 7: Pitch and exposure dose effect on DSA CD bias for bar-shape GPs.

Although the shrink amount is different in major and minor axis and depends on dose and pitch, a nearly-linear correlation was observed between the
aspect ratio of the GPs and the post-DSA structures, as shown in Fig. 8. The designed AR of the GP was 2.5, but due to process variation, the observed AR ranged from 2.2 to 2.7 over all the doses and pitches tested. One should note that no dependency of the observed AR on dose and/or pitch was found. The post-DSA AR was found to be ~1.1 - 1.2 times higher than the AR of the corresponding GP.

Fig. 8: The correlation between the aspect ratio of the GP and the post-DSA structure.

Top-down SEM images of GPs with various aspect ratios at fixed pitch, i.e. 112nm, are shown in Fig. 9. The shrink amount along the major and minor axis was found to vary with the aspect ratio of the GP. Fig. 10 shows that the difference between the shrink amounts in the two axis peaked at an AR of ~1.5 to 2.0. As the AR increased above 2.5, the difference between the major and minor axis decreased. Furthermore, the DSA CD bias in minor axis was found to be close to a constant value of -15nm with GP AR from 1 to 3.5.

Because the polymer blend shrunk the GP by 15nm to 23nm, one can expect the AR to increase slightly after DSA, as can be seen in Fig. 11. The open circle and dashed line in Fig. 11 assume a constant shrink amount, i.e. 15nm, in both axis and were calculated based on the AR of the GP. However, due to the non-conformal shrink in the major and minor axis, one can find the post-DSA AR deviated from simple conformal shrink and varied with GP AR.

3.3. DSA behavior in trench-type guiding patterns with aspect ratio larger than 30

The shrink amount in trench type GP was measured only in minor axis simply because the end of the trench in major axis is outside of the field of view. Shrink amount was found to be

Fig. 9: SEM images of post-litho and post-DSA structures of 112nm pitch with (a) various aspect ratio and (b) exposure dose at AR=2.5.

Fig. 10: DSA CD bias along major and minor axis of GPs of aspect ratio ranging 1 to 3.5.

Fig. 11: Aspect ratio change before and after DSA in GPs with a fixed pitch of 112nm. The open circle and dotted line represents the cases in which the AR before and after DSA remains unchanged.
around 18nm for both dense (112nm-pitch) GPs and isolated (800nm-pitch) GPs, which is almost the same as that of circular GPs with pitches larger than 220nm.

4. Conclusions
The behavior of polymer blend DSA was studied using three types of guiding patterns, i.e. circular GP (AR = 1), bars (1 < AR < 5), and trenches (AR > 30). The shrink amount in circular GPs was found to increase with the pitch of the GPs and reached a plateau at pitch of ~220nm. MEEF of the DSA structure was found to be lower than that of the corresponding GP. The DSA shrink amount in fixed-AR, bar-shape GPs had a similar pitch-dependency as in circular GPs, but is always higher along the major axis than that along the minor axis. In fixed-pitch, bar-shape GPs with various AR, the shrink amount along the minor axis was nearly a constant while that along the major axis had a maximum at an AR of ~2.0-2.5. Compared to that of GPs, the AR was found to increase after the DSA process and a nearly linear correlation between the AR of the GPs and the DSA structures. For trench-shape GPs, the shrink amount along the minor axis was close to a constant at 112nm-pitch and 800nm-pitch.

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