Directed self-assembly (DSA) is being actively investigated as a potential patterning solution for future generation devices. While SEM based CD measurement is currently used in research and development, scatterometry-based techniques like spectroscopic CD (SCD) are preferred for high volume manufacturing. SCD can offer information about sub-surface features that are not available from CD-SEM measurement. Besides, SCD is a non-destructive, high throughput technique already adopted in HVM in several advanced nodes. The directed self assembly CD measurement can be challenging because of small dimensions and extremely thin layers in the DSA stack. In this study, the SCD technology was investigated for a 14 nm resolution PS-b-PMMA chemical epitaxy UW process optimized by imec. The DSA stack involves new materials such as cross-linkable polystyrene (XPS) of thickness approximately 5 nm, ArF immersion resist (subsequently removed), -OH terminated neutral brush layer, and BCP material (Polystyrene-block-methyl methacrylate of thickness roughly 20 to 30 nm). The mask contains a large CD and pitch matrix, for studying the quality of self-assembly as a function of the guide pattern dimensions. We report on the ability of SCD to characterize the dimensional variation in these targets and hence provide a viable process control solution.

Keywords: Directed self-assembly metrology, Scatterometry, SCD

1. INTRODUCTION

DSA is being actively investigated as a potential solution for future generation devices. SEM is used for CD measurement in R&D, but scatterometry-based techniques are preferred for high throughput measurement in HVM. In this investigation, we studied the characterization of an IMEC DSA chemo-epitaxy process using SCD technology (scatterometry). The L/S pattern was investigated at the “post PMMA removal” step as well as the “post etch” step, where the BCP pattern was transferred into underlying the SiN as well as into the Si substrate.

In a previous work, implementation of the UW chemo-epitaxy process (Figure 1) in a 300mm wafer flow has been demonstrated.[2] A thin (~5nm) cross-linkable polystyrene (X-PS) layer is coated on an SiN substrate wafer. Subsequently, ArF immersion lithography provides an 84nm pitch pre-pattern targeted at ~38nm CD. Next, a plasma etch step trims the CD to ~18nm and simultaneously etches through the uncovered X-PS layer. The resist is selectively stripped using a wet process. Next, an -OH-terminated neutral brush is coated over the X-PS pattern. During the subsequent anneal bake, the -OH group grafts to the SiN substrate, but not to the X-PS guide stripes. A solvent rinse is used to remove excess brush material,yielding the chemical pre-pattern. A 28nm L0 lamellar phase poly(styrene-b-methyl methacrylate) BCP material is coated over it and thermally annealed, resulting in 28nm pitch line/space structures (3X frequency multiplication). Finally, a dry plasma process affords selective removal of the PMMA blocks from the BCP to give free standing polystyrene (PS) lines.
2. EXPERIMENTAL

2.1 Materials

Cross-linkable poly(styrene) (X-PS, AZEMBL™ NLD128), hydroxyl-terminated poly(styrene-random-methyl methacrylate) (P(S-r-MMA)-OH) brush (AZEMBL™ NLD127), and poly(styrene-block-methyl methacrylate) (PS-b-PMMA, AZEMBL™ PME312) BCP with Lo = 28 nm, were synthesized by AZ Electronic Materials and were used as received. ArF immersion photoresist AIM5484, was purchased from JSR Micro. Organic solvent RER600 was purchased from Fujifilm and Orgasolv STR 301 was obtained from BASF.

2.2 Processes

The process used for this experiment is based on our previously reported method for the fabrication of chemical nanopatterns, and readers are referred to Reference #1 for details [1]. The mask used in this experiment consisted of scatterometry pads of size 60x60 μm² with various pitch and CD for the guide pattern. The DSA process was optimized for 84 nm Pitch and 35 nm CD. We investigated pads of various dimensions as indicated in Table 1.

![Figure 1: imec (UW) chemo-epitaxy process flow](image)

![Figure 2: image of scatterometry pads](image)
2.3 Metrology

For spectroscopic CD (SCD) analysis, the tool utilized in this study is KLA-Tencor SpectraShape™ with spectroscopic ellipsometry and reflectometry options. Data were collected from the ellipsometry channel, and at two azimuth angles relative to the grating direction. Model fitting was performed using AcuShape™ 3 scatterometry modeling software.

3. RESULT AND DISCUSSION

3.1 Modeling and fitting result for PMMA removal

As a first step, we coated bare Si wafers with individual thin materials as described in Section 2.1, and measured ellipsometric spectra were used to generate index and extinction (n and k) spectra for the materials. These n and k spectra were used to build the model for the post-PMMA removal process step. We observed that the DUV wavelength range (<250 nm) provided better measurement performance due to higher material contrast in the UV wavelength range. An effective medium model (EMA) was used to in place of the polymer brush and XPS patterned structure (Figure 3). This model tracked the expected process variation very well.

![Figure 3: Post-PMMA removal model](image-url)
Since the DSA process and BCP chain length are optimized for a given pitch and CD of the guide pattern, non-optimal guide pattern dimensions could result in defective patterns. For example, Pad # 25 (Pitch =86nm and CD= 28nm) had dislocation clusters (Figure 5). The DUVSE spectra at 90 and 180deg azimuth angles had a clear signature that indicated either good or defective BCP assembly. The spectra from Azimuth angle 90 degrees and 180 degrees should be as distinct as in Figure 4 when the directed self assembly process is in control.

![Figure 4: Good model fit with DUVSE spectra at Pad# 13 (Pitch =84nm and CD =35nm)](image)

![Figure 5: Poor model fit with DUVSE spectra at Pad# 25 (Pitch =86nm and CD =28nm)](image)

### 3.2 Within wafer variation of BCP line shape for PMMA removal

We observed that the chi-square model fit metric on CD27nm pads was worse than on other pads, within the group with pitch of 84nm, and at all 9 measured sites (Figure 6). The within-wafer chi square pattern agreed with SEM review images (cf. Figure 7), which identified dislocation clusters for CD27nm sites. This provides a quick method to assess the quality of DSA and identify poorly yielding regions.

![Figure 6: Model fit result (chi-square) at 9 sites (Pad #s 3,8,13,18,23; pitch 84nm group)](image)
We quantified the BCP shape variation (Figure 8) among the pitch 84 nm pad group (except the CD27nm pads); this group of targets was expected to have a good quality DSA pattern. Our EMA model for the chemical guide pattern layer gave a very good correlation between the nominal XPS CD and the EMA fraction (Figure 9). This indicated the potential of the model and measurement to track small details in the structure. The variation of BCP dimensional parameters was very small within the 9 sites measured on the wafer (Figure 10).

![Figure 7: SEM review images for 9 sites and Pad #s 3,8,13,18,23; pitch 84nm group)
Dislocation clusters were found at CD27nm Pads (indicated by black outline)](http://proceedings.spiedigitallibrary.org/)
3.3 Modeling and fitting result for post etch

The post-etch model allowed for the presence of a small top SiN hard mask residual layer (Figure 11). We used the full wavelength range for model fitting to get stable analysis results. Again as in the pre-etch case, the difference in spectra between 90 and 180 degrees azimuth angles was correlated to the quality of the DSA. Examples are shown Figure 12 for a good fit at Pad #13 and Figure 13 for a poor fit at Pad #21.
3.2 Within wafer variation of line shape for post-etch

We made measurements in the 25 pads in 9 locations distributed across the wafer as indicated in Fig 14. We observed that chi-square model fit results in some pads being worse than for several other pads. The chi-square model fit result has a very good correlation with SEM review images as shown in Figure 15, which show dislocation clusters at the higher chi-square sites. Again as in the pre-etch case, optical measurements show promise for rapid assessment of the quality of DSA and for identifying poorly yielding regions.
We quantified Si line shape variation (cf. Figure 16) using the sites that have a lower chi-square, since they are expected to have a good quality DSA formation. In this case, the variation of the line pitch and Si trench depth agree with the expected trends (Figure 17). Interestingly, a “donut” type signature was observed in the CD measurement wafer maps (Figure 18) which was later confirmed to be in agreement with a known etch process characteristic. The cross section and CD-SEM data also match well with wafer signature observed in SCD measurement (Figure 19).
Figure 16: Model for post etch with parameters defined

Figure 17: Trend of Line shape parameters at low chi-square pads from 9 sites of wafer

Figure 18: Wafer map of Si Line shape parameters at Pad #13 (CD35nm, Pitch84nm)
The “donut” type signature was also observed in the pattern inspection result by the 2915 KLA-Tencor broadband plasma wafer inspection tool (Figure 20). We may conclude that “flat microbridge defect” can appear at deeper and wider trenches.

We observed good correlation between the programmed pattern pitch and measured pitch (averaged from the center 5 points of wafer) (Figure 21).
4. CONCLUSIONS

Scatterometry shows promise for characterizing process variation in directed self assembly line/space structures at the PMMA-removal process step. The DUV wavelengths are most sensitive for shape metrology. The difference in spectroscopic ellipsometry data as a function of illumination azimuth angle can be used to quickly assess the quality of DSA and identify poorly yielding regions. Post-etch measurements demonstrated good correlation with the programmed guide pattern pitch variation. Good correlations were found between SCD measurement and a known etch signature. And good correlations were found between SCD measurement and defect wafer map.

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