Wafer CD Uniformity Improvement in Negative Tone Development Process

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WCDU (wafer critical dimension uniformity) has become one of the most momentous factors in the resist process for mass production. Non-uniform WCDU, CD value changes from wafer center to edge, can occur in resist process despite tight critical dimension uniformity (CDU). In this paper, the resist components and the resist process conditions that influence on WCDU variation in negative tone development (NTD) process will be discussed. WCDU was measured with various parameters to understand the causes of current performance.

Keywords: 193 nm, NTD, CDU, WCDU, Immersion, Lithography

1. Introduction

Feature size continues to shrink as devices continue to get smaller, thus achieving tighter CDU has become a significant assignment in lithography processes. The performance of negative tone development (NTD) process in 193 nm lithography has been studied, and research supports that it has advantages in imaging [1]. Negative tone imaging can provide high quality image contrast due to the high image-log-slope under the unexposed region in the areal image [2-4]. For that reason, an NTD process allows a good lithography performance at specific patterns such as contact hole (C/H) and narrow trenches, and it also provides valuable CDU [5].

WCDU is 3σ of total wafer CD from the center to the edge of the wafer. In wafer lithographic processes, there are a lot of factors that effect on WCDU such as wafer topology, substrate reflectivity, and optical/chemical flare effects [6]. In addition, CDU is directly related to WCDU. In this paper, the effects of chemical compatibility of resist components and the resist process conditions on WCDU variation will be discussed to figure out the causes of non-uniform critical dimension of wafer from center to edge.

2. Experimental

2.1. Photoresists

Photoresists were prepared with methacrylate polymers, photo acid generator (PAGs), an amine compound as a base, and a hydrophobic polymer as an additive in organic solvents.

2.2. Lithography conditions

NTD lithography was carried out on 300 mm silicon wafers by a Nikon S610C immersion scanner linked with a TEL LITHIUS coater/developer. ART™ 40A bottom-antireflectant was spin-coated on silicon wafers and baked at 215 °C for 60 seconds to yield a first BARC film with a thickness of 710 Å. A second BARC layer, ART™ 124 bottom-antireflectant, was spin-coated over the first BARC film and baked at 205 °C for 60 seconds to generate a 210 Å top BARC layer. A photoresist was spin-coated on the dual BARC-coated wafers and soft-baked at 100 °C for 60 seconds to provide a resist layer with a thickness of 1100 Å. The photoresist-coated wafer was exposed through a 6% half tone phase-shift mask under a single exposure annular illumination with 1.30 NA, 0.8 outer sigma, 0.64 inner sigma and XY polarization. The exposed wafers were post-exposure baked at 90 °C for 60 seconds and developed with n-butyl acetate (nBA) as an organic solvent developer. As a result, the resist pattern with
52 nm 96 nm pitch diameter (C/H pattern) was obtained.

2.3. Metrology
C/H pattern width and CDU were measured by Hitachi CG4000 scanning electron microscope (SEM). CDU was defined as a 3σ of C/H width distribution, and the threshold algorithm and a threshold level of 50% were employed for detecting the contact hole in top-view images obtained. To quantify CDU, 40 images were taken per die and 9 contact hole measurements per image were taken at 300K magnification. To investigate WCDU trend, 9 images were taken per die and 230 repeated exposure shots were measured; a total of 2070 holes were measured.

3. Results and discussion
3.1. Effect of polarity of PAG
The relationship between polarity of PAG and WCDU variation was investigated. Three photoresists were prepared for testing. All resists have a same polymer backbone but different PAGs. The polymer backbone has hydrophobic property that makes the polymer well-dissolve in nBA organic developer. The three PAGs have different polarities that were determined by logP values (Table 1).

Table 1. Polarity characteristics of PAGs.

| Sample | A-Resist | B-Resist | C-Resist |
|--------|----------|----------|----------|
| PAG    | A        | B        | C        |
| logP   | Middle   | High     | Low      |

LogP value is a conventional measurement of hydrophobicity of compounds in general, and logP of each PAG was calculated by ACD program. Here, a high logP value indicates that a material has a hydrophobic property.

As shown in Fig. 1, all three resists showed similar lithographic performance. However, different WCDU trend was observed among the three resists (Fig. 2).

B-resist, containing the most hydrophobic PAG, showed more stable WCDU performance than that of others. This result demonstrates that the polarity between PAG and polymer plays a significant role in controlling the WCDU variation.

3.2. Effect of bake temperatures
The resist process condition strongly affects the lithographic performance. Therefore, the relationship between the bake conditions and WCDU variation was examined.
3.2.1. Effect of soft bake (SOB) temperature

There is a SOB process before exposure for solvent evaporation, solvent diffusion, and polymer compaction. The photo acid generator was also diffused in a photoresist during SOB process. The occurrence of photo-chemical reaction during exposure largely depends on the diffusion ability of a photo acid generator in a photoresist, and the free volume content of a photoresist significantly affects its lithographic properties [7]. Therefore, the relationship between the WCDU variation and SOB condition was investigated.

Three different SOB bake conditions were applied on A-Resist, a range from 90 ℃ to 110 ℃ by 10 ℃. As shown in Fig. 3, the resist showed similar photo-speed under all three SOB conditions. However, the resist soft-baked at low SOB temperature (90 ℃) showed a better CDU value than others soft-baked at higher SOB temperatures (100 ℃ and 110 ℃). As can be seen in Fig. 4, higher SOB condition (110 ℃) provided more stable WCDU trend for A-resist than lower SOB conditions (90 ℃ and 100 ℃). This significant contribution of high SOB temperature to WCDU is due to the capability of redistribution of both PAG and quencher that makes the balanced acid density from wafer center to edge.

| SOB     | 90 ℃  | 100 ℃ | 110 ℃ |
|---------|-------|-------|-------|
| Top Image | 53.02 | 52.03 | 52.98 |
| Exp. (mJ) | 25.9  | 25.5  | 25.5  |
| EL (4%, 10% CD) | 6.8   | 7.6   | 8.5   |
| DOF (nm) | 174   | 189   | 180   |
| CDU (nm) | 9.29  | 10.14 | 9.90  |

Fig. 3. Top-down images of lithography performance of A-resist on 52 nm 96 nm pitch (C/H) with varying SOB temperatures.

However, the resist soft-baked at low SOB temperature (90 ℃) showed a better CDU value than others soft-baked at higher SOB temperatures (100 ℃ and 110 ℃). As can be seen in Fig. 3, the resist showed similar photo-speed under all three SOB conditions. However, the resist soft-baked at low SOB temperature (90 ℃) showed a better CDU value than others soft-baked at higher SOB temperatures (100 ℃ and 110 ℃). As can be seen in Fig. 4, higher SOB condition (110 ℃) provided more stable WCDU trend for A-resist than lower SOB conditions (90 ℃ and 100 ℃). This significant contribution of high SOB temperature to WCDU is due to the capability of redistribution of both PAG and quencher that makes the balanced acid density from wafer center to edge.

3.2.2. Effect of PEB temperature

When ArF photoresist is exposed to light, acids are generated as a result of the conversion of PAGs. During a subsequent post exposure bake (PEB), the photo-generated acids catalyze a thermally induced reaction that cleaves the protecting groups of the polymer, rendering the reacted (deprotected) region non-dissolve by nBA organic developer in NTD process [7]. PEB condition has effects on acid diffusion that directly influences on resist profile and lithographic performance. Thus, the relationship between PEB condition and WCDU variation was examined.

SOB condition was set at 100 ℃ for 60 seconds and PEB temperature was varied in a range from 85 ℃ to 95 ℃ by 5 ℃. As shown in Fig. 5, A-resist with low PEB temperature (85 ℃) showed a better CDU value than the resists post exposure-baked at higher temperature (90 ℃ and 95 ℃). Figure 6 shows the WCDU comparison of the patterns obtained from varying PEB conditions. However, the resist with 95 ℃ PEB condition showed more stable WCDU trend than others with lower PEB conditions (85 ℃ and 90 ℃). These results imply that higher acid diffusion helps to obtain better WCDU variation but results in higher CDU variation.
4. Conclusion
Parameters that influence on WCDU variation in 193 nm NTD resist were investigated. From this study, it was found that the hydrophobicity of PAG is one of the most critical factors effecting on WCDU variation. NTD resist has hydrophobic polymer backbone, and a miscibility of PAG and polymer is a key factor of WCDU trend. SOB and PEB conditions were also significant factors effect on WCDU variation. High SOB and PEB conditions provide stable WCDU variations by redistribution of PAG and quencher and high acid diffusion, respectively.

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