Process Feasibility Investigation of Freezing Free Process

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Double patterning technique with 193nm immersion lithography is recognized as a potential candidate for 32nm hp node, and possibly for sub-32nm hp node with recent. In this technique Litho-Process-Litho-Etch (LPLE) because of its simplicity is regarded as an attractive process. However, a workable application of this process has not yet been demonstrated.

Posi/Posi process that doesn't require freezing material has been investigated from the view-point of process simplification, and has been shown to be successful in printing images below 32nm hp. Furthermore contact hole imaging by employing cross-line method has also been proven to be quite successful.

Here we present the results of our work on freezing free Posi/Posi process as applied to cross-lined contact hole, and results of the evaluation of high resolutions obtained from pitch splitting.

Key words: Double patterning, LPLE, Freezing free, 193nm immersion,

1. Introduction

Double patterning technique with 193nm immersion lithography has been recognized as a promising candidate for 32nm hp and beyond. However, the cost of double patterning can be considerably higher than that of single patterning lithography. Most chip manufacturers, therefore, are looking for simpler ways to do the job such as by employing double exposure or LPLE (Litho-Process-Litho-Etch).

We have been working to simplify double patterning by modifying the LPLE process that does not require a freezing. Elimination of freezing from the process could result in cost saving because additional materials and chambers would no longer be needed.

Our quest for LPLE without freezing led to the development of a Posi/Posi process which is the subject of this paper. The Posi/Posi process is the simplest among the double pattern techniques, ex-

cept for the process of double exposure. And moreover, the Posi/Posi process is likely to cost less because of its simple structure of posi-resist film on posi-resist stack.

In recent days the chip manufacturers have also begun to focus on cross-line contact hole in addition to their currently employed pitch splitting dual line processing. Hence, we have investigated the feasibility of both pitch splitting and cross-line contact hole.

In this paper we present our test results to explore the feasibility of Posi/Posi process for pitch splitting and cross-line contact hole applications.

2. Experiment

2.1 Freezing free Posi/Posi Process flow

Freezing free Posi/Posi process involves application of posi-resist on posi-resist. A Posi/Posi process entails two areas of concerns. One is the mixing of

1st and 2nd resists and the other is exposing of 2nd pattern on top of 1st pattern. As reported before, the first concern can be resolved by application of an alcohol solvent for 2nd resist. Because the solubility of the 1st resist in alcohol solvent is quite low. The other concern can be addressed by devising methods to widen the gap between the activation energies and of the 1st and the 2nd resist functional groups. In case of the 2nd exposed on the 1st pattern, lower PEB for the 2nd imaging can keep 1st pattern, because activation energy of 1st pattern is too high [4, 5]. In this study, 150°C postbake after the 1st imaging was found to be necessary in order to reduce the impact from the 2nd imaging. As it appears from the FT-IR chart in Fig. 1, that no significant changes in cross-linking, and in polarity occur as a result of 150°C postbake. The difference between *before* and *after* 150°C postbake seems a peak at 1240cm⁻¹. According to GC-MS results presented in Fig. 2, the

Fig.1 FT-IR chart before and after 150°C postbake

1st resist film before 150°C postbake shows 1.6wt% of PGMEA remaining in film. And after 150°C postbake no trace of PGMEA is seen. This means that postbake simply removes the solvent from the 1st pattern. So, freezing free Posi/Posi process would require a high activation energy for the 1st resist, and a low activation energy for the 2nd resist by using an alcohol solvent, and by employing a 150°C postbake after the 1st imaging. Actual process flow of Posi/Posi is shown in Fig. 3. In this work, we prepared TARF-Pi6-001 as the 1st resist and TARF-PP006 as the 2nd resist. TARF-Pi6-001 requires 120°C for PAB, and 110°C for PEB, both for 60s. TARF-PP006 requires 120°C for PAB, and 90°C for PEB, both for 60s also.

Fig.2 GC-MS of 1st resist film w/ and w/o 150°C

Fig. 3 Freezing free Posi/Posi process flow

2.2 Pitch splitting dual line

For imaging below 32nm hp dual line, Pi6-001 was coated on ARC29SR with 95nm of thickness and PP006 was coated with 70nm of thickness. The Pi6-001 film was also covered with a top-coat. All wafers for pitch splitting tests were marked for the purpose of alignment. Both the 1st and 2nd resists were exposed under the same conditions. The exposure was made by ASML XT1900i with att-PSM. The Illuminations were set to 1.35 NA annular, and 1.0 NA dipole with polarization. Development was carried out with TMAH 2.38wt% aq, using ECO-nozzle.

2.3 Cross-line contact hole

For cross-line contact hole imaging, the film thicknesses of both resists were set to be same as in case of pitch splitting. The illumination was set to 1.35NA dipole with polarization. Exposure tool and development procedure were same as in case of pitch splitting. An additional step here was to apply a 90degree roatation to the wafer at the 2nd exposure

as shown in Fig. 4. In addition, TARF-6a-trial 100nm and TARF-PP006 90nm combination was tested with S609B using 1.07NA dipole to read a cross-section profile.

Fig. 4 Cross-line contact hole method

■ 1st line ■ 2nd line

3. Results and Discussion

3.1 Pitch splitting dual line

At first, we proceeded to print 32nm hp dual line by using 1.35 NA annular. Mask sizes for both resists were 56nm line with 128nm pitch. From the imaging results, the 1st resist CD was 31.4nm and the 2nd resist CD was 31.9nm. And after the imaging, the pattern height of the 1st line was almost same as that of the 2nd line (Fig. 5). This result pointed out that freezing free Posi/Posi process has good potential for controlling CD from litho down to the step of etching. We then studied the shift in the 1st line CD as it went through the process. If the 2nd resist process had an impact on the 1st pattern, in case of the 1st pattern CD change would have been larger. The results in Fig. 6, show that after the 1st image, the 1st line CD was 34.5nm and CD change was almost zero after 150°C postbake. And then after the 2nd imaging, the 1st pattern CD was 32.5nm. The CD shift was thus less than 2nm. This negligible CD shift is indicative of a good CD control. Thus we studied the CD uniformity data for the 1st and 2nd lines on 32nm hp. The CD uniformity of the 1st line was 1.45nm (3 σ) and the uniformity of the 2nd line was 2.74nm. These are considered to be quite good results for LPLE process. This means that Posi/Posi process is one of the promising candidates of LPLE

Fig. 5 32nm hp resolution result

Fig. 6 CD shift of 1st pattern through process

in terms of CD control.

3.2 Further resolution by pitch splitting

To achieve further resolution down to 22nm hp, we evaluated same combination using NA 1.35 dipole. Figure 7 also shows that the 24nm hp and 22nm hp resolution images were obtained without any collapse. In this case k1 value was 0.15.

3.3 Cross-line contact hole

3.3.1 Aerial contrast calculation

For contact hole application, cross-line contact

Fig. 7 Imaging result below 32nm hp

hole has become quite important for discussion and further investigations since the last year [6,7]. In

Fig. 8 NILS 45nm contact hole Annular, 45nm Line Dipole

Fig. 9 55nm contact hole by cross-line

Fig. 10 contact hole imaging with “Posi/Posi” process

order to obtain 45nm contact hole with 90nm pitch, we calculated Normalized Illumination Log Slope (NILS) of cross-line method and of single imaging method. According to our calculation, cross-line method for contact hole has much higher NILS than single image method for contact hole has (Fig. 8). This means cross-line contact hole can have wider process latitude than conventional method can.

3.3.2 Cross-line contact hole results

To obtain smallest contact hole, a cross-line contact method requires line and space array with dipole illumination for the 1st and 2nd lines. The 2nd line was exposed with 90degree rotation as mentioned above.

A 55nm cross-line contact hole image by using 1.07NA optics is shown in Fig. 9. We observed the cross-section profile for the 1st and 2nd patterns. The pattern heights in the 1st and 2nd resists were found to be different. This difference in heights is supposedly caused by the coatings on the topography from the 2nd lithography. If the 2nd resist film is kept thinner, the heights of the two patterns could be quite close [5]. For the smaller contact hole target, 6a716 and PP006 were exposed with 40nm line and space, and, then 40nm contact hole 80nm pitch pattern was obtained by using 1.35 NA dipole. Furthermore, 38nm contact hole with 76nm pitch was also obtained (Fig. 10). In this case, k1 value was down to 0.27. In addition, DOF of 40nm contact hole was studied and was found to be more than 0.24 μm. (Fig. 11)

For process feasibility, CD uniformity of cross-line contact hole was studied. A 40nm contact hole array was imaged on a full wafer by using a combination of 6a716 and PP006 with NA 1.35 dipole illumination. The result of CD uniformity indi-

Fig. 11 DOF of 40nm CH with Posi/Posi process

Fig. 12 CD uniformity of 40nm contact hole

Fig. 13 Etching

cated 2.01nm on intra-wafer (Fig. 12).

These results showed that cross-line contact hole method using freezing free Posi/Posi process is a strong candidate for shrinking the contact hole size, especially in contact hole array

3.3.3 Etching results

Etching capability of Posi/Posi cross-line contact hole was investigated. After development 60nm contact hole was imaged on SiON with ARC29SR by 1.07 NA exposure. The etching was done by Hitachi U-8250 with CF₄/CHF₃ gas. By SiON etching, the 1st resist height was eroded by 32nm and the 2nd resist height was eroded by 36nm (Fig 13). CD biases through etching and ashing, were 6.5nm and 10.5nm for the 1st and 2nd lines. From these results, it is inferred that etching tolerance of the 1st resist and 2nd resist remain almost same

4. Summary & Future work

A freezing free Posi/Posi process has been evaluated for its feasibility. The resolution capability of pitch doubling and cross-line contact hole were quite acceptable for 32nm node application and possible for sub-32nm node application. CD shift during the 2nd imaging was small and CD uniformities of line and contact hole were also quite good. Moreover the etching tolerances of the 1st and 2nd resists were evaluated and found to be almost same. According to our results, freezing free Posi/Posi process has the potential for LPLE processing.

In future, the productivity of Posi/Posi process such as defectivity and lot-to-lot CD variation will be investigated.

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