Double Exposure Using 193nm Negative Tone Photoresist

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ABSTRACT

Double exposure is one of the promising methods for extending lithographic patterning into the low k_1 regime. In this paper, we demonstrate double patterning of $k_{1\text{-effective}}=0.25$ with improved process window using a negative resist. Negative resist (TOK N- series) in combination with a bright field mask is proven to provide a large process window in generating 1:3 = trench:line resist features. By incorporating two etch transfer steps into the hard mask material, frequency doubled patterns could be obtained.

Keywords: Double exposure, double patterning, 193 nm, negative tone

1. INTRODUCTION

Resolution is expressed by $P/2 = k_1\lambda/NA$, where P/2 is the minimum half pitch, k_1 is a process factor, λ is the wavelength of the exposure light, and NA is the numerical aperture of the projection optics. In order to extend the resolution limit, many resolution enhancement techniques have been developed. Among those many potential techniques, double exposure methods are being considered to be promising in 193 nm lithography (Fig. 1).

Recently, several double exposure techniques have been reported such as UV resist-modification [1], double dipole [2], spacer technique [3], and double patterning [4]. Among those, double patterning schemes (Fig.2) are known to be feasible because all of the processes involved utilize common integration schemes, and thus there is no need to develop a special technique including the resist aspect. A common characteristic of this technique is that it often involves an etch step between two separate lithographic processes. The 2nd etch transfer finally provides the desired feature of low k_1 that is hard to be accomplished by a single lithographic step. In general, conventional implementation of this approach uses a positive resist in combination with a dark field mask, in spite of a small process window, due to the lack of a negative-tone resist of high resolution. In this report, the potential of using a new negative-tone resist system for the double patterning technique in 193 nm lithography is discussed. Using newly developed negative resists (TOK N-series), the advantages in process window aspect and experimental resolution limit of the double patterning is explored.

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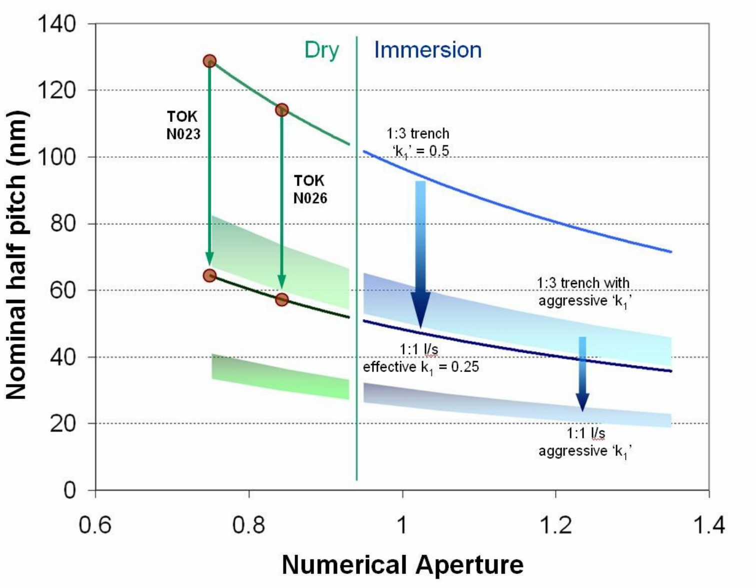
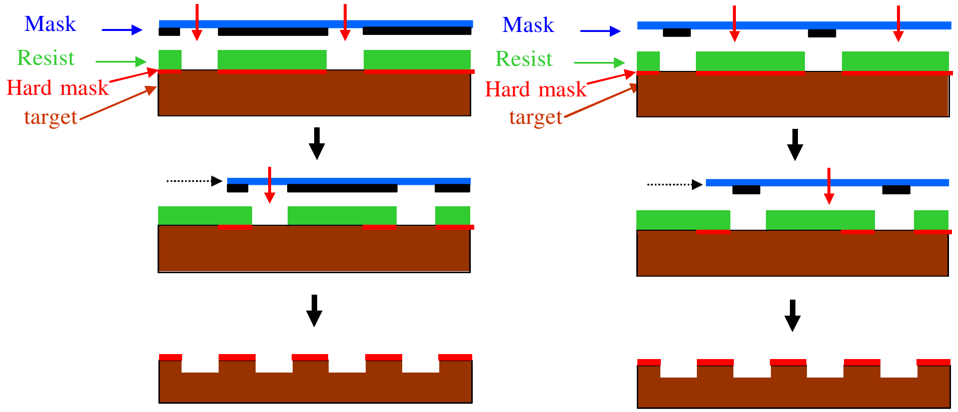


Fig. 1. Schematic illustration of resolution enhancement achievable using double exposure

For a bright field/negative tone resist combination, offset 1:3 trenches printed at high k_1 factors are used to generate 1:1 line-space patterns at $k_{1\text{-eff}}$ factor (= k_1 factor after the double exposure) below the single-exposure theoretical limit. Improved resists and more aggressive illumination (shaded regions in Fig. 1) will allow scaling of the method.



(a) (b)

Fig. 2. Schematic illustration of double patterning; (a) using a dark field/positive tone resist combination, and (b) using a bright field/negative tone resist combination

2. SIMULATION PROCESS WINDOW STUDY BETWEEN A DARK FIELD AND BRIGHT FIELD MASK

A process window study of simulated aerial images gives a convenient insight for the decision of which resist and tone mask should be used for the design of the double patterning. As already shown in Fig. 2, the final designated resist feature is 1:3 = trench:line in one lithographic patterning step. As simulation parameters, 1:3 = L/S and 1:3 = S/L mask features were inserted, which will be incorporated with a negative-tone resist and a positive-tone resist, respectively. The $k_{1\text{-eff}}$ factor was designed to be 0.25 with a numerical aperture (NA) of 0.75 using a dipole illumination. No OPC or line bias was taken into consideration for simplicity in the simulation. Fig. 3 shows the exposure latitude versus depth-of-focus (DoF) plotted.

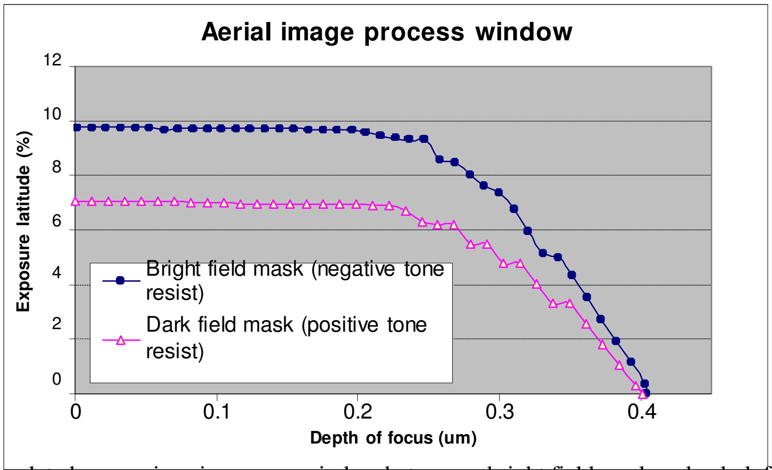


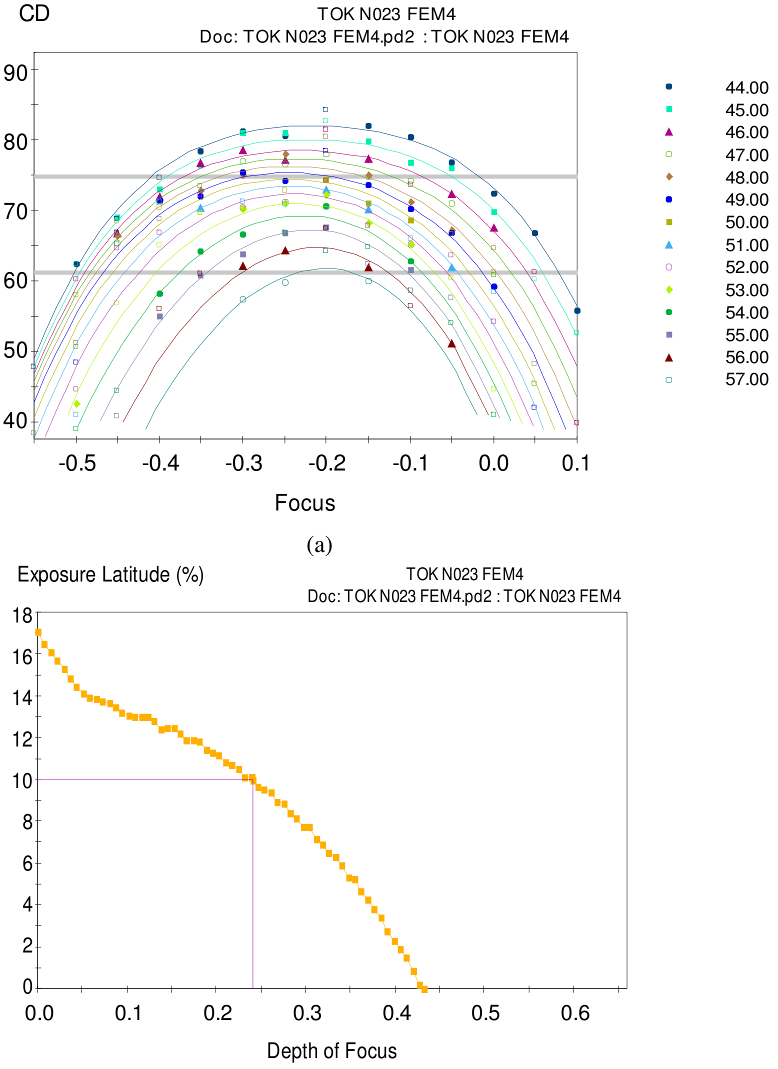
Fig. 3. Simulated comparison in process window between a bright field mask and a dark field mask

As shown in Fig. 3, for a given k_1 factor, the aerial image process window of a bright field mask that needs a negative resist clearly gives an advantage over a dark field mask in a double patterning scheme. With 5% of the exposure latitude restriction, the use of a bright field gives more than 50 nm of DoF advantage over the use of a dark field mask. As long as the resist resolution can support the extremely aggressive patterning scheme in the double patterning, it is clear that the negative resist-bright field mask combination is much more beneficial in the achievement of low-k_1 double patterning.

3. EXPERIMENTAL RESULTS AND DISCUSSION

In double patterning method, a hard mask is generally used to store final image from the double patterning method. This hard mask pattern is transferred into the target material with the information of desired $k_{1\text{-eff}}$. As a hard mask, silicon-rich nitride (SiRN, n_{real}~2.45) provides a good index matching between a bottom-antireflection coating (BARC) and the silicon substrate. It can act as an element in a dual-bottom antireflection coating in order to further reduce the standing wave effect when appropriate thickness and refractive index are provided. From a series of simulations, SiRN with a thickness of 350 Å was selected as a hard mask in these experiments. As a photoresist, negative tone resists (TOK N-series) for 193 nm lithography were evaluated, and results from TOK N023 and TOK N026 will be provided in this paper.

Fig. 4 shows the experimental process window measured out of the first exposure pattern using TOK-N023 negative-tone photoresist. Close to 1:3 = line:space features in the mask used for patterning the resist with a numerical aperture of 0.75 using a dipole illumination.



(a)

(b)

Fig. 4 Process window analysis for TOK N023; (a) Bossung curve and (b) exposure latitude vs. DoF

As observed in Fig. 4, with 10% exposure latitude restriction, the depth of focus obtained was 240 nm, which is in good agreement with the simulation result performed prior to the experiment. This also indicates that the resist resolution is high enough to support the aerial image printing for these fine features. Fig. 5 shows the scanning electron microscopy (SEM) photographs of the resist pattern for the 1^{st} exposure in double exposure with a target space CD of 67 nm. The features shown in these images are within ±10% of the target CD after the development.

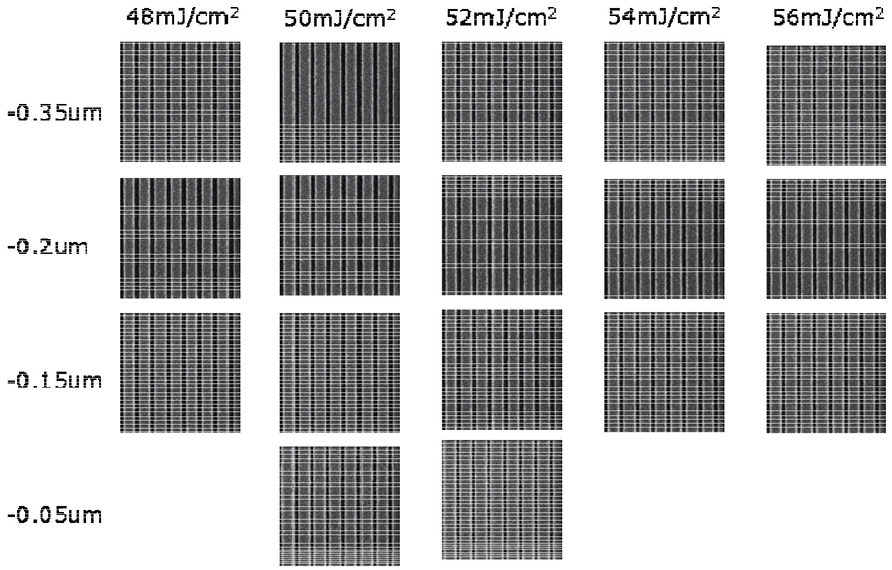
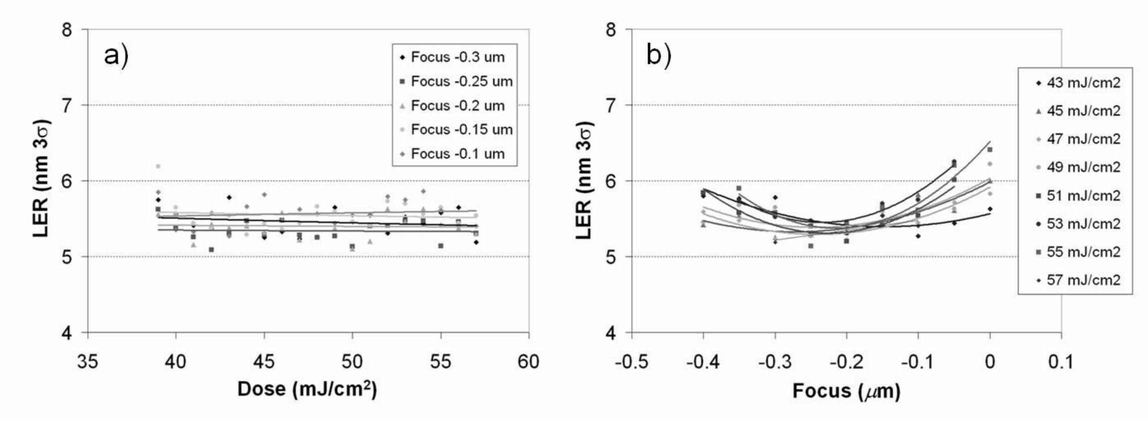


Fig. 5 SEM images of focus-exposure matrix for 1st exposure in double exposure using TOK N023

In order to assess the resist pattern quality of TOK N023, we examined its line-edge roughness (LER) behavior. Within the specified process window, 3σ LER for the target 70 nm trenches is essentially constant at 5.4 +/- 0.6 nm. Fig. 6(a) illustrates that LER does not vary significantly with dose, while Fig. 6(b) shows the anticipated (but slight) LER increase in defocus. The constant LER within the process window can be attributed to both high mean image log-slopes (ILS) (approx. 17.5 μm^{-1}) for the illumination condition chosen, as well as the narrow range of ILS (approx. 15-20 μm^{-1}). We note that, as anticipated, trench edges are uniformly uncorrelated.



(a) (b)

Figure 6. TOK N023 LER behavior through (a) dose and (b) focus

LER is fundamentally linked to both exposure conditions and resist materials properties [5]. Given that the chemistry associated with TOK N023 is quite different from positive-tone 193 nm resist system, we chose to examine LER behavior in more detail. Fig. 7 illustrates the power spectra of both TOK N023 and TOK TArF 6239, a high-performance 193 nm positive photoresist. The power spectra observed are essentially indistinguishable. (At very high spatial frequency, slight differences can be seen; these result from image-to-image noise variation, rather than resist behavior.) This finding alleviates potential concerns about unexpected LER behavior in negative-tone materials. Taken in sum, these observations are qualitatively in good agreement with previous comparisons of LER in positive and negative-tone systems in a longer wavelength regime [6].

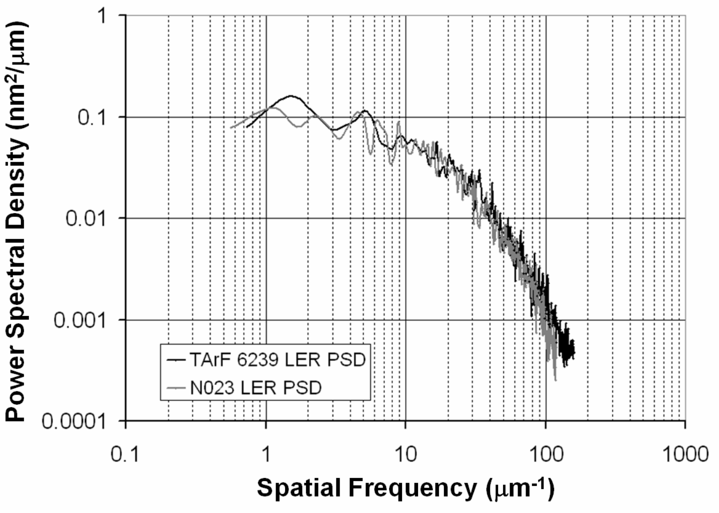


Fig. 7 Comparison of the LER power spectra of TOK N023 and TArF 6239

In Fig. 8, a SEM image of SiRN that passed through the second etch is shown. After the second etch, the residual photoresist and BARC were removed. The desired 130 nm pitch, frequency-doubled pattern is obtained.

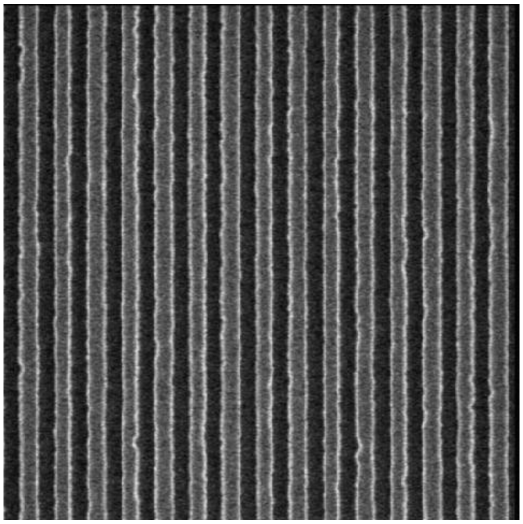
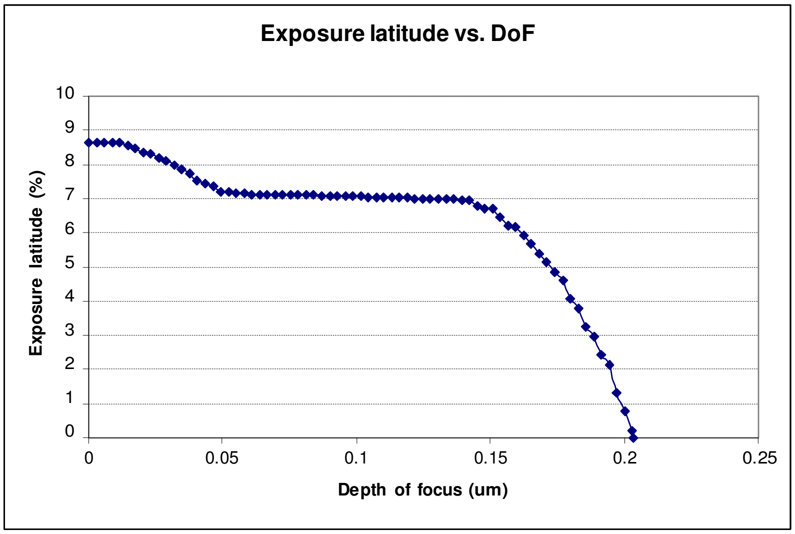
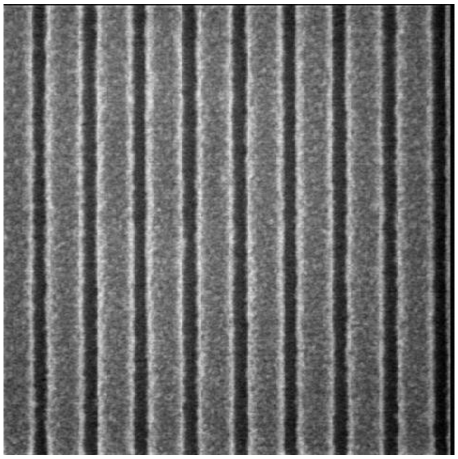


Fig. 8 SEM image of etch transferred SiRN dense L/S pattern after second etch

Further resolution gain can be accomplished by using improved negative-tone formulations. Fig. 8 illustrates TOK N026 imaging at NA=0.85. This improved formulation resolves 50 nm trenches on a 220 nm pitch with a modest process window (Fig. 9 (a)). If extended to a double patterning process, this material would enable dense line/space printing of $k_{1\text{-eff}}$ = 0.24 on a 110 nm pitch using NA=0.85 dry lithography.



(a)



(b)

Fig. 9 Generation of 1:3 = trench:line using TOK N026 for target trench CD= 50 nm in 220 nm pitch; (a) exposure latitude vs. DoF, and (b) SEM image

As shown above, a negative resist of high resolution shows a potential to be used in the double patterning. Further studies on later generations of the negative resist for the double patterning is in progress.

4. CONCLUSIONS

Using a negative resist (TOK N-series) for 193nm, 1:1 lines/spaces with effective k_1 factor of 0.25 was realized using a double patterning technique. DoF of 240 nm at 10% EL was obtained from the process window analysis for the generation of $k_{1\text{-eff}} = 0.25$. This comparably large DoF is obtained by the use of a bright field mask and a negative resist with a high resolution. This shows a good potential for the negative resist to be used in the double exposure area.

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