High-Sensitivity and High-Resolution Contact Hole Patterning Enhanced by an Optimized Developer

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We have determined that high-sensitivity and high-resolution contact hole resist patterning can be achieved by using an optimized combination of developer, added surfactant and ammonium chloride salt. The addition of surfactant improves the wettabilitiy of the developer and promotes resist dissolution. The presence of ammonium chloride salt protects the sidewall of the contact hole resist pattern. The optimal developer can form contact hole patterns smaller than the illumination wavelength of the stepper without phase shifting technology.

1. INTRODUCTION

Developments in photoresist materials and exposure systems have made it possible to achieve fine photoreis patterns for semiconductor device fabrication. Advanced Novolac-based resists1,2 and chemically amplified resists3-6 have been proposed for i-line and KrF excimer lithography, respectively. Recently, phase-shifting mask technology7-9 and the steppers with innovative illumination systems9,10 are being developed to improve the resolution and the depth of focus of resist patterns. Although line and space (L&S) resist patterns have been extensively evaluated at the research level, failures of contact hole (CH) resist patterns still often occur in production. Since the resolution capability of CH patterns is lower than that of L&S patterns, the exposure energy for CH patterns is required to be two or three times higher. The purpose of this paper is to overcome this problem by presenting the high performance formation of CH patterns by using a developer which contains surfactant and ammonium salt.

2. EXPERIMENTAL

The pre-bake (90°C/90s) thickness of the Novolac–based resists was 1.26µm. We employed g-line and i-line stepper systems (FPA-1550MII, MIVW, FPA-2000i : Canon) and evaluated CH patterns larger than 0.3µm. After exposure, the samples were post-exposure baked (110°C/90s). Next, the wafers were developed in 2.38wt% tetramethylammonium hydroxide (TMAH) aqueous solutions for 70 seconds and then rinsed in ultrapure water for 60 seconds; two TMAH solutions (TMAH–1, TMAH–2) and one surfactant were examined. The TMAH–2 solution included a tetramethylammonium chloride (TMAC) concentration of approximately 25ppb. The surfactant, a nonionic hydrocarbon type, was added to the developers in concentrations ranging from 0ppm to 200ppm. Cross-sections of the CH patterns were observed by scanning electron microscope (SEM). In order to evaluate the development characteristics of the CH resist pattern of various developers, the threshold exposure energy of contact hole (E_T), the exposure energy necessary for the bottom of contact hole to reach the substrate, was determined.

3. RESULTS AND DISCUSSION

Figure 1 shows the cross-sectional SEM views of 0.8µm to 0.6µm CH patterns formed by developer without surfactant (TMAH–1). When the exposure dose of 220mJ/cm² (fig.1(a)) is supplied, the 0.8µm CH pattern is precisely clear, but the others are under exposed. In the case of 280mJ/cm² (fig.1(b)), the 0.7µm CH pattern is good, but the others are failures. This

![Fig.1 Contact hole pattern profiles formed by developer without surfactant under the following exposure conditions: (a) 220mJ/cm², (b) 280mJ/cm²](image-url)
data says 200ppm developer. considered larger than line TMAH-I as a 22.4", unexposed developer, TMAH-2 hole decline, surfactant contact hole developers between increases, and Fig.2 using stepper function of 0.8µm sizes does the E∗ decreases, the E∗ difference between varying pattern sizes becomes lower. It is confirmed that CH patterns as small as 0.6µm can be formed under the same exposure condition and that TMAH-2 + surfactant enhances the resist resolution of CH patterns.

Figure 3 exhibits the SEM micrographs of 0.8µm to 0.6µm CH patterns using the differing developers. While patterns smaller than 0.8µm could not be obtained by using developer without surfactant, the addition of 200ppm surfactant allows the formation of CH patterns down to 0.6µm. The results of TMAH-1 + surfactant show walls of CH patterns with curved profiles, but the CH walls obtained by TMAH-2 + surfactant are straight. It is therefore suggested that the addition of surfactant improves the wettability of the developer and promotes the resist dissolution, and that the existence of chloride provides an inhibition effect[3], which prevents the resist dissolution of the CH sidewall.

Figure 4 presents the SEM micrographs of 0.4µm CH patterns exposed by a g−line stepper as a function
1.0pm

Fig. 4 SEM images of 0.4μm contact holes as a function of exposure energy. Patterns were formed by a g-line stepper (NA=0.55) and the following developers: TMAH-2, TMAH-1 + 200ppm surfactant, and TMAH-2 + 200ppm surfactant.

Fig. 5 SEM images of 0.35μm contact holes patterned by an i-line stepper (NA=0.52) and following developers: TMAH-2, TMAH-1 + 200ppm surfactant, and TMAH-2 + 200ppm surfactant. Exposure energy: 279mJ/cm²

of exposure energy for different developers. In the case of TMAH-2 + surfactant, the resist sensitivity is much higher, and the exposure latitude is much greater. Figure 5 shows 0.35μm CH pattern profiles of various developers, exposed by an i-line stepper. Accurate 0.35μm CH patterns can be resolved by using TMAH-2 + surfactant. We have also confirmed the formation of 0.3μm CH patterns by TMAH-2 + surfactant.

4. SUMMARY
We have found that developer including surfactant and ammonium salt enhances the resist performance: high-sensitivity and high-resolution of contact hole patterning. Due to the additional surfactant to the developer, its wettability becomes good and resist dissolution in narrow spaces is promoted. The presence of ammonium chloride salt in the developer prevents the dissolution of the sidewall of the contact hole pattern. By matching resist materials with this optimized developer, we can achieve ultrafine contact hole patters as well as line and space patterns.

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References
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