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Defects Elimination for ArF Implant Lithography

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***Abstract*—The application of ArF photoresist for implant process poses big challenge for process qualification in terms of defects control. Resist cracks and post development resist residues are the two most evident defects. In this study, two ArF photoresists for implant process have been selected to investigate the defect elimination. Lower PEB (post exposure bake) temperatures could help to reduce the tensile stress accumulated in the resist thus lower the risk of resist cracks. To reduce resist residue defect, longer de-ionized (DI) water rinse should combine with special puddle steps to relieve the developer pH shock during developing process. For better understanding the relationship between crack defects and contact angle, one advanced adhesion promotion material was introduced and investigated. It was found the spin-coated adhesion promotion material can significantly enhance the adhesion between the resist film and the underlying substrate due to lower contact angle formed. The implementation of the advanced adhesion promotion material resolved the resist cracks issue successfully. Finally, defects free ArF implant process was achieved through process optimization in our study.**

***Index Terms*—defects, ArF, lithography, implant**

I. Introduction

As Critical Dimension (CD) in lithography field keep shrinking in recent years, controlling and reducing defect levels becomes increasingly important in both R&D and manufacturing environments [1], [2]. In a conventional Si process flow, wafers usually need go through several mask layers to fulfil specific purposes, e.g., an implant layer mask is required to open areas which need for N+ or P+ doping to form N well or P well. At the same time, the Photo Resist (PR) thickness is supposed to be thick enough to protect those areas covered by PR during the implant process. Normally, the CD of implant layers is much larger than that of critical layers in the same technology node, such as gate or contact layers, and the dimensions are from several microns to several hundred nanometers. Accordingly, the lithography tool sets required could be from I-line (365 nm), KrF (248 nm) to even ArF (193 nm) in the case for below 20 nm technologies. Although better resolution and overlay performance can be achieved by ArF lithography, much more defects were also found in using ArF PR for implant layer [3]. Numerous studies were carried out to investigate the defects reduction on conventional implant layers, but study on defects elimination on ArF implant lithography has rarely been reported yet.

In this paper, we will present a systematic investigation to optimize an ArF implant lithographic process from defects reduction point of view. And the possible defect reduction mechanisms will also be discussed.

II. Experimental

Experiments were conducted both on 200 mm bare silicon wafers and topology wafers. Two types of ArF implant photoresist (PR_1 and PR_2) provided by resist venders have been selected for evaluation. The lithographic processes were performed by ArF dry scanner integrated with in line tracks. Standard 2.38 wt% tetramethylammonium- hydroxide (TMAH) was used to resolve the photoresist. Metrology data and defect data were taken on both a scanning electron microscope (SEM) and DRSEM.

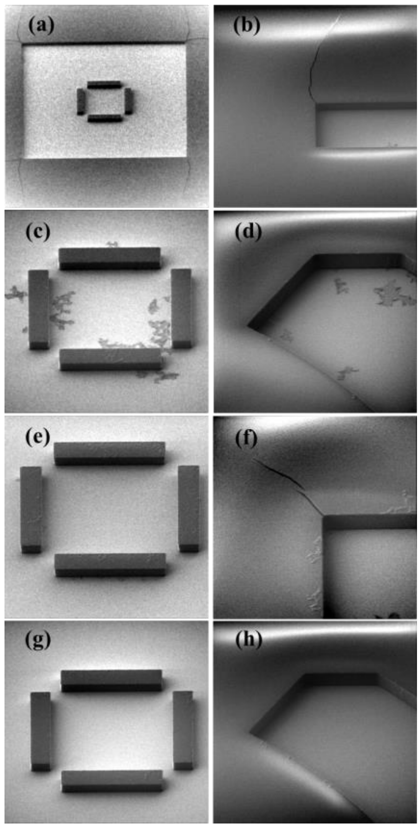

Figure 1. Defect images of wafers under different process conditions: (a) and (b) from Trial Run; (c) and (d) from Split_1; (e) and (f) from Split_2; and (g) and (h) from Split_3. The process details are listed in Table I.

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III. Results and Discussion

A. Effects of PEB and Development Recipe

PR_1 has been selected as the first candidate for the ArF implant process qualification. The trial run process parameters were based on the recommendations from vender. From the SEM images shown in Fig. 1 (a) and (b), severe PR cracks can be observed after development inspection (ADI), and over >50% area of the wafer were affected. In addition, little amount of resist residues can be observed in the resist open area, which would be a critical yield killer for the implant process. To address the PR crack and resist residue issues, the splits on post exposure bake (PEB) and development recipe optimization were conducted.

Resist film cracks are believed to be strongly related to the stress development during the thermal process, such as softbake and PEB [4]. In this study, the softbake temperature and time fixed at 120°C and 60 seconds as vendor recommended while split on PEB temperatures. It is clear that when PEB temperature decreased from 130°C to 120°C, the resist cracks disappeared as shown in Fig. 1(c) and (d). Although large amount of post development resist residues showed up in this split (Split_1 in Table I, will discuss later), lower PEB temperature reduced the tensile stress accumulated in the resist films essentially thus eliminated the crack formation.

TABLE I. The Process Split Conditions of HMDS, PEB and Development Recipes

SPLIT	HMDS	PEB	Development Recipe
Trial Run	90°C /36sec	130 °C /60sec	Dev Pre-Wet , Single Puddle, DI Rinse (25sec)
Split_1	120 °C /90sec	120 °C /60sec	DI Pre-Wet , Double Puddle, DI Rinse (25sec)
Split_2	120 °C /90sec	130 °C /60sec	DI Pre-Wet , Double Puddle, DI Rinse (25sec)
Split_3	120 °C /180sec	120 °C /60sec	DI Pre-Wet , Special Double Puddle, DI Rinse (40sec)

Post development residue is one of the common lithographic resist defects, which could be observed from I-line, KrF, ArF and even ArF immersion process [5]. This kind of defects is believed to occur due to the redeposisition of dissolved photoresist solids back onto the wafer surface during processing or insufficient removal due to poor rinse [6]. Thus, stronger puddle (double puddle vs single puddle) with longer DI water rinse would be the normal option to remove resist residue related defects. In our investigation of Split_1 and Split_2, the development recipe was evolved from single puddle (Trial run condition) to double puddle, while unfortunately the SEM defect pictures showed no improvements on the resist residues (Fig. 1 (b), (d) and (f)). This phenomenon could refer to as pH shock, which usually occurs during the transition from a puddle step to a rinse step [7]. At the end of the puddle step, the rapid addition of DI water (pH=7) to the puddle (pH=13) changes the solubility of developer and makes it impossible to keep dissolved resist solids still in solution, thus the resist solids precipitate back onto the wafer surface to become the residues. For all developed wafers with pH shock, the electrostatic attraction of the particles to the resist surface makes them ‘sticky’ and difficult to remove by normal rinse techniques. To verify this assumption, Split_4 was deliberately designed to add one short puddle before the DI water rinse step. This was to reduce the risk and potential amount of redeposition. In addition, a prolonged rinse cycle (40 seconds) was applied to more effectively remove adhered particles. Finally, a wafer with good sidewall and resist residue free (on open area) was observed as shown in Fig. 1 (g) and (h). Repeatability study on 6 more wafers with same process condition as Split_4 showed the same good resist profile and residue free performance (images not shown here). This implied our process was firmly robust.

B. Effects of Adhesion Treatment

Adhesion of PR on substrate is one of the key issues in photolithography as poor adhesion between PR and the substrate will cause patterns dislocated or peeled in the developing process. This becomes a more serious issue by using ArF PR than by KrF or I-line ones [3]. Hexame--thyldisilazane (HMDS) and vapor priming systems has long been used to promote the resist adhesion to the underlying substrates, such as polysilicon, metals and SiO_2 layers in lithographic process. The mechanism of HMDS adhesion promotion lies in the fact that the spray of HMDS could change the substrate from hydrophilicity to hydrophobicity, thus enhance the adhesion between the photo resist and the substrate [8]. Normally, longer heating time could further promote the adhesion, while it will adversely affect the wafer throughput. In this section, we will introduce one advanced adhesion treatment method to improve the crack defects and the possible improvement mechanism will be discussed.

The investigation was conducted on another ArF implant process photoresist (PR_2). With normal HMDS treatment, the cracks appear at the corners of the printing patterns. Different combination of HMDS treatment (such as longer adhesion time) and PEB temperature variation could relieve the severity of the cracks to some extent but cannot fully eliminate. One typical example of crack defects is as shown in Fig. 2(a). It is known that the adhesion of resist depends directly on the surface tension of the materials involved [9]. The adhesion strength W_a between the resist film and the substrate can be described to the surface energy components of the two surfaces by following equation:

$$W_a=2(\gamma_s^P\gamma_r^P)^{1/2}+2(\gamma_s^d\gamma_r^d)^{1/2} \quad (1)$$

where γ_s and γ_r refer to the surface energies of the substrate and the resist film, respectively. The γ^P and γ^d

represent the polar component (caused by dipole interactions) and the non-polar component (caused by dispersion energy between molecules) of the surface energy. According to the study by Deckert and Peters [10], best adhesion could be obtained if polar surface energy components (γ^P) of both the photoresist and the substrate are as small as possible. In case of a large γ^P substrate used, such as untreated silicon dioxide thin film substrate thermally grown at 1000°C on a silicon wafer, the γ^P value could be remarkably reduced from 32-43 dyn/cm to 4.8-16 dyn/cm after HMDS treatment [10]. This implies an appropriate surface treatment reagent could greatly reduce the surface tension of the substrate and thus improve the adhesion strength.

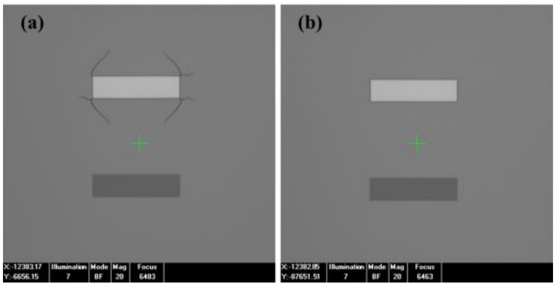

Figure 2. The SEM images of 2 wafers processed with different adhesion treatments: (a) and normally HMDS treatment; (b) AAPM treatment.

To address this resist crack issue, we start to improve the adhesion strength between the ArF photoresist and the SiO_2 substrate by investigating the adhesion promotion materials used. Apparently, commercially available HMDS cannot meet our requirements for the ArF implant process PR_1 and PR_2. Working with material venders, an advanced adhesion promotion material called AAPM has been introduced and evaluated. Different from HMDS which is usually through spraying, AAPM is more like a resist through spin-coating system, and need go through short dehydro bake and coating bake respectively. Wafers processed with AAPM showed good profile and resist cracks free images, as shown in Fig. 2(b). As more epoxy type polymers are featured in novel AAPM, the defects elimination from AAPM is believed to originate from the better adhesion between photoresist and substrate due to lower contact angle formed after AAPM treatment. It has been established by Bauer *et al.* [9] that the surface tension of substrates as well as photoresists or developers could be determined by contact angle measurements. The relationship between adhesion strength (or Work of adhesion) and contact angle can be derived from (1) as that [11]:

$$W_a=\gamma_r\,(1+\cos\theta) \qquad (2)$$

γ_r is the surface tension of the resist film on substrate, θ is the static contact angle between the resist film and the substrate. For one appropriate resist candidate and the known silicon substrate, the adhesion strength is strongly determined by the contact angle formed. Compared to HMDS normally baked at 90°C to 120°C, the AAPM material has a wider range of baking temperature and a higher optimum baking temperature. Under extreme conditions, it can be heated up to 300°C. As investigated in our study, the contact angle of AAPM reduced with the increase of the baking temperature (not shown here). When the baking temperature was within 120°C to 200°C, the contact angle gradually reduced from around 70° to 60°. The reduction is more remarkable when baking temperature is higher than 200°C. At a baking temperature of 240°C (60 seconds), the contact angle could be as low as 50°, which is much lower than that surface from HMDS treatment. Thus better adhesion has been obtained through the AAPM process (Fig. 3, $\theta_2<\theta_1$).

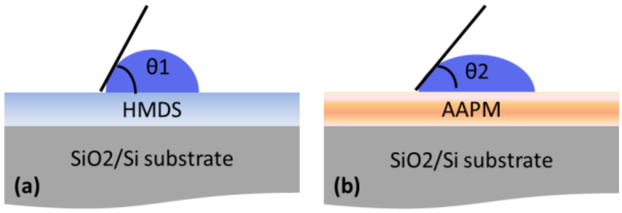

Figure 3. The schematic diagram of contact angles between photoresist and substrate under different surface adhesion treatments: (a) HMDS treatment; (b) AAPM treatment.

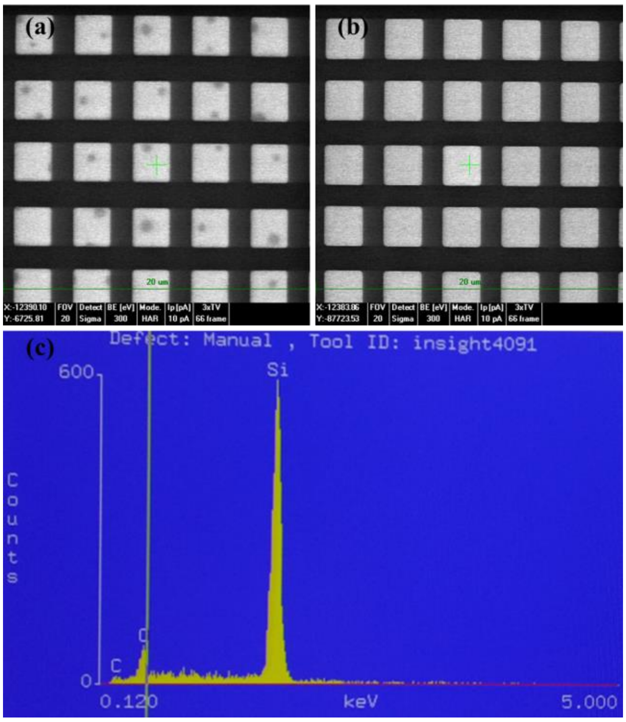

Figure 4. The SEM images of wafers processed with (a) normal AAPM treatment and (b) enhanced version of AAPM surface adhesion treatment; (c) EDS analysis of dark spot defect as shown in (a).

It is worthy to point out that during the starting phase of the new AAPM material application, although AAPM successfully resolved the defects such as crack and residues, a new defect appeared unexpectedly (as shown in Fig. 4(a)). These irregular dark spots on resist open areas were discovered during post development inspection. Energy dispersive X-ray spectroscopy (SEM-EDS) on dark spots revealed that they contained C and O (Fig. 4(c)). The possible source of the defect could be the resist material eluted from the exposed area or the AAPM material itself as both of them contain C and O elements.

Further inspection on AAPM coating only wafers showed similar random distributed dark spots on whole wafers, which confirmed the defects were brought by the adhesion promotion material. Different thermal treatments could mitigate the severity of the dark spots but cannot eliminate them fully. This issue was finally resolved through work with vendor from material modification point of view. Fig. 4(b) showed the defect clean SEM image of wafers processed with enhanced AAPM material.

IV. Conclusions

In this study, two ArF photoresists have been investigated in terms of defect elimination for implant application purpose. It is found that lower PEB temperatures help reduce the tensile stress accumulated in the resist films and lower the risk of resist cracks. To reduce resist residue defect, longer DI water rinse should combine with special puddle steps to relieve the developer pH shock during developing recipe optimization. As one advanced adhesion promotion material, AAPM can significantly enhance the adhesion force between the resist film and the underlying substrate due to lower contact angle formed. The implementation of AAPM solved the resist cracks issue successfully. Finally, defects free ArF implant process have been achieved through process recipe optimization in our study.

Acknowledgment

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