

Control ability of spin coating planarization of resist film and optimal control of developers

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Abstract

The issue of how to transfer a pattern onto a wafer during photolithography is very important. Normally, the resist is treated as a pattern-transferring medium. Such a medium should have a very smooth surface to reduce the focus error. In this experiment, spin coating is used. The velocity of the center differs from that of the outer edges of a rotating disk, so a perfectly smooth surface cannot be obtained. Therefore, resist temperature, cooling temperature, heating temperature, cup temperature, cup humidity and exhaust pressure were controlled to eliminate this imperfection to yield an acceptable error. A lower cooling temperature yields a thicker center, such that the surface of the wafer protrudes at the center. A lower cooling temperature also corresponds to a thicker center, with the same effect. The cup temperature was set to the cooling temperature so that thickness distribution would be the same as. A higher heating temperature yields a thinner wafer. Higher humidity yields a thinner wafer.

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1. Introduction

Resist spin coating has been successfully modeled using a detailed non-Newtonian analysis, which allows local fluid viscosity to vary with concentration and shear rate [1–6]. The cleavage of a butylester is acid-catalyzed and yields carboxylic acid and isobutene after exposure to the photo-active component (PAC) and post-exposure back (PEB) [7]. When an acid generator is present in a CAMP resist formulation, the mechanism for producing a lithographic pattern is simple. The strong acid formed causes deprotection at a relatively low temperature with an activation energy of around 11–14 kcal/mol [8,9].

During photolithography, spin coating is used to apply photo-sensitive material onto the surface of a wafer. Several methods were used to apply the resist onto the wafer surface as required. The resist was applied to the top of the wafer by spin coating, but at a given speed; the center of the wafer would spin more slowly than the outer edges, causing the resist at the center of the wafer to be thicker than at the edges, creating poor

smoothness during exposure, and causing experimental errors. Several methods were used to solve this problem. One changed the rate of rotation of the wafer; another used the post-exposure back (PEB) temperature and baking time to control uniformity and exhaust pressure to control the thickness at the outer edges of the wafer [10–13].

2. Equipment and functions

(1). The TEL CLEAN ACT-8 machine was used for spin coating and as a developer. The main functions of the ACT-8 are (1) priming, (2) spin coating, (3) soft baking, and (4) developing.

(1) A layer of hexamethyldisilazane (HMDS) is sprayed onto the wafer. HMDS functioned as a medium that strengthened the bond between resist and wafer surface. After suitable priming, the wafer surface energy can be adjusted to a level similar to the resist surface energy to increase the adhesive strength between the wafer surface and the resist. (2) After dehydration baking and priming, the liquid resist must be evenly applied to the wafer surface. The resist was dripped onto the center of the wafer and distributed over its surface by the centrifugal force due to high-speed rotation. A higher rotation speed yields a thinner and more uniform resist liquid. The resist includes a very volatile organic solvent. After the resist is sprinkled onto the wafer surface, the stickiness of the resist

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changes with the volatility of the solvent. Failing to complete the coating before the solvent becomes volatile yields poor uniformity. (3) The main purpose of the soft baking was to eliminate the solvent that remains in the resist after spin coating, to transform the resist from a semi-solid to a solid film. (4) The main purpose of developing was to display the pattern that followed the exposure and leave the required pattern after the developer reacts.

(2). After the coating process is completed, the thickness of the resist must be known. Therefore, a KLA_Tencor PROMETRIX UV-1280SE was used to measure the thickness of the resist film, by applying optical methods to measure accurately the thickness of the resist from the center of the wafer to the edges of the wafer after the resist has solidified.

3. Experiment and analysis

3.1. Photo exposure

Priming → cooling (23 °C) → spin coating → pre-exposure bake → cooling (23 °C) → stepper/exposure → post-exposure baking (PEB) → cooling (23 °C) → development → post-development baking → cooling (23 °C).

3.1.1. Priming

The surface of a wafer typically absorbs water molecules from moisture in the air. Before spin coating, therefore, the plate was heated to 90 °C for 30 s to remove the few water molecules from the wafer's surface. Then, 3000 ml/min of HMDS is sprayed onto the wafer surface to increase the adhesion between the resist and the wafer surface. The same priming experimental conditions were used for I-line and DUV; (Deep Ultra-Violet) resist.

3.1.2. Special spin coating and resist characteristics

Resist is a liquid chemical at a constant temperature. During photolithography, it was evenly spread over the surface of the wafer by spin coating, and it was used as a medium for changing the reticle pattern. The resist was a mixture of three components, resin, sensitizer and solvent. Resin was as a binder, and the sensitizer was a compound with a very strong photo-activity. After mixing, the binder and solvent are liquid. Positive and negative resists are distinguished. The characteristic of a positive resist is that after exposure to UV light, the developer can more easily dissolve the exposed-areas, because of a chemical reaction that follows the developing process. However, areas unexposed to UV light do not undergo this reaction. However, during exposure to light, a negative resist produces cross-links that strengthens the structure of the resist. This experiment used a positive for I-line and DUV.

The resist contained solvent that causes it to remain in a liquid state if kept at a constant temperature and not exposed to air. Thus, spin coating was used to coat the wafer surface with a very thin film. The thickness of this film was determined by the resist used. The primary purpose of this film was to transfer smoothly the pattern from the reticle onto the wafer. Satisfactory thickness and smoothness are sought. A very

low uniformity causes defocus, while a high uniformity destabilizes the size of the critical dimension (CD) Bar. The speed of rotation of the wafer, the resist temperature, the cooling temperature, the heating temperature, the cup temperature, the cup humidity and the exhaust pressure all affected the thickness of the film. The most important of these factors was (1) speed of rotation of the wafer, which affected the thickness and uniformity of the film. The center of the wafer rotated more slowly than its edges, and it was therefore thicker at the center than at the edges. The SEPR 432 Resist Spin Coating was thus divided into three steps to prevent this occurrence and its effect on the accuracy of the experiment. The first step applied a rotational speed of 3200 rpm for 1.4 s, after acceleration at 10,000 rpm/s. The second step applied a rotational speed of 100 rpm for 1 s, after acceleration at 16,000 rpm/s, while the third step applied a rotational speed of 2510 rpm for 20 s, after acceleration to 10,000 rpm/s. PFI58 resist was also applied in three steps. The first step applied a rotational speed of 3200 rpm for 1.4 s, after acceleration at 10,000 rpm/s. The second step applied a rotational speed of 100 rpm for 1 s, after acceleration at 35,000 rpm/s, while the third step applied a rotational speed of 2750 rpm for 20 s, after acceleration at 10,000 rpm/s. In IX950 spin coating, the rotational speed of the wafer applied in the first step was 4300 rpm for 1.7 s, after acceleration at 10,000 rpm/s. The second step applied a rotational speed of 100 rpm for 1 s, after acceleration to 35,000 rpm/s, and the third step applied a rotational speed of 2600 rpm for 20 s, after acceleration to 10,000 rpm/s. In PFI56 A6 Spin Coating, the rotational speed of the wafer in the first step was 3700 rpm for 2.8 s, after acceleration at 10,000 rpm/s. The rotational speed in the second step was 100 rpm for 1 s, after acceleration to 35,000 rpm/s, and that in the third step was 3370 rpm for 20 s, after acceleration to 10,000 rpm/s. The rotational speed was higher in the first of the three steps in each case because, in this step, solvent was used to clean the wafer's surface. The second step had a lower rotational speed, but a greater acceleration because the resist was sprayed onto the center of the wafer during this step. The subsequent further acceleration to a high-speed was required to spread the resist, but the speed in the second step was lower in the DUV process since the resist used in the DUV was less sticky than that used in the I-line process. The second step was used to control the thickness of the resist, since rotational speed affects this thickness. This step is continued for a long period to give the solvent in the resist sufficient time to evaporate, turning the resist into a solid state.

3.1.3. Soft back

A very low soft back temperature causes the evaporation of the solvent in the resist to be incomplete. If the temperature is too high, the solvent on the surface of the resist becomes volatile more quickly than that inside the resist, causing the surface of the resist to harden, before the interior solvent has evaporated, leading to deformations at the resist surface.

As well as affecting solidification, PEB also affects the result of the development. If either temperature or time was inadequate, the resist and its adhesion to the wafer surface

Table 1
Main conditions, parameters and components used in the experiment

	Resist name	I-LINE			DUV SEPR432
		IX950	PFI 56A6	PFI-58A	
HMDS	HMDS main conditions	1. Hexamethyldisilazane	1. Hexamethyldisilazane	1. Hexamethyldisilazane	1. Hexamethyldisilazane
		2. Hexamethylsiloxane	2. Hexamethylsiloxane	2. Hexamethylsiloxane	2. Hexamethylsiloxane
		3. Hexane	3. Hexane	3. Hexane	3. Hexane
		4. Trimethylsilanol & ammonia	4. Trimethylsilanol & ammonia	4. Trimethylsilanol & ammonia	4. Trimethylsilanol & ammonia
		HMDS flow(ml/min)	3600	3600	3600
Coat unit	HMDS temp. (°C)	90	90	90	90
		Resist temp. (°C)	23	23	23
	Resist main conditions	1. Methyl 3-methoxy propionate	1. Methyl amyl ketone	Methyl amyl ketone	1. Propylene glycol monomethyl ether acetate
		2. Phenolic resin	2. Novolac resin derivatives		2. Ethyl lactate
		3. Phenolic oligomer	3. Photo-active compounds		3. Polyhydroxystyrene derivatives
	Cup temp. (°C)	23	23	23	23
	Cup humidity (%)	45	45	45	45
	Cup win velocity (m/s)	0.40	0.40	0.40	0.40
	Cup exhaust press. (Pa)	45	45	45	45
	Cooling unit	Temp. (°C)/time (s)	23/60	23/60	23/60
Soft bake		Temp. (°C)/time (s)	90/90	90/90	100/90
Development	Developer main conditions	Tetramethylammonium hydroxide	Tetramethylammonium hydroxide	Tetramethylammonium hydroxide	Tetramethylammonium hydroxide
		Developer temp. (°C)	23	23	23
	Developer flow (ml/min)	1500	1500	1500	1500
	Cup exhaust press. (Pa)	60	60	60	60
	DI water flow (ml/min)/(s)	600/60	600/60	600/60	600/60

deteriorates and after exposure, the CD Bar is deformed due to the presence of the solvent in the resist. Table 1 lists the temperatures and times used in this experiment. During this experiment, PEB temperature and time were found to affect the CD Bar standing wave. Figs. 1 and 2 indicate that both I-line and DUV undergo the standing wave phenomenon

because the ‘light’ applied during exposure created interference, or uneven ‘light’ intensity. This ripple shape was particularly clear on a white wall. The experiment revealed that the PEB temperature and time had to be controlled to minimize the ripple, because PEB caused the resist to produce diffusion. The diffusion would improve the standing wave, even though

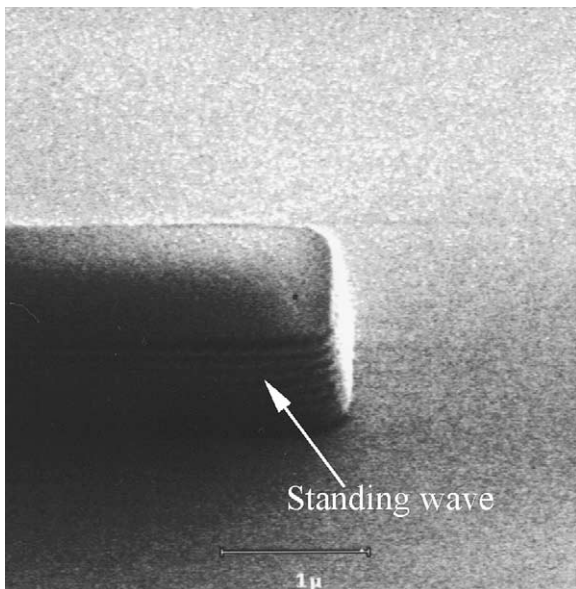


Fig. 1. I-line light source. Applied Materials’ SEM Vision used to observe the standing wave phenomenon.

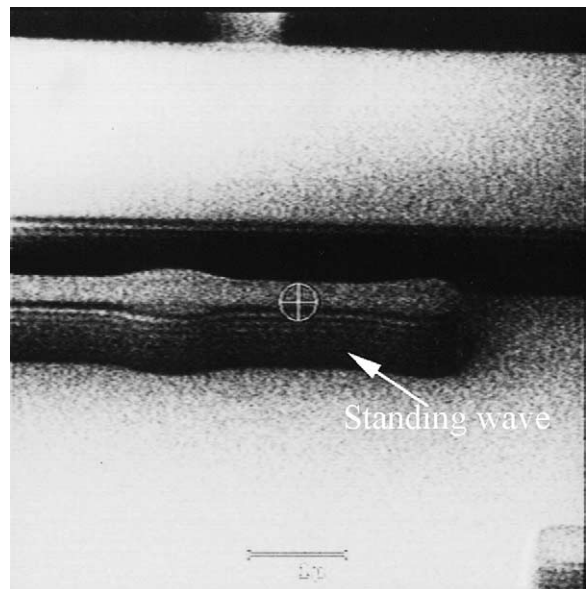


Fig. 2. DUV light source. Applied Materials’ SEM Vision used to observe the standing wave phenomenon.

excessive diffusion degrades the resolution. All soft back and applied PEB conditions were the same. PEB may improve promote the standing wave phenomenon. However, the purpose of the soft back was only to evaporate the solvent inside the resist: accordingly, soft back conditions were coordinated with post-exposure soft back. Temperatures and time vary with the type of resist because the duration and temperature of the experiment were repeatedly varied. These circumstances resulted in the weakest standing wave phenomenon.

3.1.4. Development

A positive resist after exposure produces carboxylic acid. Adding alkali would neutralizes this acid.

Development is to remove the positive resist from the wafer's surface, and proceeds by neutralizing the resist's reaction to light. DI water was used to remove the developer from the surface. The main factors that control the development process were the development time, the tetramothlamoniumhydroxide (TMAH) components and temperature.

In the development experiment, a spray method was adopted; it was divided it into three stages. First, TMAH was sprayed onto the surface of the wafer. Second, the wafer was developed in a static state. Third, after the pattern was obtained, DI water was sprayed onto it at high-speed to remove the post-reaction developer. The three stages were divided between I-line and DUV. The same development conditions were applied for the I-line, while individual development was used for DUV. Different conditions were adopted in the experiment because I-line and DUV used different resists. During the first step of the I-line process, a rotational speed of 20 rpm was applied for 9 s, after acceleration at 10,000 rpm/s. The second step applied a rotational speed of 0 rpm, which was held for 52 s to allow the resist and developer to neutralize. The third step applied a rotational speed of 4000 rpm for 20 s, after acceleration at 10,000 rpm/s, while DI water was sprayed onto the wafer, primarily to remove the post-reaction developer. During the first step of the DUV process, a rotational speed of 20 rpm was applied for 9 s, after acceleration at 10,000 rpm/s. During the second step, a rotational speed of 0 rpm was held for 40 s to allow the resist and developer to neutralize for 40 s. During the third step, a rotational speed of 4000 rpm was applied for 20 s, after acceleration to 10,000 rpm/s while DI water was sprayed onto the wafer to remove the developer that remained after the reaction with the resist.

4. Results and discussion

Several methods were used to control the smoothness of the resist surface to increase the exposed surface of the stepper. Using the spin coating method to spray the resist directly onto the wafer surface makes the resist adhere to the wafer surface due to the centrifugal force. The center of the wafer rotates more slowly than its edges, causing an undesirable higher thickness at the center than at the edges. However, this

smoothness is still not that required in this experiment, and certain conditions must therefore be controlled to achieve an even smoother surface. They include resist temperature, cooling temperature, heating temperature, cup temperature, cup humidity and exhaust pressure.

The resist temperature is fixed at 23 °C, because a higher the resist temperature increases the thickness at the center of the wafer, making it protrude. A lower resist temperature yields a thinner or even depressed center of the wafer center.

The cooling temperature was fixed at 23 °C and the cooling time at 60 s. The cooling time was lengthened to ensure that the temperature of the wafer was maintained at 23 °C. A higher

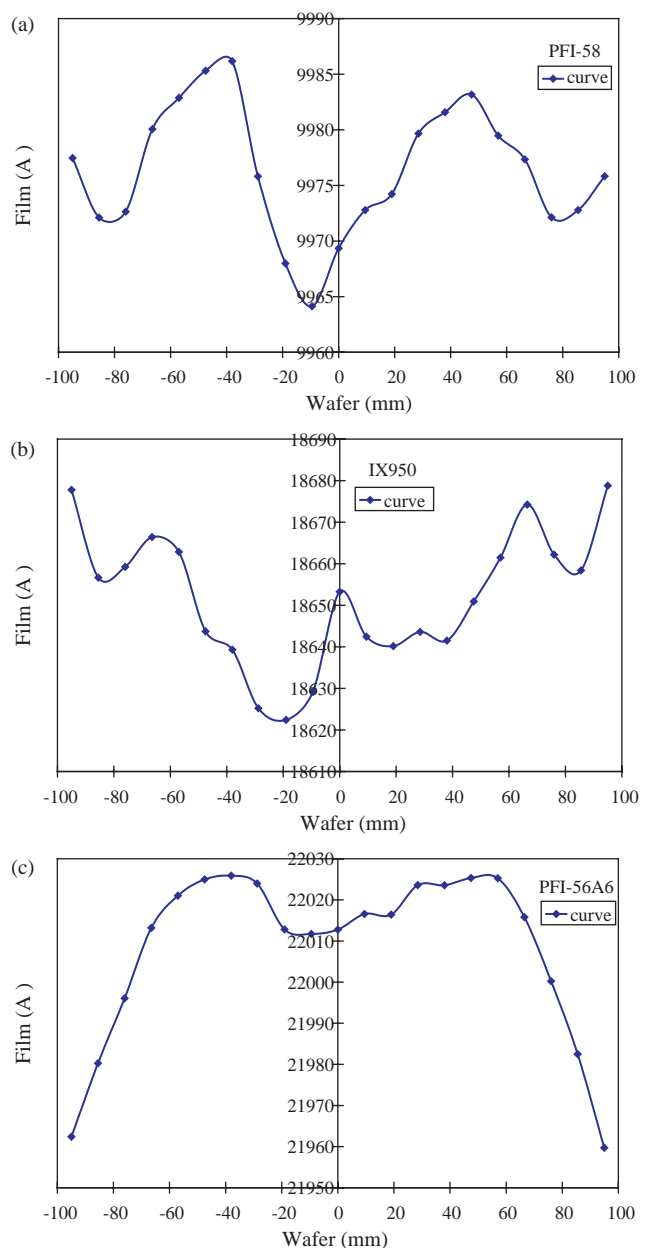


Fig. 3. I-line Resist (a) PFI-58, (b) IX950, (c) PFI56A6 film distribution curve obtained under controlled conditions.

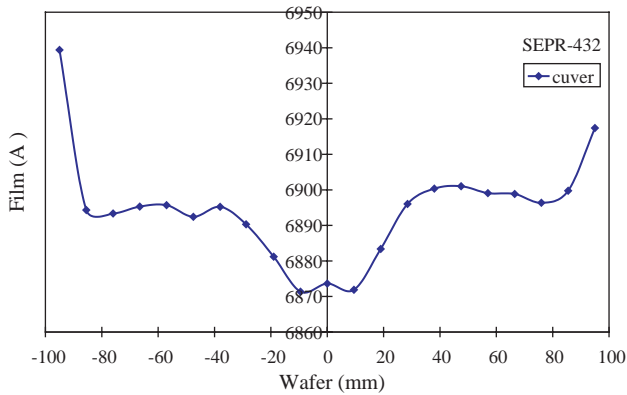


Fig. 4. DUV SEPR 432 Resist film distribution curve obtained under controlled conditions.

cooling temperature yielded a thinner or even a depressed center of the wafer. A lower cooling temperature yielded a thicker or even protruding center.

The cup temperature was set to the cooling temperature so that the thickness distribution would be the same.

A higher heating temperature corresponds to a thinner wafer overall. Homogeneity was greater at higher temperatures, but excessive temperatures deformed the wafer and detrimentally changed the resist.

The cup humidity was set to 45%. A higher humidity corresponded to a thinner wafer, and a lower the humidity to a thicker the wafer, but humidity did not cause the center of the wafer to be depressed or to protrude. A cup humidity of 45% created a smoother surface.

Exhaust pressure does not impact the center of the wafer but only the wafer edges, because an exhaust pressure of only 45 Pa was insufficient to impact the center. A higher exhaust

pressure yields thicker wafer edges. An excessive exhaust pressure causes low environmental humidity.

From Table 1, the above conditions yield the different degrees of thickness and smoothness in Figs. 3 and 4. DUV is thinner than I-line because of the viscosity of the resist. Viscosity was not measured in this experiment since only the smoothest surface was sought. Fig. 5 of CD Bar and edge distribution caused by inappropriate control of temperature and duration of the development process and inappropriate DI water flow.

5. Conclusions

The results of these experiments revealed that PEB temperature and time affect the standing wave in the CD Bar. Changing the PEB temperature and time reveals that longer or shorter exposures do not yield better or worse standing waves, and that only fixed periods of optimized. Each type of resist has an optimal PEB that reduces the standing wave effect. The standing wave cannot be improved by increasing the temperature. The best results are obtained within a specified period. The standing wave also displays some relatively complex chemical phenomena. PEB could thus reduce the standing wave effect mainly because the increased temperature of a resist after exposure rearranges its structure, suppressing the standing wave.

The wafer's center region spins more slowly than its outer region. Therefore, the center region is made thicker than the outer region. However, if the exhaust pressure is applied to the edge of the wafer, the surface tension effect generates an unstable wavy thin film surface on the resist layer of the wafer's surface. The surface tension was lower than that of the other I-line resists, indicating that the wavy thin film surface was hard to produce on the DUV resist. Also, the resist temperature is an important factor that affects the production of the thin film. A higher resist temperature is higher increases the energy of the resist. Increasing the resist temperature causes the surface tension of the wafer to become unstable. These phenomena were caused by the absorption of much energy by the resist, destroying the originally stable surface tension and causing instability of the thin film on the surface of the resist.

The developing time and the contents and temperature of the developer can affect the line-width and white wall of the CD Bar. A longer developing period may cause the carboxylic acid to be neutralized by the alkaline for too long, resulting in a CD Bar that is too small with a white wall that is too large. If the developer contains too many or too few ingredients, the CD Bar can become unstable. Also, if the developer's ingredients are not evenly mixed, some regions will become over-neutralized, while others are insufficiently neutralized, causing unevenness of the CD SEM's line-width. A developer at a temperature that is too high accelerates the neutralization, causing the CD Bar's white wall to become too large.

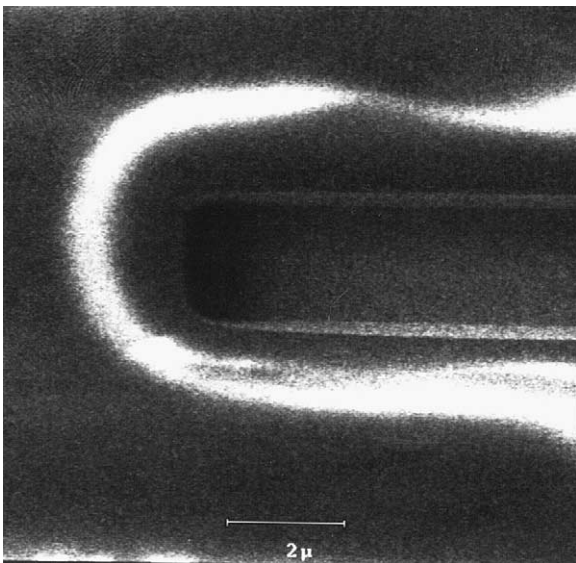


Fig. 5. Chart of CD Bar and edge distribution caused by inappropriate control of temperature and duration of the development process and inappropriate DI water flow.

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