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ORIGINAL ARTICLES

Resist Uniformity Evaluation through Swing Curve phenomena

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ABSTRACT

In fabrication of Micro/ Nano structure, alignment and exposure are the most critical steps in photolithography process, the resolution requirements and precise alignment are vital; each mask needs to be precisely aligned with original alignment mark. Otherwise, it can't successfully transfer the original pattern to the wafer surface causing device and circuit failure and the photo resist must be very sensitive to the exposure light to achieve reasonable throughput and the standard thickness should be 1.2µm. 24 wafers are used in this study, the wafers are separated into 2 sets, and each set which consists of 12 wafers. The first set is coated, exposed and development and the second set is also exposed and developed after being coated. after the wafer went through the standard cleaning procedure, the wafers were then coated using standard recipes which the spin speed ranging from 6500 to 7600 rpm in 100 rpm incremental Subsequently, the photoresist thickness of each wafer is measured using elipsometer. The study revealed that the minima for the dose-to-clear are at 7200 rpm where the thickness is 1.21 µm. Though, the result is slightly thicker than the expected 1.2 µm. This may be due to some unavoidable experimental errors and may due to the changing k' of the coater because coater is a bit old.

Key words: clearing point (dose to clear); coater; elipsometer; stepper; wafer, critical dimension

Introduction

The key element in photolithography is the line width of the photoresist pattern or critical dimension (CD). The CD is significantly impacted by several variables that must also be monitored to ensure quality (Weng Khuen Ho *et al*, 2007). Improvements to CD uniformity have been made through optimization of various lithography sequences. They include die-to-die exposure dose optimization (H.W.Kim *et al*, 2004), focus control (J. Shoot *et al*, 2002) grid size adjustment for optical proximity correction (C.E. Chemali *et al*, 2004) writing a multitude of shading elements inside the mask to adjust wafer level CD uniformity (D. Y. Lee *et al*, 2004) and post-exposure bake temperature profile optimization by adjusting heater power in a multi-zone controlled bake plate (L. Berger *et al*, 2004; Q. Zhang *et al*, 2005; Y. Morikawa *et al*, 2006) Photoresist thickness variation is one of the major contributors of CD variations (Photoresist is typically spin coated on the wafer and its thickness and uniformity are controlled in part by the spin speed and ramp of spin coaters as well as the volatility of the solvent and the viscosity of the resist (C. Berger, *et al*, 2006; G. S. May *et al*, 2006; S. K. Kim *et al*, 2002). The final thickness is also affected by environmental conditions. Photoresist thickness nonuniformity of 2% was reported in (C. K. Manu, 2003). Nonuniform lithography properties are expected and they vary as a swing curve or sinusoidal function of photoresist thickness due to thin film interference effects. The swing curve effect for an alternating phase shift mask was studied in (M. M. J. Decre *et al*, 2000) With the application of high numerical aperture exposure tools, the characteristic of swing curve with high numerical aperture was given in (N. Singh *et al*, 2006; D. Dio, 2006; J. Beur *et al*, 2006) An analytical study of resist CD variation with respect to resist thickness was carried out in (T. A. Brunner *et al*, 2002) and (S. S. Yu *et al*, 2005) using rigorous electromagnetic theory with stringent specification on CD, the demand for a uniform and repeatable resist thickness can be expected.

In the I-line stepper, the monochromatic light as interference effects that strongly influence the energy coupling in the resist film. This energy coupling causes the variation in dose-to-clear resist as resist thickness varies. However the variation is minimizing when the resist thickness is at a quarter lambdas divided by refractive index minimized when the resist thickness is between quarter and half of lambda divided by the refractive index. This maxima and minima values can be determines by investigating the swing curve. The swing curve is periodic and the curve descending as the resist thickness decreases. Thus, it is very important to find the swing curve to determine the change in line-width caused by resist thickness variation. In other words, small resist thickness variation can caused big variation in critical dimension (CD) depending on the resist thickness. Swing curve can also be described as the dose-to-clear versus thickness plot. In the experiment, the

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values for does-to-clear or clearing point were obtained by ranging both resist thickness (Stanley Wolf *et al*, 1986; William B. *et al*, 1991).

Material and Methodology:

The objective of the experiment is to test the effect of standing resist before exposure and development to the dose-to-clear. The experiment started with cleaning the wafers using standard RCA cleaning method after wafer coding and then followed by annealing process using high temperature furnace for 15 minutes at 800˚C. The wafers are then primed with HMDS. The first set of wafers are coated, exposed and developed and the second set of wafers are also exposed and developed after being coated. The exposure is done by creating a job that will expose the wafers in 20 by 10 arrays of small squares of open field with the size of 2x2 mm. The exposure is done in such a way where resist thickness and the exposure time will step up to the right and down to the left from the center after each column. These wafers are then developed and measured the thickness at 9 points on the wafer using elipsometer.
The first step in the experiment is to find the value of k, where

k = t*sqrt(rpm), and k= k’(s^2) where

k’ is the machine constant and *s* is the solid content of the resist. This value of k is used to find the expected resist thickness for the assigned rpm. Thus the thickness variation cannot be done from ± (λ/2)/nf. These two maxima will give one complete curve with one minimum. 3 wafers are coated using the same recipe as as described above, the standard program for 1.2 µm resist thickness in IMS. The wafers are used and their code assigned shown in table 1.12 steps are chosen starting from 7600 to 6500 rpm with 100 rpm difference for each step with the designated rpm for 1.2 µm

Table 1: Wafers assignment base on spin speed (rpm).

Spin speed (rpm)	7600	7500	7400	7300	7200	7100	7000	6900	6800	6700	6600	6500
Wafer no.	1	2	4,5	6,7	8,9	10,11	12,13	14,15	16,17	18,19	20,21	22,23

The increasing and decreasing rpm with the 700 rpm (increasing and decreasing resist thickness as the middle is in the hope that the minima for dose-to-clear will be some where near the middle. This is an example of a swing curve with minima and maxima. Wafer numbers 1,2,4, 6,8,10,12,14,16,18,20 and 22 are in first set while wafer 5,7,9,11,13,15,17,19,21,and 23 are in second set. Wafer number 24 is exposed and developed first to find out the center exposure so that the clearing points are in the middle of the 20 by 10 matrix. This wafer is exposed by using expose parameters, time/step (180/5 respectively). It means that the center column (in this case the stepper chooses column number 10 as center) is exposed 180 mille second and steps: -5 mille second to the left and +5 mille second to the right after each column. From the clearing point obtained in wafer 24, a new exposure center/step is used to exposure the first and second set of wafers.

Result and Discussion

The thickness measured for wafer number 1 and wafer number 2 were used to calculate value of k. It is found that average value of k = 103. 78. This value is used to calculate expected t for each spin speed. table2: shows the resist thickness measurements on the first set of data, table3: shows clearing points result on the first set of data, table4: shows the resist thickness measurements on the second set of data and table5: shows clearing points result on the second set of data .The resist thickness is measured by using elipsometer and the average t is obtained. All the measurement was done is micrometer (µm).

Table 2: The resist thickness measurements on the first set of data.

Wafer no.	sp-hsl	Teal	Point 1 (t1)	Point 2 (t2)	Point 3 (t3)	Point 4 (4t)	Point 5 (t5)	Point 6 (t6)	Point 7 (t7)	Point 8 (t8)	Point 9 (t9)	Average Point (!ave)	Dev
1	7600	1.19	1.18	1.18	1.19	1.18	1.19	1.18	1.19	1.21	1.18	1.19	1.26
2	7500	1.20	1.20	1.21	1.19	1.20	1.19	1.20	1.22	1.19	1.19	1.20	1.25
4	7400	1.21	1.20	1.20	1.21	1.22	1.20	1.21	1.21	1.20	1.20	1.21	0.83
6	7300	1.21	1.22	1.22	1.21	1.23	1.21	1.22	1.22	1.21	1.21	1.22	0.82
8	7200	1.22	1.22	1.22	1.22	1.23	1.22	1.23	1.22	1.22	1.22	1.22	0.41
10	7100	1.23	1.24	1.24	1.23	1.24	1.23	1.23	1,24	1.23	1.23	1.23	0.41
12	7000	1.24	1.25	1.25	1.24	1.25	1.24	1.25	1,26	1.25	1.24	1.25	0.80
14	6900	1.25	1.26	1.26	1.26	1.26	1.26	1.26	1,27	1.26	1.25	1.26	0.79
16	6800	1.26	1.27	1.27	1.26	1.27	1.26	1.26	1,27	1.26	1.26	1.26	0.40
18	6700	1.27	1.27	1.28	1.27	1.28	1.27	1.27	1,27	1.27	1.27	1.27	0.39
20	6600	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1,28	1.28	1.28	1.28	0.00
22	6500	1.29	1.28	1.28	1.28	1.28	1.29	1.28	1.28	1.28	1.28	1.28	0.39

Table 3: The clearing points result on the first set of data.

Wafer no.	sp-hsl	Teal	Tm,ave	Exp (c/s)	mill	Clr pt	max
1	7600	1.19	1.19	150/5	165	167.5	170
2	7500	1.20	1.20	150/5	140	155.0	170
4	7400	1.21	1.21	150/5	145	152.5	160
6	7300	1.21	1.22	150/5	145	152.5	160
8	7200	1.22	1.22	150/5	145	150.0	155
10	7100	1.23	1.23	150/5	150	155.0	160
12	7000	1.24	1.25	150/5	150	155.0	160
14	6900	1.25	1.26	150/5	155	167.5	180
16	6800	1.26	1.26	150/5	165	170.0	175
18	6700	1.27	1.27	150/5	170	185.0	200
20	6600	1.28	1.28	150/5	175	190.0	205
22	6500	1.29	1.28	150/5	185	195.0	205
24	7000	1.24	1.24	180/5	160	165.0	170

Table 4: The resist thickness measurements on the second set of data.

Wafer no.	sp-hsl	tm,ave	Teal	exp(c/s)	mill	clr pt	max
5	7400	1.21	1.21	170/5	155	162.5	170
7	7300	1.21	1.21	170/5	160	162.5	165
9	7200	1.23	1.22	170/5	165	167.5	170
11	7100	1.23	1.23	170/5	155	160.0	165
13	7000	1.24	1.24	170/5	165	170.0	175
15	6900	1.25	1.25	170/5	165	175.0	185
17	6800	1.26	1.26	170/5	180	185.0	190
19	6700	1.27	1.27	170/5	185	195.0	205
21	6600	1.28	1.28	170/5	195	200.0	205
23	6500	1.28	1.29	170/5	205	207.5	210

Table 5: The clearing points result on the second set of data.

Wafer no.	sp-hsl	Point 1 (t1)	Point 2 (t2)	Point 3 (t3)	Point 4 (t4)	Point 5 (t5)	Point 6 (t6)	Point 7 (t7)	Point 8 (t8)	Point 9 (t9)	Average Point (!ave)	Dev
5	7400	1.22	1.21	1,2	1.20	1.23	1.22	1.21	1.20	1.20	1.21	1.24
7	7300	1.21	1.22	1,21	1.21	1.22	1.22	1.21	1.21	1.21	1.21	0.41
9	7200	1.22	1.23	1,22	1.22	1.24	1.25	1.22	1.22	1.22	1.23	1.22
11	7100	1.24	1.23	1,23	1.23	1.24	1.24	1.23	1.23	1.23	1.23	0.41
13	7000	1.25	1.24	1,24	1.27	1.23	1.24	1.25	1.23	1.24	1.24	1.61
15	6900	1.25	1.25	1,25	1.25	1.26	1.27	1.25	1.24	1.25	1.25	1.20
17	6800	1.26	1.25	1,27	1.26	1.26	1.26	1.25	1.25	1.25	1.26	0.80
19	6700	1.27	1.27	1,26	1.26	1.28	1.29	1.27	1.26	1.26	1.27	1.18
21	6600	1.28	1.28	1,27	1.27	1.28	1.30	1.27	1.27	1.27	1.28	1.17
23	6500	1.28	1.28	1,28	1.28	1.29	1.29	1.28	1.28	1.28	1.28	0.39

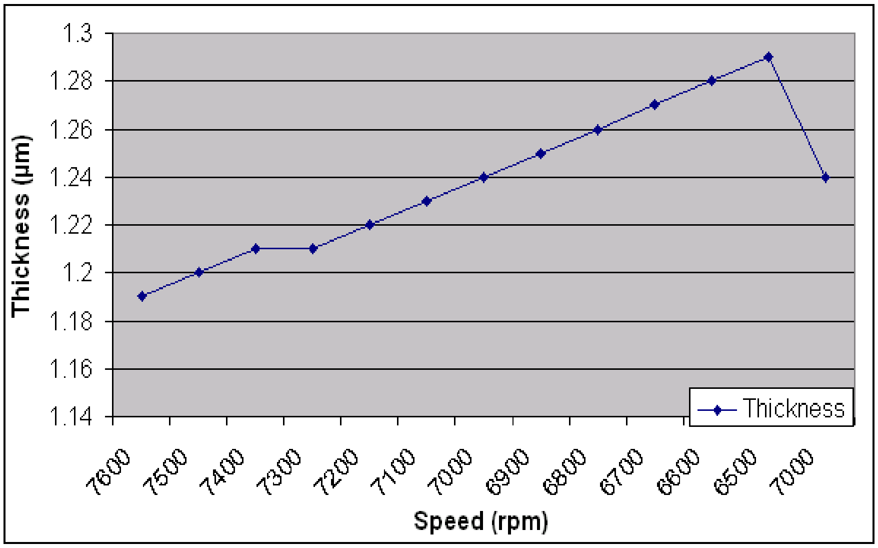

Fig. 1: Thickness against Speed graph for 1st set of data.

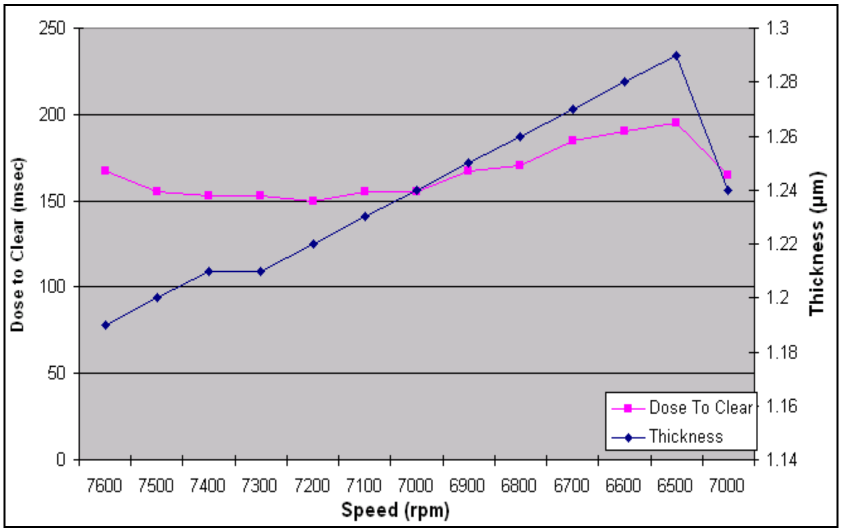

Fig. 2: Dose to Clear and Thickness against Speed graph for 1st set of data.

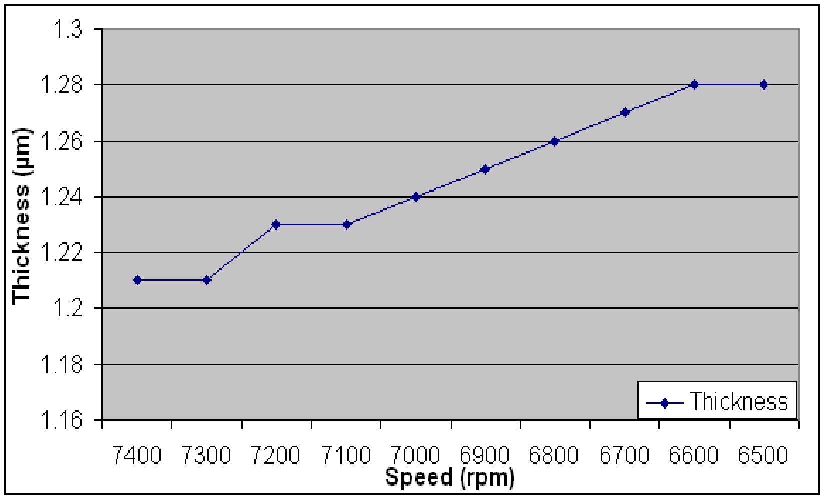

Fig. 3: Thickness against Speed graph for 2nd set of data.

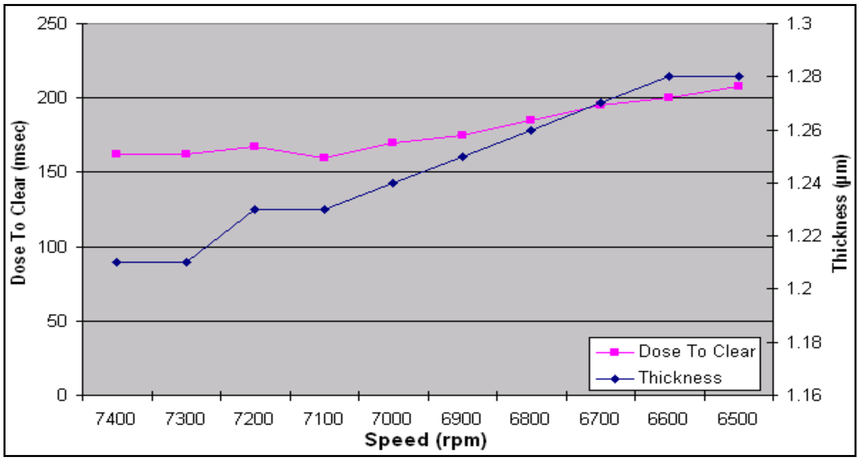

Fig. 4: Dose to Clear and Thickness against Speed graph for 2nd set of data.

Spatial variation can be introduced to the lithography process by altering the propagation of light through the photoresist during exposure. Since light is absorbed as it travels down through the photoresist, the top of the photoresist will receive a higher dose than the bottom. This leads to wider resist profiles at the bottom for positive photoresist. Light is also reflected off the substrate back toward the top of the photoresist, which can lead to standing waves and possibly swing curves. It is expected that the photoresist will exhibit only two states of spatial variation upon exposure, either the resist thickness will be comparable to the original thickness when coated or it will all be gone. The sidewalls of the photoresist will be vertical if there is no spatial variation as a function of photoresist thickness. Vertical sidewalls would be an ideal result of lithography, however the reality of the materials involved makes this a difficult goal to achieve but in this study ,from the results, it is derived that the minima for the dose-to-clear is at 7200 rpm where the thickness is 1.21 µm figure1, 2 and 4. It means that the 7200 rpm produce slightly thicker than the expected 1.2 µm. This may be due to some unavoidable experimental errors and may due to the changing k' of the coater because coater is a bit old. But generally, the results are exactly as expected and one of the minima is used in the process, this means that the 7200 rpm is producing the right resist thickness to get a minima dose-to-clear.

The 1st set and the 2nd set produce a slight variation in clearing point figure2 and 4. It can be due to standing resist, stepper variation or development method. However, in this experiment the causes cannot be determined because there are only 2 sets of wafers and the experiment is not repeated to get the consistency of results and in our next experiment we are planning to introduce special design of experiment optimize the dose-to-clear. Upon reflection at the photoresist/substrate interface a phase shift occurs in the light reflected back toward the photoresist surface. The path length that the light travels through the resist determines its phase and whether the interference will be constructive or destructive. Interference between the outgoing and incoming light waves due to a phase difference between them will result in a swing curve. The swing curve is a sinusoidal variation or dose-to-clear due to changes in the phase difference between incoming and outgoing radiation induced by varying resist thickness. The dose-to-clear is a parameter of the photoresist that defines the amount of energy required to induce a sufficient change in the resist chemical properties so that all of the resist will develop away or stay depends on the requirement and purpose of the experiment.

Conclusion:

The experiment gives one of the simple methods to characterize resist. It is a simple way of finding the right thickness, coater speed and exposure time so that the critical dimension (CD) is easily controlled (small variation). However, the experiment needs more repetition to confirm that the result is repeatable. The experiment also must be organized to make sure that the developing is done when fresh developer is used so that the effect of variation in developer concentration is not obvious. This experiment can be further used for various layer e.g. meta11ayer and topography so that the exact exposure and resist thickness can be determined for every layer and topography. Also the value of k' can be determine using this experiment if the process is already stable. the team members in the Institute of Nanoelectronic Engineering especially in the Nano Biochip Research Group.

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