Study of Optimization Condition for Spin Coating of the Photoresist Film on 3 Inches Wafer by Taguchi Design of an Experiment

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Abstract

This paper reports the study in suitable conditions of 5 parameters in order to spin coat positive photoresist AZ-P4620 on 3 inches silicon wafers. The design of experiments (DOE) is Taguchi $L_{16}(4^5)$ which can reduce number of experiments from 1024 to 16. By analyzing the main impact plot of signal to noise ratio (SNR or S/N), it is found that the most suitable values of the 5 parameters that give the desired thickness and uniformity is photoresist dispense time of 25 seconds then spin at the speed of 500 rpm for 5 seconds, accelerate the spin speed at 200 rpm per seconds until the speed reaches 1500 rpm. The speed is maintained at 1500 rpm for 60 seconds with the exhaust pressure of 300 Pascal. The wafer is later baked at 100°C for 90 seconds. The calculated thickness of the final film is 70274±908.233 Angstroms. This DOE can be applied to the Air Bearing Surface (ABS) of a read/write heads in the hard disk drive industry.

Keywords: Air Bearing Surface, Photolithography, Spin coating, Photoresist, Taguchi DOE method

Introduction

Formation of ABS on the read/write head of the Hard Disk Drive (HDD) starts from dicing a processed wafer into bars of equal size. Then sit 30-40 bars on a 3 inches diameter pallette in order to simulate a smooth surface of a bare unprocessed wafer, so that photolithography process can be done on the bars. The lithography process starts from (1) Photoresist coating, (2) Pre-bake, (3) Exposure, (4) Develop, (5) Etching, and (6) Photoresist stripping. It is important that the final photoresist film before exposure must be smooth with good uniformity and right thickness. This will in turn allow good uniform focal distance and exposure energy of an exposure tool. This means that good film uniformity at the right thickness will results in controllable critical dimension (CD) and sidewall slope profile because they have direct impact on the focal distance of a lithography tool, *e.g.* a stepper (Kuo and Chao, 2006). However, there are many

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parameters to control in the spin coating step which are photoresist dispense rate, first spin speed, Second spin speed, spin speed acceleration, second speed spinning time, exhaust pressure, baking temperature, and baking time (Levinson,1999). In order to reduce the number of experiments, cost, and time, Taguchi DOE is employed (Hui et al.,). The purpose of this work is to find the suitable conditions of 5 controlled parameters (all, except photoresist dispense rate, baking temperature and baking time) in order to obtain film thickness of 70,000-75,000 Angstrom and uniformity of ±1400 Angstrom. The results of the studies can be applied in the Hard disk drive read/write head ABS fabrication.

Background

A. Photoresist spin coating process

Regarding photoresist film coating, there are many techniques which are (1) Spray coating, which dispense the photoresist chemical through the ultrasonic nozzle during the sample has been rotated at 30 to 60 rpm. This technique is suitable for the photoresist, which has a viscosity less than 20 cst, to make photoresist can spray. The advantages of the spray coating method is that, it using a small volume 70% less than spin coating technique. Moreover, this technique can be deposit the photoresist film cover a deep cavity. The other coating technique is (2) Electrodeposition, which can be coat the photoresist film on high topology surface. However, the photoresist used in this method is a Caphoretic and the substrate must be an electrical conductivity surface (Pham and Boellaard,2004). The other coating method are (3) Extrusion coating, which extrude the photoresist film onto the substrate surface (Bagan et al., 1996). This method use the photoresist chemical 95% less than spin coating method but it has many parameters to control. Moreover, it has a new coating method called (4) Scheneider-Picard's coating method, which can control the film uniformity in Angstrom scale (Schneider et al.,). However, this technique is in the developing stage. The most popular method to coat photoresist film on a circular substrate is a spin coating technique. This technique has 4 process steps, which are (1) Dispensing the photoresist on the substrate surface, (2) Spin-up, which the substrate is accelerated up to low velocity. This step use to dispense the photoresist cover all area of substrate surface by using centrifugal force. Next, (3) Spin-off, which the substrate is accelerated up to final velocity. This step used to control the photoresist film thickness, increasing the final velocity, decreasing the final photoresist film thickness. The final step is, (4) Evaporation, which the substrate is spinning at a constant rate of final velocity and solvent evaporation dominates the coating thinning behavior to control the film uniformity (Wolf and Tauber,2000). The spin coating process steps has shown in Figure 1.

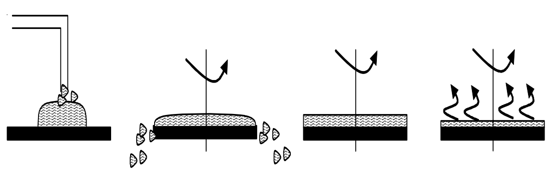

Figure 1. The spin coating process step a) Dispensing b) Spin-up c) Spin-off and 4) Evaporation.

B. Taguchi's DOE

The Taguchi method has been successfully applied for designing experiments in recent years. Depending on the objective, there are three different mean square deviations for the signal-to-noise ratios (S/N ratios) that can be defined including larger-the-better and smaller-the-better. The mean square deviation can be considered to be the average performance characteristic values for each experiment (Montgomery D.C;Yang and Chang, 2006). The different S/N ratios, corresponding to an experiment are presented in the eqs. 1, 2, and 3 which shown below:

Larger-the-better

$$Q_{a,total} = \left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{1}{y_{1i}} \right)^2 \right] + \left[\frac{1}{m} \sum_{j=1}^{m} \left(\frac{1}{y_{2j}} \right)^2 \right] \quad (1)$$

Smaller-the-better

$$Q_{a,total} = \left[\frac{1}{n} \sum_{i=1}^{n} (y_{1j})^2 \right] + \left[\frac{1}{m} \sum_{j=1}^{m} (y_{2j})^2 \right] \quad (2)$$

$$\frac{S}{N} = -10Log(Q_{a,total}) \quad (3)$$

Where, $\frac{S}{N}$ is signal-to-noise ratio.

$Q_{a,total}$ is total quality loss.

y_{1i} is the film thickness of the experimental run i, when $i = 1,2,...,n$.

y_{2j} is the film uniformity of the experimental run j, when $j = 1,2,...,m$.

n is total experimental runs for film thickness measurement.

m is total experimental runs for film uniformity measurement.

After that, the suitable condition for film thickness and film uniformity will be use to predict the expected performance value by using eq. 4.

$$Y_{opt} = T + \sum_{i}^{k} (x_i - T) \quad (4)$$

Where Y_{opt} is expected performance of the response.

T is the total average response in the experiment.

x_i is the average response from the suitable condition of factor i, when $i = 1,2,...,k$.

k is the number of the factor.

Experimentals

C. Taguchi's DOE

There are in total 5 parameters, all of which have impact on the thickness and the uniformity of the final photoresist film before exposure. In the experiments, each parameter contains 4 levels as shown in Table 1. There are in total 1,024 experiments with Full factorial DOE and it can be reduced to 16 experiments with Taguchi's DOE: L_{16} (4^5) as shown in Table 2 (Levinson,1999).

Table 1. Factor levels of all 5 parameters.

Factors	Factor levels			
	1	2	3	4
A: First spin speed (rpm)	250	500	750	1000
B:Acceleration (rpm/sec)	200	300	400	500
C: Second spin speed (rpm)	1500	2000	2500	3000
D: Second spin time (sec)	45	60	75	90
E: Exhaust(Pa)	0	100	200	300

Table 2. Taguchi's DOE for all parameters with L_{16} (4^5).

Run	A	B	C	D	E
1	250	200	1500	45	0
2	250	300	2000	60	100
3	250	400	2500	75	200
4	250	500	3000	90	300
5	500	200	2000	75	300
6	500	300	1500	90	200
7	500	400	3000	45	100
8	500	500	2500	60	0
9	750	200	2500	90	200
10	750	300	3000	75	0
11	750	400	1500	60	300
12	750	500	2000	45	200
13	1000	200	3000	60	200
14	1000	300	2500	45	300
15	1000	400	2000	90	0
16	1000	500	1500	75	100

B. Photoresist coating

The photoresist used in this study is a positive photoresist AZ-P4620. The photoresist is spin-coated on a substrate in a photoresist spinner POLOS model MCD200. The initial spinning speed is 100 rpm and the wafer is spinned for 5 seconds. Then EFD model 2415 dispenses photoresist on the center of the spinning substrate for 25 seconds with pressure of 2.5 psi. The wafer spin speed is then accelerated to high spin speed. The substrate then goes through the conditions as designed and then finally backed at 100°C for 90 seconds.

C. Photoresist film thickness measurement

The thickness of the final photoresist film on 3 inches Silicon wafer is measured by Spectro-photometer model Lambda 1000. The average is taken from 25 points for one experiment. The distance between any 2 points and between Si and the photoresist is 1.5 cm as shown in Figure 2. The uniformity is calculated from the standard deviation of the film thickness.

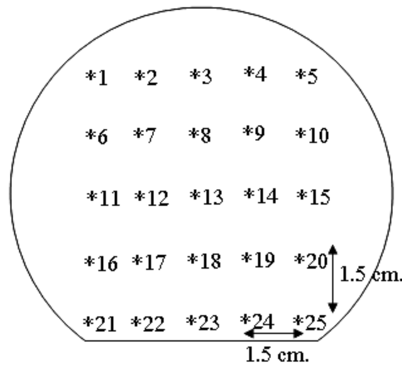

Figure 2. Measurement positions of the photoresist film thickness 3 inches Silicon wafer.

Results and Discussions

The target film thickness is 70000-75000 Angstroms with very good uniformity of ±1400 Angstroms. This is required in the manufacturing process. With the given target, the larger the better signal-to-noise ratio or SNR (S/N) is chosen for analysis of the film thickness as shown in Figure 3. while the smaller the better S/N is chosen for film thickness uniformity as shown in Figure 4. On one hand, the best condition (larger-the-better) for getting thick film as depicted in Figure 3. is A3 B1 C3 D2 E1. On the other hand, the best condition (smaller-the-better) S/N or to get good film thickness uniformity is A2 B1 C1 D2 E4 as shown in Figure 4. Evidently, both conditions cannot be consolidated, therefore not practical in manufacturing environment and it is inevitably to consider S/N for thickness and uniformity simultaneously. By doing that, the most suitable condition is A2 B1 C1 D2 E4. That is to dispense the photoresist for 25 seconds at spin speed of 100 rpm then accelerate the spin speed to 1500 rpm at 200 rpm/second and maintain the speed for 60 seconds with exhaust pressure at 300 Pascal. Finally bake the wafer at 100^{o}C for 90 seconds as shown in Figure 5. Regarding most suitable condition, the film thickness and uniformity of the photoresist film can be described with eq. (5) and (6).

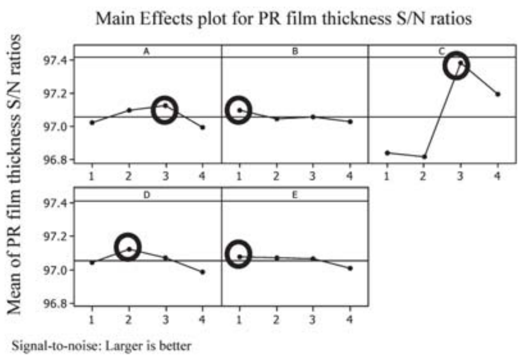

Figure 3. The resulting S/N plot of thickness for different conditions.

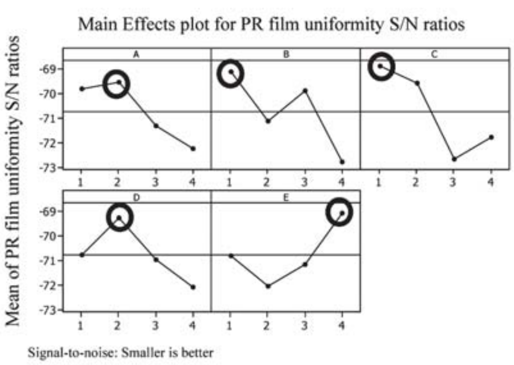

Figure 4. The resulting S/N plot of thickness uniformity for different conditions.

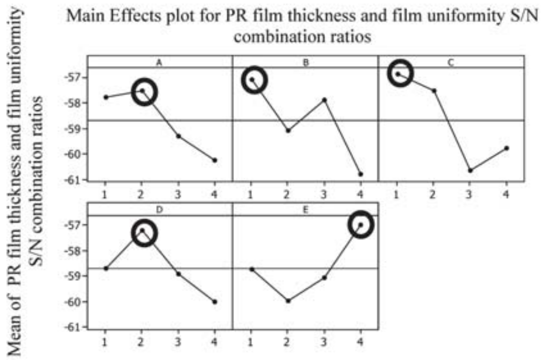

Figure 5. The most suitable condition to get the target thickness and uniformity.

$$T_{opt} = \bar{x} + (\overline{x_{A2}} - \bar{x}) + (\overline{x_{B1}} - \bar{x}) + (\overline{x_{C1}} - \bar{x}) + (\overline{x_{D2}} - \bar{x}) + (\overline{x_{E4}} - \bar{x}) \quad (5)$$

$$U_{opt} = \sigma + (\overline{s_{A2}} - \sigma) + (\overline{s_{B1}} - \sigma) + (\overline{s_{C1}} - \sigma) + (\overline{s_{D2}} - \sigma) + (\overline{s_{E4}} - \sigma) \quad (6)$$

Where, T_{opt} is expected performance of photoresist film thickness.

$\bar{x}$ is film thickness average of 16 experimental runs.

$\overline{x_{A2}}$ is film thickness average of factor A-level 2.

$\overline{x_{B1}}$ is film thickness average of factor B-level 1.

$\overline{x_{C1}}$ is film thickness average of factor C-level 1.

$\overline{x_{D2}}$ is film thickness average of factor D-level 2.

$\overline{x_{E4}}$ is film thickness average of factor E-level 4.

U_{opt} is expected performance of photoresist film uniformity.

σ is film uniformity average of 16 experimental runs.

is film uniformity average of factor A-level 2.

$\overline{s_{B1}}$ is film uniformity average of factor B-level 1.

$\overline{s_{C1}}$ is film uniformity average of factor C-level 1.

$\overline{s_{D2}}$ is film uniformity average of factor D-level 2.

$\overline{s_{E4}}$ is film uniformity average of factor E-level 4.

The film thickness and the film uniformity under the most suitable condition for spin coating process can be predicted by using eq. 5 and eq. 6, respectively. The results shown that the suitable condition can form the photoresist film with the thickness is 70274±908.233 Angstroms. This predicted value is in the acceptable range for the manufacturing process.

Conclusion

Taguchi's DOE can be used to study suitable conditions for spin coating photoresist film. It also proves to be time and cost-economical. The best condition for spin coating the positive photoresist AZ-P4620 on 3 inches silicon wafers is to dispense the photoresist for 25 seconds at pressure of 2.5 psi at the spin speed of 100 rpm. Then speed up to 500 rpm for 5 seconds and accelerate to 1500 rpm at the acceleration of 200 rpm/second and maintain the top speed for 60 seconds with exhaust pressure of 300 Pascal. Finally, bake the wafer at 100°C for 90 seconds. The resulting coated film has thickness of 70274±908.233 Angstroms. This result can finely be used in the semiconductor and hard disk drive manufacturing.

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