Taguchi Method Applied In Optimization Of Shipley SJR 5740 Positive Resist Deposition

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ABSTRACT

Taguchi Methods of Robust Design presents a way to optimize output process performance through an organized set of experiments by using orthogonal arrays. Analysis of variance and signal-to-noise ratio is used to evaluate the contribution of each of the process controllable parameters in the realization of the process optimization. In the photoresist deposition process, there are numerous controllable parameters that can affect the surface quality and thickness of the final photoresist layer. To maximize the thickness and minimize the bubble formation of Shipley SJR 5740 photoresist (our optimum goal), eleven control parameters were selected and evaluated at two distinct levels. For a full factorial matrix experiment, 2048 experiments would have been necessary. Instead, by utilizing the orthogonal array concept, only 12 experiments were necessary for the optimization.

I. INTRODUCTION

The Shipley SJR 5740 positive photoresist is a viscous resist with 42 % solids and 585 centipoise viscosity at 25°C.[1] Because of this property, the 5740 resist can be deposited on a substrate for deep UV lithography and electroplated for an X-ray mask in the LIGA process.

The process for deposition of photoresist involves many parameters that affect the final thickness of the resist as well as its surface quality. These parameters represent controllable variables at each step of the photoresist deposition process. Eleven parameters were identified and evaluated at two levels. In the classical experimentation approach of identifying the critical parameters and finding the optimum values for achieving maximum thickness and minimum bubble formation, a full factorial matrix of 2048 experiments would have been required. This would involve holding all parameters constant while changing one parameter in the experiment. The process would be repeated until an optimal condition was realized.

With respect to time and budget considerations, the full factorial matrix setup and experimentation is very costly and practically un-doable due to time constraints. The Taguchi Methods of Robust Design offers a shorter matrix experimental design based on the Latin Square concept of orthogonal array. For our study, using the Taguchi Method concept, only 12 experiments (L12 orthogonal array) were required. From the measured output performance (deposition thickness and surface bubble formation) of the selected 12 orthogonal array experimentation set, all critical parameters and their values were identified. These parameters and values were used to theoretically predict the optimized output performance. Based on the Taguchi Method, we followed the two step optimization procedure: 1) variability reduction , and 2) mean adjustment. The output quality characteristic optimization was considered successful. The predicted theoretical photoresist thickness and bubble formation optimization were confirmed by practical experimental trials.

For this study, both STATIC and DYNAMIC Robust Design approaches were implemented.
In the static approach, TIME, or life of monomer on the shelf, was considered as a NOISE factor. The intent for the static approach was to obtain the same thicker photoresist deposition (the thicker the better) and photoresist bubble formation (the smaller the better) and be insensitive to the age of the monomer (the noise TIME.)

In the dynamic approach, TIME was considered as the SIGNAL factor. For the dynamic approach, the intent was to increase the deposition thickness as a function of the age (time) of the monomer. Also, the second intent was to reduce the number of bubbles as a function of age (time) of the monomer.

The above two optimization studies were initiated based on the speculation that an inherent property exists in the 5740 photoresist. We suspect that evaporation of the solvent in the photoresist is happening during storage after its initial opening. The evaporation could significantly affect the results in the deposition process. Confirmation of these properties was undertaken by applying both the static and the dynamic robust design approaches of the Taguchi Methods.

II. METHOD

For the Shipley SJR 5740 photoresist deposition process, 11 control parameters were considered. These parameters are:

1. Volume of photoresist deposited before spin (ml)
2. Deposition of HMDS
3. Spin speed (rpm)
4. Duration of spin (sec)
5. Relaxation time after spin (min)
6. Contact prebake starting temperature (°C)
7. Contact prebake ending temperature (°C)
8. Contact prebake ramp (°C/hr)
9. Contact bake time (min)
10. Contact ramp down end temperature (°C)
11. Contact ramp down ramp (°/hr)

Each of these 11 parameters was considered at two levels. Table 1 below describes the 11 parameters and the associated two levels. The Taguchi L12 orthogonal array matrix and the 12 experimental runs are shown in Table 2.[2]

Table 1. Two sets of values for each parameter.

Photoresist Optimization Parameter List

# Parameter	Set 1	Set 2
Photoresist Deposition		
1 Deposition Quantity (ml)	5	8
2 HMDS	Yes	No
3 Spin Speed (rpm)	1200	1500
4 Spin Length (sec)	10	15
5 Relaxation Time (min)	5	10
Wafer Bake (°C)		
6 Contact Prebake Start Temp.	50	70
7 Contact Prebake End Temp.	108	104
8 Contact Prebake Ramp (°/hr)	555 (9.25 °/min)	200 (3.33 °/min)
9 Contact Bake Time (min)	6	10
10 Contact Bake End Temp.	50	70
11 Contact Bake Ramp (°/hr)	555 (9.25 °/min)	200 (3.33 °/min)

Table 2. Taguchi L12 experiment matrix.

Photoresist Optimization Experiments

The L12 Matrix

#	Date	1 (ml)	2 (y/n)	3 (rpm)	4 (sec)	5 (min)	6 (°C)	7 (°C)	8 (°/hr)	9 (min)	10 (°C)	11 (°/hr)
1		5	y	1200	10	5	50	108	555	6	50	555
2		5	y	1200	10	5	70	104	200	10	70	200
3		5	y	1500	15	10	50	108	555	10	70	200
4		5	n	1200	15	10	50	104	200	6	50	200
5		5	n	1500	10	10	70	108	200	6	70	555
6		5	n	1500	15	5	70	104	555	10	50	555
7		8	y	1500	15	5	50	104	200	6	70	555
8		8	y	1500	10	10	70	104	555	6	50	200
9		8	y	1200	15	10	70	108	200	10	50	555
10		8	n	1500	10	5	50	108	200	10	50	200
11		8	n	1200	15	5	70	108	555	6	70	200
12		8	n	1200	10	10	50	104	555	10	70	555

Using a 200 μm silicon wafer as a base substrate and evaporated chrome/gold (50/300 angstroms respectively) as a plating base and experimental surface, the actual experimentation process is presented below.

The volume of photoresist deposited is measured with a syringe. When necessary, Hexamethyl-Disilazane (HMDS), as a surface primer, is deposited to cover the entire wafer surface. The HMDS is spun off for 30 seconds at a fast speed. The photoresist is deposited with the syringe in the center of the wafer. Several seconds are allowed for the photoresist to spread without spinning the wafer. Then, for the first of the total 12 experiments, the photoresist is spun at the indicated speed and duration shown on the matrix of Table 2. The photoresist on the wafer is then allowed the time indicated to remain undisturbed before baking. Contact oven pre-bake involves starting at a low temperature, then ramp the oven until the end temperature is reached. The bake time starts and when the duration has been achieved, the oven is ramped down to a low temperature. Finally the wafer is removed and its thickness measured and the bubbles counted. The process is repeated until the entire 12 experiments of Table 2 are completed.

III. ANALYSIS

After a shelf life of five months of the Shipley SJR 5740 monomer, three independent trials of the matrix experiment were performed at approximately two month intervals. Each experimental trial was made up of 12 experiments as described in Table 2 matrix. For good statistical data gathering, each experiment was performed twice, thus 24 runs at each of the two months interval. Thus, for the three independent trial, a total of 72 runs were performed. For each experimental run, two output characteristics were measured: photoresist deposition thickness and number of bubbles formed. Both, the static and dynamic robust design of the photoresist deposition optimization process made use of the same output measurements. Nevertheless, the data analysis was performed differently.

A. Static Analysis

Independent of the monomer shelf life, with TIME considered as noise, the intent of the static approach of data analysis was to optimize the deposition process as to obtain the same maximum deposition thickness and least number of bubbles formed. From the measured output data, by using an Analysis of Variance (ANOVA) software package, the parameter contributions to the measured outputs were generated. This was performed for both output thickness and bubble formation. In this study, the emphasis was placed on the MEAN of the process average rather than on the SIGNAL-TO-NOISE (S/N) value. In other words, we were more interested in improving the mean photoresist thickness deposition and less interested in the output variance of the deposition process. Nevertheless, the final optimization accomplished both increased deposition thickness and reduced variability.

For the mean deposition thickness, Table 3 describes the 12 parameters (identified in capital letters from A to K) and their contribution to deposition thickness at the two distinct levels 1 and 2. The graphical representation of this data is presented on Figure 1. The mean thickness of the 12 experimental runs was MEAN = 19.7292μm. The theoretical forecast of the optimized deposition thickness was generated from the largest values of the parameter contribution to the mean. The following parameter and output values were selected: A2, B1, C1, D1, E1, F1, G1, H1, I2, J2, K1. The theoretical predicted optimized thickness deposition value showed a Projected Process Value = 24.2639μm.

Table 3. Parameters contribution to deposition thickness at two levels 1 and 2.

Parameter	Thickness	Parameter	Thickness
A 1	19.5972	A 2	19.8611
B 1	19.6667	B 2	19.7917
C 1	21.7917	C 2	17.6667
D 1	21.5139	D 2	17.9444
E 1	19.8889	E 2	19.1694
F 1	19.9861	F 2	19.4722
G 1	19.5972	G 2	19.8611
H 1	19.6528	H 2	19.8056
I 1	19.6944	I 2	19.7639
J 1	19.4306	J 2	20.0278
K 1	19.8056	K 2	19.6528

Also, for the same parameters and values as above, the signal-to-noise ratio improvement prediction for the thickness indicated a S/N ratio improvement of 8 dB.

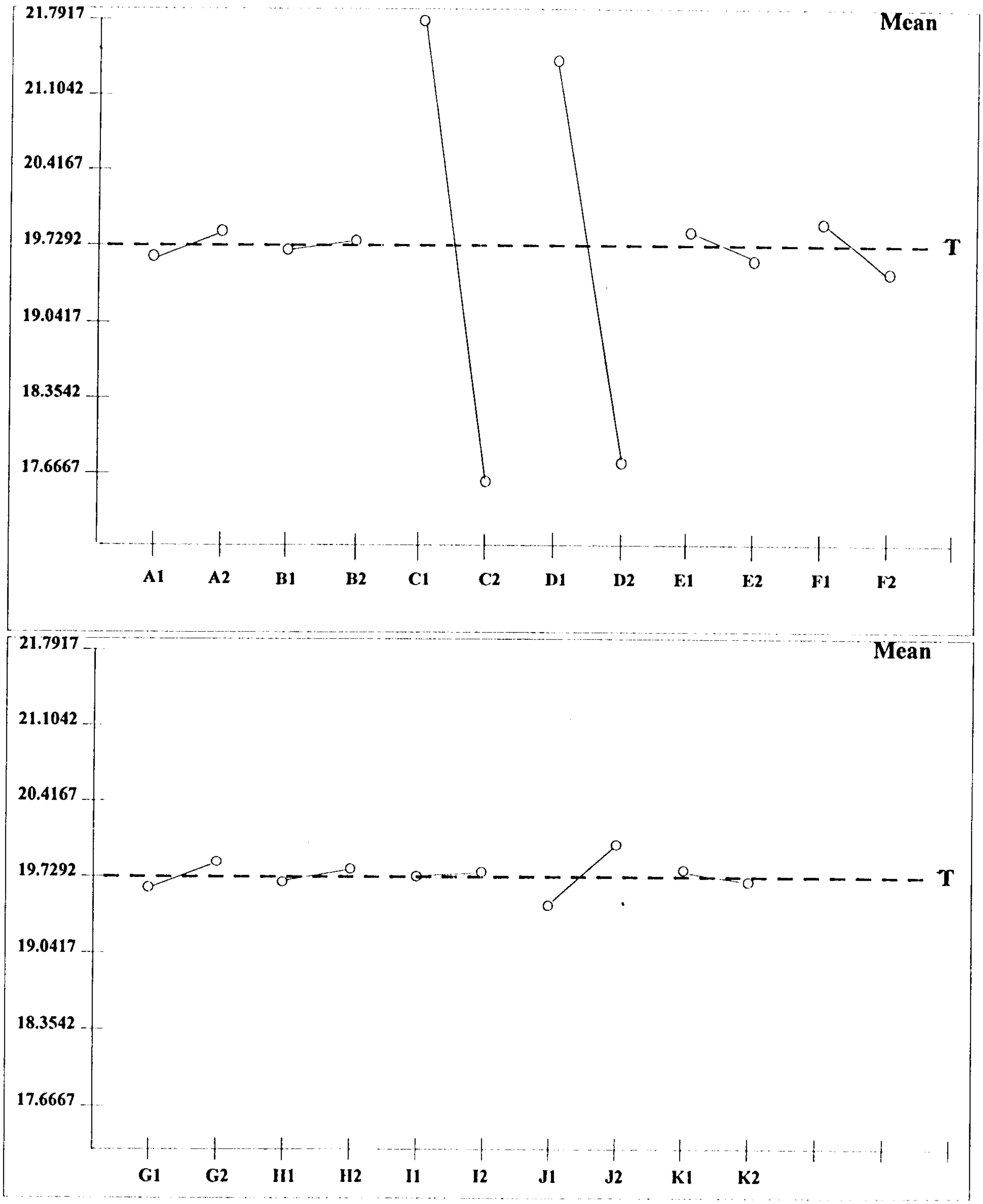

Figure 1. Parameters contribution to mean deposition thickness

For the mean bubble formation, Table 4 describes the parameters contribution. The graphical representation is shown in Figure 2. The mean number of bubble formation was calculated to be MEAN = 2.917. The Projected Process Average was 0.611.

Table 4. Parameters contribution to bubble formation at two levels 1 and 2.

Parameter	Number of Bubbles	Parameter	Number of Bubbles
A 1	3.111	A 2	2.722
B 1	3.056	B 2	2.778
C 1	2.611	C 2	3.222
D 1	3.611	D 2	2.222
E 1	2.944	E 2	2.889
F 1	2.917	F 2	2.917
G 1	3.367	G 2	2.472
H 1	2.472	H 2	3.361
I 1	2.861	I 2	2.972
J 1	2.917	J 2	2.917
K 1	2.806	K 2	3.028

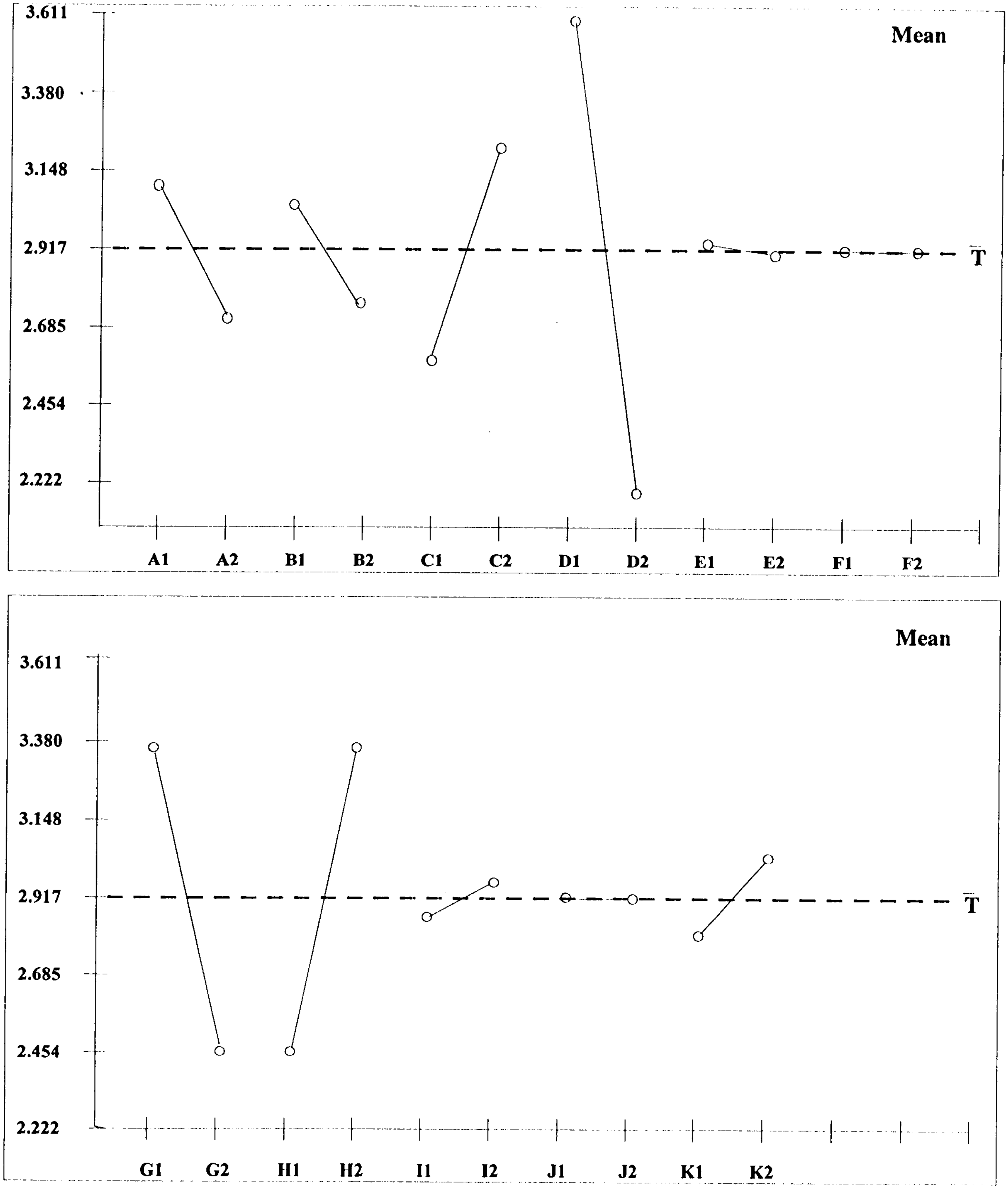

Figure 2. Parameters contribution to the mean bubble formation

B. Dynamic Analysis

With TIME considered as signal, the intent of dynamic approach of the data analysis was to optimize the deposition process as to obtain thicker photoresist depositions as a function of monomer shelf life.
For the 12 experiments, Table 5 describes the calculated S/N ratio and the Beta {which is "M" (time) divided by "y" (thickness)}, which is also called the slop or sensitivity.

IV. RESULTS

Confirmation trials were performed for both static and dynamic design optimizations. The confirmation trials were performed with a newly opened photoresist.

Analysis of bubble formation data proved to be impossible due to certain runs in which there were excessive bubble formations such that photolithography could not be performed. The randomness in the quantity of bubbles appearing leads to speculation that the bubbles may not be a function of the parameters chosen.

The static confirmation of the thickness generated an optimized thickness of ~25μm. This confirmed the theoretically projected value of 24.2639μm. The S/N ratio improvement was calculated to be 6.8dB. This value was below the 8dB projected theoretically. Nevertheless, the confirmation trial demonstrated a definite variability improvement.

Table 5. Calculated S/N ratios and Beta values for the 12 experiments of dynamic deposition thickness

Exp.	S/N Ratio	Beta
1	7.4188	1.2500
2	0.0000	0.2500
3	-5.2951	0.5000
4	-5.2951	0.5000
5	-4.8883	1.1250
6	-3.1096	-0.8750
7	0.0000	0.3750
8	0.0000	0.8750
9	0.7084	0.8750
10	0.0000	0.2500
11	-5.4114	1.6250
12	0.0000	0.5000

The dynamic confirmation of the thickness deposition is described by the diagram of Figure 3. The X axis of the table identifies the three time intervals of the "Signal M" (M1, M2, and M3) at which the measured deposition thickness "y" was performed. The parameters selected for this optimization were: A2, B1, C1, D1, E1, F1, G1, H1, I2, J1, K1. From the diagram of the confirmation trial, it is revealed that thickness is a linear function of shelf life. Thus, it can be concluded that we can obtain thicker depositions by increasing the monomer shelf life as a straight line and with little or no variation.

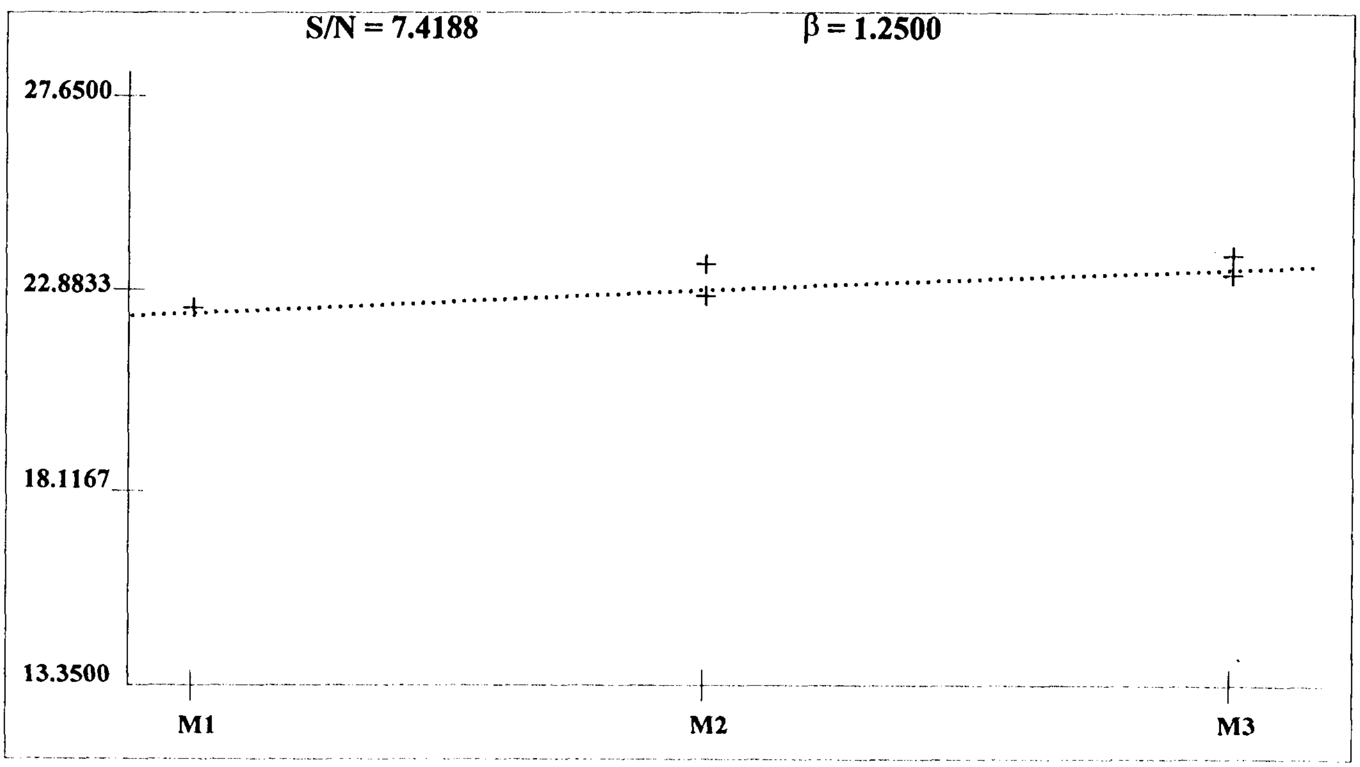

Figure 3. Dynamic photoresist deposition thickness confirmation experiment results.

V. DISCUSSION

With the results from the optimization of the photoresist deposition process for the Shipley SJR 5740 resist, we utilized the optimum values to achieve the maximum thickness in one layer. Multiple layers can then be deposited to achieve thickness of up to 75 microns. The interfaces between layers were indistinguishable by SEM observation or further processing.

VI. CONCLUSION

The Taguchi Method offered a validated procedure for robust design of experiments. In the photoresist deposition process, the experiment presented here was designed for Shipley SJR 5740 positive resist. From the analysis and results, the parameters and their trend identified to be critical to thickness are as listed:

Very significant

1. SPIN SPEED: Shorter the better
2. SPIN LENGTH: Shorter the better

Significant

1. CONTACT BAKE END TEMP: Higher the better

Little or not significant

1. DEPOSITION QUANTITY: Higher the better
2. HMDS: Does not matter
3. RELAXATION TIME: Smaller the better
4. CONTACT PREBAKE START TEMP: Smaller the better
5. CONTACT PREBAKE END TEMP: Larger the better
6. CONTACT PREBAKE RAMP: Does not matter
7. CONTACT BAKE TIME: Does not matter
8. CONTACT BAKE RAMP: Does not matter

VII. REFERENCES

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3. Phadke,M.S.(1989),"Quality Engineering Using Robust Design", AT&T Bell Laboratories, NJ, USA.