RESPONSE SURFACE METHODOLOGY USING EXPERIMENTAL DESIGN

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ABSTRACT

A Central-Composite Full Factorial design was performed in aiming to optimize the develop and bake processes on KTI 820 resist and KTI 934 developer using the GCA Wafertrac. The responses looked at were critical dimension and resist thickness after development with the independent variables of postbake temperature, postbake time and developer time. Analysis of the data was done using SAS as a software tool.

INTRODUCTION

Repsonse surface methodology, or RSM, is a collection of mathematical and statistical techniques useful for analyzing problems in which several independent variables influence a dependent variable or response. Often, they are employed to optimize the response.

The first step in RSM is to find a suitable approximation of the relationship between the response or the random variable and the set of independent variables. A low-order polynomial in some range of the independent variable is employed. If the response is well modeled by a linear function of the independent variables, then the approximating function is the first- order model. If there is curvature in the system, then a polynomial of higher degree must be used. The method of least squares is used to estimate the parameters in the approximating polynomial. Response surface analysis is then done in terms of the fitted surface. If the fitted surface is an adequate approximation of the true response function, then analysis of the fitted surface will be approximately equivalent to analysis of the actual system. If not, revisions to the initial guess will be decided on from the results obtained. RSM is a sequential process and the objective is to quickly and efficiently lead the experimenter to the general vicinity of the optimum. Once this region has been found, a more elaborate analysis is performed to locate the optimum.

To effectively use RSM three things must be kept in mind: 1) a through understanding of Experimental Design, 2) an appropriate statistical software tool and 3) a good understanding of the process to be optimized.

The three basic principals of experimental design are replication, randomization, and blocking. Replication requires the repeatation of the experiment at it's center points which allows experimenter to estimate the experimental error. This becomes a unit of measurement for determining whether the observed differences in the experimental data are actually statistically different and thus gives an accurate representation of the effects of the different factors. Randomization requires both the allocation of the experimental materials and the order of the experimental runs to be randomly determined. Thereby "averageing out" the effects of extraneous factors. A 'Block' is defined as a portion of the experimental material that should be more homogenous that the entire set of materials. Blocking involves making comparisons among the conditions of interest within each of these blocks. Thus, blocking is defined as a technique used to increase the precision of an experiment.

The purpose of the experiment was two fold. First, to determine the effects of three factors: 1) Postbake temperature (ranging from 120-140C, in increments of 5C), 2) Postbake time (ranging from 90-130secs, in increments of 10secs), and 3) Develop time (ranging from 21-25secs, in increments of 1sec) on the responses: 1) Critical dimension (4um pitch) and 2) Resist thickness after development. The second, was to find the optimum operating conditions to simultaneously maximize the resist thickness after development and minimize the critical dimension loss.

EXPERIMENT

The resist evaluated was KTI 820 and the developer was KTI 934 with a one to one dilution with DI water. The resist thickness after development was measured on a Lietz system at Kodak and the critical dimensions were measured on the Nanoline system at RIT.

The model used was based on the assumption that all third order and above interactions were negligable or did not exist. This assumption is based on prior knowledge of the system and was believed to be an accurate assumption. The model for this experiment is stated below.

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THICKNESS, CD's = F [ POSTBAKE TEMPERATURE
                      POSTBAKE TIME
                      DEVELOPER TIME
                     (POSTBAKE TEMPERATURE)
                     (POSTBAKE TIME)
                     (DEVELOPER TIME)
                      POSTBAKE TEMPERATURE * POSTBAKE TIME
                      POSTBAKE TEMPERATURE * DEVELOPER TIME
                      POSTBAKE TIME * DEVELOPER TIME ]
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The selection of an experimental design is based on the complexity of the model. The design selected was a Central Composite - Full Factorial 2 design.[1] This was selected based on the complete information that could be obtained from using this design type with the least number of runs. They were 8 Factorial Point runs, 6 Axial Point runs and 4 Center Point runs, for a total of 18 runs.

An interactions table, was set-up and the 18 runs were determined. The runs were randomized to keep with the general principals of experimental design. A listing of the runs and the randomized sequencing is shown in Table 1 below. (For a complete understanding of how the table was set-up and how the runs were randomized please refer to Reference 3.) The basic processing sequence began with growing a wet thermal oxide of approximately 5000 A. This was followed by applying resist on the wafers at 5000 rpm for 30 secs with the standard RIT program which would give us an initial resist thickness of 1.4um. The randomized runs with the various different develop and bake cycles were performed next. The resist thickness after development and critical dimensions were then measured at three points on each wafer, top, center and bottom.

REF #	B_TEMP	B_TIME	D_TIME	REP
1	125	100	22	1
2	135	100	22	1
3	125	120	22	1
4	135	120	22	1
5	125	100	24	1
6	135	100	24	1
7	125	120	24	1
8	135	120	24	1
9	120	110	23	1
10	140	110	23	1
11	130	90	23	1
12	130	130	23	1
13	130	110	21	1
14	130	110	25	1
15	130	110	23	1
16	130	110	23	1
17	130	110	23	1
18	130	110	23	1

Table 1. - DESIGN RUNS

RESULTS

The measured resist thickness after development and the critical dimensions measured were recorded in table 2. Measurements were taken from three locations on each wafer, top, center and bottom. In table 2 below, TAD refers to the thickness after development and CD refers to critical dimension.

REF #		TOP	CEN	BOT	MEAN	SD_DEV
1	TAD (A)	13222	12571	13258	13017	386.66
1	CD (um)	1.91	1.90	1.89	1.90	0.01
2	TAD (A)	13240	13116	13119	13158	70.74
2	CD (um)	1.89	1.82	1.85	1.85	0.04
3	TAD (A)	12937	13038	12930	12968	60.43
3	CD (um)	2.03	1.87	1.90	1.93	0.90
4	TAD (A)	12688	12417	12546	12550	135.55
4	CD (um)	1.85	1.85	1.94	1.88	0.05
5	TAD (A)	13636	13508	13544	13562	66.01
5	CD (um)	1.89	1.85	1.87	1.87	0.02
6	TAD (A)	12569	12512	12678	12586	84.34
6	CD (um)	2.23	2.04	1.87	2.04	0.18
7	TAD (A)	12986	12760	12902	12882	114.23
7	CD (um)	2.01	2.14	1.86	2.00	0.14
8	TAD (A)	12650	12687	12783	12706	68.65
8	CD (um)	1.98	1.82	1.90	1.90	0.08
9	TAD (A)	13678	13548	13585	13603	66.98
9	CD (um)	1.97	1.92	1.92	1.94	0.03
10	TAD (A)	12882	12858	13017	12919	85.71
10	CD (um)	1.93	1.85	1.92	1.90	0.04
11	TAD (A)	12787	12737	12899	12808	82.95
11	CD (um)	1.85	1.86	1.94	1.86	0.05
12	TAD (A)	13235	13226	13270	13243	23.25
12	CD (um)	1.88	1.84	1.87	1.88	0.02
13	TAD (A)	13548	13643	13670	13620	64.08
13	CD (um)	1.91	1.86	1.86	1.84	0.03
14	TAD (A)	13209	13015	13003	13076	115.63
14	CD (um)	1.93	1.78	1.82	1.84	0.08
15	TAD (A)	13254	13177	13226	13219	38.97
15	CD (um)	1.89	1.80	1.78	1.82	0.06
16	TAD (A)	12546	12800	13032	12793	243.09
16	CD (um)	1.96	1.93	1.92	1.94	0.02
17	TAD (A)	12869	12418	12579	12622	228.55
17	CD (um)	1.77	1.77	1.85	1.80	0.05
18	TAD (A)	13213	12964	12951	13042	147.66
18	CD (um)	1.90	1.92	1.82	1.88	0.05

TABLE 2 - EXPERIMENTAL DATA

Implementing the obtained data on SAS we obtain a F value, and a PR value for each dependent variable, that is, AVGCD (average critical dimension), STDCD (standard deviation of the cd values), AVGTAD (average resist thickness after development) and STDTAD (standard deviation of the resist thickness after development). The F value is defined as the ratio of how well the model fits the experimental data to the actual experimental data and so for a good approximation we would like this number to be very large.[2] The PR or probability value is defined as the probability or the confidence of the model and ideally would be in the range of .05, which is a 95% confidence level. A summary of these values is presented in table 3.

DEP VARIABLE	F-VALUE	PR-VALUE
AVGCD	0.59	0.7729
AVGTAD	0.83	0.6063
STDCD	1.51	0.2857
STDTAD	0.76	0.6539

TABLE 3 - SAS ANALYSIS VALUES

Clearly we see that the model is insignificant and this could have been due to one of many reasons. We could have had a lot of varibility in the process or the factors that we looked at could not have explained the variability. Also, the range of values we looked at may not have been in the correct area. A lack-of-fit analysis followed and this was to determine if we had accounted for all the terms that we should have. This was to check if the assumption made regarding three factor and above terms being negligable was a valid one. From the F value and sum of squares value obtained we were able to justify making that assumption.

Finally, to decide on an optimum run or set of runs, we compared the means and the standard deviations of both the resist thickness after development and the critical dimensions. The run that gave us the least resist thickness loss and the best critical dimension with the lowest standard deveation was Refrence run 9 with a resist thickness after development of 13603A (STD = 66.98) and critical dimension of 1.9um (STD = .03)

CONCLUSION

The optimum run was determined to be reference run 9 with the following parameters. Bake temperature = 120C, Bake time = 110sec, and Develop time = 23secs. The resist thickness after development was measured as 13603A with a standard deveation of 66.98 and the critical dimension measured was 1.9um with a standard deveation of 0.03.

As a follow up to this experiment I would decrease range on the bake temperature and increase the range on the develop time.

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