A Holistic Approach To The Design Of Experiments - Part 2

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Part I of this paper appeared in the Spring issue of the ASQC Statistics Division Newsletter. It described a "Template" to show how the design of experiments fits into the overall scheme of developing or improving products and processes.

Part II gives an application of the design of experiments. Since the purpose of this paper is to give a broad-brush picture of going through the steps of designing and analyzing an experiment, some of the data and details have been omitted.

APPLICATION 1: RESIST OPTIMIZATION

This example describes experimentation for a semiconductor resist optimization study. In this study, previous experimentation and physical considerations had prompted the experimenters to find the coefficients for a particular type of polynomial.

STEP 1: DETERMINE AND AGREE UPON THE PURPOSE OF THE EXPERIMENT

The purpose of the experiment is to find the best operating conditions to maximize exposure latitude.

STEP 2: DEFINE THE MAIN FUNCTION

The processes studied are a subgroup of processes for transferring a pattern to a wafer, from softbaking to exposure.

STEP 3: DETERMINE THE CHARACTERISTICS TO BE MEASURED AND THE METHOD OF MEASUREMENT.

The characteristic measured is dimension. It is desirable to have a large exposure dose latitude, i.e., we want to find conditions of the resist processes such that a variation in the exposure dose does not affect the dimensions of the pattern on the wafer. "Latitude" was the output that was modeled.

STEP 4: DETERMINE THE INPUTS

INPUTS	LOW	MED	HIGH
SOFTBAKE TEMPERATURE	-	0	+
POST EXPOSURE BAKE TEMPERATURE	-	0	+
DEVELOP TEMPERATURE	-	0	+

The values for the low (-), medium (0), and high settings (+) were determined and used in the experiment.

STEP 5: CHOOSE AN EXPERIMENTAL MATRIX

The design used was a "Box-Behnken RSM Design" for three variables. This is used for fitting a second order response surface model. See Figure 1 and Table 1.

STEP 6: RUN THE EXPERIMENT

The experiment was run, and the data was collected. See Table 1.

TABLE 1: RESIST OPTIMIZATION EXPERIMENT MATRIX AND RESULTS

RUN#	BAKE TEMPERATURE LEVEL	POST EXPOSURE BAKE TEMPERATURE LEVEL	DEVELOP TEMPERATURE LEVEL	EXPOSURE LATITUDE LEVEL
1	0	0	0	32
2	+	+	0	28
3	+	-	0	31
4	-	+	0	22
5	-	-	0	35
6	+	0	+	34
7	+	0	-	37
8	0	0	0	32
9	-	0	+	24
10	-	0	-	23
11	0	+	+	30
12	0	+	-	30
13	0	-	+	36
14	0	-	-	31
15	0	0	0	32

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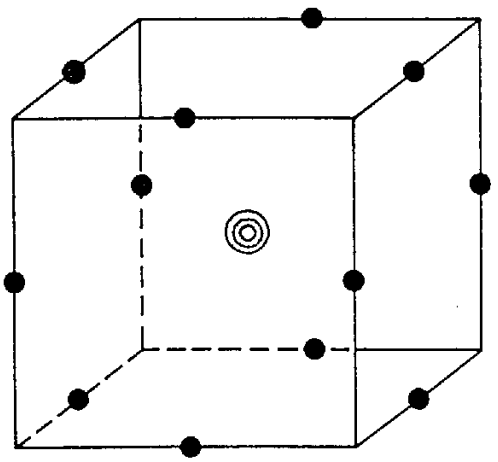

Figure 1: The Box-Behnken RSM Design
(12 points on the edges and 3 centerpoints)

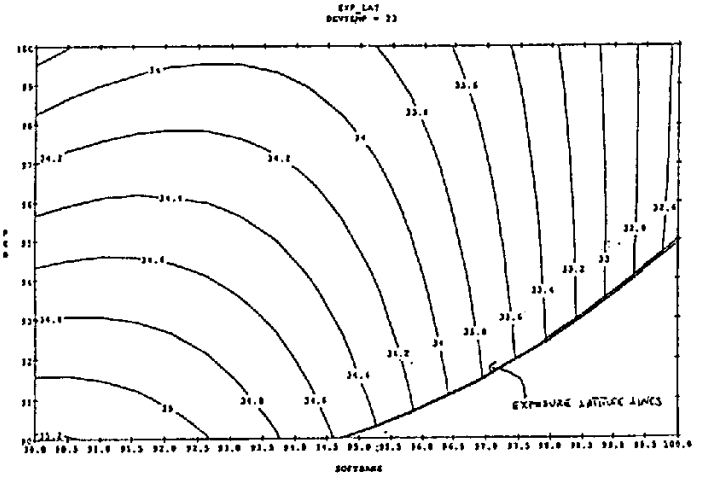

Figure 2: Response Surface for Exposure Latitude vs. Post Exposure Bake and Softbaked Temperature for a constant Develop Temperature

STEP 7: ANALYZE THE DATA

An analytical model, with only pure quadratic terms and no qualitative factors was developed. The methods for fitting such a model are beyond the scope of this paper, and can be found in many references (e.g., see References 5.1 and 5.7 in PART I of this paper). The model used was:

$$y = B_{11} X_1^2 + B_{22} X_2^2 + B_{33} X_3^2 + \epsilon$$

where B_{ii} , i = 1,2,3 are the coefficients, ϵ is the error term, and X_1, X_2, and X_3 represent the actual (uncoded) values for softbake temperature, post exposure bake temperature, and develop temperature, respectively.

The coefficients were computed and response surfaces were created from the equation. See Figure 2 for an example of a response surface. Since only two factors can be examined at one time in this type of analysis, the develop temperature was set at a constant, and the exposure latitude was examined as a function of the Softbake and PEB temperatures.

STEP 8: CONFIRM THE "BEST CANDIDATE" CONDITIONS AND CONCLUSIONS

From the data, the high latitude area was at low values of Softbake Temperature and low Post Exposure Bake Temperatures. These conditions were confirmed. But due to other technical considerations related to manufacturability, these were not the final conditions used.

STEP 9: DOCUMENT EACH STEP OF THE EXPERIMENT

This was done.

STEP 10: CRITIQUE THE EXPERIMENT

Now that we know that other outputs may be strongly affected by the changes in the conditions, they will also be studied at an earlier stage.

STEP 11: CONCLUSIONS

The lower temperatures for Softbake and Post Exposure Bake gave the highest latitude, but were not chosen due to other manufacturability problems. Although this experiment provided much information, additional experimentation was carried out to reach the final conditions. This is not unusual —— the design of experiments is a tool for helping to draw conclusions, and the experimentation may require several iterations, where the information from one iteration helps to design the next experiment. Δ