DESIGN OF EXPERIMENTS AND DIFFUSION CHARACTERIZATION

by

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ABSTRACT

An ANOVA and factorial designs for optimization were compared using a hypothetical LPCVD process situation. The three factorial proved superior Boron diffusion was optimized using the three factorial design.

INTRODUCTION

Today's engineers have come to realize that design of experiments is necessary. It provides a structured plan of attack, it meshes with statistical analysis tools , it forces the experimenter to organize and most of all it is more efficient. It gives us the required information at the least expenditure of resources(time,money,materials).

This project has two objectives. One is to review design of experiments, using the example of an LPCVD system and the second is to apply this tool to characterize RIT's Boron diffusion process. Diffusion characterization is necessary if one is to maintain control over a system while optimizing it. One can determine which factors or combination of factors can be adjusted to obtain a desired result with controllable repeatability. One will also gain insight into the causes of any arising problem in the process.

For the hypothetical LPCVD example a comparison is made between a lower level design called an ANOVA(analysis of variance) and a high level three factorial design, showing how each is designed and applied. For this example it is desired to determine the effects of time, temperature and pressure on percent contamination in the system. From Table 1 it is seen that the classical approach took a total of sixteen wafers. The analysis gives little information overall and it gives no information on interactions or sources of variability. The ANOVA design gives information on interactions and variability but again uses sixteen wafers. The higher level factorial gives all the necessary

information with only eight wafers, proving efficiently superior.

Table 1

THE CLASSICAL APPROACH

Example : study the effects of time , temperature and pressure on % contamination in a LPCVD process.

Factors	Level (High)	Level (Low)
A Pressure (P)	P_1	P_0
B Temperature (T)	T_1	T_0
C Time (t)	t_1	t_0

Set up:

	Levels of Factors	Replicates r1	r2	r3	r4	Ave % con.
1	$P_0\ T_0\ t_0$					
2	$P_1\ T_0\ t_0$					
3	$P_0\ T_1\ t_0$					
4	$P_0\ T_0\ t_1$					

A total of 16 wafers are needed.

Analysis: Look at the difference when the factor is high and low.

Shortcomings: Little information for the expended resources
- No info. on interactions of sources of variability.

ANOVA ANALYSIS:

Objective: Test the hypothesis that % contamination is a function of temperature, time, and pressure.

Set up

	P_0				P_1				
	T_0		T_1		T_0		T_1		
	t_0	t_1	t_0	t_1	t_0	t_1	t_0	t_1	
r1									T9
r2									T10
	T1	T2	T3	T4	T5	T6	T7	T8	TT

ANALYSIS: Looking for statistical significance of the effects of the factors or the interaction of factors. Accomplished by comparing the mean square of the factors and interactions with the error mean square. Significant at an f at 95% confidence.

Advantage over the previous approach: With the same number of wafers we obtain more information.

FACTORIAL DESIGN:

Using the same example as before we use a higher level factorial design to obtain the same info. as the ANOVA analysis with less materials and less work.

Factors: a Pressure
b Temperature
c Time

Response variable
- % contamination

Levels: (+) high
(-) low

Set up:

		P	T	t
1	1	-	-	-
2	a	+	-	-
3	b	-	+	-
4	ab	+	+	-
5	c	-	-	+
6	ac	+	-	+
7	bc	-	+	+
8	abc	+	+	+

Total of 8 wafers.

Analysis using Yates Method to obtain sum of squares for each factor and the interactions.

Results of	Col.I	Col.II	Col.III	SS $(\text{Col.III})^2/2^3$
1	1+a	1+a+b+ab		
a	b+ab	c+ac+bc+abc		a
b	c+ac			b
ab	bc+abc			ab
c	a-1			c
ac	ab-b			ac
bc	ac-c			bc
abc	abc-bc			abc

After we obtain sum of squares for each factor and interaction we test for significance as in the ANOVA.

EXPERIMENT

Using the superior factorial design to characterize RIT's boron diffusion process, sheet resistivity(ps) and variability of ps were chosen as the response variables determining our diffusion characteristics. The factors assumed to be affecting the variables were time,temperature and position in the tube. The goal here, is to determine an optimum diffusion process to obtain a desired ps while maintaining the lowest possible variability. And the objective was to test the hypothesis that ps and the variability of ps are functions of time,temperature,and position. A three to the two factorial with a midptoint was designed. The three factors were taken at two levels each, 30 and 60 min, 850 and 1100 C,load and source sides of the center respectively. The midpoints were 45 min,975 C, and center respectively. This design requires eleven runs, each one to be run in random order and separately to give independence of the results. The wafers were four point probed in three locations and the average ps and standard deviation were determined. The results were then analysed using Yates method.[1]

RESULTS/DISCUSSION

The set up and results of the experiment can be seen in Figure 1. The analysis using Yates method can be seen in Figure 2 for the effects of the factors on average ps. Figure 4 shows the effects on variability of ps.

effects on variability of ps.

Figure 1

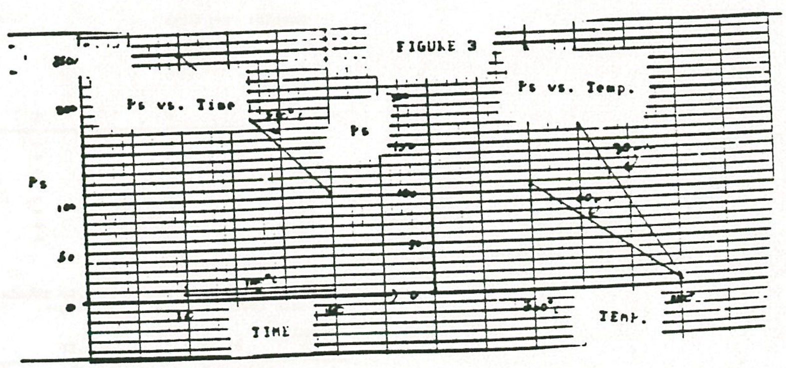
Set up:

	Time(hrs.)	Temp.(°c)	Zone	ps	var.
1	.5	850	1	218.25	.605
a	1	850	1	6.929	.1062
b	.5	1100	1	106.23	5.93
ab	1	1100	1	5.869	.0199
c	.5	850	3	300.29	7.956
ac	1	850	3	7.07	.0822
bc	.5	1100	3	107.26	4.545
abc	1	1100	3	6.053	.342
	.75	975	2		
mid.	.75	975	2	s^2 = 18.17	.097
pt.	.75	975	2	ave = 35.55	.336

Figure 2

BORON DIFFUSION ! AVERAGE Ps

INDEX	TOTAL OBSERVATION	SUM OF SQUARE	HALF EFFECT	MEASURES	DF	MEAN SQUARE	F RATIO
1	218.2500	71811.2300	94.744	AVERAGE			
2	6.9290	62323.7400	-88.264	A	1	62323.7400	3430.036
3	106.2300	11790.8800	-38.391	B	1	11790.8800	648.920
4	5.8690	11474.0800	37.872	AB	1	11474.0800	631.485
5	300.2900	869.3412	10.424	C	1	869.3412	47.845
6	7.0700	855.8418	-10.343	AC	1	855.8418	47.102
7	107.2600	819.4573	-10.121	BC	1	819.4573	45.099
8	6.0530	821.1986	10.132	ABC	1	821.1986	45.195
	ERROR	-0.0156			0	18.1700	
	TOTAL	88954.5200			7		



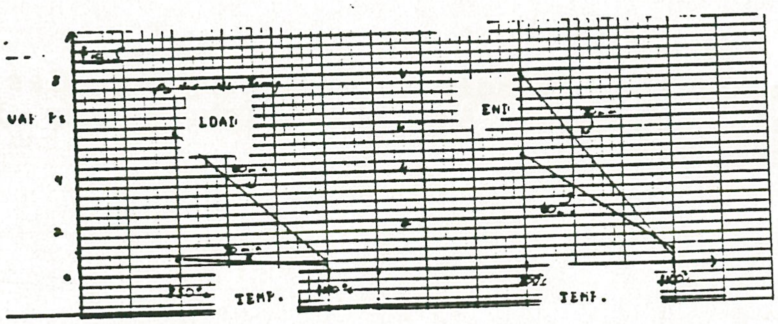
From Figure 2 it is seen that temperature has the most significant effect on ps, which is understandable since diffusivity is a strong function of temperature. Time also shows a significant effect on ps and the interaction of temperature and time is also significant. This is again understandable since boron concentration increases with temperature and time and therefor ps should decrease. Position in the tube shows no significant effect on ps. This shows there is low variability of ps across the tube (it doesn't matter which zone a wafer is in, it will statistically have the same ave ps). To fully understand the effects of temperature , time and the interaction, one should examine the plots of these effects. From Figure 3 it is observed that at high temperature ps is independent of time. This is due to such a high diffusivity that we reach saturation quickly. If it is desired to adjust ps one must use a lower temperature and determine the needed time.

Figure 4

BORON DIFFUSION Ps Variability

INDEX	TOTAL OBSERVATION	SUM OF SQUARE	HALF EFFECT	MEASURES	DF	MEAN SQUARE	F RATIO
0		47.9676	2.449	AVERAGE			
1 (1)	0.6050	42.7290	-2.311	A	1	42.7290	437.797
2 (a)	0.1062	0.5463	0.261	B	1	0.5463	5.597
3 (b)	5.9320	0.3800	-0.218	AB	1	0.3800	3.893
4 (ab)	0.0199	4.9033	0.783	C	1	4.9033	50.239
5 (c)	7.9560	4.0142	-0.708	AC	1	4.0142	41.129
6 (ac)	0.0822	8.8009	-1.049	BC	1	8.8009	90.173
7 (bc)	4.5460	10.3128	1.135	ABC	1	10.3126	105.664
8 (abc)	0.3420						
ERROR		0.0000			0	0.0976	
TOTAL		71.6865			7		

Figure 5



From Figure 4 one sees the effect of the three factors on the variability of ps across the wafer. Temperature shows a significant effect on variability. But more importantly there is a significant three factor interaction that must be examined. The plots of this interaction are in Figure5. As temperture increases variability decreases. At the end position 30 min shows the least variability and at the source 30 min shows a large variability. This shift could be attributed to fluctuations in the heating unit for this zone at low temperatures or possibly due to the direct nitrogen flow into this zone. In any case the source has a variability problem and should be investigated and avoided if unfixed.

SUMMARY

Factorial designs proved to be an efficiently superior design and a necessary tool for engineering. One gets all the necessary information at the least expenditure of resources.

From the boron diffusion factorial design , this diffsion process was characterized. If one wants to adjust ps and maintain low variability, temperature should be chosen as high as the process will tolerate and where adjustments in time will have an effect in changing ps. Time around the 30 min area proved superior for low variability and should be used if possible. And the source position should be avoided if processing below 1000 C because of its instability.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Montgomery Douglas C. Design and Analysis of Experiments. John Wiley and Sons, N.Y. , 1984 PP 43-80 , 261-292.

[2] Burr Irving W. Statistical Quality Control Methods. Marcel Dekker inc. , N.Y. , 1976 PP- 1-5, 353-381.