

OPTIMIZATION OF NITRIDE DEPOSITION PROCESS USING TAGUCHI METHOD

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ABSTRACT

In this work, Taguchi method of optimization is being employed in the deposition process of silicon nitride to obtain the targeted deposition rates of 250 Å/min and refractive index in the range of 1.8 to 2.2. The deposition of the silicon nitride (Si₃N₄) films is carried out using Plasma Enhanced Chemical Vapor Deposition (PECVD) method to take advantage of lower temperature operation and cost as well as higher surface uniformity and throughput [1]. The statistical 'Design Expert' software is being used to identify the factors that significantly affect the performance of the process and to obtain the optimum combination of parameters which will produce the targeted responses. From the results of ANOVA, it is found that the most significant factors that affect the deposition rate are 5% SiH₄/Ar gas ratio and pressure, while Nitrogen (N₂) flow rate is the most significant factor for the refractive index. The combination of input parameters of RF power of 60 Watt, pressure of 1000 mTorr, 5% SiH₄/Ar gas ratio of 80 sccm and Nitrogen (N₂) flow rates of 310 sccm is found to be the optimum combinations to produce the targeted responses. In order to validate the solution obtained from the software, confirmation experiment is conducted. A very small percentage of differences which are of between 1.8% to 6.6% are obtained between predicted and actual value for both the deposition rates and refractive index.

INTRODUCTION

Surface passivation of silicon nitride (Si₃N₄) films has been increasingly adopted in semiconductor manufacturing processes in recent years. This is because Si₃N₄ is a good electrical insulator with very high dielectric strength (breakdown voltage). It is generally being used as the final passivation layer for the passivation dielectric application and as the barrier layer for the doped oxide in premetal dielectric (PMD) application. An effective way of fabricating Si₃N₄ films was by using Plasma Enhanced Chemical Vapor Deposition (PECVD) method to take advantage of lower temperature operation and cost, as well as higher surface uniformity and throughput [1]. However, process operations of PECVD systems are very complex involving operating variables and the nature of plasma reactions. In this work, the optimization of Si₃N₄ deposition process by PECVD was carried out by using the Design of Experiment (DOE) method. The DOE method helps to study many factors (variables) simultaneously and most economically. By studying the effects of individual factors on results, the best factor combination can be determined. When applied to product or process design, the technique helps to seek out the best design among the many alternatives.

METHODOLOGY

In this work, Taguchi method of optimization is being employed in the deposition process of silicon nitride to obtain the targeted deposition rates of 250Å/min and refractive index in the range of 1.8-2.2. The input parameters selected as the factors are RF power, pressure, 5% SiH₄/Ar gas ratio and Nitrogen (N₂) flow rates, with each parameters varied at 3 levels ($3^4 = 81$ input combinations) as tabulated in Table 1.

Table 1: Summary of factors used in the PECVD silicon nitride deposition study

FACTORS		FACTOR LEVELS		
	Units	Level 1	Level 2	Level 3
RF power	Watt	20	60	100
Pressure	mTorr	200	600	1000
5% SiH ₄ /Ar gas ratio	sccm	40	60	80
Nitrogen (N ₂) flow rates	sccm	260	285	310

By employing the Taguchi method, only 9 experiments need to be carried out instead of 81 (L-9 array). However, in order to develop robust products and processes, it is necessary to test more wafers. When reducing variability is of interest, multiple samples per trial condition must be run. In this work, 3 samples at each condition were tested, making the total number of experiments that need to be conducted is of 27 experiments. The results were then analyzed with an aid of “Design Expert” software. An important analysis that was carried out was the analysis of variance (ANOVA) to find out how much effect each factor has on the results [2]. From the ANOVA, the important information that can be obtained is the percentage influence of all factors over responses. The level of each factor required to achieve the optimum condition can then be predicted.

RESULTS AND DISCUSSION

Analysis of Variance (ANOVA)

Table 2 and 3 show the summary of ANOVA results obtained for the deposition rates and refractive index respectively. From the results of ANOVA, it is found that the most significant factors that affect the deposition rate are 5% SiH₄/Ar gas ratio and pressure. The 5% SiH₄/Ar gas ratio factor has about 50% of influence on the deposition rate while the pressure contributes to about 45% of total influence. Meanwhile, for the refractive index, Nitrogen (N₂) flow rate is found to be the most significant factor with over 46% influence. The determination of the most significant factor on the response can also be made by observing the p-value. It can be seen that for the deposition rates (Table 2), the 5% SiH₄/Ar gas ratio and pressure has a p-value of less than 0.0001, while for the refractive index (Table 3), Nitrogen (N₂) flow rate has a p-value of < 0.0001. The p-value represents the observed significance level. The lower the p-values, the more confidence is placed on the

fact that those factor has an effect on the responses and are statistically significant [3].

Table 2: Analysis of Variance (ANOVA) for deposition rates

Design Factors	Total Sum of Squares (ST)	Pure Sum (S')	Percentage P [%]	p-value
5% SiH ₄ /Ar gas ratio	125050.27	62252.7	49.78	< 0.0001
Nitrogen (N ₂) flow rate		2118.5	1.69	0.1042
Pressure		55885.9	44.69	< 0.0001
RF Power		4793.17	3.83	<0.0112

Table 3: Analysis of Variance (ANOVA) for refractive index

Design Factors	Total Sum of Squares (ST)	Pure Sum (S')	Percentage P [%]	p-value
5% SiH ₄ /Ar gas ratio	0.99	0.16	16.16	0.0133
Nitrogen (N ₂) flow rate		0.46	46.46	< 0.0001
Pressure		0.15	15.15	0.0158
RF Power		0.22	22.22	0.0037

Table 4: Predicted vs. actual results of deposition rates and refractive index

	Deposition rate (Å/min)	Percentage of difference [%]	Refractive Index	Percentage of difference [%]
Target Value predicted by software using proposed parameter combinations	250	-	1.9492	-
Confirmation Experiment: Trial I	258.95	3.58	2.0528	5.31
Confirmation Experiment: Trial II	266.40	6.56	1.9957	2.39
Confirmation Experiment: Trial III	254.48	1.79	2.0219	3.73

Predicted Optimum Condition and Confirmation Test

Based on the results obtained from Table 2 and 3, the predicted optimum combinations of input parameters to be used to produce the targeted deposition rates of 250Å/min and refractive index of between 1.8–2.2 is of RF power of 60 Watt, pressure of 1000 mTorr, 5% SiH₄/Ar gas ratio of 80 sccm and Nitrogen (N₂) flow rates of 310 sccm. In order to validate the solution proposed by the software, confirmation experiment is conducted. In order to take into account the effect of variations, the experiment is conducted for three times. The results obtained are shown in Table 4.

From the results, it is found that there is only a very small percentage of differences between predicted and actual value for both the deposition rates and refractive index which are of between 1.8% to 6.6% only. Generally, error within 10% is allowable [2].

CONCLUSION

Based on the results obtained, it can be concluded that the utilization of a systematic approach in designing an experiment is indispensable in today's world. By using DOE, one can easily perform optimization on any product and processes with lesser number of experiments while still maintaining the accuracy and reliability of the results obtained. In this work, by only performing 27 experiments instead of 81, the optimum parameters to be used to produce targeted responses of deposition rates of 250Å/min and refractive index of between 1.8–2.2 has been successfully obtained. In order to validate the predicted results, a confirmation experiment is carried and it is found that a very small percentage difference of between 1.8% to 6.6% is obtained between actual and predicted values.

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