DESIGNED EXPERIMENT FOR A SEMICONDUCTOR CHEMICAL VAPOR DEPOSITION PROCESS

RELEVANT JMP PLATFORMS AND STATISTICAL TECHNIQUES

Graph Builder :	Comparative Dotplots and Line Graph
Fit Model :	Factorial ANOVA Models , Profilers, Model Diagnostics, Simulation
Distribution :	Histograms, Summary Statistics, Bar Chart/Freq Table, Capability Analysis
Formula Editor:	Conditional if/then statement

PROBLEM STATEMENT

Plasma-Enhanced Chemical Vapor Deposition (PECVD) is an essential process in semiconductor fabrication. In a high-temperature PECVD reactor furnace, gaseous chemicals are added to form a solid film on the surface. Stable control of temperature, gas flow, pressure, power, among other variables is essential for creating a film with consistent thickness to desired specifications. Figure 1 is a simplified schematic diagram of the process.

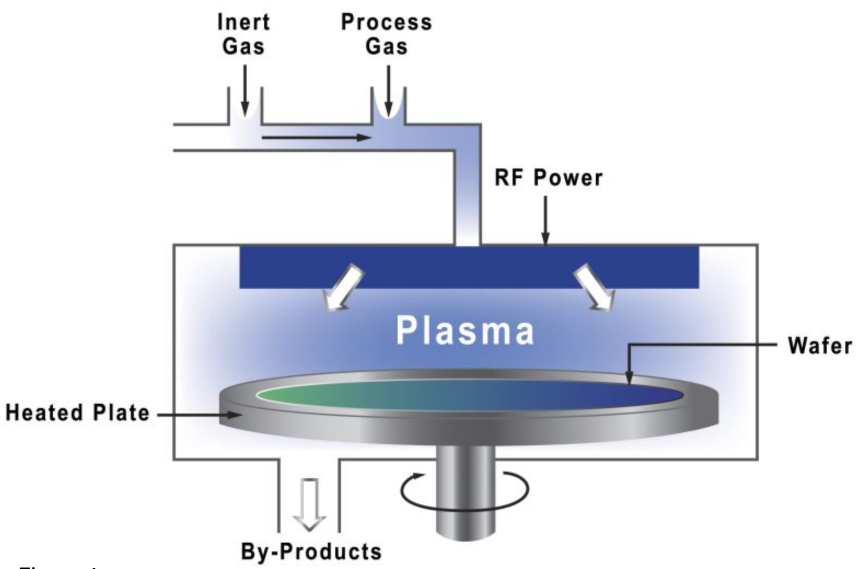

Figure 1

An engineering team is looking to better understand the impact that gas flow and power inputs have on the resulting thickness of the thin film. The team designs an experiment that will vary gas flow between 240 and 300 Standard cubic cm per minute, high frequency power between 750 and 850 Watts, and low frequency power between 180 and 220 Watts. To study the impact each factor may have along with their possible interactions, and a potential curvature effect, the particular experimental design chosen is a 3-Factor 2-Level Design with Center Points. Figure 2 is a diagram of that experimental design. Note that there are 2 experimental runs at each of the 8 corner points and 4 runs at the center point resulting in a total of 20 experimental runs. The order of the runs was performed randomly. For each run, 5 thickness measurements were made on the wafer. The Average and the Standard Deviation in Thickness will be used as the outcome variables for the analyses.

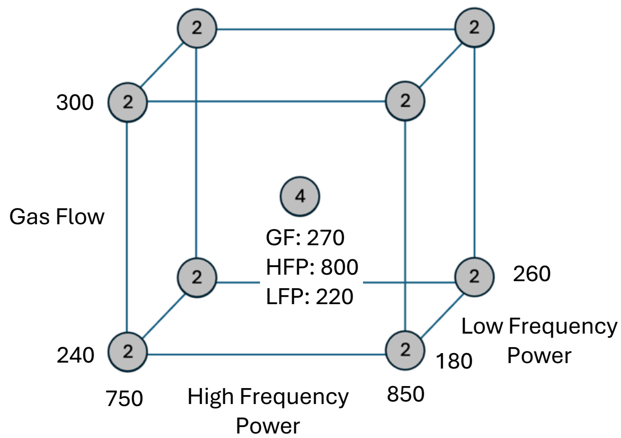

Figure 2

The target thickness in this process is 6650 Angstroms though it is still considered acceptable if the average thickness is between 6600 and 6700. Consistency across the wafer is also an important goal. The specification on the variation in thickness within a wafer is a standard deviation < 220 Angstroms.

DATA SET

Designed_Experiment_for_a_Semiconductor_Chemical_Vapor_Deposition_Process

HF Power	High Frequency Power (in Watts) used in the experimental run (750, 800, 850)
LF Power	Low Frequency Power (in Watts) used in the experimental run (180, 220, 260)
Gas Flow	Gas Flow (in Standard cubic cm per minute) used in the experimental run (240, 270, 300)
Center Point	Binary Indicator of the center point runs in the experiment (0,1)
Avg Thickness	The average thickness (in Angstroms) of the 5 measurements on the wafer for each experimental run
Var Thickness	The standard deviation in thickness (in Angstroms) of 5 measurement on the wafer for each experimental run

EXERCISES

The exercises consist of analyzing the experimental results to identify those factors that impact the average and/or variation in thickness, those impacts through creating a linear statistical model, and using those resulting models to find the optimal factor setting and simulating the process if run at those settings.

1. Create two graphs (one for 'Avg Thickness' and 'Var Thickness') that display the outcomes for each experimental run. Provide a brief description of the potential impact that the experimental factors have on the responses. Note: Formal statistical tests will be done in the next steps to determine if the necessary statistical evidence exists to support your conclusions. These graphs are meant to get some initial perspective into the experimental results.

> *Instructions:* *Use Graph Builder. Place the variable 'Avg Thickness' on the Y axis. Place 'HF Power' on the X axis and 'LF Power' in the Group X role. Place 'Gas Flow' in the Overlay role. Choose the dotplot and line graph icons.*
>
> *Repeat using 'Var Thickness' as the response variable.*
>
> *Note: The Response Limits and the Goal were added to the Column Properties and the option to show as reference lines on graphs selected. You can double-click on the column to see these settings.*

2. Create a linear statistical model for the Avg Thickness outcome variable that includes the three main effects (HF Power, LF Power, and Gas Flow), the three two-way interactions (HF Power*LP Power, HF Power*Gas Flow, and LF Power*Gas Flow'), and the Center Point factor.

> *Instructions:* *Choose Analyze > Fit Model. Choose 'Avg Thickness' as the Y variable. Select the three variables 'HF Power' , 'LF Power' and 'Gas Flow' from the columns list. Choose Macro > Factorial to Degree in the Construct Model Effects section. Add 'Center Point' into the Model Effects. Choose Minimal Report in the Emphasis drop down menu. Click Run.*

3. Reduce the model until it only includes statistically significant terms. How does this final model compare to your initial assessment in the graph created in Exercise 1?

> *Instructions:* *Examine the Effect Summary table. Start by removing any of the two-way interactions with p-values greater than 0.05. Now examine the Center Point effect and remove if not significant. Examine the main effects and remove any that are not significant being sure not to remove any term that are part of a significant two-way interaction.*

4. Evaluate model assumptions (i.e., homogeneity of variance and normality of residuals) for your final model. Is there any cause for concern?

> *Instructions: Choose Row Diagnostics > Plot Residual by Predicted under the red triangle. Choose Row Diagnostics > Plot Residual by Normal Quantiles.*

5. Display visual representations of the final statistical model. Use those graphs to provide a description of the impact the significant factors have on the response.

> *Instructions: Choose Profiler, Contour Profiler, and Surface Profiler in Factor Profiling under the top red triangle. Note: Each of the visualizations have options under their respective red triangles or control panels to enhance the graph (e.g., choosing to display the data points in the prediction profiler, adding contour lines and the data points on the surface graph, changing the spacing of the contour lines on the contour plot, among others). One enhancement that you'll find useful is to add the lower and upper response limit to the Lo Limit and Hi Limit on the surface plot and to add a contour at the target of 6650. The clear region is displaying the levels of the factor where the response is predicted to be within those limits.*

6. Are there factor settings that can achieve the desired 'Avg Thickness' of 6650? Is the solution unique or are there other levels of the experimental factors that can achieve the target of 6650?

> *Instructions: First choose Optimization and Desirability > Maximize Desirability under the red triangle for the Prediction Profiler. Then, drag the red dotted lines in the prediction profiler to see if other factor settings can be found that hit the target of 6650.*

7. Create a linear model describing the impact the significant factors have on 'Var Thickness'. What factor settings achieve the lowest variation?

> *Instructions: Repeat Exercises 2-6 for the 'Var Thickness' response with the goal of finding factor settings that result in the predicted outcome being less than 220.*

8. Find the factor settings that simultaneously achieve the target of ‘Average Thickness’ of 6650 +/- 50 and also minimizing ‘Variation in Thickness’ with upper response limit of 220. Is the solution unique or are there other levels of the experimental factors have a predicted ‘Avg Thickness’ of 6650 +/- 50 and ‘Var Thickness’ < 220.

> *Instructions:* *First bring both final models into the Formula Depot by choosing Save Columns > Publish Prediction Formula under the top red triangle in the model reports. Inside of the Formula Depot, select Profiler under the top red triangle. Then within the red triangle for the Profiler, select to add the Surface and Contour Profilers. To find the factor settings that simultaneously achieve the goals, select Optimization and Desirability > Maximize Desirability under the red triangle next to Prediction Profiler. The factor setting have now been moved to the optimal solution. The clear region in the overlay Contour Profiler is displaying the levels of the factor where it is estimated the goal of ‘Avg Thickness’ of 6650 +/-50 and ‘Var Thickness’ < 220 can be achieved.*

9. Simulate what would happen in this process if it was run at the factor settings found in Exercise 9? Based upon this simulation, how well would this process perform at producing wafers with an ‘Avg Thickness’ of 6650 +/- 50 and ‘Var Thickness’ < 220? Comment on which response variable would perform the worst. Produce an estimate of the percentage of wafers that would be within and outside of both sets of specifications simultaneously. Comment on how well you think this process will perform overall.

> *Instructions:* *Under the red triangle next to Prediction Profiler select Simulator. Choose to keep the factor levels fixed (In other words, amount of Gas Flow, HFP, and LFP wouldn’t vary from the chosen setting in running the process). Select to Add Random Noise for ‘Avg Thickness’ and ‘Var Thickness’ (These are estimates of how much variation would occur in these responses that are based upon the final models created.). Select the Simulate button. Then choose Make Table under the Simulate to Table. A new data table has been created simulating creating 10,000 wafers the chosen process settings. Within this new data table, double click on each response column and at the Specification Limits within the Column Properties (‘Pred Formula Avg Thickness’ of Lower Spec Limit = 6600 , Target = 6650 , Upper Spec Limits = 6700 ; ‘Pred Formula Var Thickness’ to Upper Value of 220). For each, choose to Show as Graph Reference Lines. Select to run the Distribution script that has been automatically created for this data table. Select to run the Scatterplot Matrix Y script. This provides a few of both responses as compared to the specifications. To create a new binary column indicating if the wafer would be within both specifications, select Cols > New Column. Title it ‘Both Responses_In Spec’. Select Column Properties > Formula, then edit formula. Create the following formula using the Conditional ‘if’ and ‘and’ statements.*
>
> If((*Pred Formula Avg Thickness* > 6600 & *Pred Formula Avg Thickness* < 6700) & *Pred Formula Var Thickness* < 220 ⇒ "In Spec"
> else ⇒ "Out of Spec")
>
> *Choose Analyze > Distribution on the ‘Both Responses_In Spec’ variable to see the estimates of the proportion of wafers that would be within and outside of specifications.*

10. What are some ideas you have for next steps the engineering team could take that would work towards improving the performance of this process?