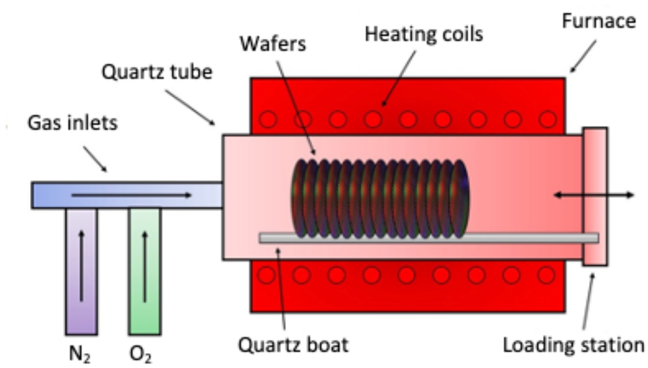
SEMICONDUCTOR WAFER OXIDATION PROCESS

RELEVANT JMP PLATFORMS AND STATISTICAL TECHNIQUES

Graph Builder :	Histogram, Comparative Boxplots ; Location Heat Map
Fit Y by X :	One-way ANOVA, Multiple Comparisons
Fit Model :	Two-way ANOVA, Multiple Comparisons

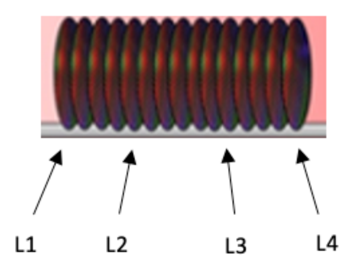
PROBLEM STATEMENT

The manufacturing of semiconductor wafers involves a process that adds a thin layer of silicon dioxide to wafers. This is done through inserting a set of wafers held in a cartridge (boat) into a thermal reactor (furnace) and slowly adding heat. Once a specified temperature is achieved, a nitrogen oxygen gas mixture is added. This oxidizes the surface of the wafer growing a thin layer of silicon dioxide. Being able to create a uniform thickness of this oxide layer at a desired specification is critical in the fabrication of the final integrated circuits. The specification for this particular process is a thickness of 90 +/- 8 angstroms.

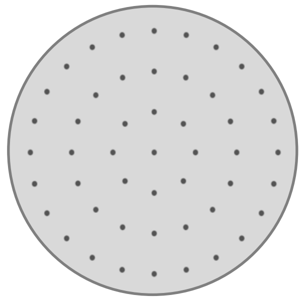


Wafers coming from one particular production line are having quality issues further downstream in the manufacturing of the circuits. Quality engineers hypothesized that this was a result of non-uniformity in the thickness of the silicon dioxide layer.

To evaluate this, a sampling plan was created where wafers were selected from 4 different fixed locations on the boat (L1, L2, L3, L4) during 12 runs of the process.



The thickness of the oxide layer was measured at 49 different locations on each of the 12 x 4 = 48 wafers using a spectroscopic measurement tool.



DATA SET

Semiconductor_Wafer_Oxidation_Process.jmp

Wafer ID	Identification of the wafer (1,2,...,48)
Run	The production run (1,2,...,12)
Wafer Position	Position of wafer in the quartz boat (L1, L2, L3, L4)
X Coordinate	Location of measurement on wafer in x-coordinate
Y Coordinate	Location of measurement on wafer in y-coordinate
Oxide Thickness	Thickness of oxide layer (in Angstroms)

EXERCISES

The exercises consist of creating a variety of visualizations of the data to explore the variation in 'Oxide Thickness'. You'll also conduct a variety of statistical tests via ANOVA models to compare the thickness across the different wafer positions and runs. As you'll see, certain analyses and visualization will be better suited at identifying and describing the different levels of variation.

Note: The 'Oxide Thickness' specifications (90 +/- 8 angstroms) was added as a column property along with choosing to show reference lines on the graphs that will be created. This can be turned off by right-clicking on the 'Oxide Thickness' column and choosing Column Properties > Spec Limits. The color and line style of the reference lines can be edited on a graph by double-clicking on an axis to open up Axis Settings. Removing them, however, would require changing through the column property.

1. Create a histogram of all 2,352 ‘Oxide Thickness’ measurements. Comment on the average and overall variation in these data and how it compares to the specifications.

> *Instructions:* *Use Graph Builder. Place the variable ‘Oxide Thickness’ on the X axis. Choose the histogram icon.*
> *The level of binning can be adjusted by double-clicking on the x-axis to open up Axis Settings. Change the Increment of “1”.*
> *Add the mean and standard deviation to the graph by selecting that check box in the controls on the left.*

2. Create comparative boxplots for ‘Oxide Thickness’ separated by the 12 runs and 4 wafer positions. Describe how ‘Oxide Thickness’ differs across the 12 runs and the 4 waer positions. Which runs and wafer positions are producing ‘Oxide Thickness’ values outside of the process specifications?

> *Instructions:* *Use Graph Builder. Place the variable ‘Oxide Thickness’ on the Y axis. Select ‘Wafer Position’ as the X variable and ‘Run’ as the Group X variable. Choose the boxplot icon and the line icon (holding the shift key down so they’re both selected).*
> *Create a second version of this graph placing ‘Run’ as the X variable and ‘Wafer Position’ as the Group X variable. Note: These graphs are simply showing the same boxplots but displayed on the graph in two different ways as each one might be better suited to compare and communication variation in ‘Oxide Thickness’ between ‘Run’ and/or ‘Wafer Position’.*

3. Perform a One-way Analysis of Variance (ANOVA) comparing the ‘Oxide Thickness’ values across the 4 ‘Wafer Positions’. Is there statistically significant evidence indicating that the average ‘Oxide Thickness’ is not equal across the 4 ‘Wafer Positions’? Perform a multiple comparison for all 6 pairwise differences (L1 vs L2, L1 vs. L3, L1 vs L4, L2 vs L3, L2 vs L3, L3 vs L4). Summarize the results. Examine the Confidence Intervals for the Mean ‘Oxide Thickness’ for each of the 4 ‘Wafer Positions’. Do you think these provide accurate estimates of what the Mean ‘Oxide Thickness’ for each ‘Wafer Position’ would be in the long run for this production line (e.g., Runs 13, 14, ...)? Explain why or why not.

> *Instructions:* *Choose Analyze > Fit Model. Choose ‘Oxide Thickness’ as the Y variable. Add ‘Wafer Position’ to the Construct Model Effects. Click Run. From the report, select Multiple Comparisons under the top red triangle menu. Choose All Pairwise Comparisons – Student’s t for the analysis to conduct. Also select to Show Least Squares Means Plot.*

4. Perform a Two-way Analysis of Variance comparing the 'Oxide Thickness' using 'Run' as a blocking factor. Compare the Root Mean Square Error (RMSE) and R-Squared values between the Two-way ANOVA and One-way ANOVA. Explain why they are different. Perform a multiple comparison for all 6 pairwise differences (L1 vs L2, L1 vs. L3, L1 vs L4, L2 vs L3, L2 vs L3, L3 vs L4). Summarize the results. Examine the Confidence Intervals for the Mean 'Oxide Thickness' for each of the 4 'Wafer Positions'. Do you think these provide accurate estimates of what the Mean 'Oxide Thickness' for each 'Wafer Position' would be in the long run for this production line (e.g., Runs 13, 14, ...)? Explain why or why not.

   Examine the Confidence Intervals for the Pairwise Differences in Mean 'Oxide Thickness' between the 'Wafer Positions'. Do you think these provide reasonably accurate estimates of what the difference in the Mean 'Oxide Thickness' between 'Wafer Positions' would be in the long run for this production line (e.g., difference between 'Wafer Position' L1 and L2 for Runs 13, 14, ...)? Explain why or why not.

   > *Instructions: Choose Analyze > Fit Model. Choose 'Oxide Thickness' as the Y variable. Add both 'Wafer Position' and 'Run' to the Construct Model Effects. From the report, select Multiple Comparisons under the top red triangle menu. Choose 'Wafer Position' as the Effect. Select All Pairwise Comparisons – Student's t for the analysis to conduct. Also select to Show Least Squares Means Plot.*

5. Create a graph that displays the 'Oxide Thickness' values for each of the 49 locations on the wafer for each of the 12 x 4 = 48 wafers. What additional insights into the variability in 'Oxide Thickness' does this graph provide that the previous graphs or analyses did not? Based upon this, how do you feel about using the results of the Two-way ANOVA to completely describe the differences in 'Oxide Thickness' between the 'Wafer Positions'?

   > *Instructions: Use Graph Builder. Drag the 'X Coordinate' and 'Y Coordinate' variables into the main body of the graph. Note: The smoother is added to the graph as a default. Deselect the smoother icon to remove it. Place 'Wafer Position' as the Group Y and 'Run' as the Group X. Resize the window by selecting and dragging from the lower right corner of the window so it displays the wafers as symmetric circles. Place 'Oxide Thickness' in the Color role. Change the color gradient to a Quantile scale by right-clicking on the color legend on the right and choosing Gradient. Then select Quantile as the Scale Type.*

6. The graph created in Exercise 5 does not explicitly identify the specific locations on the wafer where 'Oxide Thickness' is below the Lower Specification Limit of 82. Augment the graph to identify those locations.

> *Instructions: Choose Row Selection > Select Where under the Rows Menu. Choose 'Oxide Thickness' from the Columns; Choose 'is less than' from the drop down; and type '82' in the 'Compare column' field. Click OK. You should see that there are 63 rows in the data table that are now selected. Under the rows menu, choose Markers and select the open circle symbol. Returning to the wafer map will now identify those locations where the 'Oxide Thickness' is below the lower specification of 82.*

7. Create a two page summary using two of the graphs you created and a few brief sentences describing what your analyses uncovered about the variation in 'Oxide Thickness' in this process. Include any hypotheses you might have on why 'Oxide Thickness' varies the way it does, and also any recommendation or next steps you suggest for the quality engineers to take. What other data could be collected on this process to help better understand the variability and potentially find factors that are causing the excessive variation?