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Dosing Optimization for Wafer Weight and Pyramid Formation Improvement

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Abstract: This study aimed to optimize the dosage volume of Batch Etch baths in solar photovoltaic manufacturing, focusing on the relationship between wafer weight loss and pyramid formation. The primary goals of the research were to examine these relationships and identify the optimal dosing volume for better cell performance. The scope of the research included experimental trials, baseline data comparisons, and analysis using a variety of measurements and software tools such as Precision Balance, Reflectometer, ZETA-20A (3D Microscope), cetisPV-Contact, Statistical Process Control (SPC) and JMP software to determine whether the optimal dosing volume could be implemented in production. The research takes into account all of these elements and adheres to accepted methods to guarantee the system operation. The key results show that when efficiency and short circuit current climb to 0.19% and 0.25%, the system performs better overall and more effectively uses input power. The discussion highlights the achievement in maximizing the Batch Etch bath dosing volume and offers recommendations for improving manufacturing while reducing costs and abiding by industry standards.

Keywords: Batch Etch (BE), Statistical Process Control (SPC), Saw Damage Removal (SDR), Sunpower Manufacturing Malaysia (SPMY)

1. Introduction

In order to produce solar cells with the best energy production efficiency, the SPMY firm has used a new technique known as "Passivated Emitter and Rear Contact" (PERC). PERC solar cells rear passivation is carried out utilizing methods like atomic layer deposition, which improves the passivation's quality and yields a high open-circuit voltage [1]. The PERC design significantly decreases recombination and optical losses because it has laser contacts and a dielectric passivation layer [2]. There are ten procedures in the PERC processing unit, one of which is the BE tool for the second procedure. The second process was designed to remove saw-damage, produce a pyramid-like texture on the wafer, clean the wafer surface of any remaining chemicals, get rid of any foreign contamination, like organic or inorganic materials, and dry any solution from the wafer surface. Each of the BE bath

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sub processes uses a different chemical, such as sodium hydroxide (NaOH), hydrogen peroxide (H2O2), texture additives, hydrochloric acid (HCL), and hydrofluoric acid (HF).

To enhance light-trapping on a wafer, a technique known as SDR/Pre-clean and pyramid texturing will be employed in just two of the eighteen baths of the BE tool. The silicon wafers will be cleaned using the SDR technique, giving them smooth, saw mark free surfaces before the alkaline texturing procedure. The BE method third sub process, anisotropic etching, which is regarded as its most important step, produces a texture with a pyramidal shape. A device's performance can be increased by texturing by lowering front surface reflection [3]. The management of SPMY works to optimize the wafer weight and the pyramid formation by optimizing the dosing volume for the BE process in an effort to be the top solar manufacturing company. In order to better the operation of the cells, this study intends to optimize the dose volume of BE baths used in solar photovoltaic manufacture. The goal includes verifying the theoretical dosage volume, tracking the trend for dosing and bath level in real-time, monitoring using an SPC chart, and analyzing the results with JMP software to determine the experiment's conclusion. Utilizing the JMP software, the system assists in determining if an experiment's results can be put into a production line or if the experiment was a failure.

2. Methodology

This section outlines the experimental design, including a flowchart for the primary experiment that will be conducted from the start of the work to its conclusion, the Statistical Process Control chart and measurement instrument in order to optimize the dosage volume concentration for wafer weight and pyramid formation augmentation.

2.1. Design of Experiment

An experiment is a systematic procedure carried out in a regulated environment to establish or test a hypothesis, support an existing theory, or show a previously observed effect. One of its roles is Design of Experiment, a subset of applied that is involved with organizing, performing out, analyzing, and interpreting controlled experiments to establish the elements that affect the value of a parameter or group of parameters. Figure 1 illustrates the flowchart design of experiment to determine which inputs have a substantial influence on the outputs and what the goal level of those inputs should be to obtain a desired outcome (output).

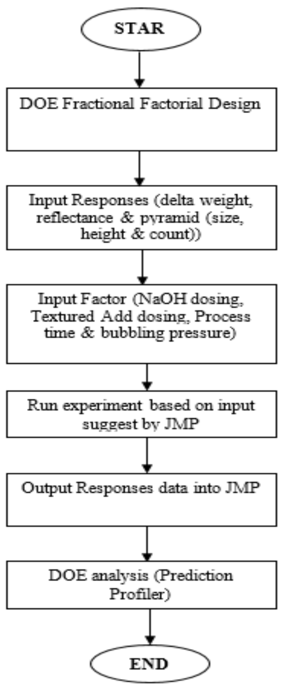


Figure 1: Flowchart Design of Experiment

This study utilized a Full Factorial Design DOE to investigate the impact of four factors, including NaOH dosage, Texturing Additive dosing, Process Time, and Bubble Pressure, on pyramid texturing in the BE experiment. This approach aimed to streamline the design process, reduce design costs, minimize process variance, and decrease manufacturing costs. The factors were varied within specified ranges (see Figure 2). Five response qualification experiments were performed on the BE bath process for wafers to evaluate reflectance, delta weight, pyramid size, height, and count. The DOE study took into account five variables: NaOH dosage, textured Additive dosing, Pre-Clean NaOH, Process Time Pre-Clean, Process time texturing, and Bubbling Pressure. JMP software was used to analyze the outcomes of 17 trials for additional analysis (see Figure 3).

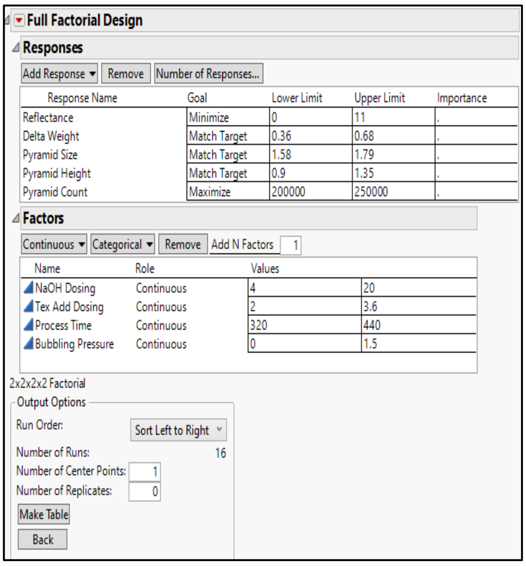
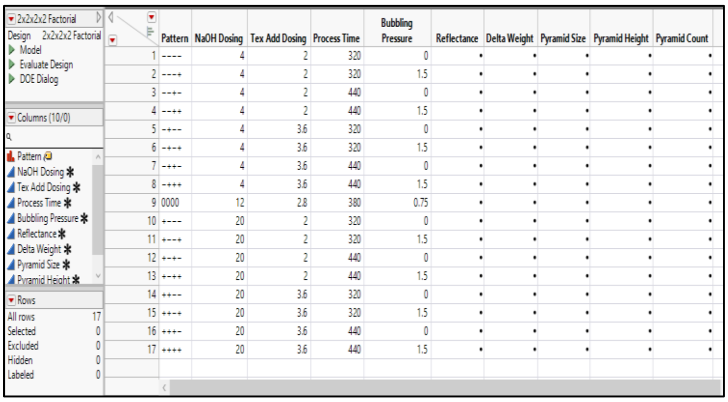


Figure 2: Design of Experiment Full Factorial Design



	Pattern	NaOH Dosing	Tex Add Dosing	Process Time	Bubbling Pressure	Reflectance	Delta Weight	Pyramid Size	Pyramid Height	Pyramid Count
1	----	4	2	320	0	•	•	•	•	•
2	---+	4	2	320	1.5	•	•	•	•	•
3	--+-	4	2	440	0	•	•	•	•	•
4	--++	4	2	440	1.5	•	•	•	•	•
5	-+--	4	3.6	320	0	•	•	•	•	•
6	-+-+	4	3.6	320	1.5	•	•	•	•	•
7	-++-	4	3.6	440	0	•	•	•	•	•
8	-+++	4	3.6	440	1.5	•	•	•	•	•
9	0000	12	2.8	380	0.75	•	•	•	•	•
10	+---	20	2	320	0	•	•	•	•	•
11	+--+	20	2	320	1.5	•	•	•	•	•
12	+-+-	20	2	440	0	•	•	•	•	•
13	+-++	20	2	440	1.5	•	•	•	•	•
14	++--	20	3.6	320	0	•	•	•	•	•
15	++-+	20	3.6	320	1.5	•	•	•	•	•
16	+++-	20	3.6	440	0	•	•	•	•	•
17	++++	20	3.6	440	1.5	•	•	•	•	•

Figure 3: 2x2x2x2 Factorial

2.2 Overall process

The overall process consists of three: The delta weight dosing process, reflectance dosing process and pyramid formation dosing process. The conclusion of the output response, which comprises pyramid formation, reflectance and delta weight, established the ideal dosage volume concentration for BE process. If the results have met the primary goal of the work, the approach for optimizing dosage volume concentration for each answer would not be used, as shown in the Figure 4. For instance, if the wafer weight loss is excessive after taking the appropriate dose, the dosing volume concentration will be deducted. The same issue occurs if the pace of weight loss is too low: additional dose volume concentration is administered.

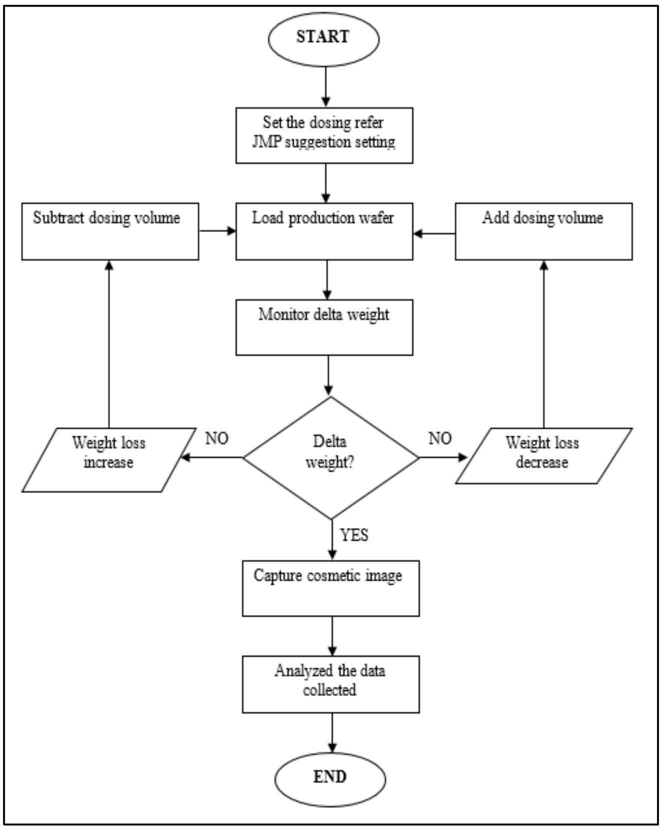


Figure 4: Delta weight dosing process

2.3 Statistical Process Control chart and measurement instrument

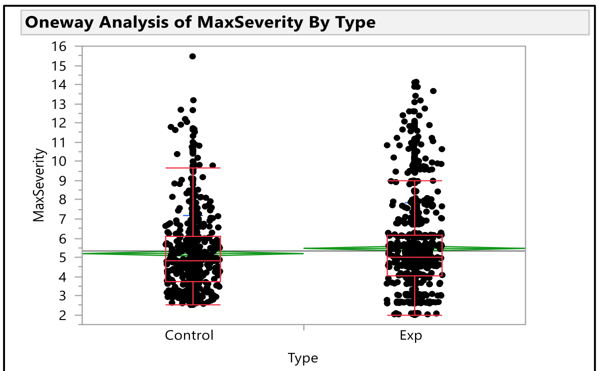
In the BE process, wafer performance was monitored using a variety of measuring instruments, and the data had to be input into SPC charts that had been established ever since the instrument was placed into full operation. The SPC was set with a control limit; any deviation from the specified control limit would trigger an email alarm, and manual intervention would be needed to go back to baseline. As the data need to be collected, below were described the specifications and properties of measurement instrument as followed:

i. Precision Balance
ii. Reflectometer
iii. ZETA-20A (3D Microscope)
iv. JMP software and 1 sigma comparison analysis
v. Halm Electrical Tester

A Precision Balance is one that is made to produce extremely accurate weighing results. Following the execution of the experiment with the aforementioned dosing volume of concentration, it was utilised to calculate the initial and final delta weight of the wafer where it would impact quality of solar cell. Four wafers from each cassette were included in the definition of the current control measurement, and each wafer will be measured once every 6 hours.

A reflectometer is an optical device used to gauge the amount of light passing through a substance or object in relation to its wavelength. They are often used to gauge how reflective a specific solution, piece of glass, or gas is. For each of the recognized wavelength ranges, reflectometers also measure the diffusivity of light [4]. The amount of light that bounces off the surface of the wafer directly relates to its reflectivity measurement. As the current control measurement, three wafers with a six-hour cycle were chosen. Throughout the experiment, additional measurements will be added every six hours, using the same quantity of wafers and five different places to look for any anomalies. The ray tracing method, which is frequently employed to explain these occurrences, may be used to approximate pyramids with diameters of several micrometers. The height, size, and number of the pyramids may be determined by using a ZETA 3D microscope to inspect the surface of the pyramid. At least five points (four from each corner and one in the center) must be gathered before the average is calculated and further analysis is done. Theoretically, smaller pyramids with greater pyramid counts should result in better light absorption and less light reflection of the solar cell.

JMP, a statistical analysis programmed, was used in this study to examine patterns and gauge how each component affected the anticipated reaction. The non-normal distribution of the gathered data necessitated the use of the nonparametric Wilcoxon signed-rank test [5]. The control and experimental samples were compared in order to find any notable differences or similarities. To determine how any identified changes will affect the results, a 1 sigma comparison analysis was performed. To evaluate the experiment's success and spot areas for improvement, JMP was used to analyze the data, such as Delta Weight and Pyramid Formation. Based on the Prob [Z]-value being higher than 0.05, the analysis in Figure 5 showed that the control and experimental data were statistically comparable.



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
Control	963	5.1976547	1.9533162	0.0629447	5.0741298	5.3211795
Exp	965	5.4660472	2.3688605	0.0762563	5.3163996	5.6156947

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
Control	963	908200	928814	943.094	-1.687
Exp	965	951356	930743	985.861	1.687

2-Sample Test, Normal Approximation

S	Z	Prob>|Z|
908200	-1.68651	0.0917

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
2.8445	1	0.0917

Figure 5: Example of JMP analysis on data collection

The manual cell contacting station cetisPV-Contact1 is a multifunctional electric contacting tool made for solar cells with different bus bar layouts and sizes. To accommodate various cell types, it has adjustable bus bar widths and positioning guidance. It provides monitoring of metallization resistance and grid resistance when used with the optional cetisPV-GR electronic switching unit. The station and flash light box can be installed in a room with anti-reflective tissue, regulated lighting, and darkness. With capabilities including hysteresis measurements, resistance evaluations, database storage, and protocol building, the PVControl software package makes it simple to configure measurement settings.

Figure 6 demonstrates how the measurement PC that comes with the cell tester system automatically processes each measurement sample that goes through the CetisPV-Contact1. The cell tester system will then deliver the findings of the daily electrical data trend based on that day's average per-piece sample wafer data.

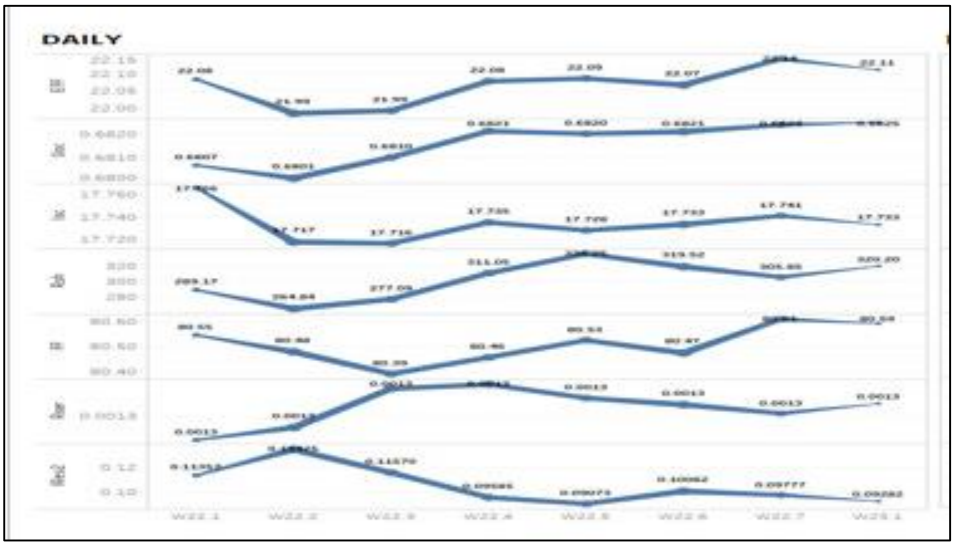


Figure 6: Data trend of each sample

3. Results and Discussion

The investigation and conclusions about the optimal dosage for BE baths are provided, along with details on how modifying the dose volume for BE baths influences advancements in formation of pyramids.

3.1 Result of Pyramid Formation

Figure 7 depicts the variation in pyramid formation between the sample experiment and sample control.

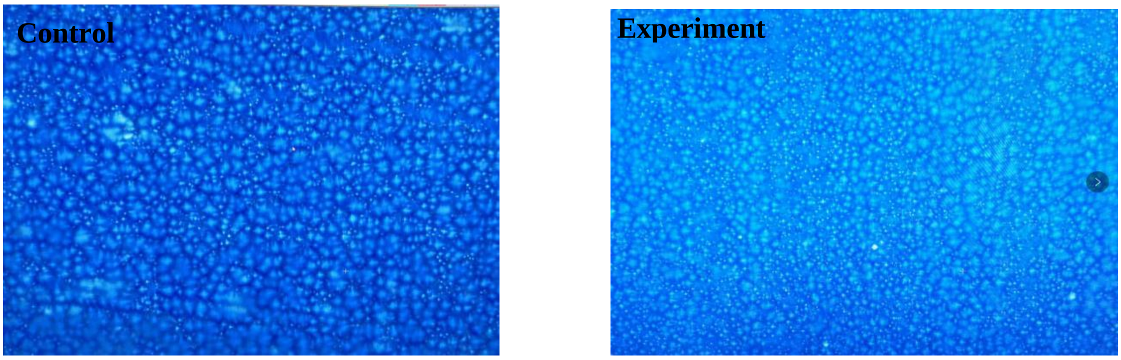
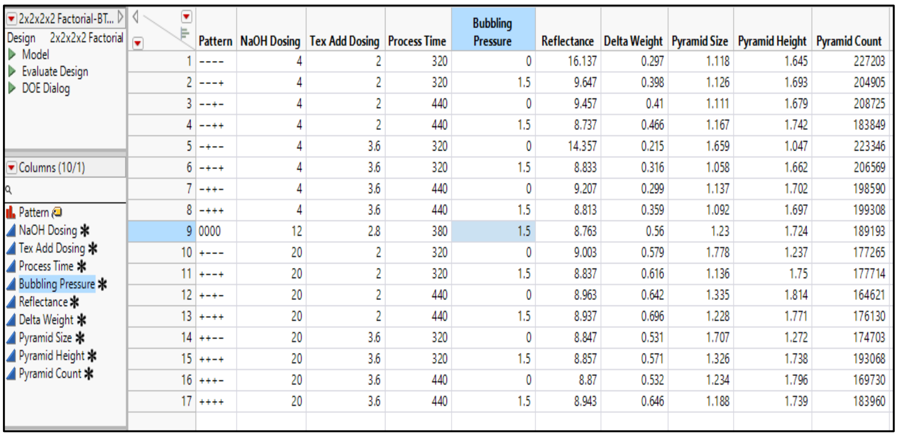


Figure 7: Pyramid Formation of control and experiment sample

Table 1 illustrates the results of the experiment's raw data collection using the selected measurement instrument. Pattern 0000 denotes the current setting for NaOH dosing, Textured Additive dosage, Process duration, and Bubbling pressure whereas pattern ++++ denotes the highest value for these parameters. In any case, ---- is the minimal setting for pattern's Bubbling pressure, Process Time, Textured Additive dosing, and NaOH dosing. The JMP Fractional Factorial Design template was then filled up with all of the measurement's raw data, as shown in Figure 8.

Table 1: Raw data experiment

Delta weight	Reflectance	Pyramid Size	Pyramid Height	Pyramid Count
0.297	16.137	1.118	1.645	227203
0.398	9.647	1.126	1.693	204905
0.41	9.457	1.111	1.679	208725
0.466	8.737	1.167	1.742	183849
0.215	14.357	1.659	1.047	223346
0.316	8.833	1.058	1.662	206569
0.299	9.207	1.137	1.702	198590
0.359	8.813	1.092	1.697	199308
0.56	8.763	1.23	1.724	189193
0.579	9.003	1.778	1.237	177265
0.616	8.837	1.136	1.75	177714
0.642	8.963	1.335	1.814	164621
0.696	8.937	1.228	1.771	176130
0.531	8.847	1.707	1.272	174703
0.571	8.857	1.326	1.738	193068
0.532	8.87	1.234	1.769	169730
0.646	8.943	1.188	1.739	183960



	Pattern	NaOH Dosing	Tex Add Dosing	Process Time	Bubbling Pressure	Reflectance	Delta Weight	Pyramid Size	Pyramid Height	Pyramid Count
1	----	4	2	320	0	16.137	0.297	1.118	1.645	227203
2	---+	4	2	320	1.5	9.647	0.398	1.126	1.693	204905
3	--+-	4	2	440	0	9.457	0.41	1.111	1.679	208725
4	--++	4	2	440	1.5	8.737	0.466	1.167	1.742	183849
5	-+--	4	3.6	320	0	14.357	0.215	1.659	1.047	223346
6	-+-+	4	3.6	320	1.5	8.833	0.316	1.058	1.662	206569
7	-++-	4	3.6	440	0	9.207	0.299	1.137	1.702	198590
8	-+++	4	3.6	440	1.5	8.813	0.359	1.092	1.697	199308
9	0000	12	2.8	380	1.5	8.763	0.56	1.23	1.724	189193
10	+---	20	2	320	0	9.003	0.579	1.778	1.237	177265
11	+--+	20	2	320	1.5	8.837	0.616	1.136	1.75	177714
12	+-+-	20	2	440	0	8.963	0.642	1.335	1.814	164621
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16	+++-	20	3.6	440	0	8.87	0.532	1.234	1.796	169730
17	++++	20	3.6	440	1.5	8.943	0.646	1.188	1.739	183960

Figure 8: JMP Fractional Factorial Design template with raw data

3.2 JMP Software Result

To maximize the creation of the Weight reduction & Texturing pyramid, the JMP Fractional Factorial Design suggests running 17 trial runs with varying variables. With P-values less than 0.05, the Pre-clean NaOH and Texturing Bubbling parameters significantly affect the desired results. The 2x2x2x2 Fractional Factorial Design template will be updated to include the raw data from the outcomes. Running the JMP Report Fit Model will forward the procedure to the following stage, as illustrated in Figure 9. The ideal setup ought to be shown on the Prediction Profiler, as shown in Figure 10, once the Report Fit Model creates the data based on the trial.

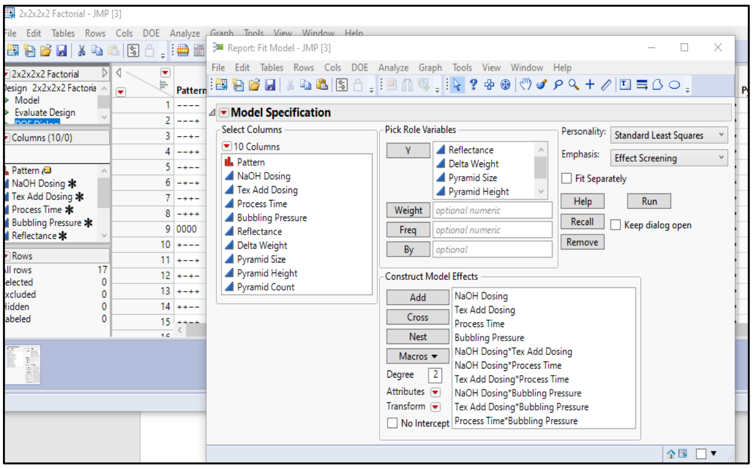

Figure 9: JMP Report Fit Model

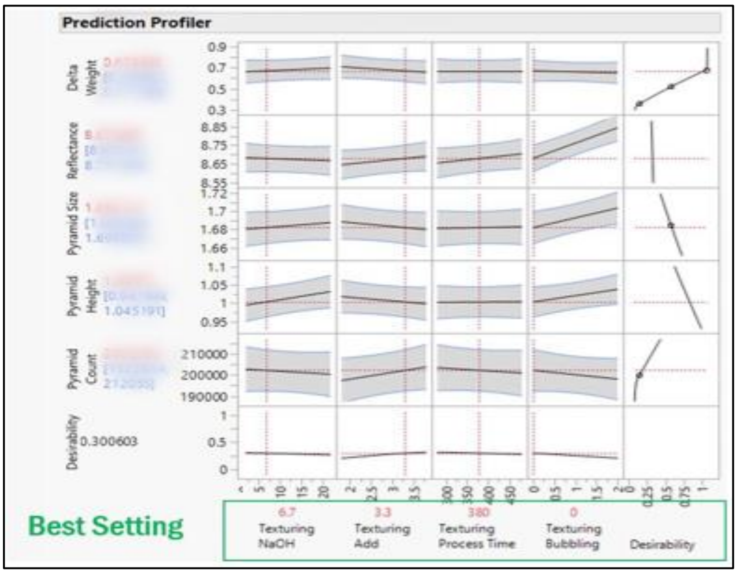

Figure 10: Prediction Profiler

The relationship between the dosage volume and the experiment's findings shows that the higher the NaOH dose, the lower the pyramid formation, however the higher the textured add dosing increase, at 17.86%, shows that the higher the Additive dosing, the higher the pyramid formation. According to Table 2 above, neither the process duration nor the bubbling pressure had an impact on the experiment's ultimate outcomes.

Table 2: Pattern Dosing Data

Pattern	Control	Experiment	Percentage
NaOH Dosing	12	6.7	-44.17%
Tex Add Dosing	2.8	3.3	17.86%
Process Time	380	380	0.00%
Bubbling Pressure	1.5	1.5	0.00%

The experiment findings shown the tested cell which is field factor (FF), the experiment's efficiency (EFF), short circuit current (Isc), and open circuit voltage (Uoc), as illustrated in Figure 11. Table 3 reveals that, despite a drop in the field factor (FF), the experiment's efficiency (EFF), short circuit current (Isc), and open circuit voltage (Uoc) all exhibit positive correlations. The rise in EFF

(0.19%), Isc (0.25%), and Uoc (0.06%) points to higher system performance as a result of the BE bath dosing volume being optimized and maybe improved cell design or decreased internal resistances. The FF, on the other hand, declines (-0.09%), indicating a deterioration in system performance overall, presumably brought on by ageing, degradation, or the use of inferior materials. A mean value for the experiment that is within 1 sigma of the control sample implies little effect on changes. With a p-value of 0.0001, the population distribution of the experiment sample's cells differs considerably from the control sample, indicating that the wafer's performance may have an impact on the cell's efficiency.

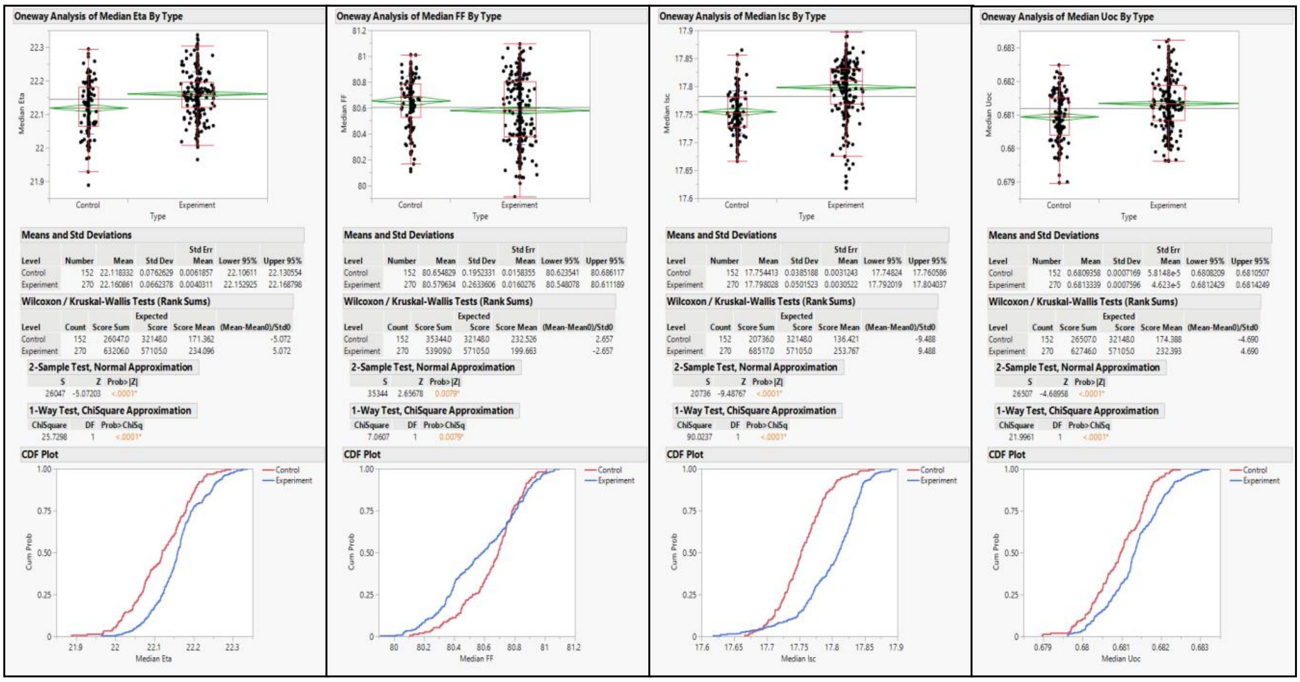

Figure 11: Tested Cell for EFF, FF, Isc and Uoc

Table 3: Electrical Parameter Data

Electrical parameter	Control	Experiment	Percentage
Efficiency (EFF)	22.1183	22.1680	0.19%
Field Factor (FF)	80.6548	80.5796	-0.09%
Short Circuit Current (Isc)	17.7544	17.798	0.25%
Open Circuit Voltage (Uoc)	0.6809	0.6813	0.06%

4. Conclusion

The results of the study demonstrate that the volume of the BE bath's dosage has a substantial impact on achieving the intended effects. Inadequate dose can cause inadequate pyramid formation and incomplete weight reduction, which can negatively affect reflectivity and the solar cell's ability to absorb light. On the other hand, a high dosage concentration could cause wafer surface defects and a drop in cell performance. The dosage volume of the BE bath must be optimized in order to provide the necessary outcomes for weight loss, pyramid formation, and cell performance in the production of solar photovoltaics. The report underlines how important dosage amount control is and offers recommendations for improving production while reducing costs and abiding by industry standards.

Acknowledgement

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