1. Introduction

This report documents the process development of amorphous silicon (a-Si) thin films deposited by plasma enhanced chemical vapor deposition (PECVD) using *Oxford PlasmaLab 100* system. Process development is done using Taguchi L9 method of design of experiments (DOE).

2. Tools and Techniques used

I. *Oxford PlasmaLab 100* PECVD system is used for deposition of a-Si films on SiO_2 films deposited on 100 mm (4-inch) <100> orientation Si wafers of thickness 525 ± 25 µm. Purpose of depositing SiO_2 film on Si wafer before deposition of a-Si is to create optical contrast which will enable optical measurements of a-Si film.

II. *Filmetrics F50* optical interferometer is used for measuring the thickness of deposited films and non-uniformity in thickness over the wafer.

III. *KLA Tencor P7* profilometer is used for measuring in-plane stress in SiO_2 and a-Si films.

IV. *Quantum XL* software is used for DOE (performing Taguchi design).

3. Process Development Methodology and Baseline Recipe

Process development is carried out based on four factors (process parameters) in the deposition recipe:

1. Silane (SiH_4) flow rate (sccm)
2. Argon (% of max Ar flow attainable, which is 1000 sccm in *Oxford PlasmaLab 100*)
3. Chamber pressure (mTorr) during deposition
4. RF Power (W)

Deposition rate, thickness non-uniformity and in-plane stress of the film are the process responses (measured outputs). To understand the effect of factors on the responses, 3 values (levels) for each factor are chosen: two extremes (low and high) and a mid-value. Analysis of responses for the 4 factors, gives a complete picture of process output trend for input variable range. Each process run will correspond to a unique combination of factors. Table 5.1.1 (see section 5) shows an example of possible input values.

Based on table 5.1.1, there are 81 unique combinations of the inputs. Each factor has 3 values and thus 3^4 (= 81) unique combinations (3 levels, 4 factors). To get an overall understanding of effect of each factor on the responses, 81 depositions would be required. Running 81 depositions is not practical in terms of time and resources. Using Taguchi L9 method (three level full factorial design) of DOE, these 81 combinations can be reduced to 9 which will still give the same complete picture of the effect of each input to the process outputs, required to optimize the process to get desired outputs (responses). Desired outputs of the process are defined to be high deposition rate, low non-uniformity of film thickness across the wafer, good optical quality, and low stress. The experiment is designed using *Quantum XL*. Once the values from table 5.1.1 are entered in the software, the method determines 9 different combinations of the factors which are sufficient to run as shown in table 5.1.2.

Process responses are measured with techniques such as optical interferometry and profilometry. Regression Analysis is run on the responses. To determine the effect of each factor on the responses, Pareto of Regression Coefficients is created. Further, Interaction Plots are created to understand the interaction between two factors on a response, based on which Main Effects Plots are used to understand the overall trend of a response on a given factor. Results of Main Effects Plots and Pareto of Regression Coefficients are discussed in section 5. Section 6 discusses the overall improvement in the process using DOE to modify the levels of factors and improvement in process with each stage. Section 7 shows the repeatability of the optimized process. Section 8 summarizes the process development and results.

Baseline Recipe

SiO_2 film of ~150 nm or ~600 nm is deposited on Si wafer pre-a-Si deposition. Details about SiO_2 thin film deposition using *Oxford PlasmaLab 100* can be found at the following URL: http://repository.upenn.edu/cgi/viewcontent.cgi?article=1034&context=scn_tooldata The following baseline recipe is used for film deposition after loading wafer in to the chamber via the load lock:

Units:

- Gas flow rate: standard cubic centimeters per minute (sccm)
- Pressure: millitorr (mT)
- Temperature: degrees Celsius (°C)
- High frequency (RF): Watts (W)

Step 1: System chamber is pumped at 5 mT base pressure for 1 minute with electrode temperature at 350 °C.

Step 2: Chamber is pre-heated and purged with Ar having flow rate of 1000 sccm at pressure set point of 1400 mT and electrode temperature at 350 °C for 1 minute (for 4-inch wafer). If you are processing pieces mounted on a carrier substrate, it is recommended that the time in step 2 be increased to 10 minutes to ensure temperature stabilization of your samples.

Step 3: a-Si is deposited in this step with following precursors and chamber conditions:

- Silane (10 % SiH_4 in Helium) flow rate: 200 sccm
- Argon (Ar) flow rate: 800 sccm (80% of 1000 sccm)
- Pressure: 1800 mT
- High frequency RF power: 75 W
- Low frequency LF power: 0 W
- Capacitor starting points: Capacitor #1: 77 %, Capacitor #2: 26 %
- Capacitor is set to auto
- Electrode temperature: 350 °C
- Deposition time set point is hh:mm:ss (hours:minutes:seconds)

Note: The above conditions are optimized based on results of third DOE (discussed in section 7).

Step 4: Chamber is pumped to base pressure and wafer removed from loadlock.

4. SiO_2 deposition: Pre-amorphous-Si deposition

Before the deposition of a-Si, SiO_2 is deposited to create optical contrast which will enable optical measurements of a-Si film. Three DOEs were performed sequentially (see section 5). For DOE-1, ~150 nm of SiO_2 was deposited. For DOE-2 and DOE-3, ~600 nm of SiO_2 was deposited. SiO_2 thickness was increased for DOE-2 and DOE-3 keeping in mind the future possibility of performing ellipsometry on a-Si films for studying optical properties. Higher SiO_2 thickness allows for easy ellipsometry as it creates larger contrast between deposited a-Si film and Si wafer used as substrate.

After SiO_2 deposition (and before a-Si deposition), the thickness and its non-uniformity across wafer were measured by *Filmetrics F50*. *Filmetrics F50* is equipped with a motorized stage allowing for the collection of full wafer maps. Thickness at 115 points per wafer was measured with 5 mm edge exclusion. Similarly, thickness and non-uniformity were measured for a-Si films post deposition. SiO_2 films deposited had ~2% of non-uniformity in thickness across the wafer.

In-plane stress is measured to study the effect of process inputs on film stress. To measure in-plane stress, 2D stress measurement option in *KLA Tencor P7* profilometer is used. Film stress is measured in two perpendicular directions in center: one (MFDWN) parallel to the major flat axis of the substrate (MFDWN) and second (MFRT) perpendicular to the major flat axis of the substrate as shown in figure 4.1. Before depositing a-Si film, radius of curvature of the SiO_2 deposited on Si substrate is measured using the 2D stress option. After the deposition of a-Si, its radius of curvature is measured. The software in *P7* calculates the stress of a-Si using the pre- and post-deposition radius of curvature and the input film thickness. The average film thickness of a-Si as measured by *Filmetrics F50* is used to calculate stress. Since the stress calculation uses average thickness and does not consider the non-uniformity, stress calculated is approximate.

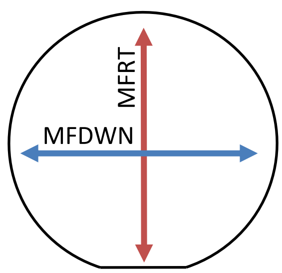

Figure 4.1: Stress measurement directions.

5. Design of experiments

To develop the a-Si thin film deposition process in *Oxford PlasmaLab 100*, an iterative approach to DOE was adopted. Three DOEs were performed, each consisting of 9 depositions of a-Si using different levels of factors. Table 5.1.1 consists of levels of factors for DOE-1 and table 5.1.2 consists of its Taguchi design. Subsequent DOE design consisted of modifying levels of one of the factor based on the previous DOE's responses. Table 5.2.1 consists of levels of factors for DOE-2 and table 5.2.2 consists of its Taguchi design. Based on DOE-1 responses, chamber pressure was increased in DOE-2. Thus, DOE-2 result reflected the effect of change in pressure. Table 5.3.1 consists of levels of factors for DOE-3 and table 5.3.2 consists of its Taguchi design. Based on DOE-2 responses, the argon flow was increased in DOE-3. Finally, to verify the repeatability of the process, optimized levels (input values of factors) from DOE 3 responses were used in 4 back-to-back depositions (discussed in section 7).

5.1 Design of experiment first iteration

Table 5.1.1 consists of levels of factors for DOE-1. For performing DOE; low, mid, and high values (3 levels) are taken. On performing Taguchi design, 9 combinations of the levels of factors are obtained as presented in table 5.1.2. As discussed earlier, 9 depositions were performed using inputs shown in table 5.1.2. These 9 depositions are designated as run numbers 1.1 to 1.9. The responses (measured as film thickness, non-uniformity, and in-plane stress) of each run are presented in table 5.1.3 and 5.1.4 which were measured as discussed in section 4. For DOE-1 runs, a-Si was deposited for 1 minute. Deposition rate was calculated from average film thickness and deposition time.

Input	Low	Mid	High
SiH_4 (sccm)	200	500	800
Ar (% of max flow)	5	10	15
Pressure (mTorr)	500	1000	1500
RF Power (W)	75	150	225

Table 5.1.1: 3 levels of 4 factors of DOE-1.

Run No.	SiH_4 (sccm)	Ar (%)	Pressure (mTorr)	RF Power (W)
1.1	200	5	500	75
1.2	200	10	1000	150
1.3	200	15	1500	225
1.4	500	5	1000	225
1.5	500	10	1500	75
1.6	500	15	500	150
1.7	800	5	1500	150
1.8	800	10	500	225

1.9	800	15	1000	75

Table 5.1.2: Taguchi design based on variables in table 5.1.

Run No.	Dep. Rate (nm/min.)	Average Thickness (nm)	Std. Dev. (nm)	Non-uniformity (%)
1.1	20.44	20.44	5.18	40.6
1.2	33.09	33.09	5.17	26.1
1.3	63.4	63.4	1.03	2.9
1.4	50.11	50.11	12.97	38.3
1.5	58.82	58.82	0.88	3.5
1.6	38.85	38.85	9.33	36
1.7	75.32	75.32	2.37	5.6
1.8	52.92	52.92	11.82	34.8
1.9	24.01	24.01	3.5	26

Table 5.1.3: Responses of DOE-1 (as measured by Filmetrics F50).

Run No.	Average Thickness (nm)	Stress (MPa) MFDWN	Stress (MPa) MFRT
1.1	20.44	-563.7	-213.1
1.2	33.09	-1165	-684.2
1.3	63.4	-766.4	-1020
1.4	50.11	-649.1	-1188
1.5	58.82	-844.1	-344
1.6	38.85	-501.6	-625.7
1.7	75.32	-845.8	-731.4
1.8	52.92	-938.3	-1265
1.9	24.01	-803.6	-60.46

Table 5.1.4: Responses of DOE-1 (in-plane stress as measured by KLA Tencor P7).

Regression analysis is performed on the responses of DOE-1. Based on regression analysis, main effects plots (marginal means) are created and pareto of regression analysis performed. A main effects plot graphs the mean of responses for each factor level, thus showing the effect on response due to each level. Pareto analysis shows the predominant factors for each response. Figures 5.1.1 to 5.1.4 are main effects plots of each response of DOE-1. Figure 5.1.5 is the pareto analysis of DOE-1.

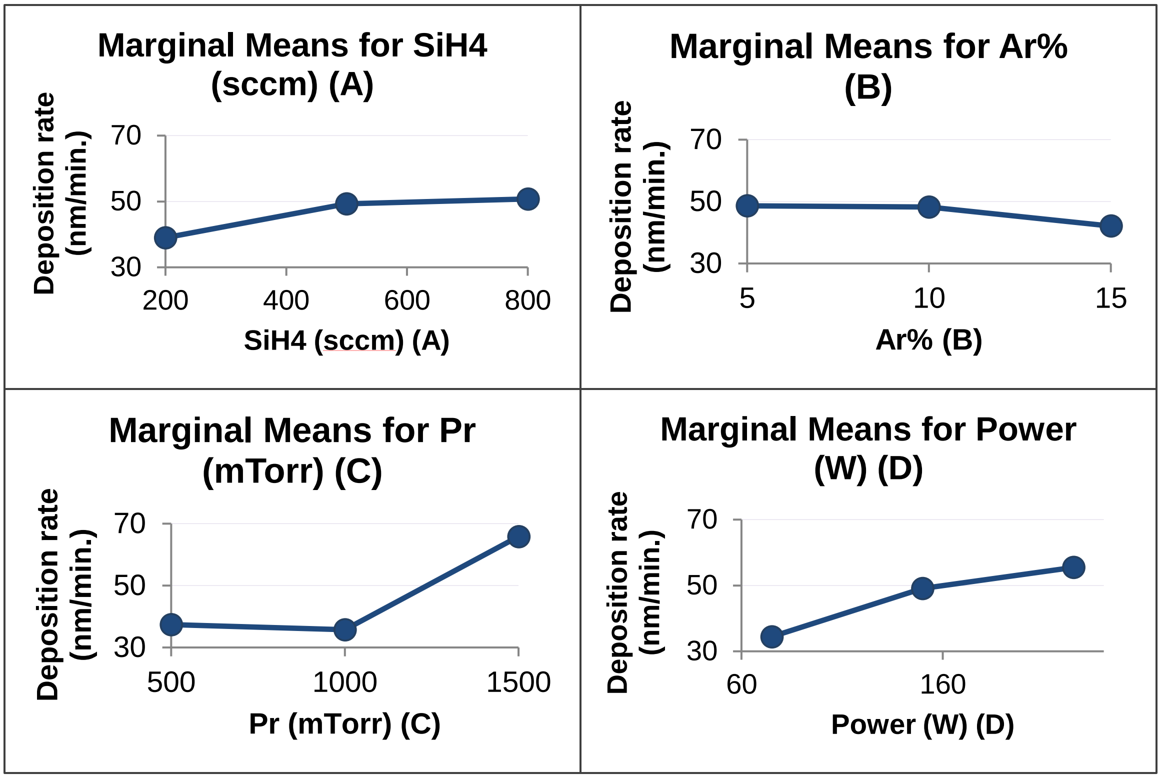

Figure 5.1.1: Main effects plot of deposition rate as response of DOE-1.

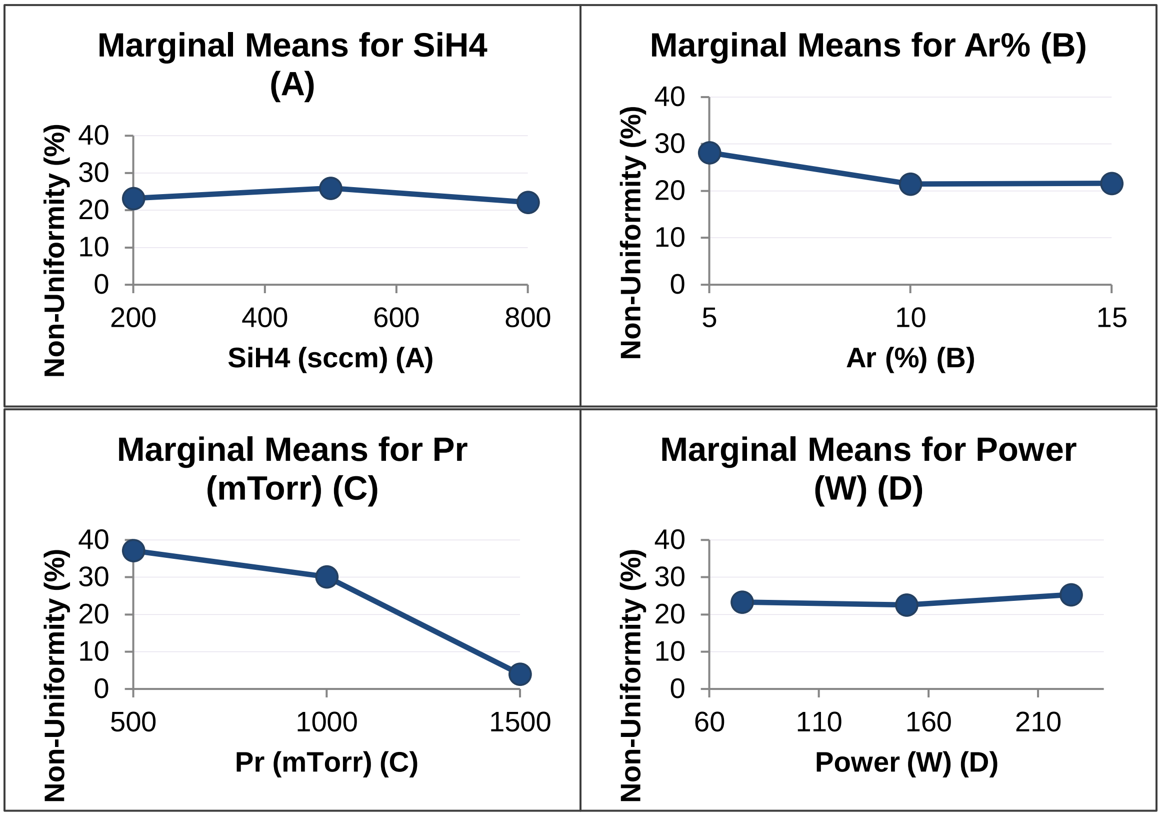

Figure 5.1.2: Main effects plot of non-uniformity as response of DOE-1.

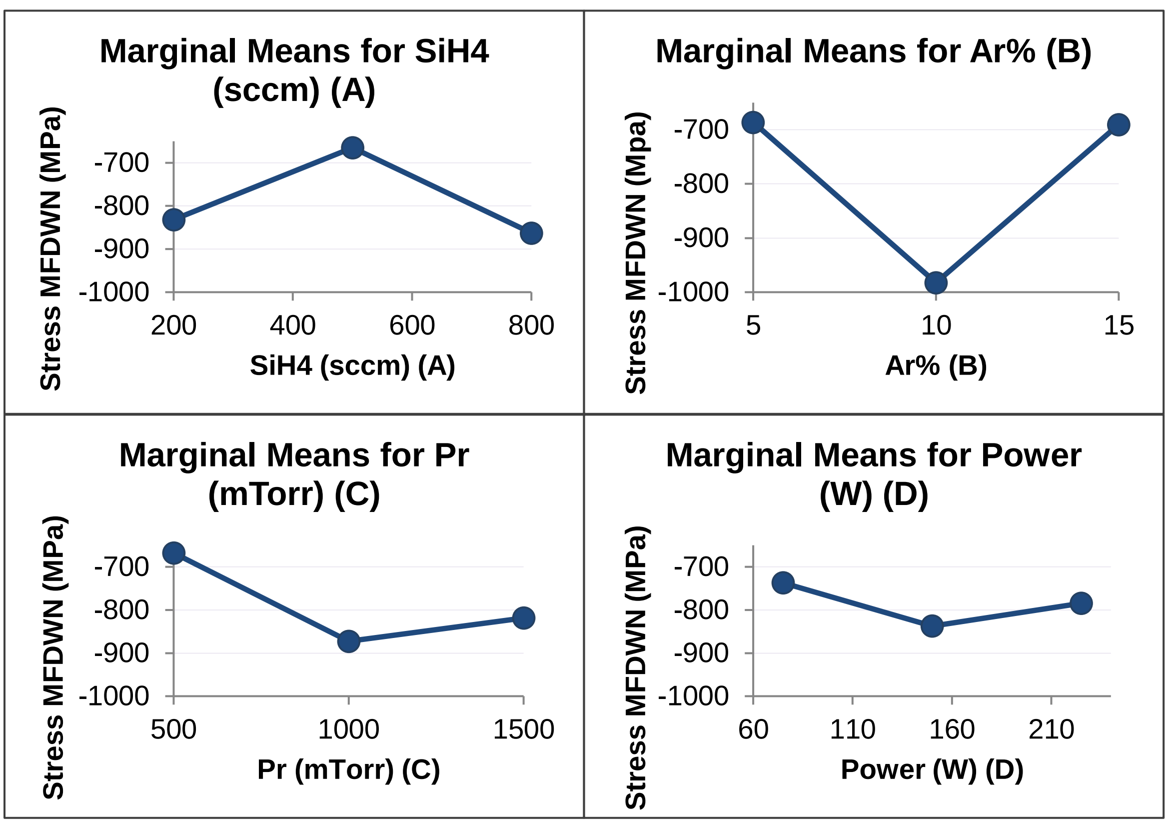

Figure 5.1.3: Main effects plot of stress MFDWN as response of DOE-1.

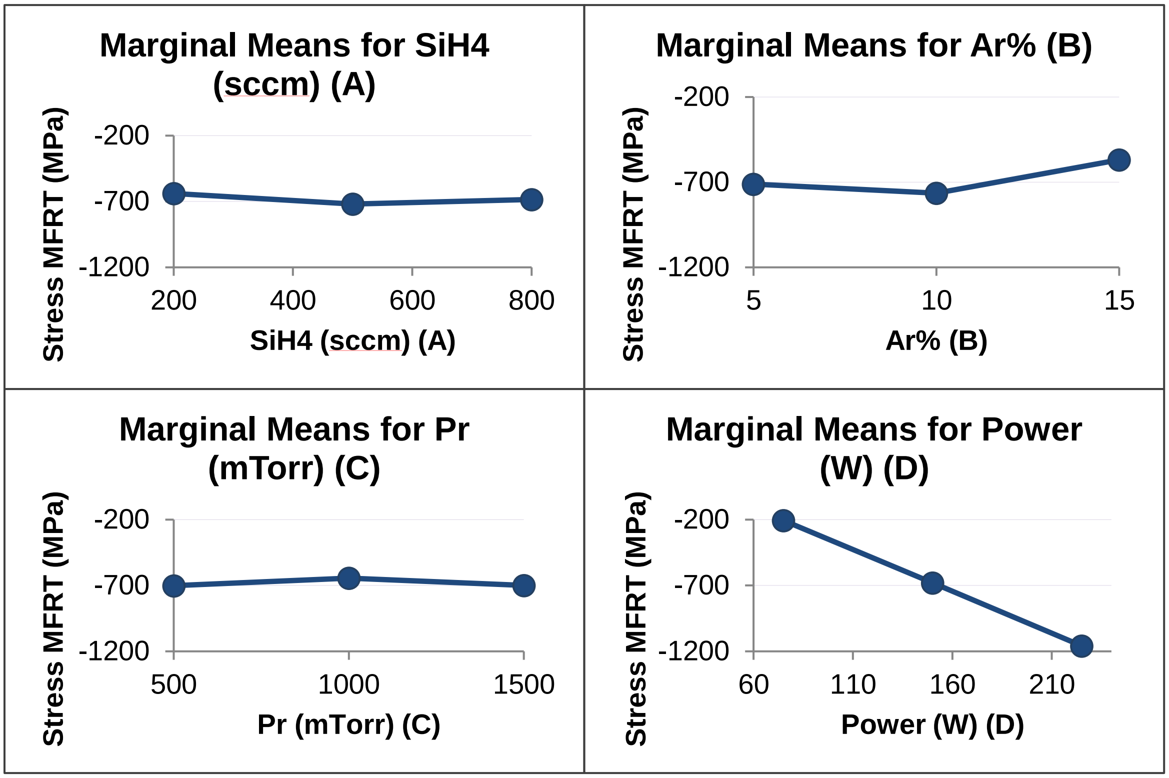

Figure 5.1.4: Main effects plot of stress MFRT as response of DOE-1.

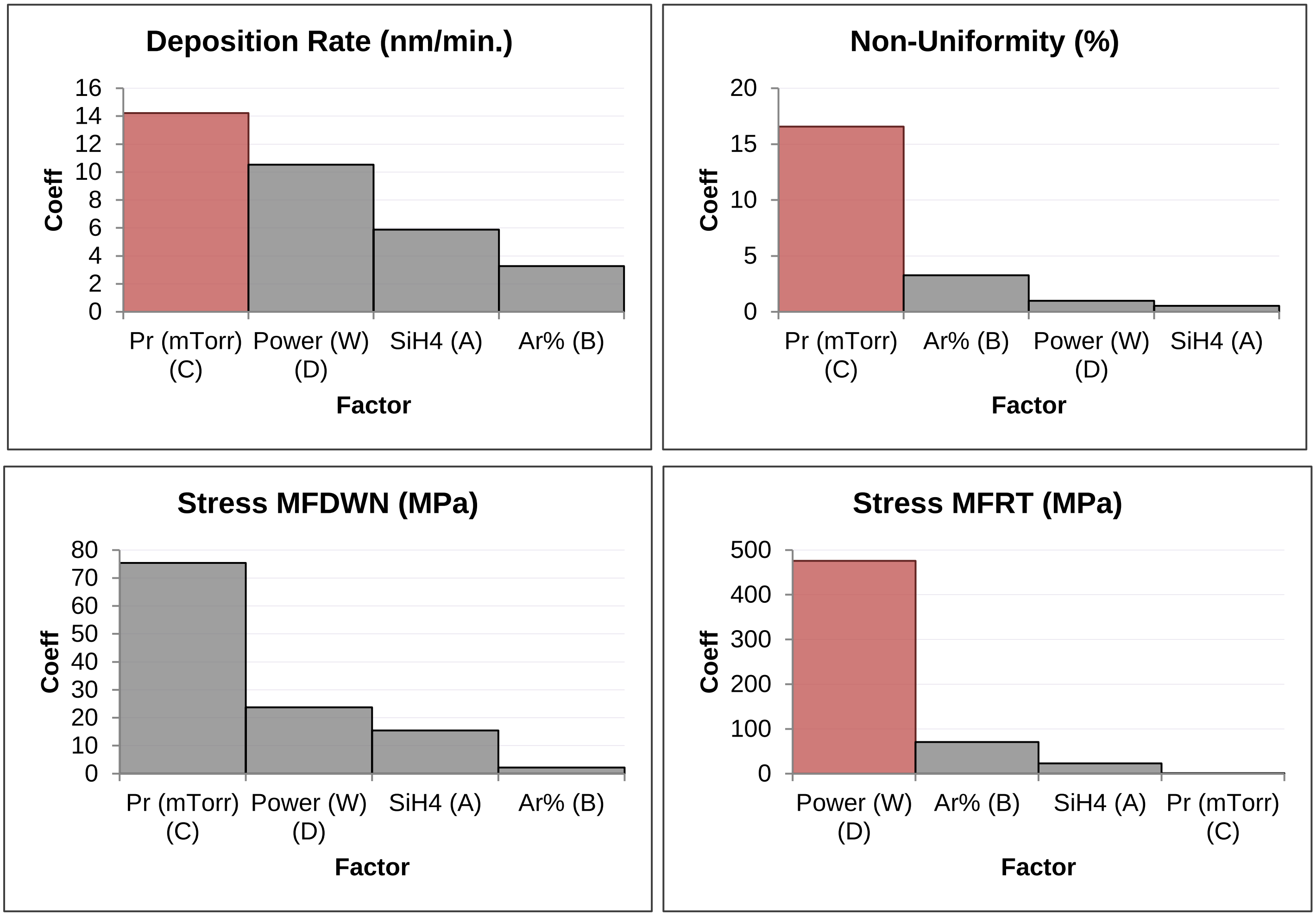

Figure 5.1.5: Pareto analysis of responses of DOE-1.

Table 5.1.3 shows that the deposition rate is low and for most runs, the non-uniformity is quite high. Table 5.1.4 shows that the deposited a-Si films are highly compressive and anisotropic. Low deposition rate, high non-uniformity and highly compressive films are not desirable process responses. To improve the responses, main effects plots are analyzed aided by Pareto analysis to determine next course of action.

From the Pareto analysis (figure 5.1.5), it is evident that pressure is the predominant factor in majority of responses, with relative dominance being higher in case of non-uniformity and MFDWN stress. Analyzing figure 5.1.1, it can be predicted that increasing the pressure would increase the deposition rate if other factors are unchanged. Similarly, from figure 5.1.2 it can be predicted that increasing the pressure would lower (improve) non-uniformity. Thus, increasing pressure is most likely to help improve the process as it would increase deposition rate and improve the uniformity of a-Si thickness over the wafer. To test this hypothesis based on the main effects plot and Pareto analysis, levels of pressure is changed for DOE-2. The pressure levels (in mTorr) are increased from 500, 1000 and 1500 to 1200, 1500 and 1800 for DOE-2 while keeping levels of other factors unchanged.

5.2 Design of experiment second iteration

Table 5.2.1 consists of levels of factors for DOE-2. Table 5.2.2 consists of Taguchi design for DOE-2. The 9 depositions are designated as run numbers 2.1 to 2.9. The responses of each run are presented in table 5.2.3 and 5.2.4. For DOE-2 runs, a-Si was deposited for 2 minutes.

Input	Low	Mid	High
SiH_4 (sccm)	200	500	800
Ar (% of max flow)	5	10	15
Pressure (mTorr)	1200	1500	1800
RF Power (W)	75	150	225

Table 5.2.1: 3 levels of 4 factors of DOE-2.

Run No.	SiH_4 (sccm)	Ar (%)	Pressure (mTorr)	RF Power (W)
2.1	200	5	1200	75
2.2	200	10	1500	150
2.3	200	15	1800	225
2.4	500	5	1500	225
2.5	500	10	1800	75
2.6	500	15	1200	150
2.7	800	5	1800	150
2.8	800	10	1200	225
2.9	800	15	1500	75

Table 5.2.2: Taguchi design based on variables in table 5.2.1.

Run No.	Dep. Rate (nm/min.)	Average Thickness (nm)	Std. Dev. (nm)	Non-uniformity (%)
2.1	14.415	28.83	1.81	11.7
2.2	59.35	118.7	1.76	2.8
2.3	61.7	123.4	2.42	3.4
2.4	85.95	171.9	5	5
2.5	69.4	138.8	1.22	2.8
2.6	77.15	154.3	7.73	7.6
2.7	93.65	187.3	5.28	4.8
2.8	89.4	178.8	31.93	30
2.9	61.6	123.2	5.23	6.8

Table 5.2.3: Responses of DOE-2 (as measured by Filmetrics F50)

Run No.	Average Thickness (nm)	Stress (MPa) MFDWN	Stress (MPa) MFRT
2.1	28.83	-677.3	-758.5
2.2	118.7	-865.2	-747.6
2.3	123.4	-772.3	-699.9
2.4	171.9	-1088	-1047
2.5	138.8	-691.3	-533.3
2.6	154.3	-930.9	-925.9
2.7	187.3	-900.8	-868
2.8	178.8	-1043	-988.9
2.9	123.2	-516.2	-515.4

Table 5.2.4: Responses of DOE-2 (in-plane stress as measured by KLA Tencor P7)

Regression analysis is performed on the responses of DOE-2. Based on regression analysis, main effects plots (marginal means) are created and Pareto of regression analysis performed. Figures 5.2.1 to 5.2.4 are main effects plots of each response of DOE-2. Figure 5.1.5 is the Pareto analysis of DOE-2. Effect of changing pressure levels in DOE-2 was analyzed. Based on the responses, and predominant factors, further course of action for process improvement was determined.

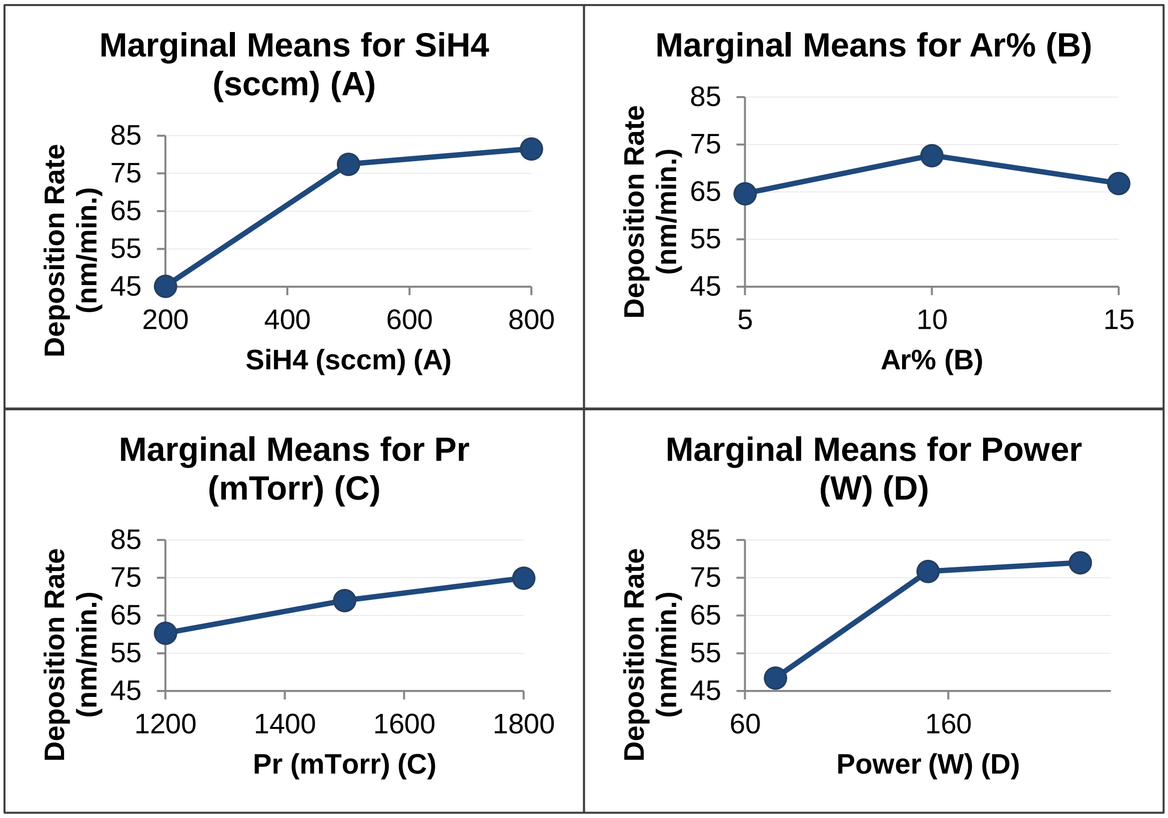

Figure 5.2.1: Main effects plot of deposition rate as response of DOE-2.

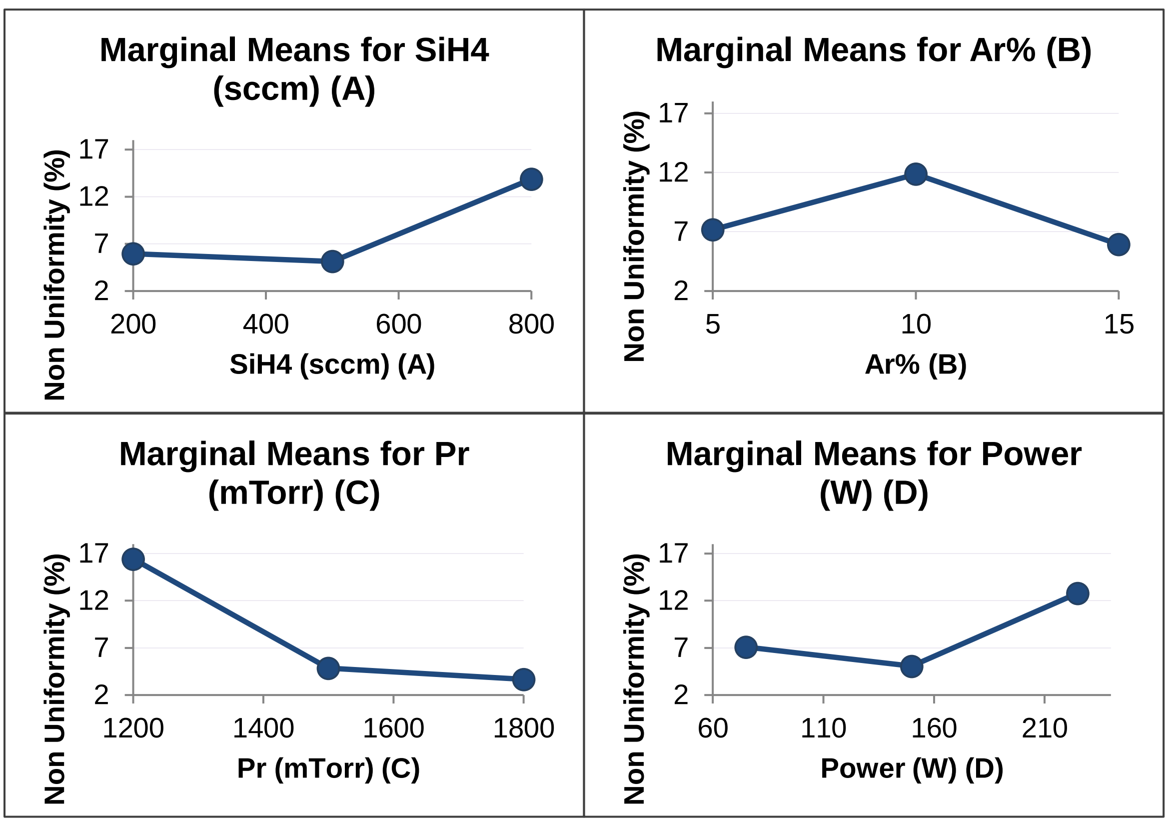

Figure 5.2.2: Main effects plot of non-uniformity as response of DOE-2.

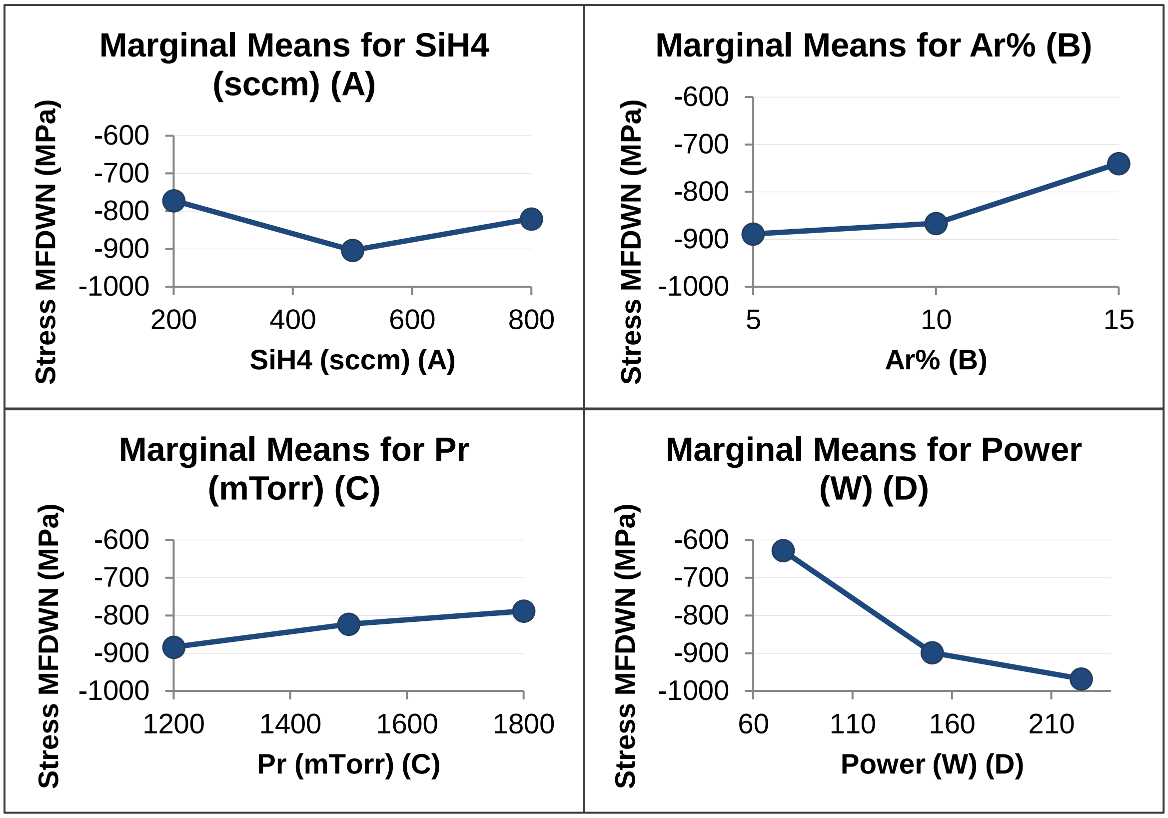

Figure 5.2.3: Main effects plot of stress MFDWN as response of DOE-2.

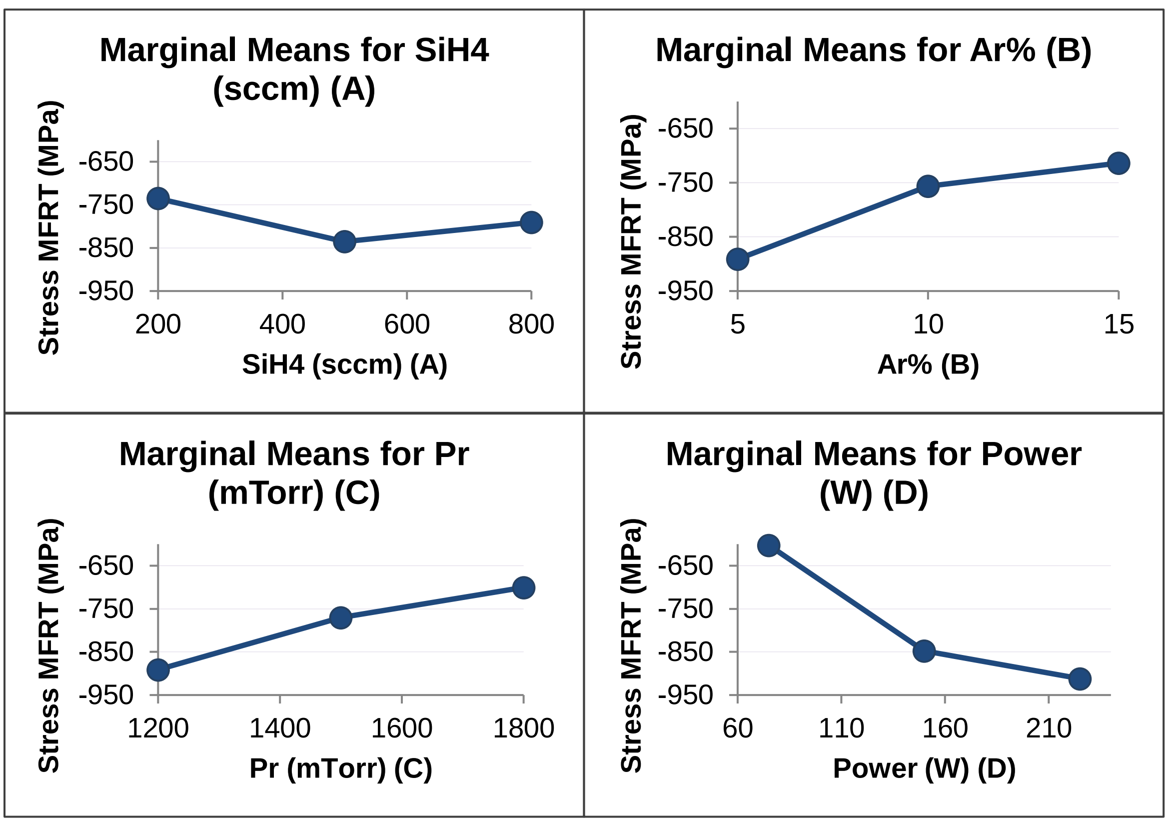

Figure 5.2.4: Main effects plot of stress MFRT as response of DOE-2.

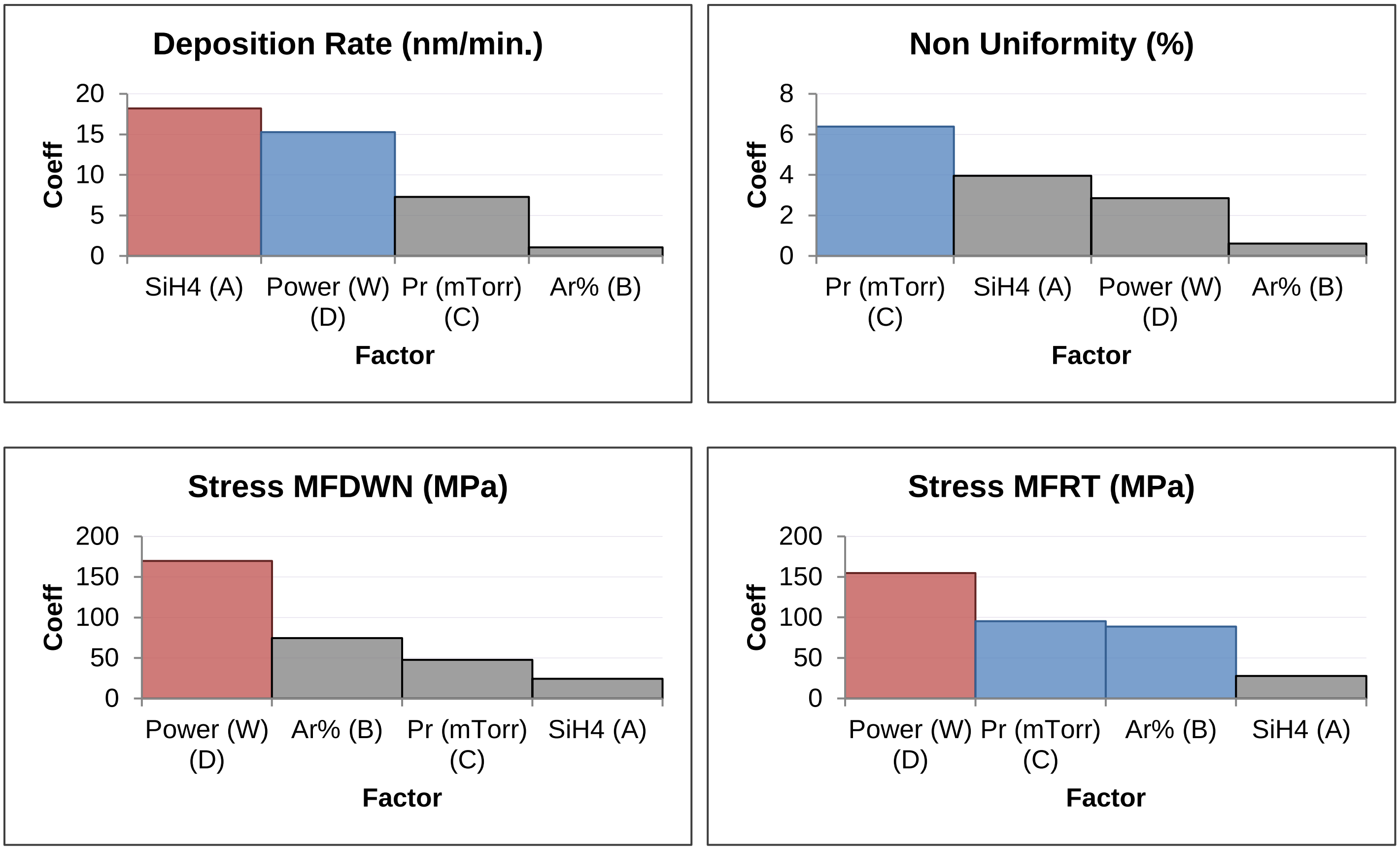

Figure 5.2.5: Pareto analysis of responses of DOE-2.

Table 5.2.3 shows that the deposition rate has improved and for most runs, the non-uniformity has improved (decreased) significantly. Table 5.2.4 shows that the deposited a-Si films are highly compressive but less anisotropic compared to DOE-1 responses. To improve the deposition rate and non-uniformity further and to lower to film stress, main effects plots are analyzed aided by Pareto analysis to determine next course of action.

From the Pareto analysis (figure 5.2.5), it is evident that power is the predominant factor in film stress, having similar weightage on both MFDWN and MFRT. Analyzing figure 5.2.1, for silane flow rate and power, the effect relatively saturates with increase in level. Similarly, from figure 5.2.2 increasing the silane flow rate and power degrades the uniformity. Thus, no change is made to silane flow rate or power in next DOE. From figure 5.2.1 and 5.2.2, it is proved that increase in pressure improved deposition rate and uniformity. Figure 5.2.3 and 5.2.4 show that pressure increase also tends to lower film stress. Pressure can't be increased more but figure 5.2.3 and figure 5.2.4 predict that increased argon could lower film stress while silane flow rate has no significant effect on film stress, also evident in Pareto analysis. Thus, to avoid degrading deposition rate and uniformity, silane flow rate and power are kept unchanged for next DOE and argon increase is predicted to lower film stress. To test this hypothesis based on the main effects plot and Pareto analysis, levels of argon are changed for DOE-3. The argon levels (in %) are increased from 5, 10 and 15 to 20, 50 and 80 for DOE-3 while keeping levels of other factors unchanged. For overall improvement in DOE-2 responses compared to DOE-1, see section 6 (figures 6.2 – 6.4 and table 6.2).

5.3 Design of experiment third iteration

Table 5.3.1 consists of levels of factors for DOE-3. Table 5.3.2 consists of Taguchi design for DOE-2. The 9 depositions are designated as run numbers 3.1 to 3.9. The responses of each run are presented in table 5.3.3 and 5.3.4. For DOE-3 runs, a-Si was deposited for 2 minutes.

Input	Low	Mid	High
SiH_4 (sccm)	200	500	800
Ar (% of max flow)	20	50	80
Pressure (mTorr)	1200	1500	1800
RF Power (W)	75	150	225

Table 5.3.1: Input values for third DOE.

Run No.	SiH_4 (sccm)	Ar (%)	Pressure (mTorr)	RF Power (W)
3.1	200	20	1200	75
3.2	200	50	1500	150
3.3	200	80	1800	225
3.4	500	20	1500	225
3.5	500	50	1800	75
3.6	500	80	1200	150
3.7	800	20	1800	150
3.8	800	50	1200	225
3.9	800	80	1500	75

Table 5.3.2: Taguchi design based on variables in table 5.3.1.

Run No.	Dep. Rate (nm/min.)	Average Thickness (nm)	Std. Dev. (nm)	Non-uniformity (%)
3.1	46.635	93.27	0.93	2
3.2	59.9	119.8	1.11	2
3.3	52.85	105.7	2.15	5.8
3.4	93.15	186.3	3.12	5.5
3.5	69.45	138.9	1.84	3.2
3.6	87.4	174.8	4.51	6.1
3.7	89.35	178.7	4.65	5.5
3.8	111.85	223.7	8.71	6.1
3.9	74.25	148.5	1.55	1.8

Table 5.3.3: Responses of DOE-2 (as measured by Filmetrics F50)

Run No.	Average Thickness (nm)	Stress (MPa) MFDWN	Stress (MPa) MFRT
3.1	93.27	-399	-367.9
3.2	119.8	-297.2	-277.3
3.3	105.7	-310.8	-313.2
3.4	186.3	-717.2	-707.2
3.5	138.9	-296.9	-291.3
3.6	174.8	-378.2	-417.1
3.7	178.7	-567.6	-563.9
3.8	223.7	-657.8	-650.4
3.9	148.5	-237.1	-329.5

Table 5.3.4: Responses of DOE-2 (in-plane stress as measured by KLA Tencor P7)

Figures 5.3.1 to 5.3.4 are main effects plots of each response of DOE-3. Figure 5.3.5 is the pareto analysis of DOE-3. Effect of changing argon levels in DOE-3 was analyzed. Based on the responses, and predominant factors, repeatability check based on an optimized level of each factor was performed by doing 4 consecutive depositions (discussed in section 7). It was noticed that the film thickness was higher towards the edge. To check that, 5 mm edge exclusion wafer maps were compared to 8 mm edge exclusion wafer maps measured by *Filmetrics F50*. Table 5.3.5 shows the difference in non-uniformity for 5 mm and 8 mm edge exclusion. It can be deduced that there is sudden increase in thickness near the edge of the wafer (~7 mm from the edge). Note that the measurements in table 5.3.3 and 5.3.4 correspond to 5 mm edge exclusion wafer maps.

Run No.	5 mm edge exclusion Non-uniformity (%)	8 mm edge exclusion Non-uniformity (%)
3.1	2	1.9
3.2	2	0.9
3.3	5.8	2.1
3.4	5.5	1
3.5	3.2	1
3.6	6.1	2.2
3.7	5.5	2.7
3.8	6.1	4.4*
3.9	1.8	1.8

Table 5.3.5: Edge exclusion comparison (*was 12 mm edge exclusion)

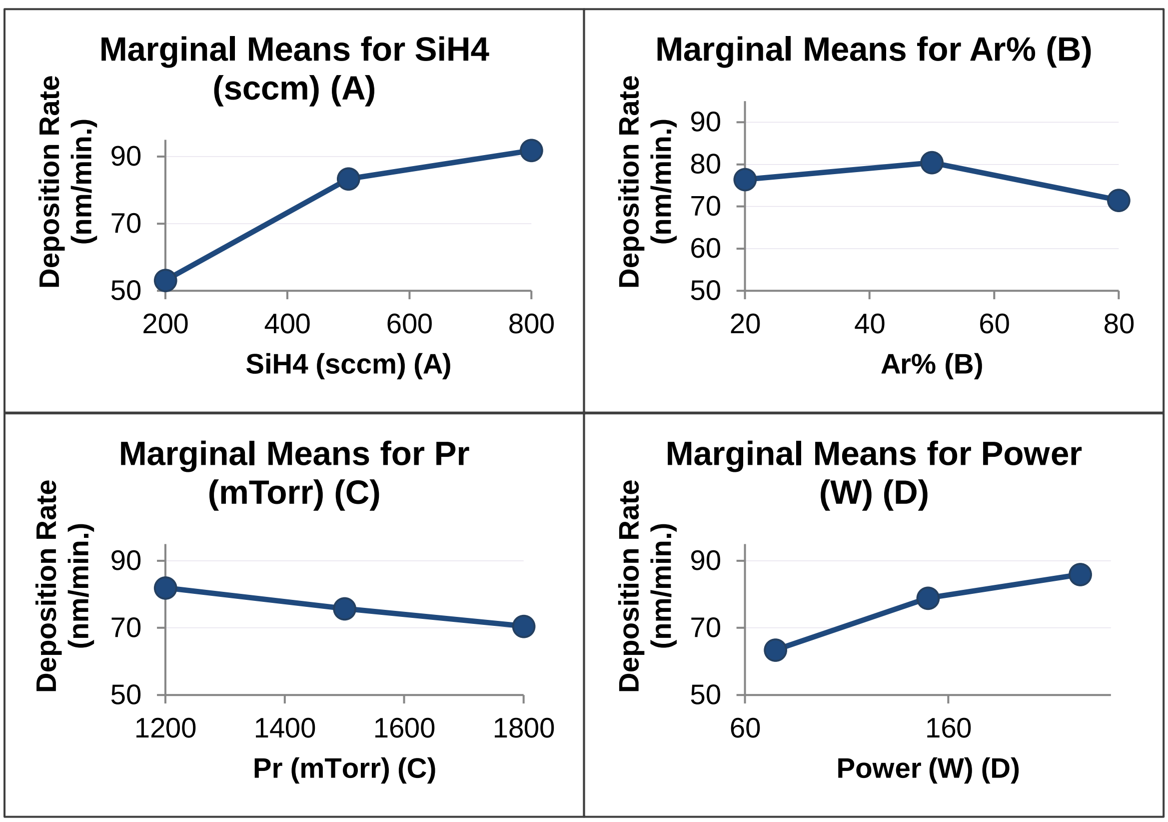

Figure 5.3.1: Main effects plot of deposition rate as response of DOE-3.

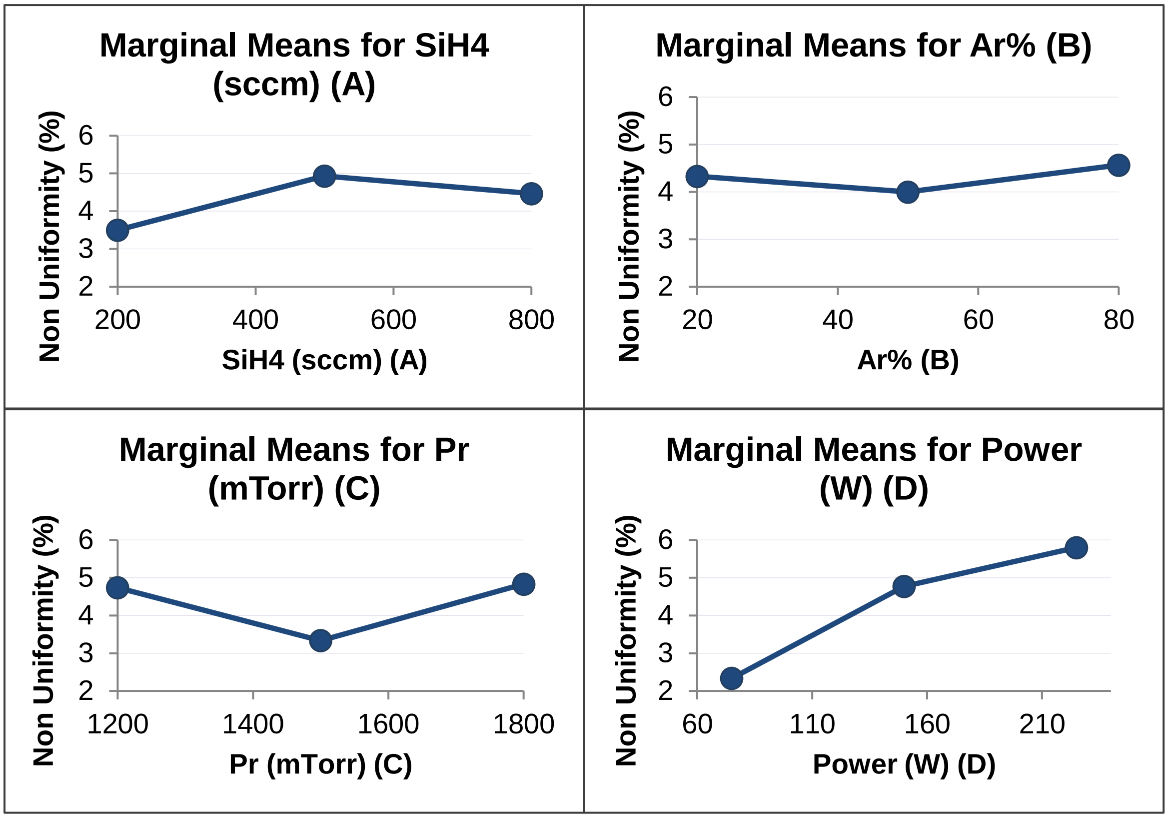

Figure 5.3.2: Main effects plot of non-uniformity as response of DOE-3.

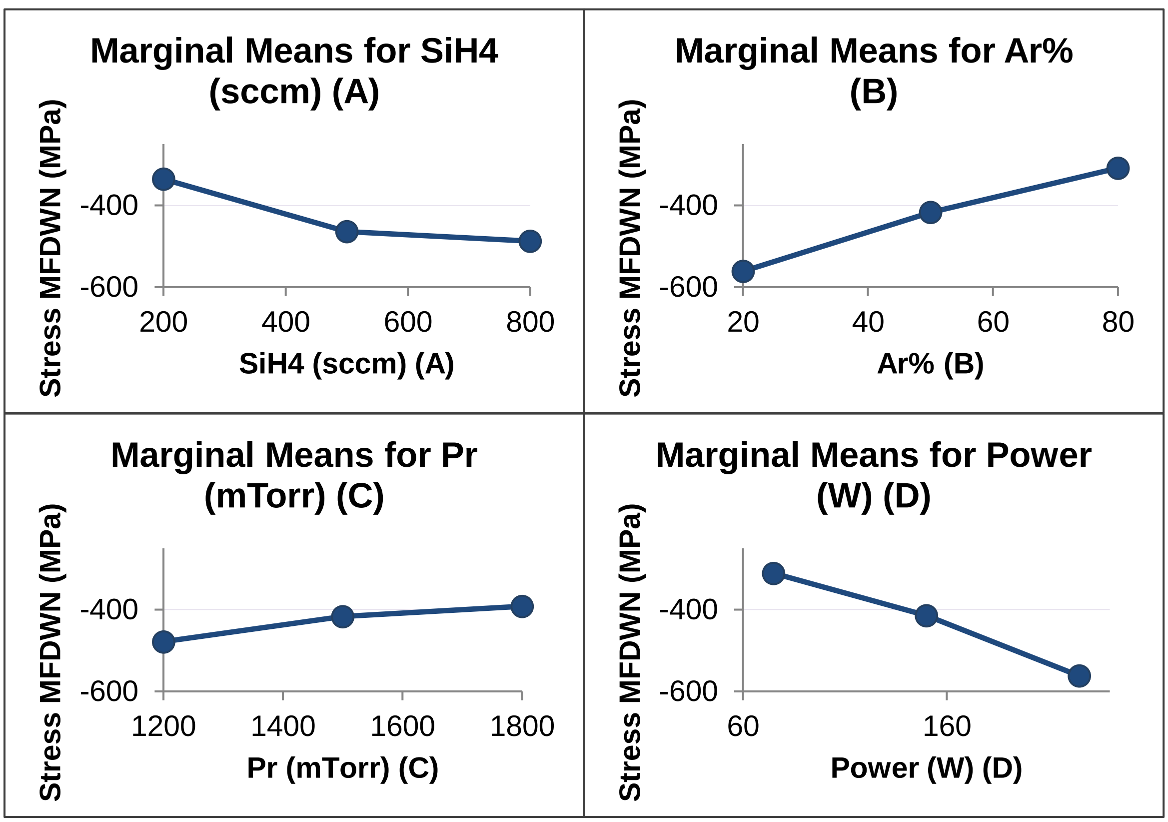

Figure 5.3.3: Main effects plot of stress MFDWN as response of DOE-3.

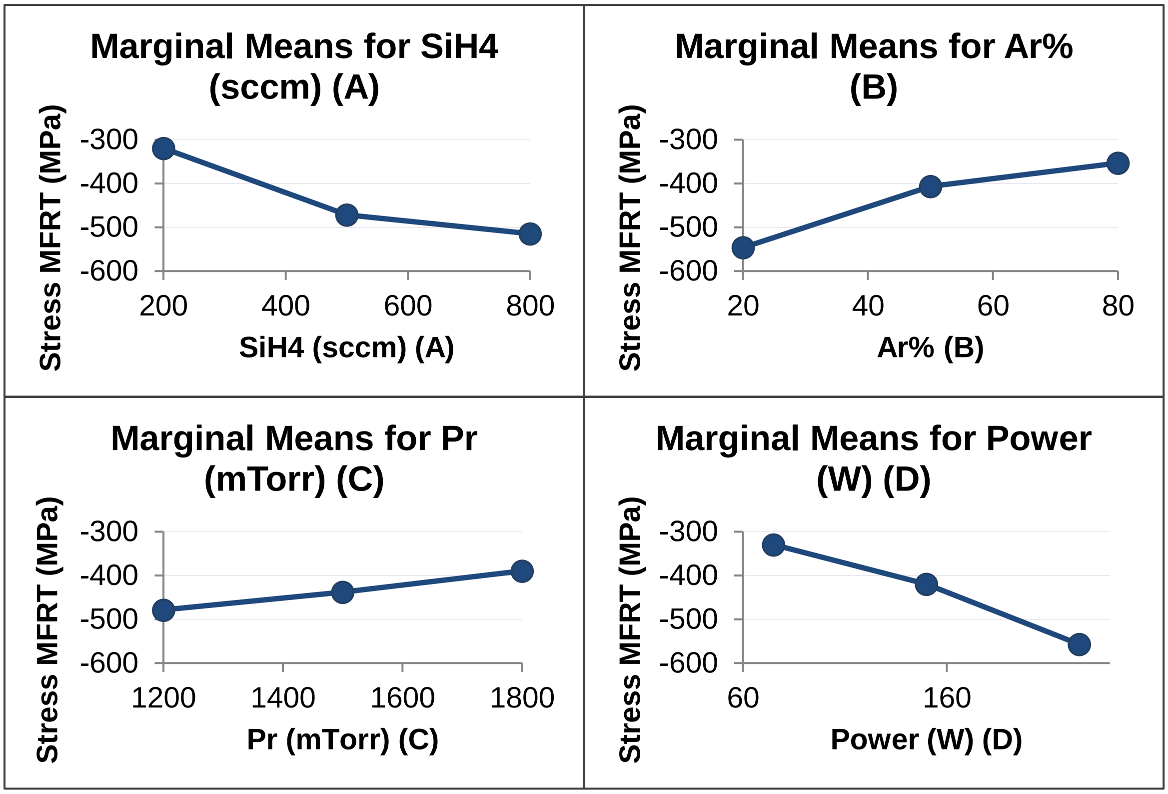

Figure 5.2.4: Main effects plot of stress MFRT as response of DOE-3.

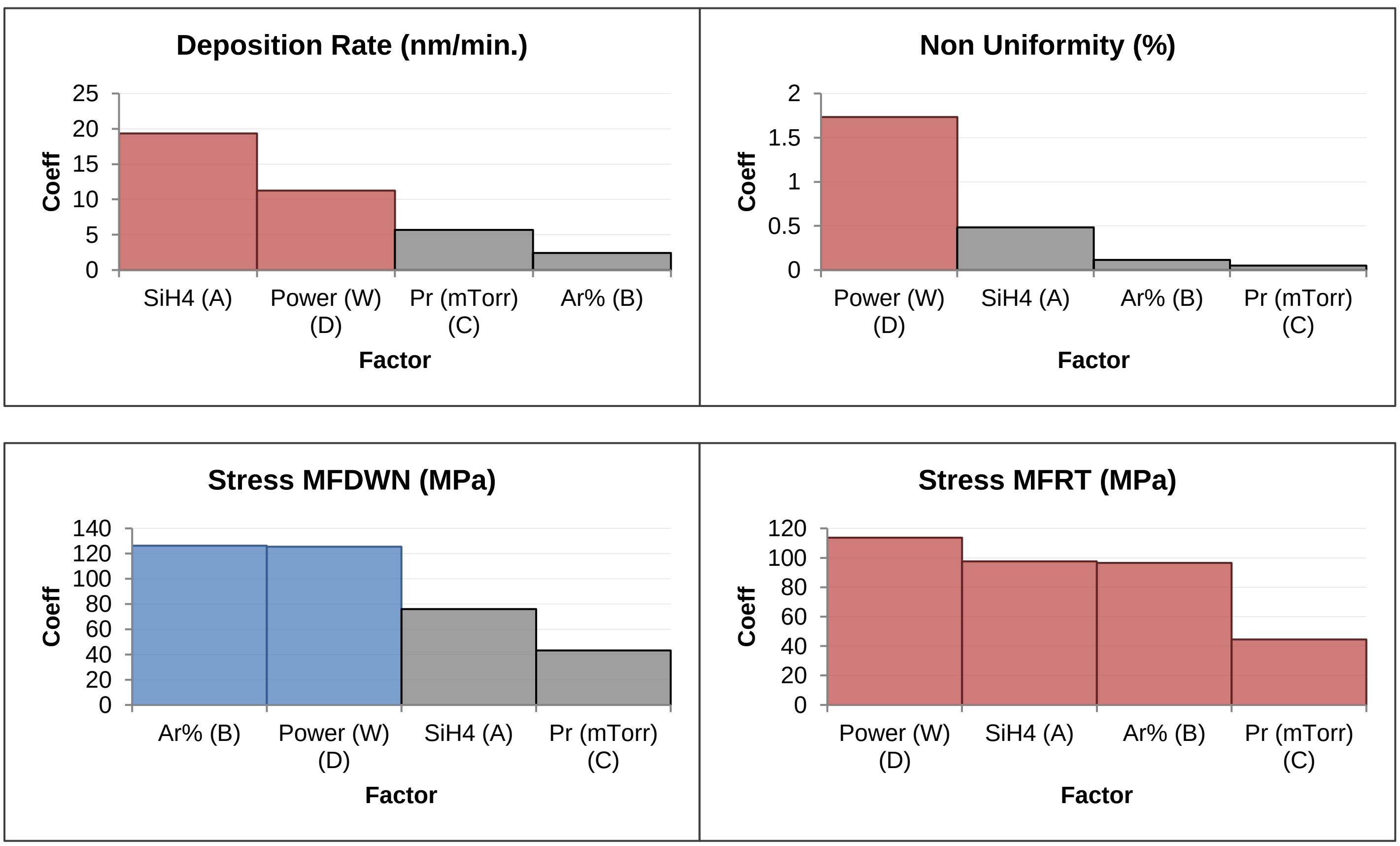

Figure 5.3.5: Pareto analysis of responses of DOE-3.

Table 5.3.3 shows that the deposition rate has improved, the non-uniformity has further improved (decreased). If 8 mm edge exclusion is considered in wafer mapping, except one sample, all have non-uniformity less than 3%. Table 5.1.4 shows that the deposited a-Si films are less compressive compared to DOE-1 or DOE-2 and highly anisotropic. Overall comparison and improvement in going from DOE-1 to DOE-3 is discussed in section 6.

Pareto analysis (figure 5.3.5) and main effects plots of DOE-3 are used to select one value of each factor to test for process optimization and repeatability. From main effects plot, it is seen that silane flow rate affects deposition rate the most (figure 5.3.1), with lower flow decreasing the deposition rate. While argon has no significant effect on deposition rate (figure 5.3.1) and non-uniformity (figure 5.3.2), higher argon can decrease in-plane stress (figures 5.3.3 and 5.3.4). Lower power decreases the deposition rate (figure 5.3.1) but improves uniformity (figure 5.3.2) and lowers in-plane stress (figures 5.3.3 and 5.3.4). Higher pressure also decrease the in-plane stress (figures 5.3.3 and 5.3.4).

6. Comparing design of experiment iterations

Using three DOE iterations, deposition rate was increased, non-uniformity was significantly lowered, and in-plane stress was lowered as well as made isotropic. As comparison, run 1.1 from DOE-1 and run 3.9 from DOE-3 are presented in figure 6.1 and table 6.1. Figure 6.1 shows the wafer maps as measured by *Filmetrics F50* of the two samples. Table 6.1 compares the measurements.

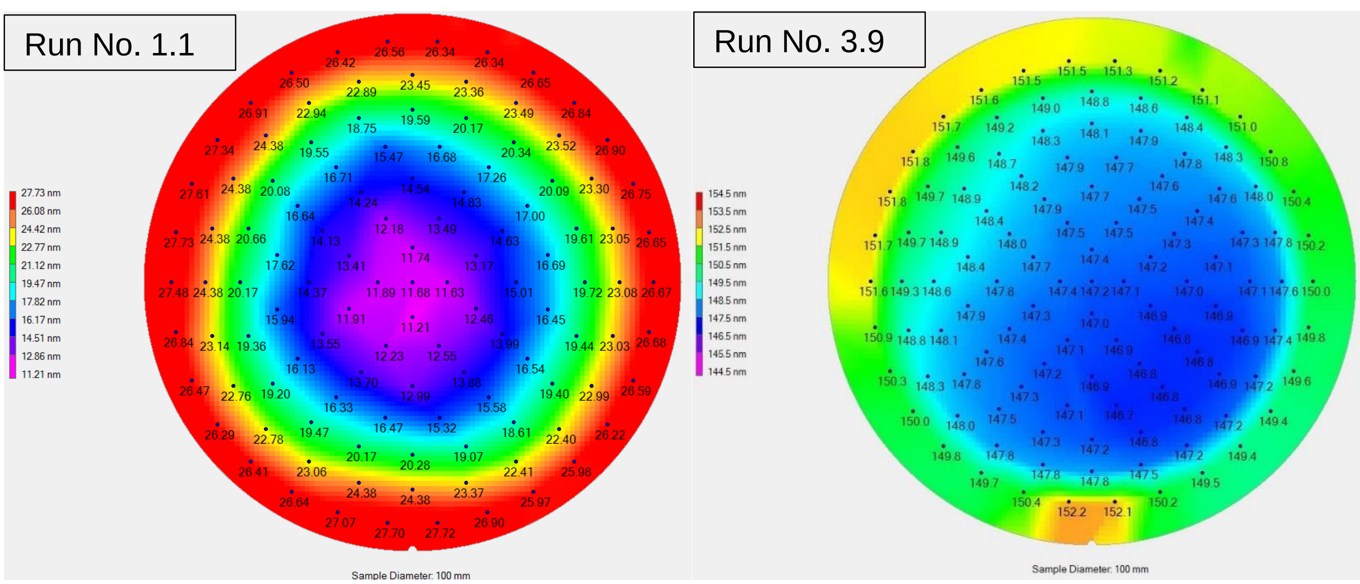

Figure 6.1: Comparing two runs from DOE-1 and DOE-3.

	Run No. 1.1	Run No. 3.9
Deposition Rate (nm/min.)	20.44	74.25
Average thickness	20.44	148.5
Thickness Std. Dev. (nm)	5.18	1.55
Non-uniformity (%)	40.6	1.8
Stress (MPa) MFDWN	-563.7	-237.1
Stress (MPa) MFRT	-237.1	-329.5

Table 6.1: Data supporting figure 6.1.

The change in responses with each DOE iteration can be seen in figures 6.2-6.4. Figure 6.1 compares the deposition rate among the three DOE. On an average, the deposition rate increased with each DOE iteration. Figure 6.2 compares the non-uniformity among the three DOE. On an average, the non-uniformity decreased with each DOE iteration with significant decrease from DOE-1 to DOE-2 and then further improvement in DOE-3. Figure 6.4 compares the in-plane stress among the three DOE. With each iteration, film stress has decreased and become isotropic. DOE-3 resulted in highly isotropic film stress. Table 6.2 presents the average of the responses (averaged over 9 runs) of each DOE. From DOE-1 to DOE-2, average deposition rate increased ~1.5 times while average non-uniformity decreased by a factor of ~3. From DOE-2 to DOE-3, average deposition rate increased marginally while average non-uniformity and average film stress decreased by a factor of ~2 along with highly isotropic stress.

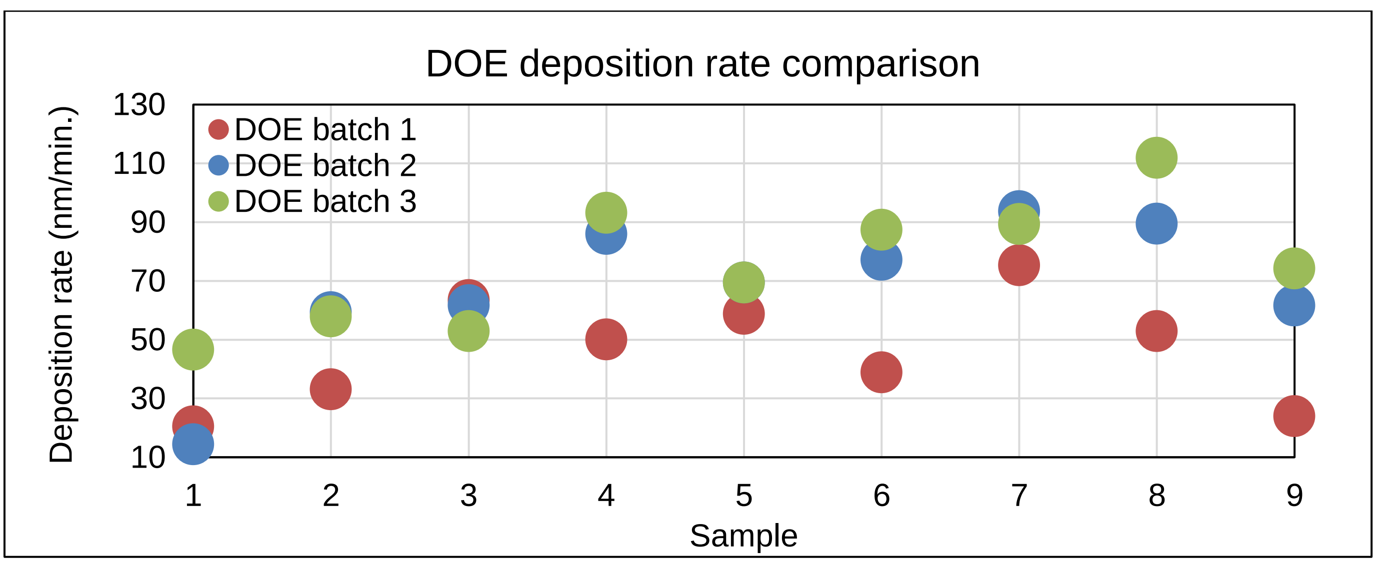

Figure 6.2: Comparison of change in deposition rate with each DOE iteration.

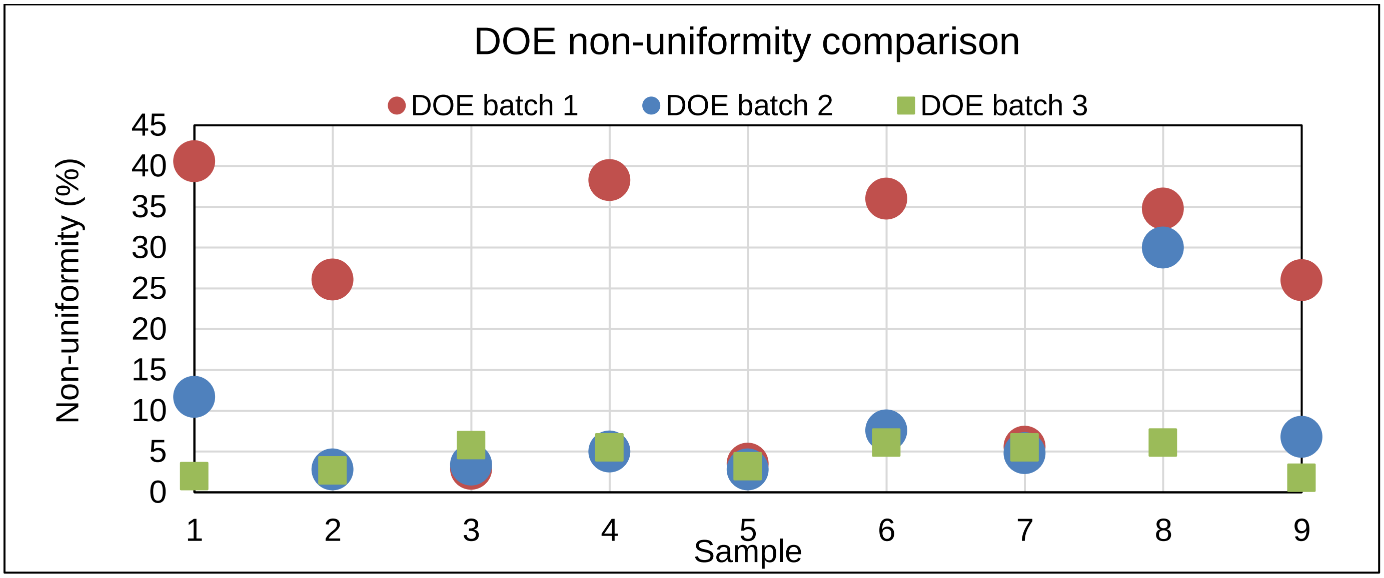

Figure 6.3: Comparison of change in non-uniformity with each DOE iteration.

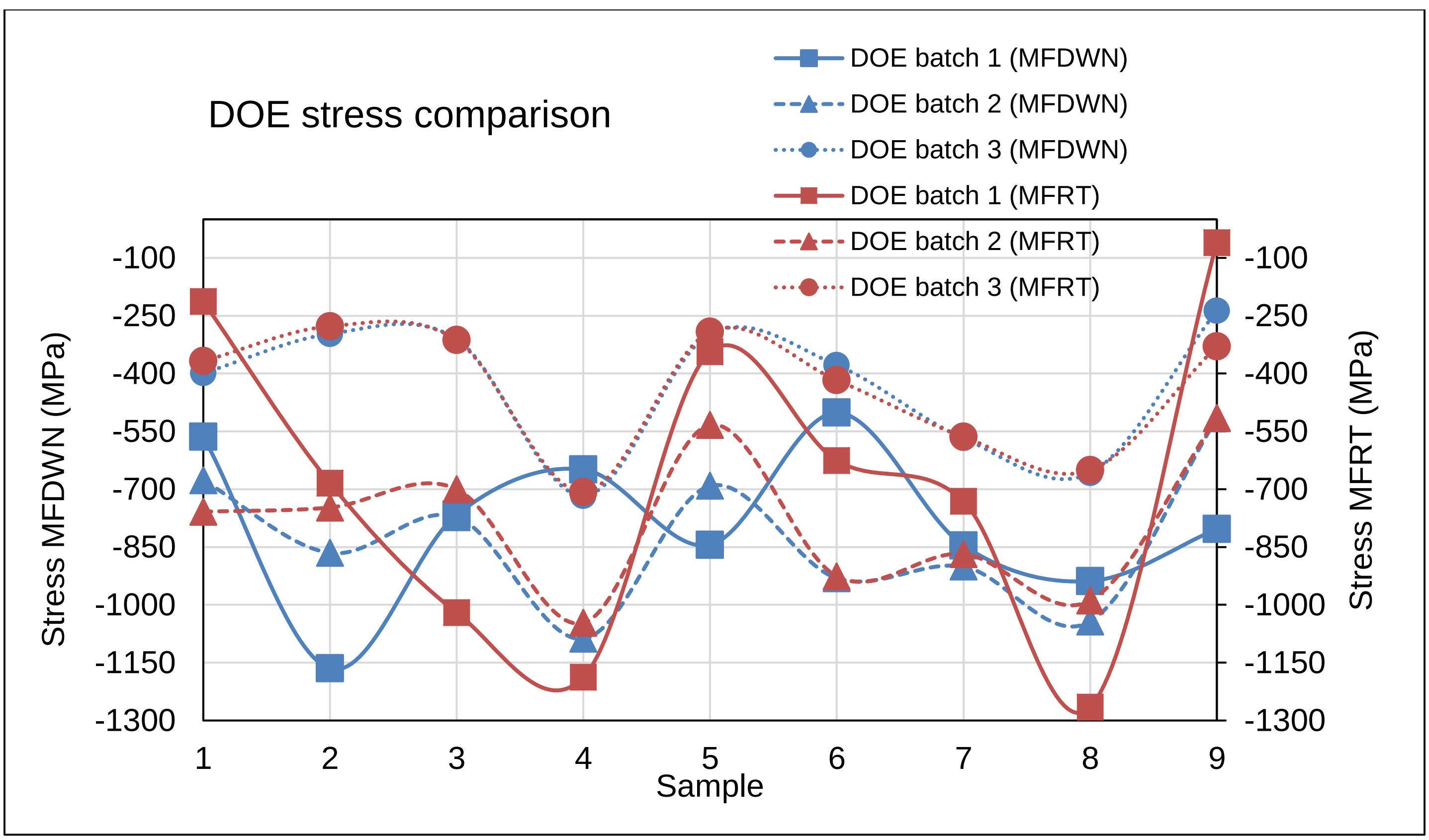

Figure 6.4: Comparison of change in stress with each DOE iteration.

Average	DOE 1	DOE 2	DOE 3
Dep. rate (nm/min.)	46.33	68.07	75.87
Non-uniformity (%)	23.76	8.32	4.07
Stress (MPa) MFDWN	-786.4	-831.7	-429.1
Stress (MPa) MFRT	-681.3	-787.2	-435.3

Table 6.2: Comparison of average of responses of each DOE iteration.

7. Optimization and Repeatability

Based on conclusions from responses of DOE-3 as discussed in section 5.3, low silane flow rate, high argon flow rate, high pressure and low power will lead to lower deposition rate but improve uniformity significantly and lower the in-plane stress. To check the optimization based on these inferences, 4 depositions were run. On the 4 wafers, ~600 nm of SiO_2 was first deposited followed by a-Si deposition for 2 minutes at silane flow rate of 200 sccm, 80% argon (equivalent to flow rate of 800 sccm), chamber pressure of 1800 mTorr and RF power of 75 W. Table 7.1 shows the measurements of the 4 depositions done at above conditions. As concluded from the DOE-3 responses and analysis, the deposition for optimized conditions led to low deposition rate, highly uniform films, low compressive and anisotropic in-plane stress. The measurements also prove the repeatability of the process conditions.

	1	2	3	4
Dep. Rate (nm/min.)	46.85	46.88	46.745	46.71
Average thickness (nm)	93.03	93.29	93.02	92.99
Thickness std. dev. (nm)	0.58	0.48	0.49	0.42
Non-uniformity (%)	1.5	1.1	1.1	1.2
Stress (MPa) MFDWN	-49.48	-97.48	-103.2	-81.45
Stress (MPa) MFRT	-28.06	-98.17	-285.5	-91.07

Table 7.1: Process optimization and repeatability measurements

8. Summary

Using design of experiments' Taguchi L9 (three level full factorial) design, a-Si PECVD process is developed. The development process went through three iterations of DOE. Based on prior knowledge, 3 levels (input values) of the 4 factors (process parameters) of DOE-1 were selected. Based on Taguchi design for DOE-1, 9 depositions were performed and its responses analyzed. Likewise, subsequent DOEs were designed based on prior responses and responses expected in next iteration. The process led to increase in minimum deposition rate of 20 nm/min. in DOE-1 to 110 nm/min. in DOE-3, decrease in thickness non-uniformity from maximum of 40% in DOE-1 to less than 1% in DOE-3. Starting from highly compressive and anisotropic stress films in DOE-1, low compressive and highly isotropic stress films were obtained in DOE-3. Further, optimization and repeatability of the process was achieved based on DOE-3 results. Future work can comprise of optimizing process conditions for longer duration depositions for uniform and low stress films. Optical quality of resultant films can also be studied. Micro factors such as dissolved gases in the film due to reactants and chemical reactions during the process and its effect on film properties is another possible avenue of investigation.