1. Read the attached Chapter 4 and use the experimental results from Table 4.4(a), (b) to

(a) re-calculate the surface defect and thickness SN ratios using only Test Wafer 1 and Test Wafer 3 data.

計算Defect的S/N ratio可從下列公式得到：

$$\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n} y^2)$$

根據wafer 1與wafer 3的結果可得到：

expt no.	test wafer 1			test wafer 3			SN-1&3
	top	center	bottom	top	center	bottom	
1	1	0	1	1	1	0	1.76091
2	1	2	8	126	3	1	-34.247
3	3	35	106	315	50	180	-43.88
4	6	15	6	15	40	18	-26.103
5	1720	1980	2000	2020	360	13	-64.005
6	135	360	1620	2500	270	35	-61.807
7	360	810	1215	1800	720	315	-60.086
8	270	2730	5000	9999	225	1	-73.442
9	5000	1000	1000	3000	2800	2000	-69.016
10	3	0	0	1	0	1	-2.6324
11	1	0	1	1	0	1	1.76091
12	3	1620	90	270	8	3	-56.541
13	1	25	270	225	3	0	-43.158
14	3	21	162	63	15	39	-37.325
15	450	1200	1800	1890	180	25	-61.506
16	5	6	40	14	1	1	-24.911
17	1200	3500	3500	9999	600	8	-73.232
18	8000	2500	3500	5000	2000	2000	-72.844

計算thickness的S/N ratio可從下列公式可先求出兩個wafer中每個測量點得到的值的平均數與標準差。其中n為測量點總各數：

$$\mu = \frac{1}{n}\sum_{i=1}^{n} \tau_i$$

$$\sigma^2 = \frac{1}{n-1}\sum_{i=1}^{n} (\tau_i - \mu)^2$$

根據wafer 1與wafer 3的結果可得到對thickness的S/N ratio為：

expt no.	test wafer 1			test wafer 3			mu	var	SN
	top	center	bottom	top	center	bottom			
1	2029	1975	1961	1952	1941	1949	1967.83	1032.97	35.7389
2	5375	5191	5242	5323	5307	5091	5254.83	10577.8	34.1672
3	5989	5894	5874	6077	5943	5962	5956.5	5300.3	38.2568
4	2118	2109	2099	2149	2130	2111	2119.33	317.067	41.5125
5	4102	4152	4174	5031	5040	5032	4588.5	239075	19.4481
6	3022	2932	2913	2934	2875	2841	2919.5	3811.5	33.4952
7	3030	3042	3028	3709	3671	3687	3361.17	129138	19.4193
8	4707	4472	4336	5073	4898	4599	4680.83	74171.8	24.7041
9	3859	3822	3850	4110	4067	4110	3969.67	19446.7	29.0866
10	3227	3205	3242	3599	3591	3535	3399.83	37445	24.8952
11	2521	2499	2499	2551	2552	2570	2532	900.8	38.523
12	5921	5766	5844	5691	5777	5743	5790.33	6566.27	37.0809
13	2792	2752	2716	2765	2786	2773	2764	759.6	40.0249
14	2863	2835	2859	2891	2844	2841	2855.5	418.3	42.8988
15	3218	3149	3124	3241	3189	3197	3186.33	1878.27	37.3283
16	3020	3008	3016	3235	3162	3140	3096.83	9105.77	30.2252
17	4277	4150	3992	4593	4298	4219	4254.83	39613.4	26.5992
18	3125	3119	3127	4120	4088	4138	3619.5	295284	16.4706

(b) Plot the surface defect and thickness SN ratio effect plots using only Test Wafer 1 and Test Wafer 3 data.

透過直交表，將六個變數進行三種水準的表現進行交錯實驗，共可得到實驗數據18組。將每個變數的水準表現對應到的實驗組別所對應到的S/N ratio取平均後，根據平均繪出主因素分析圖。

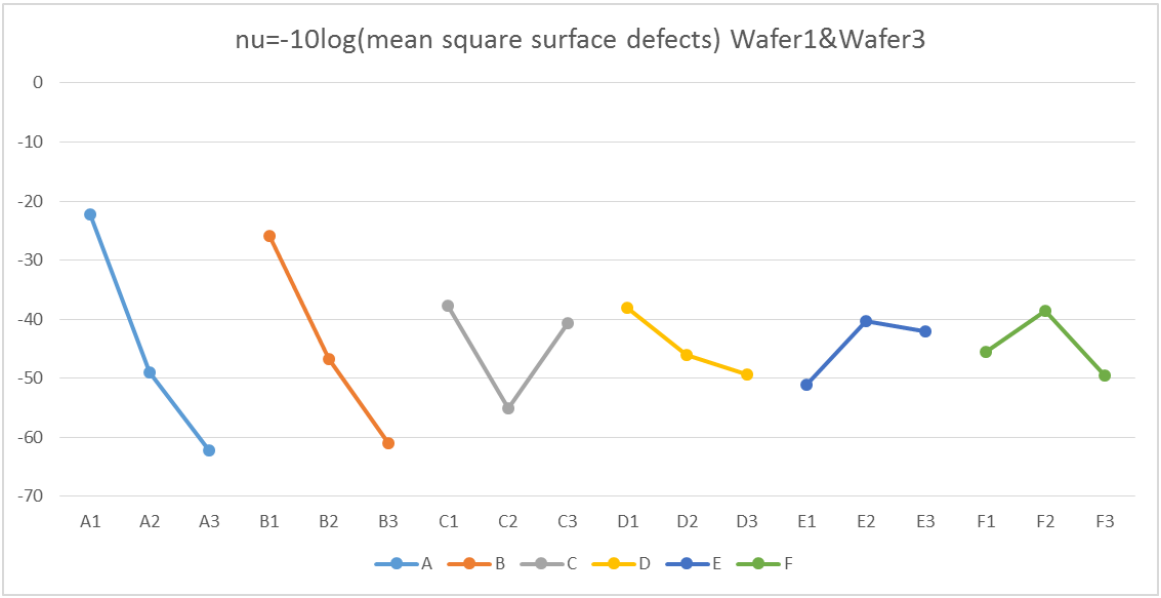
Defect的六個參數在三個水準之下的運作狀態平均S/N ratio如下表：

A1		A2		A3		B1		B2		B3		C1		C2		C3	
1.000	1.761	4.000	-26.103	7.000	-60.086	1.000	1.761	2.000	-34.247	3.000	-43.880	1.000	1.761	2.000	-34.247	3.000	-43.880
2.000	-34.247	5.000	-64.005	8.000	-73.442	4.000	-26.103	5.000	-64.005	6.000	-61.807	4.000	-26.103	5.000	-64.005	6.000	-61.807
3.000	-43.880	6.000	-61.807	9.000	-69.016	7.000	-60.086	8.000	-73.442	9.000	-69.016	9.000	-69.016	7.000	-60.086	8.000	-73.442
10.000	-2.632	13.000	-43.158	16.000	-24.911	10.000	-2.632	11.000	1.761	12.000	-56.541	11.000	1.761	12.000	-56.541	10.000	-2.632
11.000	1.761	14.000	-37.325	17.000	-73.232	13.000	-43.158	14.000	-37.325	15.000	-61.506	15.000	-61.506	13.000	-43.158	14.000	-37.325
12.000	-56.541	15.000	-61.506	18.000	-72.844	16.000	-24.911	17.000	-73.232	18.000	-72.844	17.000	-73.232	18.000	-72.844	16.000	-24.911
	-22.296		-48.984		-62.255		-25.855		-46.749		-60.932		-37.723		-55.147		-40.666
D1		D2		D3		E1		E2		E3		F1		F2		F3	
1.000	1.761	2.000	-34.247	3.000	-43.880	1.000	1.761	2.000	-34.247	3.000	-43.880	1.000	1.761	2.000	-34.247	3.000	-43.880
6.000	-61.807	4.000	-26.103	5.000	-64.005	6.000	-61.807	4.000	-26.103	5.000	-64.005	5.000	-64.005	6.000	-61.807	4.000	-26.103
7.000	-60.086	8.000	-73.442	9.000	-69.016	8.000	-73.442	9.000	-69.016	7.000	-60.086	8.000	-73.442	9.000	-69.016	7.000	-60.086
11.000	1.761	12.000	-56.541	10.000	-2.632	12.000	-56.541	10.000	-2.632	11.000	1.761	10.000	-2.632	11.000	1.761	12.000	-56.541
14.000	-37.325	15.000	-61.506	13.000	-43.158	13.000	-43.158	14.000	-37.325	15.000	-61.506	15.000	-61.506	13.000	-43.158	14.000	-37.325
18.000	-72.844	16.000	-24.911	17.000	-73.232	17.000	-73.232	18.000	-72.844	16.000	-24.911	18.000	-72.844	16.000	-24.911	17.000	-73.232
	-38.090		-46.125		-49.321		-51.070		-40.361		-42.105		-45.445		-38.563		-49.528

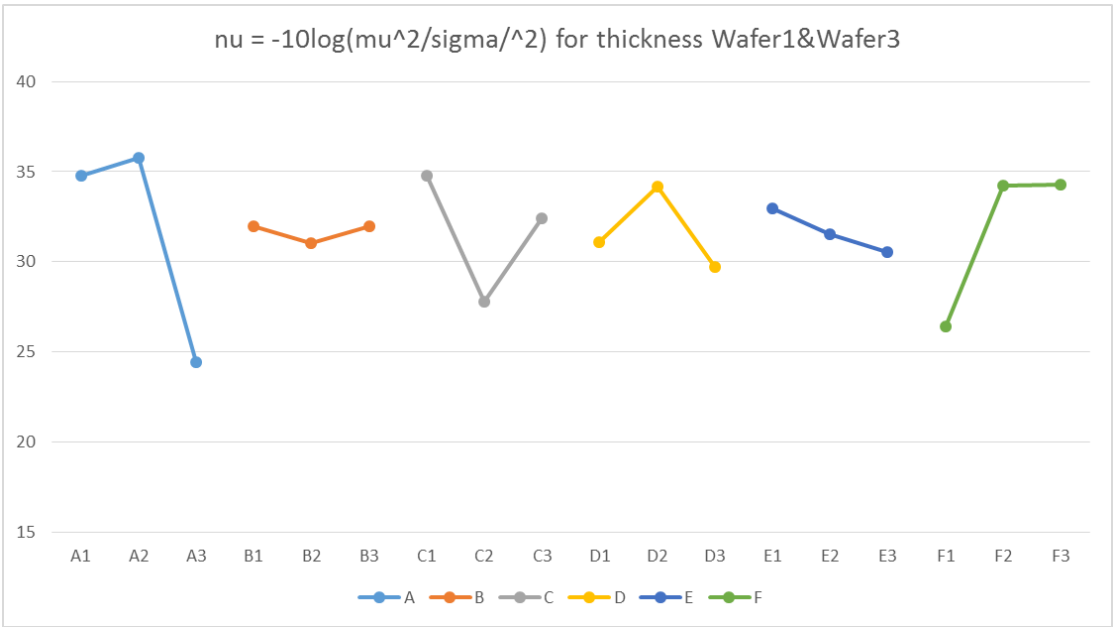
Thickness的六個參數在三個水準之下的運作狀態平均S/N ratio如下表：

A1		A2		A3		B1		B2		B3		C1		C2		C3	
1.000	35.739	4.000	41.512	7.000	19.419	1.000	35.739	2.000	34.167	3.000	38.257	1.000	35.739	2.000	34.167	3.000	38.257
2.000	34.167	5.000	19.448	8.000	24.704	4.000	41.512	5.000	19.448	6.000	33.495	4.000	41.512	5.000	19.448	6.000	33.495
3.000	38.257	6.000	33.495	9.000	29.087	7.000	19.419	8.000	24.704	9.000	29.087	9.000	29.087	7.000	19.419	8.000	24.704
10.000	24.895	13.000	40.025	16.000	30.225	10.000	24.895	11.000	38.523	12.000	37.081	11.000	38.523	12.000	37.081	10.000	24.895
11.000	38.523	14.000	42.899	17.000	26.599	13.000	40.025	14.000	42.899	15.000	37.328	15.000	37.328	13.000	40.025	14.000	42.899
12.000	37.081	15.000	37.328	18.000	16.471	16.000	30.225	17.000	26.599	18.000	16.471	17.000	26.599	18.000	16.471	16.000	30.225
	34.777		35.785		24.417		31.969		31.057		31.953		34.798		27.768		32.413
D1		D2		D3		E1		E2		E3		F1		F2		F3	
1.000	35.739	2.000	34.167	3.000	38.257	1.000	35.739	2.000	34.167	3.000	38.257	1.000	35.739	2.000	34.167	3.000	38.257
6.000	33.495	4.000	41.512	5.000	19.448	6.000	33.495	4.000	41.512	5.000	19.448	5.000	19.448	6.000	33.495	4.000	41.512
7.000	19.419	8.000	24.704	9.000	29.087	8.000	24.704	9.000	29.087	7.000	19.419	8.000	24.704	9.000	29.087	7.000	19.419
11.000	38.523	12.000	37.081	10.000	24.895	12.000	37.081	10.000	24.895	11.000	38.523	10.000	24.895	11.000	38.523	12.000	37.081
14.000	42.899	15.000	37.328	13.000	40.025	13.000	40.025	14.000	42.899	15.000	37.328	15.000	37.328	13.000	40.025	14.000	42.899
18.000	16.471	16.000	30.225	17.000	26.599	17.000	26.599	18.000	16.471	16.000	30.225	18.000	16.471	16.000	30.225	17.000	26.599
	31.091		34.170		29.718		32.941		31.505		30.533		26.431		34.254		34.295

根據上表所繪出的Defect主因素分析圖如下：

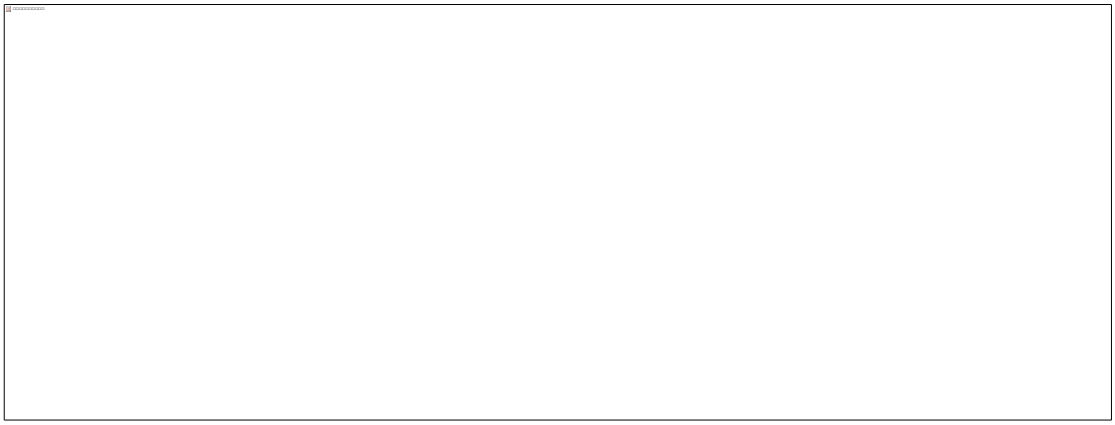


根據上表所繪出的thickness主因素分析圖如下：



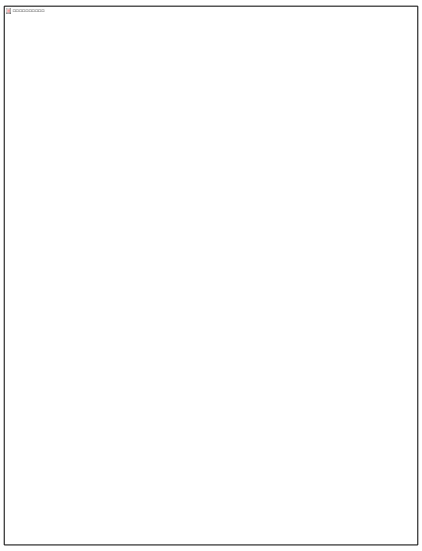
(c) Suggest the optimal factor setting with results of (a) and (b).
綜合考量Defect與thickness這兩項指標的S/N ratio，可選擇每個變數中可使S/N ratio最大者做為選項，六個變數分別挑選出來的組合及為最佳解。
根據上面兩個指標的主因素分析圖，選擇的最佳參數組合為：[A1, B1, C1, D1, E2, F2]= [temp=T_0-25, Pressure=P_0-200, Nitrogen=S_0-50, Silane=S_0-100, set Time=t_0+8, Cleaning Method=CM2]。

(d) Use the additive model to predict the results of the suggested optimal factor settings using Test Wafer 1 and Test Wafer 3.
為驗正挑選的組合為最佳解，我們透過 addictive model 來與原先的 S/N ratio 比較。分別計算原始組合的參數水準與平均 S/N ratio 的差值，再進行相加做比較。結果如下表所示：



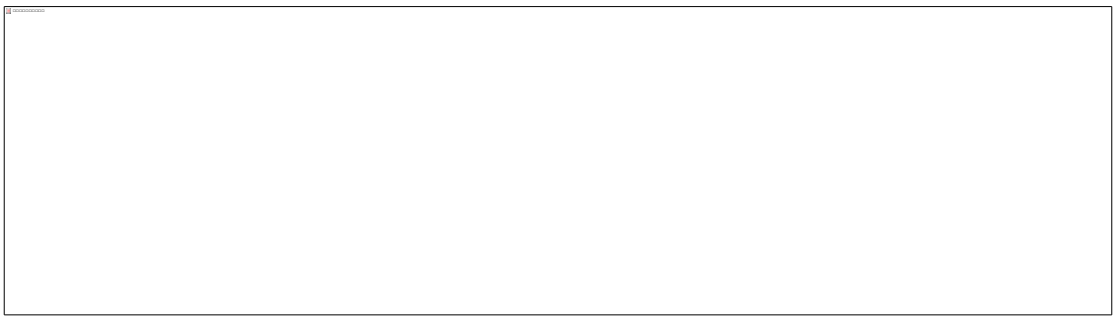
從結果我們可以看到，透過選擇最佳組合的參數表現，在Surface defect表現中提升了近76，而在thickness表現中則提升了約8，優化效果十分顯著。

(e) Re-do (a)-(d) for Test Wafer 2 and compare and discuss the results.
僅針對wafer2的三個測量點進行分析，可得defect的S/N ratio如下表：

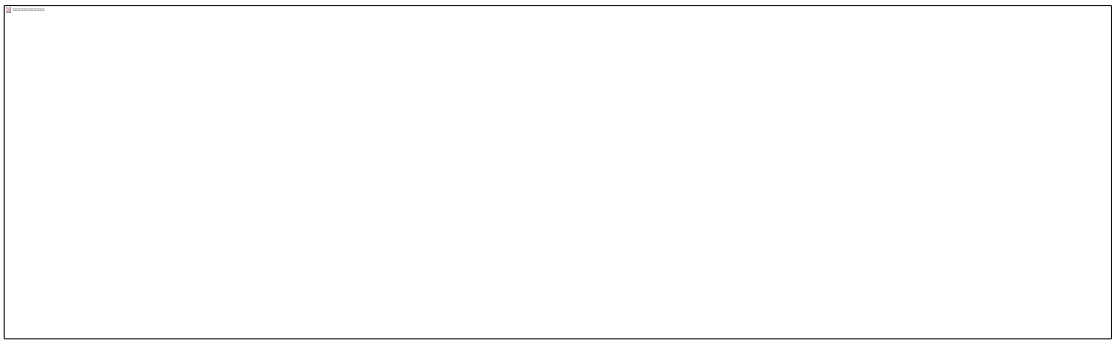


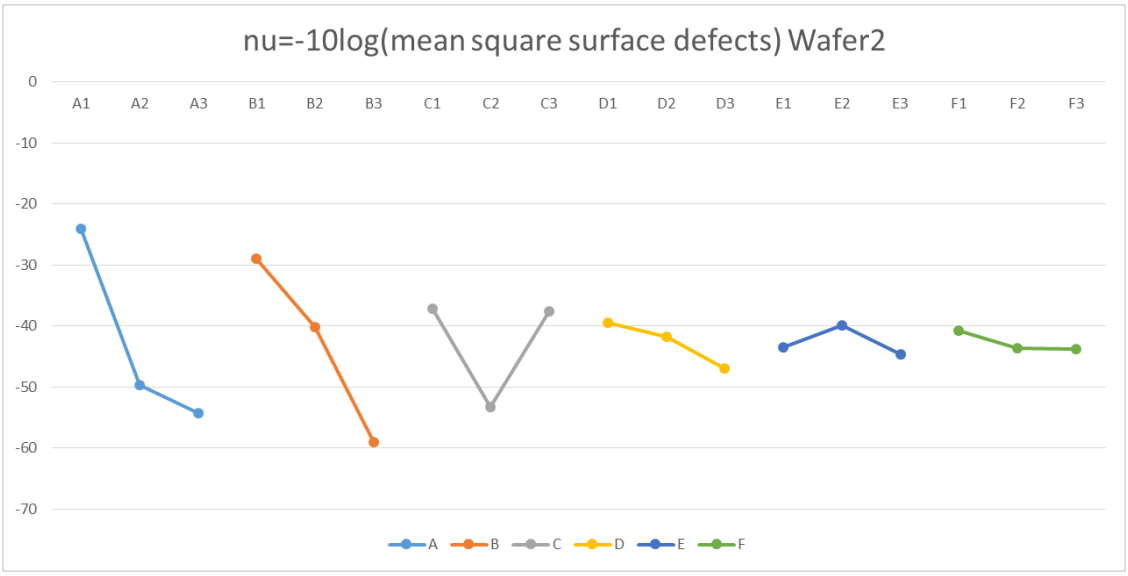
thickness的S/N ratio如下表：

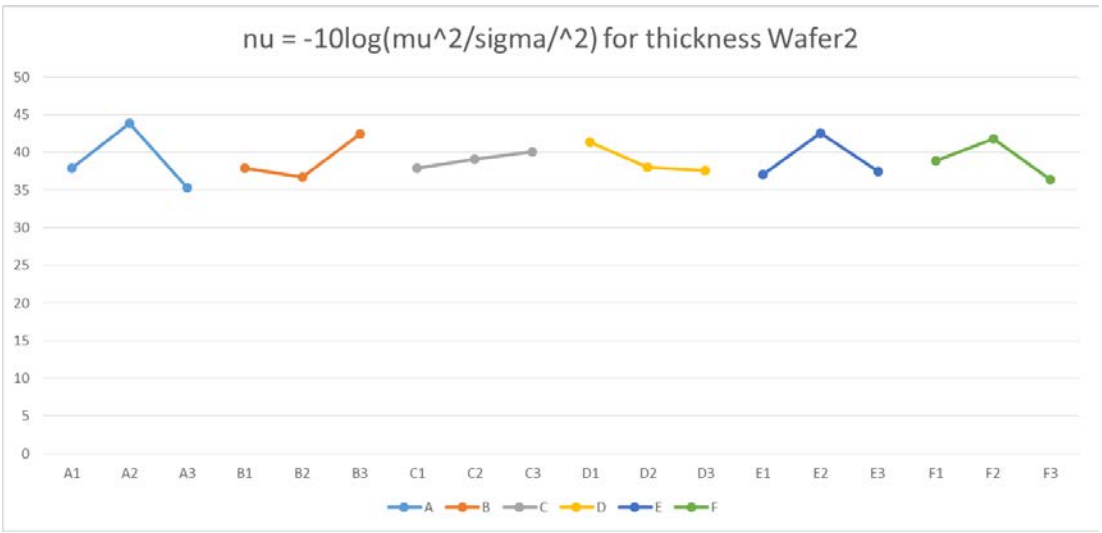
Defect的六個參數在三個水準之下的運作狀態平均S/N ratio如下表：



Thickness的六個參數在三個水準之下的運作狀態平均S/N ratio如下表：







為驗正挑選的組合為最佳解，我們透過 addictive model 來與原先的 S/N ratio 比較。分別計算原始組合的參數水準與平均 S/N ratio 的差值，再進行相加

做比較。最佳解選擇[A1, B1, C3, D1, E2, F2] = [temp=T_0-25, Pressure=P_0-200, Nitrogen=S_0-150, Silane=S_0-100, set Time=t_0+8, Cleaning Method=CM2]結果如下表所示：

	start condition			optimum condition		
		contribution			contribution	
Factor	setting	surface defects	thickness	setting	surface defects	thickness
A	A2	-6.980958871	4.84129	A1	18.63435885	-1.1175
B	B2	2.557577827	-2.3095	B1	13.74078022	-1.1508
C	C1	5.490873856	-1.1336	C3	5.148548355	1.06962
D	D3	-4.200486963	-1.3838	D1	3.25229637	2.38332
E	E1	-0.810786184	-1.9581	E2	2.775368898	3.55396
F	F1	1.980876377	-0.1564	F2	-0.878209303	2.81439
overall mean		-42.71044813	39.0264		-42.71044813	39.0264
total		-44.67335209	36.9262		-0.037304743	46.5794

從表中我們可看到，選擇最佳組合會使surface defects提升約44，在thickness上進步了大約10，優化效果十分顯著。

與謹評估wafer1&wafer3時所選擇的最佳化參數組合，只有在C的參數項目有所不同(Nitrogen)，但不論選擇C1或C3做為參數對結果皆不會有太大的影響，因此任意一組參數組合都可以對實驗有優話的效果。

2. Please find an orthogonal array suitable for an experiment for three 2-level factors and nine 3-level factors. Provide the experimental matrix.

For three 2-level factor, an $L_4(2^3)$ is sufficient.

	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

For nine 3-level factors, an $L_{27}(3^{13})$is sufficient.

	1	2	3	4	5	6	7	8	9
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2
5	1	2	2	2	2	2	2	3	3
6	1	2	2	2	3	3	3	1	1
7	1	3	3	3	1	1	1	3	3
8	1	3	3	3	2	2	2	1	1
9	1	3	3	3	3	3	3	2	2
10	2	1	2	3	1	2	3	1	2
11	2	1	2	3	2	3	1	2	3
12	2	1	2	3	3	1	2	3	1
13	2	2	3	1	1	2	3	2	3
14	2	2	3	1	2	3	1	3	1
15	2	2	3	1	3	1	2	1	2
16	2	3	1	2	1	2	3	3	1
17	2	3	1	2	2	3	1	1	2
18	2	3	1	2	3	1	2	2	3
19	3	1	3	2	1	3	2	1	3
20	3	1	3	2	2	1	3	2	1
21	3	1	3	2	3	2	1	3	2
22	3	2	1	3	1	3	2	2	1
23	3	2	1	3	2	1	3	3	2
24	3	2	1	3	3	2	1	1	3
25	3	3	2	1	1	3	2	3	2
26	3	3	2	1	2	1	3	1	3
27	3	3	2	1	3	2	1	2	1