

Detail Design for

Smart & Small Structures (Triple S)

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Design for Manufacturing

Contents

- FIB parameters
- Material selection
- Detail design
 - ▣ Ion beam parameter
 - ▣ Processing parameter
 - ▣ Geometric parameter
- Evaluation
 - ▣ Efficiency
 - ▣ Geometric error based on ion beam defect
 - ▣ Final shape evaluation
- Pre-test for ion beam selection
- On-going work
- Priority work
- Conclusion

Project plan

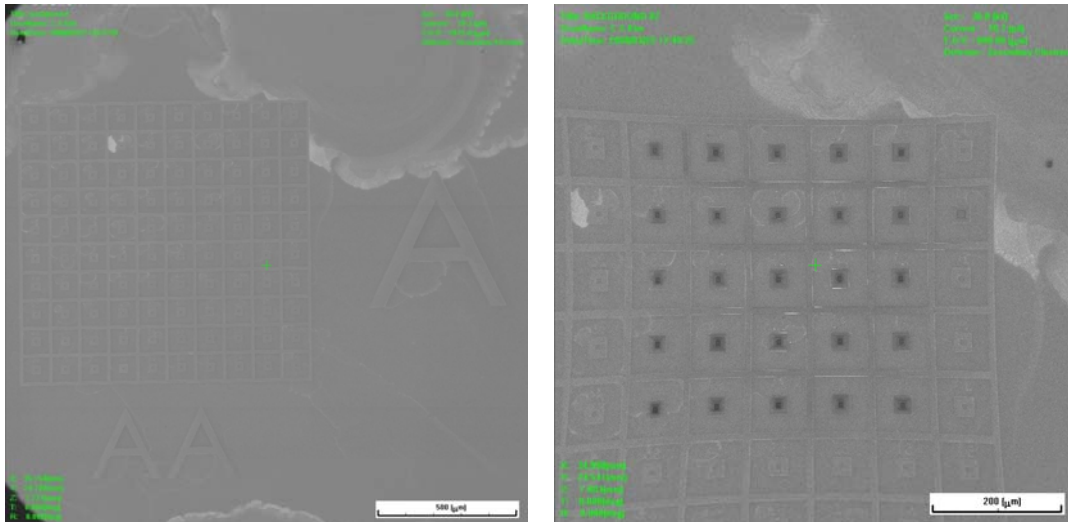
- Mission statement & Brain storming
- Conceptual design
- **Pre-study**
 - **Python**
 - **Design of Experiment**
- **Detail design**
 - **Beam current, Dimension, and so on**
- Fabrication
- Analysis
 - Relative parameter extraction
- Evaluation
- Documentation

Focused Ion Beam Nano/Microfabrication

P A R A M E T E R S	Difficulties	Angle-Dependent sputtering	Non-constant Sputter rate	Scattered Ions
	Estimation	Side Wall Effect	Aspect ratio	Bottom Shape of Etched Structures
		Sputter Yield	Redeposition	Deposition Yield
	Parameters	Ion Species	Ion Dose	Ion Energy
		Incidence Angle	Substrate	Dwell Time
		Beam Overlapping	Precursor Gas	Scan Step Size
		Structural Change by Ion Implantation	Beam Current	Refresh Time

Material Selection

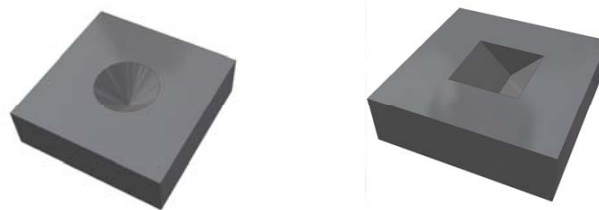
- Silicon substrate
 - ▣ Easy to get
 - ▣ Good surface roughness for evaluation



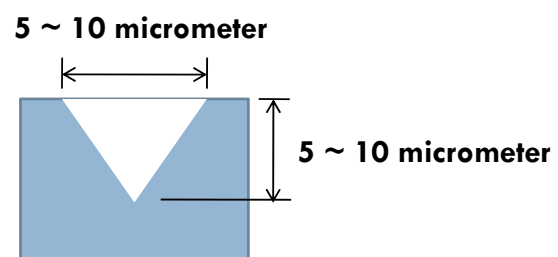
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Detail Design

- Machining shape
 - ▣ Circular & Rectangle trendches
 - V-groove



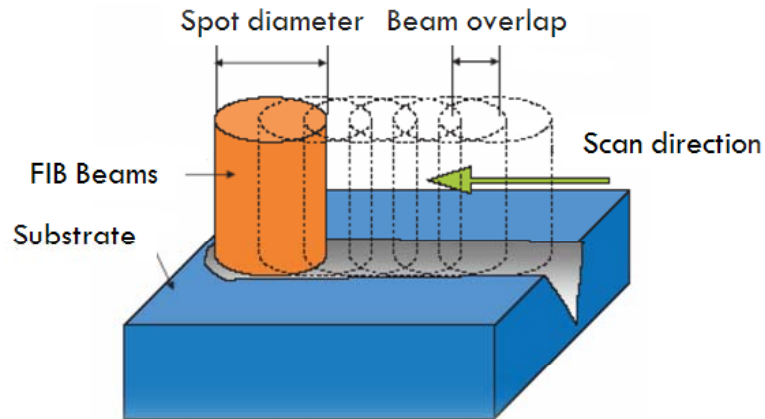
- Machining size
 - ▣ 5 to 10 micrometer



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Ion Beam Parameter

- Ion beam parameter
 - ▣ Spot diameter [nm]
 - ▣ Ion beam current [A]
 - ▣ Current density [A/cm^2]



Ion Beam Parameter

Ion beam current [pA]
10.2
89.2
282
708
3027
6640
13427
23291

High current ion beams!!
 : Effective for large milling area
 : Short fabrication time (expensive cost)

No.	Spot Size (nm)	Ion Current (pA)	Current Density (A/cm^2)
1	115	6640.625	63.96
2	160	13427.734	66.81
3	200	23291.016	74.17

Processing Parameter

□ Processing parameter

□ Ion dose

- How many ions are injected

□ Dwell time

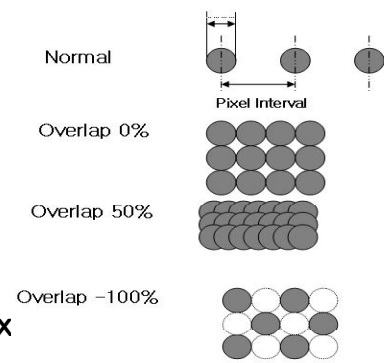
- How long ion beams are stay in one pix
 - It deals with the scan speed

□ Beam overlapping

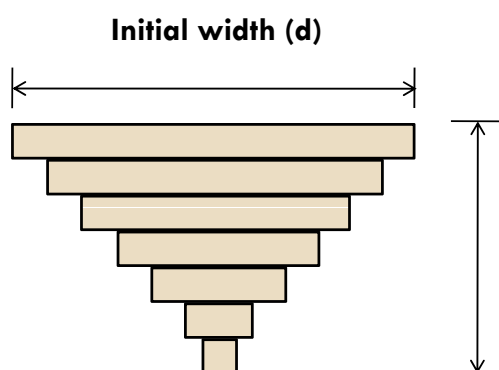
- How much the area of the ion beam overlaps
 - Related with field of view

□ Field of view

- Processing screen size (influence on pixel size)



Geometric Parameter

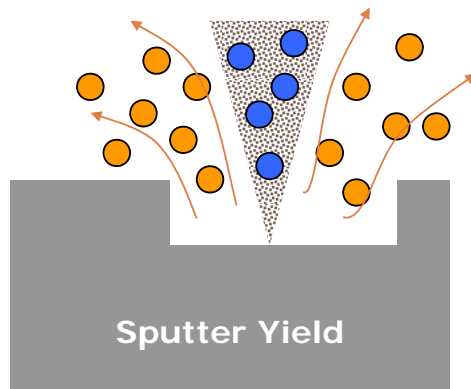


$$\text{Reduction of scan area} = \frac{d}{N}$$

No. of slice (N)

Evaluation

Efficiency



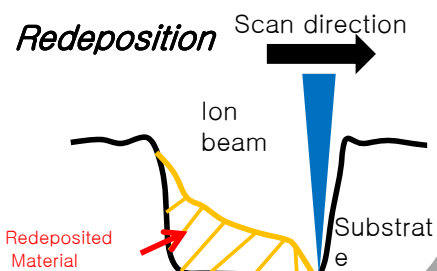
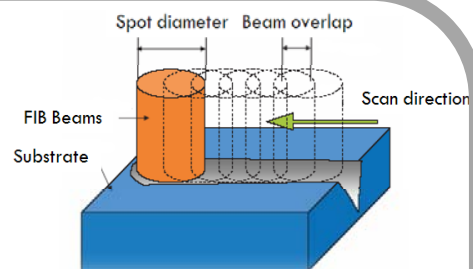
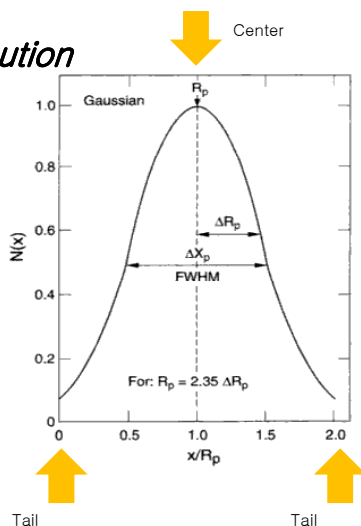
$$Y_D = \frac{w_a l_a z_a}{I t}$$

where w_a is the width, l_a is the length, and z_a is the thickness of a deposited carbon structure.

Evaluation

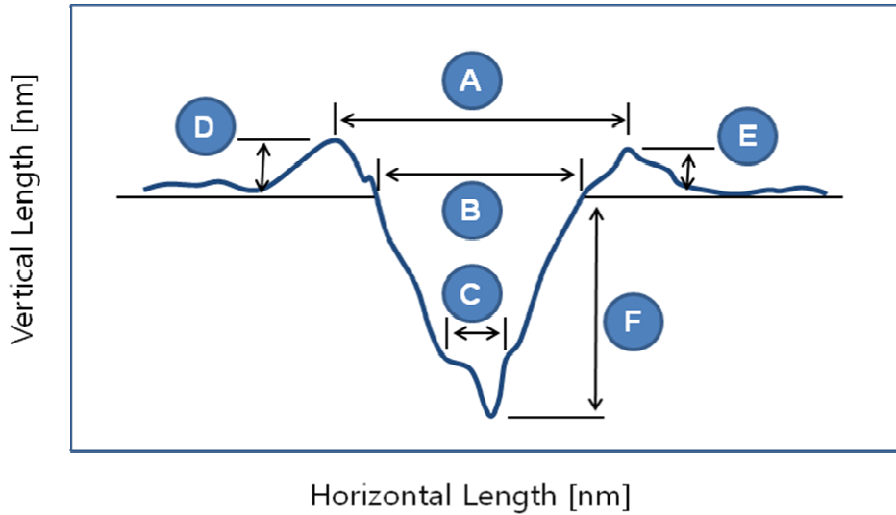
Geometry errors by ion beam defect

Gaussian Beam Distribution



Evaluation

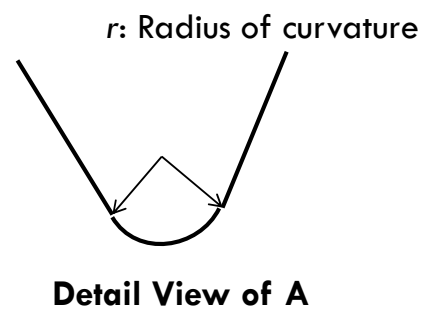
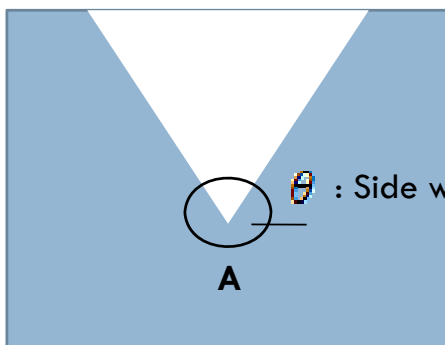
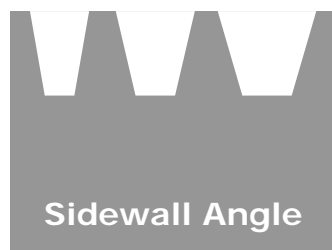
Geometry errors by ion beam defect



Definition of sputtered feature for evaluating nano/microscale effect

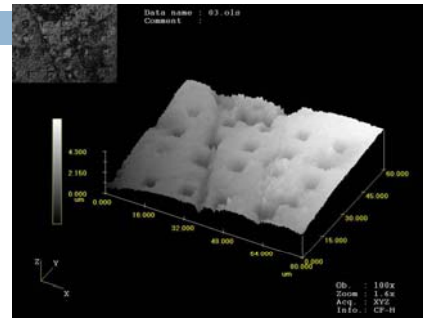
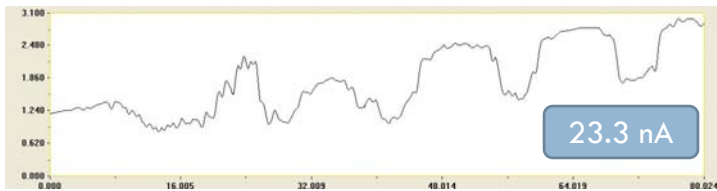
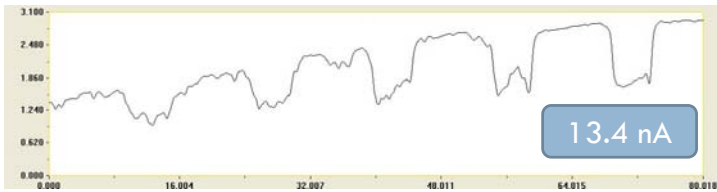
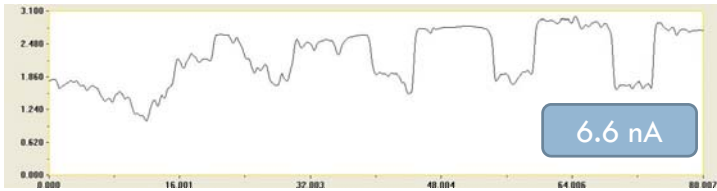
Evaluation

Geometry



Pre-Test 1

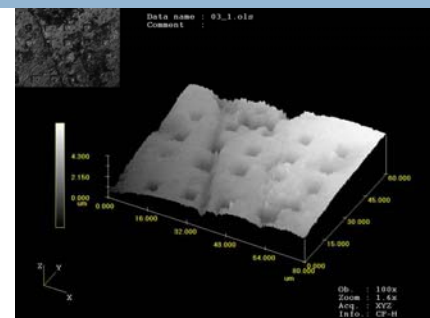
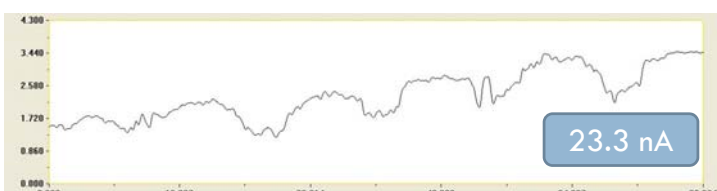
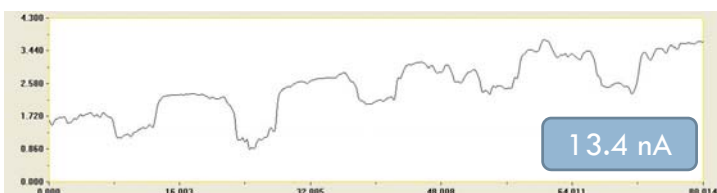
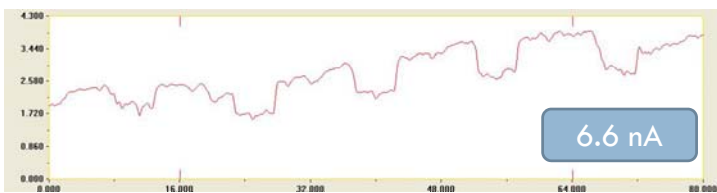
Ion dose



Parameter	Condition				
Field of View (μm)	150				
Pixel Size (nm)	187.5				
Defined Area (μm^2)	25 (5 x 5)				
Ion Energy (KeV)	30				
Ion Dose (10^{15} ions/ cm^2)	2000	3000	4000	5000	6000
Spot Size (nm)	115	160	200		
Probe Current (nA)	6.6	13.4	23.2		
Current Density (A/cm^2)	63.9	66.81	74.17		
Dwell Time (μs)	1				
Beam Overlap (%)	0				
Refresh Time (ms)	0				

Pre-Test 2

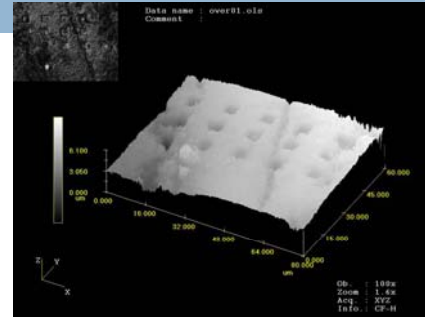
Dwell time



Parameter	Condition				
Field of View (μm)	150				
Pixel Size (nm)	187.5				
Defined Area (μm^2)	25 (5 x 5)				
Ion Energy (KeV)	30				
Ion Dose (10^{15} ions/ cm^2)	3000				
Spot Size (nm)	115	160	200		
Probe Current (nA)	6.6	13.4	23.2		
Current Density (A/cm^2)	63.96	66.81	74.17		
Dwell Time (μs)	1	10	20	50	100
Beam Overlap (%)	0				
Refresh Time (ms)	0				

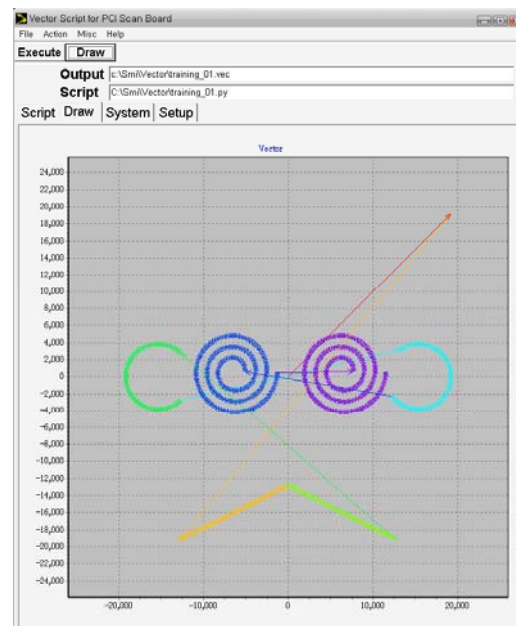
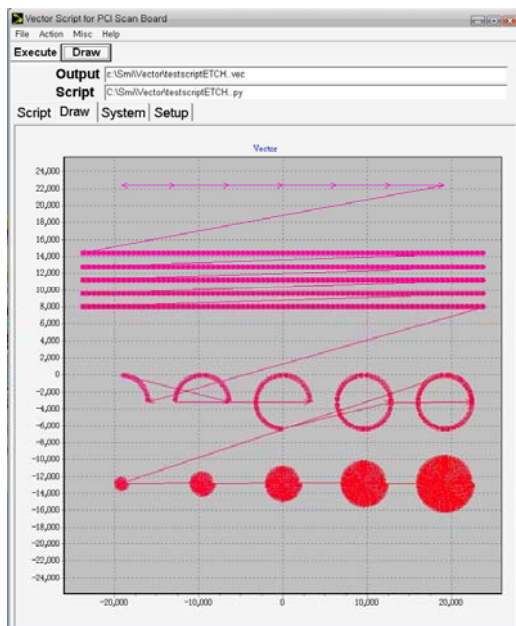
Pre-Test 3

□ Beam overlapping

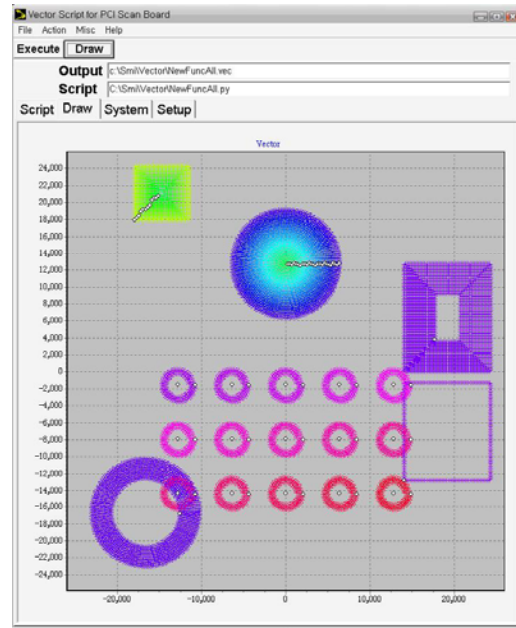
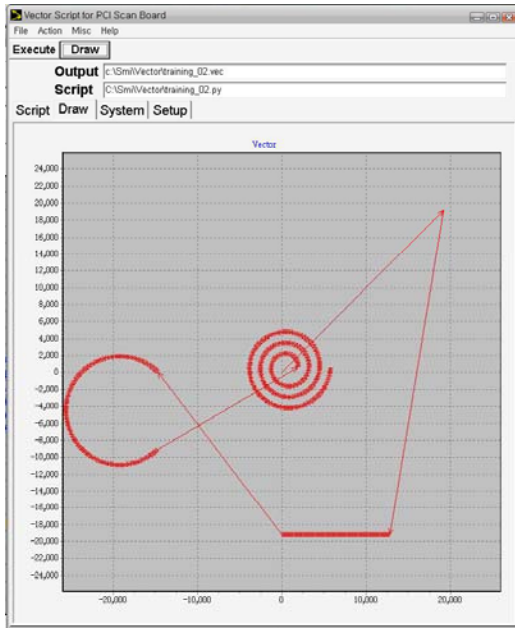


Parameter	Condition				
Field of View (μm)	150				
Pixel Size (nm)	187.5				
Defined Area (μm^2)	25 (5 x 5)				
Ion Energy (KeV)	30				
Ion Dose (10^{15} ions/cm 2)	3000				
Spot Size (nm)	115	160	200		
Probe Current (nA)	6.6	13.4	23.2		
Current Density (A/cm 2)	63.96	66.81	74.17		
Dwell Time (μs)	1				
Beam Overlap (%)	-90	-50	0	50	90
Refresh Time (ms)	0				

On-going work: Python



On-going work: Python



On-going work: Design of Experiment

- 4 factor 3 level
 - ▣ each case of experiment will be performed twice at least

	Ion dose (A)	Dwell time (B)	Beam overlap (C)	No. of slice (D)
1	Undetermined	0.5	-50	10
2		5	0	20
3		10	50	30

$L_9(3^4)$ Orthogonal array

No	Factor				Result			
	A	B	C	D	Sputter Yield	Feature definition	Side wall angle	Radius of curvature
1	1	1	1	1				
2	1	2	2	2				
3	1	3	3	3				
4	2	3	2	3				
5	2	1	3	1				
6	2	2	1	2				
7	3	1	3	2				
8	3	2	1	3				
9	3	3	2	1				

Priority Work

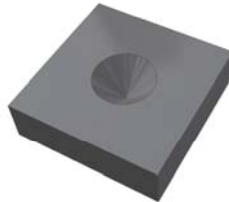
□ Finding ion dose



Find the ion dose (D_0) satisfying the aspect ratio 1

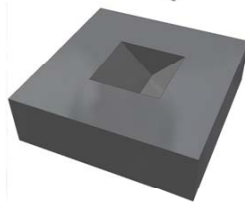
□ Circular

□ $D_C = 2/3 D_0$



□ Rectangle

□ $D_R = 1/2 D_0$



Conclusion

Determined ion beam condition

Parameter	Condition
Field of View (μm)	120
Pixel Size (nm)	150
Defined Area (μm^2)	5 x 5
Ion Energy (KeV)	30
Ion Dose (ions/cm ²)	Not determined
Spot Size (nm)	150
Probe Current (pA)	6640
Current Density (A/cm ²)	37.59
Dwell Time (μs)	Variation 0.5, 5, 10
Beam Overlap (%)	Variation -50, 0, 50
Refresh Time (ms)	0
Slice Number	Variation 10, 20, 30

Schedule boards

Plan		Week (20 March 2006 ~ Mid June 2006)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Mission statement and Brain storming		█	█											
Conceptual Design			█	█	█									
Pre-study	Python			█	█	█	█							
	Design of Experiment			█	█	█	█							
Detail design	Parameter					█	█	█						
	Material					█	█	█						
	Shape					█	█	█						
Fabrication								█	█	█	█	█		
Analysis								█	█	█	█	█		
Evaluation								█	█	█	█	█	█	
Documentation													█	█

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Thanks
Any Questions??

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