Key Methods in Reducing Pad Void Formation and Experimental Result

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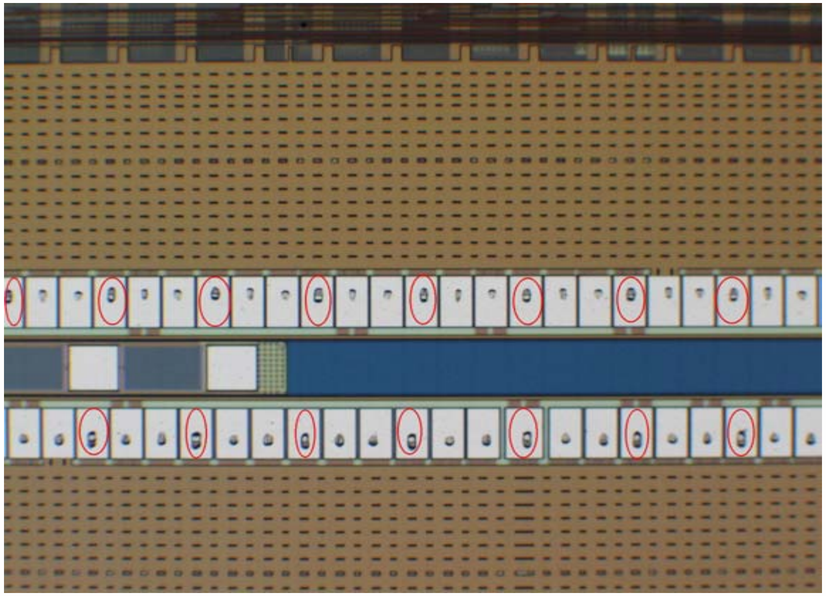
Agenda

- **Pad Void (PV) cases at TSMC mass production pipeline**
- **Theoretical and FEA**
- **DOE with Taguchi Method**
  - ✓ Experiment I
  - ✓ Experiment II
- **Scrub Depth Model Formulation (SDMF)**
  - ✓ Theory, Experiment and Verification
- **Conclusion**

PV Case in TSMC Case1

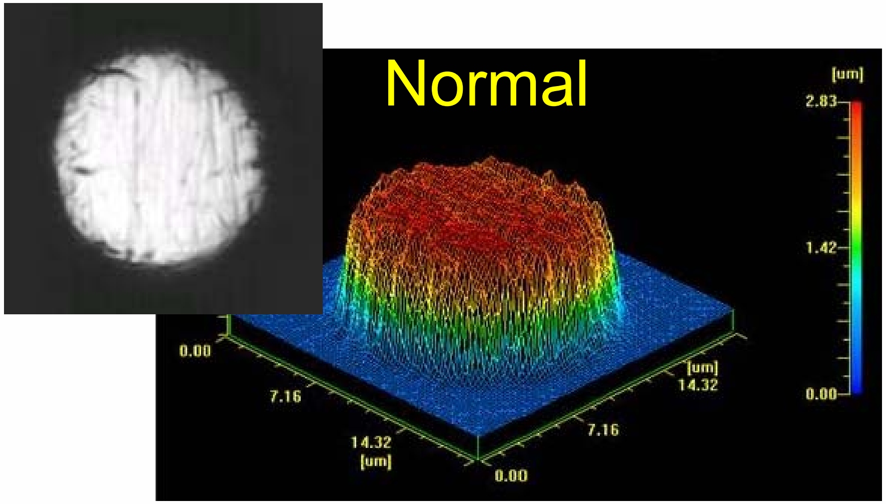
- **Problem description**
  - **Pad void by 1st layer needle**

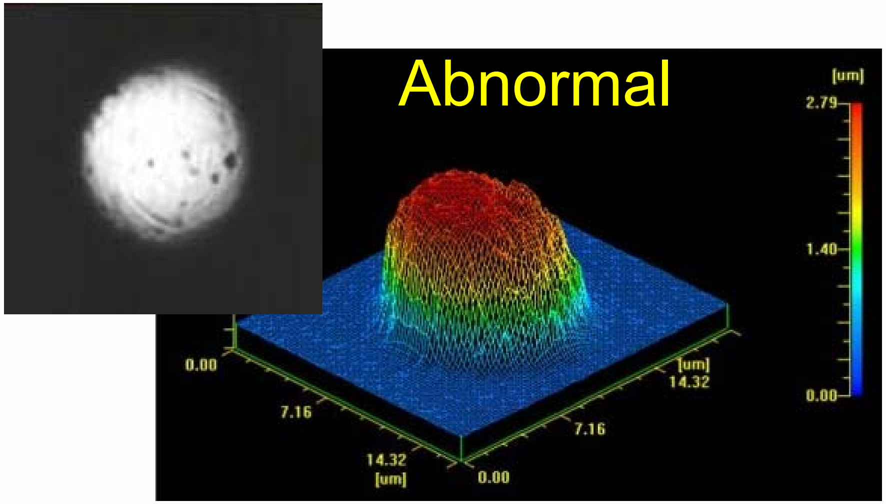


Repeated PV patterns

PV Case in TSMC Case1 Cont.

- **Analysis**
  - **CSLM* 3D scanning of tip profile revealed that tip diameter was shaped into smaller and sharper .**
  - **This is attributed to abnormal phenomenon of needle.**





Solution: Sanding and repairing tip profile

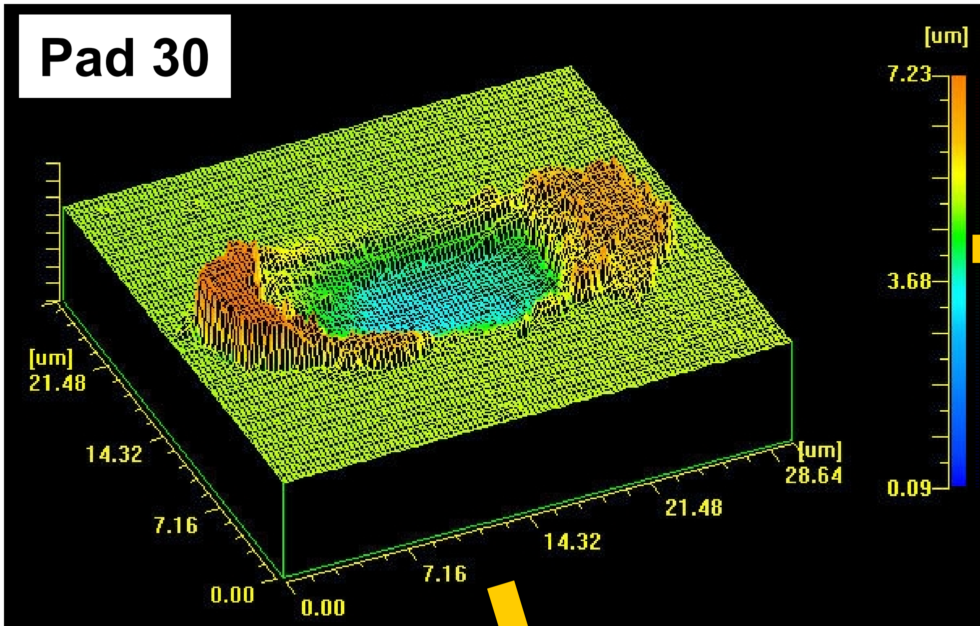
CSLM: confocal scanning laser microscope

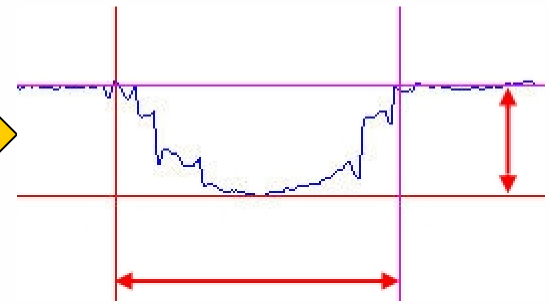
PV Case in TSMC Case2

- **Problem description**
  - PV occurred as underlying pad exposed after 670k tds
  - Different probers were used for this card.
  - But other cards were free of PV issues.
- **Analysis**
  - PV cases occurred only at 1st layer groups.
  - Chuck speed was found too high for different prober set up.

Layer	Pad No.
1	3,6,9,12,18,30 21,33
2	4,7,10,16,19,29,32
3	5,8,11,17,20,28,31

PV Case in TSMC Case2 Cont.





Depth 1.7μm

Width 10.2μm

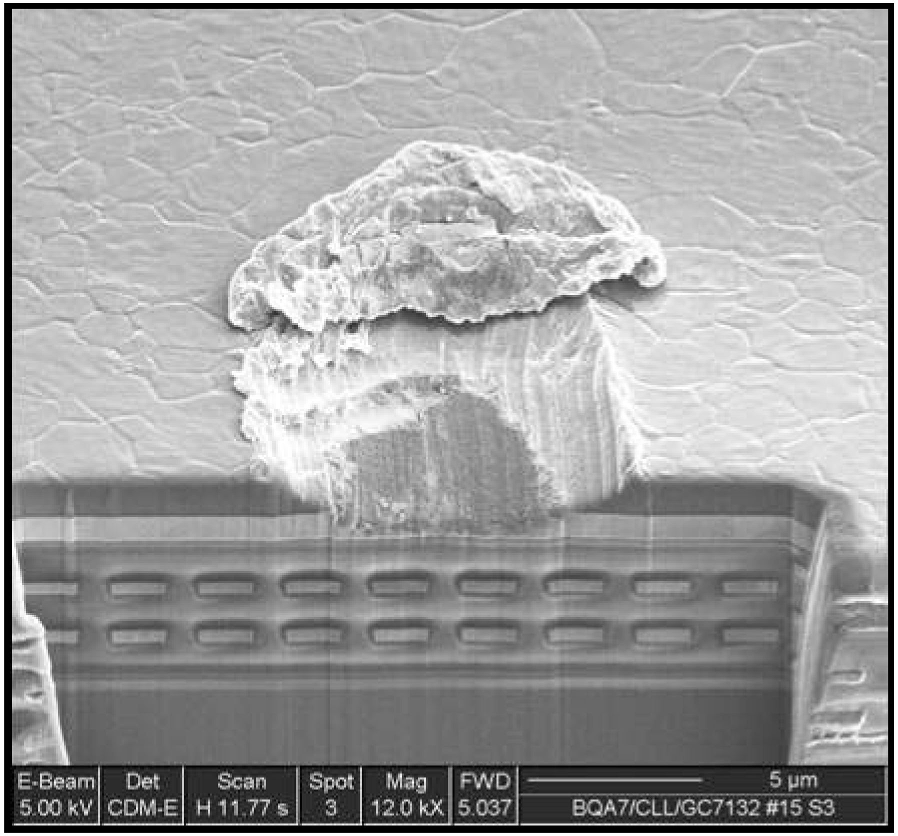
Depth 1.7μm

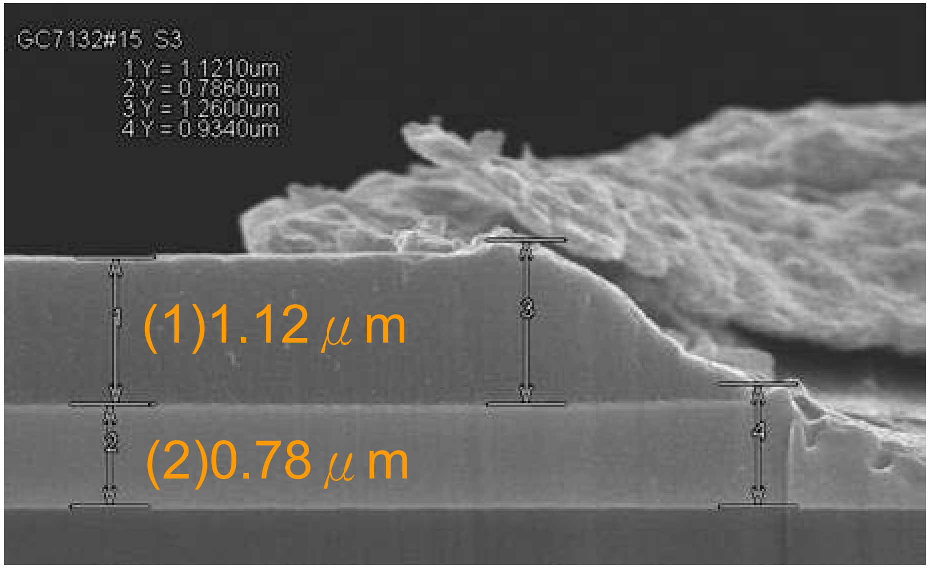
Scrub Length 27.3μm

Unbelievable !

maximum scrub depth up to 1.7μm resulted from 1st time tds.

PV Case in TSMC Case2 Cont.





- SEM micrographs and measurements showed the actual scrub depth of 1.7 μm.

Solution: Reduce Chuck Speed

PV Case in TSMC Summary

- Key causes from collected mass-productions' PV cases:
  - Smaller or sharper tip shape
  - Excessive contact force
  - Higher chuck speed set up
  - Old probe cards used after a longer period of time
  - PV cases mostly at 1st layer group needles
  - Deepest scrub depth sites of PVs measured mostly at initial touched region
- PV cases prompt to big revenue loss, thus preventive efforts needed in advance are:
  - "PV causes search" and "scientific prediction works"

-These learnings could be good references for probe card specs. establishment and also as prober set up procedures.

Theoretical and FEA

- **Analysis of Root-Cause Factors**

$$F_y = K_{yy} D_y$$ **Common definition of BCF**

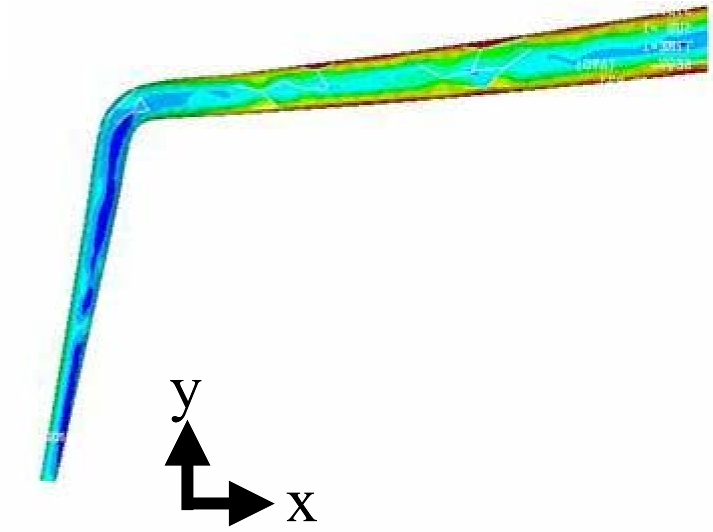
$$F_i = K_{ij} D_j$$ **General definition of Contact Force**

i : direction of overtravel force

j : direction of resulted displacement

K_{ij}: needle stiffness

D_j: displacement



Theoretical and FEA Cont.

Pad damage quantitatively also refers to “STRESS” induced at pad.

Thus, “STRESS” could be determined by main factors, such as:

Stress (σ=F/A) →

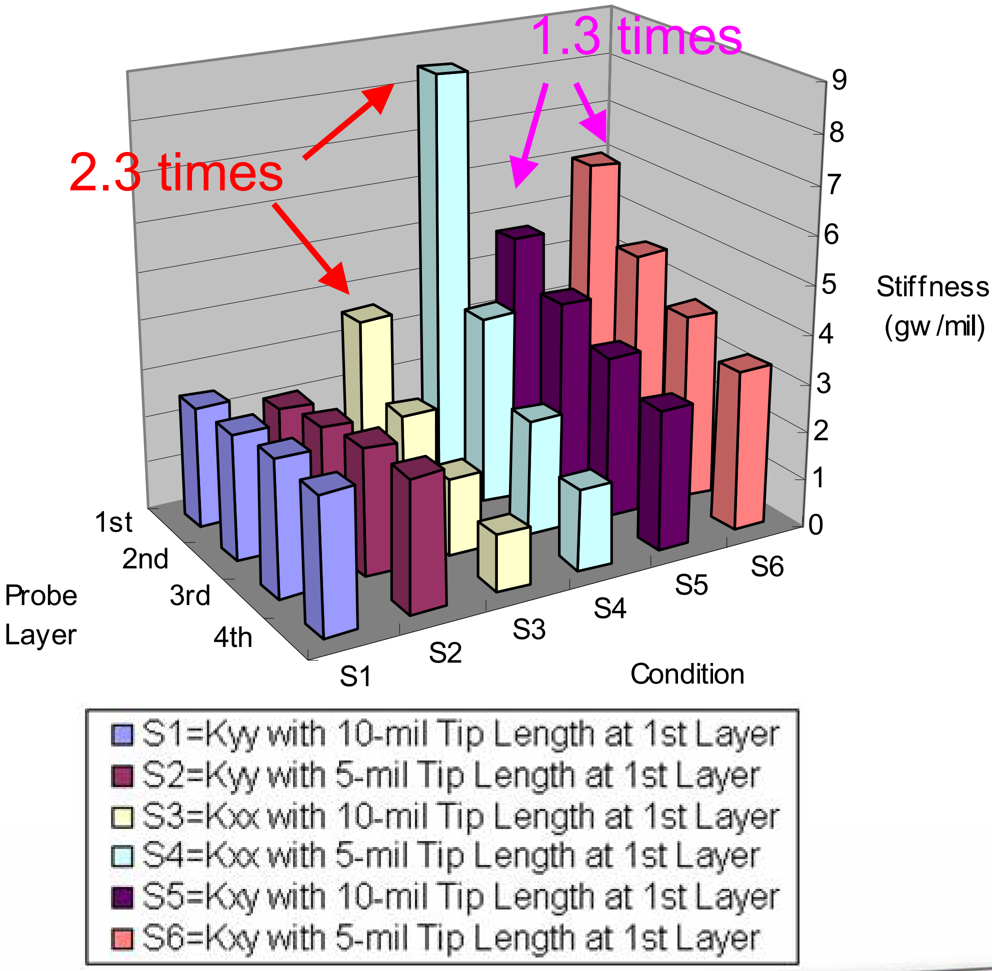
- **Force (F_x, F_y)** →
  - **Planarity**
  - **Overdrive (D_y)**
  - **Needle Stiffness** (K_{xx}, K_{yx}, K_{xy}, K_{yy})
  - **Chuck Speed (force magnification factor)**
- **Actual Contact Area (A_A)** →
  - **Tip Diameter**
  - **Tip Shape**

Theoretical and FEA Cont.

Item		gw/ mil	Needle Tier			
			1st	*2nd*	*3rd*	*4th*
Stiffness (Kyy)		PRVX*	2.20	2.34	2.43	2.62
		FEA*	2.28	2.37	2.67	2.75
PRVX / FEA (Kyy)			96%	99%	91%	95%
FEA	Tip Length 1st tier = 10mils	Kxx	**3.61**	**2.23**	**1.60**	**1.17**
		Kyy	2.49	2.63	2.83	2.84
		Kxy=Kyx	**4.74**	**3.88**	**3.35**	**2.88**
	Tip Length 1st tier = 7.5mils *	Kxx	5.17	2.83	1.94	1.47
		Kyy	2.28	2.37	2.67	2.75
		Kxy=Kyx	4.98	3.81	3.36	2.97
	Tip Length 1st tier = 5mils	Kxx	**8.43**	**3.91**	**2.39**	**1.68**
		Kyy	2.10	2.37	2.61	2.72
		Kxy=Kyx	**6.03**	**4.61**	**3.87**	**3.32**

Theoretical and FEA Cont.

Variation of stiffness in X and Y direction with different tip lengths



- Reducing tip length would not vary the probe stiffness $K_{yy.}$ (see graph S1 & S2)
- Reducing tip length 10 mil to 5 mil at 1st layer needles, needle stiffness K_{xx} radically changed from 3.61 gw/mil into 8.43 gw/mil, magnified by **2.3 times**. (see graph S3 & S4)
- Reducing tip length 10 mil to 5 mil at 1st layer needles, stiffness Kxy or Kyx changed from 4.74 gw.mil into 6.03 gw/mil, magnified by **1.3 times**. (see graph S5 & S6)

Experiment Ⅰ

- **Control factors and their range of settings for the experiment**

  Tip Length ⇨ 5 and 9 mils
  Tip Angle ⇨ 100° and 106°
  Needle Diameter ⇨ 6 and 10 mils
  Stiffness, K_{yy} ⇨ 2 and 3.3 gw/mil
  Tip Diameter ⇨ 0.5 and 1 mil

Fix factor !
1st layer needle

Sample No.	Tip length (mil)	Tip angle (Degree)	Needle Dia. (mil)	Stiffness (gw/mil)	Tip Dia. (mil)
1	5	100	6	2	0.5
2	5	100	10	3.3	1.0
3	5	106	6	2	1.0
4	5	106	10	3.3	0.5
5	9	100	6	3.3	0.5
6	9	100	10	2	1.0
7	9	106	6	3.3	1.0
8	9	106	10	2	0.5

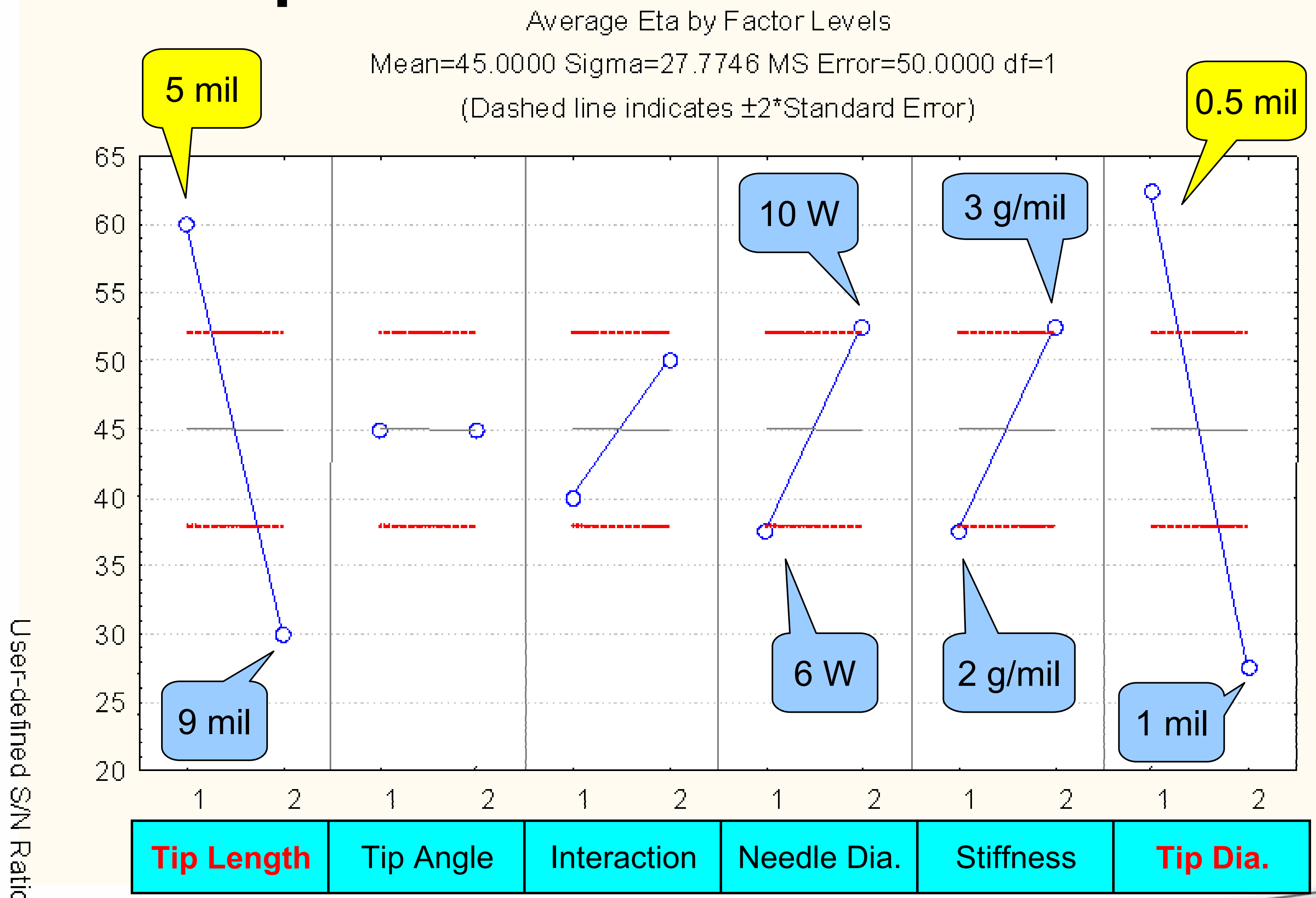
Table of Taguchi experimental factors

Experiment Ⅰ Cont.

- **Analysis and Result**
  - Carried out repeated tds on same pad to observe PV.
  - Sample 4 indicated PV occurrence at 2nd tds. (remarked as 100 pts count)
  - PV appeared after 11th times probing for sample 7.

Sample No.	TD x1	TD x2	TD x3	TD x4	TD x5	TD x6	TD x7	TD x8	TD x9	TD x10	TD x11	Count
1						pv	pv	pv	pv	pv	pv	60
2							pv	pv	pv	pv	pv	50
3									pv	pv	pv	30
4		pv	pv	pv	pv	pv	pv	pv	pv	pv	pv	100
5							pv	pv	pv	pv	pv	50
6										pv	pv	20
7											pv	10
8								pv	pv	pv	pv	40

Experiment Ⅰ Cont.



Short
Tip Length
+
Small
Tip Dia.
+
Large
Stiffness
+
Thick
Needle Dia.

Pad Void

Experiment Ⅱ

- **Design of Experiment**

Inner orthogonal array

	Sample	K_{yy} (gw/mil)	Tip Dia.(mil)	Tip Length(mil)
Control Factor	1	1.5	0.4	4
	2	1.5	0.7	7
	3	1.5	1	10
	4	3	0.4	7
	5	3	0.7	10
	6	3	1	4
	7	4.5	0.4	10
	8	4.5	0.7	4
	9	4.5	1	7

Outer orthogonal array

Noise	Temperature(℃)	25	25	85	85
	Overdrive(mil)	1.5	4	1.5	4

Experiment Ⅱ Cont.

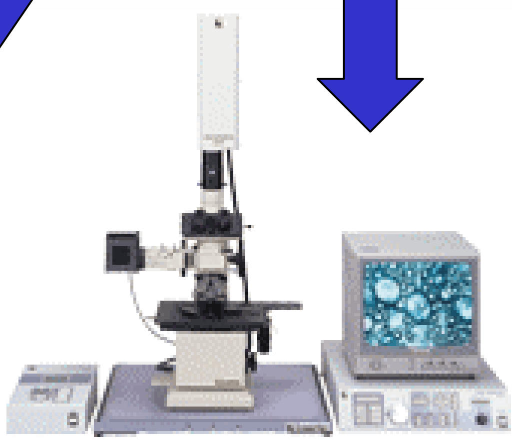
- **How to execute:**

1.Prepare Dummy Wafers

	Sample
P/C 1	1、6、8
P/C 2	1、6、8
P/C 3	2、4、9
P/C 4	2、4、9
P/C 5	3、5、7
P/C 6	3、5、7

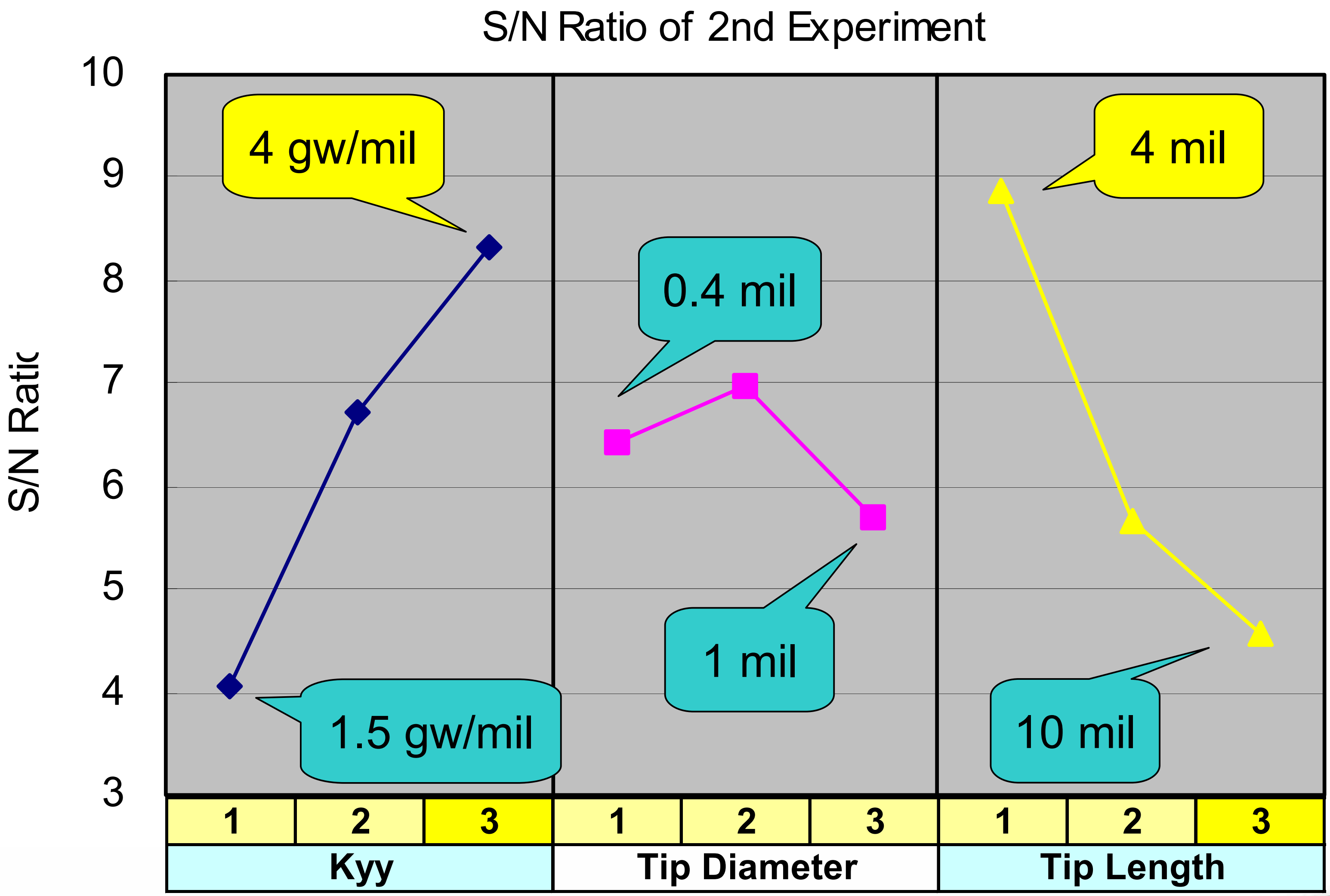
2.Build 3 samples in one piece of P/C

3.Probe Wafer with Different Conditions



4.Measure Scrub Depth

Experiment Ⅱ Cont.



Summary of Experiment I & II

- By choosing all critical parameters, a two-level L8 orthogonal array experiment Ⅰ has been performed, the influential factors have been determined as follow:

  Primary dominant factors ➔ **tip length, tip diameter**

  Secondary dominant factors ➔ stiffness K_{yy}, tip diameter
- From TSMC mass production testing, three critical parameters were chosen to perform experiment Ⅱ with a L9 three-level setting. The summarized results are:

  Primary dominant factors ➔ **tip length, stiffness K_{yy}**

  Secondary dominant factors ➔ tip diameter
- The slight variation in results of these two experiments, it was recognized that these experiments still had uncontrolled noise.
- It is concluded that these two experiments indicated that **tip length**, **tip diameter**, **stiffness K_{yy}** were the three most influential primary parameters.

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- **Recall Ref. #1, Assumption:**

  Uniform normal stress, no frictional force, thus scrub depth of Point Cobra Probe can be described as

$$\bar{U}_{Z_a} = \frac{4(1-v^2)F}{\pi^2 Ea}$$

$$\left(\bar{U}_{Z_a} = \frac{2}{\pi} \cdot \bar{U}_{Z_0}\right)$$

$$\bar{U}_{Z_0} = \frac{2(1-v^2)F}{\pi Ea}$$

wherein $F = K \cdot \delta$

δ: Overdrive
K: Stiffness (spring constant)
F: Balanced contact force
E: Equivalent modulus of elasticity of pad
a: Probe tip radius
v: Poisson's ratio
$\bar{U}_{Z_0}$: Scrub depth at center
$\bar{U}_{Z_a}$: Scrub depth around

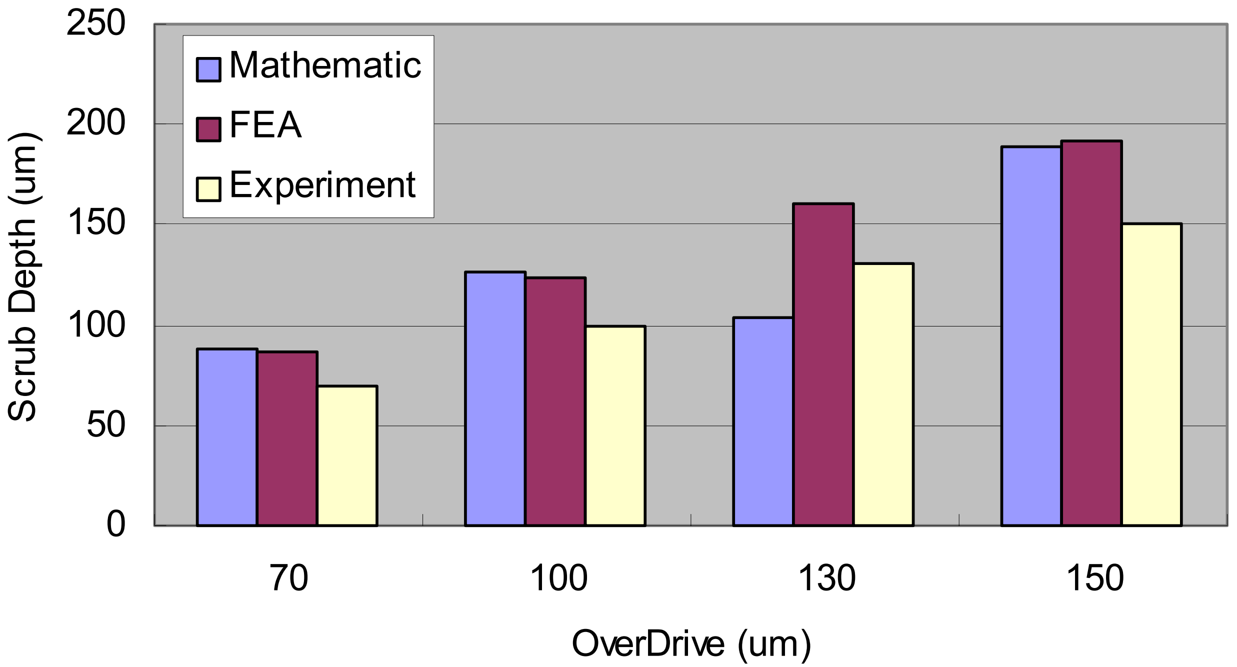
#1 Chen, K. M., 2003, *"A Study of Microelectronics Probing Depth and Electromigration Effect of Solder Bump,"* Ph.D. Dissertation, Department of Power Mechanical Engineering, University of Tsing Hua in Taiwan.

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

But!
Cantilever Type Needle
is more complex

Scrub Depth of Experiment, FEA and Mathematic Method
(source: Ref. #.1)



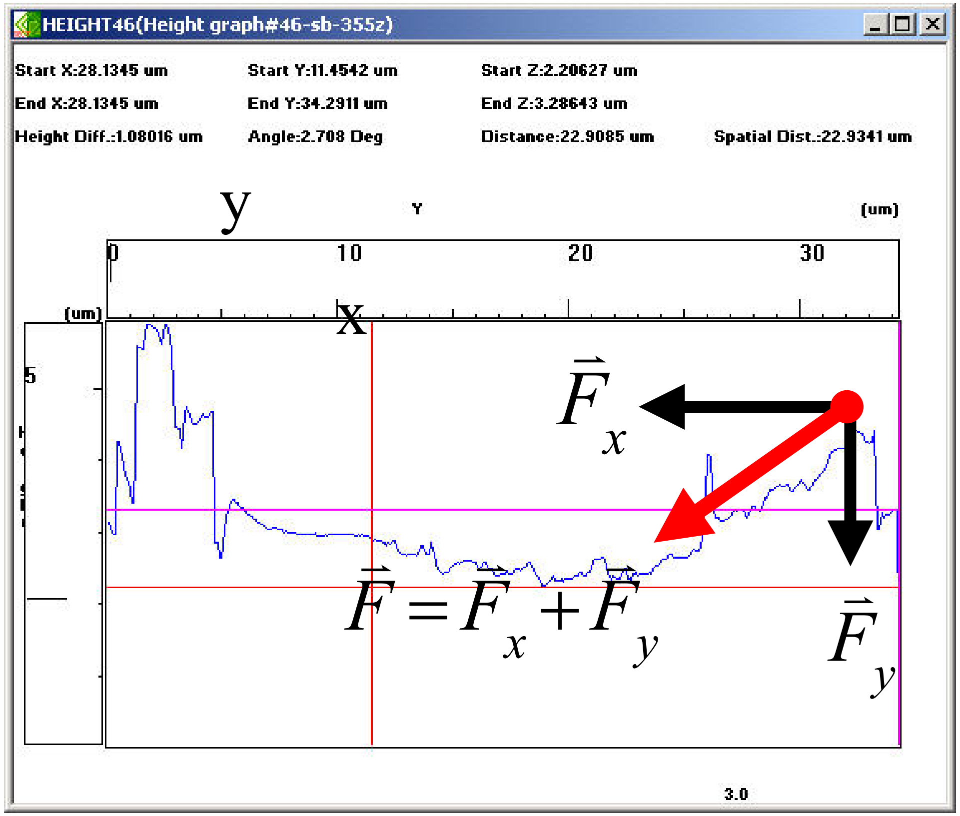
Correlation between theoretical and experimental is 4.6%~6% which evidently implied that simply a normal pressure the scrub depth is quantitatively predictable.

#1 Chen, K. M., 2003, *"A Study of Microelectronics Probing Depth and Electromigration Effect of Solder Bump,"* Ph.D. Dissertation, Department of Power Mechanical Engineering, University of Tsing Hua in Taiwan.

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- **SDMF of cantilever type needle:**



Assumption:
Matrix of **initial** contact force on pad as follow :

$$\begin{bmatrix} F_x \\ F_y \end{bmatrix} = \begin{bmatrix} K_{xx} & K_{xy} \\ K_{yx} & K_{yy} \end{bmatrix} \begin{bmatrix} D_x \\ D_y \end{bmatrix}$$

i : direction of overtravel force

j : direction of resulted displacement

K_{ij}: needle stiffness

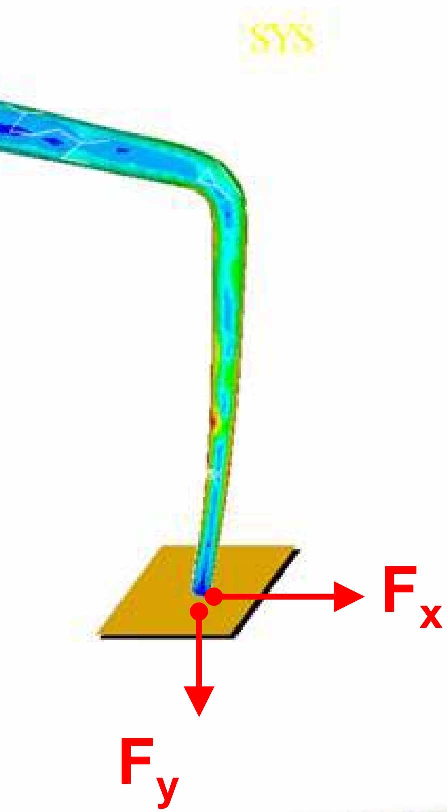
D_j: displacement

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- **SDMF of cantilever type needle:**

Contact force vector F is rectangular component vector of F_x & F_y



$$F_x = K_{xx} D_x + K_{xy} D_y$$
$$F_y = K_{yx} D_x + K_{yy} D_y$$

Recall:

For Cobra point tip needle:

$$D_x \cong 0 \quad \therefore F_y = K_{yy} \times D_y$$

For present SDMF of cantilever needle:

$$F_y = K_{yx} D_x + K_{yy} D_y$$

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

Assumption:

(1) Scrub depth is governed by F_y

(2) Pad material properties based on standard TSMC processes

Thus,

$$\overline{U}_z = C \times \frac{F_y}{D}$$

where $\overline{U}_z$: Max. Scrub Depth

C & B : Constant

D : Tip Diameter

Then, assume:

$D_x = BD_y$

Thus,

$$F_y = K_{yx} D_x + K_{yy} D_y = K_{yx} B D_y + K_{yy} D_y = \left(K_{yx} B + K_{yy}\right) D_y$$

$$\therefore \quad \overline{U}_z = C \times \left(K_{yx} B + K_{yy}\right) \frac{D_y}{D}$$

K_{yx} could be solved by FEA, and correlate with experimental works to find the correct value of C & B.

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- **How to Execute:**
  - Parameter Selection

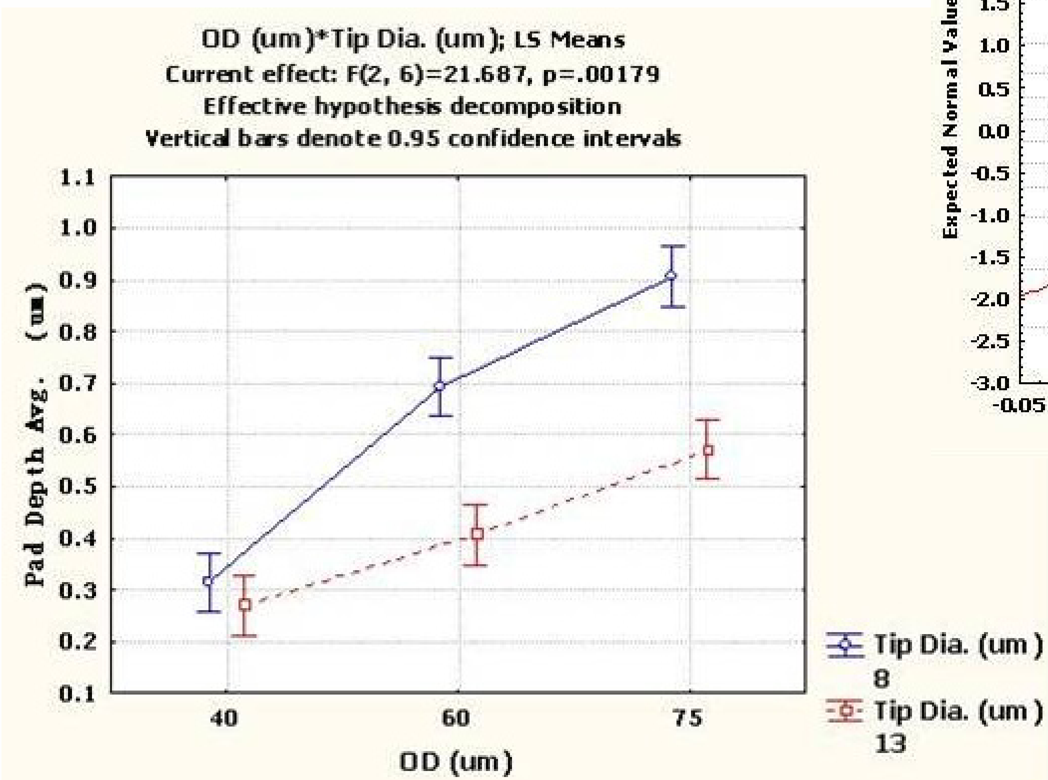
Parameter	Spec.
Tip Dia.(um)	8 , 13
OD(um)	40 , 60 , 75
Kyy(gw/mil)	2.5
Needle Dia. (mil)	5
Tip Length (mil)	7.5 , 11.5 , 15.5 , 19.5

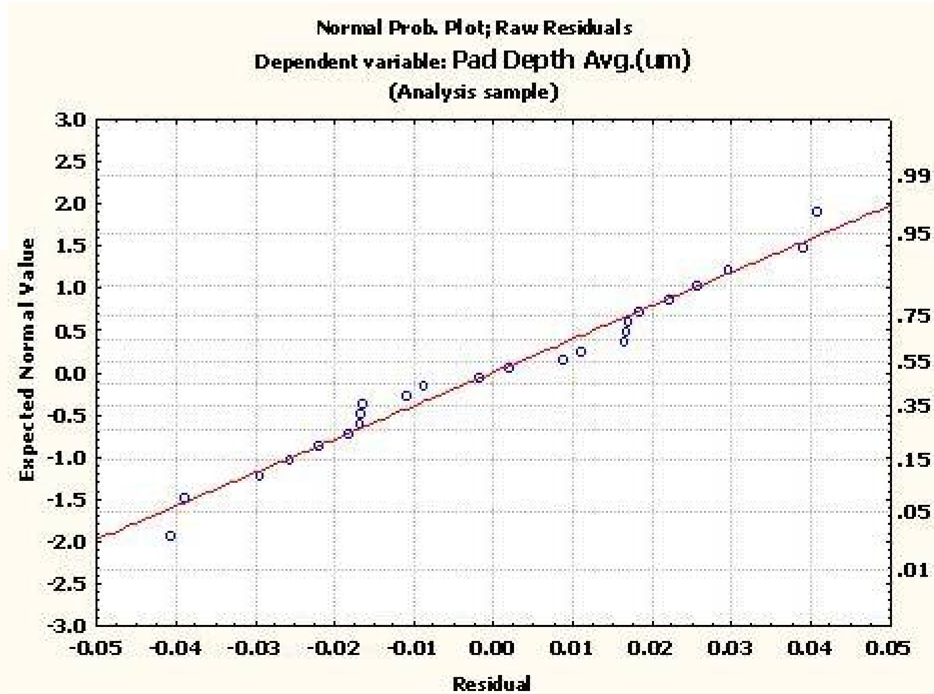
  - Pick up one production wafer as probing test.
  - Five pads were used to determine each interested parameters and measured scrub depth.

Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- **Result and Analysis:**





According to the residual plot, it showed the experimental works are in agreement with the **normal distribution** pattern.

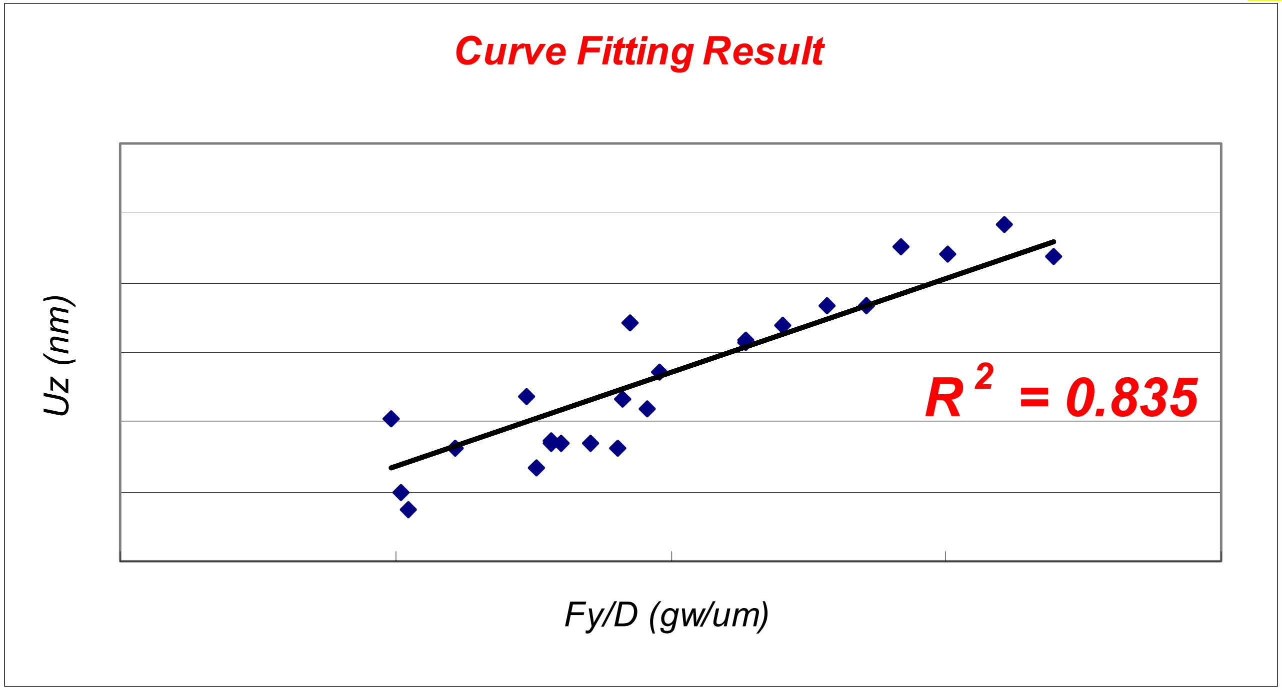
Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

- Constant values B & C were found from curve fitting.

$$\overline{U}_z = C\frac{F_y}{D}$$

$$= C\left(BK_{yx} + K_{yy}\right)\frac{D_y}{D}$$



Unit :

$\overline{U}_z$: nm

K_{yx}, K_{yy} : gw/mil

D_y : mil

D : μm

Conclusion

- PV occurrence has been one of the most troublesome issue for mass production processes.
- Key learnings from TSMC PV cases: reducing stiffness, sanding tip into larger diameter, and lowering chuck speed.
- Three primary dominant factors determining the scrub depth are stiffness, tip length and tip diameter.
- Scrub Depth Model Formulation (SDMF) was established and proven as an useful engineering method for preventing PV. This worth-noted innovative works still need more comprehensive verification works.

Follow-On Works …

- SDMF verification for different needle diameters.
- SDMF verification for different chuck speed to determine the exact range of constant values.
- Verification works by utilizing wafers, particularly built from different processes, and assigned by different testing conditions.