Key Methods in Reducing Pad Crack Risk at Probing Low-k Wafers

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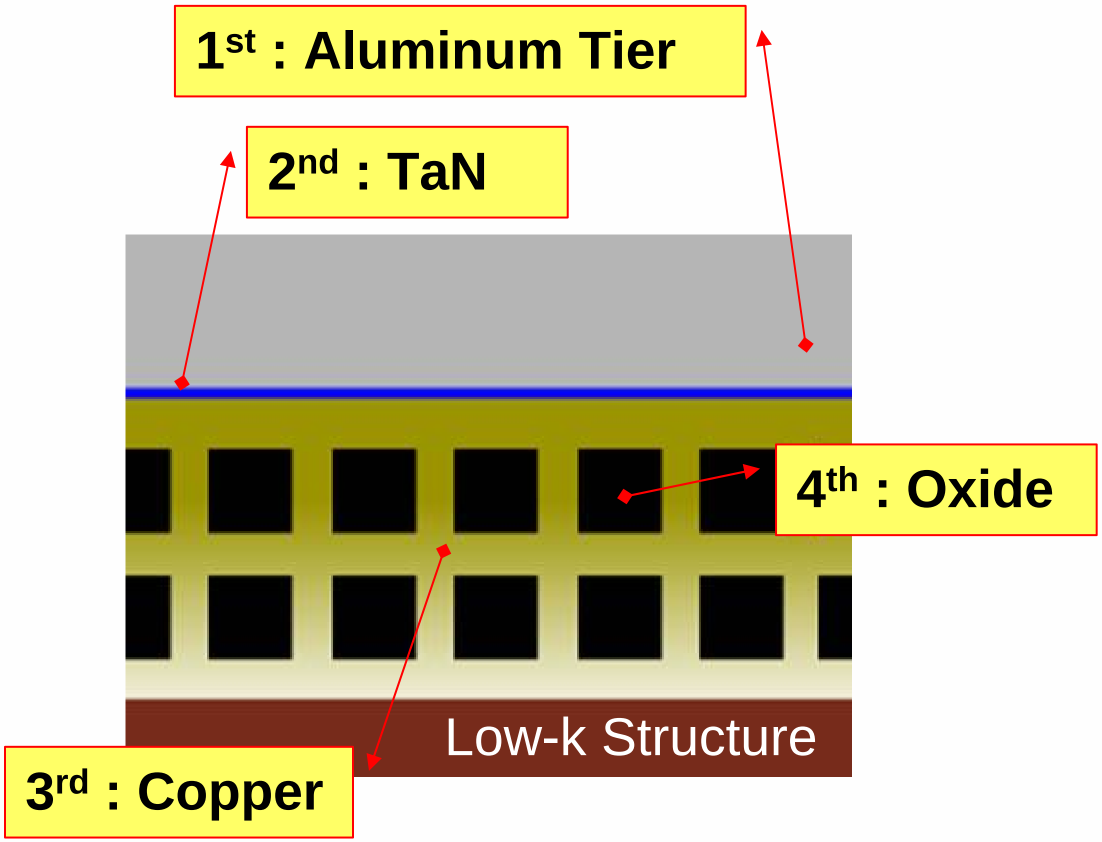
Agenda

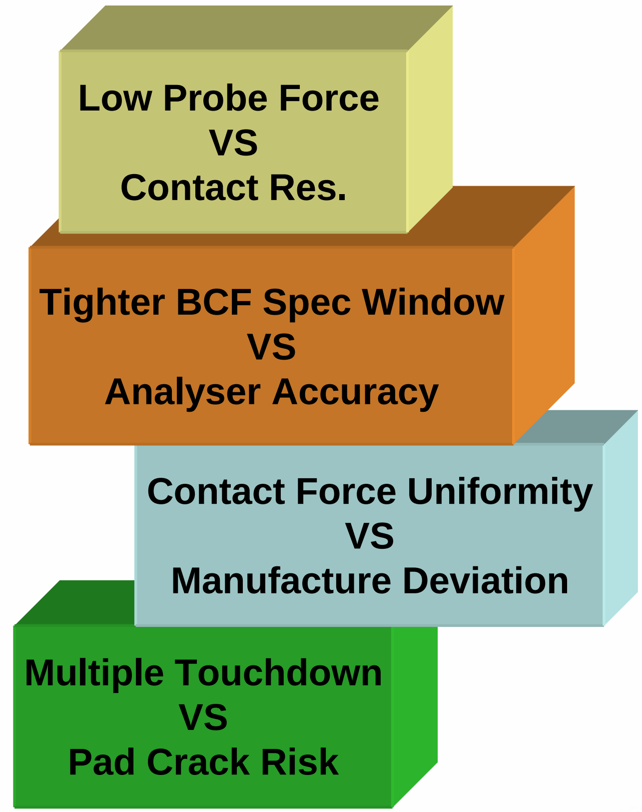
- **Probing Challenge on Low-k Devices**
- **Scrub Depth Correlates with Underneath Layers**
- **Scrub Depth Model Formulation (SDMF)**
  - Review -2005
  - Experiment and Result
  - Constant Parameter Calculation
- **BCF Measurement Limitation**
- **Conclusion**

Probing Challenge on Low-k Devices



Low-k experimental wafer – Pad matrix cross section

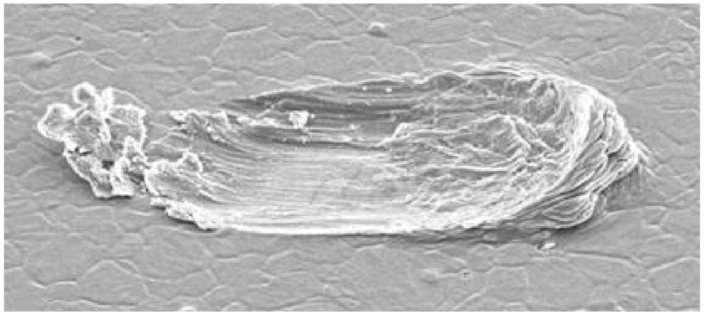
Probing contradictory!

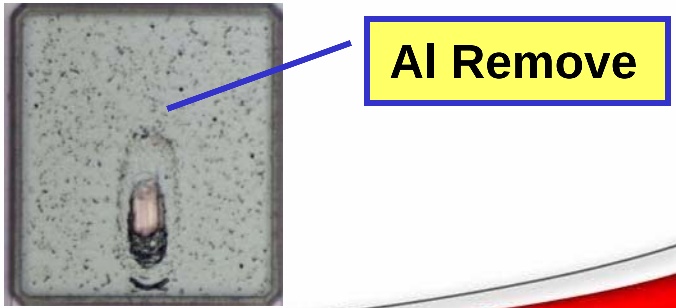


Probing Challenge on Low-k Devices

What Should Be Concerned on Low-k?

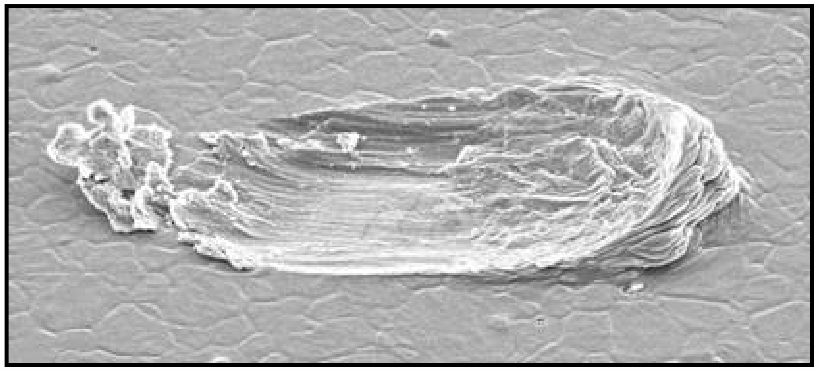
- Except Pad Void (PV), what risks will be suffered when probing Low-k wafer?
- In comparison with the low-k defects, It's "lucky" to suffer PV, because of the observable defects where after aluminium layer removal, copper is physically exposed on TaN surface.
- How about the scrub below?
  It's OK or NG? In fact, microscope and wafer inspector show you "No PV."



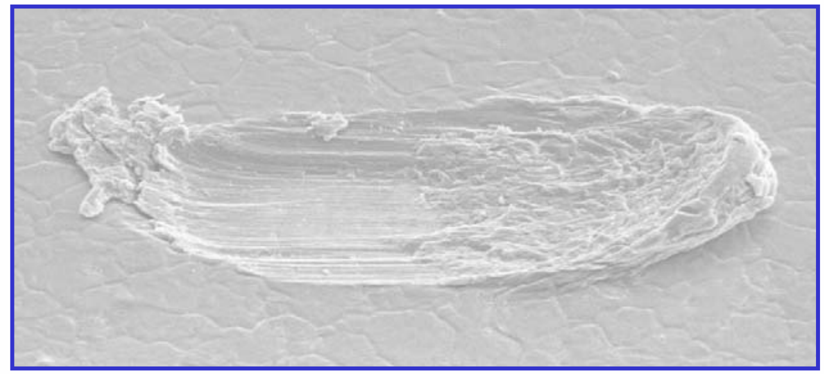


Probing Challenge on Low-k Devices
Hidden Underneath Layer Deformation

- **No PV ≠ Free Damage**



BCF:4gw/mil Tip Dia.=8um
OD= 45 μm Probe:6 times



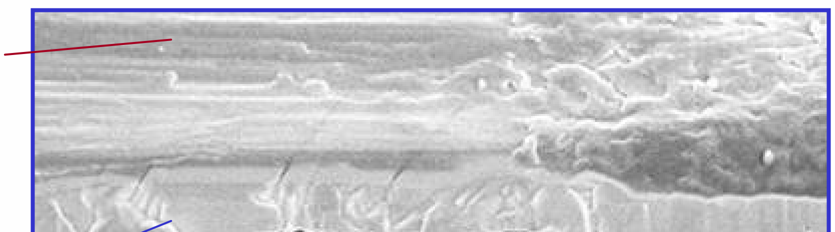
BCF:4gw/mil Tip Dia.=14um
OD=45 μm Probe:6 times

Cross Section

Deformation

Al

Cu

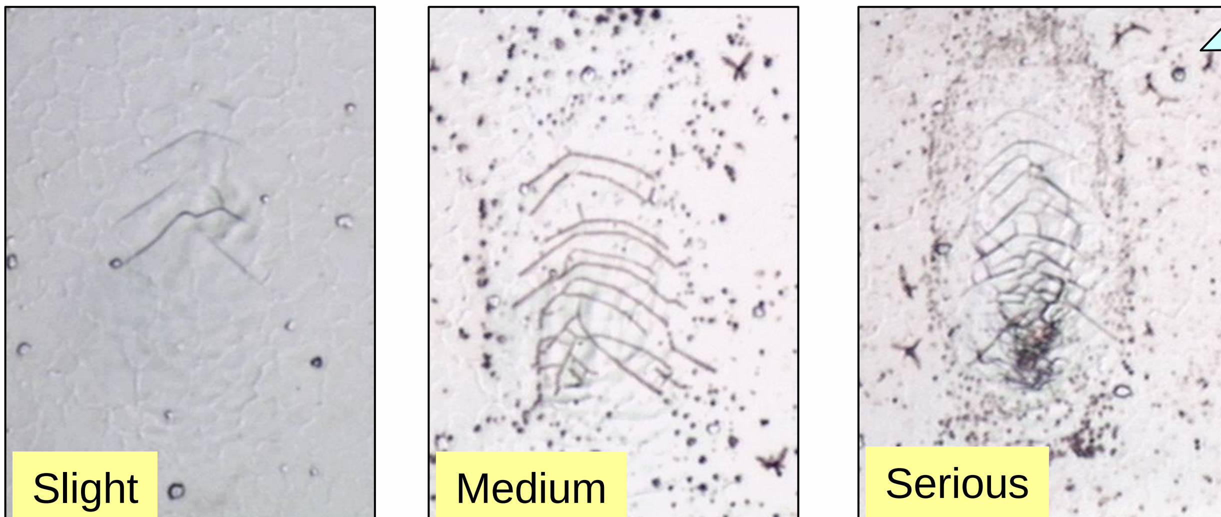


Serious Destruction

Probing Challenge on Low-k Devices

Initial Probing Damage

- After Al was removed, we found micro scratches and cracks as below images:



OD= 65 μm
TD=6 times
Tip Dia.=8 μm
BCF=4gw/mil

Scrub direction

- Evaluation showed the probability of probing damage:

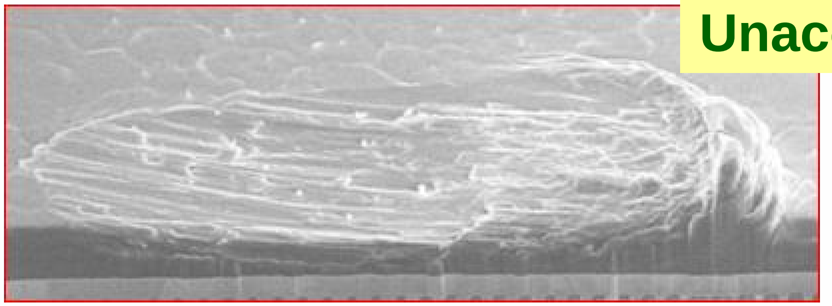
  TaN Crack > Underlying Deformation > Pad Void

- Safe probing method is to prevent TaN-crack!

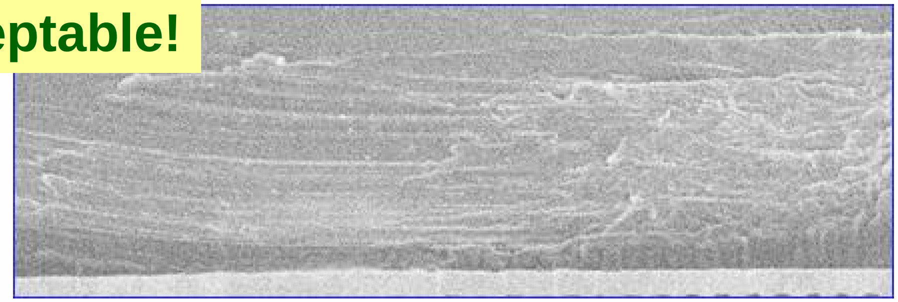
Scrub Depth Correlates with Underneath layers

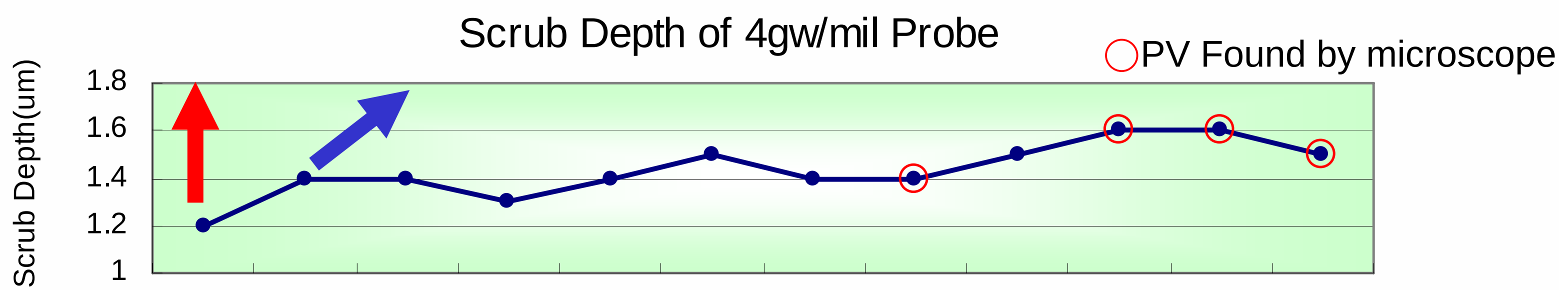
Underneath Layer Evaluations

- Measurements identified underneath layer deformation risk was at stake.



Unacceptable!





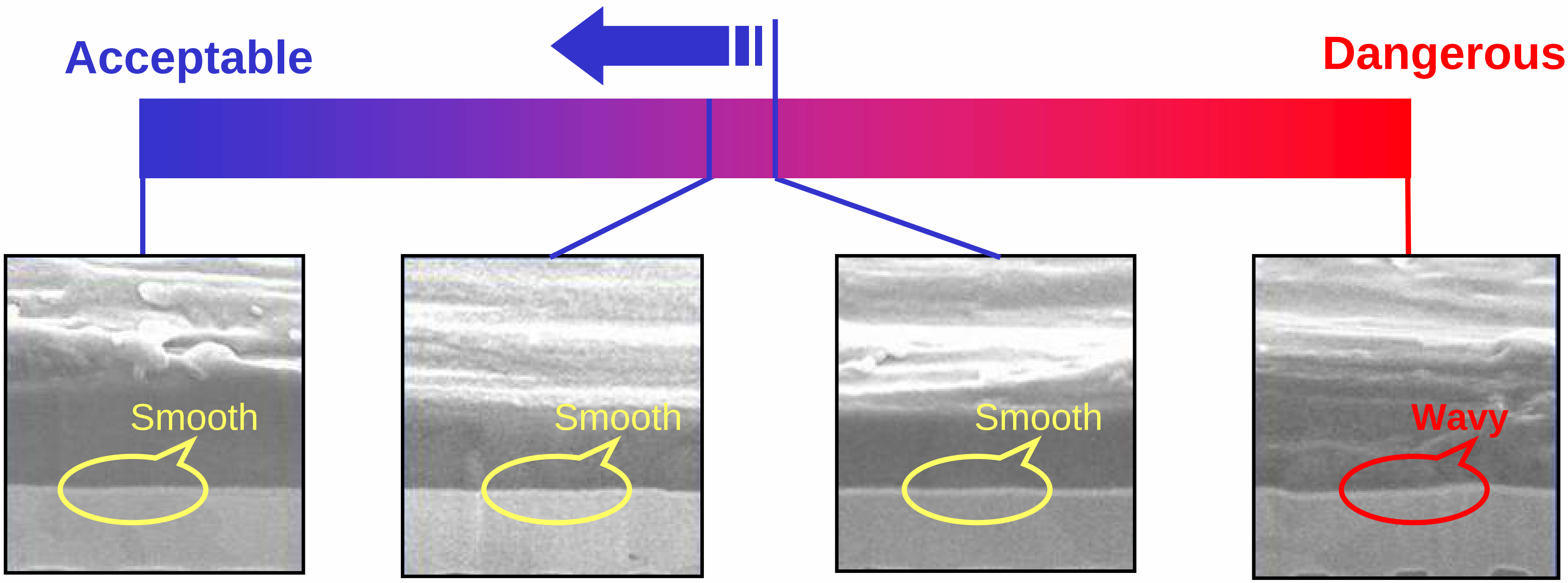
TD	2	2	2	2	4	4	4	4	6	6	6	6
OD(um)	45	55	65	75	45	55	65	75	45	55	65	75
Depth(um)	1.2	1.4	1.4	1.3	1.4	1.5	1.4	1.4	1.5	1.6	1.6	1.5

Parameters

Scrub Depth Correlates with Underneath layers

Acceptable Scrub Depth Region

- Monitor the TaN layers of shallow scrubs.



Scrub Depth 30% of α | Scrub Depth 54% of α | Scrub Depth 60% of α | Scrub Depth 86% of α

α = Thickness of Al Layer

Scrub Depth Correlates with Underneath layers

Scrub Depth Control is Necessary

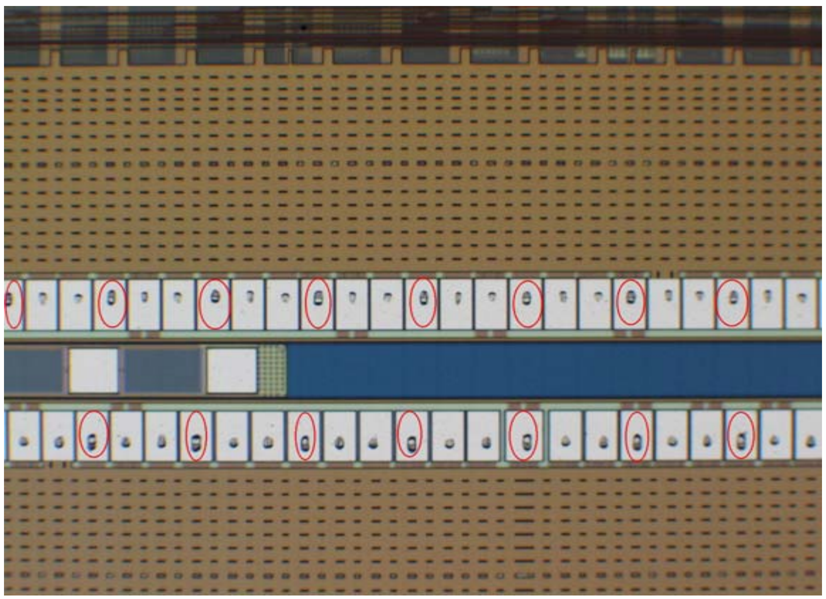
- Low-k devices are highly sensitive to probing force issue, more severely is the unobservable physical damage inside the pad.
- Hidden damage not seen at wafer inspect after probing, but identified at test failure during packaging/final test.
- Experiment and evaluation works indicated the safety band probing depth region is fallen below 60% of total Al thick.
- Efficient methodology to control the scrub depth is proposed by monitoring the Kyy as the primary dominant factor.
- Continuing the last year presentation on SWTW 2005, the proposed SDMF will be demonstrated again as an effective backend assessment methodology to prevent the probing damage.

Scrub Depth Model Formulation (SDMF)

PV Case in TSMC

2005 SWTW

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



Repeated PV patterns

Scrub Depth Model Formulation (SDMF)

Primary Factors of Experiment I & II

2005 SWTW

- 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}, needle 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.

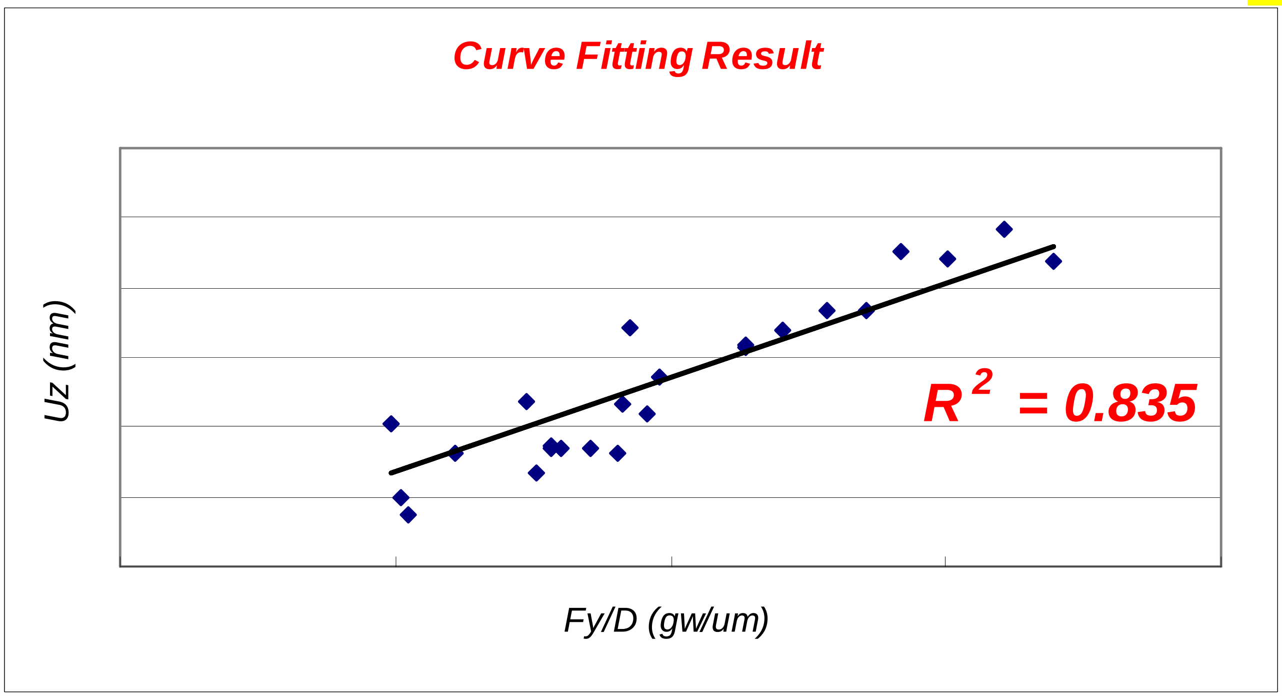
Scrub Depth Model Formulation (SDMF)

Theory, Experiment and Verification

2005 SWTW

- 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

Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

- Experiment background
  - Applicability of the model is evaluated.
  - Two more parameters included:
    - (1) Three most commonly used prober machines
    - (2) Different needle diameter (4 mils)
  - Prober set-up based on TSMC production used methods.

- Results

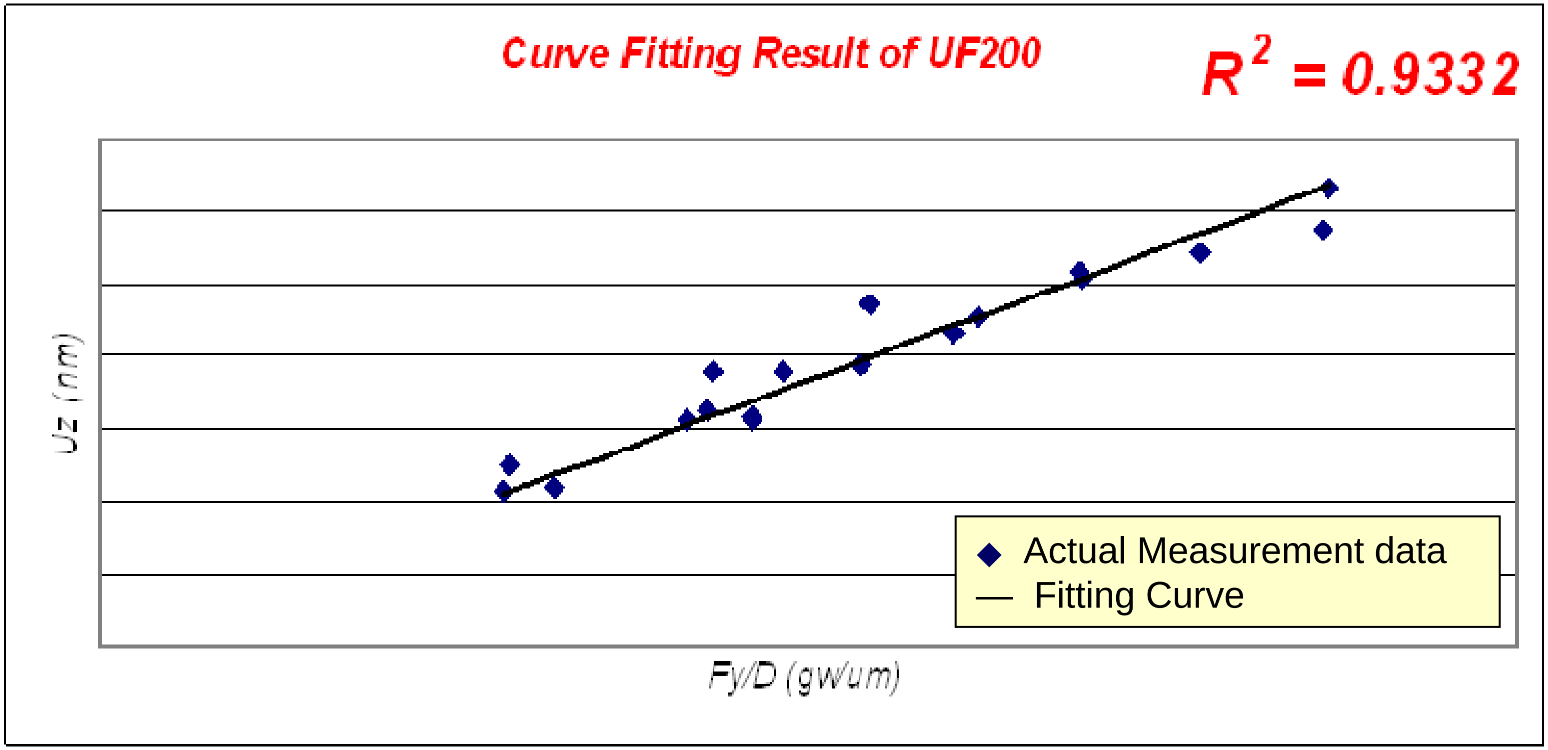
Prober		Probe			
Type	OD (μm)	Tip Dia. (μm)	Tier	Stiffness-Kyx (gw/mil)	Stiffness-Kyy (gw/mil)
UF200 **UF3000** **TEL P12**	40 60 75	8 13	1-3	1st: 7.28 2nd: 5.23 3rd: 4.19	2

Additional set up notes:. undershoot at UF prober is 25 um, while on TEL P12, double touchdown function is activated.

Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

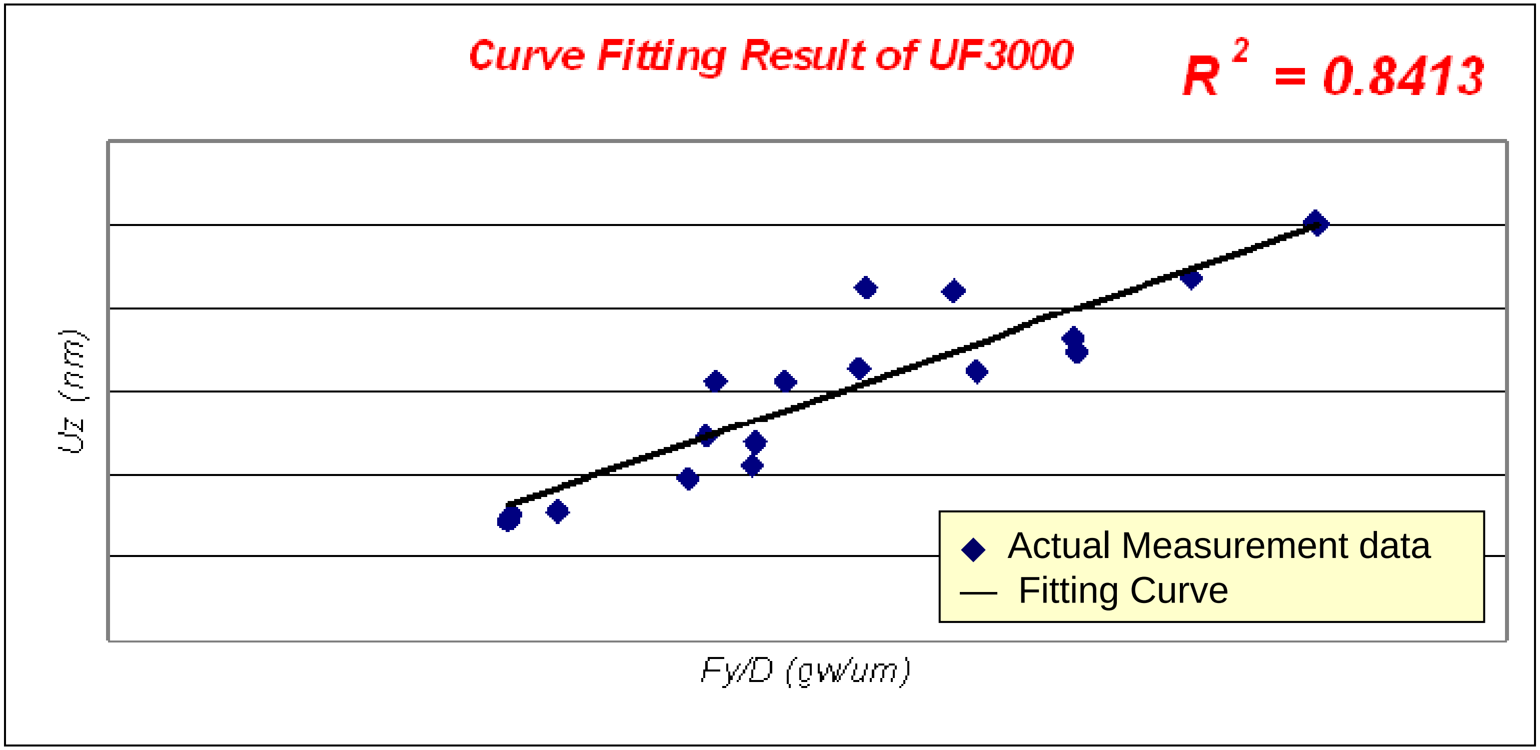
- **R-square was in high agreement for UF200**



Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

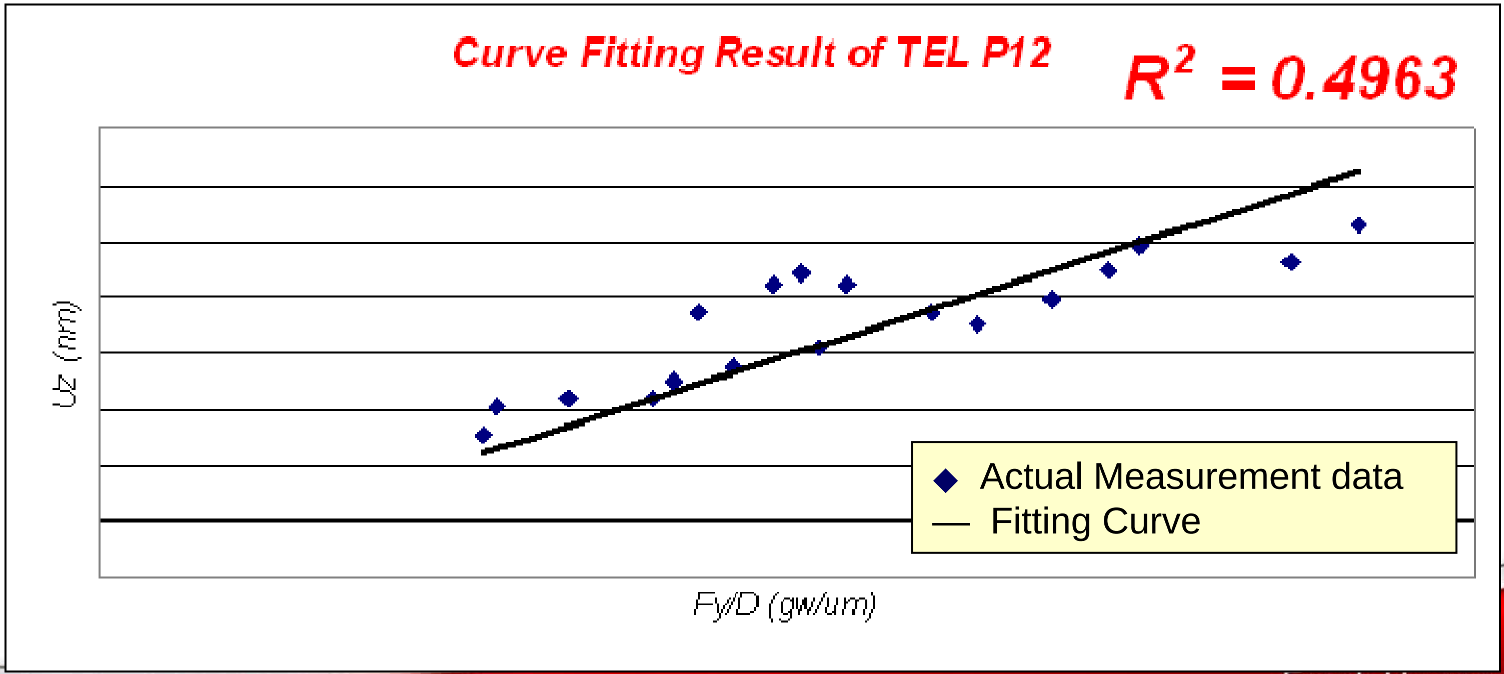
- **UF3000 also showed appreciable agreement**



Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

- **R-square showed lower fitting agreements.**
- **Prober chuck movement mechanism was attributed as major factor in the result variation.**
- **Initial guess is TEL P12 having deeper probing height than UF families.**

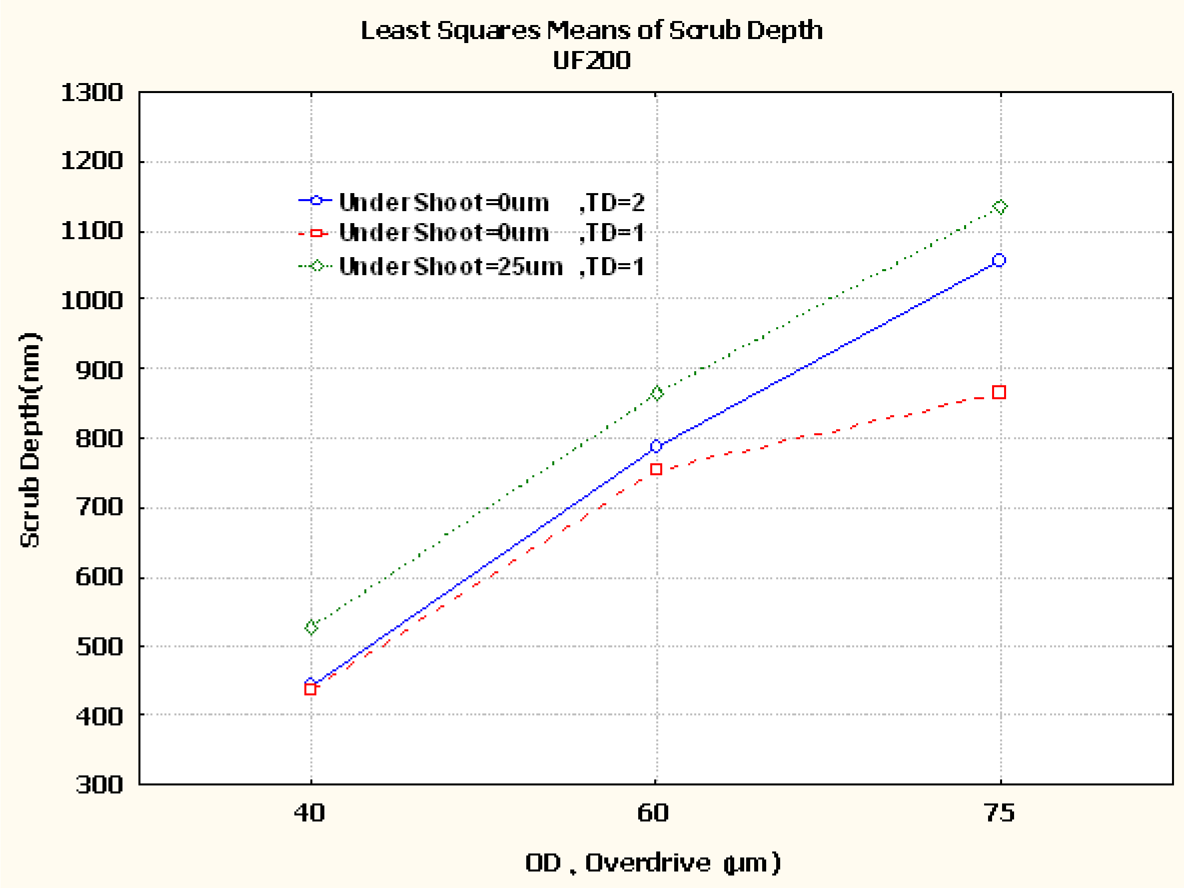


Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

- **SDMF – Constant parameter calculation**

【UF200】



Two normal TDs scrubbed 2~22% deeper than single TD. (see blue vs. red line)

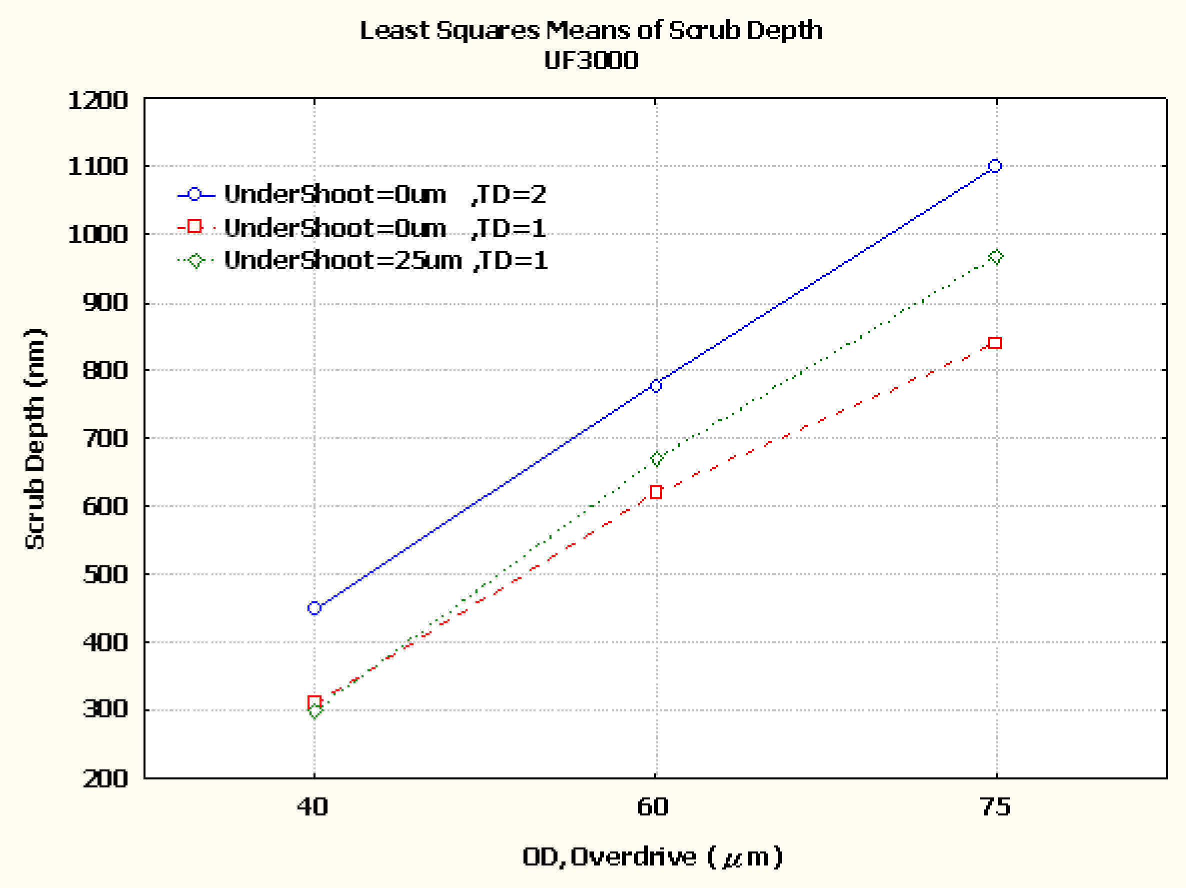
25um undershoot TDs has 15~30% deeper scrub mark than the non-undershooting one. (see green vs. red line)

Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

- **SDMF – Constant parameter calculation**

【UF3000】



Two common TDs generated 25~45% deeper scrub than with only 1 TD. (see blue vs. red lines)

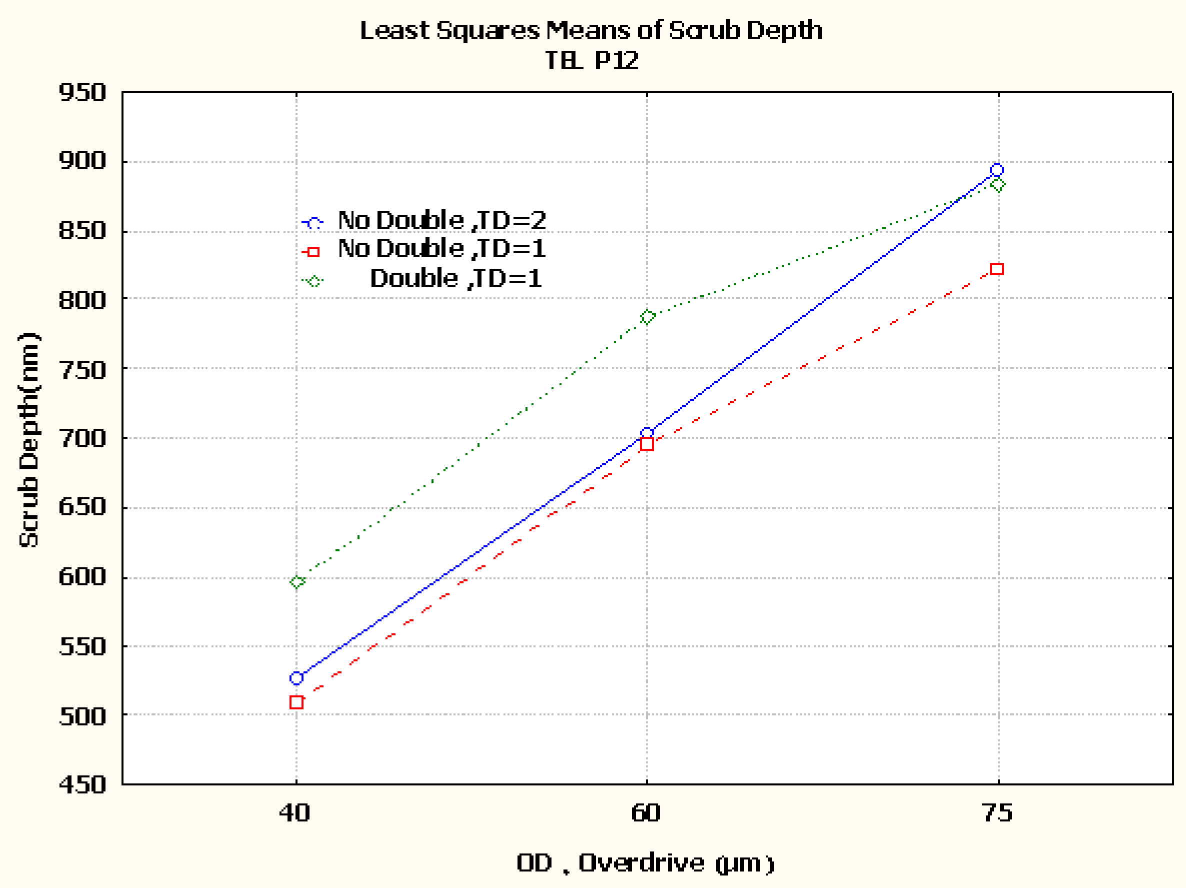
Activating undershoot 25um, scrubs became 0~15% deeper than non activated one. (see green vs. red lines)

Scrub Depth Model Formulation (SDMF)

Theory Ⅱ, Experiment Ⅱ, and Verification Ⅱ

- **SDMF – Constant parameter calculation**

【TEL P12】



"TEL double touchdown" function physically differs with UF's "undershoot function."

Two normal TDs' scrub marks were 4~9% deeper than the one by single TD.
(blue vs. red)

After activating "double touchdown", scrub is increasingly 8~17% deeper than non-activated one.
(green vs. red)

Scrub Depth Model Formulation (SDMF)

Summary

- SDMF results again showed the high level of quantitative prediction agreement with the corresponding experimental measurement data.
- "Linear Scrubbing / Slope Scrubbing" based assumption of SDMF is theoretically and experimentally proven to be capable of predicting the scrub depth the complex scrubbing action.
- Constant parameter modification factors of prober including set-up and multiple TDs functions, still need further statistic sampling data to obtain accurate results.
- Measurement errors existed in the experimental data is still acceptably tolerable as to be used in engineering level application.
- Production data feedback is always an on-going process for better modification results of certain constant values of the model.

BCF Measurement Limitation

Analyzer, Statistic, Experiment

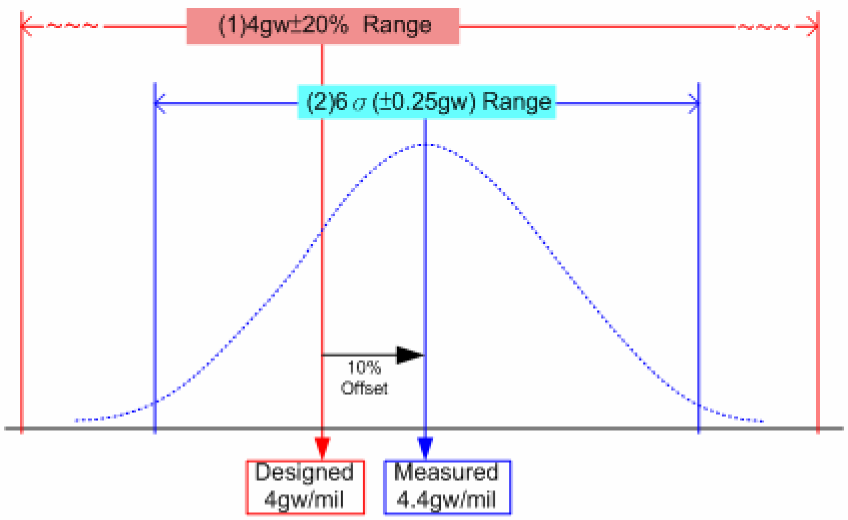
- BCF control is unavoidable for low-k probing
- How to address a common BCF definition by suppliers and vendors ?
- Currently the industry available BCF measurement tooling (ex. Equipment A) showed spec as below：

Probe Force & Z-Force	Travel	Load	Repeatability	Accuracy
Probe Force shown @ 3σ	0-30 grams	Max Load: 50	± 0.12 grams	± 0.25 grams
Maximum Z-Force		130 lbs. (60 kgs)		

Simply states:
With measured value 1gw/mil, it will have confidence intervals 99.7%
that the deviation range should fall from 0.75~1.25 gw, also denoted as (1gw ± 25%)

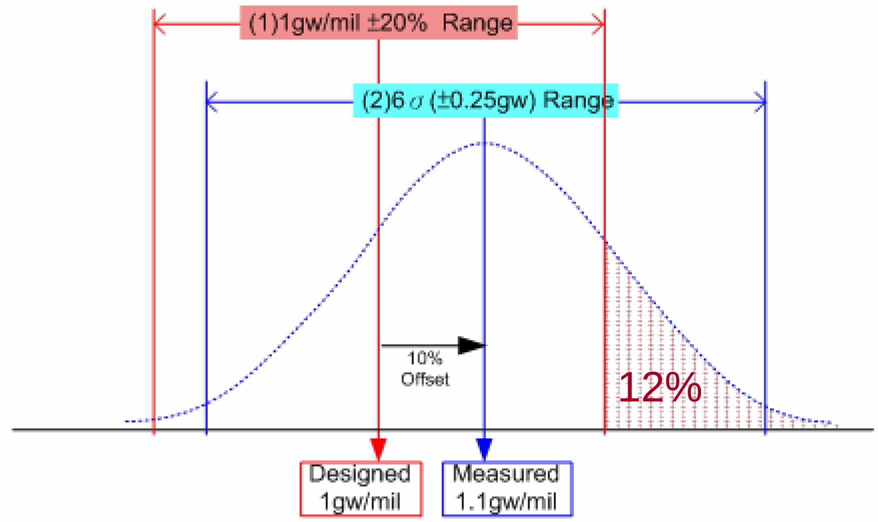
BCF Measurement Limitation

Analyzer, Statistic, Experiment



(1)BCF Spec:4gw/mil ±20%
(2)Accuracy:±0.25gw @3σ

10%-offset BCF Measure
100% confidence within Spec.



(1)BCF Spec:1gw/mil ±20%
(2)Accuracy:±0.25gw @3σ

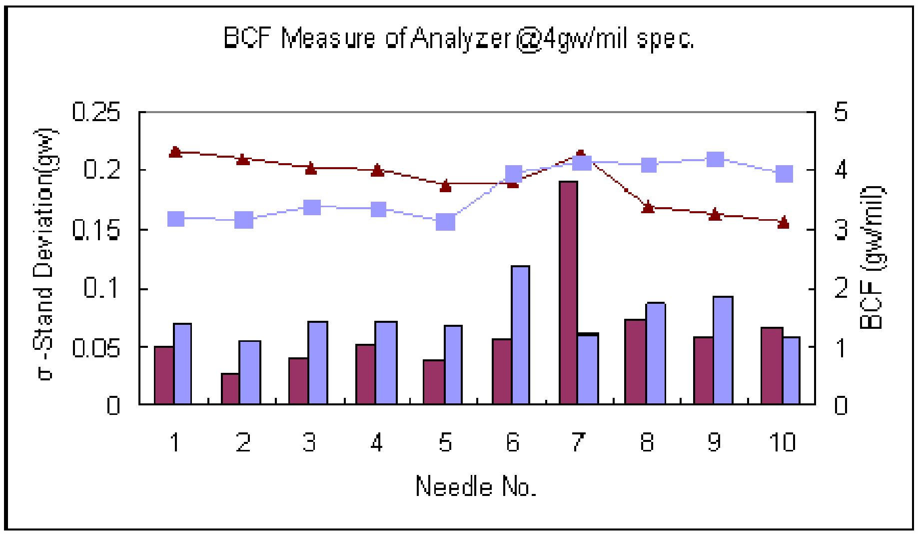
10%-offset BCF Measure
88% confidence within Spec.

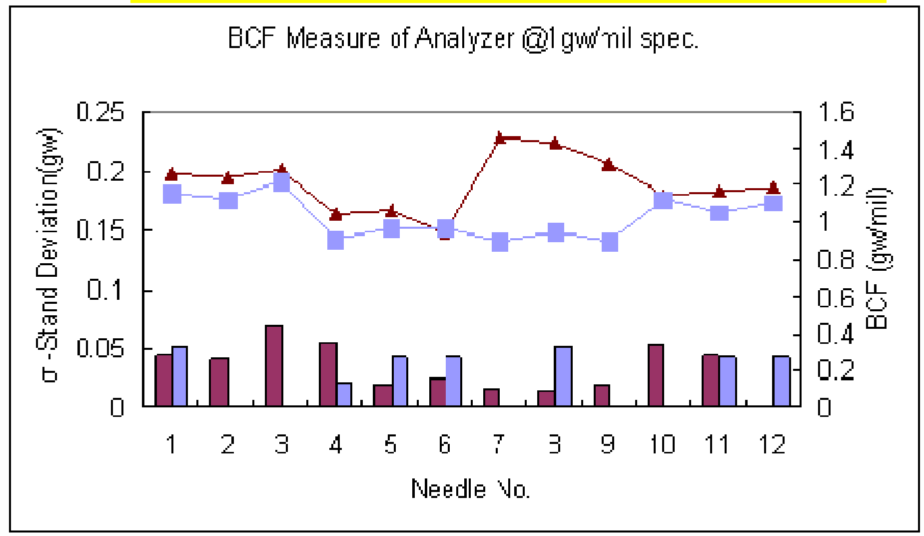
As metrology accuracy has been pushed to its limit, allowable manufacture deviation suffers more and more tighter tolerance. New BCF metrology platform is urgently needed.

BCF Measurement Limitation

Analyzer, Statistic, Experiment I

- At low BCF values, measurement accuracy is degraded to marginal range





Average Standard Deviation:

σ_{Ave}-TSMC is 0.065

σ_{Ave}-MPI is 0.075

BCF under 3 σ confidence interval:

TSMC ≒ μ ±0.195 4 gw/mil ±5%

MPI ≒ μ ±0.225 4 gw/mil ±5%

Average Standard Deviation:

σ_{Ave}-TSMC is 0.033

σ_{Ave}-MPI is 0.025

BCF under 3 σ confidence interval:

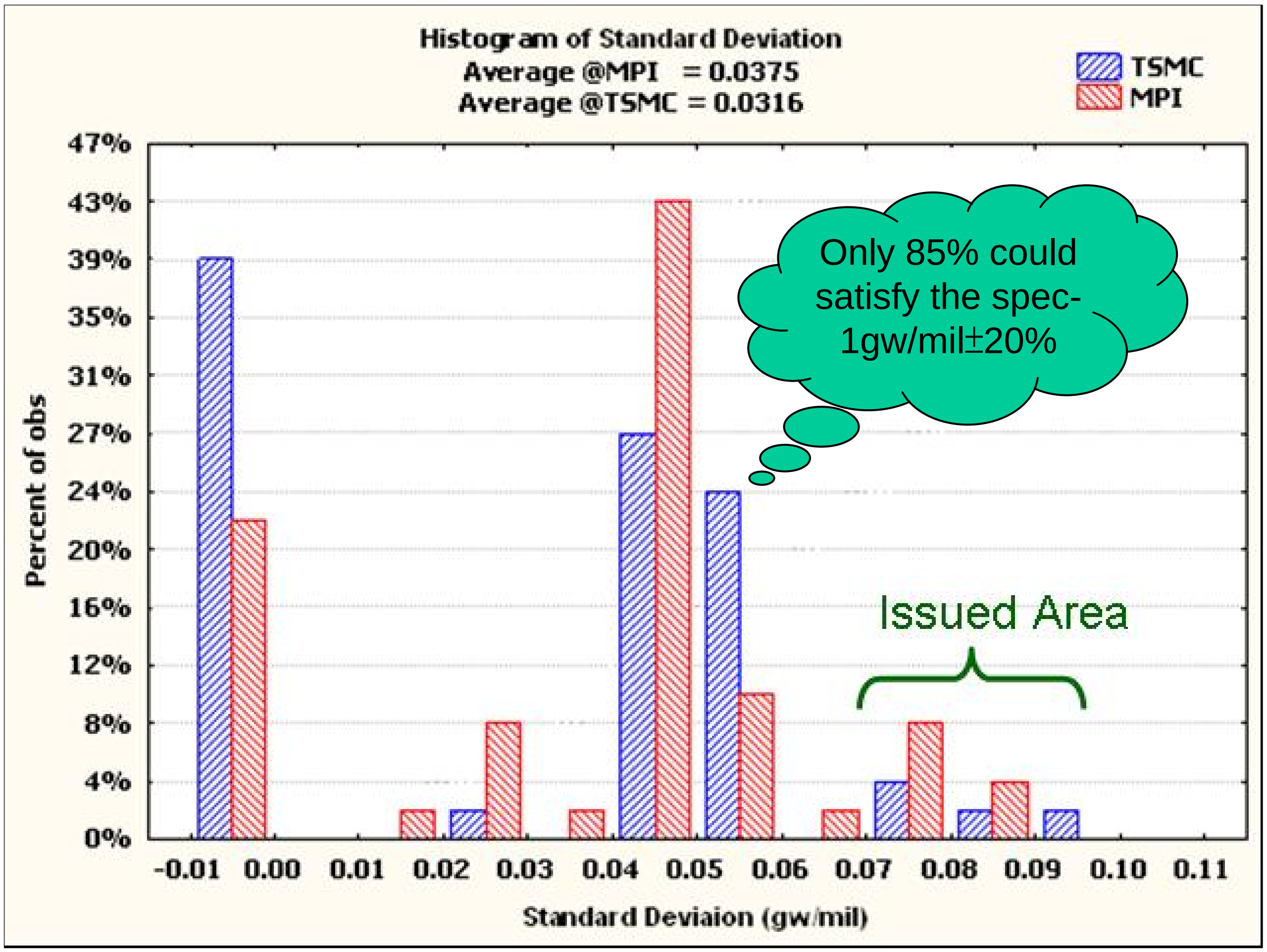
TSMC ≒ μ ±0.1 1 gw/mil ±10%

MPI ≒ μ ±0.075 1 gw/mil ±7.5%

Accuracy is getting worse！

BCF Measurement Limitation

Analyzer, Statistic, Experiment II



Procure a qualified low-k probe card.

Carried out 5 repetitive BCF measurements from selected 50 pins.

For required spec 1gw/mil ±20%, sigma must at <0.07 for obtaining less debatable data

More sampling data for meaningful statistics.

Conclusion

- High density of mechanically weak structural layers of IC pad introduced in low-k wafers will increase the pad crack possibilities.
- Now TSMC keeps practicing the SDMF as the standard guideline for monitoring and controlling the probing scrub marks in achieving the robust wafer sort.
- SDMF results can also be further implemented into probe card design in order to obtain acceptable probe depth.
- SDMF was again validated experimentally under consideration of more complete practical probing parameters. However, prober set-up (particularly chuck movement) still considered as important factor.
- Available BCF metrology is recently at its bottleneck limit, for low-k card, new enhancement tooling to obtaining accurate measurement is under request.

Q&A