



Application of Picosecond Acoustic Metrology for monitoring Metal Films in Advanced Packaging

MARCH 19TH 2024

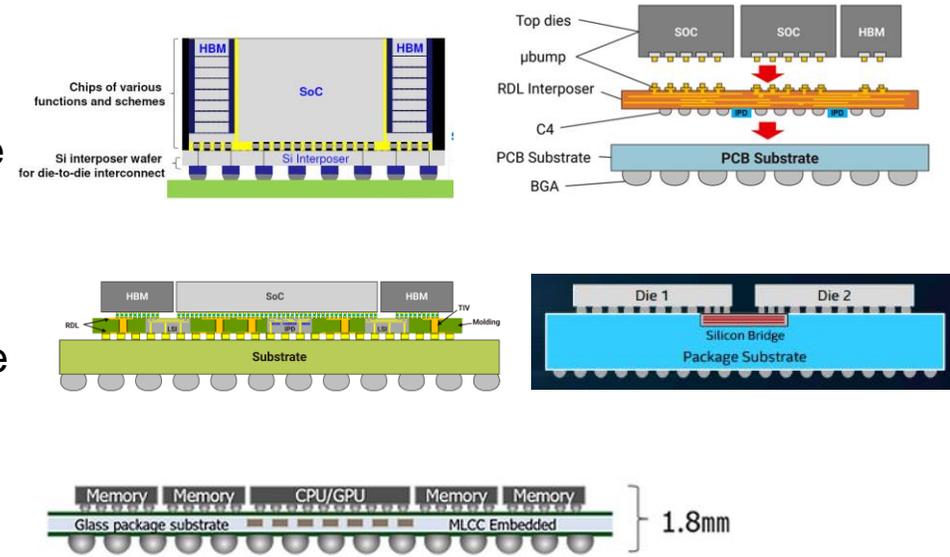
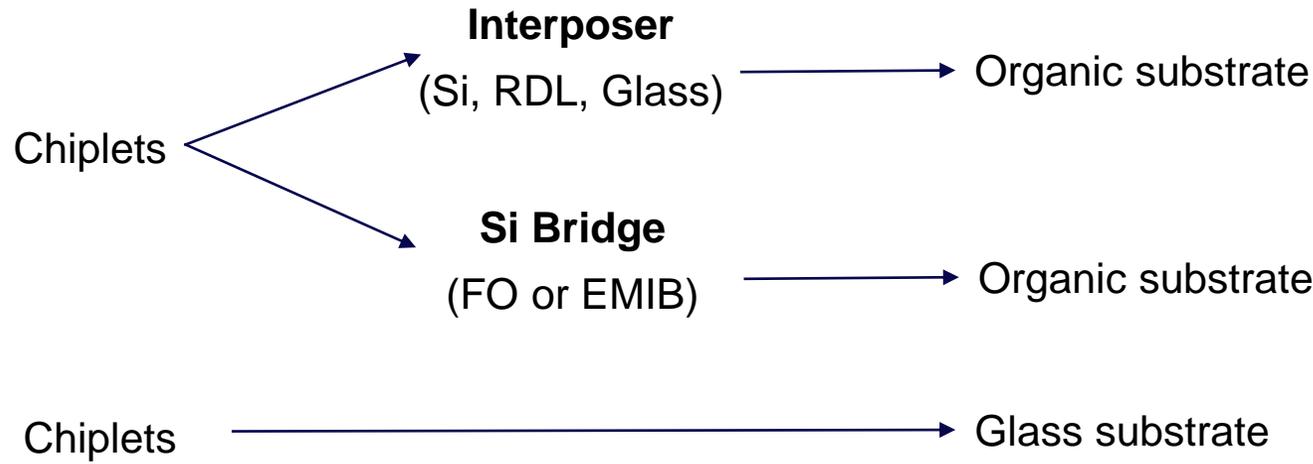
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Agenda

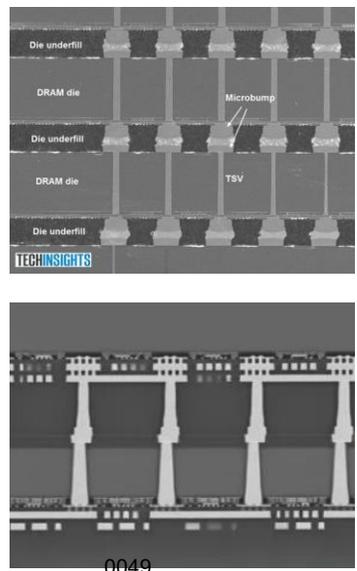
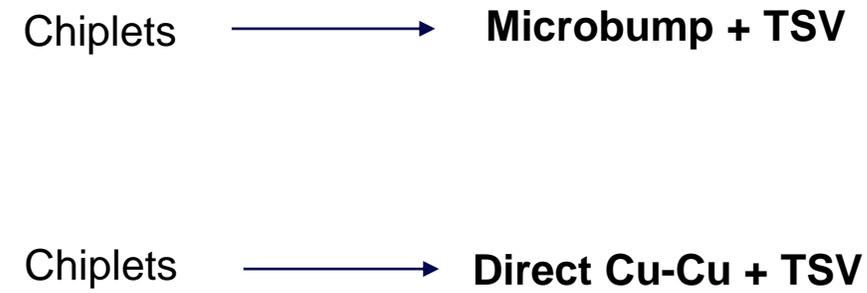
- Introduction to PULSE Technology
- Challenges in Advanced Packaging
- System Improvements
- Selected Examples
 - FOWLP
 - 2.5D Integration

Advanced Packaging Trends: Chiplet Integration Schemes

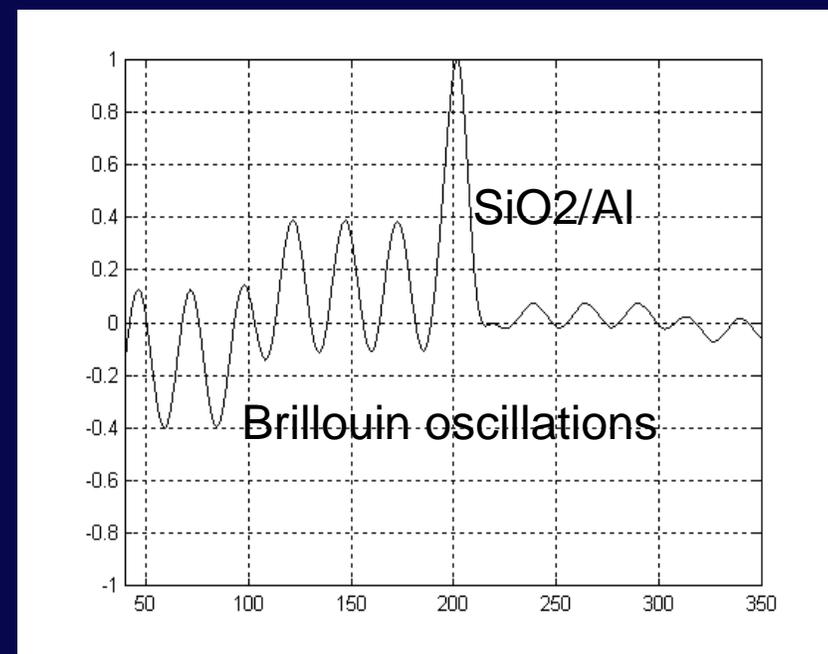
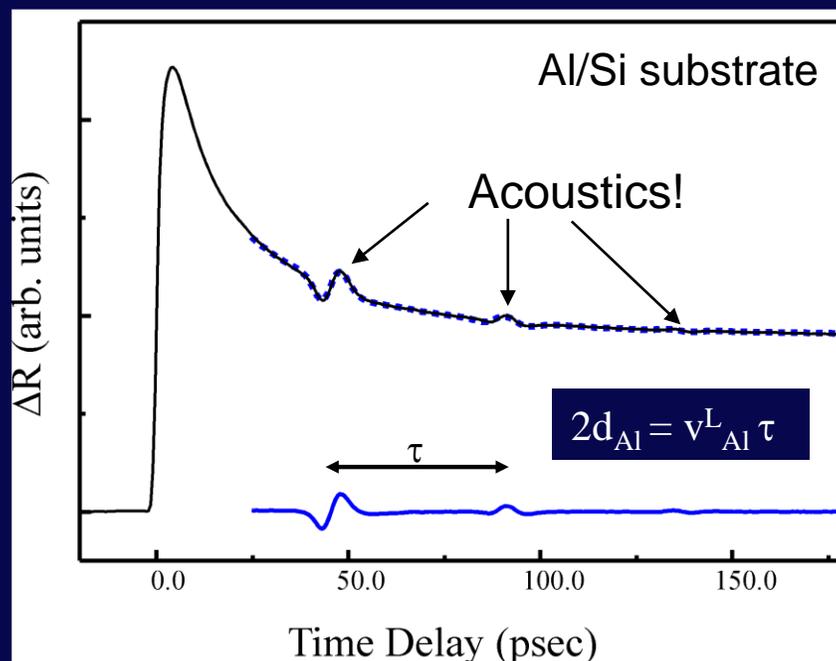
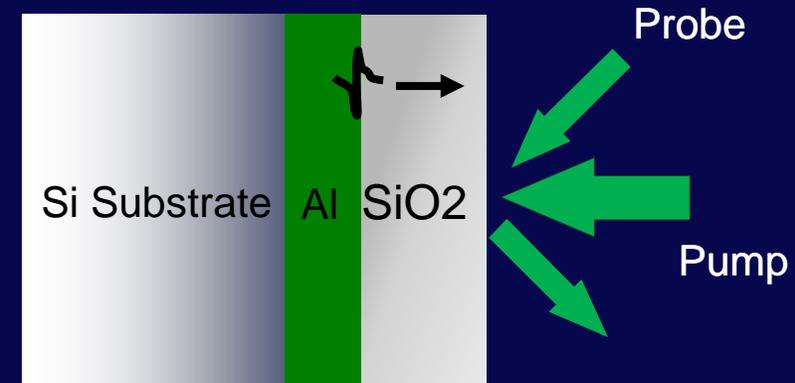
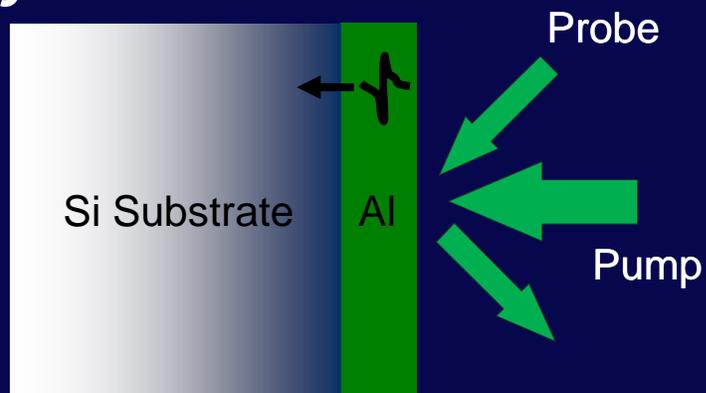
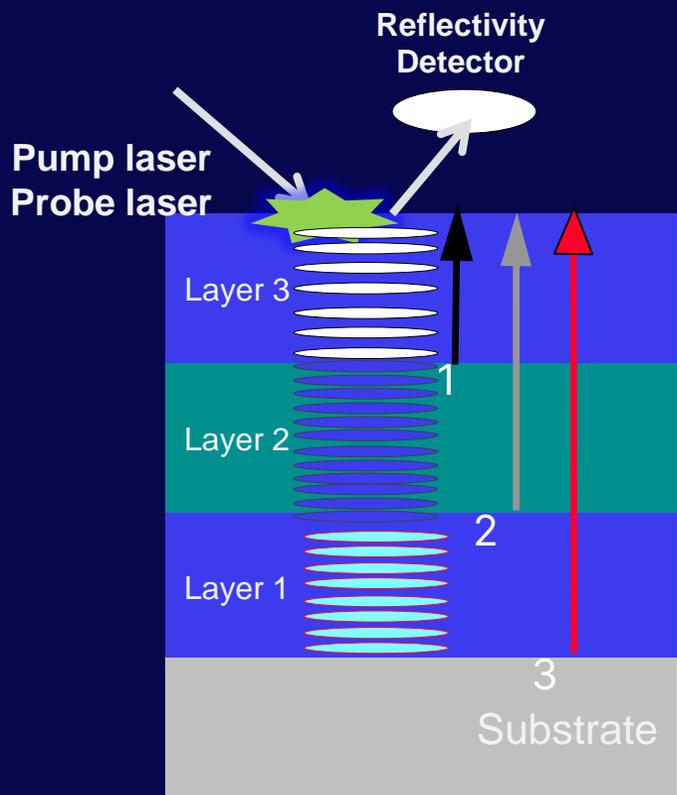
2.5D Integration



3D Integration



PULSE™ Technology



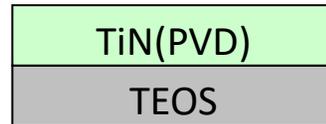
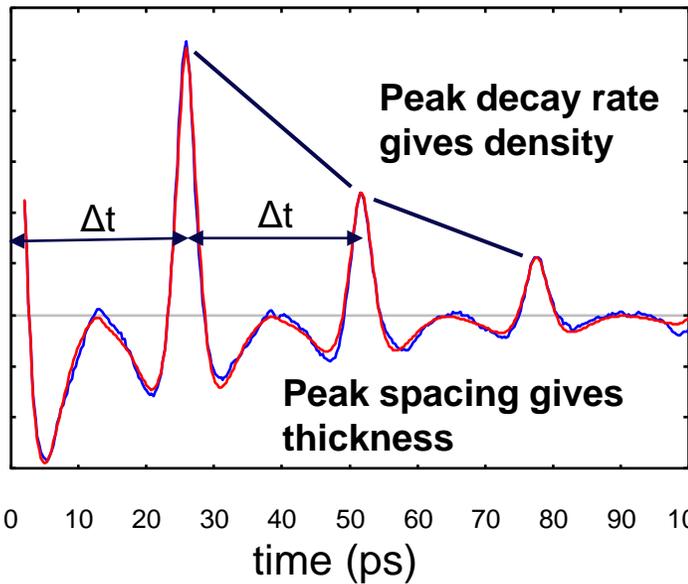
Time Scales of Response*

fs – electronic, ps – acoustic, ns – thermal

Opaque Film Measurement

Single Layer Measurement

- time is the round-trip travel time of sound wave inside the film. This gives us thickness.
- Decay of the peak height (ratio of adjacent peak height) depends on “acoustic reflection coefficient”. This allows us to calculate density of the layers.



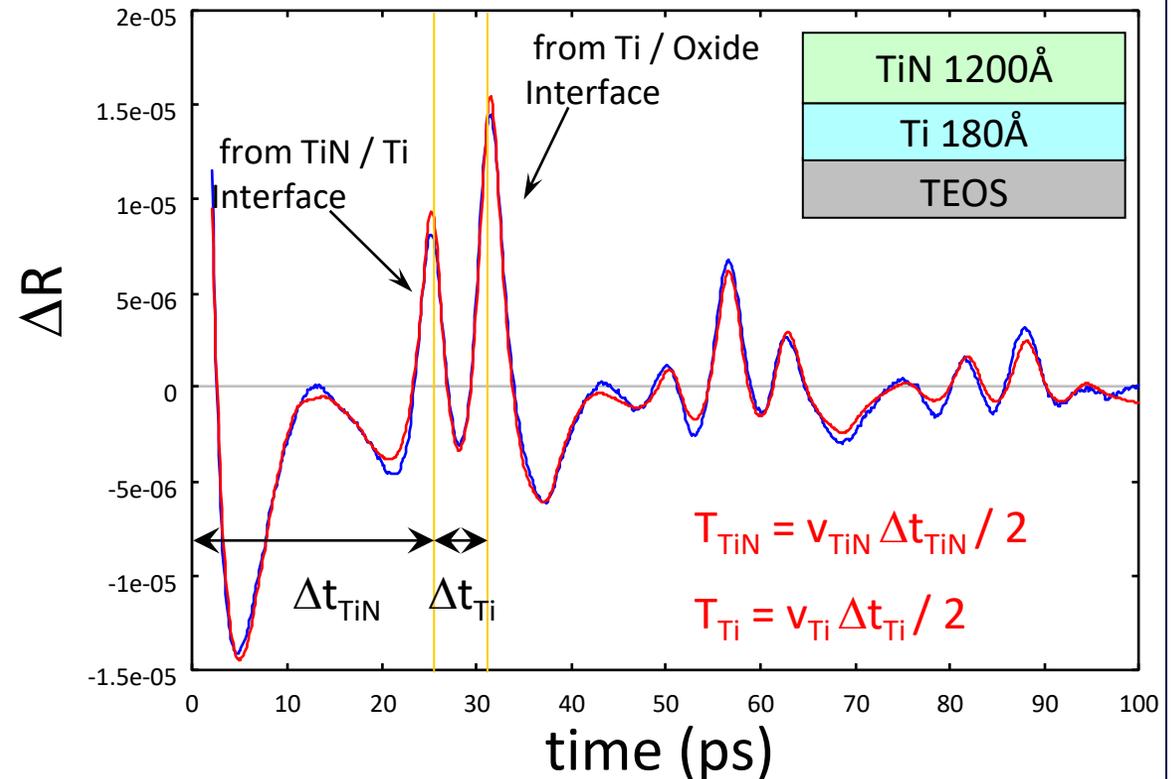
$$d = \frac{v\Delta t}{2}$$

$$R = \frac{\rho_2 v_2 - \rho_1 v_1}{\rho_2 v_2 + \rho_1 v_1}$$

d : Thickness
R : Acoustic impedance coefficient
ρ : Density
v : Sound velocity

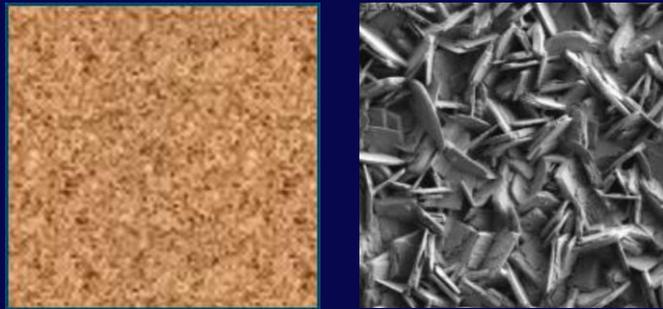
Multi Layer Measurement

- Signals from different layers are showing up at different time delay that enable us to measure multi-layer thickness simultaneously.

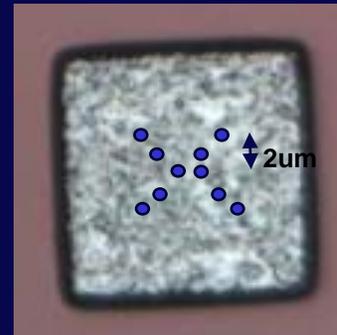


Challenges in Advanced Packaging Applications

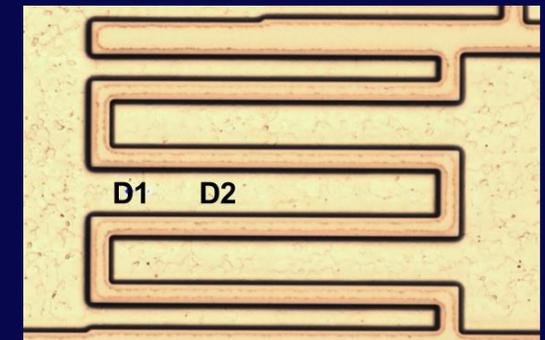
Rough surface



Local non-uniformity



RDL Dimension Measurements

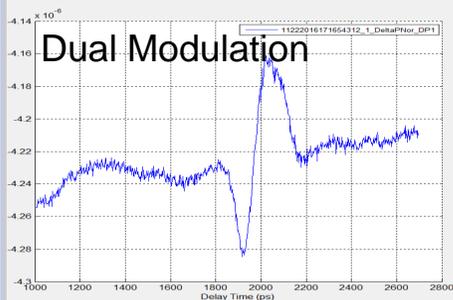
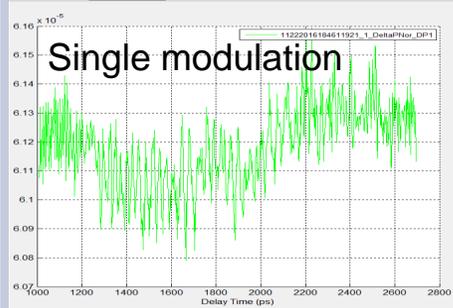


Thick, rough, non-uniform films require excellent SNR to meet gage-capable measurements. While measuring RDL structures, requirement to measure both thickness and CD

Improved Configuration to Serve Advanced Applications

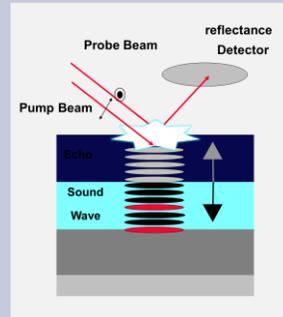
Rough Films
DRAM RDL AI

7X SNR
Improvement



Cross Polarization

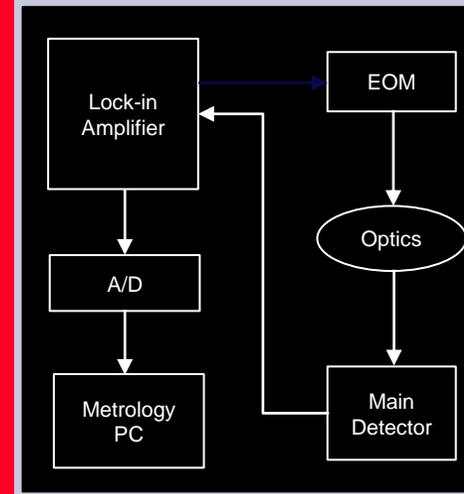
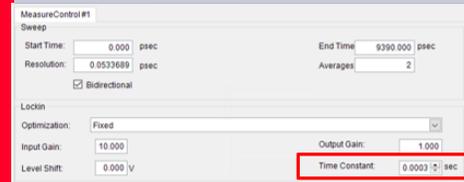
Films-specific
polarization selection



	Film	SNR (STD)	SNR (X-Pol)	Improvement Factor
1	a-C 2 μ m	5.95	14.7	3
2	Cu700 \AA	90.5	115.3	1.3
3	Cu2 μ m	78.1	168.6	2.1
4	W650 \AA	32.7	75.9	2.3
5	W5k \AA	64.3	203.1	3.1
6	Al7k \AA	53.1	157.4	3.0

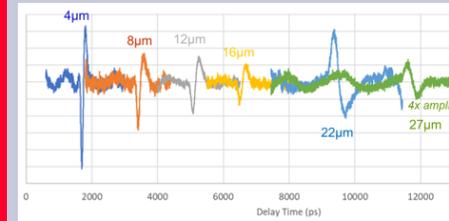
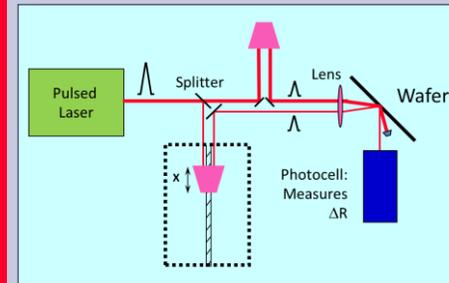
Faster Data Acquisition

Improved throughput



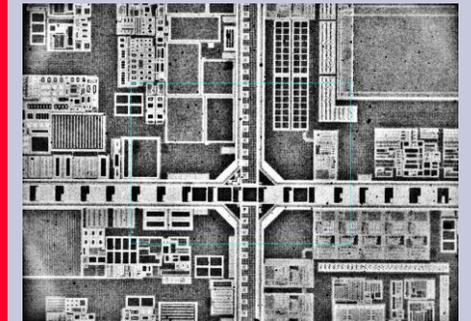
Extended Thickness
Capability

16ns Delay ~ 35 μ m
Cu



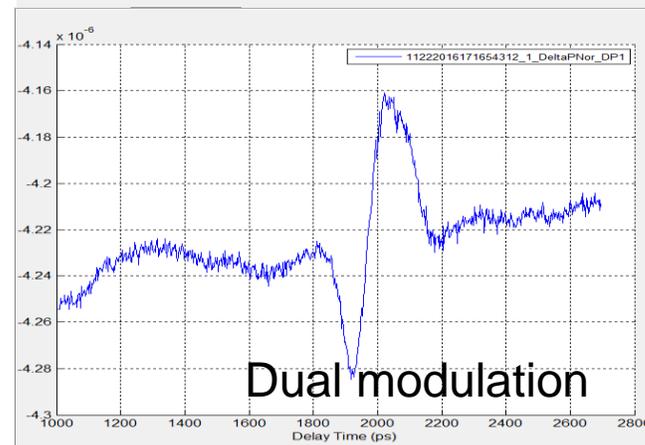
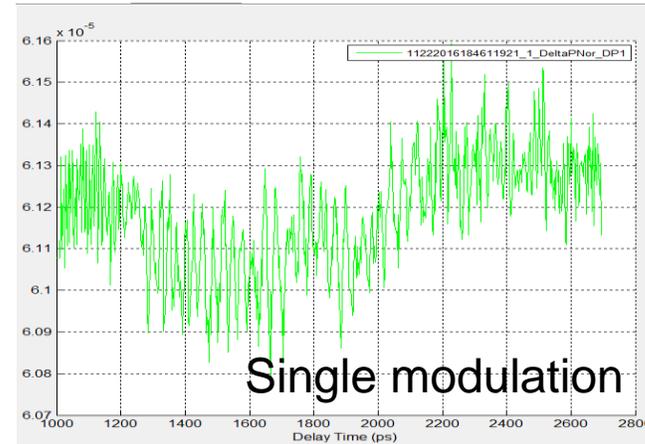
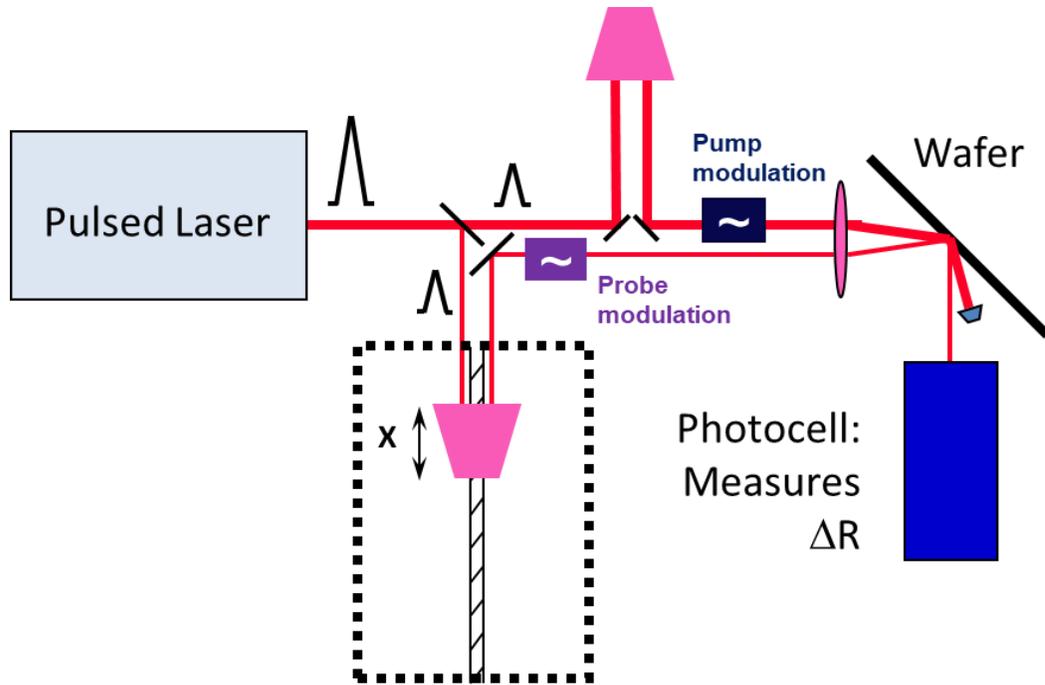
Pattern Rec
Enhancements

Advanced pattern
recognition including
dimensioning



Applications performance improvements demonstrated!

Dual Modulation for Rough Film Measurement



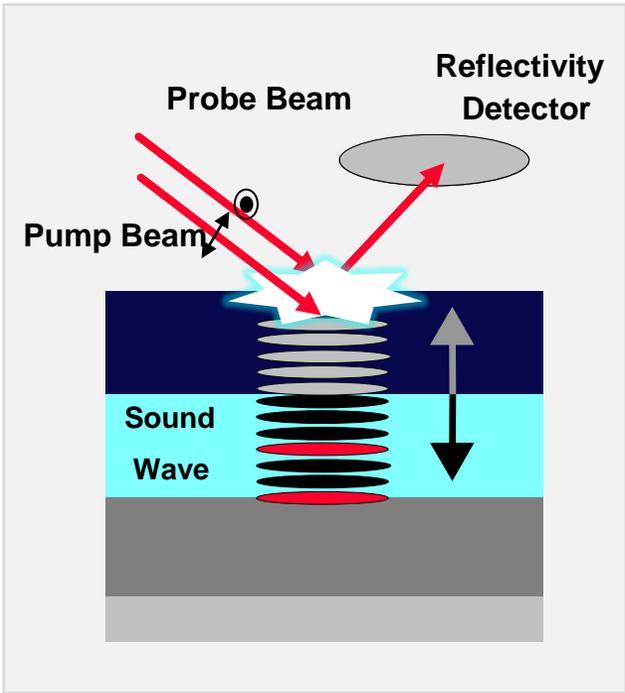
Single modulation:
Excessive scatter and depolarization of pump beam after reflection from rough surface affects SNR.

Dual Modulation: Modulate pump (5MHz) and probe (0.5MHz) beams and demodulate signal at sum freq. (5.5MHz)

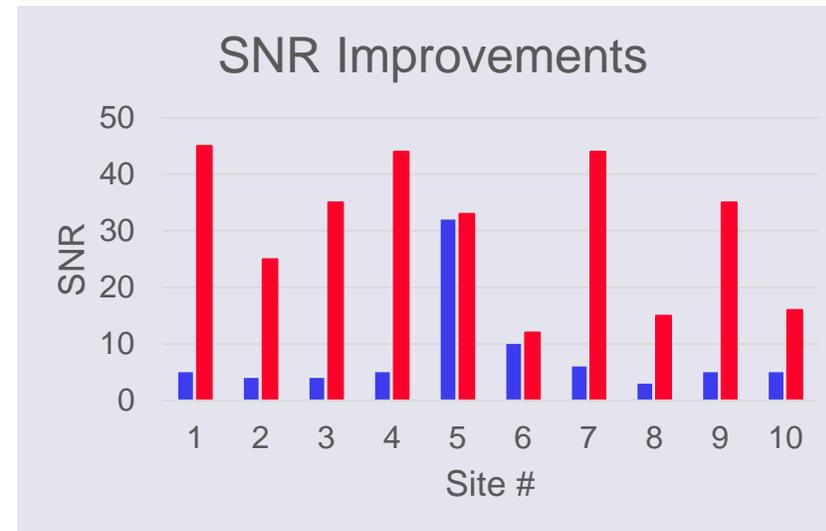
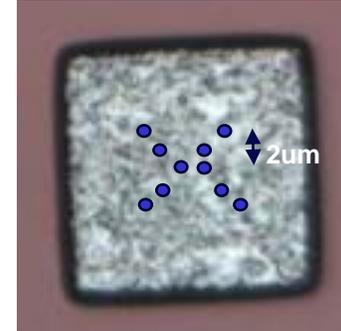
> 3X improvement in Signal to Noise when measuring rough films.

Cross Polarization Option: Enhanced Signal to Noise

Rough Multi-layer Stack



Some applications have stronger absorption for s-polarized light and stronger reflectivity for p-polarized light. This helps enhance SNR



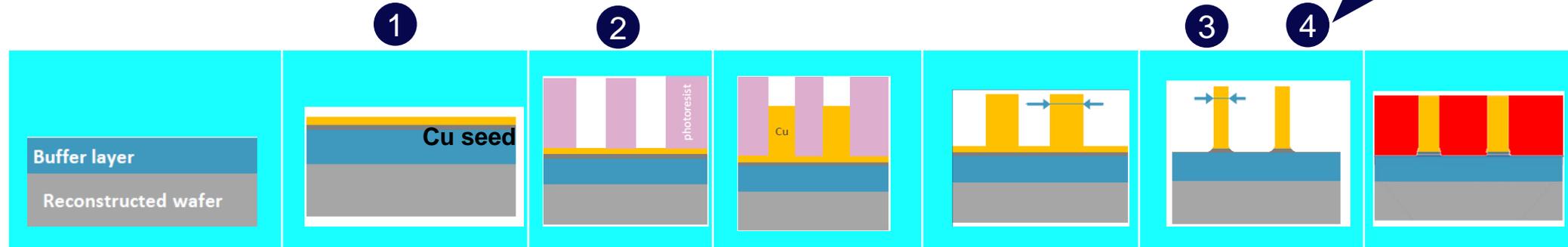
Standard
Cross Pol + Dual Modulation

Combination of Cross Polarization + Dual modulation provides gage capable repeatability

RDL Process Flow: Process Requirements

Cu seed etching without impacting electrical characteristics of the line is critical

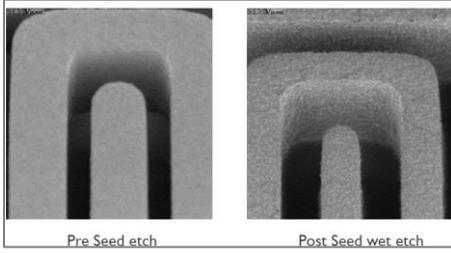
PULSE Technology



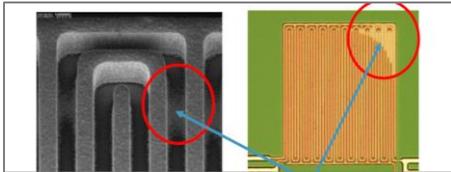
Poor Cu seed adhesion can cause delamination of conducting lines and vias.
Impact to downstream process

Seed Thickness impacts plating, **WIW uniformity and coverage**

RDL Thickness Measure post resist strip to establish baseline



RDL Thickness & CD loss post-etch: **Impacts line resistance, line resistance uniformity and leakage current**

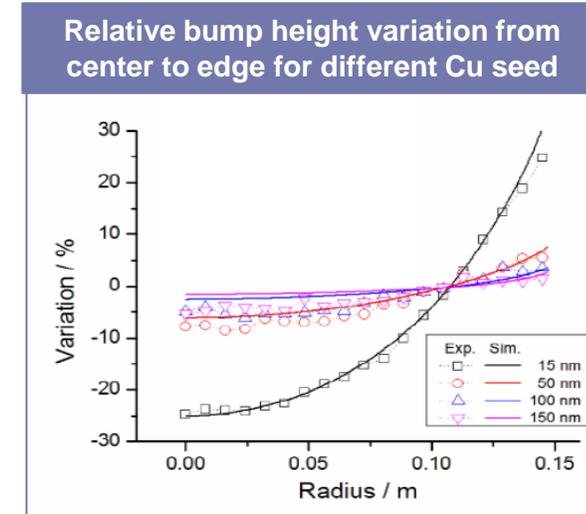


Residual Cu seed on polyimide causes **shorts= yield killers**

Thickness and CD are critical parameters in fine pitch RDL

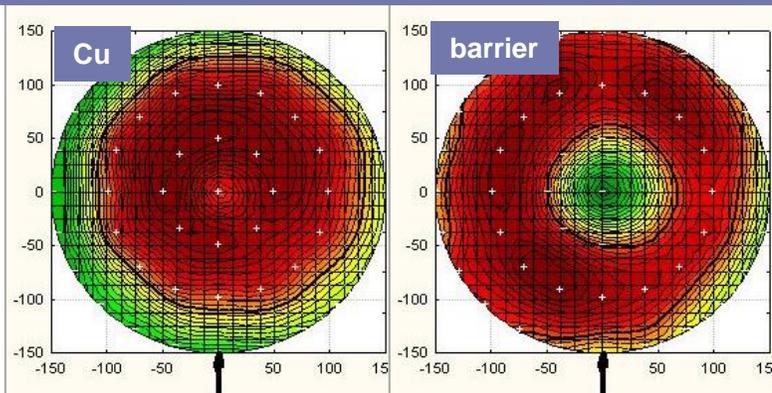
Cu seed/barrier: Process Challenges

Process Step	Process role/challenge	Metrology Requirement
Cu seed/barrier deposition	<ul style="list-style-type: none"> Current path for wafer edge for plating adhesion diffusion barrier 	<ul style="list-style-type: none"> thickness uniformity of Cu seed and barrier layer

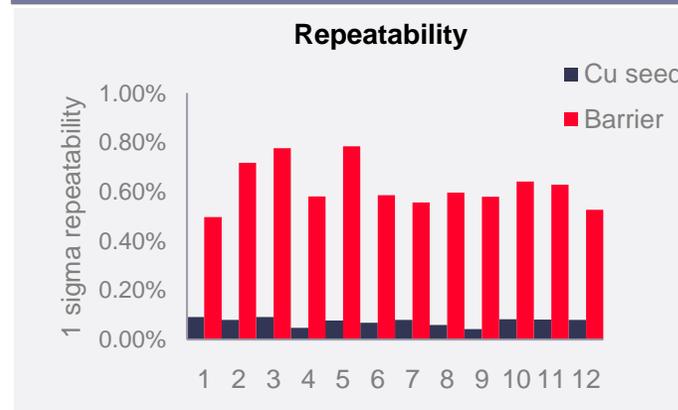


Solution

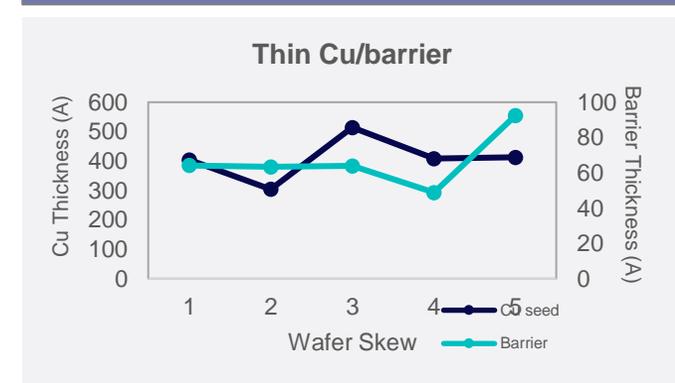
49pt uniformity maps



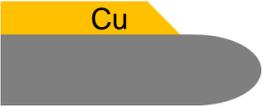
Excellent repeatability



Sensitivity to thin Cu seed/barrier



Simultaneous measurement of Cu seed and barrier- excellent repeatability and sensitivity

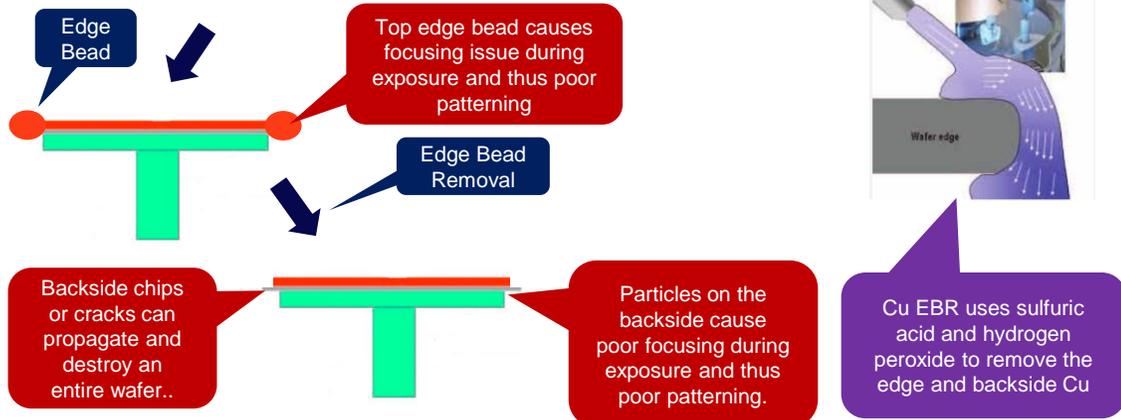
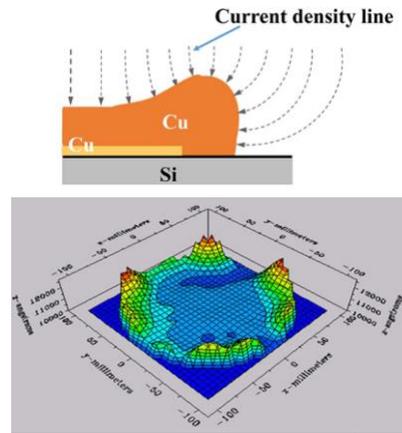


Cu Edge Bead Removal (EBR) Monitoring

Process Flow & High Value Problems

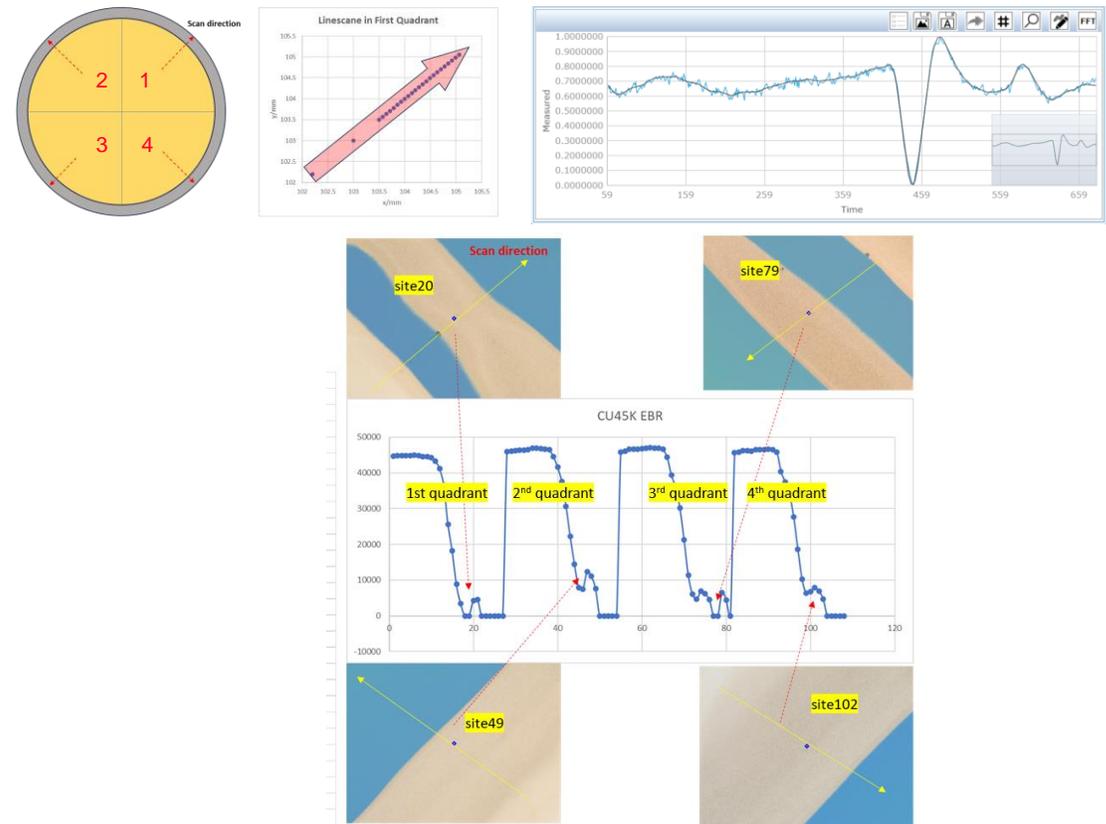
Cu EBR (Edge Bead Removal)

- Cu ECP process consists of three steps: Cu plating, EBR and annealing.
- ECP Cu tends to deposit excessive Cu near the edge of the wafer due to higher electric field.
- EBR width in top metal layer ECP is key to the chip manufacturing, since wider EBR may not only affect the yield of chips located in wafer edge, but also lead to wafer ID miss-auto read issue..



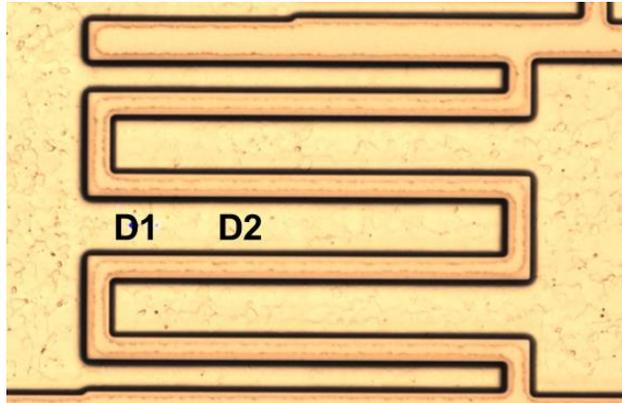
Results

Measurement Result

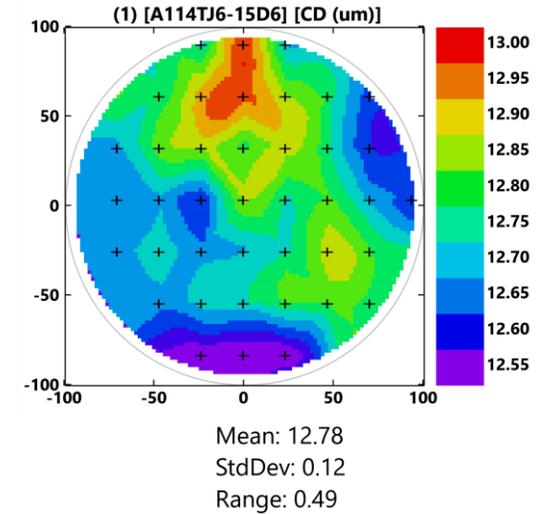


RDL CD Measurement : Dynamic Repeatability

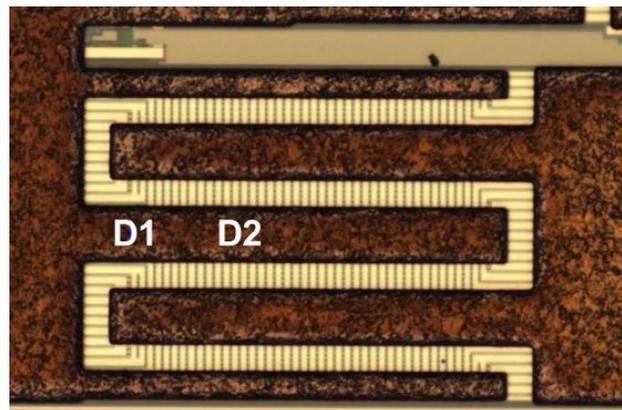
Pre-Etch Pooled 1 σ , 25 Shot



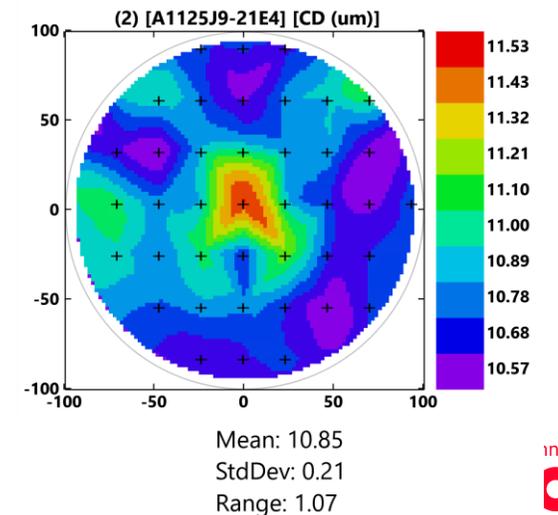
Site	CD (μm)	Stdev (%)
D1	12.79	0.45
D2	14.11	0.23



Post-Etch Pooled 1 σ , 25 Shot

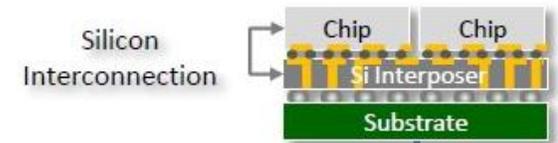


Site	CD (μm)	Stdev (%)
D1	10.82	0.97
D2	11.55	0.31



CD shows good repeatability for both pre-etch and post-etch wafers.

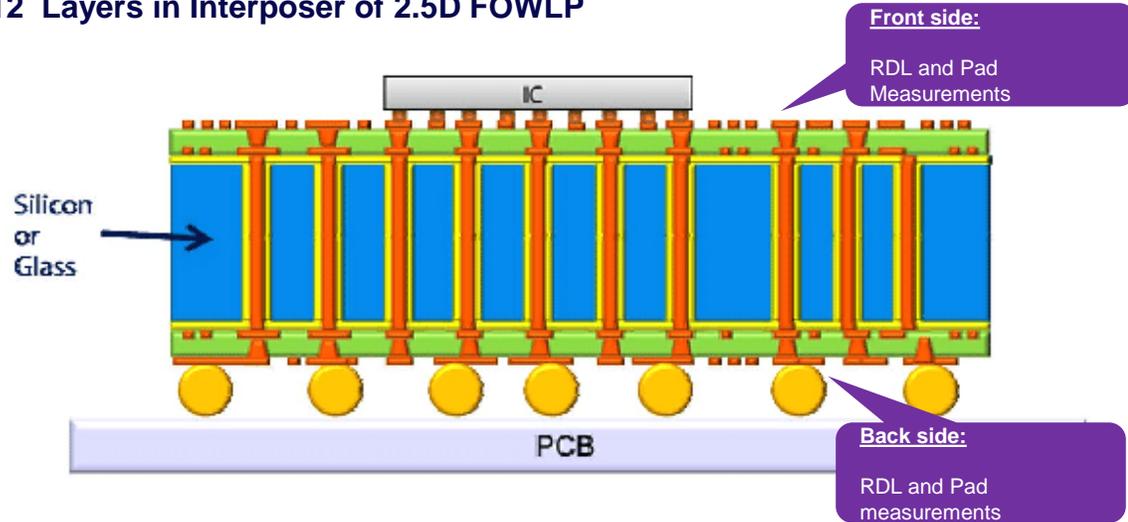
Applications Interposer in 2.5D FOWLP



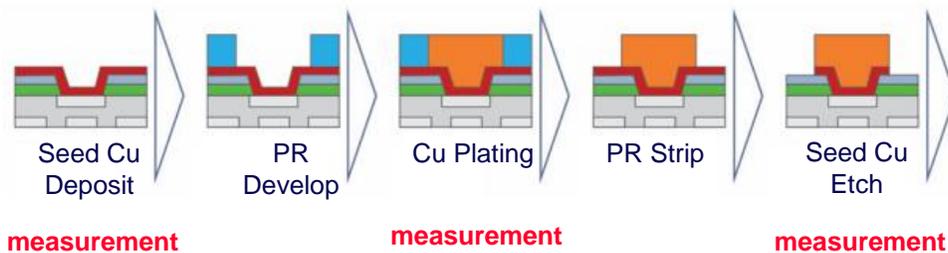
2.5D

Process Flow & Metrology Requirements

12 Layers in Interposer of 2.5D FOWLP



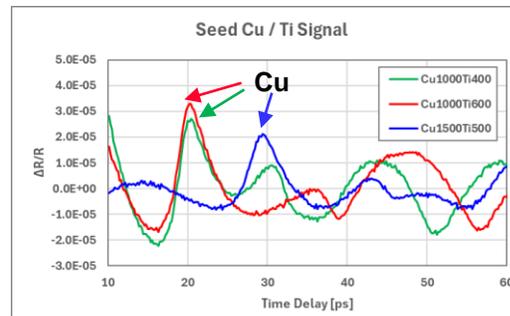
RDL Process Flow in FOWLP – Metrology Requirements



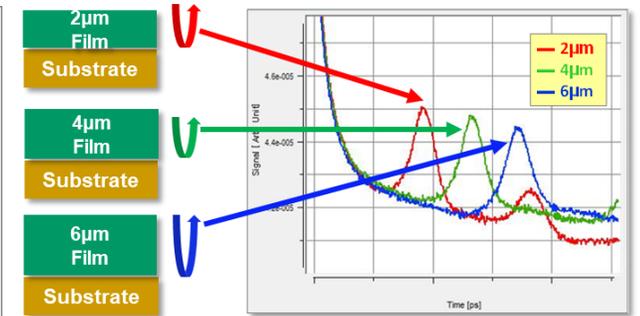
Solution

Measurement Result for RDL

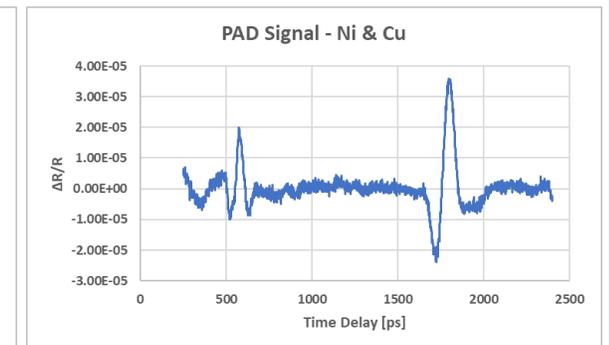
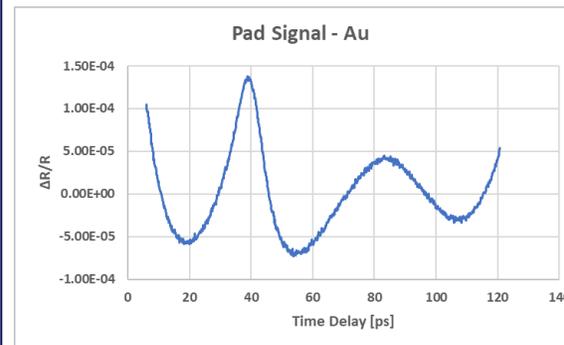
Seed Cu and Barrier



EP Cu

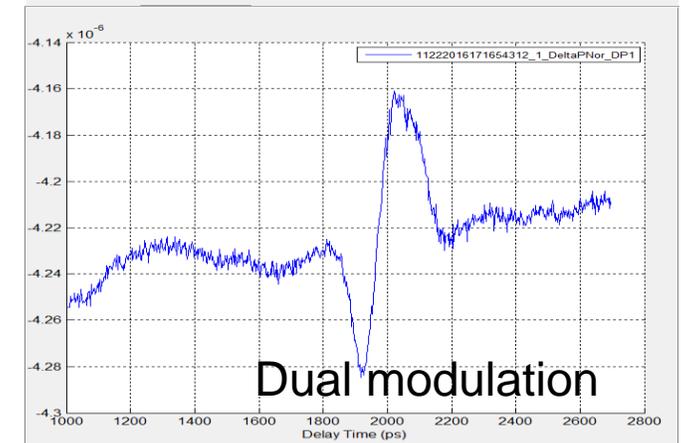
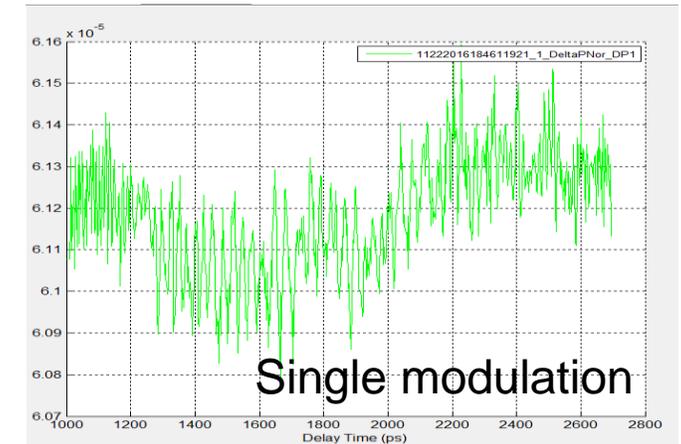
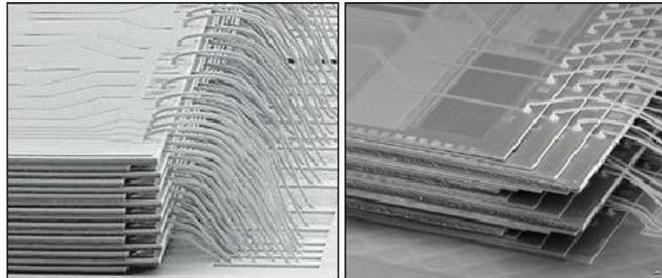
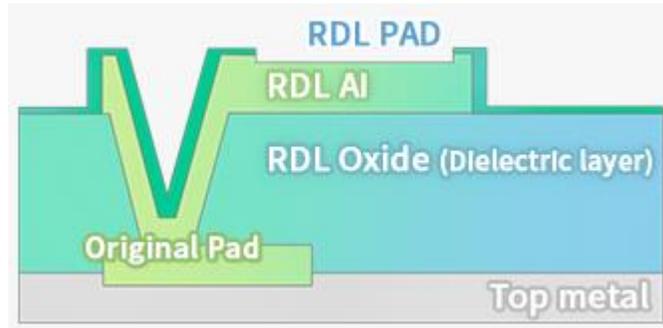


Measurement Result for Pad – Au 0.15μm / Ni 3μm / Cu 2μm

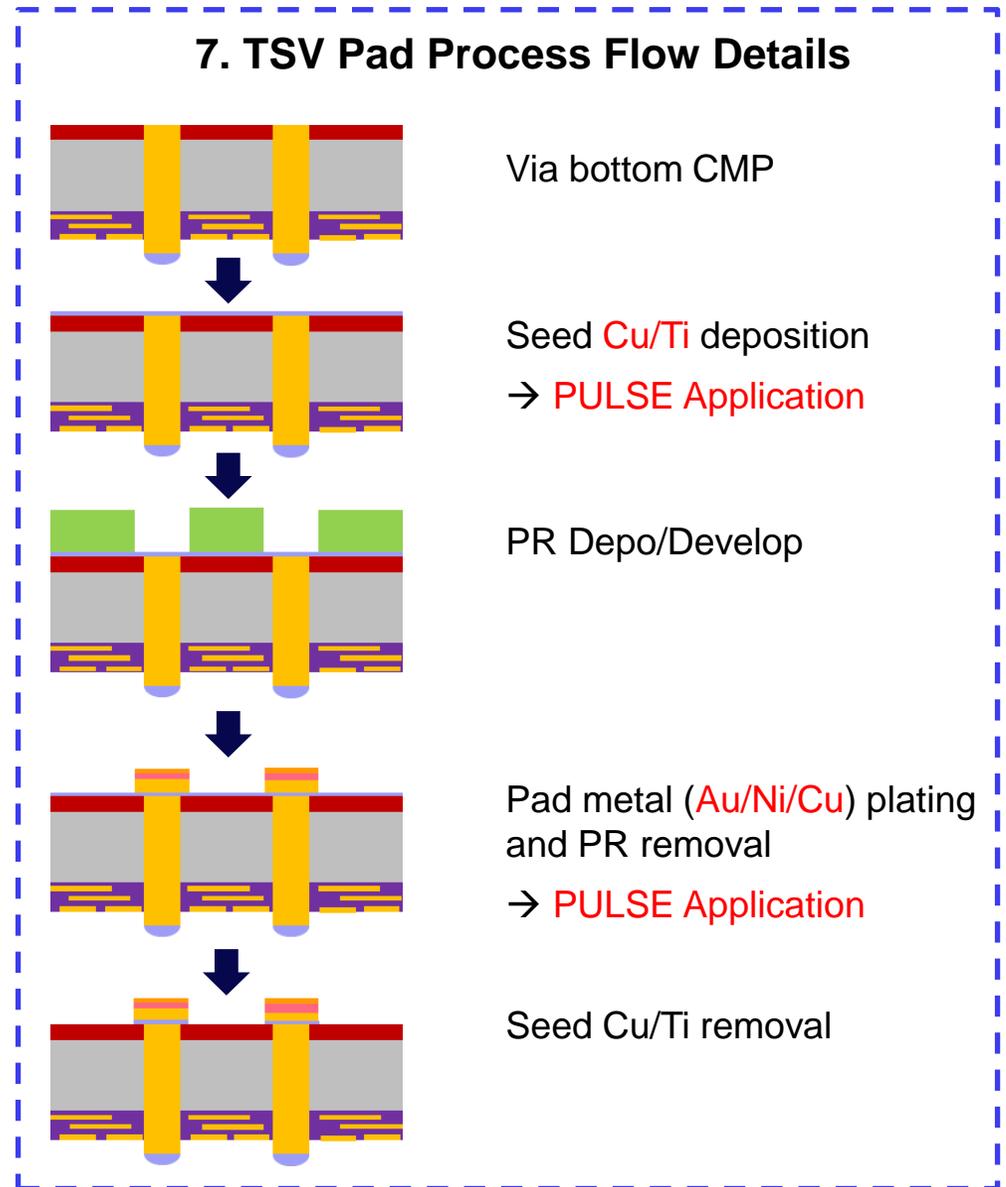
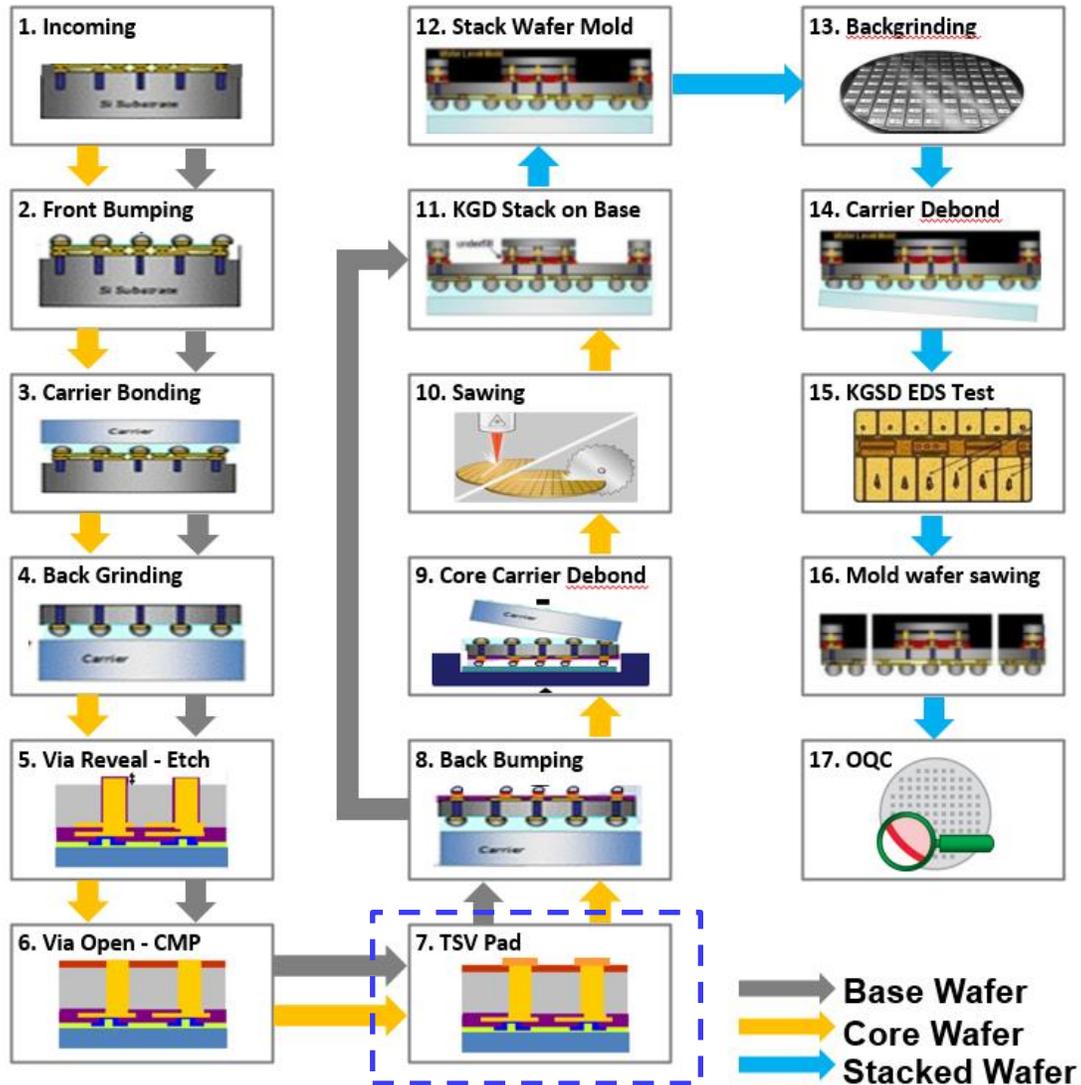


AICu RDL Process Monitoring

- RDL is an extra metal layer enabling IO pads to relocate freely to the PKG wire bonding position where necessary.
- 4~5 μm thick AICu is used for RDL on devices like DRAM. No good in-line metrology for such a thick AICu except for .
- For very thick metal film, surface roughness causes a strong noise due to laser scattering.
- Using dual modulation, we can effectively filter out noise from the laser scattering to measure thickness of very thick and rough metal film.

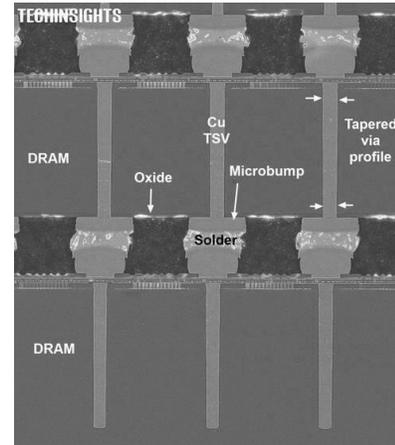


HBM - Applications

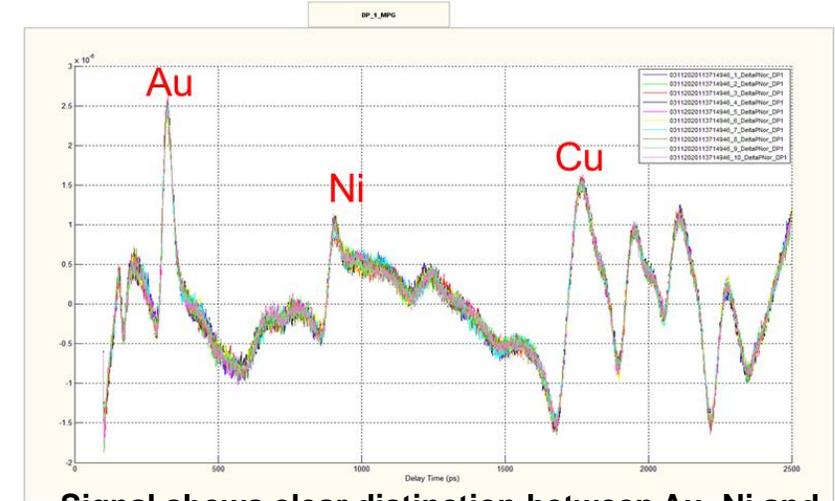
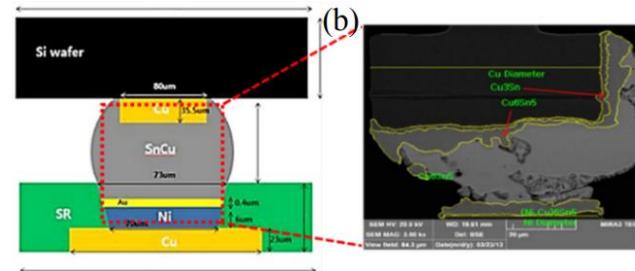


TSV Pad Process Monitoring

- Advanced packaging for 2.5D and 3D requires pads for TSV where Cu pillar bump can be connected.
- For solder pad, Ni works as diffusion barrier between solder and Cu to prevent resistive IMC that may lead to voids by electromigration.
- Au film is needed to protect Ni from oxidation, but too much Au reduces solder joint reliability due to the formation of tin-gold inter-metallics.
- Thickness of Au and Ni need to be controlled for reliable solder joint.
- Each layer thickness needs to be controlled carefully.



Structure of Bump Pad



Signal shows clear distinction between Au, Ni and Cu peaks. This allows us to measure Au, Ni and Cu thickness simultaneously with very good accuracy and repeatability.

Repeats	Site 1			Site 2			Site 3		
	Cu	Ni	Au	Cu	Ni	Au	Cu	Ni	Au
1	20204.0	17641.4	5315.0	20092.5	17549.0	5364.1	20326.3	17858.7	5450.4
2	20161.4	17635.4	5323.5	20126.8	17577.6	5370.6	20117.0	17742.4	5449.9
3	20358.7	17676.5	5314.1	20100.1	17570.1	5365.8	20250.8	17728.9	5452.4
4	20435.5	17636.0	5309.9	20083.1	17551.5	5369.1	20220.3	17793.8	5442.1
5	20251.8	17586.8	5312.5	20136.2	17540.1	5375.4	20215.7	17764.0	5450.0
6	20154.6	17609.3	5314.6	19998.6	17568.3	5376.9	20209.9	17797.8	5444.9
7	20235.3	17597.7	5313.9	20083.6	17547.6	5370.6	20184.5	17777.2	5456.5
8	20189.7	17631.9	5300.5	20294.2	17522.7	5377.9	20211.3	17763.8	5447.7
9	20238.6	17605.4	5309.9	20072.8	17592.3	5367.9	20237.0	17735.3	5455.8
10	20212.1	17616.6	5322.5	20139.1	17554.4	5372.7	20228.8	17732.7	5445.9
Average	20244.2	17623.7	5313.6	20112.7	17557.4	5371.1	20220.2	17769.5	5449.6
Stddev	88.4	26.0	6.5	75.5	20.1	4.6	52.4	40.0	4.6
1 Sigma	0.44%	0.15%	0.12%	0.38%	0.11%	0.09%	0.26%	0.22%	0.08%

Picosecond Ultrasonic Technology

PULSE

- In-line, non-contact, non-destructive metrology
- Fully automated enhancements to serve advanced packaging

Applications

- Successful demonstration of simultaneous multi-layer measurement (GRR < 10%)
- Insertion in high volume manufacturing in 2.5D and 3D applications

Advantage

- Front end leadership and applications expertise
- Extendible platform and roadmap to serve next generation applications

References

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