SW Test Workshop
Semiconductor Wafer Test Workshop

AMD high pin count probing challenges on leading edge GPU: Technoprobe TPEG™ MEMS vs. Cobra

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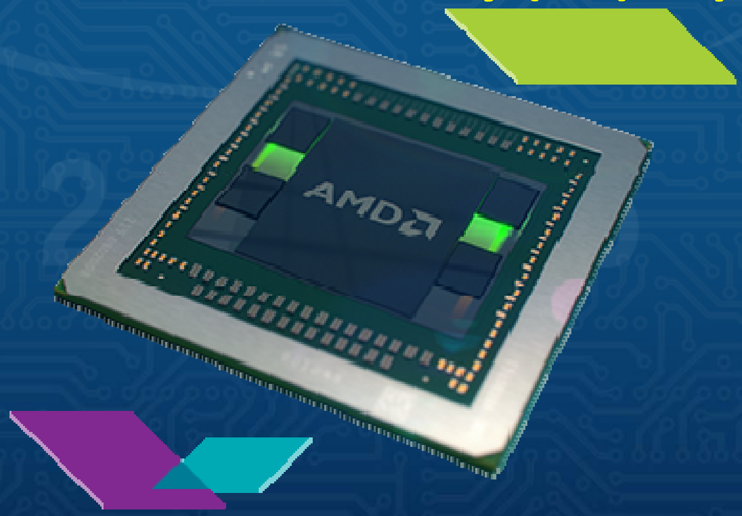
Outline

- **Radeon™ R9 Series GPU : World's first GPU featuring advanced HBM**
  - Single die, more than 20K sacrificial Al pads
- **Technoprobe TPEG™ MEMS Al probing solution**
- **High pin count probing on V93K DD**
  - AMD's case: a simplified model
  - Technoprobe probing BKM
- **TPEG™ MEMS T4 vs. Cobra benchmark**
- **Conclusions and next steps**

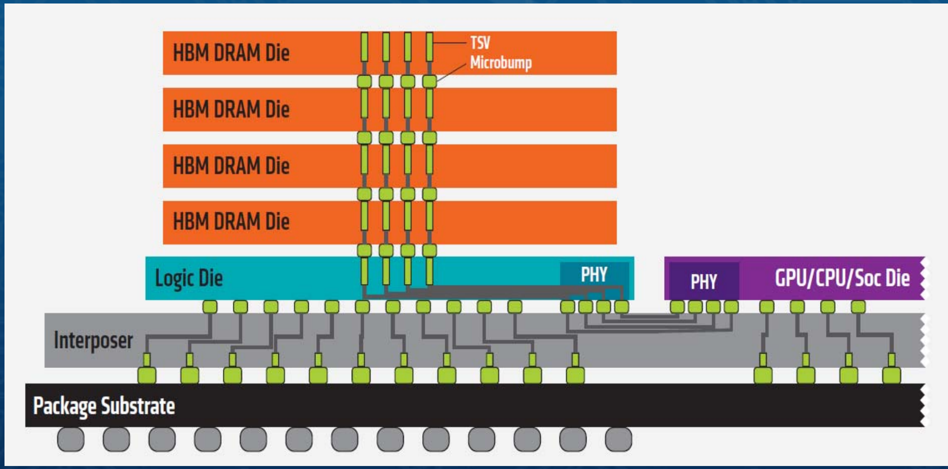
Radeon™ R9 Series GPU product introduction

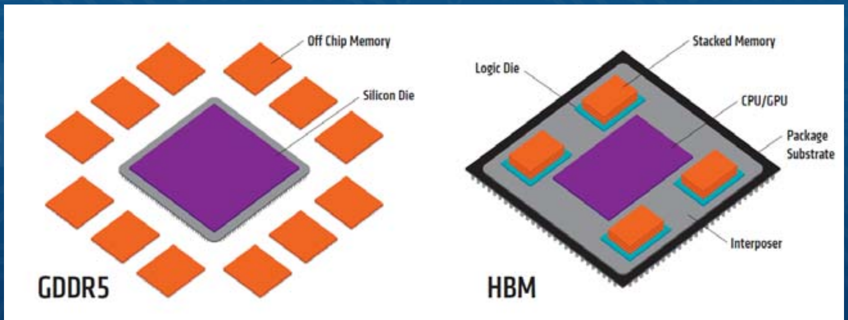
- Radeon™ R9 Series GPU is the world's first GPU taking advantage of high bandwidth memory (HBM) DRAM stacks in a 2.5D assembly delivering a breakthrough in bandwidth and real estate
- It is designed for 4K ultra settings for smooth gameplay and delivers an impressive virtual reality (VR) experience.



AMD High-Bandwidth Memory

- **Revolutionary HBM breaks the processing bottleneck**
  - HBM is a new type of memory chip with low power consumption and ultra-wide communication lanes.
  - It uses vertically stacked memory chips interconnected by microscopic wires called "through-silicon vias," or TSVs.
- **HBM shortens your information commute**





Source: High-Bandwidth Memory (HBM)- REINVENTING MEMORY TECHNOLOGY
https://www.amd.com/Documents/High-Bandwidth-Memory-HBM.pdf

AMD High-Bandwidth Memory (2)

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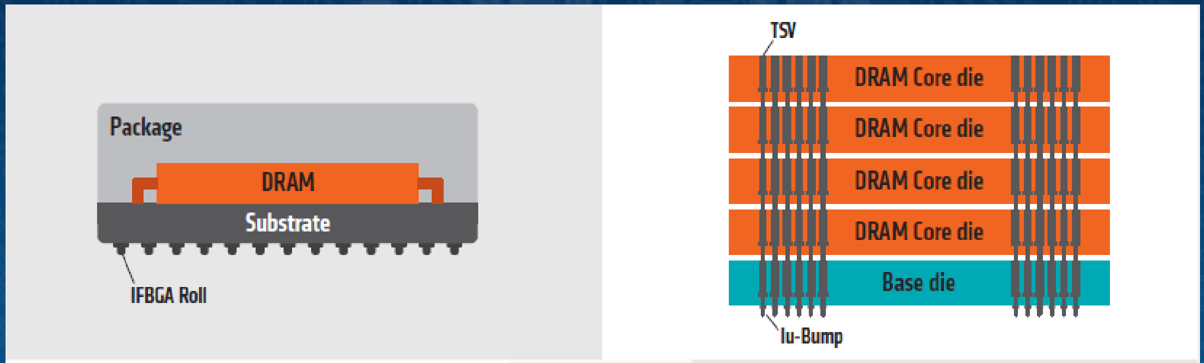
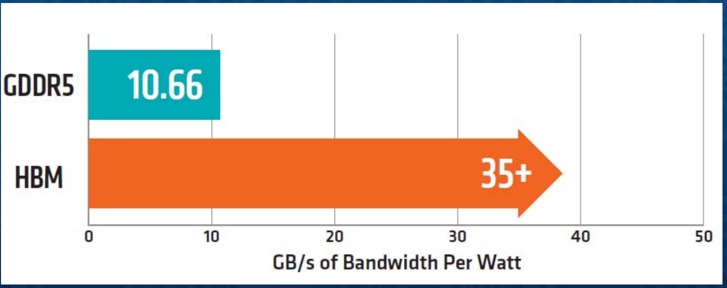
- **Compare side by side**

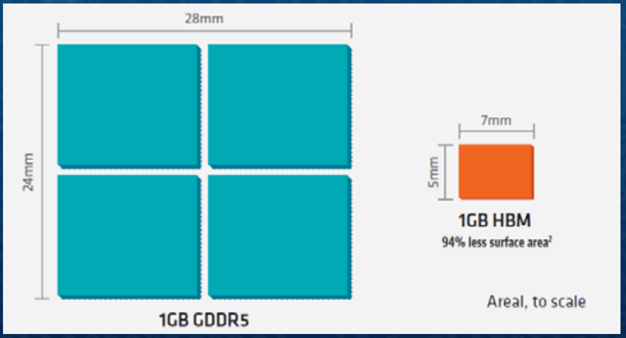


GDDR5	Per Package	HBM
32-bit	Bus Width	1024-bit
Up to 1750MHz (7GBps)	Clock Speed	Up to 500MHz (1GBps)
Up to 28GB/s per chip	Bandwidth	>100GB/s per stack
1.5V	Voltage	1.3V

- **Better Bandwidth per watt**



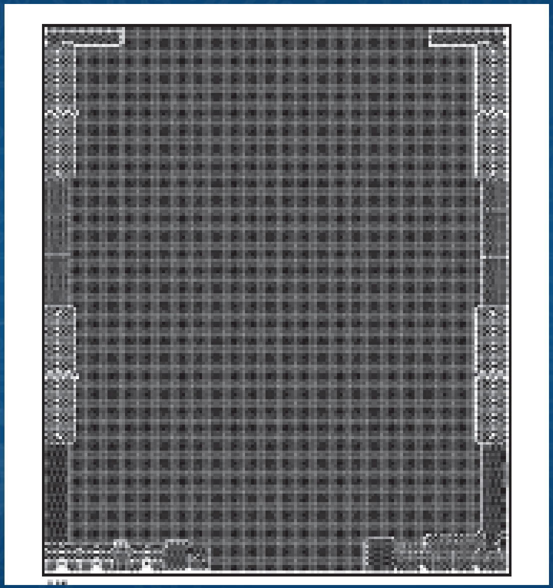
- **Massive Space Savings**



Radeon™ R9 Series GPU die features

- 28 nm GPU architecture
- Single die probing with more than 20K sacrificial Al pads:

	Typical die
Min Pitch	165 µm
Pad Size	60x60 µm
Pad Opening	55x55 µm
Pad Thickness	28 KÅ
Number of Sac pads	> 20K
Max current per probe	>500ma
Probing Temp	0 °C



AL Sac pads – Why?

- **Multiple ubumps VS Al Sac pads for each signal that leaves the package.**
  - Trace length matching for each high speed signal not possible.

- **High number of probes required to touch > 100K ubumps .**
  - Cost !!!
  - Designing a space transformer is not possible

- **AL Sac pad is a better choice to overcome to cost and technical challenges.**

TPEG™ - Al pads probing solution

- Technoprobe has developed a strong expertise on Al pad probing, by dealing with automotive requirements and more recently with GPUs (such as AMD's Radeon™ R9 Series GPU)
- Depending on the pad dimensions, the specific pad metallization and the requested max current per needle, we may envision the use of either TPEG™ MEMS T1 or T4 (or S90 pointed in case of special high speed requirements)

TPEG™ - Al pads probing solution

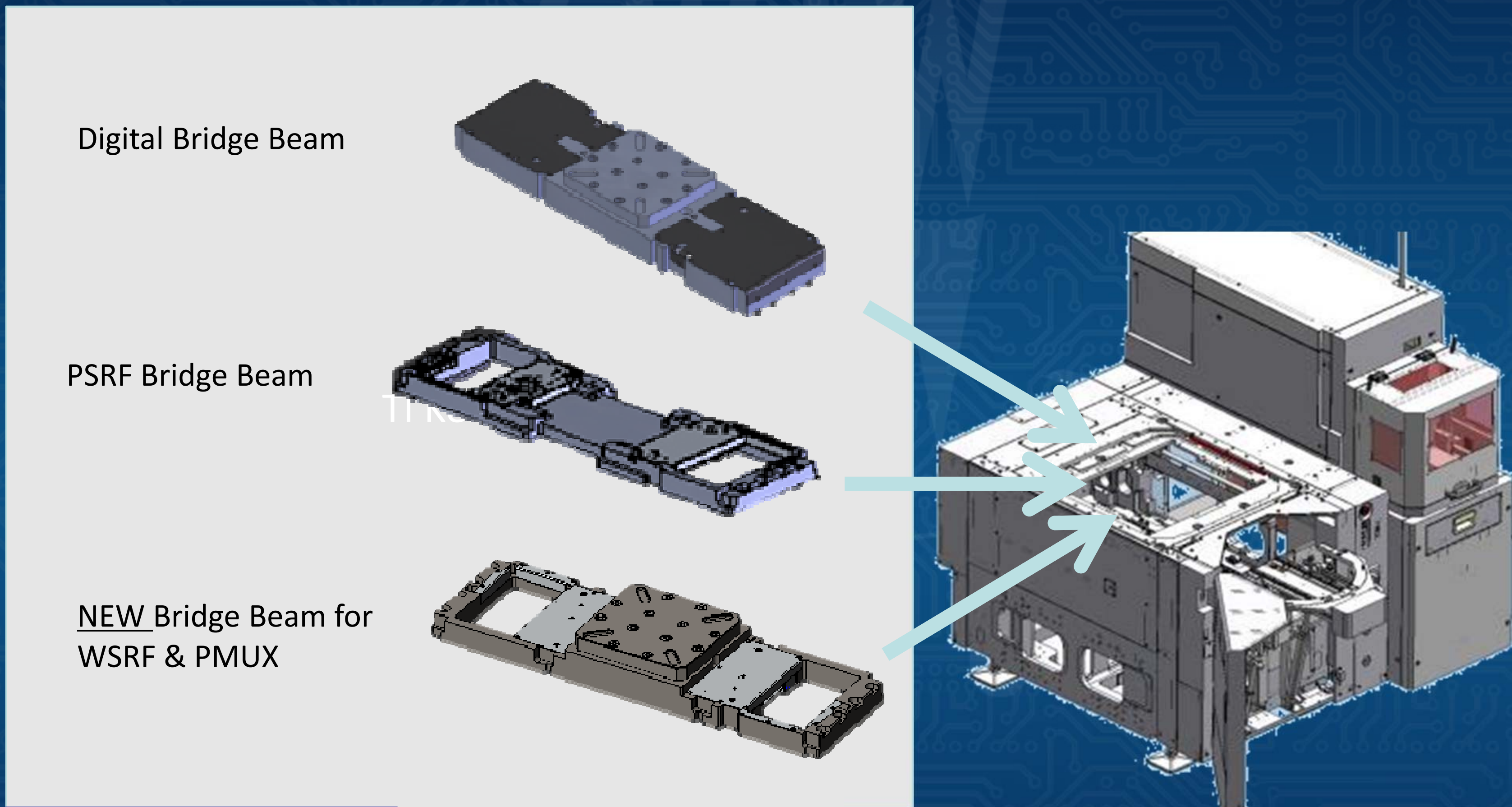
- **Main probing features**

PARAMETER	TPEG™ MEMS T1	TPEG™ MEMS T4
Probe size	< 1.5 mils equivalent	< 3 mils equivalent
Tip shape	Pointed	
X,Y & Z accuracy	X,Y: ± 8 µm; Z : Δ 20 µm	
Min pitch	55 µm linear	78 µm linear
CCC	400 - 600 mA (HC)	1000 mA
Force (at 3 mils OT)	2 g or 3 g	4.5 g

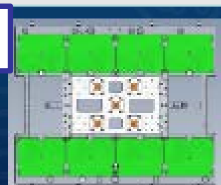
TPEG™ MEMS T4

- **Challenge for this product was not on the needle technology side (already delivered in volume) but rather on the Probe Card integration on an already defined prober setup, due to a large number (> 20K) of relatively high-force needles**
  - The total load experienced by the Probe Card was indeed about 100 Kg
- **A thorough optimization of the following parameters has been achieved (as a team work between AMD and TP):**
  - Probe Card mechanics: optimized mechanical interference between Probe Card Boss and PCB and between Probe Card Boss and V93K bridge beam
  - Prober Setup: Probe Card planarization optimized to limit the tilt arising from prober calibration inaccuracy
  - Prober Setup: introduced the concept of POD (Programmed OverDrive) vs AOD (Actual OverDrive)

Advantest Direct-Probe Solution



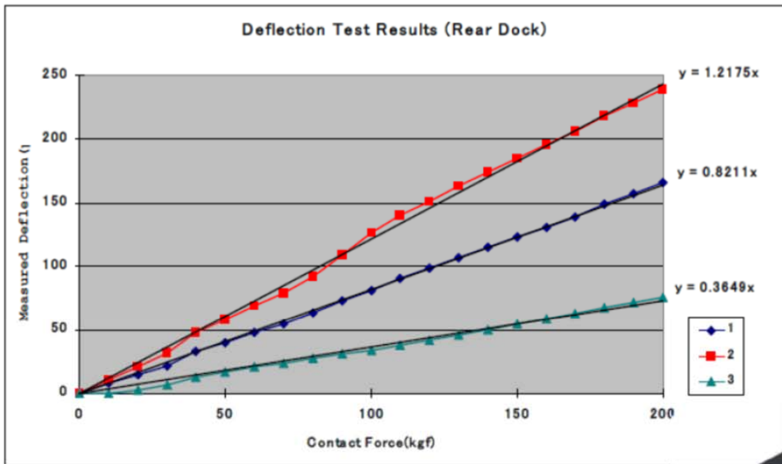
Direct-Probe VPG E5210B

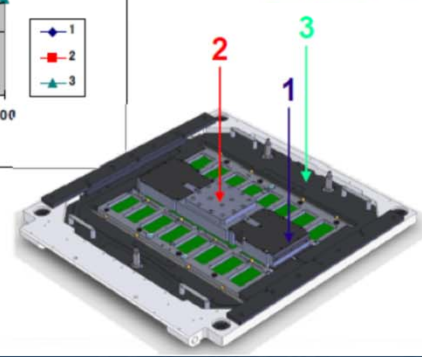


Certified Direct-Probe Stiffeners

Advantest Direct-Probe Solution

- **Test cell system rigidity data**
  - Overall rigidity is about 1 kg/ 1 µm (PC + bridge beam + prober head plate + stage)

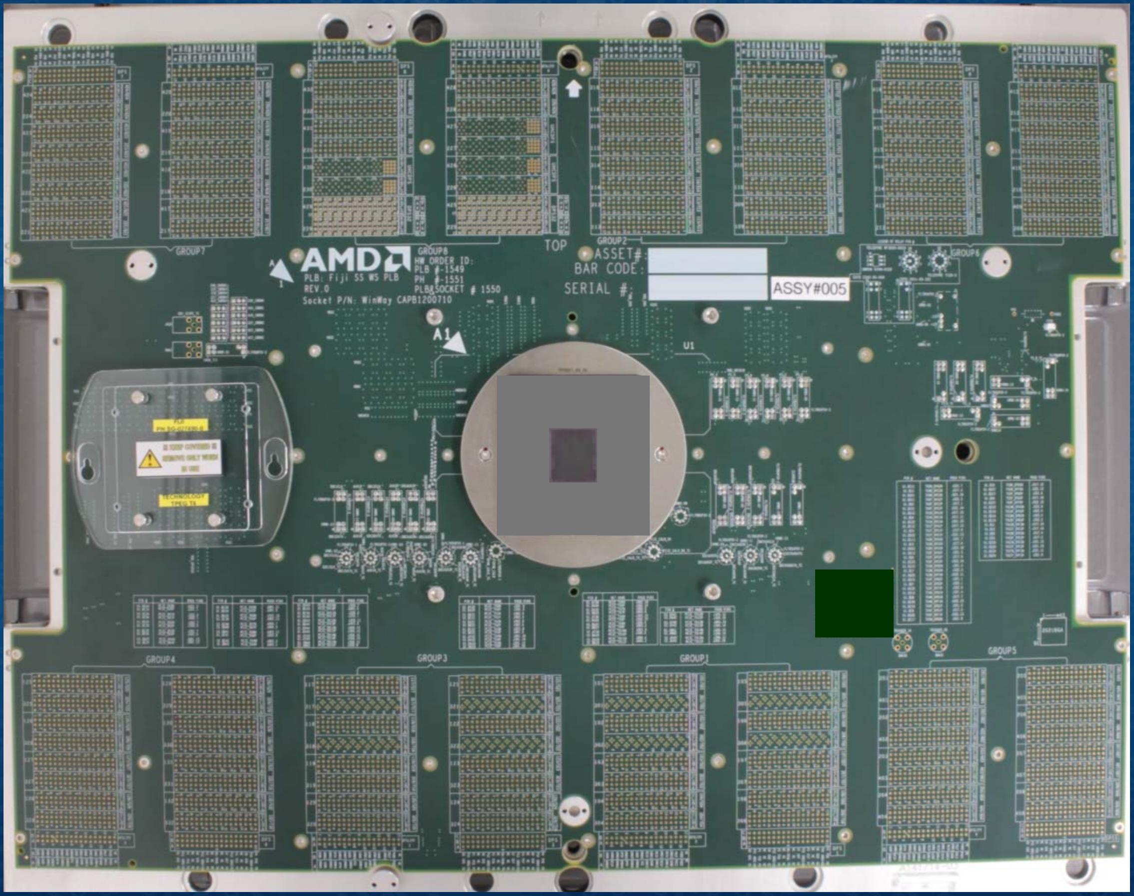




- Load Cell between Chuch and Headplate
- 3 Dial gauges
- ~1u deflection for each kg force

AMD's Radeon™ R9 Series GPU: TPEG™ MEMS T4 Probe Card

- **Advantest V93K Direct probe tester platform**



Actual OD vs. Programmed OD

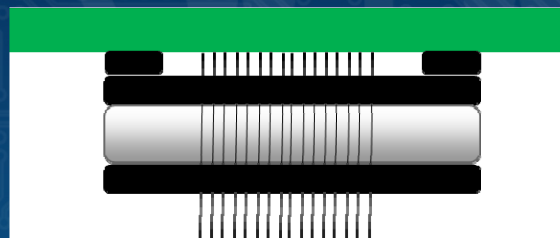
- **Assumptions**
  - PC mechanical planarity delta = 20 µm max
  - Buckling starts to occur @ 25 µm of actual OD
  - System rigidity = K_{syst} = 1 Kg/ 1 µm

- **AOD = (POD – system deformation)**
  - where system deformation is also a function of AOD
  - When max deformation is reached, AOD = (POD – max def) : at that point, AOD is linearly increasing with POD

- **Next slides are describing AMD Radeon™ R9 Series GPU's Probe Card case**

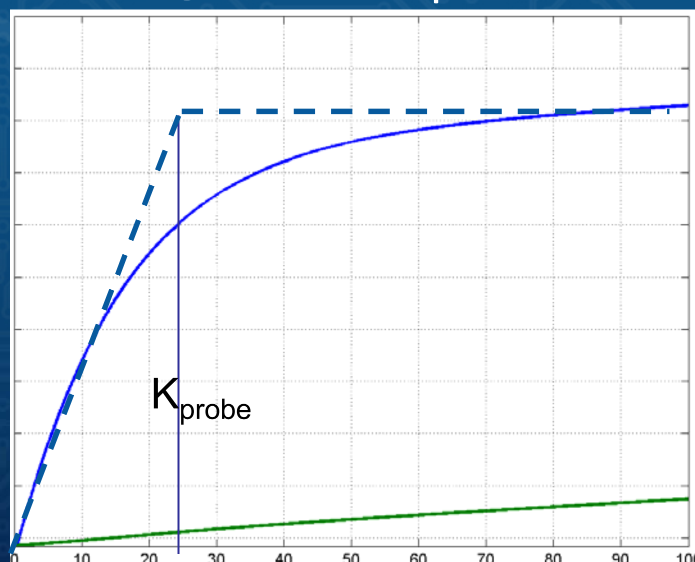
Simplified mechanical model

- **TP probe head mechanics: buckling beam concept**



- **Force is almost constant in the probing working OD range**
  - Buckling starts to occur @ about 25 µm of actual OD

Force (g)



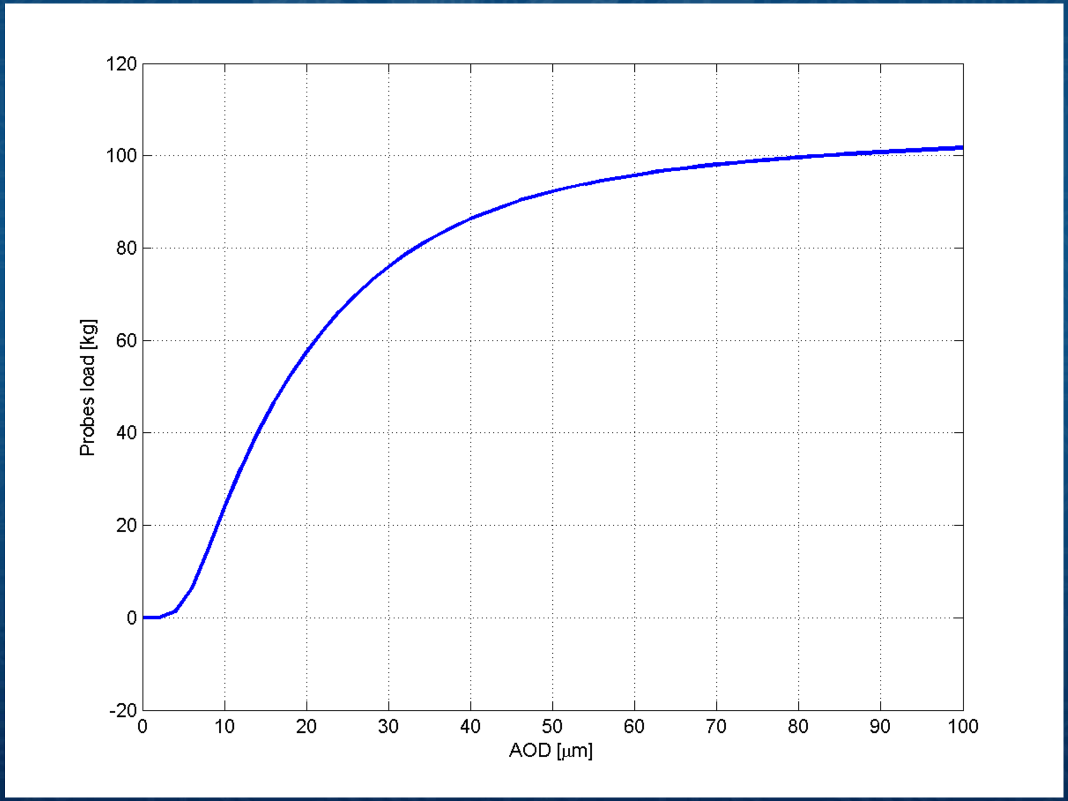
Actual OD (µm)

Actual OD vs. Programmed OD: calculation algorithm

- **Algorithm assumptions:**
  - AOD is the independent variable → POD = f(AOD)
  - Mechanical planarity reference: zero on the longest probe
- **Algorithm input:**
  - PH mechanical planarity measurement
  - System stiffness K_{syst}
  - Force vs OD probe chart for a single probe
- **Algorithm procedure: pseudo-code**
  - For each iteration, AOD_N varies from 0 to 100 µm (step = 2 µm)
    - The number X of contacting probes is determined : $Plan\_probe_i \leq AOD_N$
    - Then the OD is defined for each contacting probe as $OD_{N,i} = AOD_N - plan\_probe_i$
    - The force of each contacting probe is derived from the experimental F-OD plot : $F_{N,i}$
    - Total probe force is calculated as the sum of the Force of all contacting probes (sum of $F_{N,i}$ where i= 1 to X)
    - Total deformation DEF_N is derived, based on system stiffness
    - PODN is then calculated as $PODN = AOD_N + DEF_N$
- Algorithm output:
  - Programmed OD vs Actual OD chart

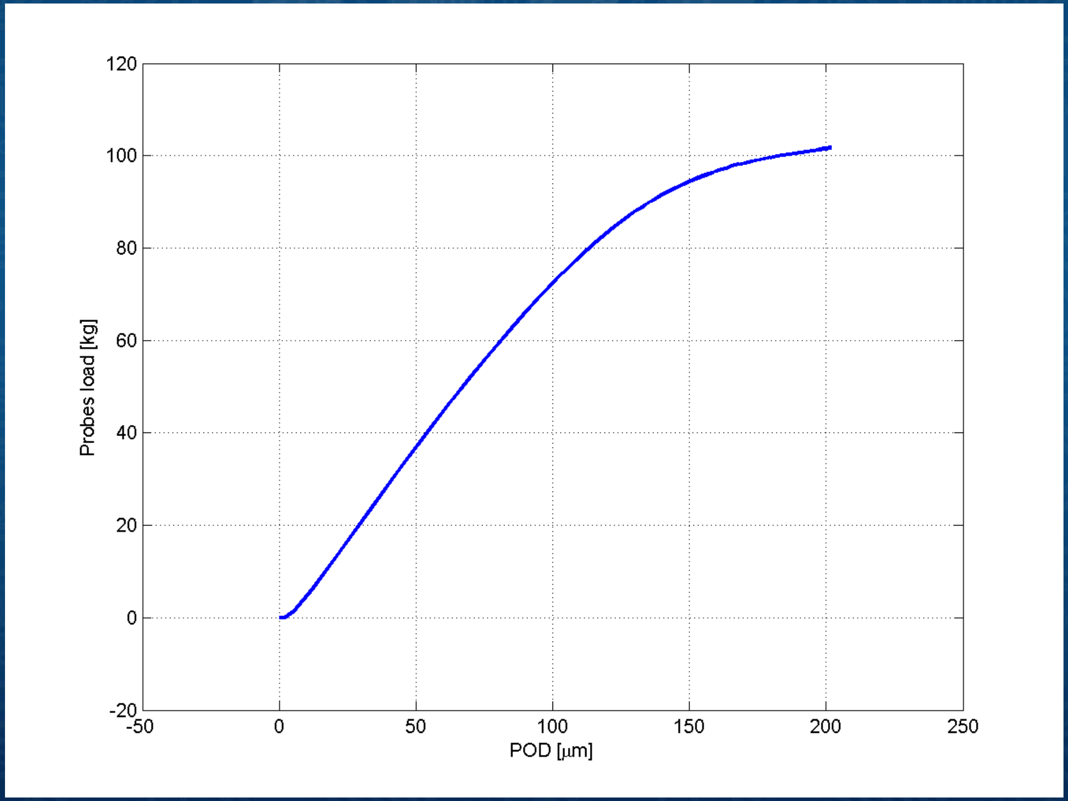
PC load vs. AOD

- **Number of probes: >20K; total PC load ~ 100 Kg**
  - Max probe load is reached at about 40-50 um of AOD.
  - PC load is then slightly increasing and becomes asymptotic at the end.



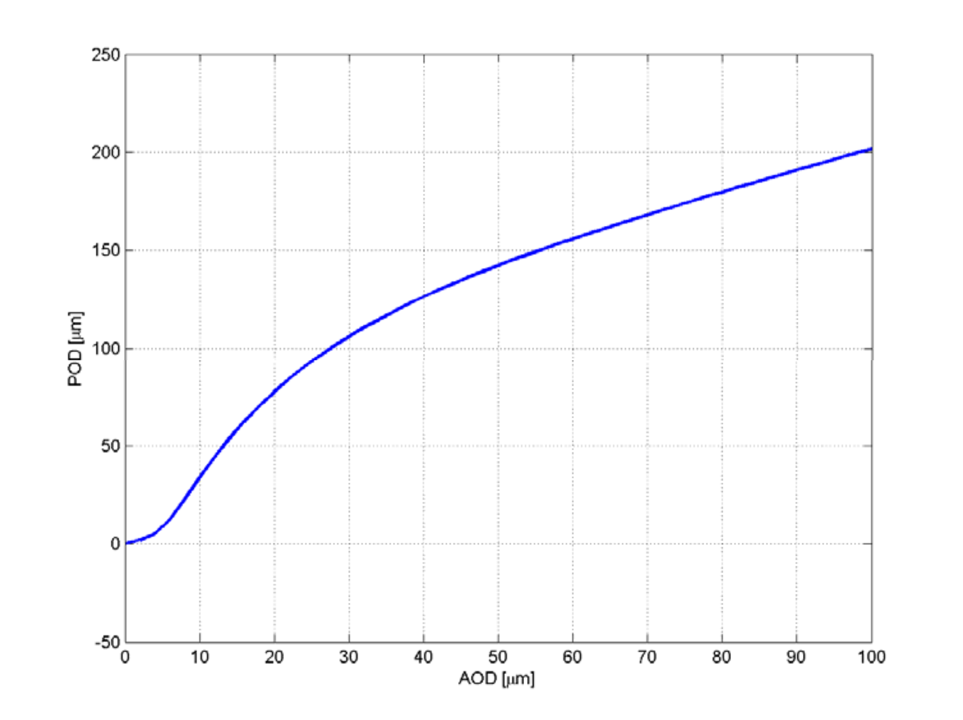
PC load vs. POD

- Max probe load (100 Kg) is reached at about 200 um of POD .
- At this point we have max probe force and thus max system deflection (~ 100 um)



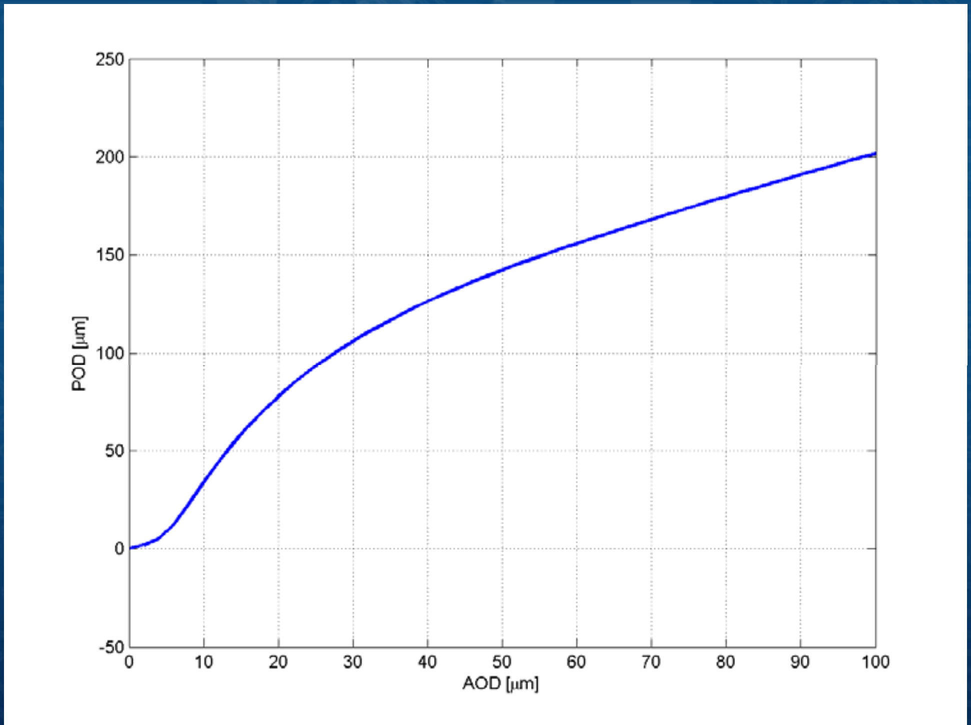
POD vs. AOD

- **Once AOD is reaching about 50 um max PC force (about 100 Kg) and max system deflection (about 100 um) are reached.**
  - From now on an almost linear relation between POD and AOD is found: 1 um of increased POD will lead to 1 um of increased AOD while max PC force and deflection are almost constant and equal to maximum values (100 Kg – 100 um)



Electrical planarity

- **Electrical zero planarity (EZP) estimation**
  - EZP ~ (Prober coplanarity + PC mech planarity + buckling + max deformation)
  - Radeon™ R9 Series GPU's case: EZP = 140 to 160 µm (POD)



High pin count PCs: TP BKM

- **Over the last years TP defined a quite comprehensive BKM to cover following points. See an extract of prober setup BKM in next slide:**
  - Probe card planarization
  - Probe card testing on probe card analyzer (PRVX4)
  - First setup on prober

- **In addition standard User and Maintenance instructions will apply**

High pin count PCs: TP BKM

- **STEP 1: PC – prober chuck co-planarity check**
  - Methodology: measurement of Z height of 4 corners alignment pins by means of prober alignment camera
  - Criteria: all 4 corner pins planarity must be minimized.
  - In case high planarity values are found, probe card/ prober PC holder must be planarized by means of Advantest VPG
  - This operation is key because any even small optical planarity tilt will be largely magnified at full load

High pin count PCs: TP BKM

- **STEP 2: Electrical z planarity window (EZP) definition**
- **STEP 3: Define probing and cleaning OD settings to get correct values of Actual OD**
  - NOTE: the rigidity of wafer chuck and cleaning plate can vary quite a lot depending on prober type
  - TP suggests to define experimentally POD - AOD and PCOD – ACOD curves by adopting special mechanical gauge pins specifically developed by TP

TPEG™ MEMS T4 vs. Cobra

- The following table shows a comparison between Cobra-like and TP TPEG™ MEMS T4 probe cards.

Parameter	Cobra-like	TPEG™ MEMS T4
Needle diameter	3mil (76.2 µm)	< 3 mils equivalent
Max Pin count	Limited by prober chuck force	> 20K probes
Min Pitch	~ 135 µm	78 µm
X,Y alignment	~ 15um radial	± 8 µm
Z Planarity	~ Δ 35 µm	Δ 20 µm
Force (4 mil OD)	7– 10 g	~4.0g

TPEG™ MEMS T4 Production Performance

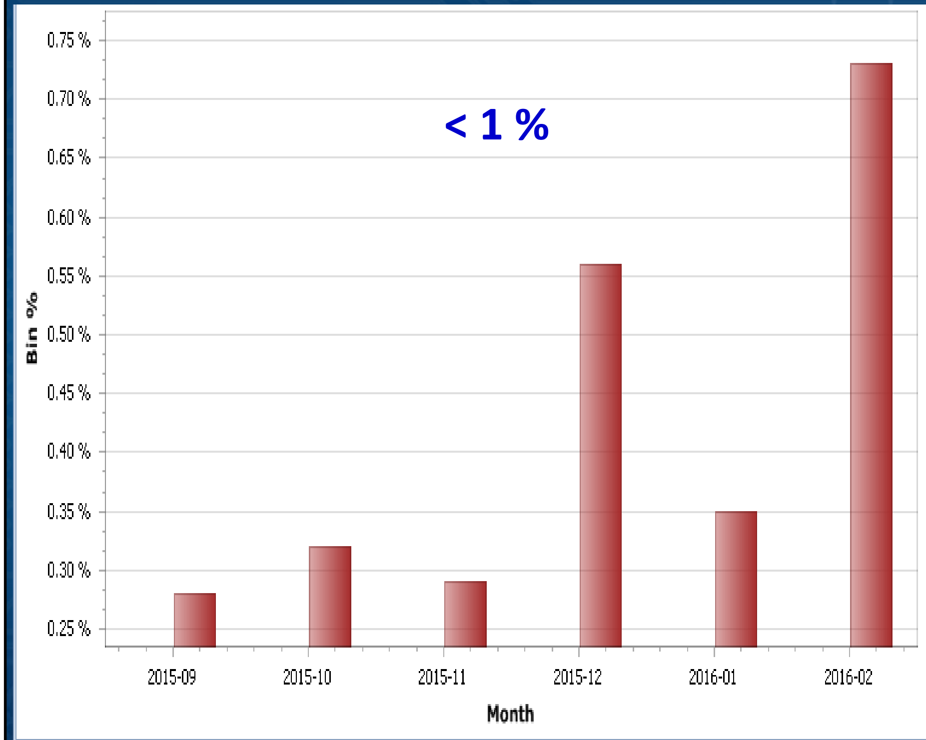
- **TPEG™ MEMS T4 probe cards delivered in volume to AMD proved to be a production worthy solution, with respect to AMD's expectations**

Parameter	AMD Requirement	TPEG™ MEMS T4
Tester uptime	> 95%	Meet requirement
First Time Right Delta	<6%	~2%
Offline Intervention	Max 1 per week	~ 0 per week
Prober Setup Stability	No change over PC lifespan	Stable
Contact Related failures	<1 %	Meet requirement
Barrier Layer damage	No damage	No damage
Probe Mark drift to passivation	No Occurrence	No Occurrence

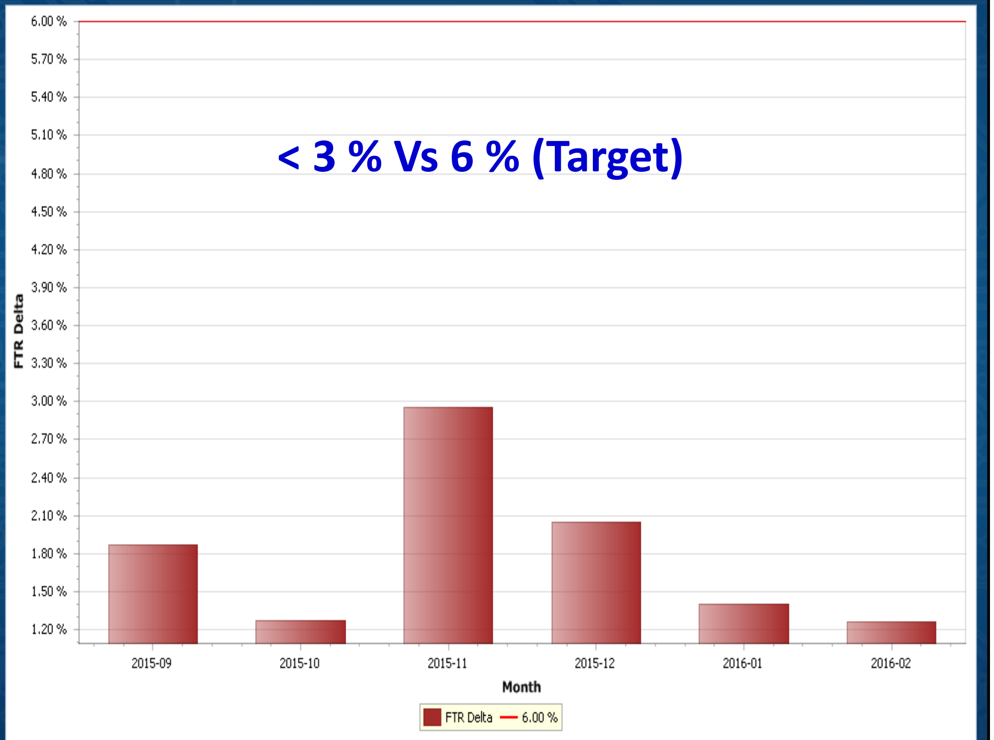
TPEG™ MEMS T4 Production Performance

Performance VS AMD requirement

Contact Related Failures



First Time Right Delta

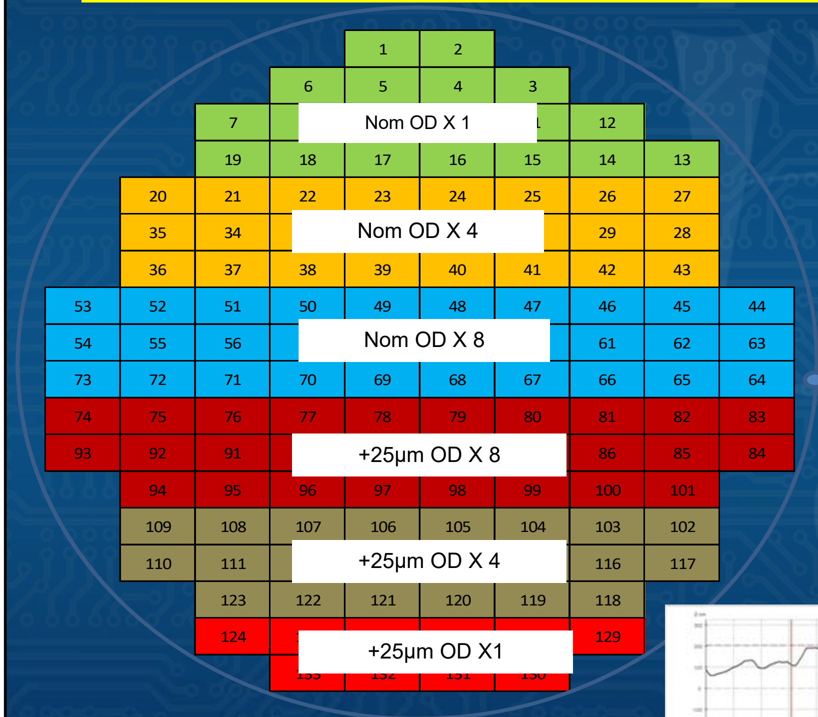


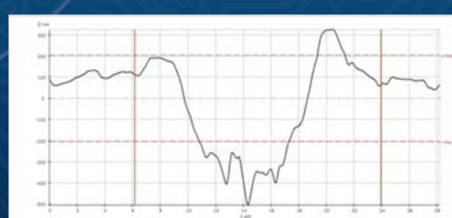
TPEG™ MEMS T4 Production Performance

- No Barrier Level Damage is observed during production
- Engineering studies have been conducted in AMD to evaluate the performance of TPEG T4 probes

BARRIER LAYER DAMAGE

Probe Mark Study – Profiling Microscope





Total dimension of perturbed area by scrub motion

Wf Index		TDs parameter		Scrub Dimension		
X	Y	OT [µm]	TDs	X [µm]	Y [µm]	Z [µm]
4	1	85	1	17.9	17.7	0.340
-2	1	85	1	19.3	17.6	0.330
6	2	85	1	19	17.9	0.500
-2	3	85	1	19.2	18.9	0.490
-5	5	85	4	18.7	17.3	0.590
-3	4	85	4	19.5	18.9	0.510
3	5	85	4	18.4	17.8	0.580
7	6	85	4	19.4	18.8	0.540
-6	7	85	8	19.2	18.9	0.600
-7	8	85	8	18.3	17.6	0.580
1	9	85	8	18.7	17.6	0.630
9	9	85	8	19.6	17.5	0.600

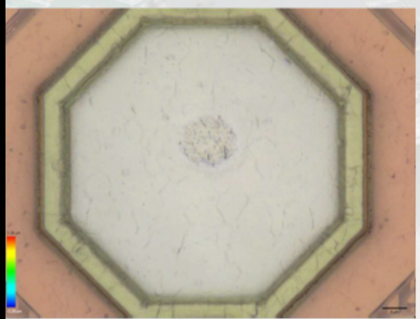
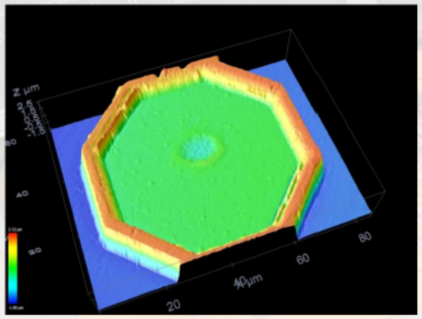
Wf Index		TDs parameter		Scrub Dimension		
X	Y	OT [µm]	TDs	X [µm]	Y [µm]	Z [µm]
-8	10	100	8	22.8	19.5	0.640
-2	10	100	8	20.3	18.8	0.680
-6	10	100	8	19.3	17.7	0.650
-4	11	100	8	20.6	19.4	0.790
8	11	100	8	23.7	21.5	0.760
-3	13	100	4	20.0	19.3	0.820
-6	14	100	4	21.3	20.4	0.790
3	14	100	4	20.9	19.1	0.770
-3	14	100	4	21.4	18.1	0.740
6	15	100	4	19.9	19.1	0.730
-3	16	100	1	21.2	19.9	0.690
2	16	100	1	19.4	18.3	0.650
0	17	100	1	19.5	18.4	0.680
4	17	100	1	20.1	18.0	0.690

TPEG™ MEMS T4 Production Performance

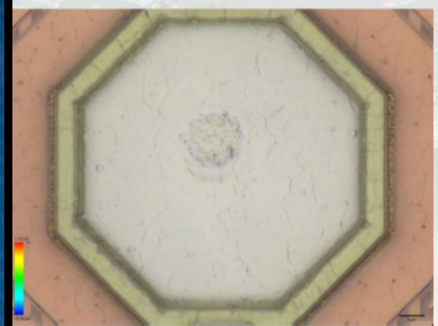
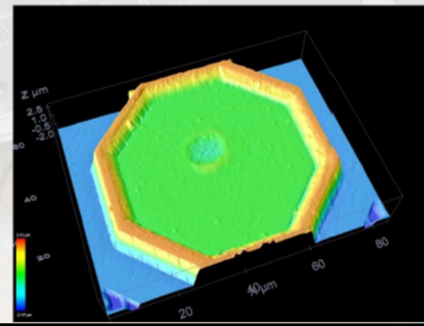
BARRIER LAYER DAMAGE

Probe Mark Study – Profiling Microscope

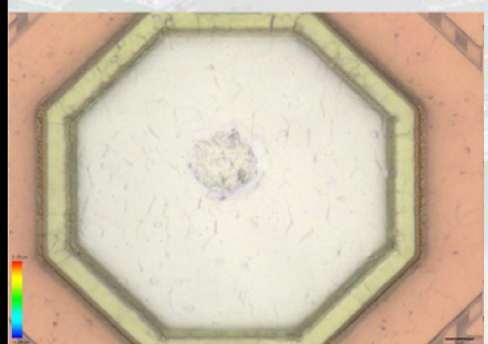
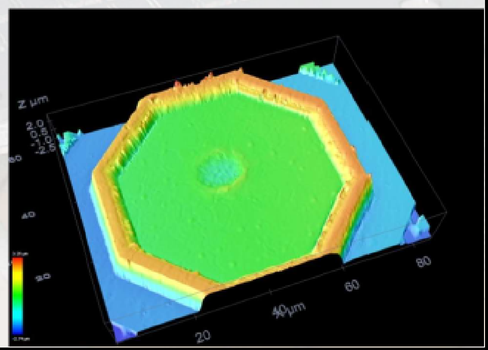
Wf Index		TDs parameter		Scrub Dimension		
X	Y	OT [µm]	TDs	X [µm]	Y [µm]	Z [µm]
4	1	85	1	17.9	17.7	0.340

Wf Index		TDs parameter		Scrub Dimension		
X	Y	OT [µm]	TDs	X [µm]	Y [µm]	Z [µm]
-5	5	85	4	18.7	17.3	0.590

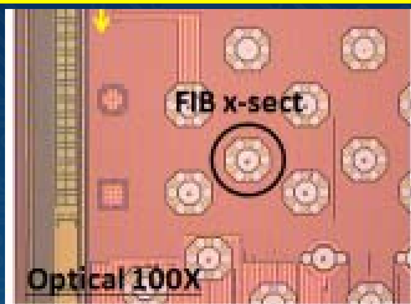
Wf Index		TDs parameter		Scrub Dimension		
X	Y	OT [µm]	TDs	X [µm]	Y [µm]	Z [µm]
-6	7	85	8	19.2	18.9	0.600

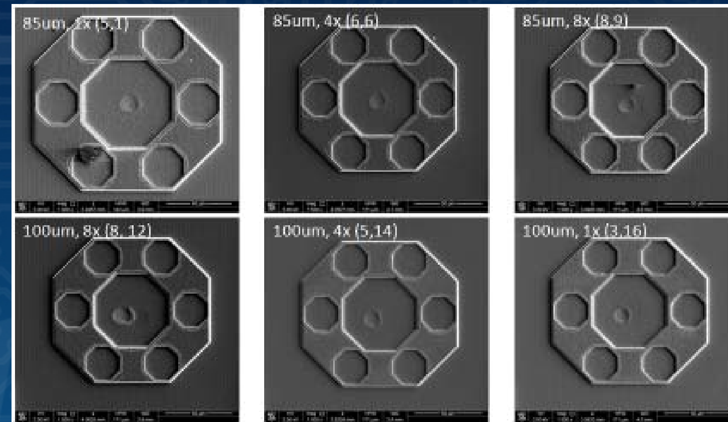
TPEG™ MEMS T4 Production Performance

BARRIER LAYER DAMAGE

Probe Mark Study – FIB X-section

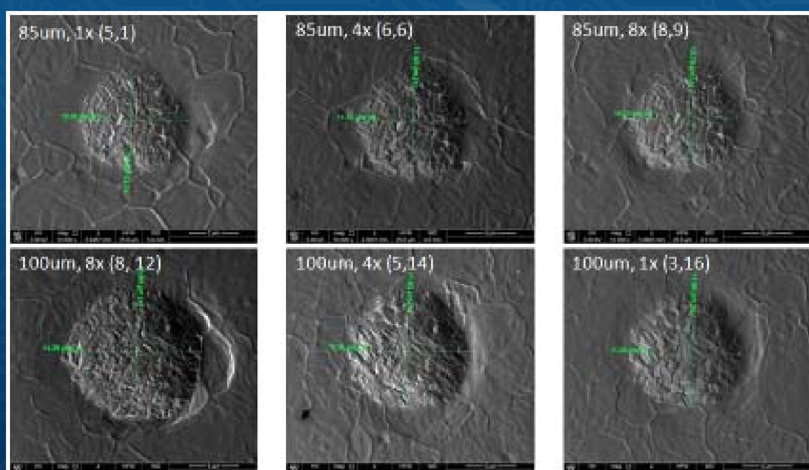


FIB x-sect and measurements were performed on the highlighted pad location for all 6 dies.

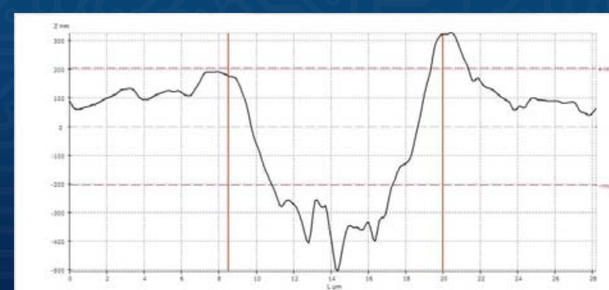


Probe Mark SEM Image

Length / Width



Over drive	Touchdown	Coordinate	Length (um)	Width (um)
85um	1	5,1	10.73	10.97
85um	4	6,6	11.90	11.13
85um	8	8,9	10.78	10.73
100um	8	8,12	13.80	14.28
100um	4	5,14	11.93	12.35
100um	1	3,16	11.58	11.30



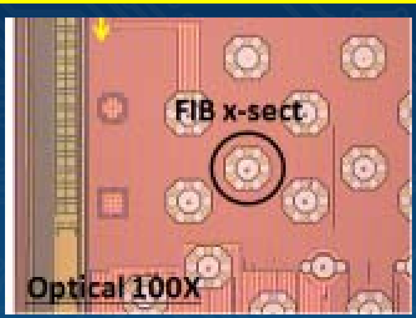
Peak to Peak

- Probe mark length and width generally increases with touchdowns and overdrive

TPEG™ MEMS T4 Production Performance

BARRIER LAYER DAMAGE

Probe Mark Study – FIB X-section



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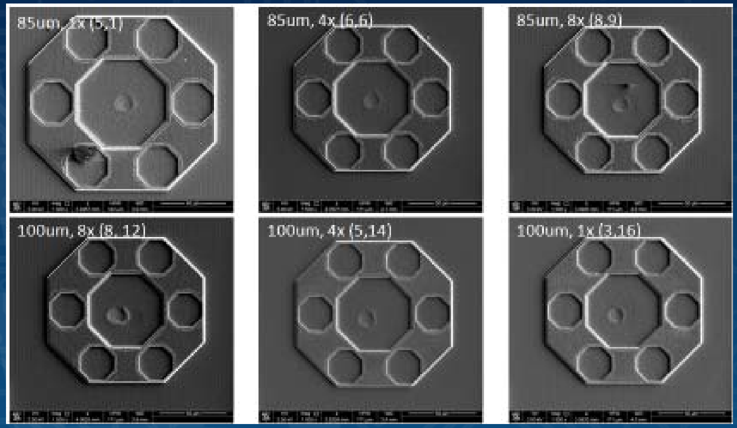
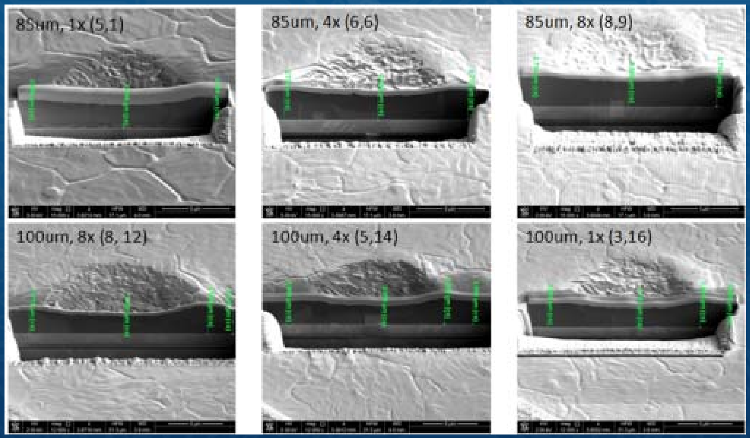


Probe Mark SEM Image

85um, 8x (8,9)

Depth



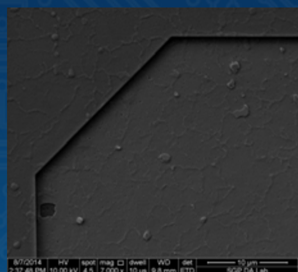
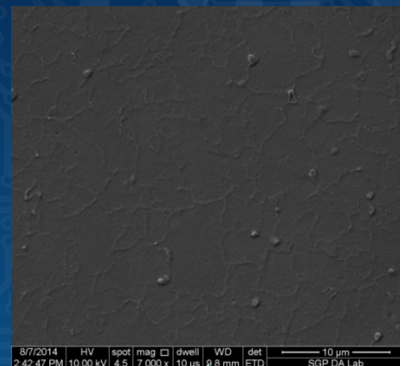
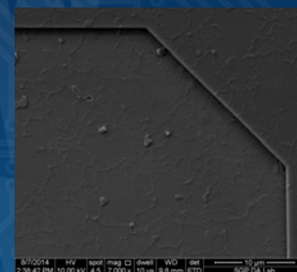
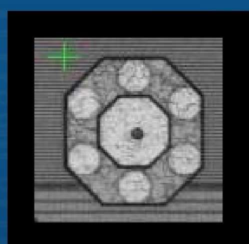
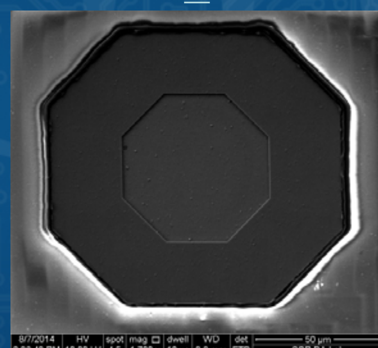
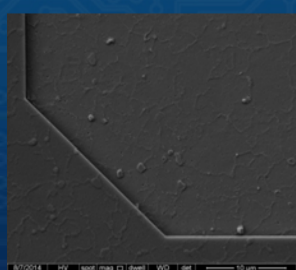
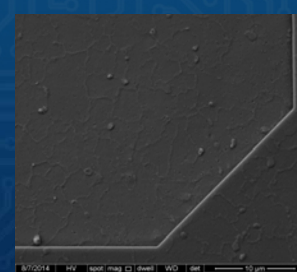
Over drive	Touchdown	Coordinate	Depth (um)
85um	1	5,1	0.51
85um	4	6,6	0.47
85um	8	8,9	0.46
100um	8	8,12	0.74
100um	4	5,14	0.58
100um	1	3,16	0.52

- 100um overdrive: Probe mark depth increases with increasing touchdowns
- 85um overdrive: Probe mark depth remains relatively constant with increasing touchdowns
- All probe marks are well-contained within the Al pad layer - probe depth is less than half of Al thickness (~25%).

TPEG™ MEMS T4 Production Performance

Barrier Layer Damage

<u>Chemical De-processing</u>

- The 100um OD + 8 touchdown die (coordinate 8,12) was subjected to Al etching.
- 5 pads were inspected (4 at each corner and 1 at the center) under SEM.
- No signs of Cu cracks were observed.

Conclusions and next steps

- Radeon™ R9 Series GPU, world's first GPU featuring advanced HBM successfully introduced into the market.
- Successful win-win partnership with Technoprobe and Advantest demonstrated the possibility to outperform Cobra-like solutions.
- High pin count BKM has been defined and a new probing reference has been demonstrated.
- Next steps will be to incorporate lessons learned to future stacked die probing.

Disclaimer & Attribution

Thank you !

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