



# A Full-Automatic Test System for Direct Probing of JEDEC Wide-I/O Micro-Bumps



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## 1. Introduction

### Micro-Bump Probing for 3D-SiC Pre-Bond Test

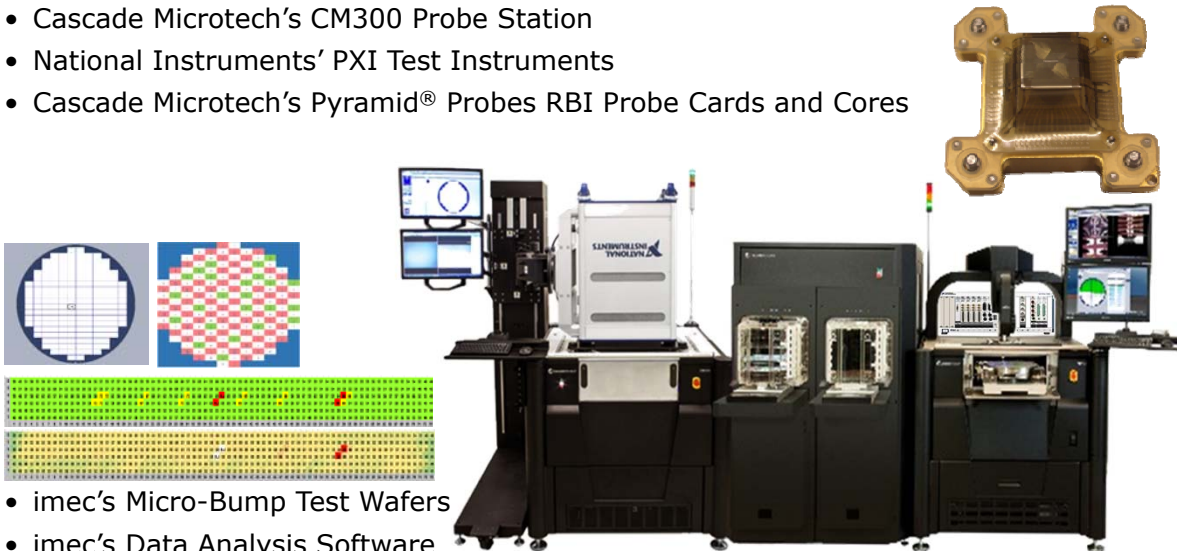
- Pre-bond test is necessary to take die yield out of stacked-die yield equation
  - Without pre-bond test, the compound stack yield decreases drastically
- Non-bottom dies have only micro-bump arrays as their functional interface
- Micro-bump array characteristics
  - Small diameters : 25µm, 15µm
  - Dense pitches : 50µm, 40µm
  - Large arrays : WIO1: 4×(50×6)=1,200  
WIO2: 4×(73×6)=1,752
  - New metallurgies: Sn: soft  
Cu, Cu/NiB: hard
- Probe Challenges
  - Probes on grid; landing on bump
  - Fan-out routing in space transformer
  - #Tester channels, interfaces
  - Probe mark damage; dirt on tips
  - Electrical contact; probe tip wear-out
- Conventional probe technology does not handle such micro-bump arrays
  - Cantilever probe cards : fine pitch, but not full-array
  - Vertical probe cards : full-array, but not fine pitch
- Industry adds dedicated pre-bond probe pads [ISSCC'11, CDNLive'11]
- Cascade Microtech and imec enable direct micro-bump probing [SWTW'11, ITC'11, 3D-TEST'12, ITC'14]

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**1. Introduction**

## Test System for Micro-Bump Arrays

- Cascade Microtech's CM300 Probe Station
- National Instruments' PXI Test Instruments
- Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores



- imec's Micro-Bump Test Wafers
- imec's Data Analysis Software

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## Presentation Outline

1. Introduction
2. Cascade Microtech's CM300 Probe Station
3. National Instruments' PXI Test Instruments
4. Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores
5. imec's Micro-Bump Test Wafers
6. imec's Data Analysis Software
7. Conclusion

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2. Cascade Microtech's CM300 Probe Station

**CM300 Dual Configuration**

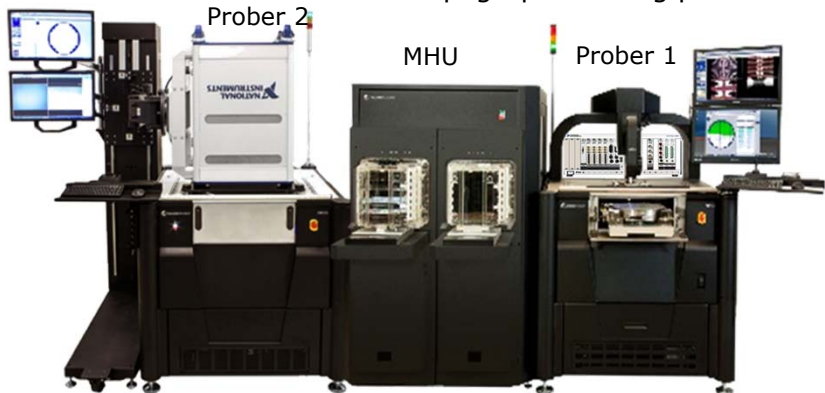
- **Probers 1 and 2** (identical)
  - Manual front-port loading of
    - Ø200mm wafers
    - Ø300mm wafers
    - Tape frames ≤Ø300mm wafers
  - MicroAlign for use with vertical probe cards
  - Anti-vibration table
  - Thermal Control System: -60 – 200°C
  - GPIB command interface
  
- **MHU: Material Handling Unit**
  - Automatic loading of Ø200/Ø300mm wafers from FOUP/FOSB
  - Automatic wafer identification
  - One or two load-ports shared between two probers



2. Cascade Microtech's CM300 Probe Station

**CM300 Adapted For Test Head Docking**

- **Differences between Probers 1 and 2**
  - Prober 1:
    - 4.5" rectangular engineering probe cards
    - Cable interface from test instruments to probe cards
  - Prober 2:
    - No microscope bridge (for test head)
    - Ø300mm circular Apollo probe cards with 1644 pogo-pin landing pads



2. Cascade Microtech's CM300 Probe Station  
**'Vortex-2' in imec's Fab-2**



• Vortex-2/2: left-hand system

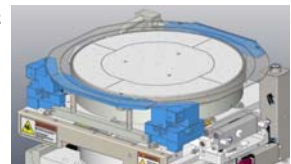
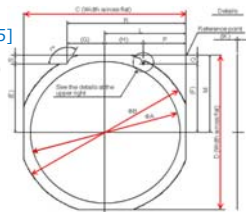
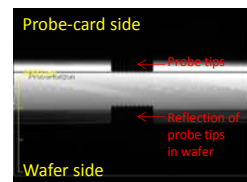


• Vortex-2/1: right-hand system



2. Cascade Microtech's CM300 Probe Station  
**Probe Station Features**

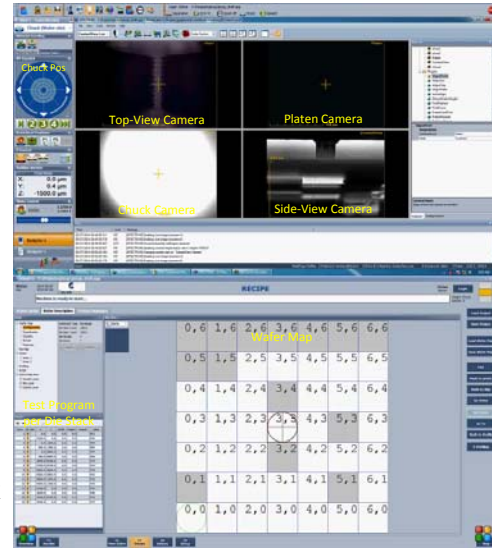
- **Four Cameras per Prober**
  - ↓ Top-view camera on bridge (\*absent on Prober 2)
  - ↓ Platen camera
  - ↑ Chuck camera } Software overlay for non-see-through probe cards
  - ➔ Side-view camera ('Probe Horizon')
- **Handles Large Tape Frames** [Marinissen - ITC'15]
  - Up to Ø300mm wafers (SEMI G74-0699)
    - Extra maneuver space
    - Chuck camera away from chuck
    - Extra support bars for large frames
  - Manual loading through front-port
- **Five Auxiliary Chucks per Prober**
  - 2.5×2.5cm<sup>2</sup> each
  - For tip-cleaning and calibration substrates
  - Three aux chucks inaccessible if large tape frame is loaded



## 2. Cascade Microtech's CM300 Probe Station

### Control Software Functions

- **Velox™** – Probe Station Control Software
  - WaferMap with Z-profiling, binning, sub-die stepping, etc.
  - Integrated thermal control, automated environment conditioning
  - CellView: stitched image of full device
  - ProbeHorizon™ for easy wafer loading
  - Cleaning routines for probe tips
- **VeloxPro** – Test Automation Software
  - Cassette mapping and visualization
  - Test sequence customization
  - Load new wafers into cassette during test
  - AutoInventory: address wafers by wafer ID
  - Multiple wafer types in single cassette
  - Load any wafer out of any cassette to any chuck
  - Setup new recipes, parameters, and pattern recognition



Screen capture of CM300 Velox software

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6. imec's Data Analysis Software
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### 3. National Instruments' PXI Test Instruments

## STS Hard-Docking Test Head

Test head

PXI Rack 1

PXI Rack 2

Docking approach

Manipulator

Test head: 160 kg

12x137=1644 probe pins

Docked!

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### 3. National Instruments' PXI Test Instruments

## Instrumentation for Wide-I/O Probing

#### PXI Rack for Wide-I/O Probing

- PXI-4072 Digital Multi-Meter
- PXIe-2535 Switch Matrix 4x136 FET (9x) (136x9=1224 columns)

Enables two- and four-point (Kelvin) resistance measurements between any pair of micro-bumps

DMM

DMM Force-Hi

DMM Sense-Hi

DMM Force-Low

DMM Sense-Low

SMX1

SMX9

SMX Columns

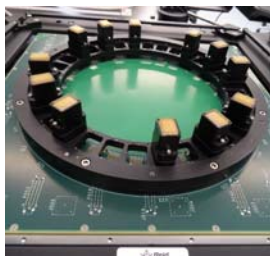
1 2 ..... 135 136 ..... 1089 1090 ..... 1223 1224

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**4. Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores**  
**Test System's Interconnect Overview**



**Pogo Pins**

- Spring-loaded pins
- 12 blocks × 137 pins = 1644 pogo pins
- Connected to PXI instrumentation outputs (e.g., Wide-I/O Switch Matrix columns)



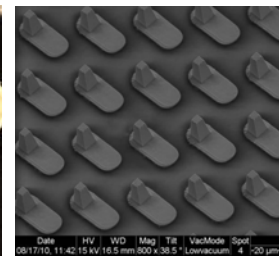
**Probe Card**

- Pogo pad pattern matches the pogo pin layout
- Pogo pads connect one-to-one to Core-I/Os through multi-layered probe card



**Probe Core**

- Chip-design specific insert in probe card hole
- Consists of
  - Metal frame + 'plunger'
  - First thin-film membrane for routing signals from Core-I/Os to center of probe core
  - Second thin-film coupon contains the MEMS probe tips



**Probe Tips**

- Probe tip pattern matches the micro-bump layout
- Probe tips
  - Probe area 6×6µm<sup>2</sup>
  - Tip height: 12µm
  - On Rocking Beam Interposer ("RBI")

**4. Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores**  
**Test Head to Probe Card Interface: Pogo Pins**

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**4. Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores**  
**Probe Card to Core Interface: Core-I/Os**

Probe Card with hole for Probe Core

Pyramid® Probe RBI MSI-HD Probe Core with  $4 \times (38 \times 8) = 1216$  Core-I/Os

Probe Core membrane layout from core-I/Os to probe tips

South Core-I/Os: Columns 1-38, Rows A-H =  $38 \times 8$  core-I/Os

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### 5. imec's Micro-Bump Test Wafers

## imec's Micro-Bump Probe Applications

### 1. Probe-Card Characterization

- Micro-bumps all shorted
- Execute 'ProbeCheck' routine:

```
for ch=2 to 48 do {
    Gang = {2...48}\{ch};
    measure Rc between ch and Gang with I constant;
}
```
- Wafers cannot be used for subsequent stacking

### 2. Pre-Bond Micro-Bump Probing


- Main driver for this work
- Evaluation of test system: probe station, test instrumentation, probe card + core
- Evaluation of micro-bumps-under-test (MBuTs)

### 3. High-Density Post-Bond Daisy-Chain Testing

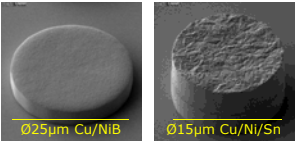

- Use as high-probe-count probe card,  
e.g., for testing post-bond micro-bump daisy-chains with higher tap-off density

### 5. imec's Micro-Bump Test Wafers

## imec's Blanket Micro-Bump Wafers



- BMB Design**
  - All micro-bumps shorted by blanket Cu
  - Everything drawn in micro-bumps
    - Identification and alignment markers
    - Arrays: 50/50µm pitch, WIO1, WIO2
    - Banks with 0/1/2 rings of dummy bumps
- BMB Design Statistics**
  - Dies / Ø300mm wafer : 93
  - 50µm/WIO1/WIO2 arrays / die : 18/27/27
  - Funct. micro-bumps / die : 101,304
  - Funct. micro-bumps / wafer : 9,421,272
- Micro-Bump Types**
  - Ø25µm Cu/NiB
  - Ø25µm Cu
  - Ø15µm Cu/Ni/Sn

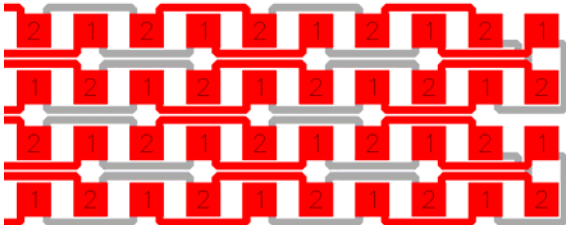
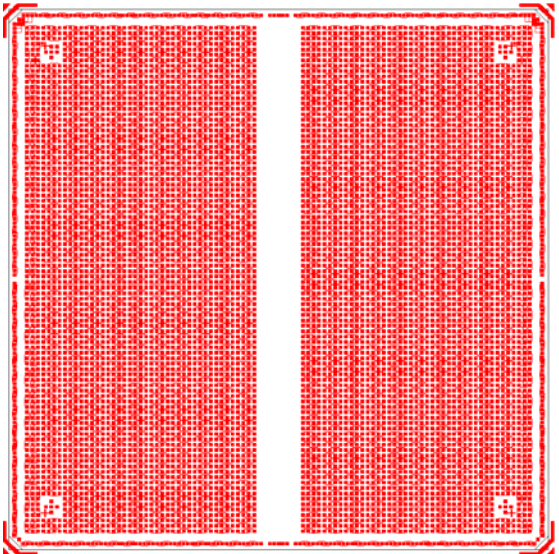
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### 5. imec's Micro-Bump Test Wafers

## imec's PTCN Wafers

- Two mirror-symmetrical banks of 43×94 - 11 = 4031 micro-bumps at 50µm pitch**
  - Two interwoven horizontally-running daisy-chains
  - Exceptions
    - Wrap-around at array edges
    - For alignment markers


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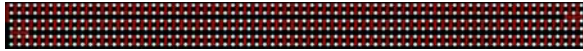
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5. imec's Micro-Bump Test Wafers

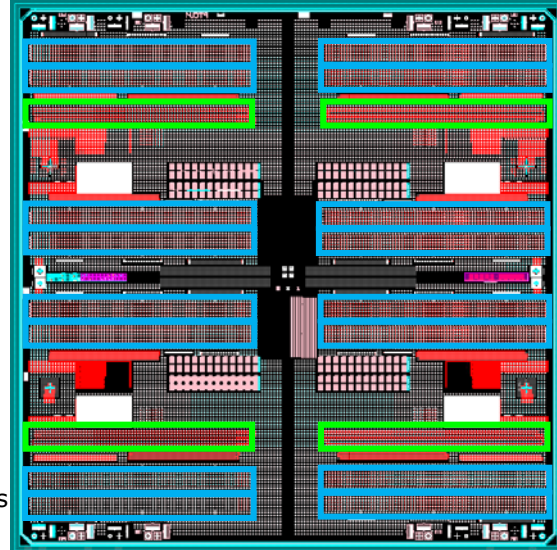
## imec's PTCU Wafers

Four symmetric-identical quadrants

- **Pre-Bond:**  
**single-bank WIO2 arrays 40µm pitch** 
  - For developing pre-bond micro-bump probing
  - Micro-bumps pairwise connected by M1, pre-dominantly in diagonal fashion



- **Post-Bond:**  
**single-bank WIO2 arrays 40µm pitch** 
  - Connected to post-bond daisy-chains through micro-bump arrays of 40µm, 20µm, and 15µm pitch or 10µm, 7.5µm, and 5µm pitch
  - 438 individual tap points per 3 daisy-chains



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6. imec's Data Analysis Software

**Input: Describing the Test System and Test Chip**

• **Test System**

- Look-up table; per line: Example
  - Probe number 3
  - Core-I/O SH03
  - Pogo block/pin S13\_H08
  - Switch matrix/column SMX5\_COL010
- Probe core parameters

PROBE	CORE I/O	POGO PIN	SMX_COL	SMX F	COL F
1	WH23	S19_G05	SMX7_COL	SMX7	c113
2	SD02	S13_M06	SMX5_COL	SMX5	c86
3	SH02	S13_H08	SMX5_COL	SMX5	c14
4	SD03	S13_M05	SMX5_COL	SMX5	c90
5	SH03	S13_H07	SMX5_COL	SMX5	c10
6	SD04	S13_M04	SMX5_COL	SMX5	c94
7	SH04	S13_H06	SMX5_COL	SMX5	c6
8	SD05	S13_M03	SMX5_COL	SMX5	c98
9	SH05	S13_H05	SMX5_COL	SMX5	c112
10	SD06	S13_M02	SMX5_COL	SMX5	c102
11	SH06	S13_H04	SMX5_COL	SMX5	
12	SD07	S13_M01	SMX5		
13	SH07	S13_H03	SMX5		

Card Name	IMEC-36
Core Type	WIO2-1ch
Banks	1
Rows	6
Columns	73
Pitch	40
Rec. OT	150
Max OT	150
Gap Row	0
Gap Col	0

• **Test Chip**

- High-level description
- Netlist: daisy-chain segment
  - From micro-bump: (bank, column, row)
  - To micro-bump : (bank, column, row)
- Wafer map: automatically generated in Velox

NAME	PTCU
BANKS	4
ROWS	6
COLUMNS	73
PITCH	40
GAP ROW	0
GAP COL	0

1:1:2	1:3:2
1:1:4	1:1:6
1:7:5	1:7:5
1:7:3:1	1:7:3:3
1:1:1	1:2:2
1:2:1	1:3:2
1:3:1	1:4:2
1:4:1	1:5:2
1:5:1	1:6:2
1:6:1	1:7:2
1:7:1	1:8:2
1:8:1	1:9:2
1:9:1	1:10:2
1:10:1	1:11:2
1:11:1	1:12:2
1:12:1	1:13:2



6. imec's Data Analysis Software

**Example Input: Netlist of Test Chip PTCU**

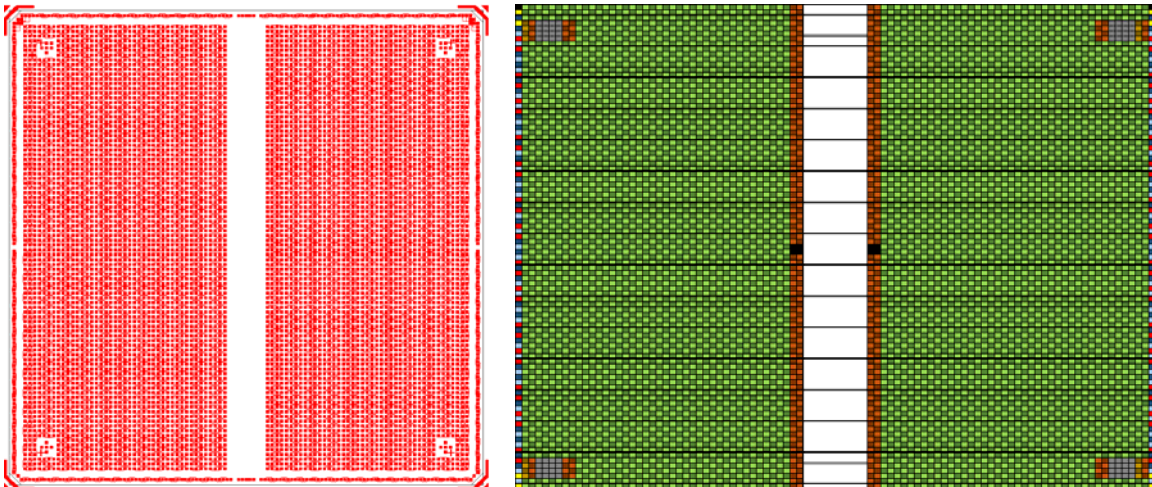
NAME	PTCU
1:1:2	1:3:2
1:1:4	1:1:6
1:7:5	1:7:5
1:7:3:1	1:7:3:3
1:1:1	1:2:2
1:2:1	1:3:2
1:3:1	1:4:2
1:4:1	1:5:2
1:5:1	1:6:2
1:6:1	1:7:2
1:7:1	1:8:2
1:8:1	1:9:2
1:9:1	1:10:2
1:10:1	1:11:2
1:11:1	1:12:2
1:12:1	1:13:2
1:13:1	1:14:2

Netlist layout (for verification of test chip layout)

6	268	269	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800
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6. imec's Data Analysis Software

## Layout vs. Netlist Visualization of Test Chip PTCN



- Probe core: 43×6 probe tips; two Core-I/Os per probe tip (for Kelvin measurements) – 6 different “netlists” per bank

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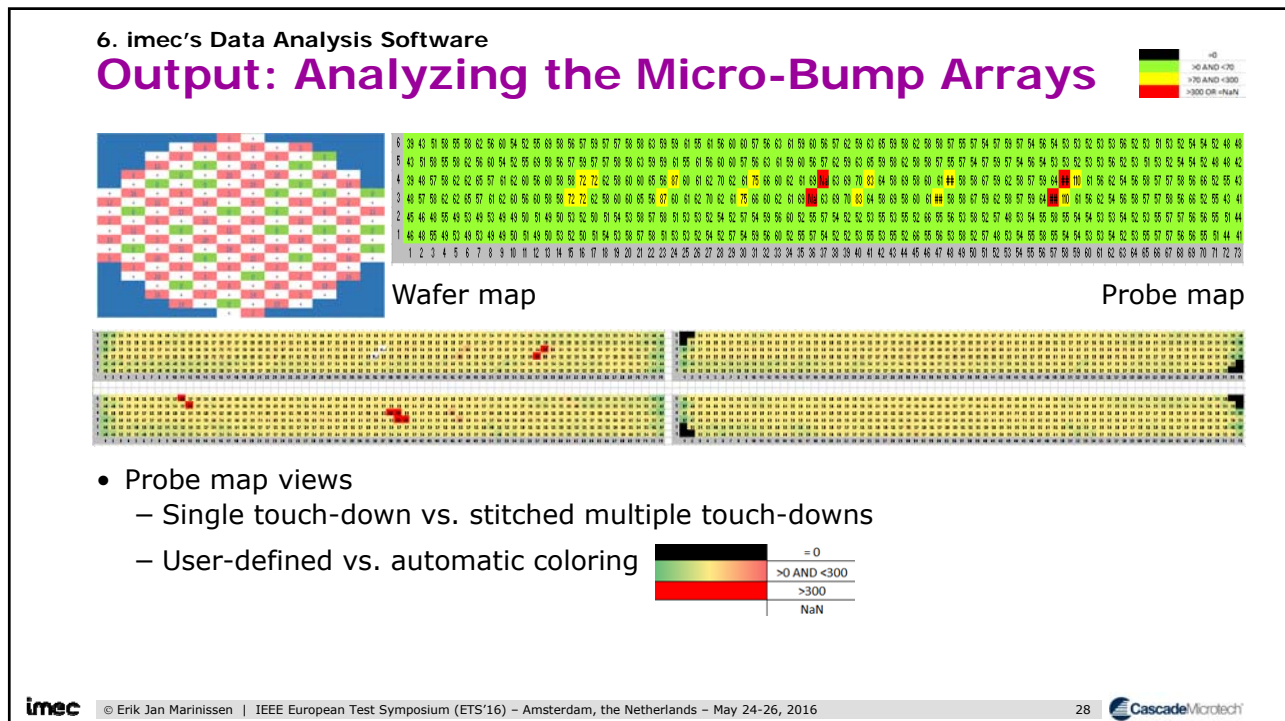
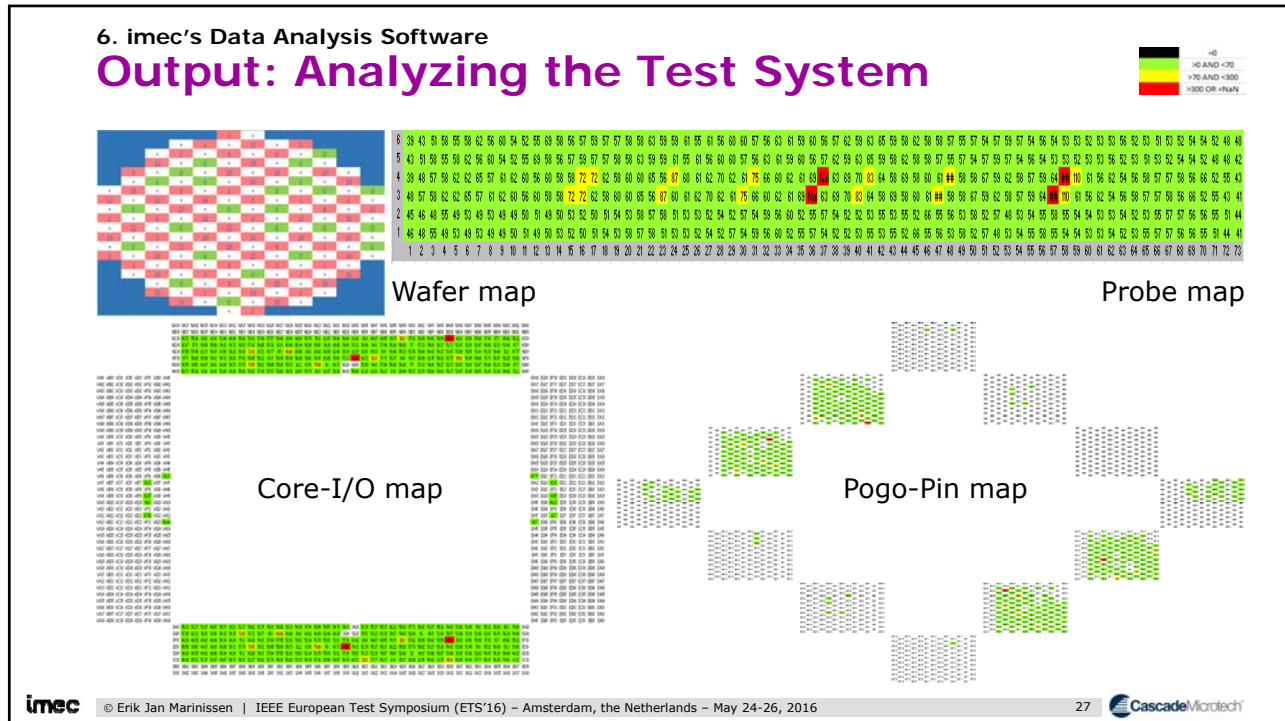
6. imec's Data Analysis Software

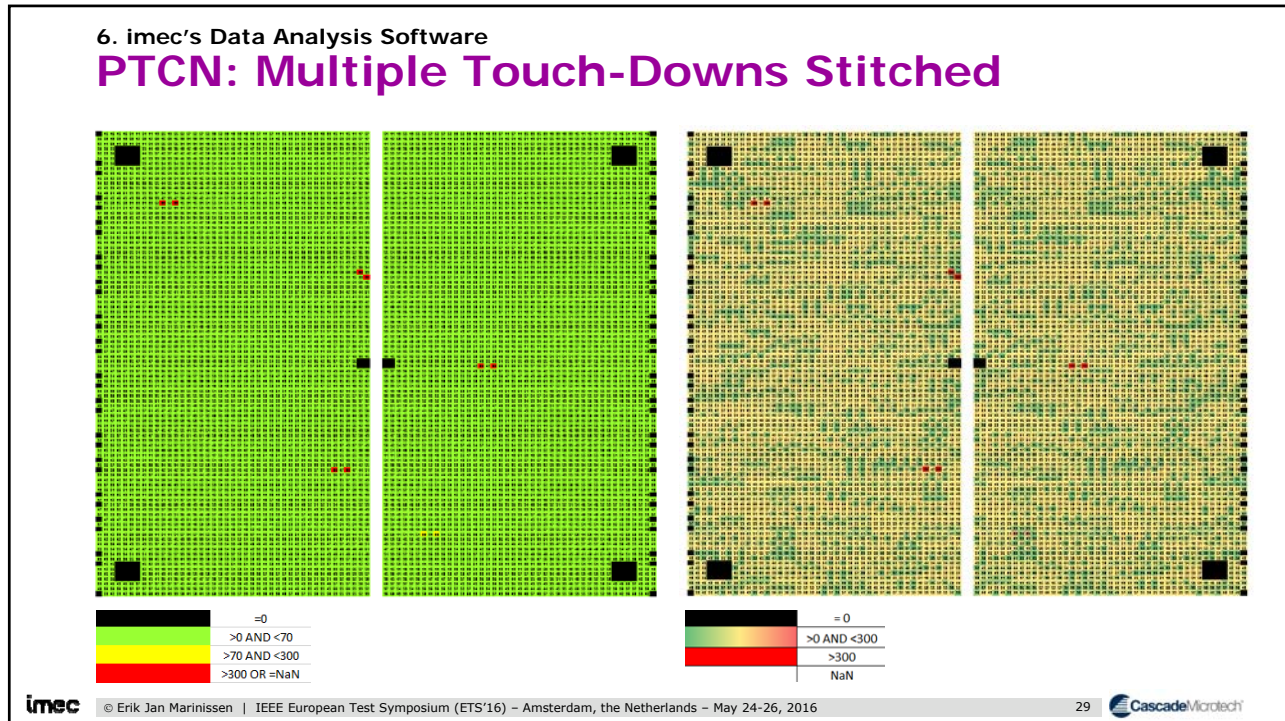
## Output: Raw Data

- Raw Data:** list of
  - Date and time stamp
  - Daisy-chain segment
    - From micro-bump: (bank; column; row)
    - To micro-bump : (bank; column; row)
    - Measured resistance value  $R$  (in Ohm)
- Lots of Measurement Data**  
 Example: BMB wafers, WIO1 Arrays
  - #Wafers : 5
  - #Dies / wafer : 93
  - #WIO1 arrays / die : 27
  - # $R$  measurements / WIO1 array : 1,200
  - Total # $R$  measurements / 5 wafers: 15,066,000
- Data Abstraction & Visualization is Necessary!**

PROBE STATION	CM300 VORTEX 2/2		
DATE	8/4/2016		
SAS DATE	08Apr2016:14:00:42.25		
CORE [TYPE]	IMEC-36 [WIO2-1ch]		
CHIP TYPE	PTCU		
OPERATOR	user		
08Apr2016:14:00:42.90	1;1;2	1;3;2	44.80485
08Apr2016:14:00:43.12	1;1;4	1;1;6	39.22808
08Apr2016:14:00:43.33	1;7;5	1;7;5	41.65223
08Apr2016:14:00:43.54	1;7;3;1	1;7;3;3	40.69714
08Apr2016:14:00:43.75	1;1;1	1;2;2	46.43578
08Apr2016:14:00:43.96	1;2;1	1;3;2	48.29134
08Apr2016:14:00:44.18	1;3;1	1;4;2	55.32705
08Apr2016:14:00:44.38	1;4;1	1;5;2	49.34558
08Apr2016:14:00:44.59	1;5;1	1;6;2	53.37437
08Apr2016:14:00:44.80	1;6;1	1;7;2	49.41641
08Apr2016:14:00:45.01	1;7;1	1;8;2	52.96967
08Apr2016:14:00:45.22	1;8;1	1;9;2	48.96112
08Apr2016:14:00:45.43	1;9;1	1;10;2	
08Apr2016:14:00:45.64	1;10;1		
08Apr2016:14:00:45.85	1;11;1		
08Apr2016:14:00:46.07			

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### A Full-Automatic Test System for Direct Probing of JEDEC Wide-I/O Micro-Bumps

## Presentation Outline

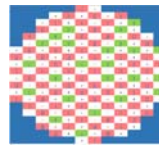
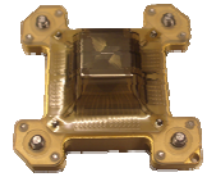
1. Introduction
2. Cascade Microtech's CM300 Probe Station
3. National Instruments' PXI Test Instruments
4. Cascade Microtech's Pyramid® Probes RBI Probe Cards and Cores
5. imec's Micro-Bump Test Wafers
6. imec's Data Analysis Software
7. Conclusion

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7. Conclusion

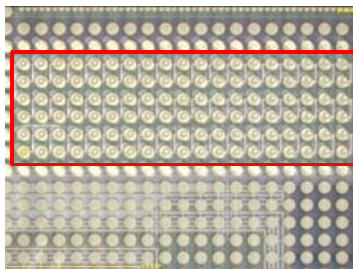
**Summary**

- For 2.5D- and 3D-SICs, pre-bond testing is typically economically beneficial
- To avoid dedicated probe pads, non-bottom dies require micro-bump probing
  - Diameters: 15–25µm; pitches: 40–50µm; array sizes: 1,200–1,752; Cu, Sn
- We presented a full-automatic test system for direct probing of JEDEC Wide-I/O arrays of micro-bumps
  - Cascade Microtech’s CM300 Probe Station + Auto-Loader
  - National Instruments’ PXI Test Instruments in STS Test Head
  - Cascade Microtech’s Pyramid® Probes RBI Probe Cards and Cores
- User-developed software for
  - Description of test chips
  - Analysis of test system
  - Analysis of micro-bump arrays

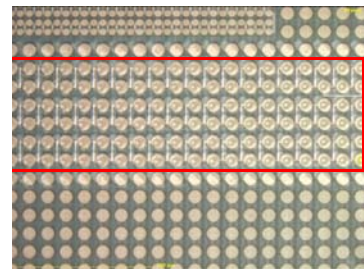


7. Conclusion

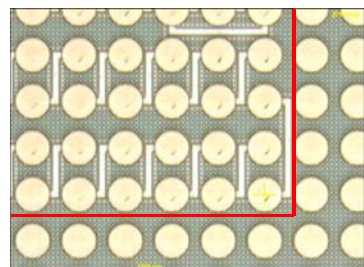
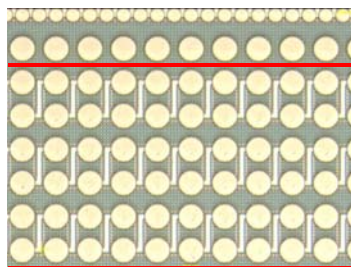
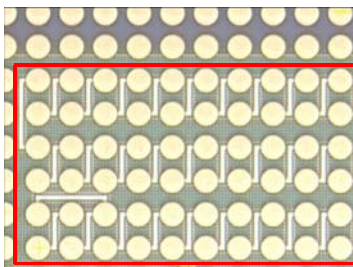
**The Test System in Action: PTCU**



- Probe-to-Pad Alignment through overlay of two camera views



- Probe marks in center of micro-bumps as silent witnesses of accurate probing





7. Conclusion

## Acknowledgments



- **IMEC** (*Leuven*)

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- **Reid-Ashman** (*Phoenix / Munich*)

Harald Kupka, Scott Nelson

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