IEEE SW Test Workshop

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Very Small Pitch Micro Bump Array Probing

Gunther Böhm
FEINMETALL

Samuel Kalt
Team Nanotech

Dr. Armin Klumpp
Fraunhofer-EMFT

Erik Jan Marinissen
IMEC

Dr. Joerg Kiesewetter
CASCADE Microtech

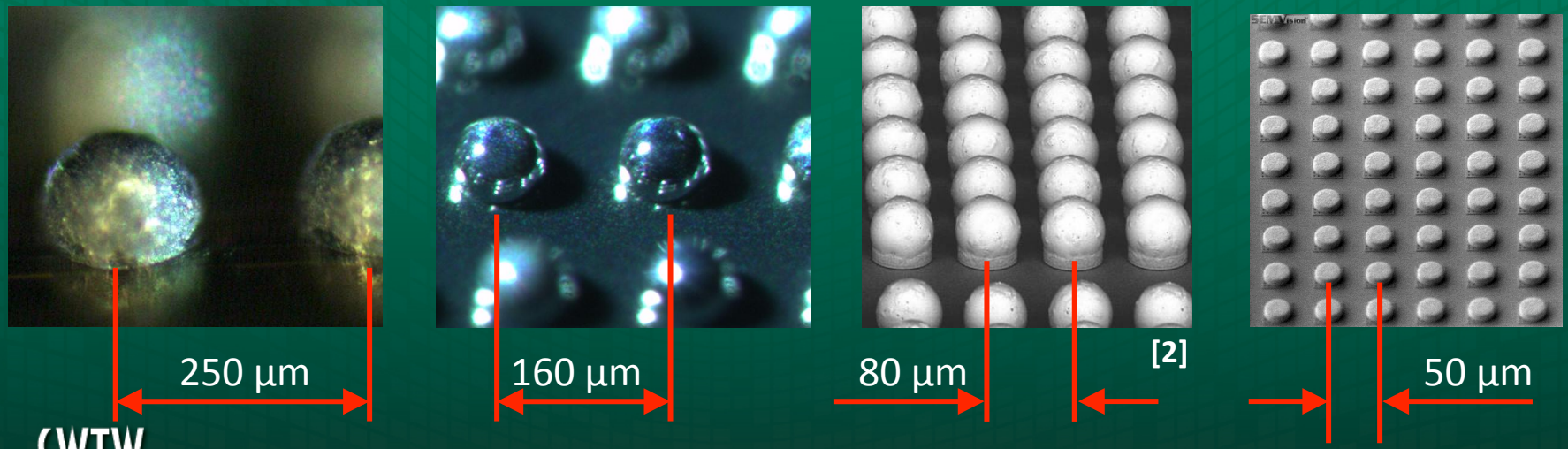
Dr. Wolfgang Schäfer
FEINMETALL

Overview

- Challenge: Probing Really Small Structures
- How the New Tips Look Like ....
  .... and How they are Built
- Functionality and Simulation
- Probe Head Design
- Overtravel Experiment
- Summary & Outlook

Contact Arrays on ICs

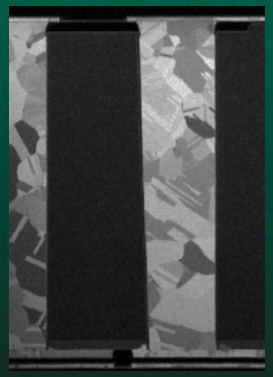
- Geometrical requirements to array probing are increasing
- Transition from solder ball to Cu-pillar and µbumps on Through Silicon Vias

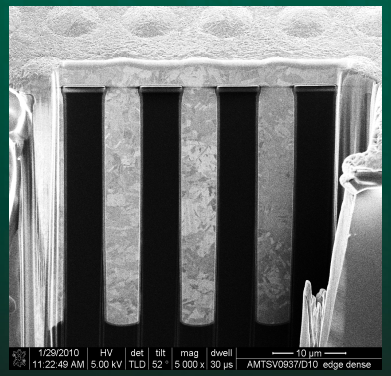


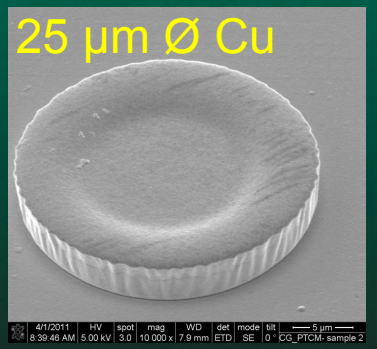
pictures 2+3 are scaled and modified to show proportions

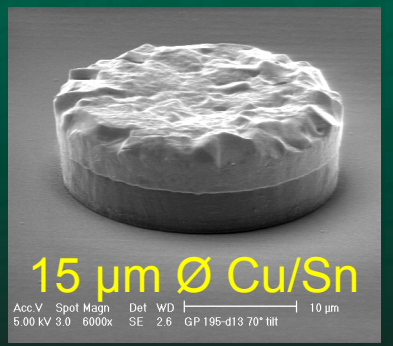
3D-SICs: TSVs and Micro-Bumps

- **Through-Silicon Vias**
  - Interconnect from front-side to back-side of silicon die
  - IMEC's Reference Process
    - Cu TSVs, min. pitch 10 µm
    - Height 50 µm, ∅5 µm (AR 10:1)
  - Scaling down dimensions
    - Fine pitch: higher density
    - Small diameter: less capacitance
- **Micro-Bumps**
  - Interconnect bonding between two dies
  - IMEC's Reference Process
    - Top bump: Cu(Ni)Sn, ∅15 µm
    - Bottom bump: Cu, ∅25 µm
    - 40/50 µm pitch
  - Scaling down dimensions
    - 40 µm → 20 µm → 10 µm pitch



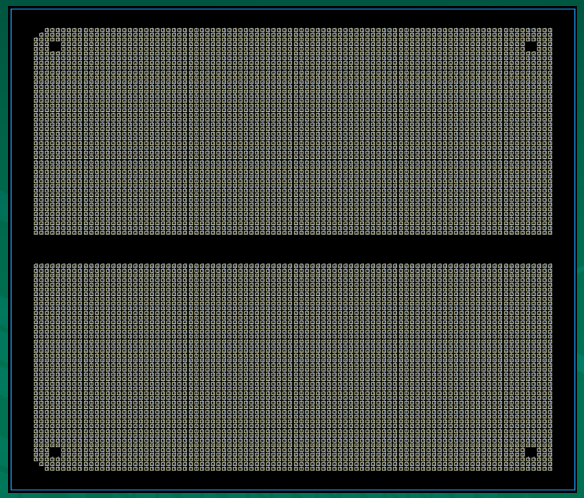






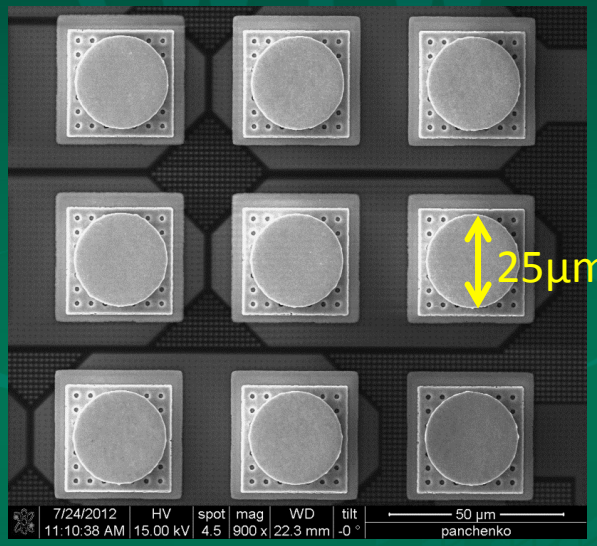
IMEC Micro-Bump Test Chips

Micro-Bump Chip



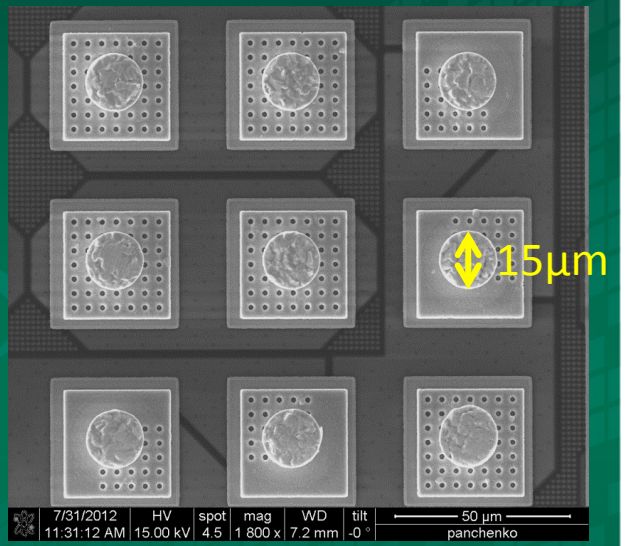
- Dedicated test chip
- Area array with ~8,000 micro-bumps per die at 50 µm pitch
- M1 daisy-chain through adjacent micro-bumps

Bottom Die: Cu, ∅25µm

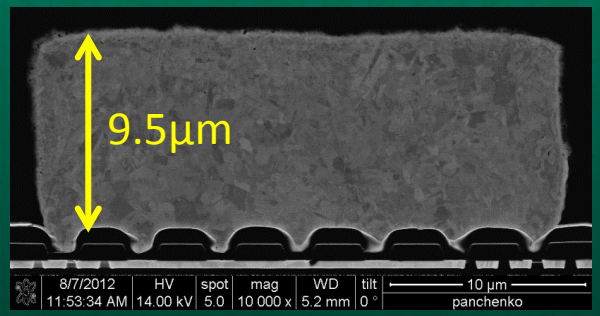


Top view

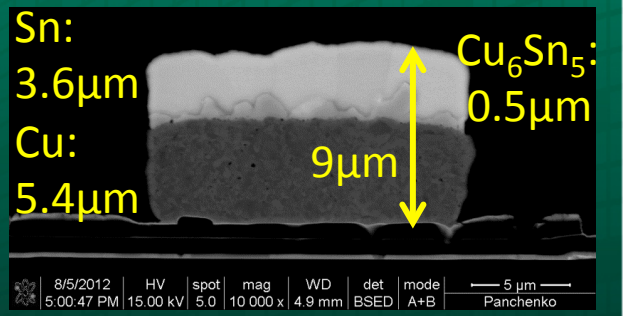
Top Die: CuSn, ∅15µm



Top view

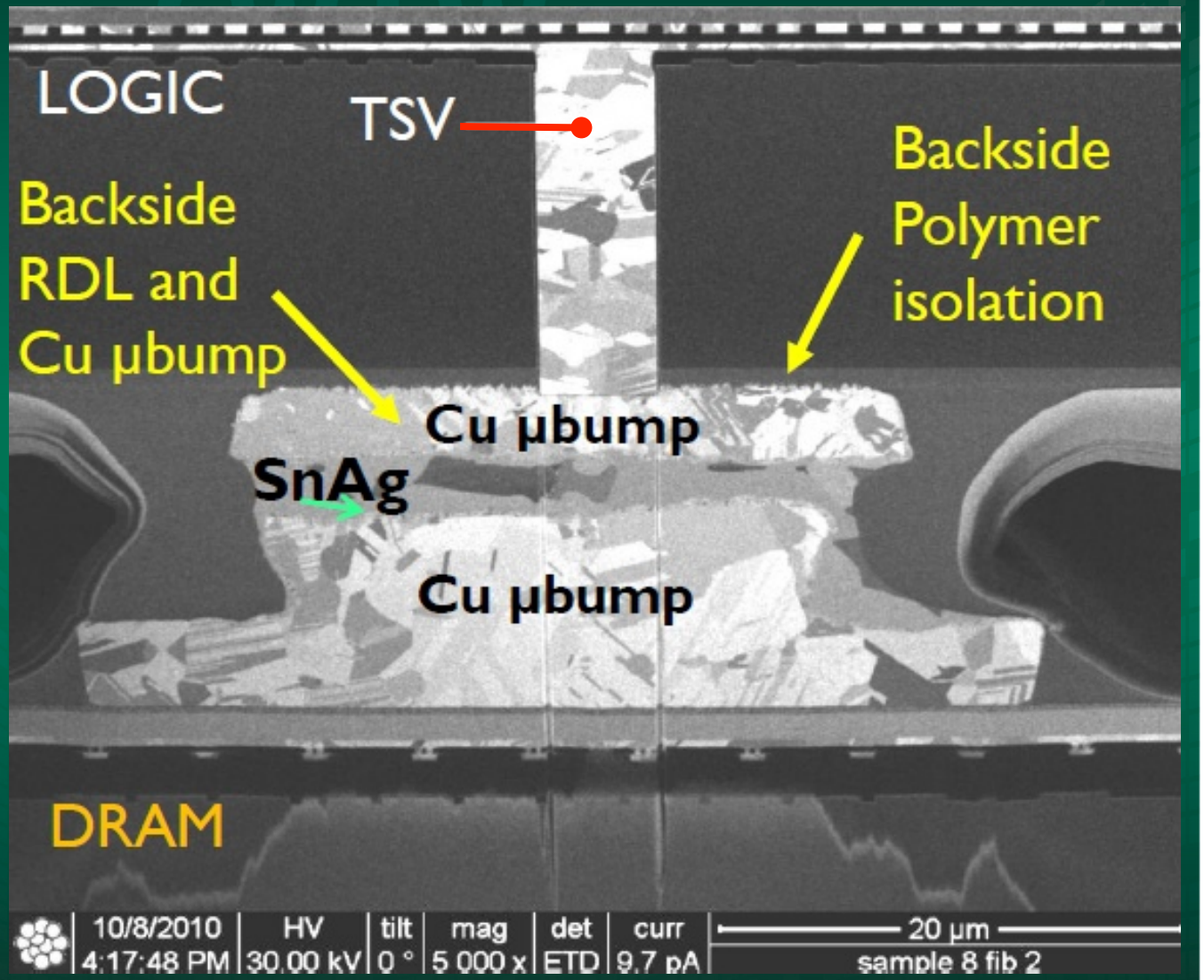


Cross section



Cross section

3D-SIC with TSVs and Micro-Bumps



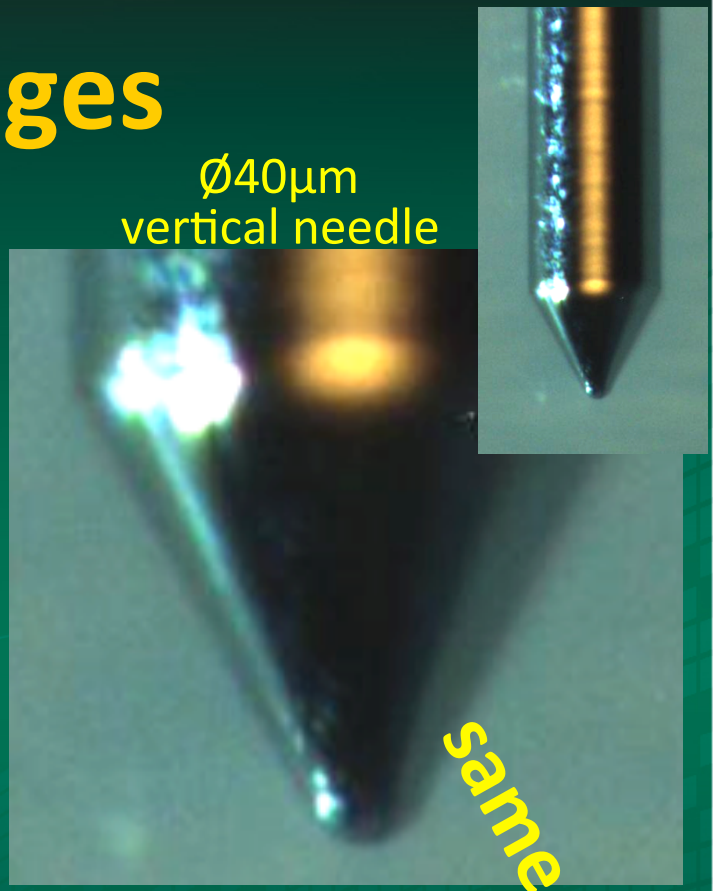
die 1

die 2

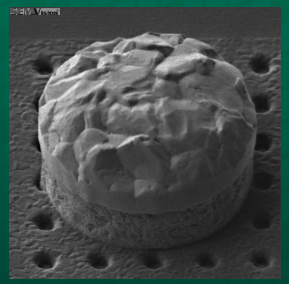
µbump Probing Challenges

- Pitch is smaller than most needles
- Dense array fan out requires small traces
  ➔ 10 µm lines/spaces
- Pad damage vs. bond capability
  ➔ no damage on contact area

Ø40µm
vertical needle



same scale

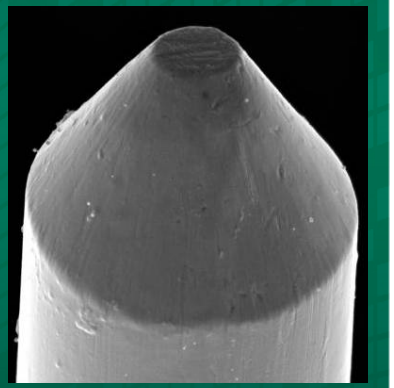


Ø15 µm CuSn micro bump

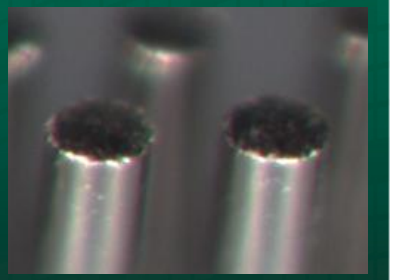
Probe Tip Selection (1)

- Sharp tip
  - good, tiny contact
  - easy to fabricate
  - poor lifetime
  - major pad damage

- Truncated cone or pyramid with scrub
  - good contact
  - hard to fabricate
  - acceptable lifetime
  - major pad damage

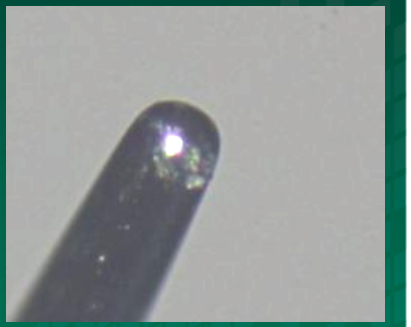


- Flat tip
  - unstable contact
  - easy to fabricate
  - good lifetime
  - medium pad damage

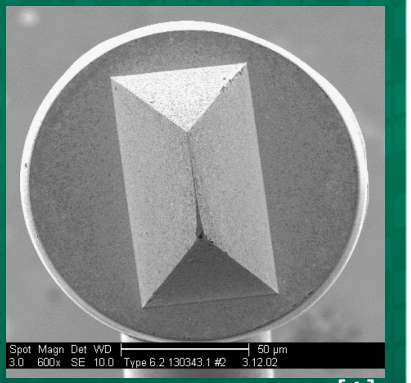


Probe Tip Selection (2)

- Rounded tip
  - unstable contact
  - hard to fabricate
  - acceptable lifetime
  - medium pad damage

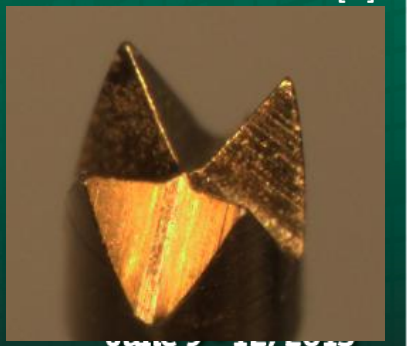


- Wedge
  - excellent contact
  - hard to fabricate
  - good lifetime
  - major pad damage

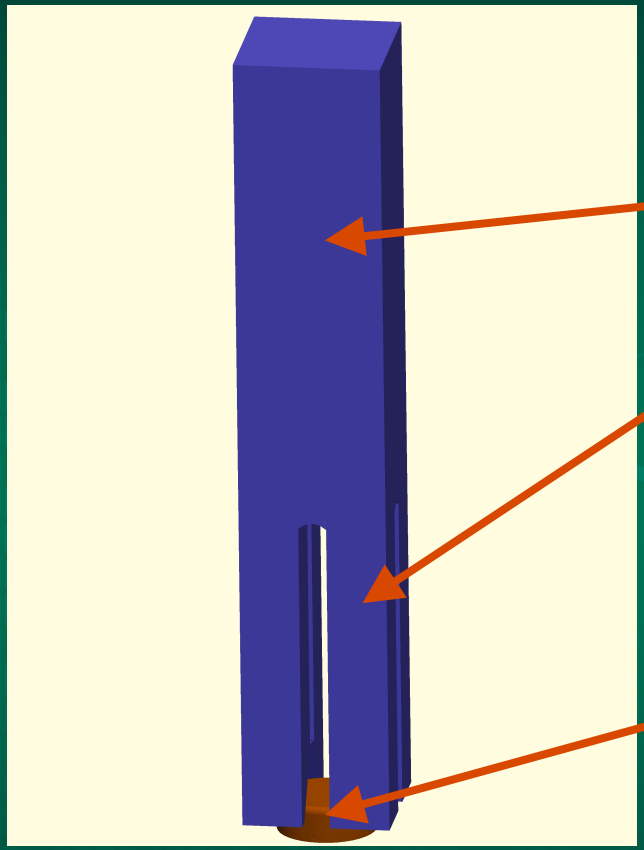


[1]

- Crown
  - good contact
  - hard to fabricate
  - good lifetime
  - minor pad damage



Silicon Crown Contact (1)

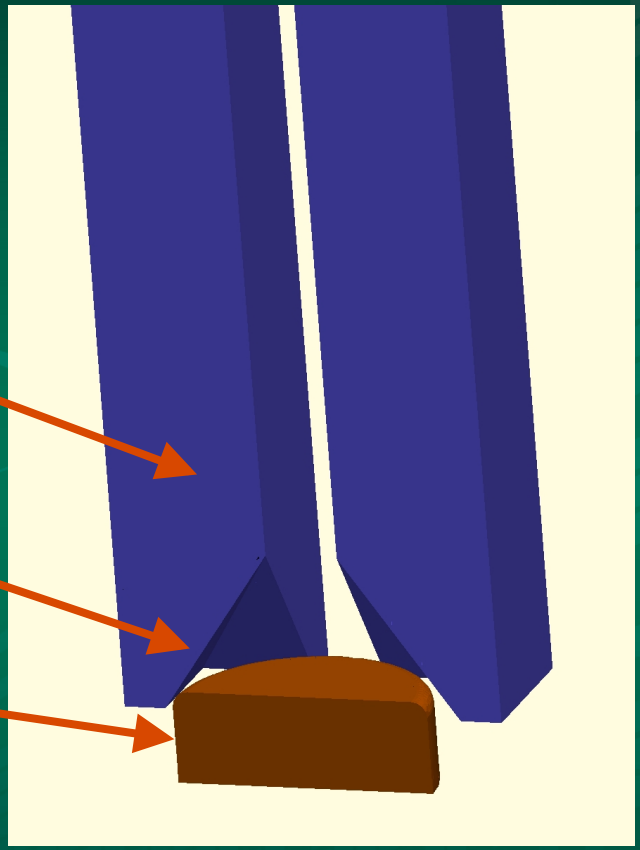


silicon tip, solid part

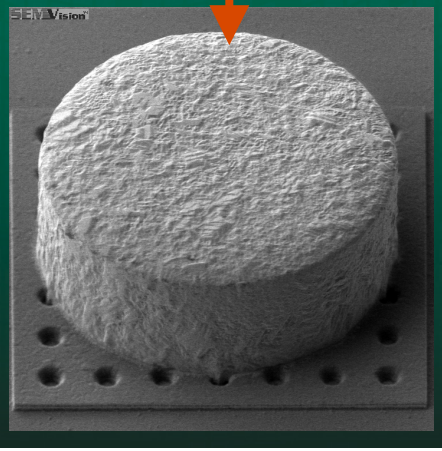
silicon tip, split part

contact edge

Ø 25 µm Cu-cylinder



one tip splits into
four segments

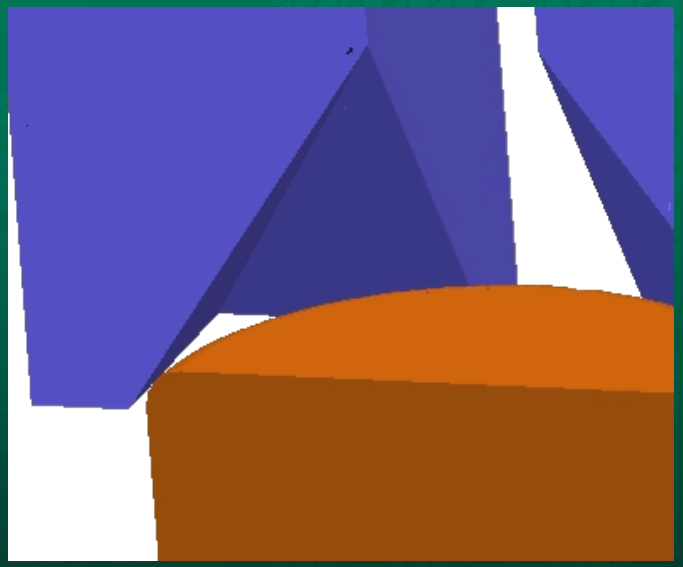


eight edges are
contacting the µbump
(sectional view)

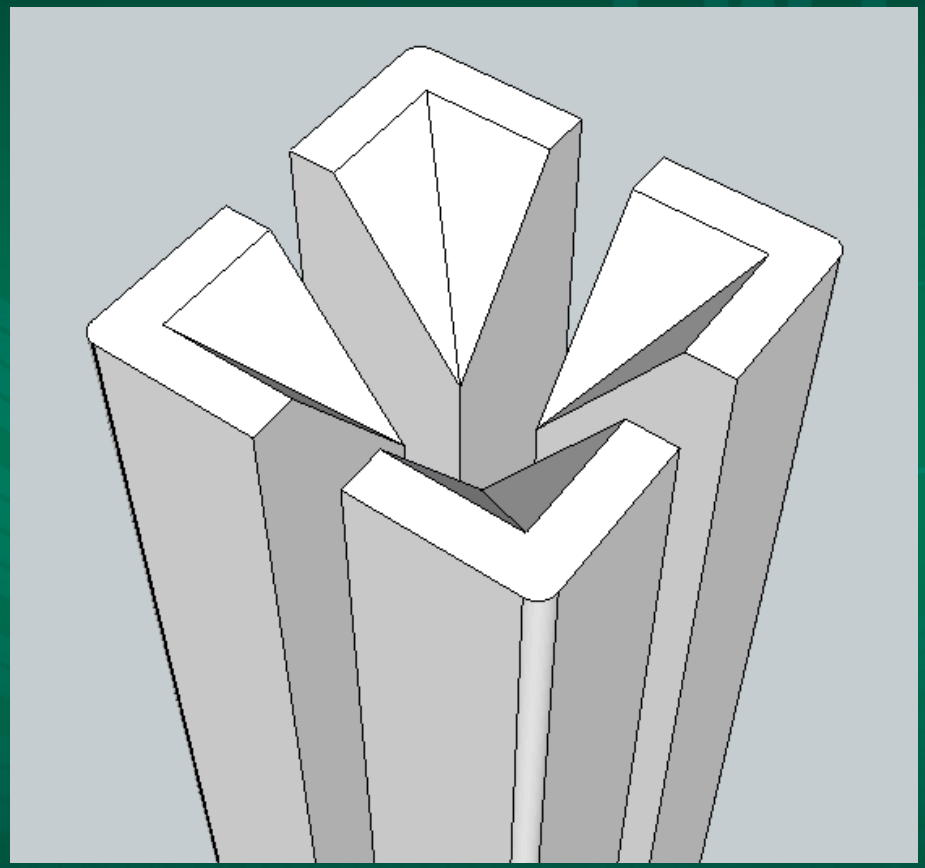
patent
pending

Silicon Crown Contact (2)

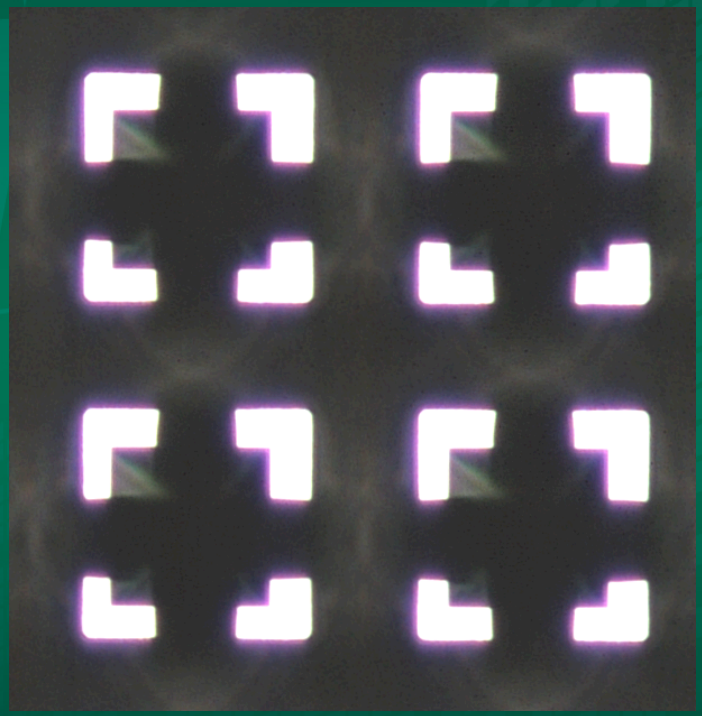
- Minor damage at the edges only to ensure bondability
- Eight contact edges to realize a stable contact
- Scrub action for stable contact and self cleaning
- Very special process to create crown
- Yet unknown lifetime and stability



Silicon Crown Contact (3)

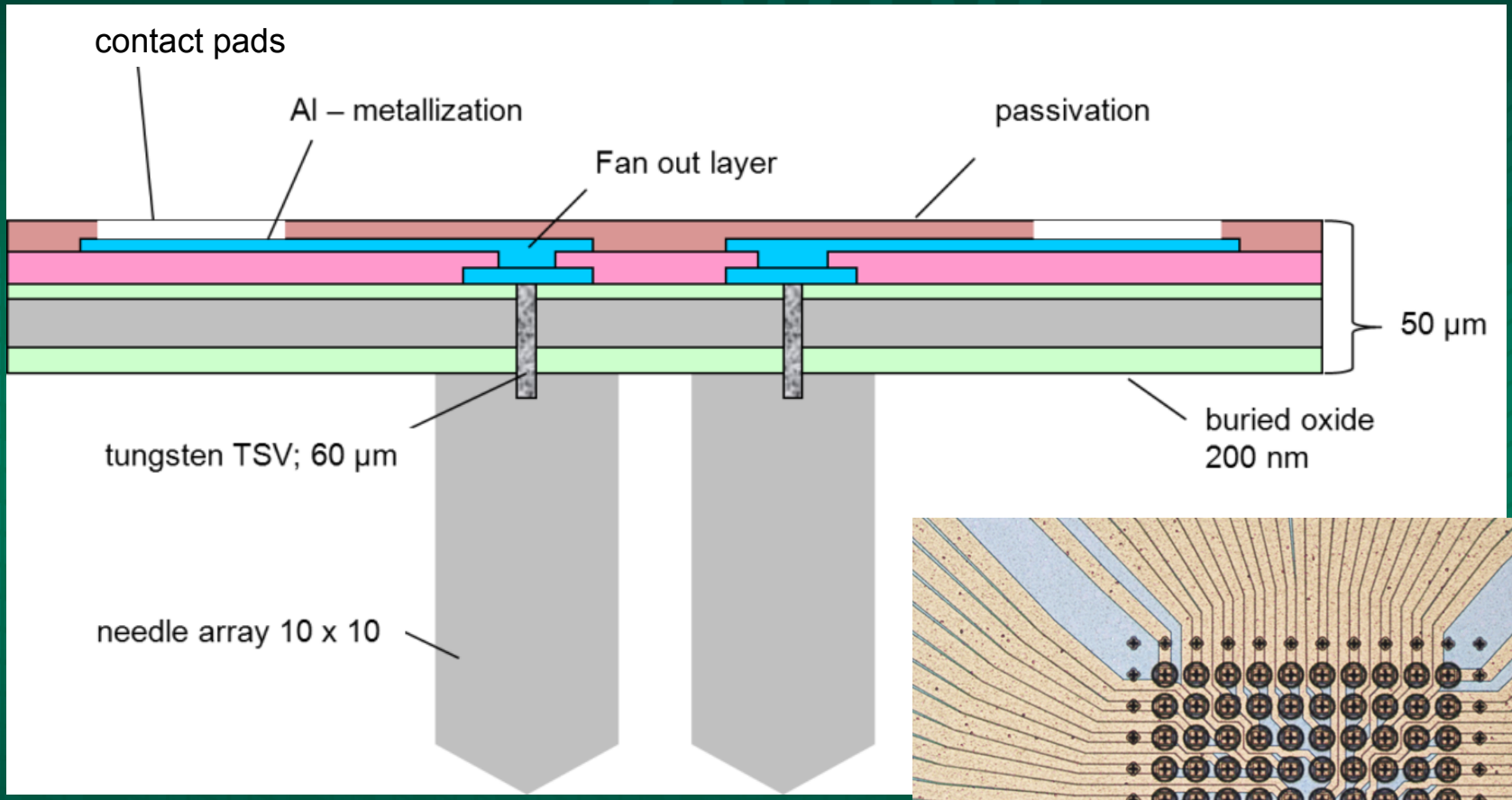


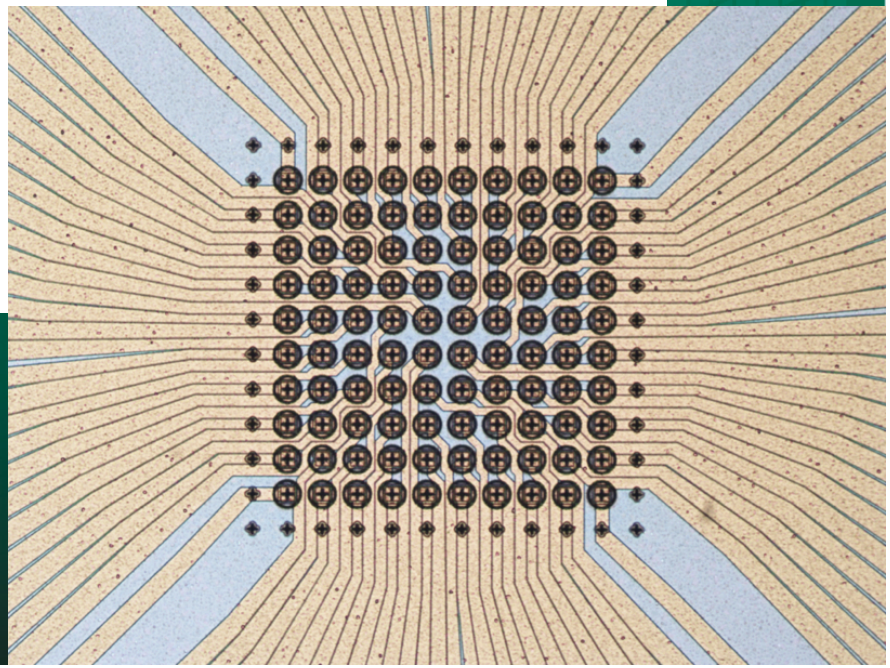
CAD-view on the tip



microscope-view on the tip

Needle Array Core Technology (1)



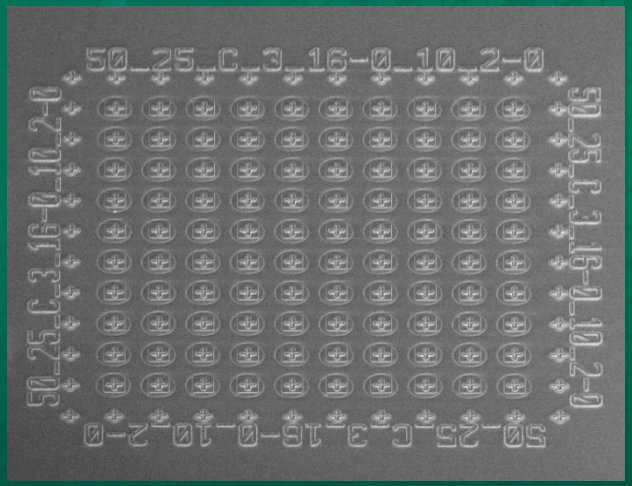


microscope top view on the array

Needle Array Core Technology (2)

- Through Silicon Vias in BESOI*-Wafers
  - CMOS compatible BESOI-Wafer fabrication
  - BESOI thickness 50 µm, 200 nm insulation oxide
  - TSV depth 60 µm

- Needle Array with 10 x 10 Needles
  - Pitch down to 20 µm possible
  - Demonstrator with pitch 50 µm
  - Fanout metallization for wire bond contact



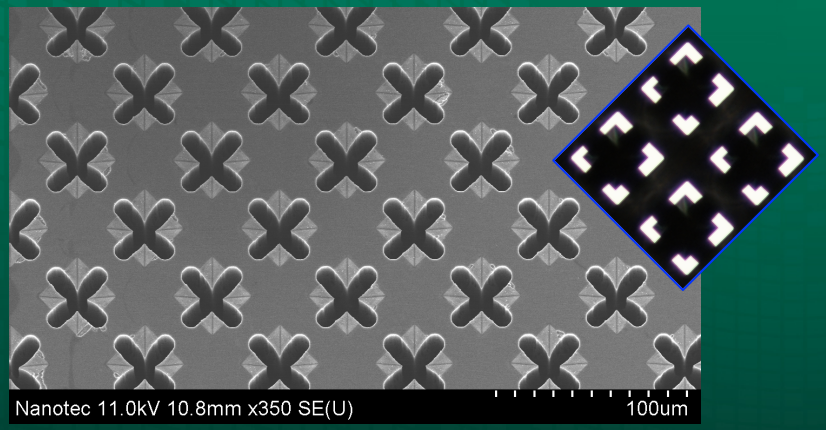
SEM top view on the array

* back etched silicon on insulator

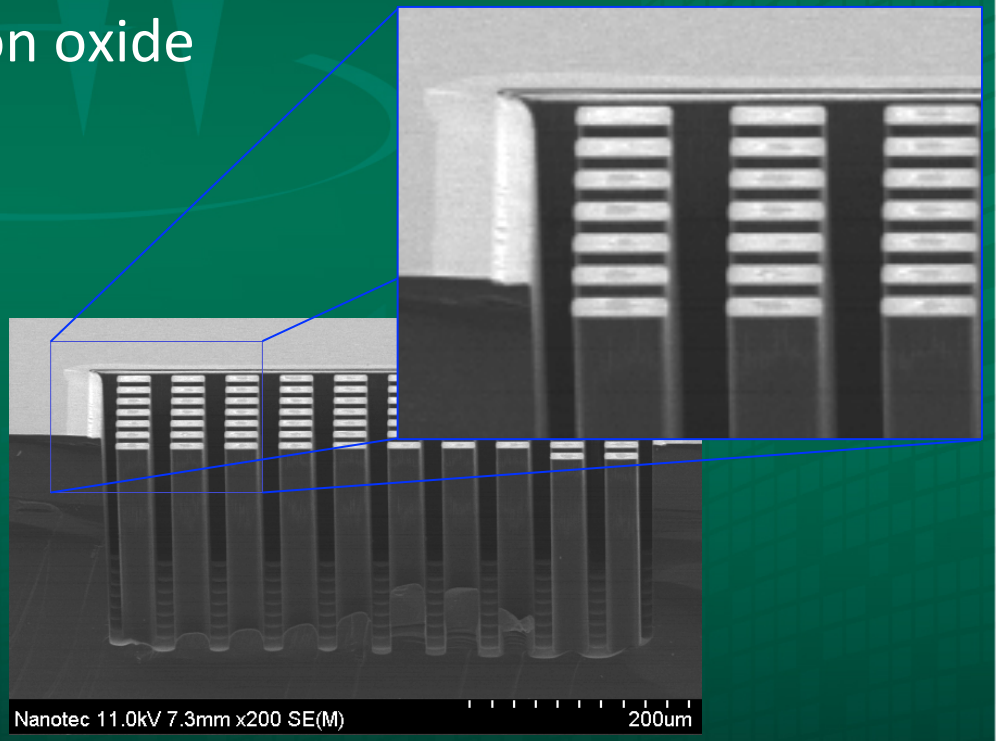
Needle Array Core Technology (3)

MEMS processing of contact elements

- Crown etching
- Needle etch on insulation oxide
- Crown metallization



crown etching



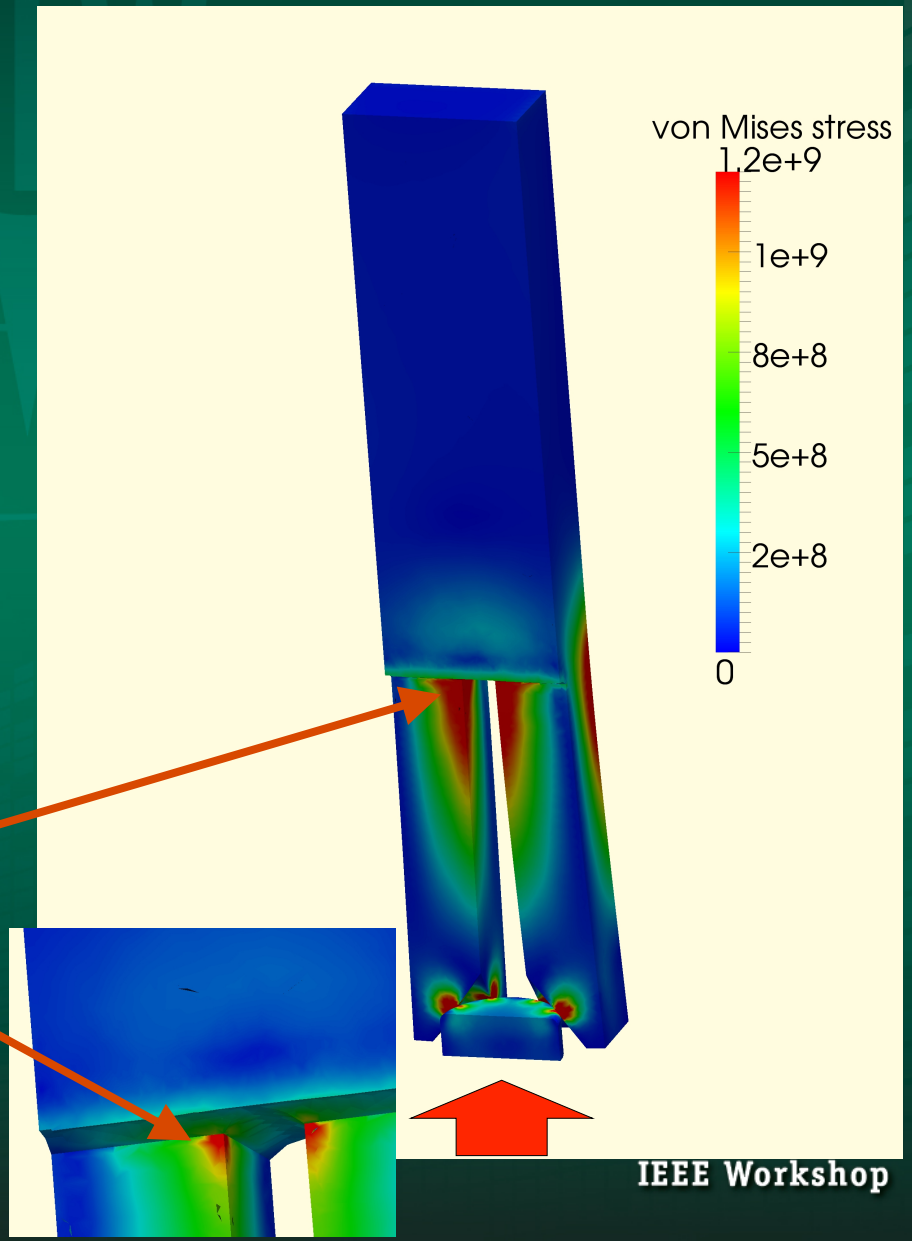
etched needles, cross section

Mechanical Simulation

FE-analysis to learn about the stability of this tip

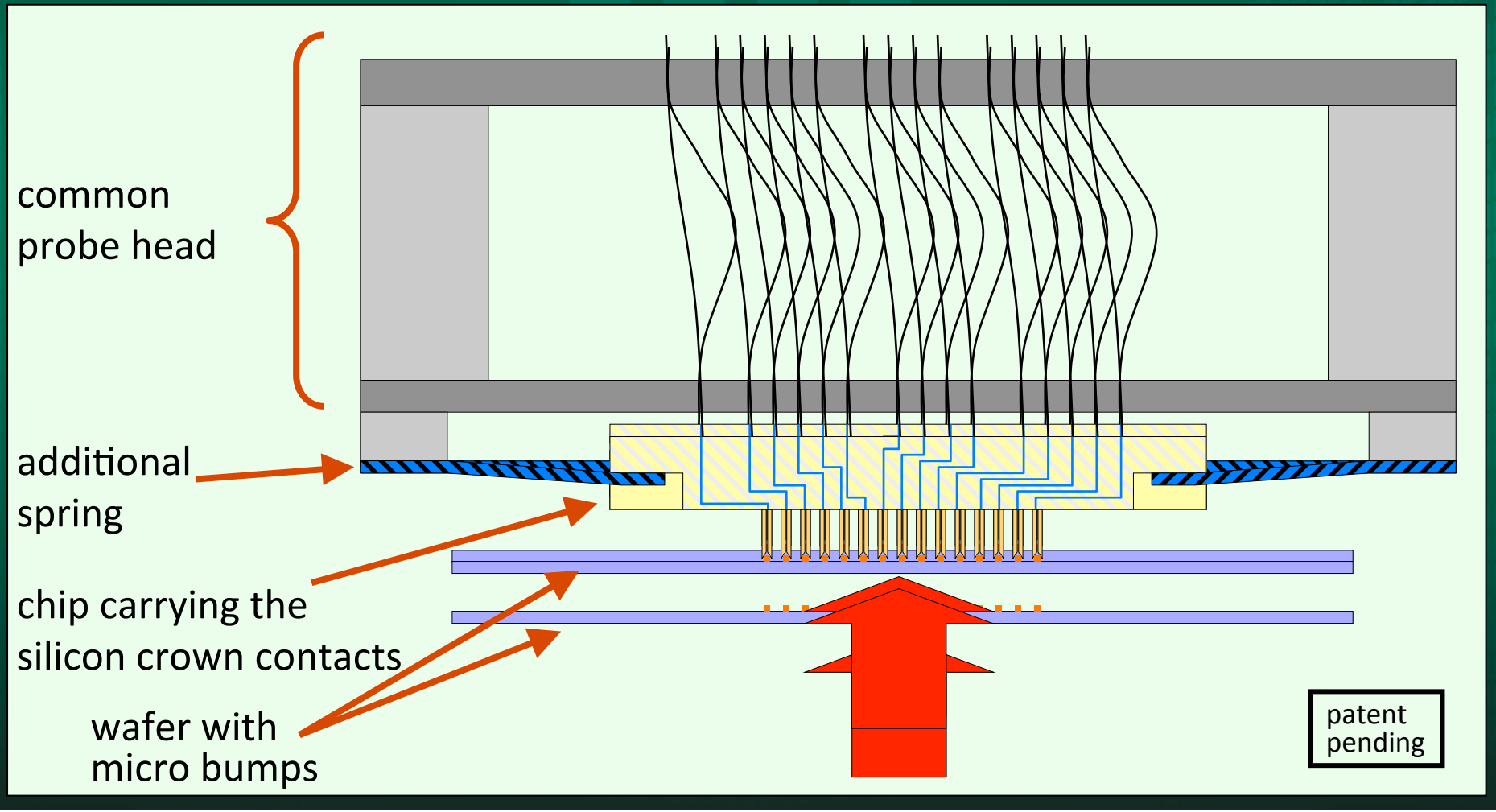
maximum insertion is limited to ~1.5 µm

most critical area

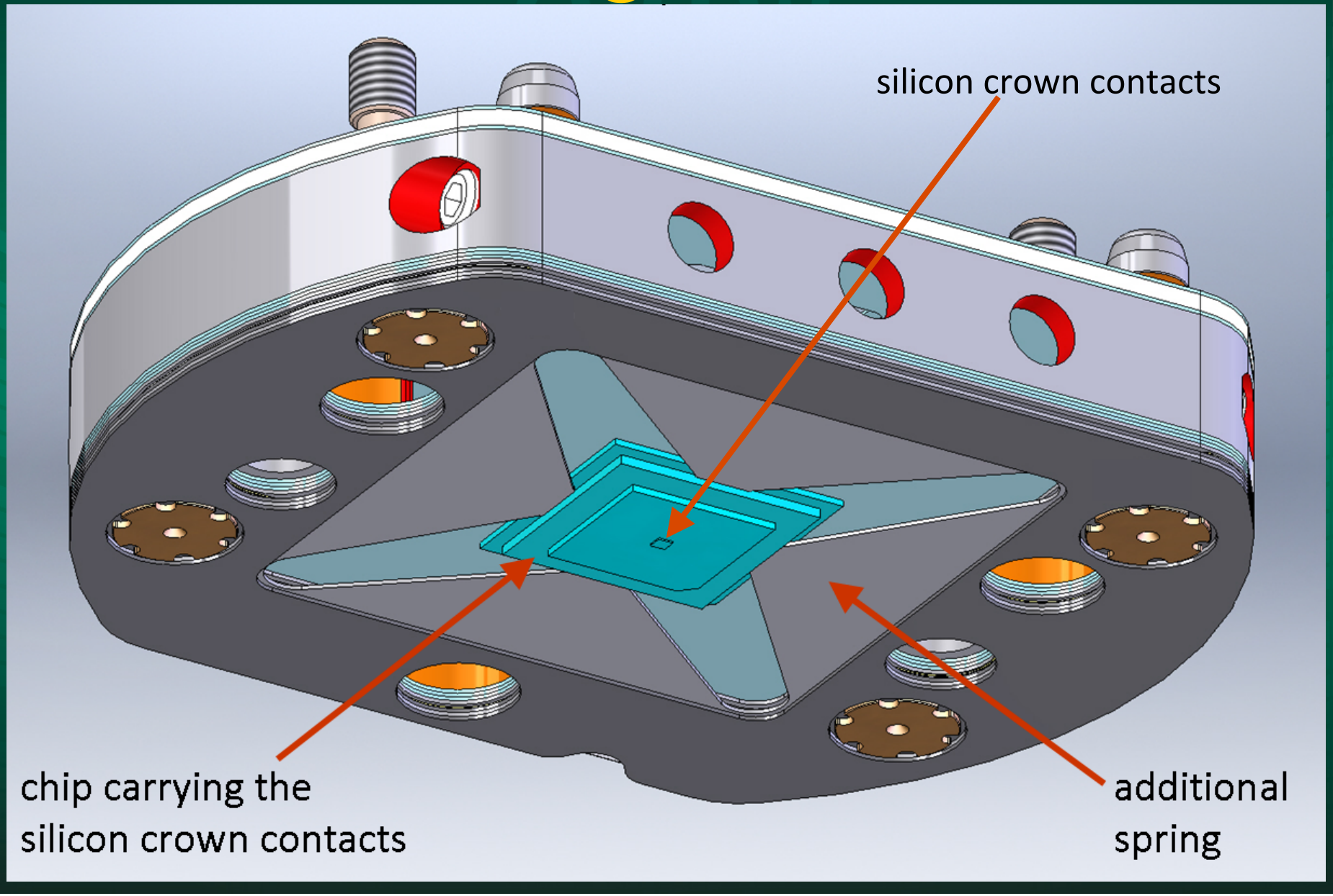


Probe Head Design (1)

To enable more than 1.5 µm overtravel we have designed a two step spring system.



Probe Head Design (2)

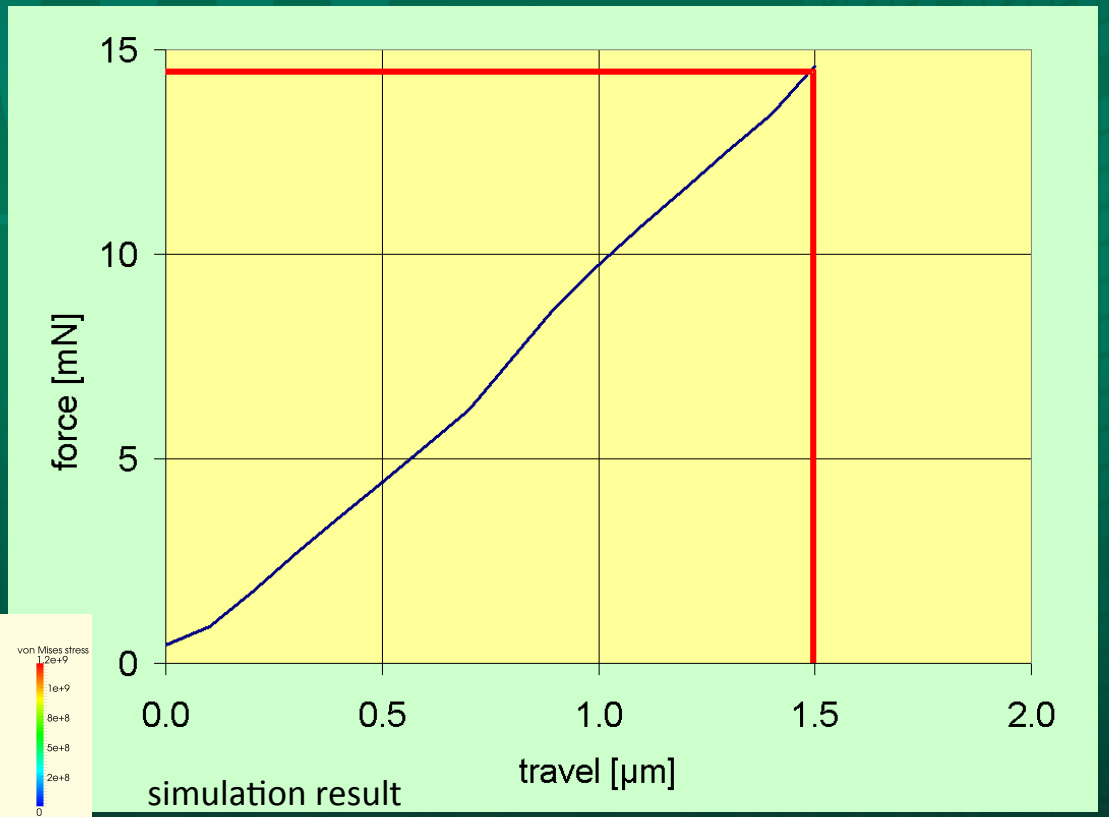


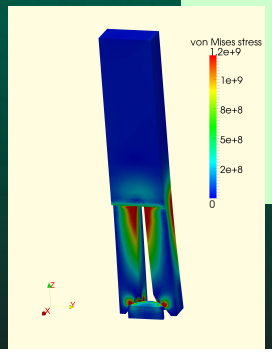
Force to Insertion Characteristics

One single silicon crown contact is expected to carry 14.5 mN force @ 1.5 µm travel.

The test setup contains 100 contacts:

expected total force is 1450 mN

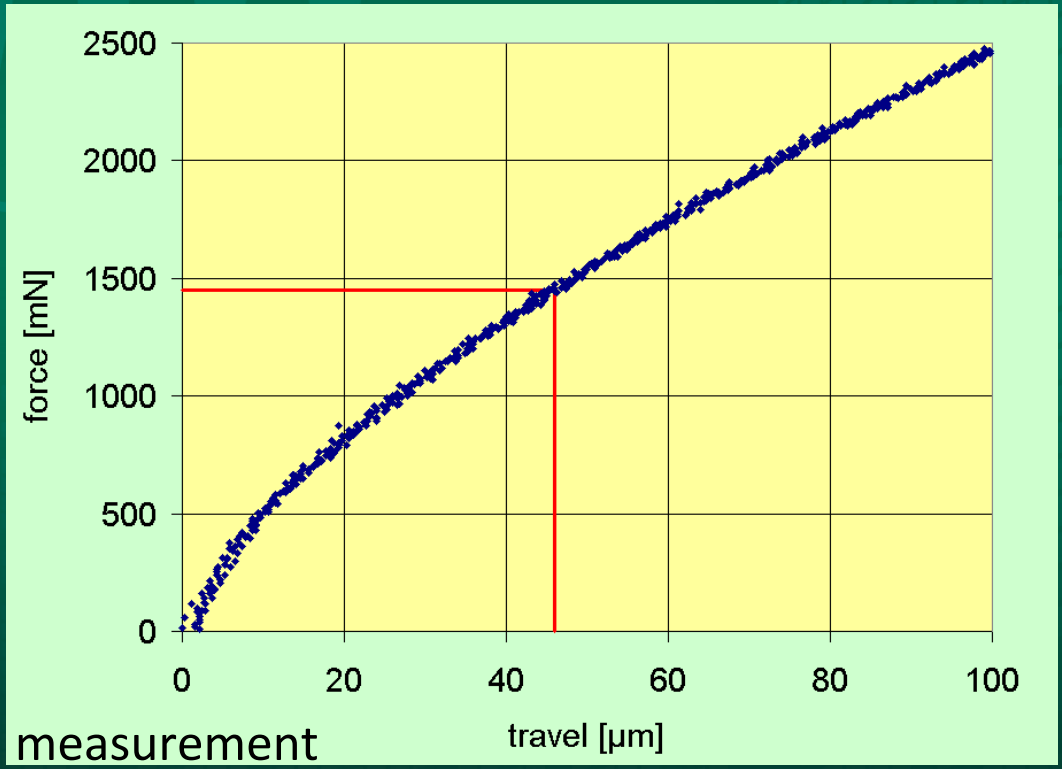




Force to Overtravel Characteristics

The main probe head together with the additional spring has a non-linear force to travel characteristic:

We expect to run an overtravel of 46 µm before the silicon crown contact breaks.



Electrical Properties

- expected DC resistance
  - ViProbe® head: 0.53 Ohm
  - Chip fan out: 1.3 Ohm
  - micro needle: 17 Ohm

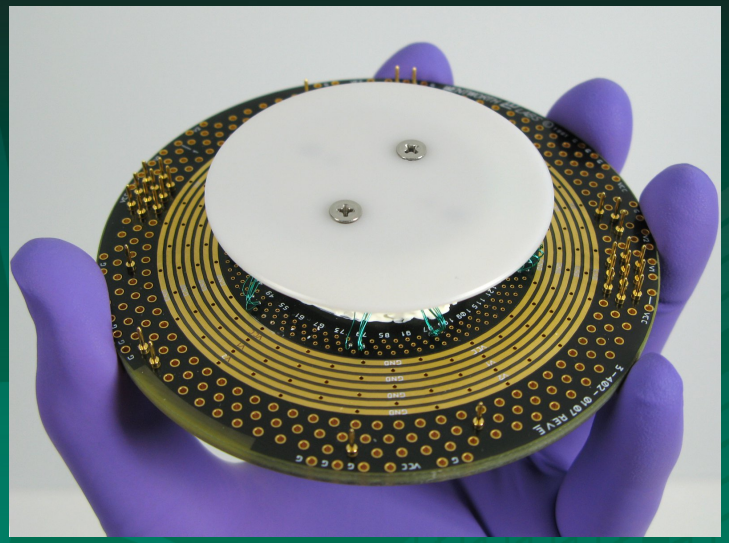
  } Σ= 19 Ohm

- high frequency properties

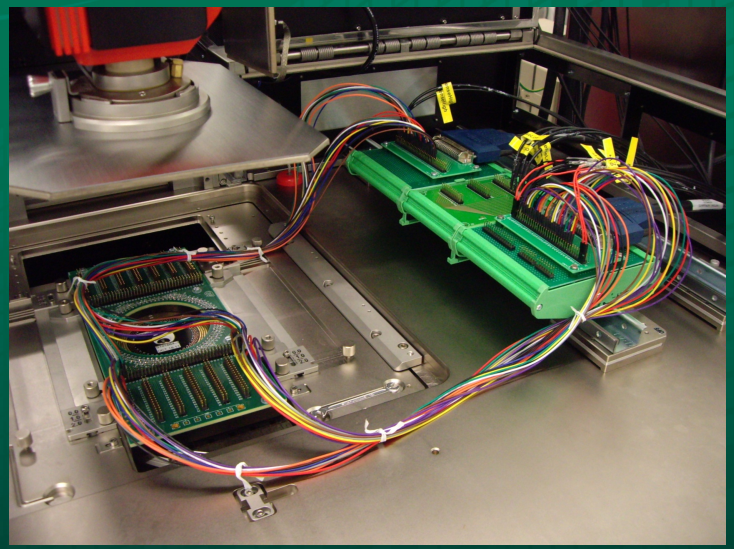
  We see an excellent opportunity to get very good performance, however, optimization and measurement is scheduled later in this project.

Probing Setup

- The 10x10 micro needle array is mounted on a ViProbe® S-type (59 µm pitch) head
- Test structures containing daisy-chain connections are probed
- CASCADE Microtech 300mm demonstrator-probe station
- 32 channel multiplexer to perform 40 individual resistance measurements per touchdown



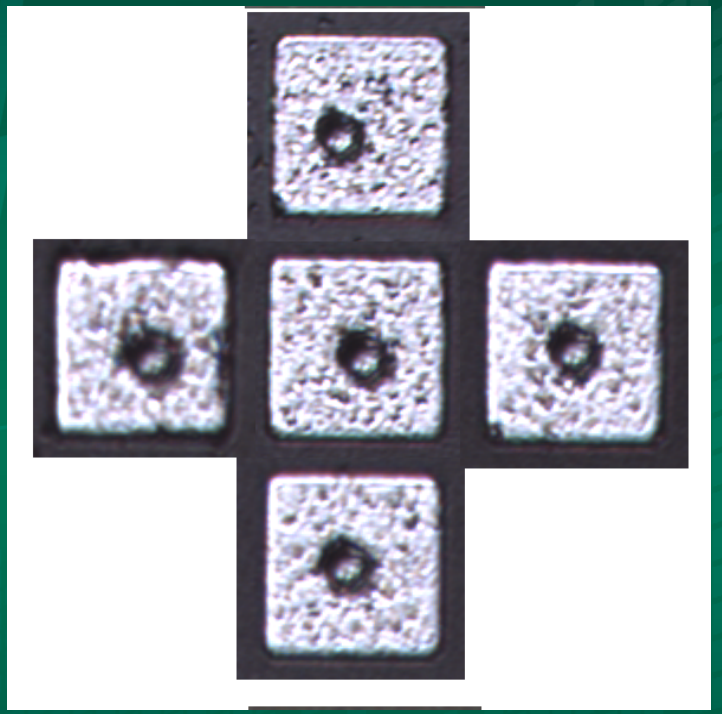
probe card



prober connection

Demonstrator – Probe Station (1)

Installation in the IMEC – cleanroom



Touchdowns after PTPA on 37 µm Al pads with standard probe needle, on centre, north, west, east, south chip of 300 mm wafer

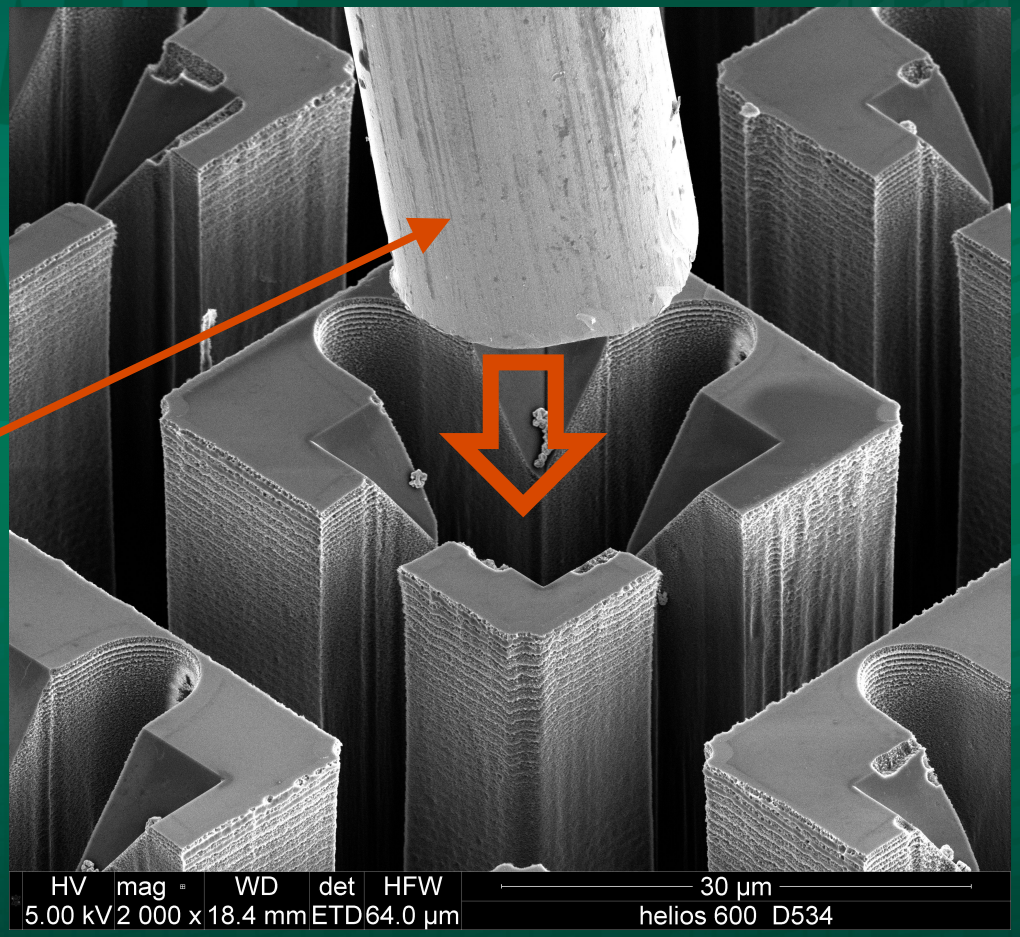
Demonstrator – Probe Station (2)

- Probestation installed in the cleanroom at IMEC
- High accuracy X,Y,Z,Θ-stage
  - Repeatability: +/- 1,5 µm (3 σ)
  - Accuracy: +/- 3,0 µm (3 σ)
  - Resolution: 0,2 µm
- Probe to Pad alignment features
  - High accuracy image acquisition
  - Flexibility for various tip shapes

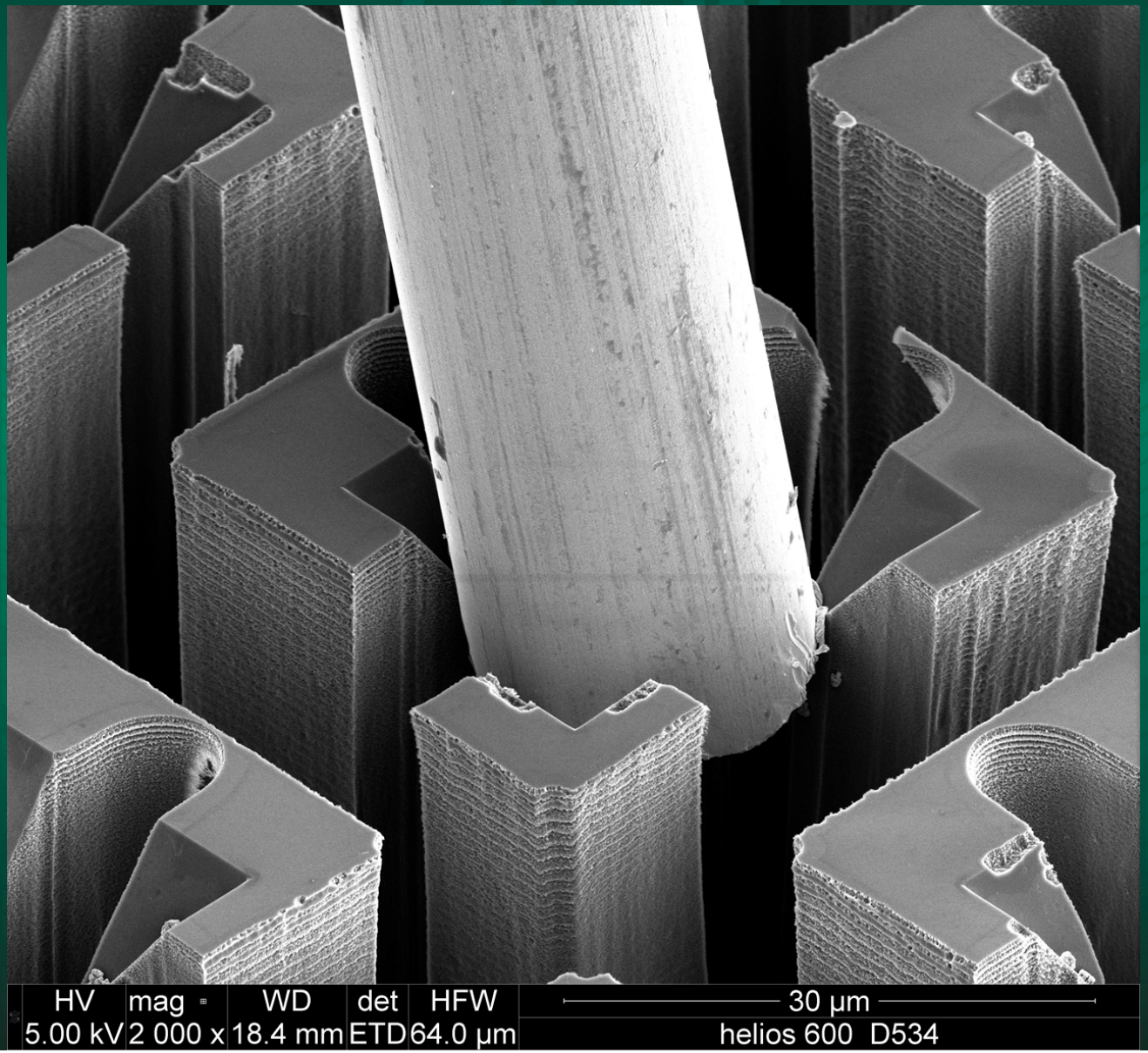
Probe Overtravel Experiment (1)

- Touching the silicon crown tip with a wire
- Estimating max. overtravel

Ø20µm wire

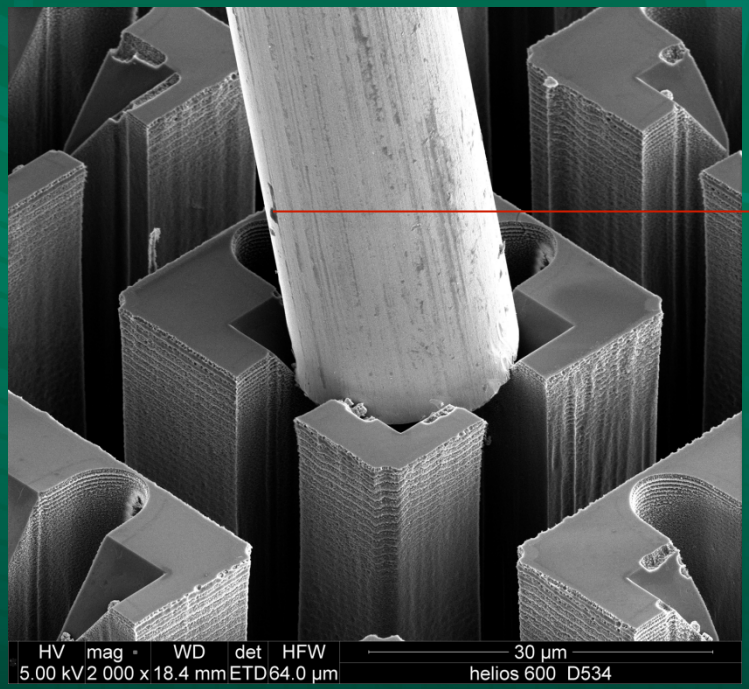


Probe Overtravel Experiment (2)

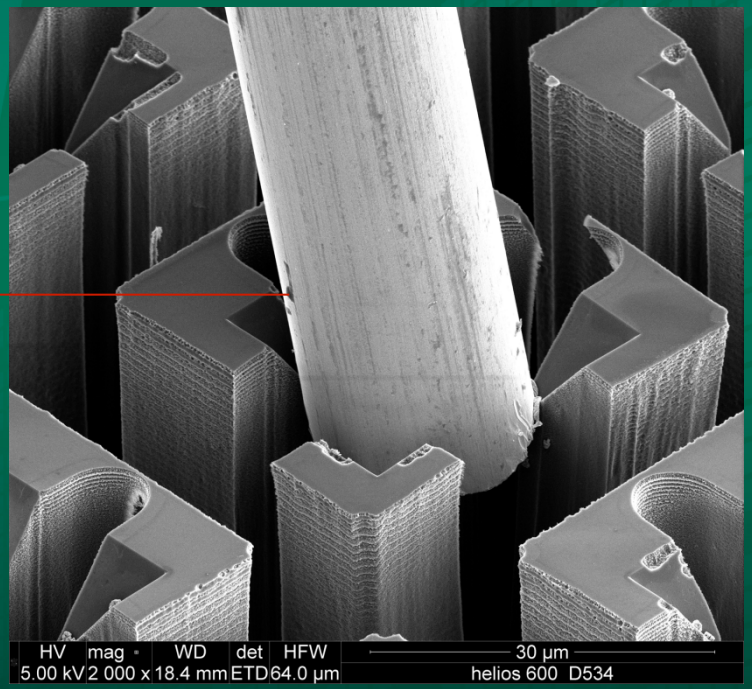


Probe Overtravel Experiment (3)

More than 5µm overtravel have been achieved.

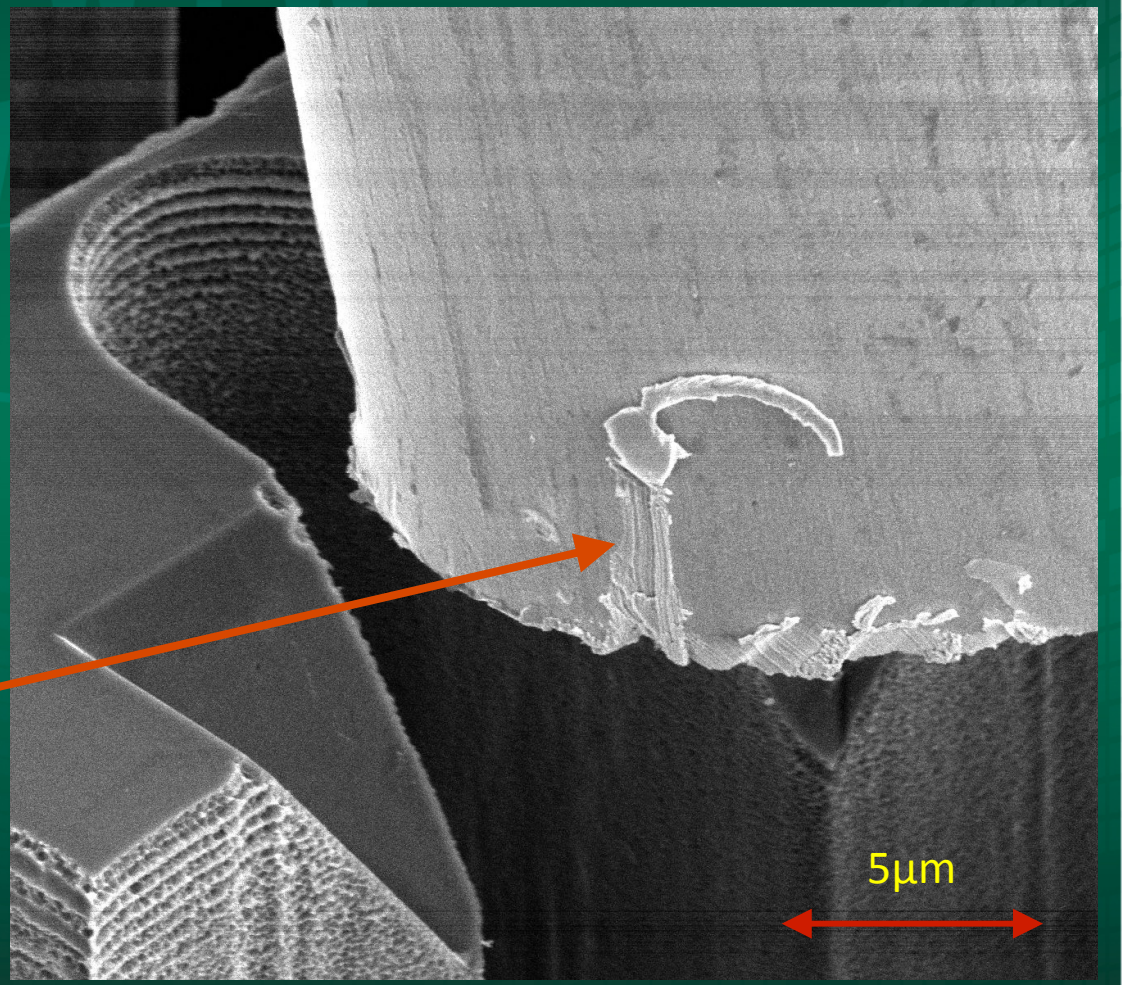


>5µm



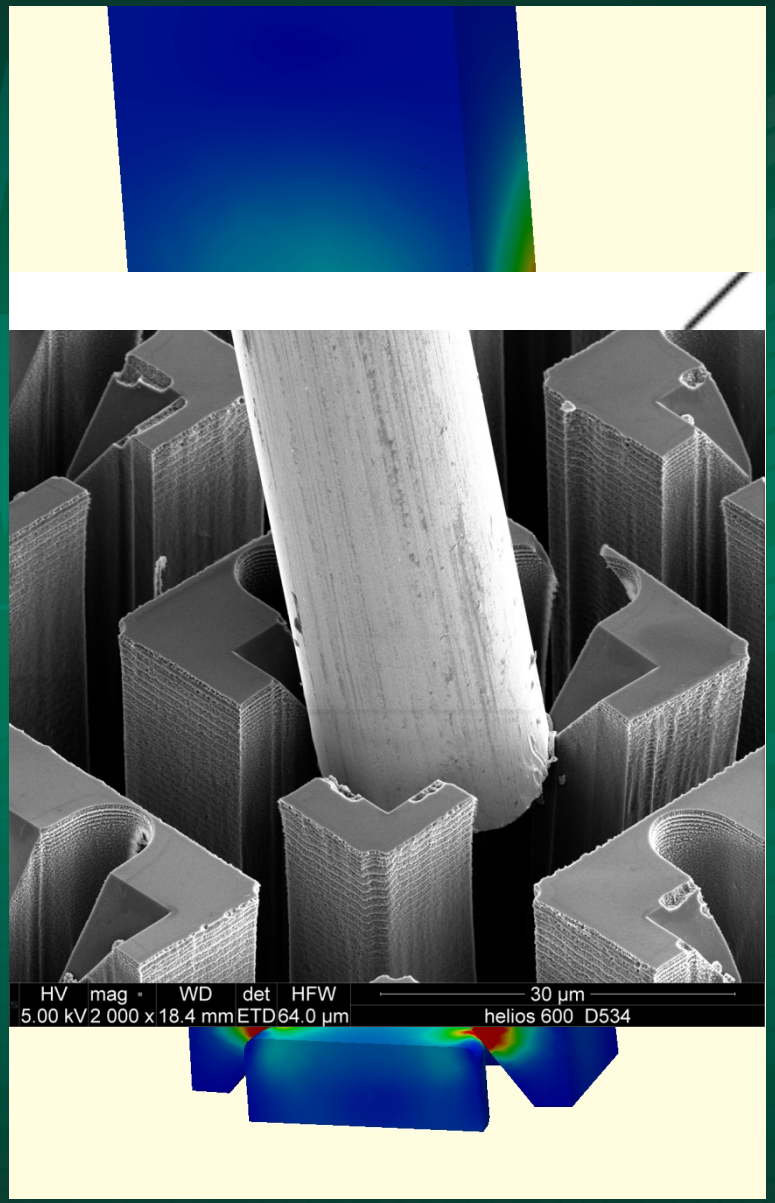
Probe Overtravel Experiment (4)

Tiny scrub marks for good contact @ low damage.



Summary

- Ø15-25µm µbumps for die2die bonding
- Special crown tip for min. pad damage
- Technology demonstrator: 100 needles @ 50µm pitch
- Two step spring system
- High precision probe station
- First tests of probe overtravel done
- Future capability: 20µm pitch



Outlook

- Real wafer probing at IMEC on Demonstrator-Probe Station
- Wafer bonding experiments
- Evaluation of reliability and cleaning
- Determination of RF properties

Acknowledgements

Georg Steidle FEINMETALL	-	probe head design, assembly, force measurements
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Bart De Wachter IMEC	-	test set-up, test program, experiments
Jens Fiedler, Michael Teich, Juliane Busch, Gavin Fisher Cascade Microtech	-	prober setup and experiments
Klaus Kölle, Erwin Hacker, Werner Muth Fraunhofer-EMFT	-	Layout, Lithographie

References

[1] Rod Martens; Formfactor;
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http://www.swtest.org/swtw_library/2002proc/PDF/S05_01.pdf

[2] Senthil Theppakuttai, Bahadir Tunaboylu; SV-Probe;
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http://www.swtest.org/swtw_library/2010proc/pdf/s08_01_theppakuttai_swtw2010.pdf

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Thank You.

Gunther Boehm
FEINMETALL
Herrenberg, Germany
www. feinmetall. de
g.boehm @ feinmetall.de