3D stacked MEMS and ICs in a miniaturized sensor node

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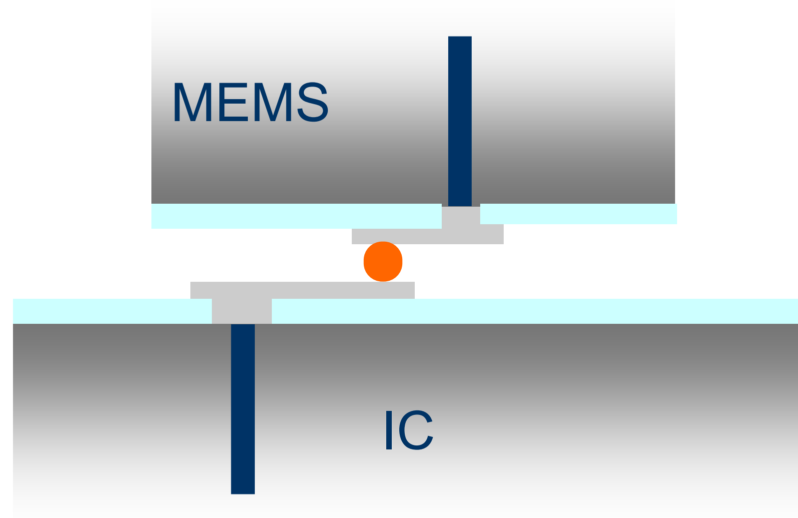
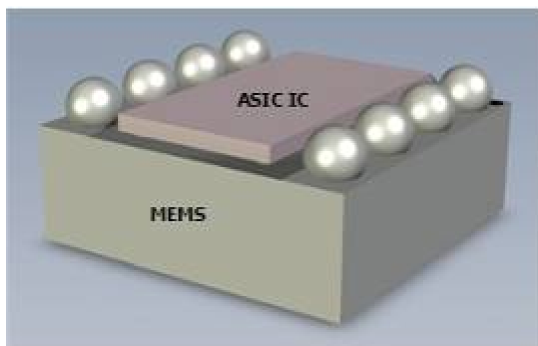
Outline

- Solutions for through silicon vias
- Solutions for interconnects
- Demonstrator for e-CUBES
  - Background for selections
  - Challenges
  - Final results
- Summary

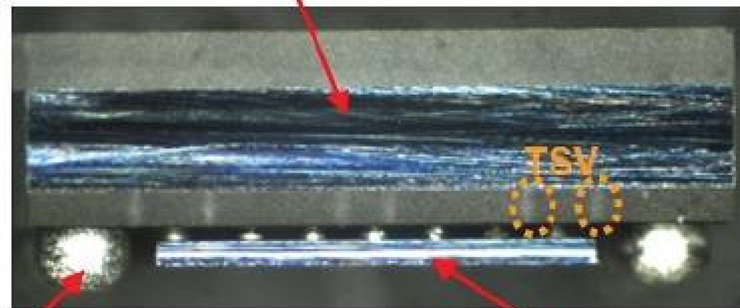


Wafer level packaging (WLP)

- More than wafer level encapsulation
- No wire bonds
  - Through Silicon Vias (TSVs) required
  - Interconnects defined on wafer level
- Ready for surface mounting after final dicing

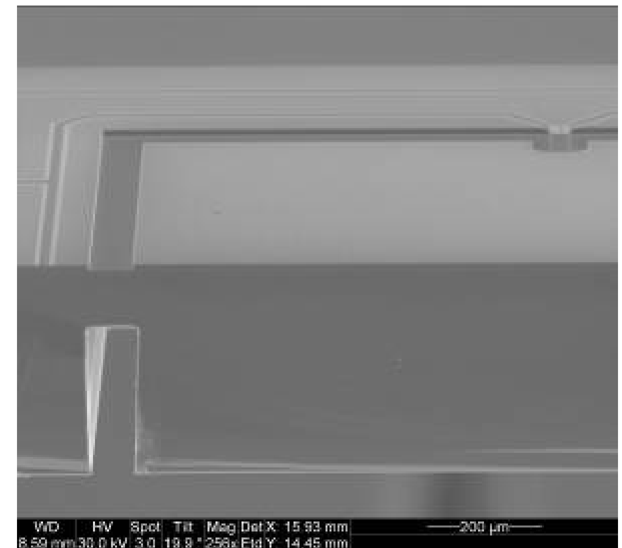


Source: VTI



TSVs for MEMS

- Restrictions for typical MEMS wafers
  - Application specific mass/volume/dimensions
  - Inlets/released structures
  - Fragile structures
  - Functional materials with temperature limitations
- Process steps for TSVs in IC wafers
  - Wafer thinning
    - Grinding
    - CMP
  - Formation of bumps
    - Resist patterning
    - Plating

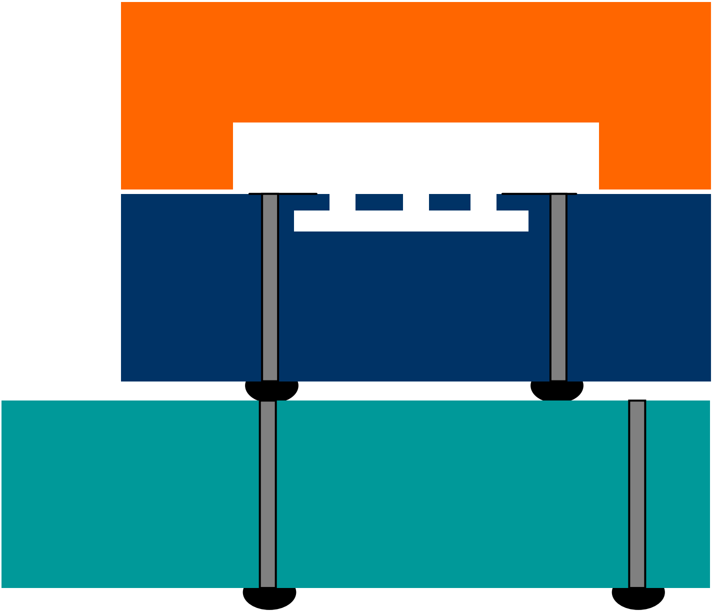


Source: SINTEF

TSVs through which wafer?

MEMS wafer TSVs

Cap wafer TSVs



Interposer TSVs

TSVs for various applications

Wafer thickness (µm): 300, 60, 30

FhG-IZM

Al

2 µm

W-filled TSV

ZyCube

Supporting LSI wafer

1st layer

Adhesive

2nd layer

3rd layer

30 µm

1st layer

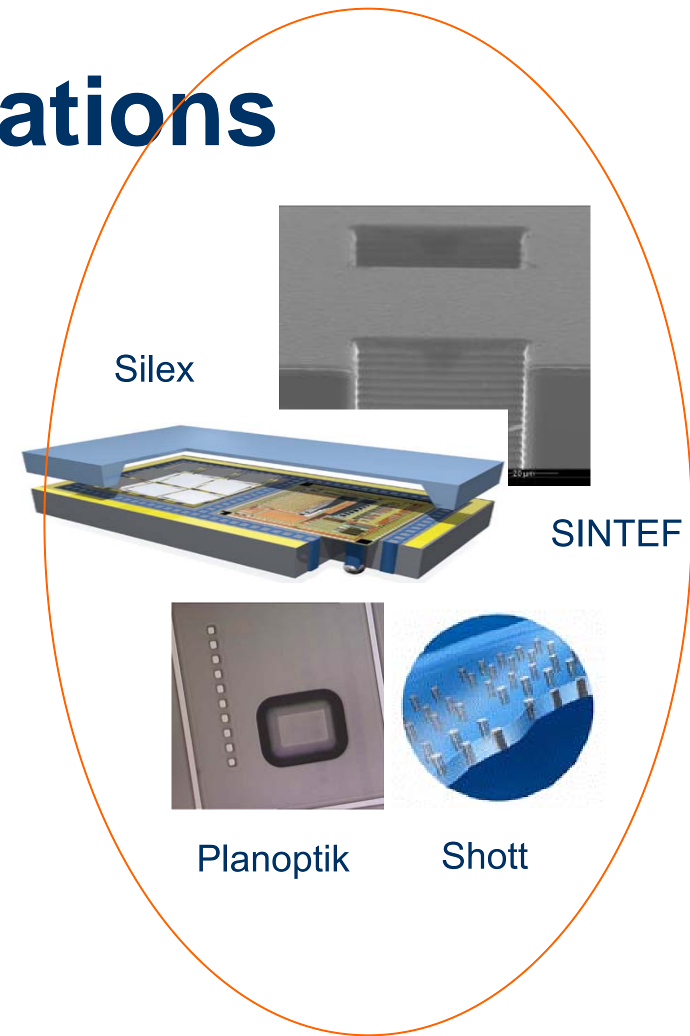
2nd layer

30~50 µm

3rd layer

Honda

Tezzaron

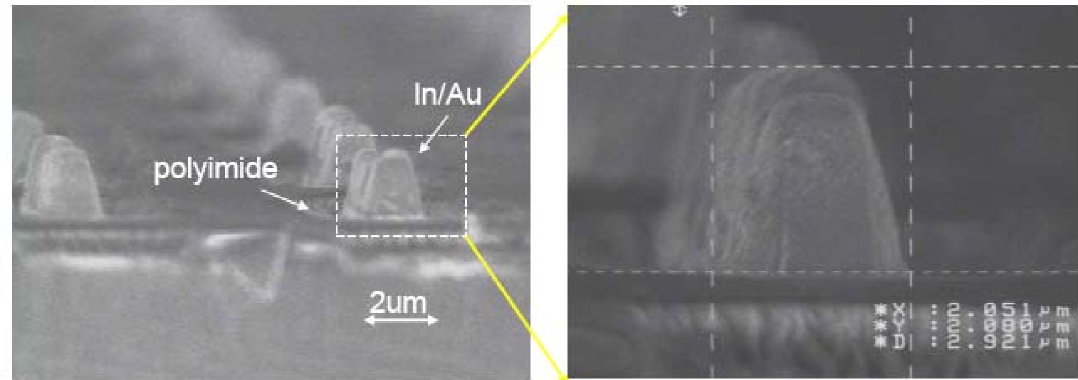


MEMS

Pitch (µm) 30 50 … 100

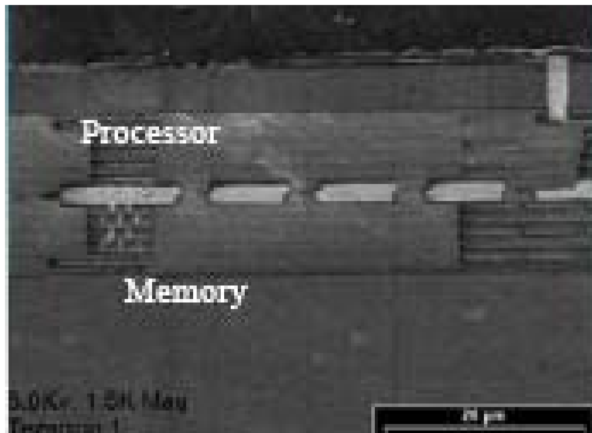
Interconnects in the IC world

Pitch <50 μm, stand-off height ~5 μm
WAFER-WAFER

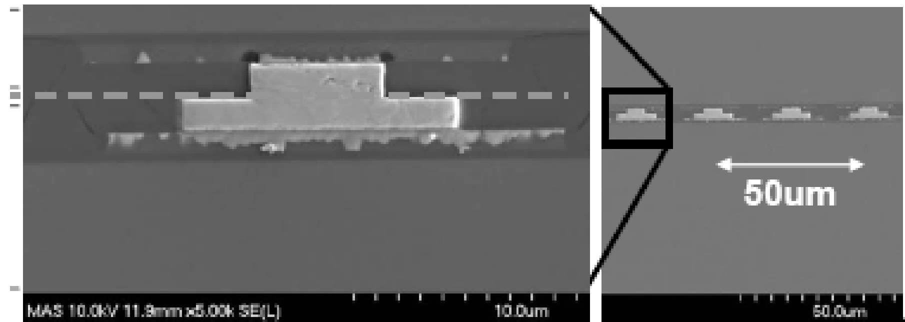


Source: ZyCube

In/Au, Cu, Ni



Source: Tezzaron

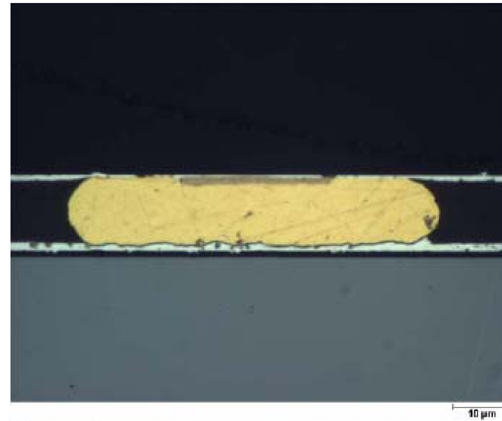


Source: Ziptronix

Interconnects tested for MEMS

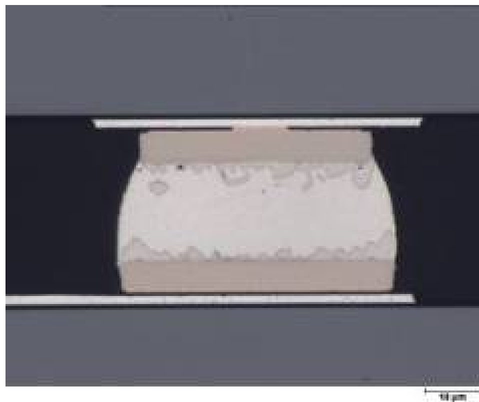
Pitch >50 µm, stand-off height ~10-20 µm
CHIP-WAFER

Au stud bump bonding (SBB)



Source: SINTEF/Datacon

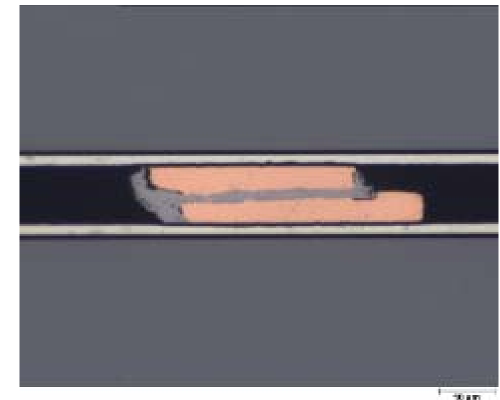
SnAg/AuSn microbumps



Source: SINTEF/Fraunhofer IZM-Berlin

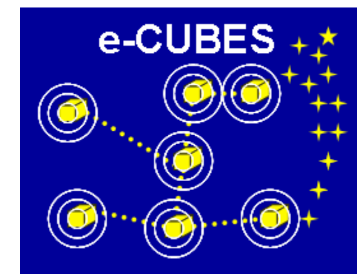
Au, Cu/Sn, SnAg, AuSn

Cu/Sn SLID

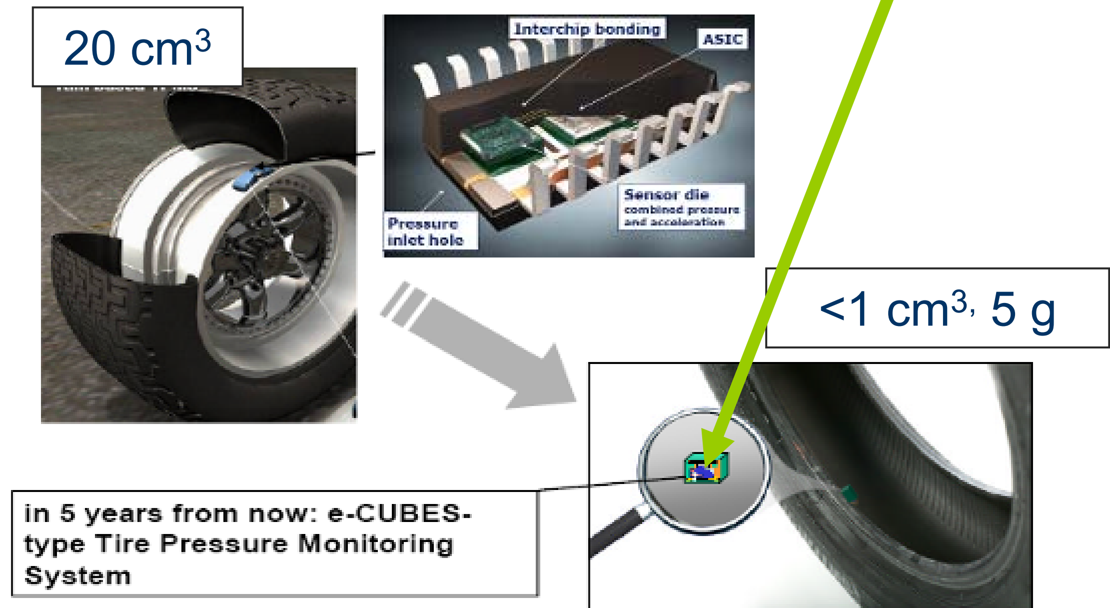


Source: SINTEF/ Fraunhofer IZM-Munich

e-CUBES TPMS demonstrator

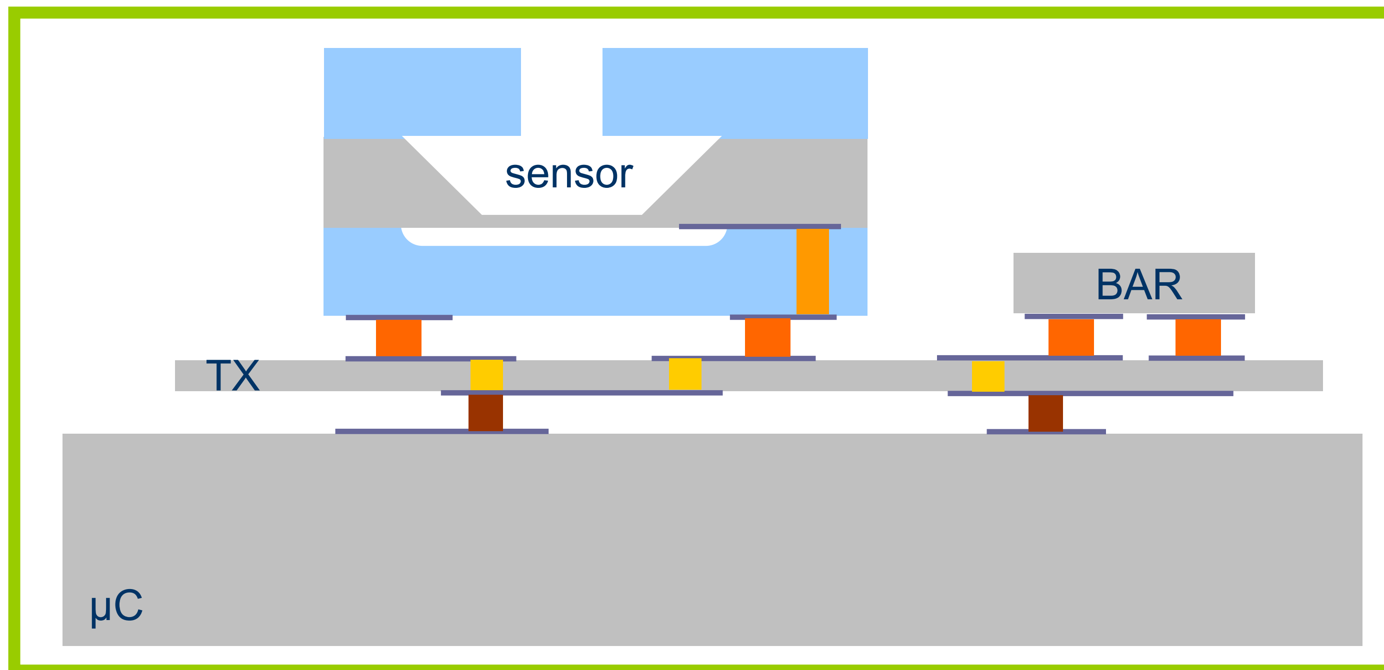


- Develop wireless sensor networks with miniaturized sensor nodes
- 3 demonstrators
  - Health and fitness
  - Aeronautics and space
  - Automotive
    - Tire Pressure Monitoring System (TPMS)



TPMS building blocks

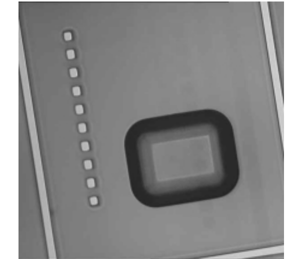
- µ-controller ASIC (µC) : 4.3 x 3.8 mm^2 (WAFER)
- Transceiver ASIC (TX): 3.8 x 3.3 mm^2
- MEMS pressure sensor: 1.8 x 2.1 mm^2
- MEMS bulk acoustic resonator (BAR): 0.8 x 1.3 mm^2
  - Antenna, battery, outer package



Technology choices

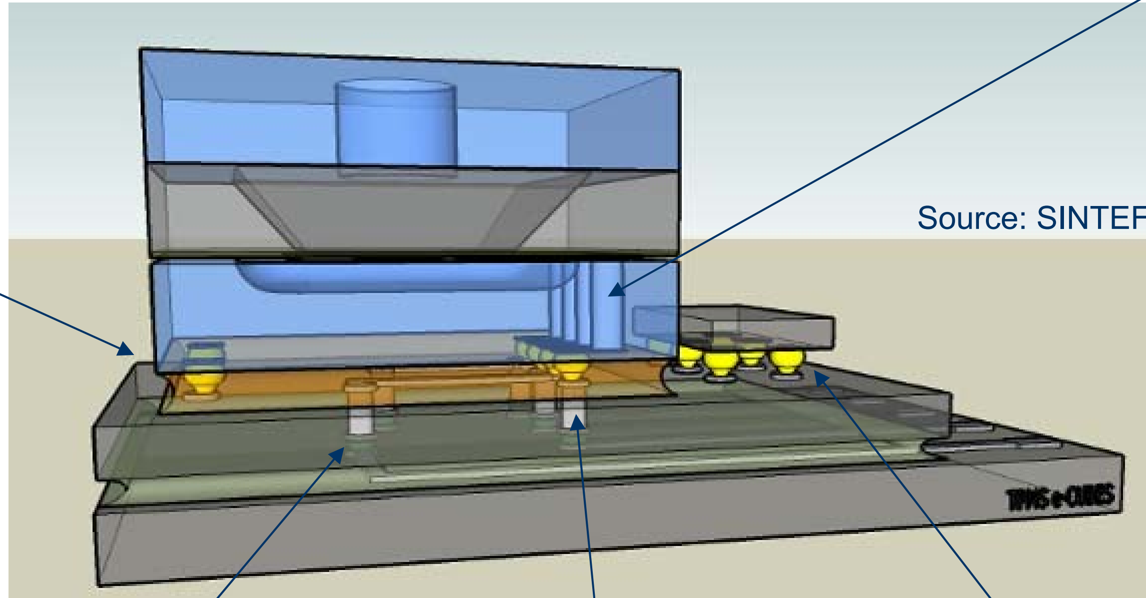
Silicon-glass compound wafer with TSVs

TSVs



Source: SINTEF/ SensoNor/ PlanOptik

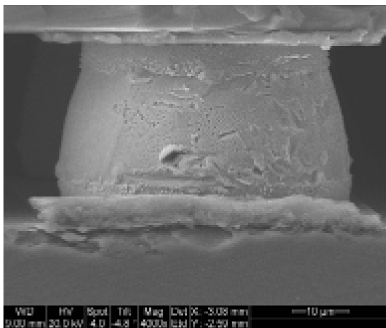
Au stud bumps with adhesive



SnAg microbumps and underfiller

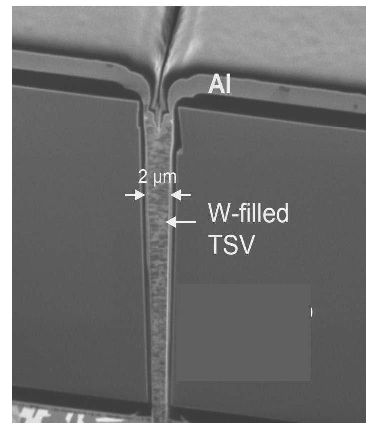
TSV with W

Au stud bumps only



Source: SINTEF/ FhG IZM- Berlin

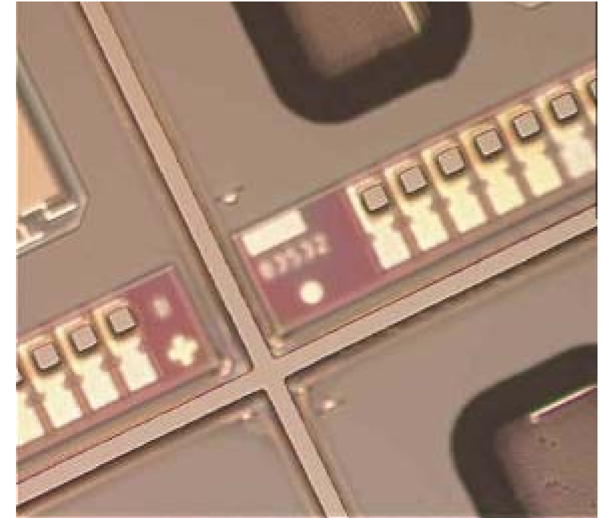
Source: Fraunhofer IZM-Munich



Source: Kulicke & Soffa

Arguments for the chosen TSVs

- Post BEOL W-filled vias for the middle IC (60 μm)
  - ASIC wafer already mainly designed
  - Metal regions could be cleared
  - Less stress than Cu

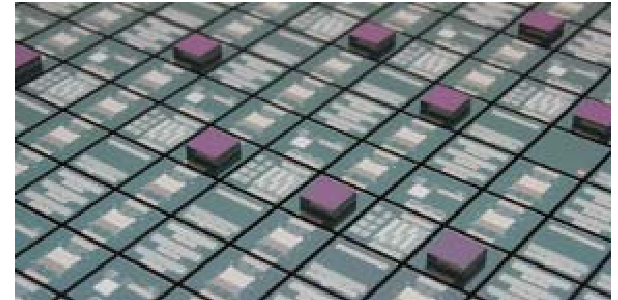


Source: SensoNor

- Silicon glass compound wafers for MEMS (300 μm)
  - Hermetic vias and hermetic seal to sensor wafer
  - Limited requirements for conductivity
  - Symmetric glass/Si/glass stack
  - Visual inspection possible
  - Competitors: Hollow vias, Silex (W in glass)
    - Silicon wafers ÷
    - More complicated bonding for hermetic seals ÷

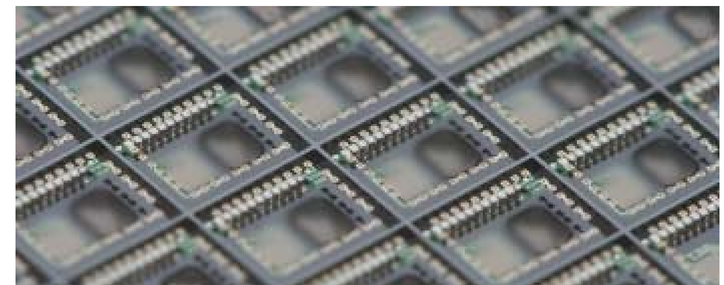
Arguments for the chosen interconnects

- SnAg microbumps for the two ICs
  - Well controlled stand-off height
  - Cost-effective for high I/O count
  - Reliable after post processing
    - *R. Johannessen, MMV Taklo, MF Sunding (2009). SnAg Microbumps for MEMS-based 3D Stacks. IEEE Transactions on Advanced Packaging*
  - Competitors: SLID, AuSn microbumps



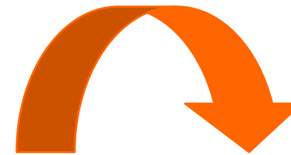
Source: SINTEF

- Au SBB for the MEMS
  - No need for UBM/passivation
  - No wet processing
  - Serial process, cost-effective for low I/O counts, flexible
  - Competitors: SnAg/AuSn microbumps, SLID



Challenges during stacking

- Combination of designs from various sources
  - Flipping, mirroring…
- Surface topographies
  - Crossing of critical lines
  - Coils for communication

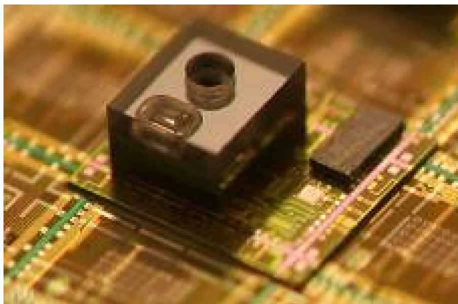


- Placement of dummy bumps for mechanical stability and heat removal
- Gradually reduced process temperatures throughout stacking sequence
  - Avoid degradation of previous bonds (260°C → 200°C)
- Mechanical pressure onto stack, planarity requirements
- Dicing and wire bonding of "Manhatten"

TPMS demonstrator results

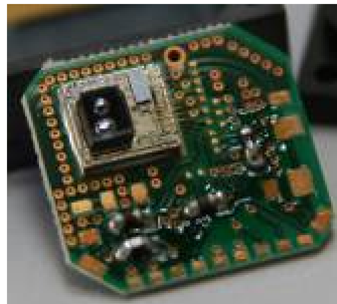
- Successful measurements after mounting on PCB
  - Communication with TX
  - Communication with µC
  - BAR is running at correct frequency
- Sensor performance to be measured soon

MEMS / TX / µC 3D stack

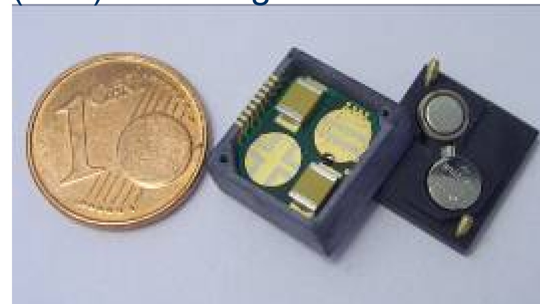


Source : SINTEF

Micro-PCB



Molded Interconnect Device (MID) with integrated antenna



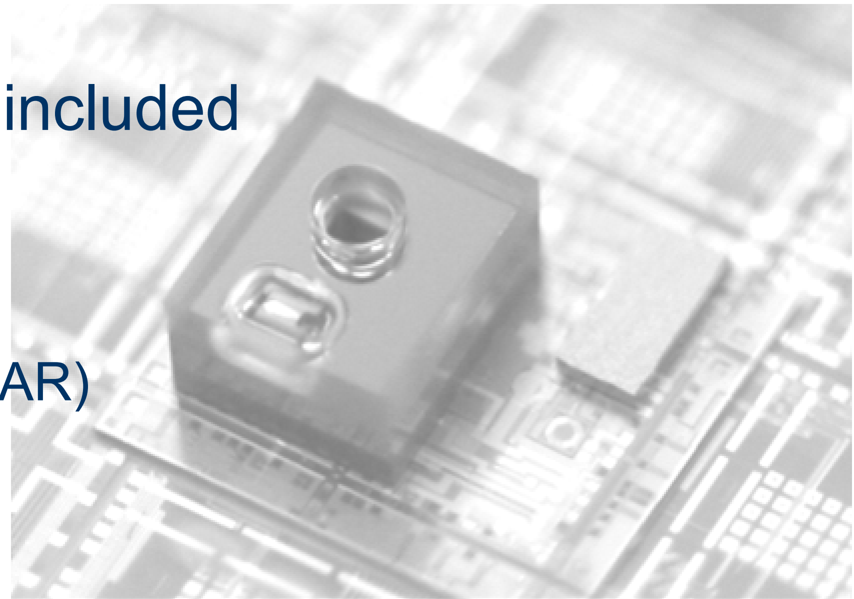
Miniaturized TPMS ~ 1 cm^3

Source : Infineon Technologies

Summary

- A TPMS demonstrator was realized using 3D stacking technologies
- Chip-to-wafer bonding
- Three layers

- Two MEMS devices were included
  - Pressure sensor
    - Silicon TSVs in glass
    - Au SBB with adhesive
  - Bulk acoustic resonnator (BAR)
    - No TSVs
    - Au SBB without adhesive



Acknowledgements

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- Gerhard Hillmann, Datacon Technology GmbH
  - For providing the chip to wafer bonding service and process development