

Temporary Wafer Bonding - Key Technology for 3D-MEMS Integration

2016-06-15, Chemnitz

Fraunhofer ENAS
System-Packaging (SP)
Back-End of Line (BEOL)



Outline

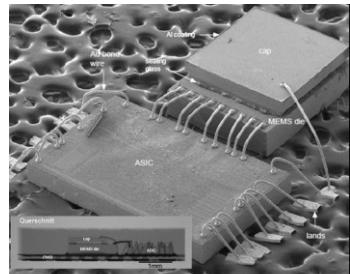
- 3D-MEMS integration
 - Motivation and challenge
 - Main processes for 3D-MEMS integration
- Temporary wafer bonding
 - Method (zone bonding process)
 - Device and carrier wafer preparation
 - Adhesive wafer bonding
 - Wafer de-bonding
- Summary and Outlook

3D MEMS Integration

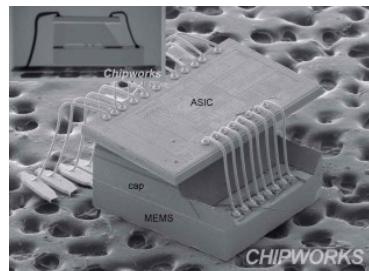
Motivation

- New applications, different functionalities and interaction with environment

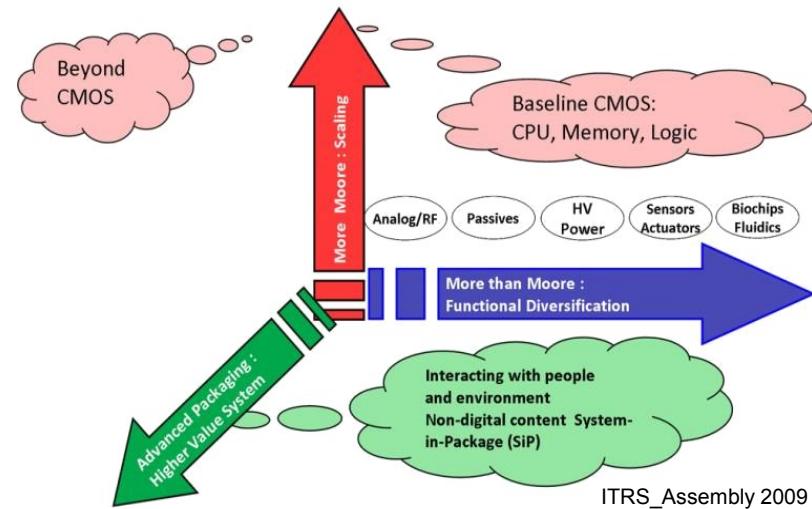
→ **Demand for Smart Systems**



Analog Devices lateral

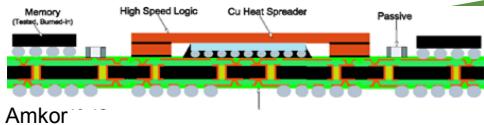


Bosch vertical

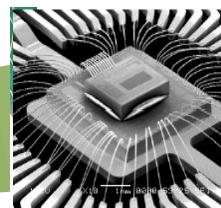


From lateral to vertical integration

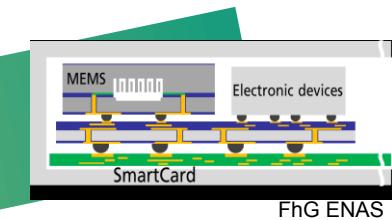
- Vertical Integration improves the driving factors: size, cost, speed and power consumption



Amkor



FhG IZM

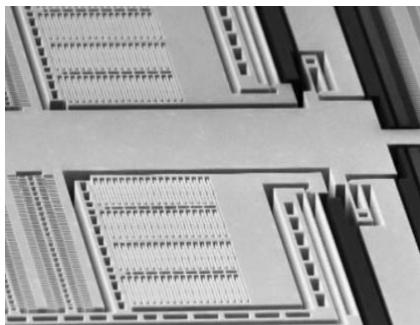
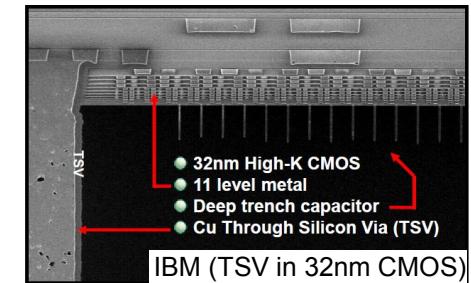
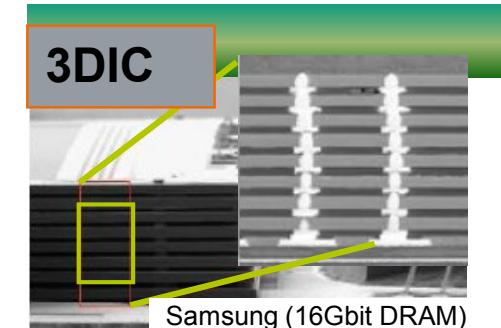


FhG ENAS

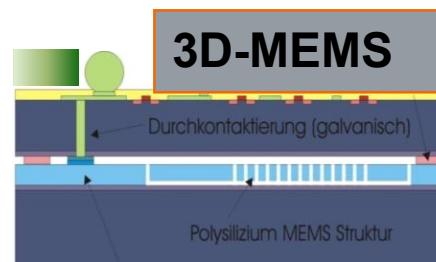
3D MEMS Integration Challenge

Challenge compared to "3DIC"

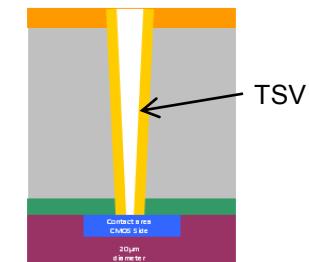
- Functionalities (optic, mechanic, fluidic + electronic)
- Different technologies, materials and substrates (e.g. silicon, ceramic, glass, metal, polymers)
- Sensible components, hermetical packaging
- TSVs with high aspect ratio and large dimensions
- No Standard solution → depending on the application



MEMS: micromechanics



Principle of integrated MEMS
(Sensor + ASIC/Cap)



CMOS based on Image Sensor with HAV TSVs

3D MEMS Integration

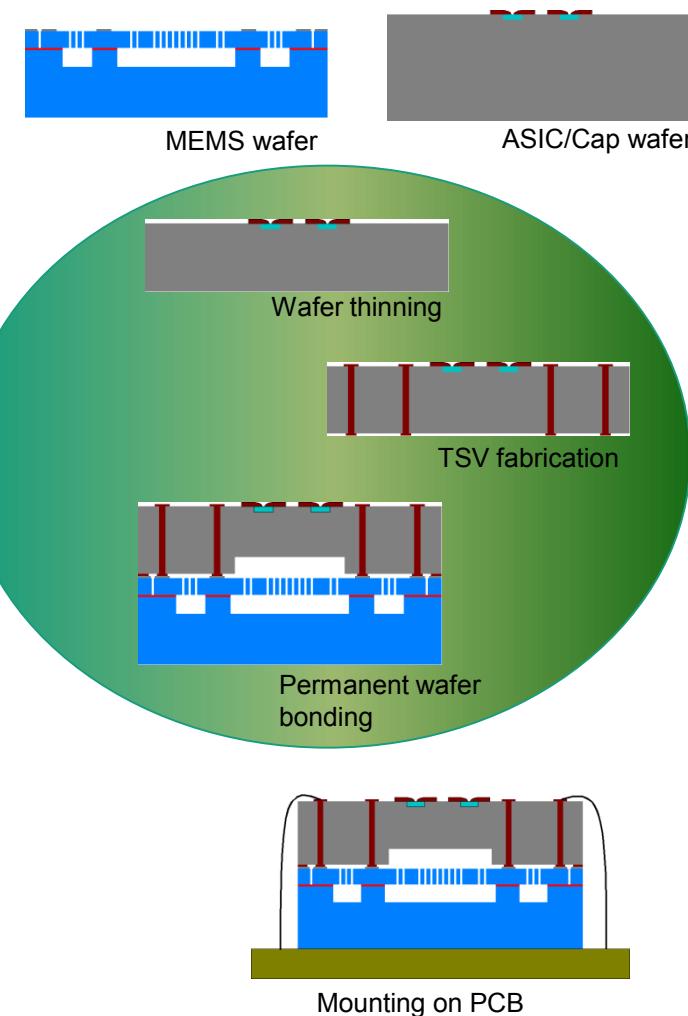
Main process steps

Principle

- Combination of different devices (MEMS+ASIC/Cap)
- Creation of miniaturized system

Main processes

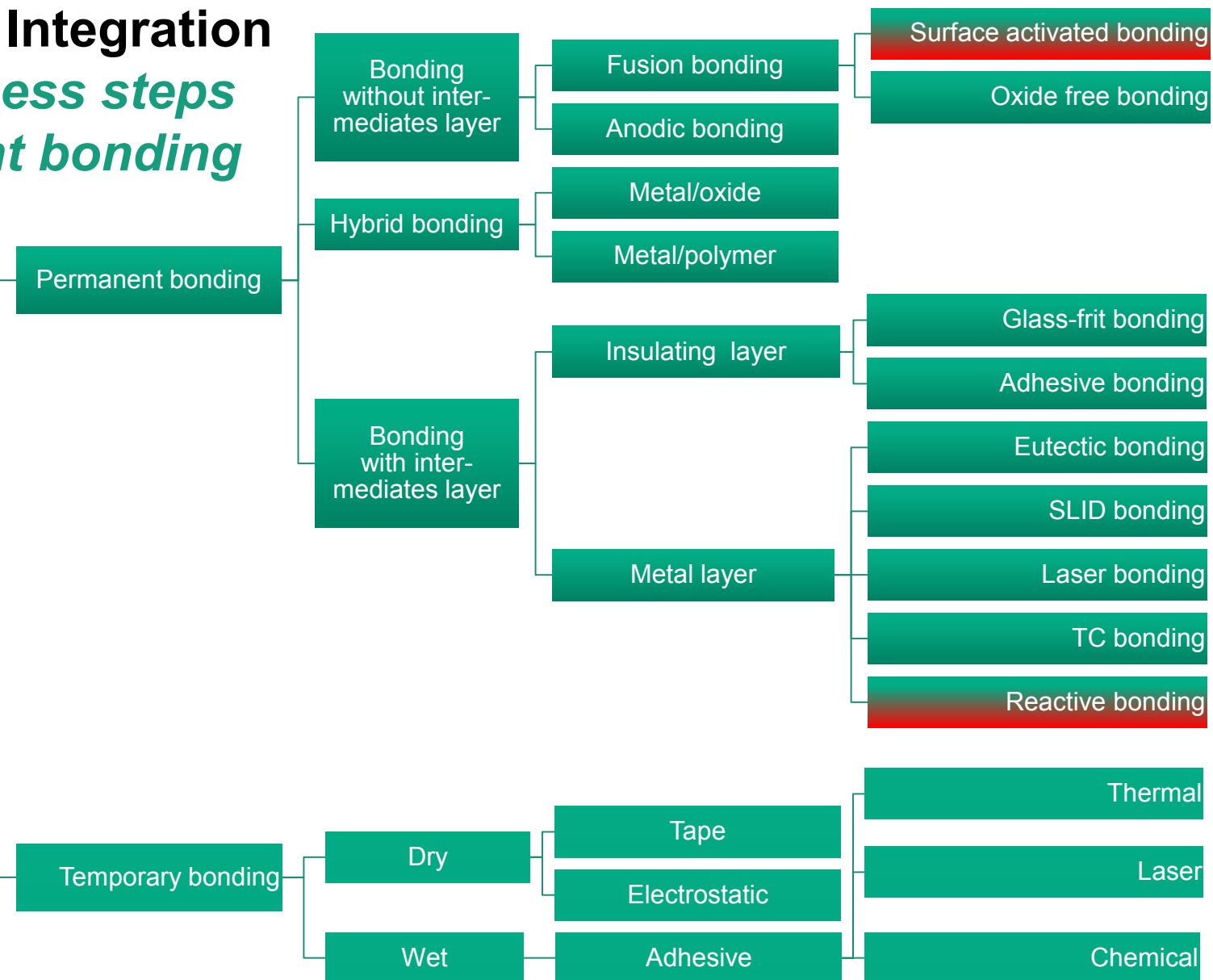
- Wafer thinning
 - Form factor/ TSV depth reduction
- Fabrication of through substrate vias (TSVs)
 - TSV etching, isolation and fill with conductive material
- Permanent wafer bonding
 - Realization of mechanical + electrical contact including other functions (e.g. hermiticity, ...)



3D MEMS Integration

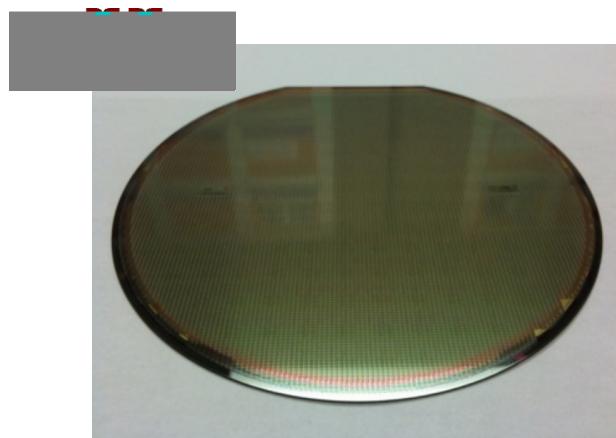
Main process steps Permanent bonding

Wafer bonding

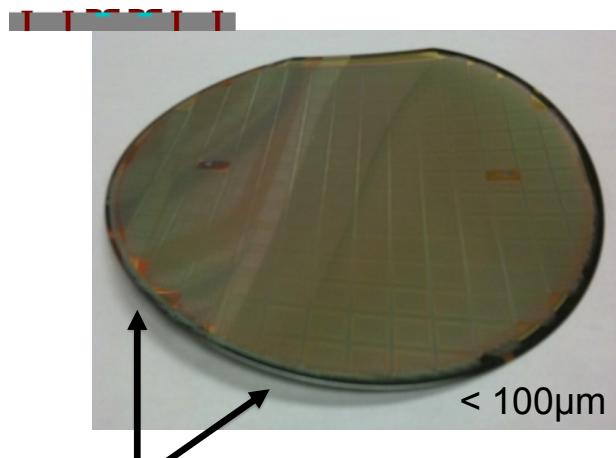


Temporary wafer bonding - key Technology for 3D-MEMS

Motivation



Source: FRT of America LLC



Extreme wafer deflection

- 3D integration required wafer thinning
- Thinned wafer: low stability, low bending stiffness and fragile
- Required temporary mechanical wafer support
 - Solution: temporary wafer bonding to fixed the device to support wafer
 - Established method in 3D IC

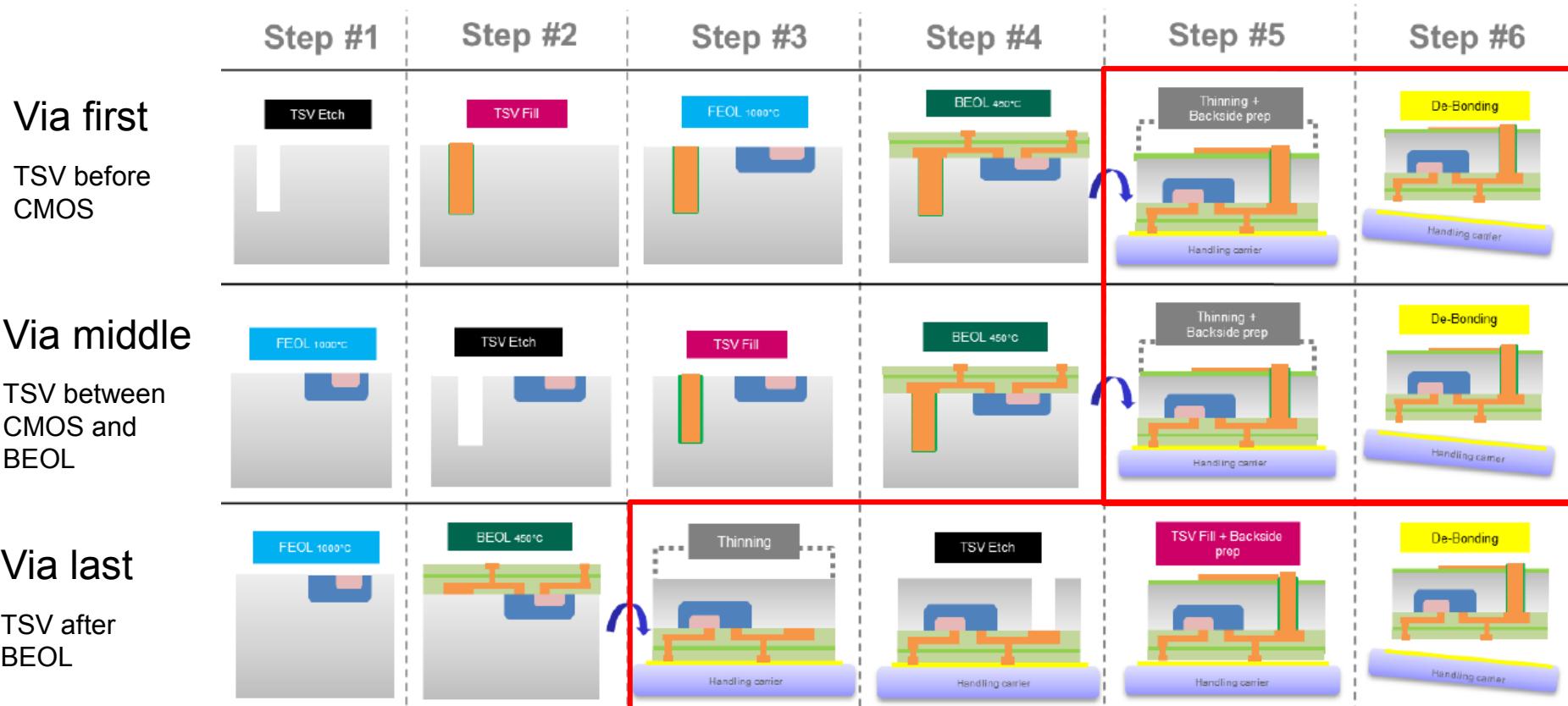


Source: ITRI

Temporary wafer bonding - key Technology for 3D-MEMS

Motivation

- Temporary wafer bonding technology important in 3D-IC:



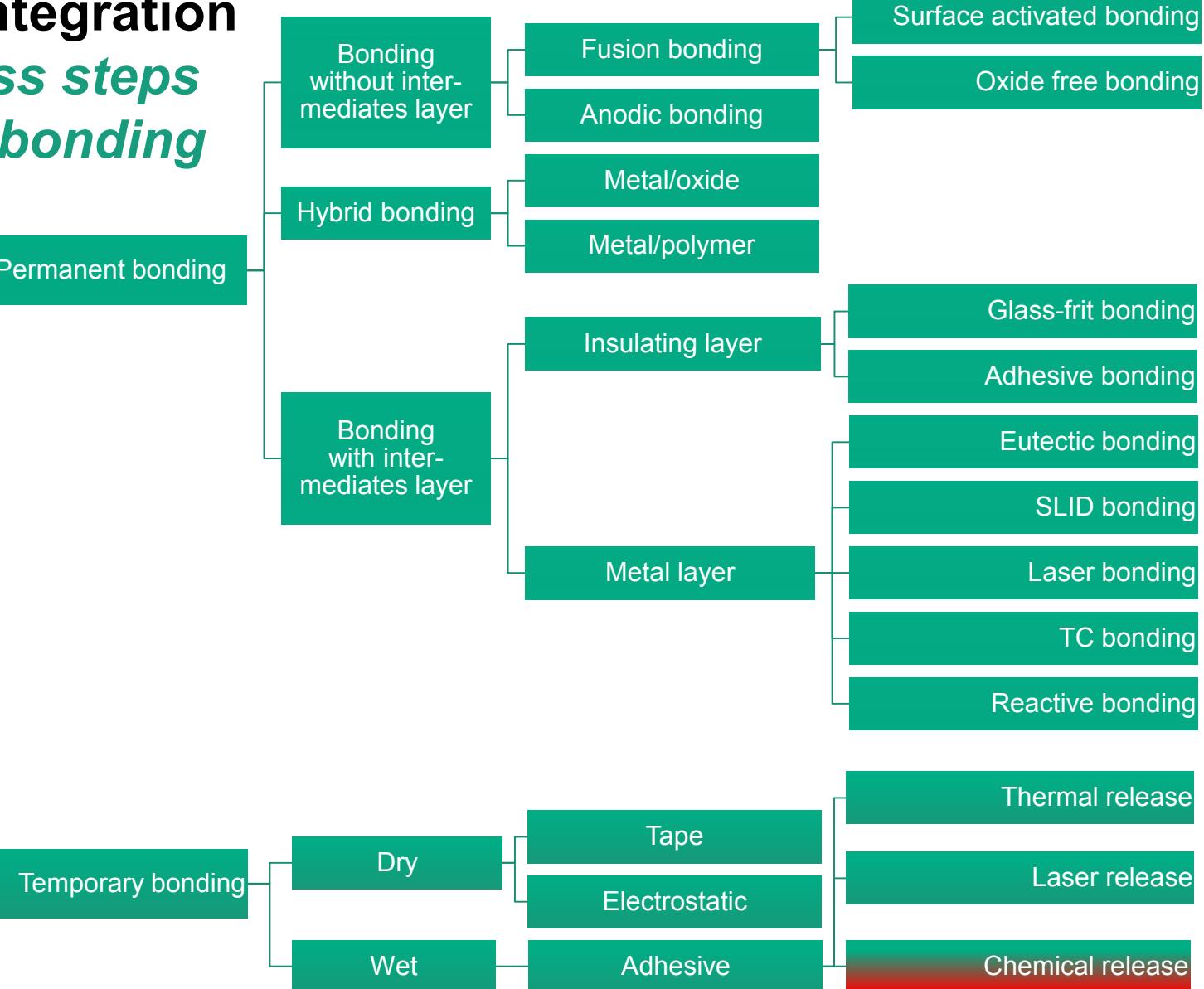
Source: Yole 2014

3D MEMS Integration

Main process steps

Temporary bonding

Wafer bonding



Temporary wafer bonding - key technology for 3D-MEMS

Methods

Various methods are available with different requirements for thermal, chemical and mechanical stress



Traditional methods:

- Thermal slide, laser release

Trend:

- Chemical release with room temperature de-bonding (peel-off)
- **Two different zones (zone-bonding)**



ENAS:

Brewer science ZoneBond® technology with temporary adhesive wafer bonding process

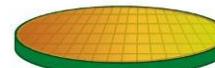
Temporary wafer bonding - key technology for 3D-MEMS

Zone-Bond® technology



Main process steps:

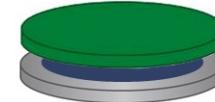
■ Preparation device wafer



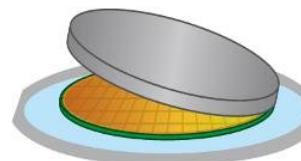
■ Preparation carrier wafer



■ Adhesive wafer bonding



■ Wafer de-bonding

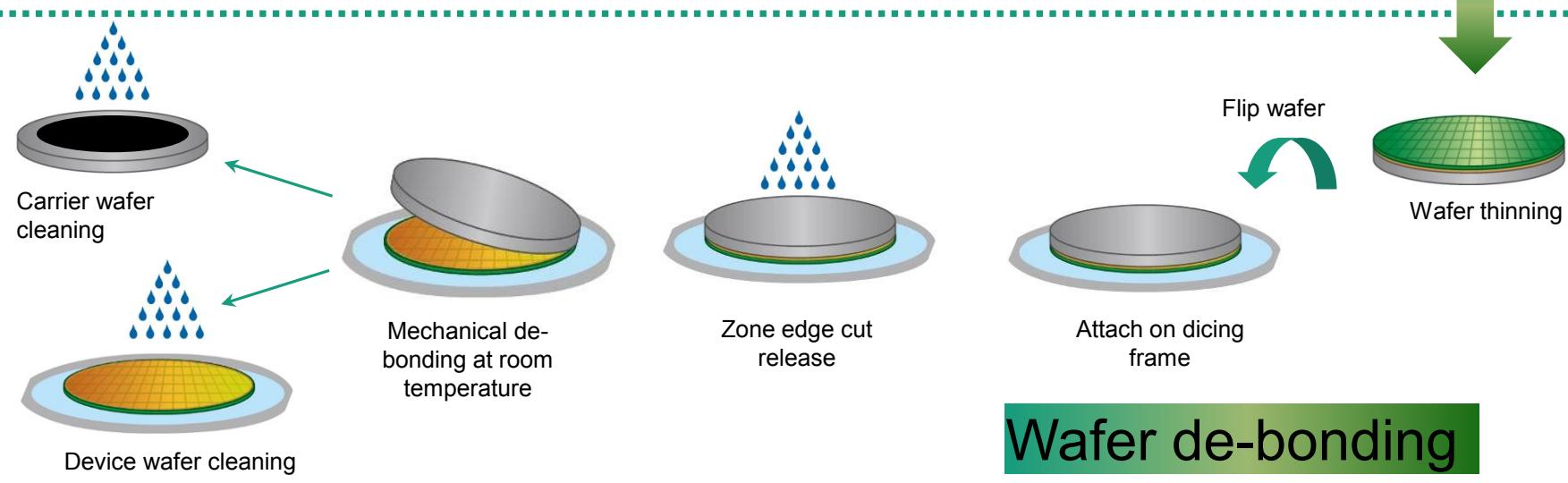
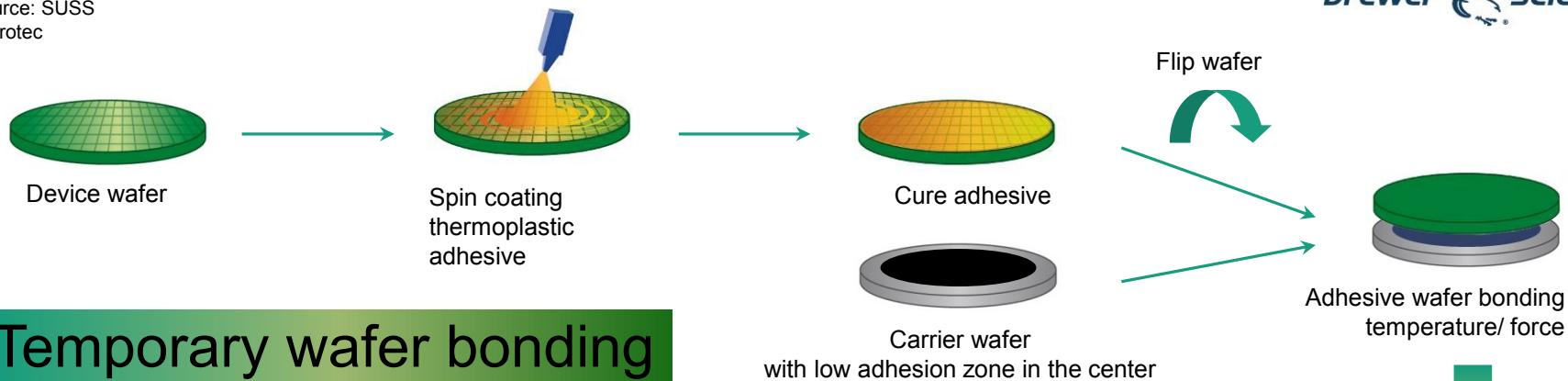


Temporary wafer bonding - key technology for 3D-MEMS

Zone-Bond® technology

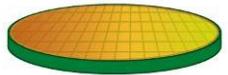


Source: SUSS
microtec



Temporary wafer bonding - key technology for 3D-MEMS

Device wafer preparation



- Preparation device wafer (100-200mm) with spin on process using SUSS RCD8 coating system (including hotplate)
- Spin on process with thermoplastic adhesive (ZoneBOND™ 5150), started in wafer center → high viscosity: 10000cp, layer thickness: 15-30µm
- Cure adhesive: 230°C, 2min

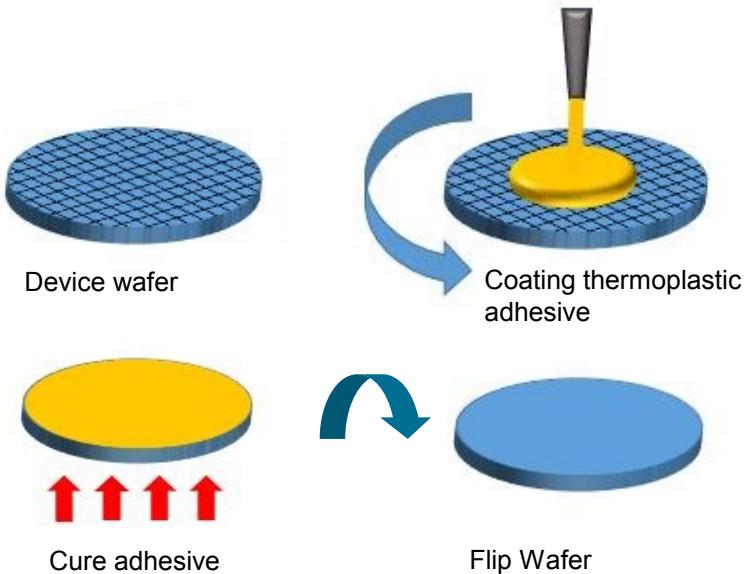


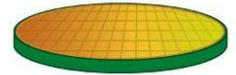
Fig.: process flow device wafer preparation



Fig.: SUSS hotplate HP8
und coating System RCD8

Temporary wafer bonding - key technology for 3D-MEMS

Device wafer preparation



- Layer thickness depends on vacuum chuck rotating speed
→ Thickness 15-30µm required rotating speed of 1000-2000 R/min
- Dispensing quantity: 5-10ml

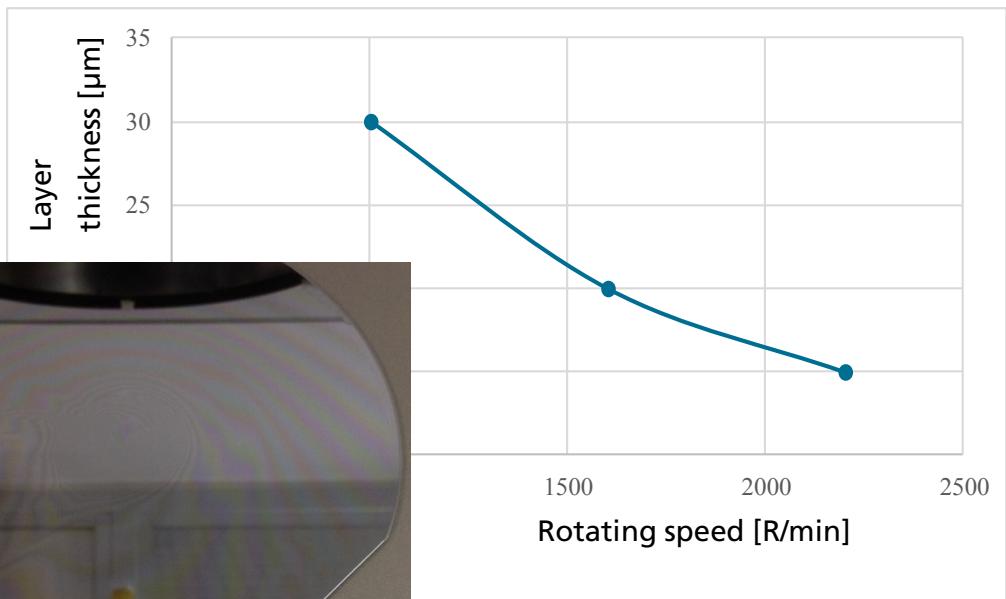
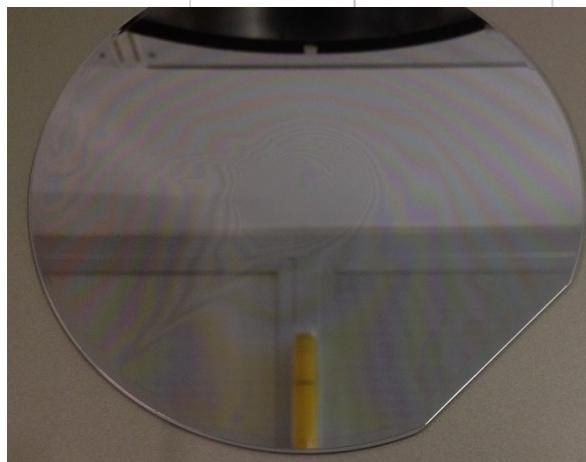
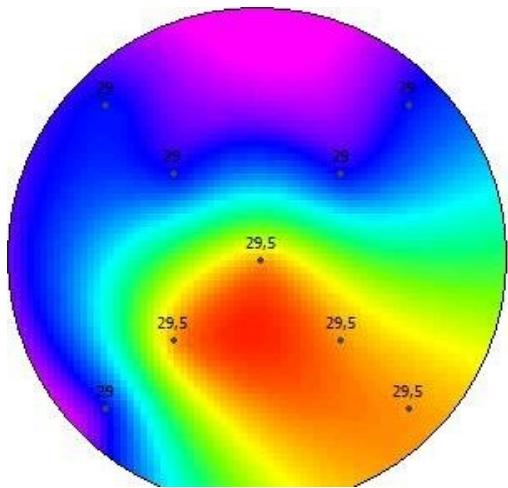


Fig.: layer thickness in dependence on the rotating speed

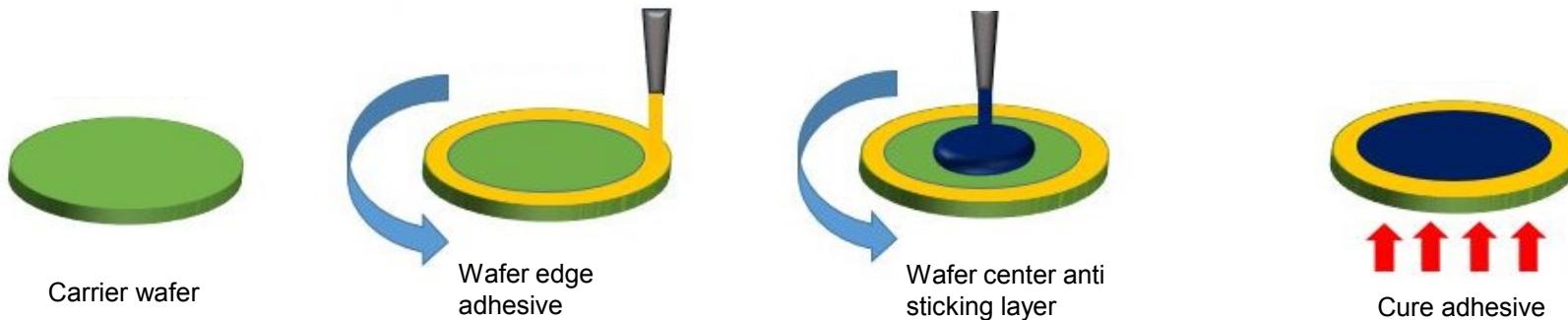
Fig.: measured layer thickness (30µm) and homogeneous coated wafer

Temporary wafer bonding - key technology for 3D-MEMS

Carrier wafer preparation



- Preparation carrier wafer (100-200mm) using SUSS RCD8 coating system (including hotplate)
- Dispensing adhesive (ZoneBOND™ EM 2320) on wafer edge
 - Medium viscosity: 400cp, layer thickness: 0.5-3µm
 - Cure adhesive: 220°C, 2min
- Dispensing anti-stick layer (ZoneBOND™ Z1 3500-02) on wafer center
 - Low viscosity: 50cp, layer thickness: 1.5-3nm



Temporary wafer bonding - key technology for 3D-MEMS

Carrier wafer preparation



- Layer thickness depends on vacuum chuck rotating speed and dispensing quantity
 - Layer thickness of 2µm required rotating speed of 300 R/min with dispensing quantity of 1-2ml
- Adhesive edge width: 1.5mm

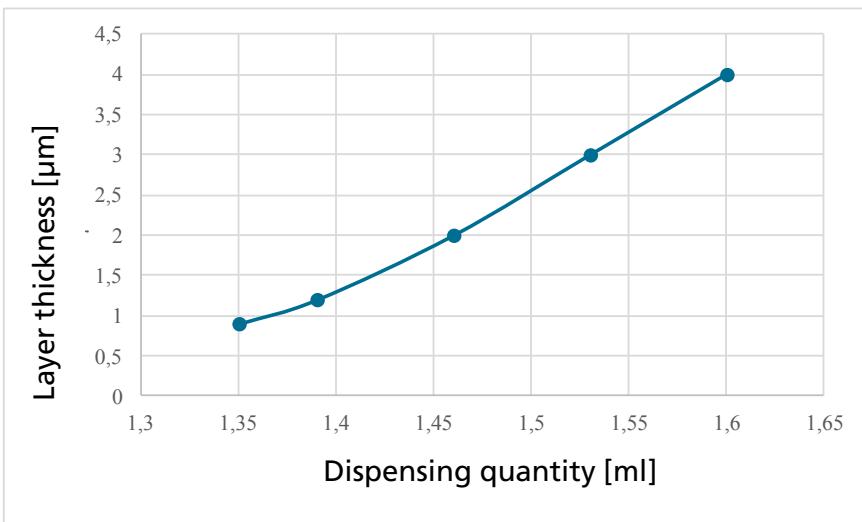
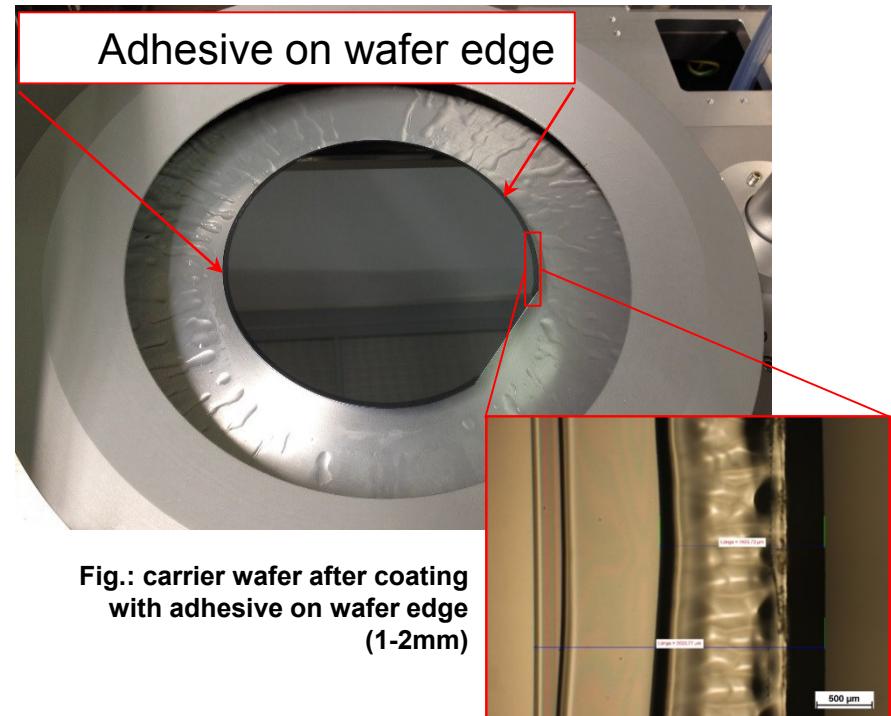
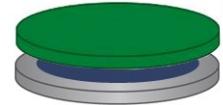


Fig.: layer thickness in dependence on the dispensing quantity with constant rotating speed 300R/min



Temporary wafer bonding - key technology for 3D-MEMS

Adhesive wafer bonding



- Adhesive wafer bonding of device and carrier wafer
- Equipment: wafer bonding system SB8e (company SUSS MicroTec)
- Process parameter:
 - Temperature: 200°C
 - Time: 2min
 - Bonding force: 170 kN/m²
- Forming of two different zones
 - Fragile adhesive region (zone 1)
→ wafer center
 - Strong adhesive region (zone 2)
→ wafer edge

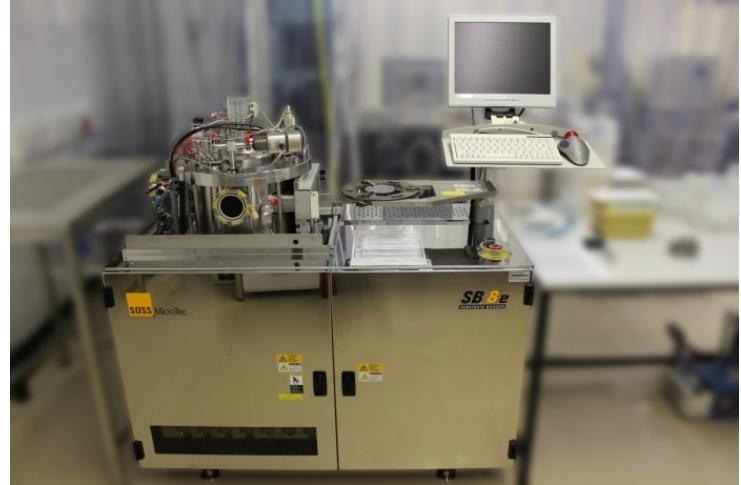


Fig.: Wafer bonding system SB 8e

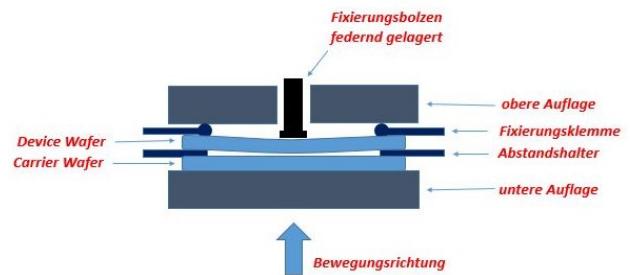
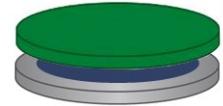


Fig.: Schematic drawing regarding adhesive wafer bonding in the SB8e

Temporary wafer bonding - key technology for 3D-MEMS

Adhesive wafer bonding



Characterization adhesive wafer bonding technology

- Quantitative: IR-Detection
- Qualitative: Compression shear test
 - Fragile adhesive zone 1:
Dicing → Yield < 5%
Bonding strength: 4MPa
 - Strong adhesive zone 2:
Dicing → Yield > 90%
Bonding strength: 8MPa

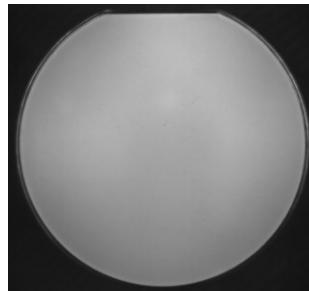
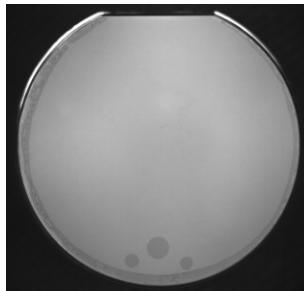


Fig.: IR-Detection after adhesive Wafer bonding
w/o defects

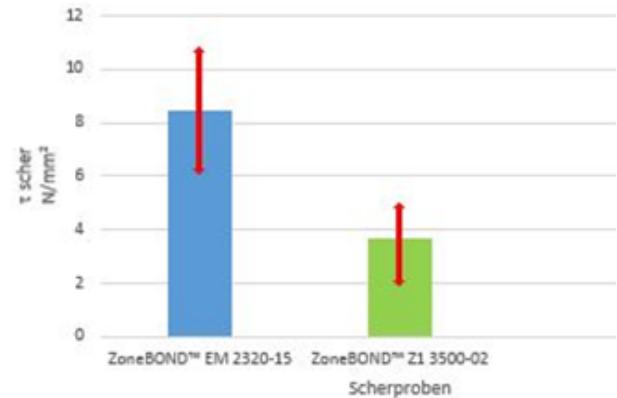


Fig.: Shear strength zone 2 (left) and zone 1 (right)

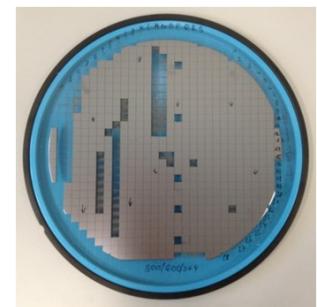
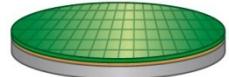


Fig.: Dicing yield zone 1 (left) and zone 2 (right)

Temporary wafer bonding - key technology for 3D-MEMS

Wafer thinning



Wafer thinning

- Wafer size: 100...200 mm
- Material: Si, glass, ceramic...

Grinding

- Disco DAG 810 semi automate
- Final thickness: < 50 µm

Spin etching

- HF/CH₃COOH/HNO₃ chemistry
- Stress release after grinding
- Surface quality: R_a = 4 nm

Chemical mechanical polishing

- IPEC and AMAT Mirra tool
- Surface quality: Ra < 0.5 nm

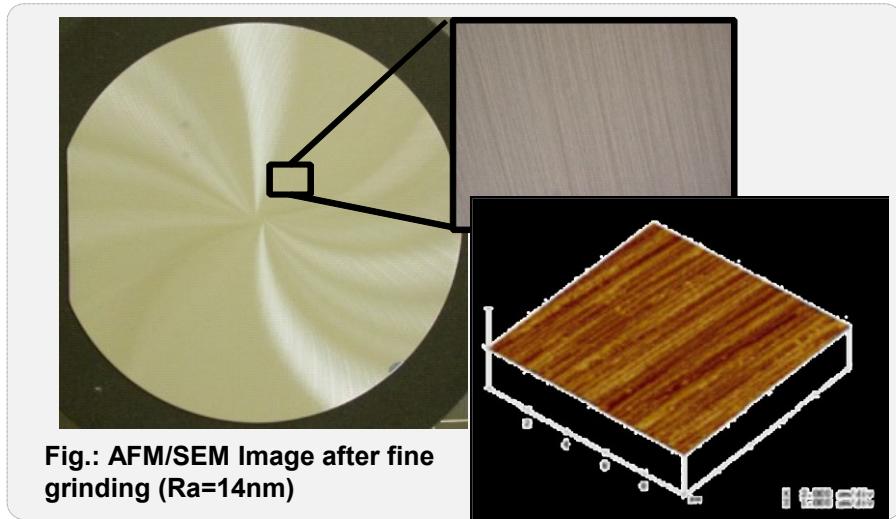


Fig.: AFM/SEM Image after fine grinding (Ra=14nm)

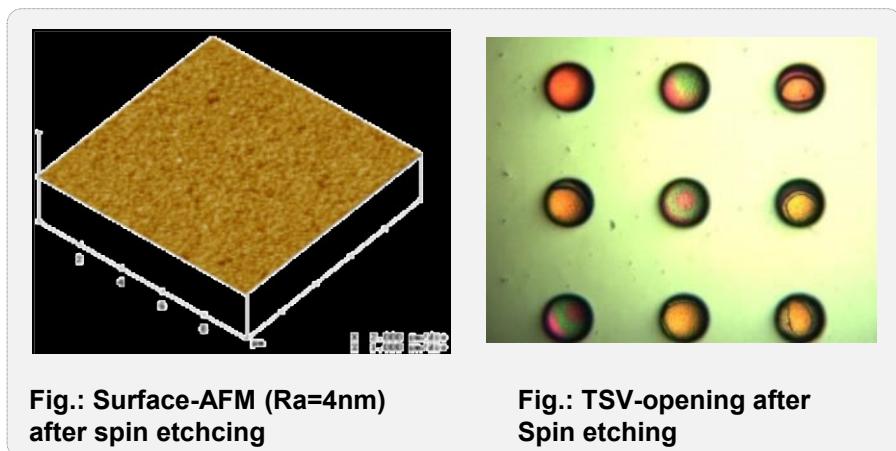


Fig.: Surface-AFM (Ra=4nm) after spin etching

Fig.: TSV-opening after Spin etching

Temporary wafer bonding - key technology for 3D-MEMS

Additional processes

- DRIE etching
- Metallization
- Photolithography
- Wet etching
- Cleaning processes with acids and bases
- ... (Processing temperatures up to 250°C)

Tab.: possible wet chemical processes after adhesive wafer bonding

Solvents	NMP	85 °C	60 min
Acetone	25 °C	25 min	
Cyclohexanone	25 °C	5 min	
Ethyl Lactate	25 °C	30 min	
IPA	25 °C	30 min	
PGMEA	25 °C	5 min	
PGME	25 °C	5 min	
PGME/PGMEA	25 °C	5 min	
Acids	HF:H ₂ O (10:1)	RT	15 min
HNO ₃ :H ₃ PO ₄ :HF (12:8:1)	25 °C	15 min	
H ₂ SO ₄ :HF (20:1)	25 °C	5 min	
Bases	H ₂ O ₂ (35%)	50 °C	60 min
KOH (30%)	85 °C	60 min	
2% TMAH (2%)	80 °C	30 min	

Temporary wafer bonding - key technology for 3D-MEMS

Wafer edge release

- Thinned wafer stack attach to dicing frame
- Chemical release of the zone 2 direct on tape frame (support with ultrasonic)
- Equipment: cleaning system AR12 (SUSS microtec)
 - Wafer size: 100-200mm
 - Time: 10-20min (depended on zone 2 width)
 - Solvent/ swell: mesitylene/limonene

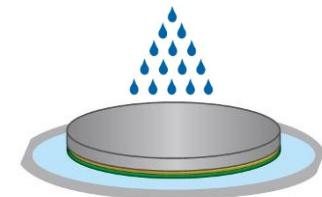


Fig.: wafer stack attached on dicing frame



Fig.: edge release process in AR12 cleaning system

Temporary wafer bonding - key technology for 3D-MEMS

Wafer de-bonding

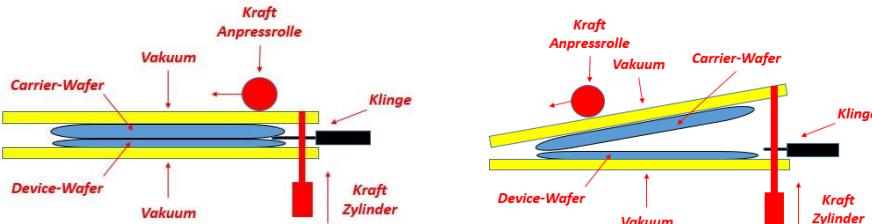


Fig.: schematic drawing to wafer de-bonding

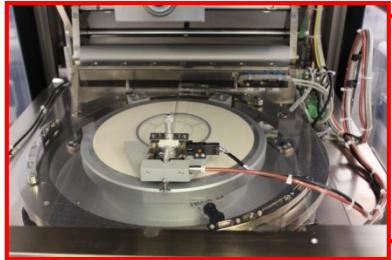


Fig.: wafer de-bonding system DB 12T



- Wafer de-bonding carrier- and device wafer
 - Room temperature peel-off process
 - Initiation with blade
 - Carrier wafer release with flexible plate
- Equipment: wafer debonder DB12T (SUSS microtec)
 - Wafer size: 100-200mm
 - Kraft: 100-500N
 - Time: 5min

Temporary wafer bonding - key technology for 3D-MEMS

Device cleaning and handling

- Cleaning carrier and device wafer
 - Combined puddle dispense- und spray cleaning process
 - Device wafer on dicing frame
 - Carrier wafer single process
- Equipment: AR12 cleaning system (SUSS microtec)
 - Wafer size: 100-200mm
 - Time: 10min
 - Solvent/swell: mesitylene/limonene, IPA
- Thinn wafer handling using electrostatic vacuum chucks

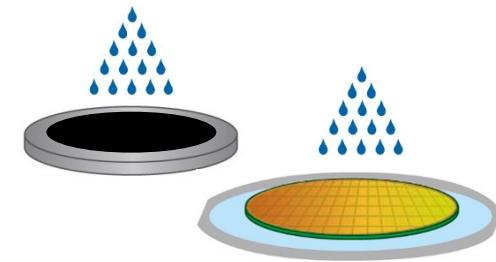


Fig.: AR12 cleaning system (company SUSS microtec)

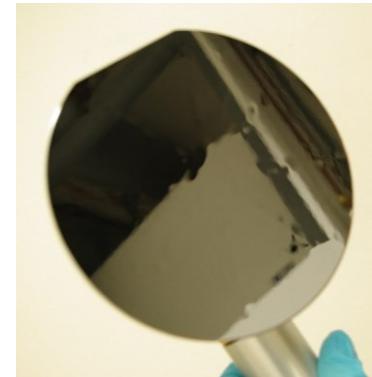


Fig.: electrostatic vacuum chuck

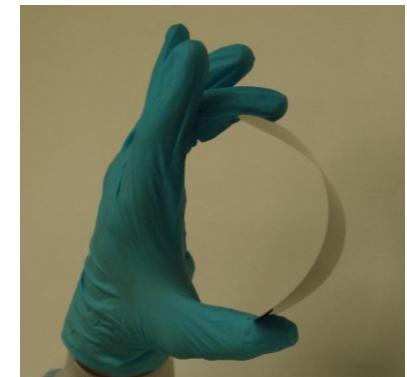


Fig.: 50µm thinned device wafer

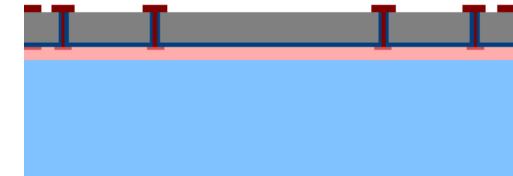
Temporary wafer bonding - key technology for 3D-MEMS

Possible scenario for 3D-MEMS Integration

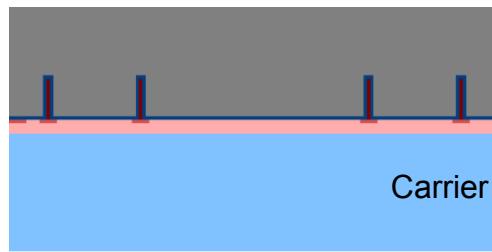
Device wafer
with Via first
TSV



Oxide opening
Bonding frame
including pads



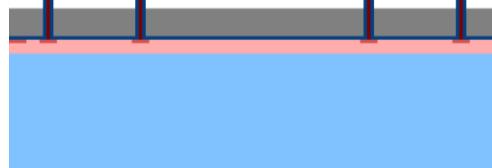
Temporary wafer
bonding



Wafer de-
bonding
cleaning



Wafer thinning
■ Stopp on TSV
■ TSV opening



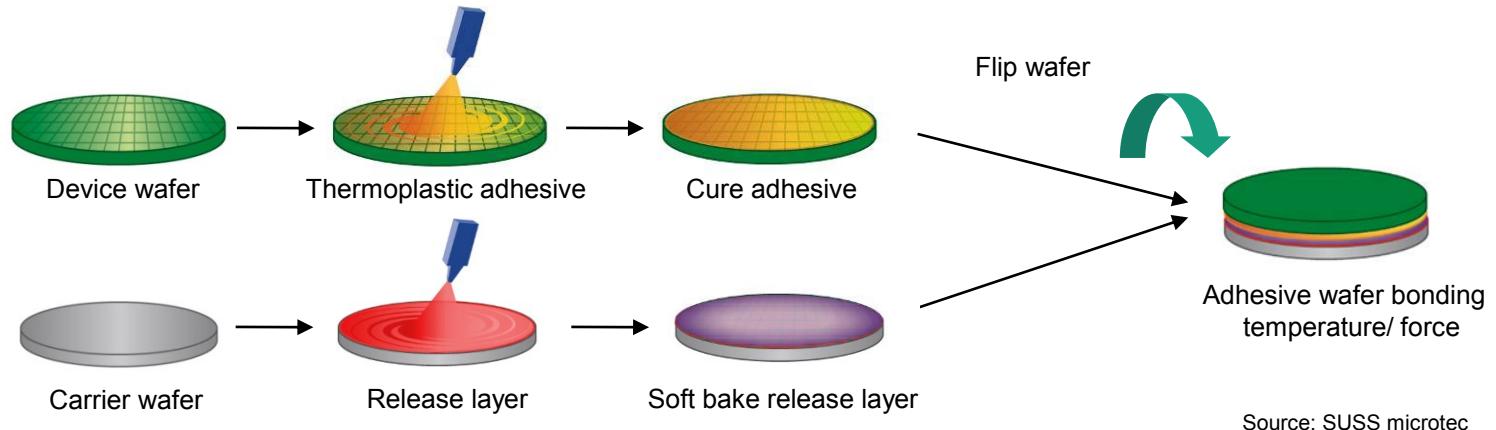
Flip and
permanent
Wafer bonding
to MEMS wafer



Temporary wafer bonding - key technology for 3D-MEMS

Summary and Outlook

- Trend: increasing of functionalities in one system and component size reducing → solution: 3D MEMS Integration
- Key technology: temporary wafer bonding
 - High priority in 3D-IC → technology transfer to MEMS devices
 - Complex two-zone approach → Reduction to one zone (new technology called BrewerBond®)



Thank you for your kind attention!

Fraunhofer ENAS
Dept. System Packaging
Dirk Wünsch
Technologie Campus 3
09126 Chemnitz Germany
Telefon: +49 (0)371 45001-262
Fax: +49 (0)371 45001-362
E-Mail: dirk.wuensch@enas.fraunhofer.de
Web: <http://www.enas.fraunhofer.de>

