confidential

WAFER BONDING WITH NOVEL METHOD FOR IMPROVED POST-BOND ALIGNMENT FOR HIGH VOLUME PRODUCTION IN MEMS APPLICATIONS

Chemnitzer Seminar 2018

CONTENTS

confidential

confidential

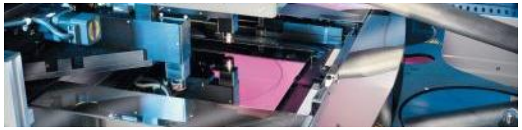
SEGMENTS AND PRODUCTION SITES

Segments

Photomask Equipment	Lithography		Wafer Bonder

Products

MaskTrack Pro



Exposure Systems

Coater/Developer

Bonding Systems

Frontend → Backend

Process Steps

- Photomask Cleaning
- **UV Projection** (Stepper, Scanner); **Laser Processing**
- **Proximity Exposure** (Mask Aligner); **Imprinting**
- Coating, Developing
- Bond Alignment, Permanent Bonding, Temporary Bonding, Debonding

Production Sites

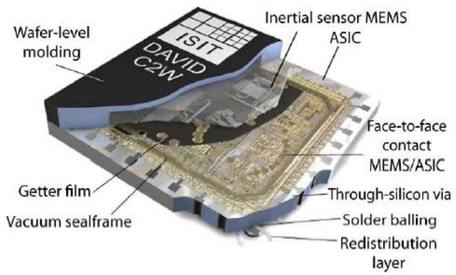
Sternenfels → Corona → Garching → Sternenfels

INTRODUCTION

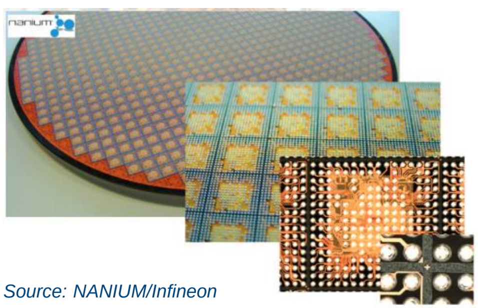
confidential

- Wafer-level packaging becomes increasingly attractive to manufacture advanced MEMS and RF devices at a reasonable cost.
- Wafer bonding is one of the key technologies in WLP of those devices. Among various bonding methods, metal-based wafer bonding is a suitable candidate to meet the requirements such as:

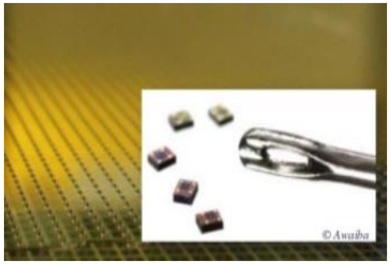
  - Miniaturization → Narrow bond frame width
  - Excellent hermeticity → Low leak rate
  - Integration → Electrical interconnection



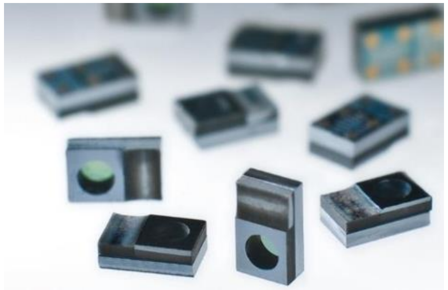
Source: FhG ISIT



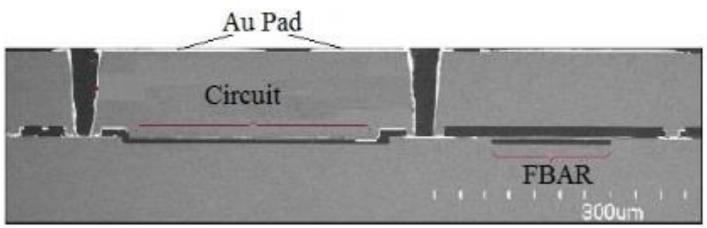
Source: NANIUM/Infineon



Source: SÜSS Microoptics



Source: Silex

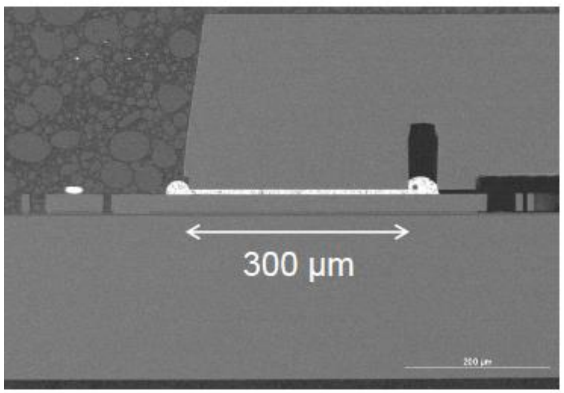


Source: Avago

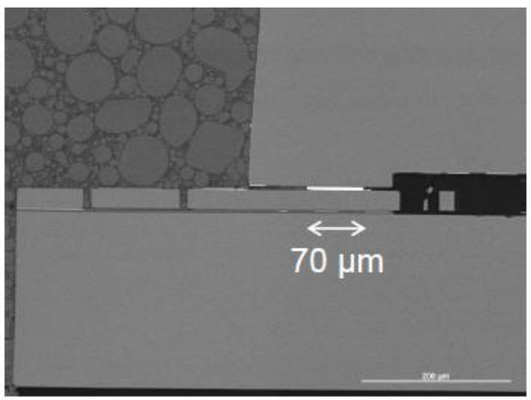
MINIATURIZATION BY METAL BONDING WITH NARROW BOND LINE

confidential

- In order to reduce the bond line width, tight post-bond alignment accuracy is required to be in the range of +/- a few µm
- In the current MEMS production, post-bond alignment accuracy is typically around 5 - 10 µm in metal bonding, due to alignment shift during the bonding process

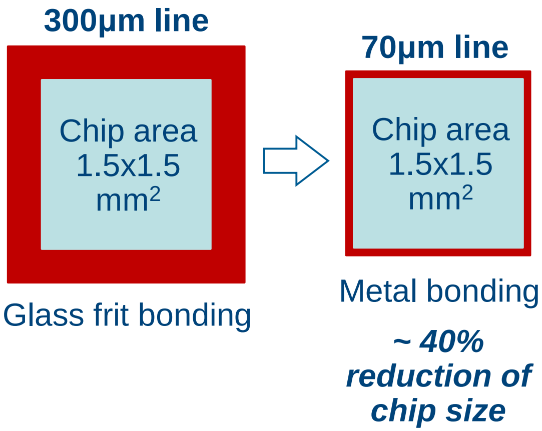


Glass-frit bonding (ST 6-axis IMU)



Au-Au bonding (ST 6-axis IMU)

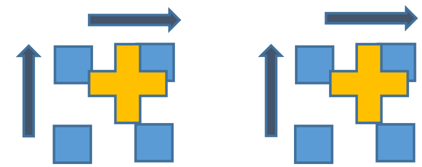
Source: System Plus Consulting



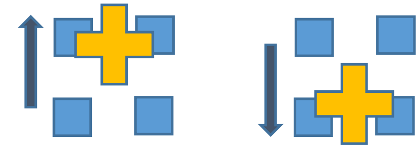
POST-BOND ALIGNMENT ERROR COMPONENTS

confidential

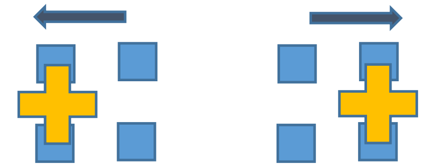
- Translational error (x-, y- shift)



- Rotational error (theta shift)



- Magnification error/thermal mismatch (run-out)



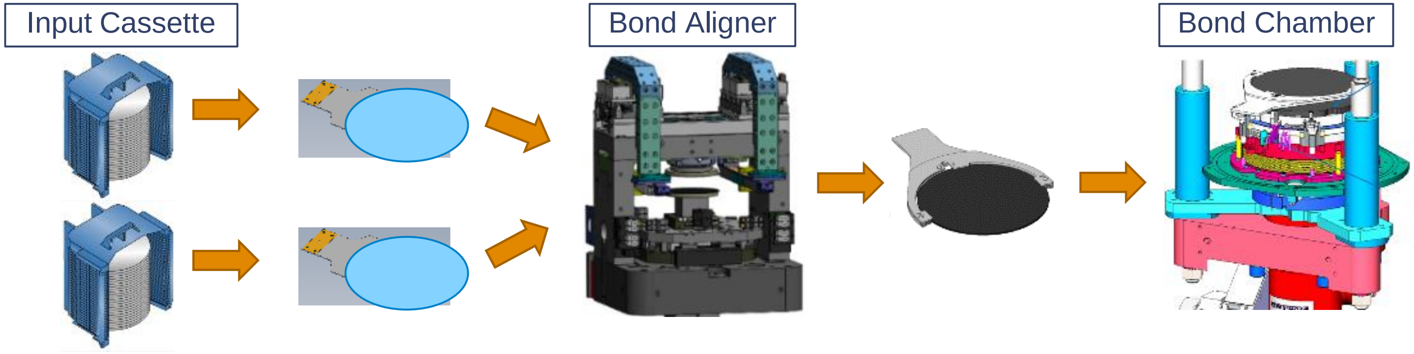
- Non-correctable error components (distortion)
  - Pre-existing lithography errors on one or both of the wafers
  - Local deformation of the wafer during alignment or bonding from non-uniform chuck flatness or particles between chuck and wafer

CORRECTABLE ALIGNMENT ERROR COMPONENTS FOR METAL BONDING

confidential

- Correction of initial translational and rotational error can be done on the bond aligner
  - State-of-the-art wafer bonding systems offer built-in global calibration and overlay verification capability for optimum alignment accuracy and repeatability
  - SUSS XBS200 bonder offers pre-bond alignment accuracy of < 500nm (3σ) and overlay repeatability of < 300nm (3σ)

- Additional translational and rotational error can be induced by
  - Bow and warp from thermal shock when using elevated chamber idle temperatures
  - Mechanical effects of removing spacer flags that keep wafers in separation during pump down
  - Squish or flow of bond line material when the bond force is applied at elevated temperature

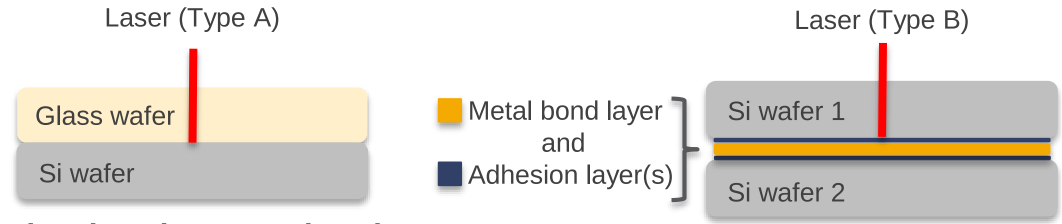


confidential

CONTENTS

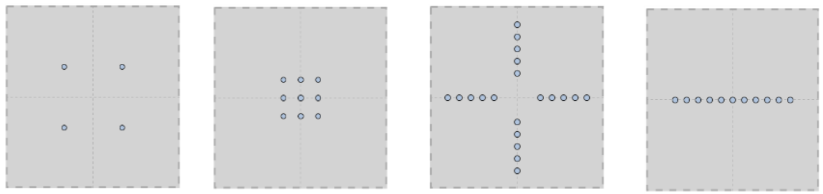
NOVEL METHOD FOR IMPROVED POST-BOND ALIGNMENT - LASER PRE-BOND 1/3

- In order to eliminate additional translational and rotational wafer shift from wafer transfer or actual bonding process, the wafer pair is pre-bonded/“spot-welded” by means of a laser
- Laser pre-bonding is done on the bond aligner right after alignment
  - Laser pre-bond is placed in the wafer center to allow thermal expansion during bonding
  - Several laser spots can be used in a preferable pattern to secure x-, y- and theta alignment, e.g. dot matrix, cross, line, …
  - Effective diffusion/melting zone is material dependent with spot size typically in the range of 50 - 400 µm with spacing in the same range



Si - Glass laser pre-bond

Si - Si laser pre-bond

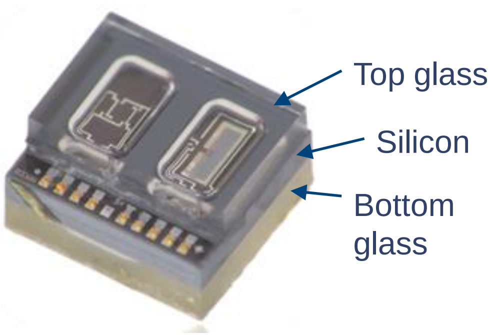


Examples of laser pre-bond patterns

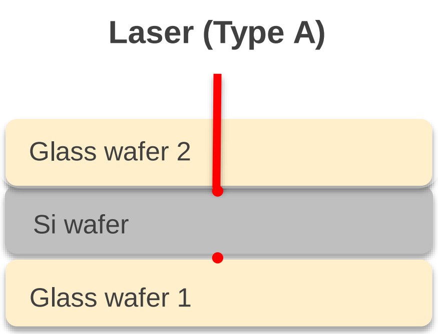
NOVEL METHOD FOR IMPROVED POST-BOND ALIGNMENT - LASER PRE-BOND 2/3

confidential

- Glass to silicon laser pre-bond:
  - IR laser wavelength can transmit glass but is absorbed at silicon interface and allows "spot welding" of glass to silicon without any intermediate layer
  - The method is used in volume production of automotive sensors using a triple stack bonding (glass-silicon-glass)
  - Both glass wafers undergo sequential laser pre-bonding to the silicon wafer prior to anodic bonding of entire triple stack sandwich
  - Significantly improved post-bond alignment (factor of 3 - 4x) compared to sequential bonding with traditional wafer transfer of non-pre-bonded wafers after alignment



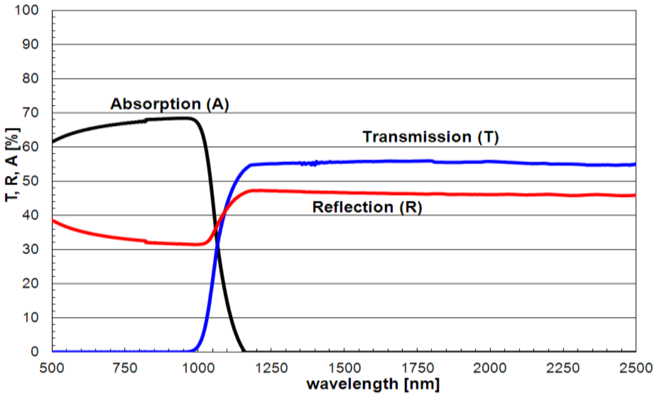
Source: SystemPlus Consulting



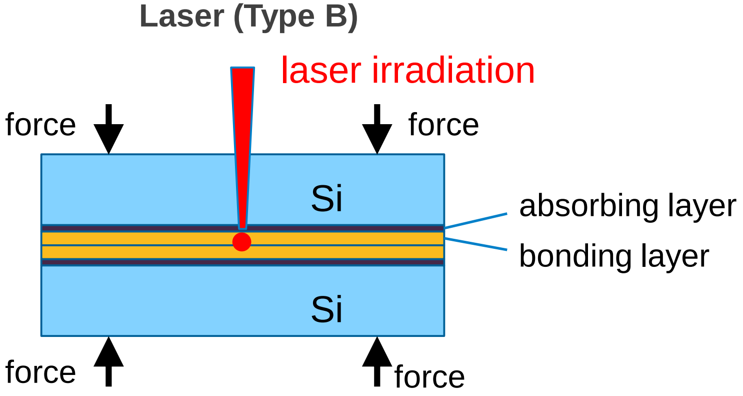
CONTENTS

NOVEL METHOD FOR IMPROVED POST-BOND ALIGNMENT - LASER PRE-BOND 3/3

- Transfer of proven method to silicon to silicon metal bonding:
  - Employing a different IR laser wavelength with very high transmission through silicon so that no energy is absorbed in bulk silicon
  - Good absorption in typical adhesion layers or diffusion barriers like Ti, TiW, TiN, Ta, TaN in combination with bond layer metals like Au, Cu, Al or AlGe
  - When laser energy is absorbed in the bond line material it melts the metal layers and forms a pre-bond

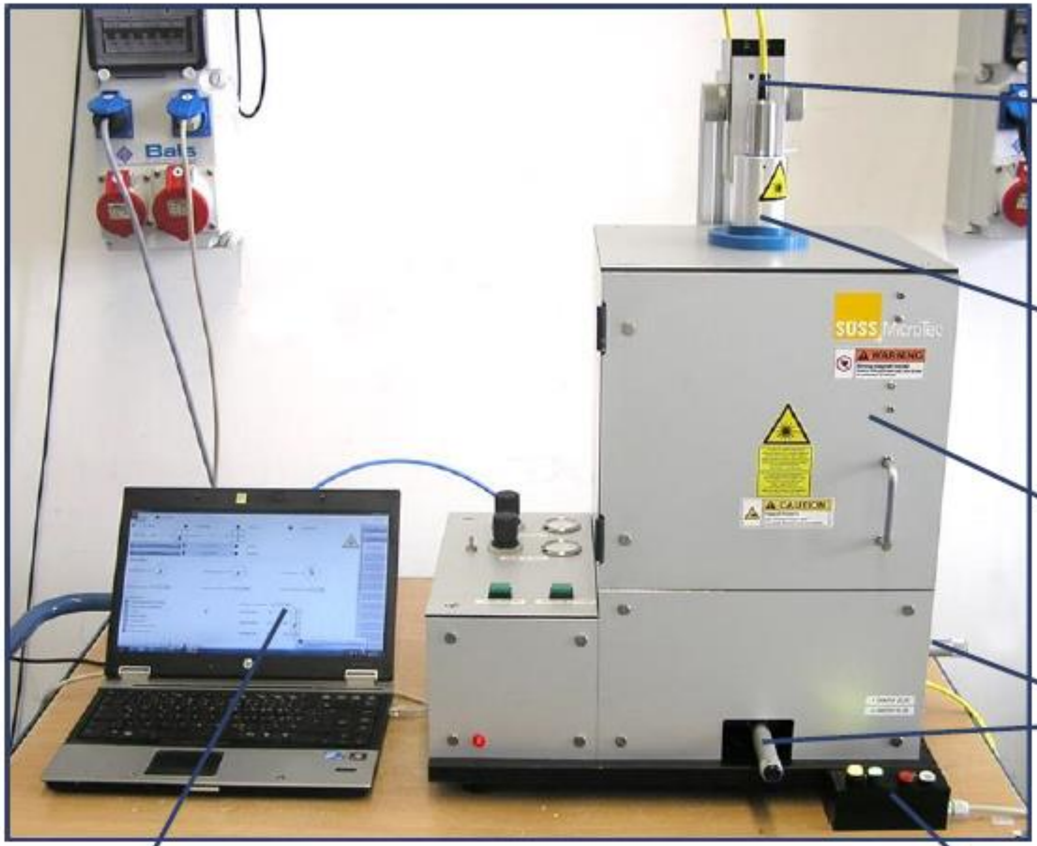


Absorption properties of 525µm thick Si wafer



PRELIMINARY LASER PRE-BONDING TEST FOR SILICON-TO-SILICON 1/3

+ Picture of the laser pre-bond test stand



Laser input:
fiber optics connected to the external laser source

Beam shaping tunnel

Laser safety door

Adjustable table (x-and y-direction) by micrometer screws

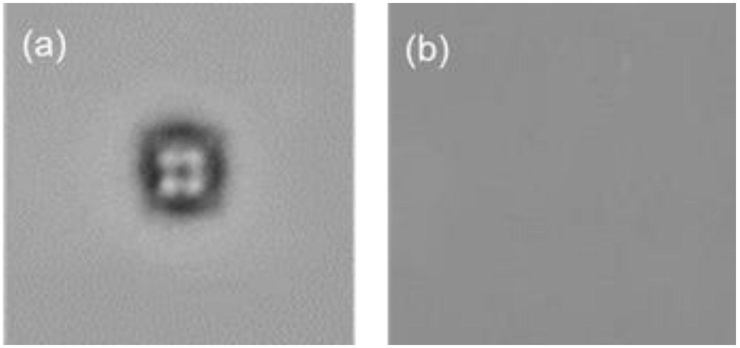
Control PC

Safety switch

PRELIMINARY LASER PRE-BONDING TEST FOR SILICON-TO-SILICON 2/3

confidential

- Laser pre-bonds can create a diffusion/melting zone which depends on absorption properties of bond line and laser energy; excess energy creates a larger diffusion/melting zone
- Laser pre-bond sites can be re-diffused during bond process as long as the diffusion/melting zone is small



SAM image of 2x2 dot matrix Si - Si laser pre-bond with Au/TiW bond line
(a) before bonding and
(b) after diffusion bonding at 400°C laser pre-bond sites no longer visible

IMPROVED POST-BOND ALIGNMENT ALLOWS BOND FRAME SCALING

confidential

+ Surface area of a 200 mm wafer consumed by bond frame and effect of bond frame scaling on number of additional dies per wafer:

Die size	0.5 mm x 0.5 mm		1 mm x 1 mm		3 mm x 3 mm		5 mm x 5 mm	
Bond frame width	Number of dies per 200mm wafer (DPW) and % of surface area consumed by bond frame							
50µm	86,526	16.0%	25,560	8.9%	3,126	3.3%	1,121	2.0%
35µm	91,040	11.7%	26,277	6.4%	3,157	2.3%	1,128	1.4%
20µm	95,915	6.9%	27,025	3.7%	3,189	1.3%	1,135	0.8%

Bond frame scaling	Additional dies per 200 mm wafer (absolute number and increase in %)							
50 µm → 35 µm	4,514	5.2%	717	2.8%	31	1.0%	7	0.6%
35 µm → 20 µm	4,875	5.4%	748	2.8%	32	1.0%	7	0.6%

- Assuming 50 µm dicing streets in all cases (added to die size)
- Dies per wafer (DPW) calculation: $DPW = \frac{\pi d2}{4S} - \frac{\pi d}{\sqrt{2S}}$ *with d = wafer diameter, S = die size (1)*

+ Scaling down the bond frame allows for smaller die areas and thus more dies per wafer:
  - **~5 % more dies** on a 200 mm wafer for 0.5 mm x 0.5 mm die size when shrinking the seal ring width from 50 µm to 35 µm or from 35 µm to 20 µm
  - Effect is especially pronounced for very small die sizes (often encountered at WLCSP)

(1) Dirk K. de Vries. "Investigation of gross die per wafer formulas". IEEE Transactions on Semiconductor Manufacturing (February 2005): 136–139

CONTENTS

SUMMARY

+ MEMS and RF devices are driven by scaling and device integration and most often require hermetic bond lines
  → metal bonding, e.g. Au/Au, Al/Ge, Cu/Sn
+ While translational and rotational wafer to wafer alignment is done on the bond aligner, there are additional factors that contribute to post-bond alignment shift
  - Mechanical transfer, squish/flow of bond line material
  - Thermal effects on aligned wafers from loading into bond chamber or heating
+ Laser pre-bonding in the center of the wafers locks the alignment prior to bonding
  - Used in production for glass to silicon pre-bonding for many years
  - Laser pre-bonding is now available for silicon to silicon pre-bonding with metal bond lines as an option on the new SUSS XBS200 automatic bonder platform
  - Allows scaling of seal rings for more dies per wafer
  - Increases the process capability/repeatability as an important manufacturing benchmark

New SÜSS MicroTec XBS200 automated bond cluster with integrated laser pre-bond option


Thank you!