Vertically-Integrated Array-Type Miniature Interferometer as a Core Optical Component of a Coherence Tomography System for Tissue Inspection

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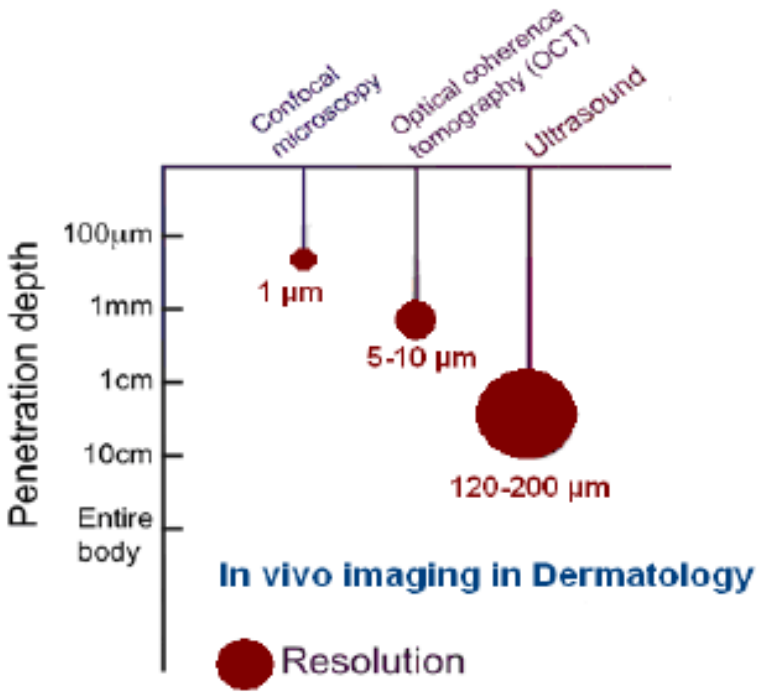
Outline

- Introduction
- Mirau Interferometer
- Design Concepts of Electrical Connection
- Bonding Technology and the assembled Mirau µ-interferometer
- Conclusion

Optical coherence tomography in dermatology

- Skin cancer is the most commonly diagonosed type of cancer
- Early diagnosis is essential
- However, a large number of unnecessary surgical procedures are still performed
- There is a need for high resolution non invasive techniques.



Ultrasounds

- frequency range 20-75µHz
- cross-sectional field of view +12x6mm2
- Low resolution

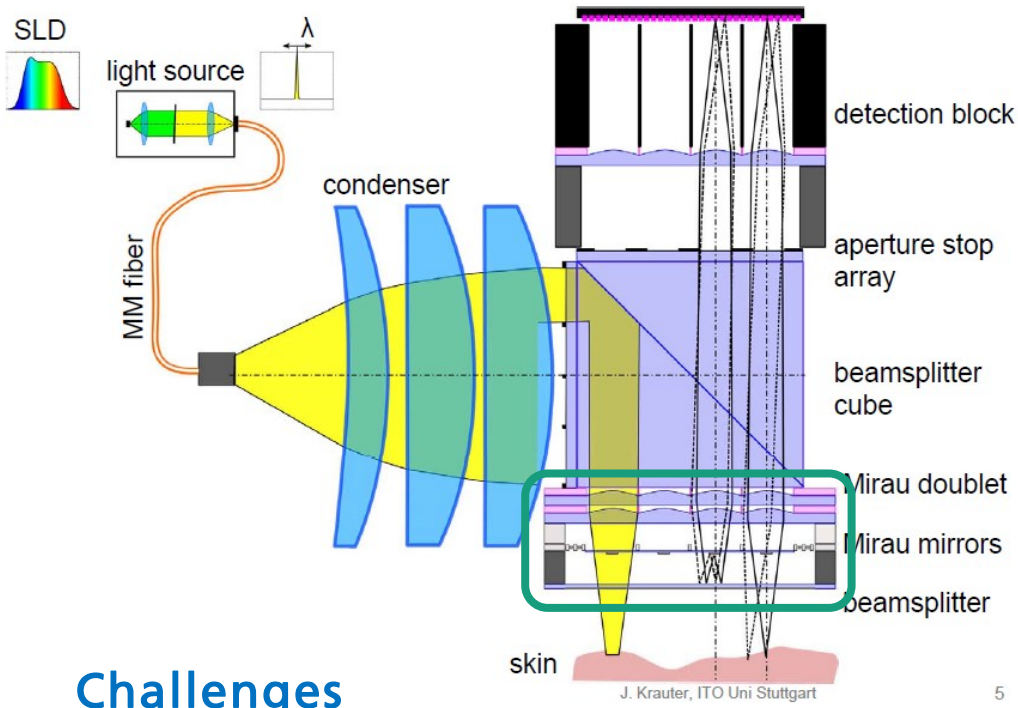
Confocal microscopy

- very high resolution (1µm)
- limited penetration depth (<200µm)

Optical Coherence Tomography (OCT)

an intermediate method between high-frequency ultrasound and confocal microscopy, regarding resolution and detection depth

Vertically Integrated Array-type Mirau-based OCT System for early diagnostics of skin cancer (VIAMOS)



Originalities

- an instrument 150 x smaller than a standard OCT system
- 10 x cheaper because of a batch-fabrication concept
- multi-functional instrument (polarisation sensitive, parallel inspection)
- high resolution 3D reconstructions of skin

Challenges

- To combine MEMS and microoptical technologies in a free-space platform
- A proposed 3D packaging and assembly approach to miniaturize the OCT system
- Low-cost preindustrial prototype of array-type OCT microsystems
- Functional validation at the Hospital and acceptation by the market

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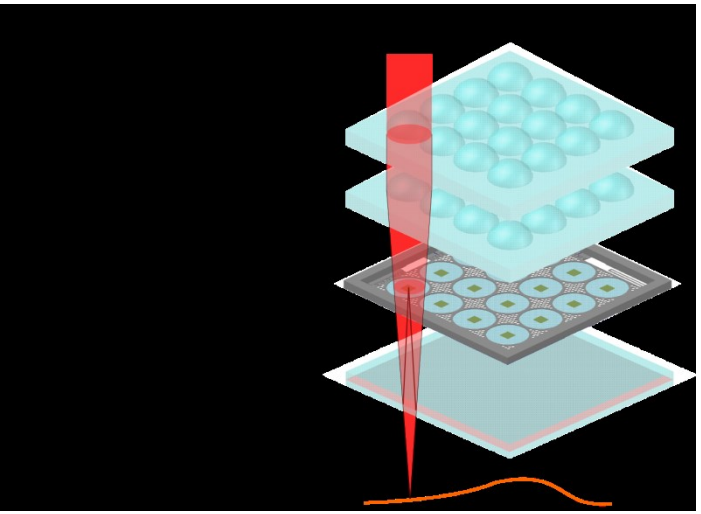
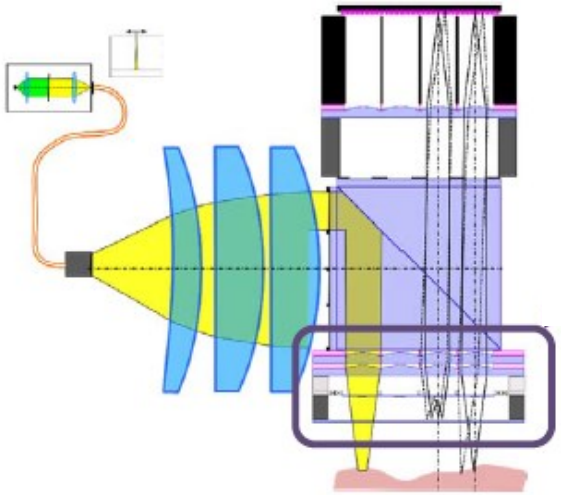
Mirau µ-interferometer



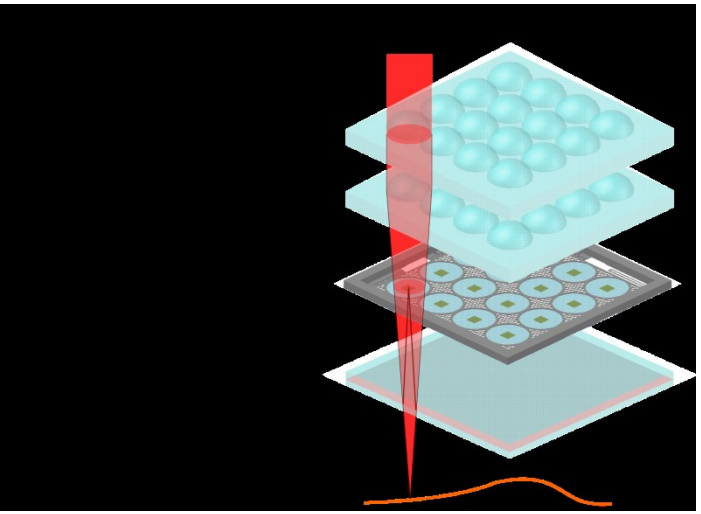


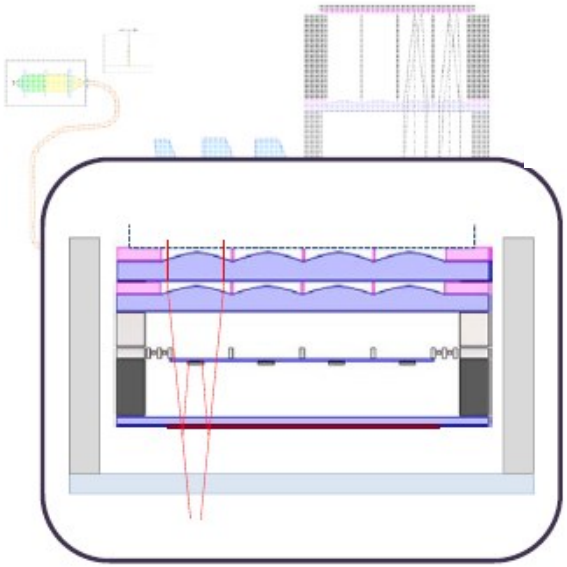
Mirau µ-interferometer: a key component of OCT microsystem which aims to image a total scan area of 8x8x0.5 mm^3

Requirement of Mirau interferometer - large actuated platform (4x4)

- Doublet of microlenses (W1) – less optical aberrations, lower sensitivity to alignment
- MOEMS Z scanner (W2) – electrostatic actuation of micro-mirrors
- Spacer (W3) – 3mm thick for focus-adjustment
- Beamsplitter (W4) – with AR coatings

Mirau µ-interferometer





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- Beamsplitter (W4)

Vertical Assembly + Electrical Connection

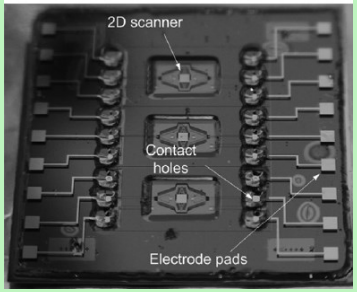
MEMS/MOEMS Packaging

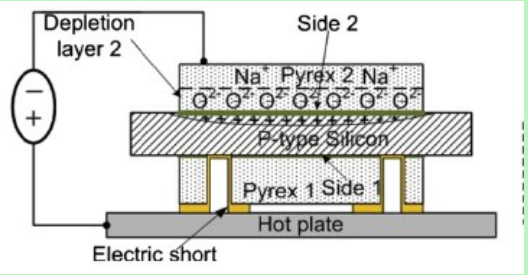
- Material and process compatibility to ensure reliable device operation
- In most cases, hermetic is needed to avoid contamination and moisture
- Electrical interconnection
- Size and cost reduction

⇨ ***Integration on Wafer Level Required***

Bonding	Temperature	Drawbacks
Direct	~1000°C	High surface requirement
Surface activated	< 200°C	Plasma effect on devices
Au-Sn eutectic	~300°C	Intermediate material
Anodic	<500°C	High surface requirement
Glass frit	<450°C	Need larger area for bond frame

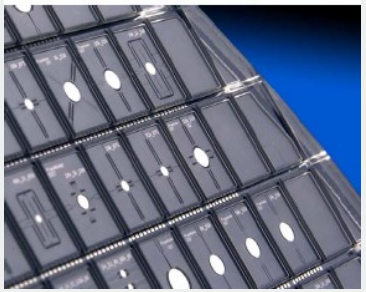
Packaging of Micro-Mirror devices

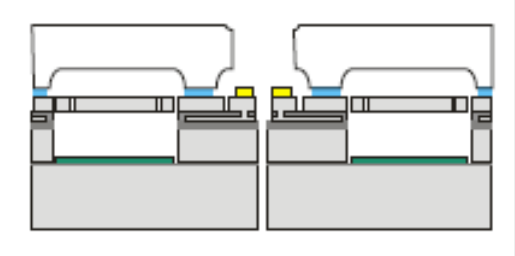




Chu etal., 2013 Tohoku Uni.

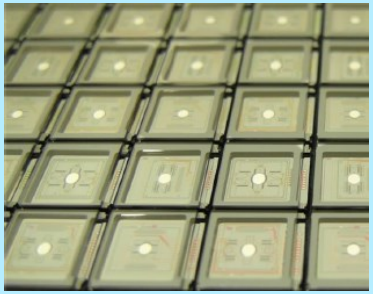
- Double-side anodic bonding
- Electric feed-through for electric short of the first bonding side.
- 400°C, 500V, 0.5 Pa for 30 min

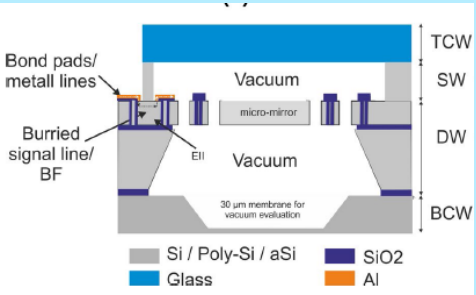




Lisec etal., 2010, FhG ISIT

- Glass frit at the cap side, Au-Si eutectic at the bottom side.
- No bond frame preparation on MEMS wafer necessary

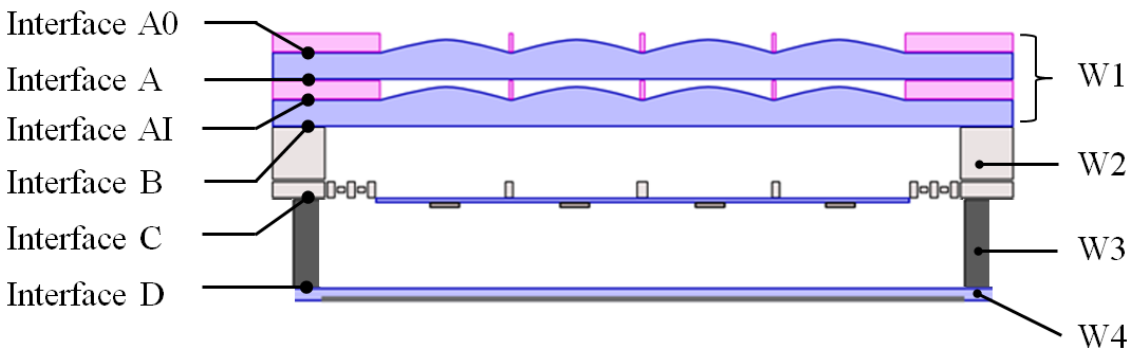




Langa etal., 2015, FhG IPMS

- Anodic bonding for top cavity wafer and spacer
- Glass frit between device wafer , spacer and bottom cavity wafer (420°C)

Bonding Requirement



Optical transparancy for the package

Ensure stability of microlens profile

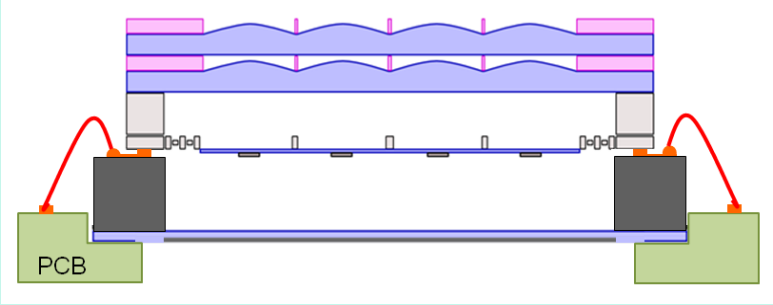
Quality of deposition layer on MOEMS Z scanner

Quality of AR coating

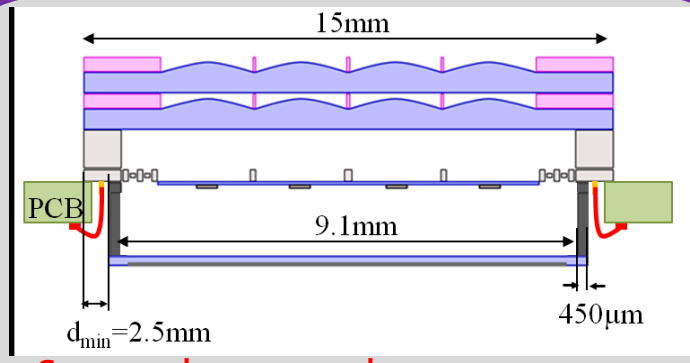
Alignment - lateral tolerance of +/- 16 µm, vertical tolerance of +/- 20 µm

Bonding process should provide high bonding strength.

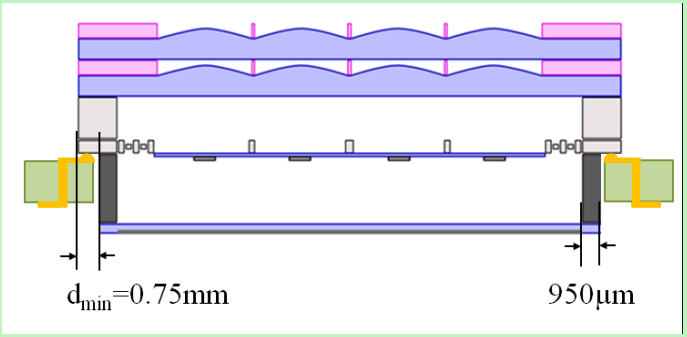
Concepts of electrical connections



+ Secured approach
- Openings on W1 and W2
- Additional metallization on W3
- More space needed

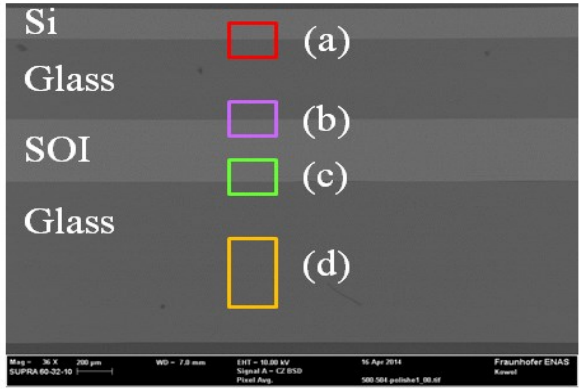


+ Secured approach
+ No additional metallization on W3
+ higher miniaturization possible
- Step structured on W3 and W4
- Fragile spacer on wafer level
- Mechanical fixing

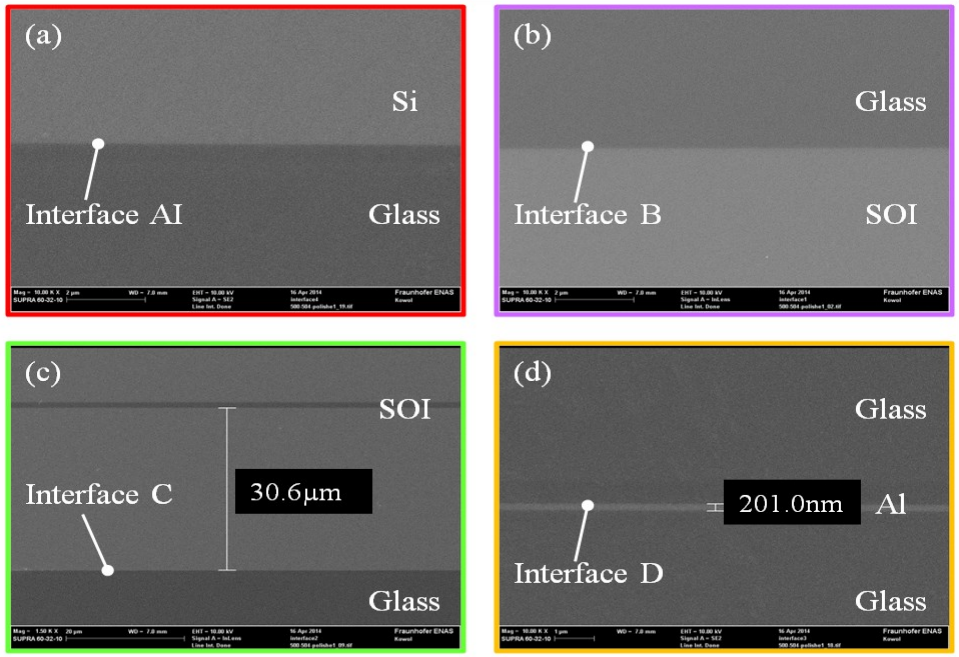


+ Mechanical/electrical through bumps
+ No additional metallization on W3
+ higher miniaturization possible
+ Stronger spacer
- Step structured on W3 and W4
- More complicated PCB

Demonstrator I simulating a Mirau Stack

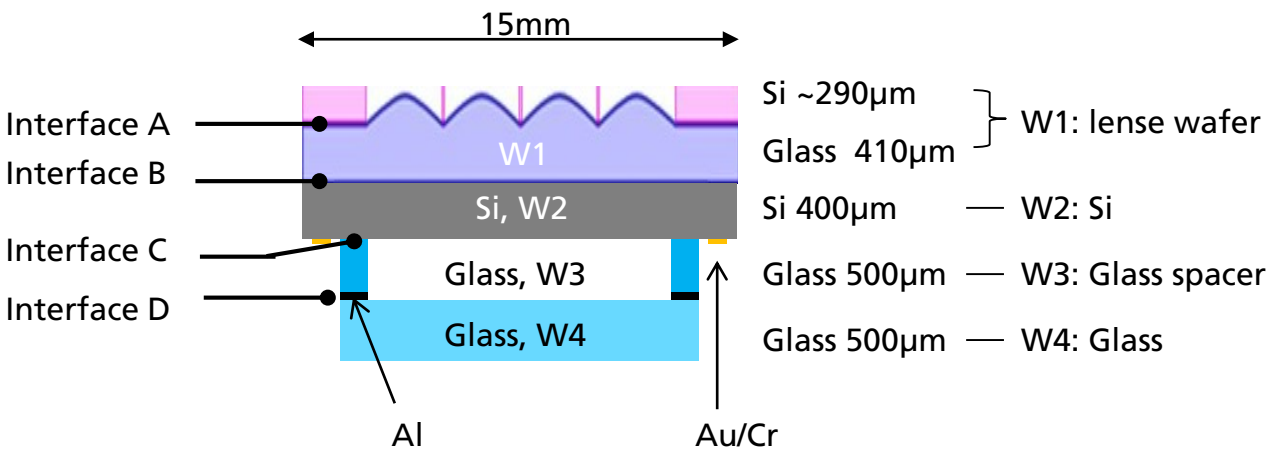


Interface	bonding step	Alignment
Interface A1	W1	+/- 8µm
Interface B	W2+W3	+/- 8µm
Interface C	W1 + W2/W3	+/- 16µm
Interface D	W1/W2/W3 + W4	+/- 16µm
Summary	All anodic bonding	



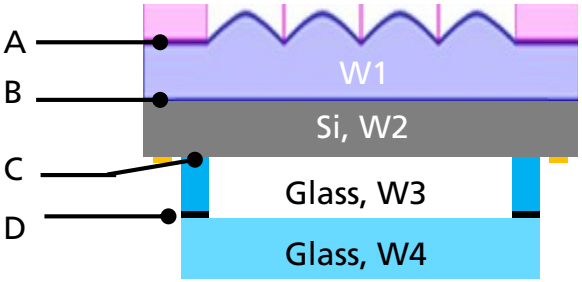
Demonstrator II including a mocrolense wafer

To decrease bonding times of W2 as well as bonding temperature



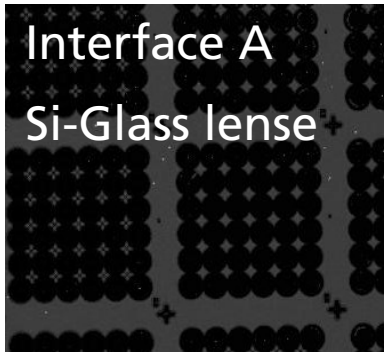
Interface	bonding step	remarks
A	Si frame+glass wafer	Self-aligning
D	W3+W4	W3 with DI rinse, W4 with RCA cleaning before bonding
C	W2+ (W3/W4)	W2 with plasma treatment (selective)
B	W1+(W2/W3/W4)	
	All anodic bonding	

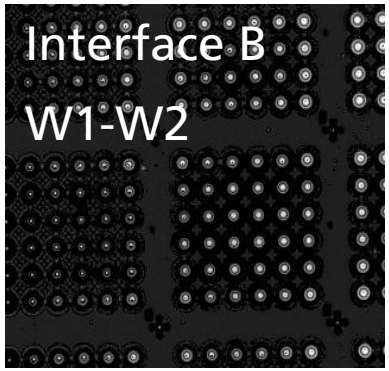
Demonstrator II : bond interfaces



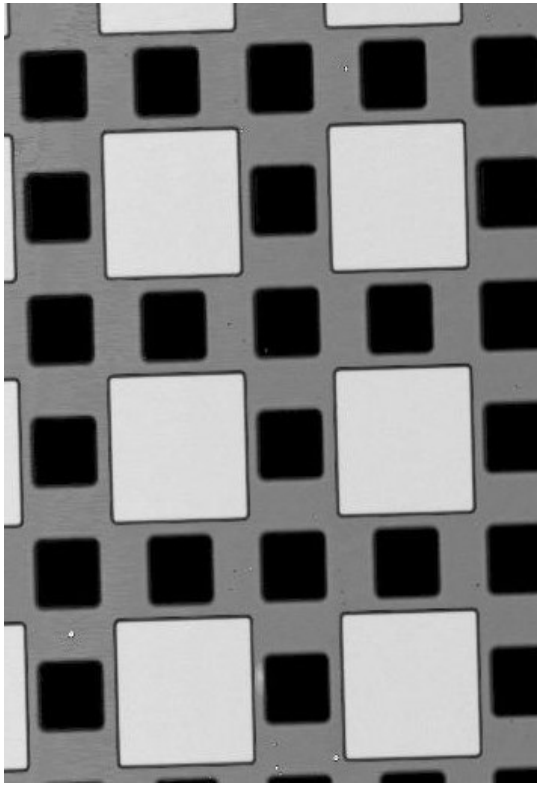
Bonding temperature: 320°C; Voltage: 500V, 600V

Scanning Acoustic Microscope pictures

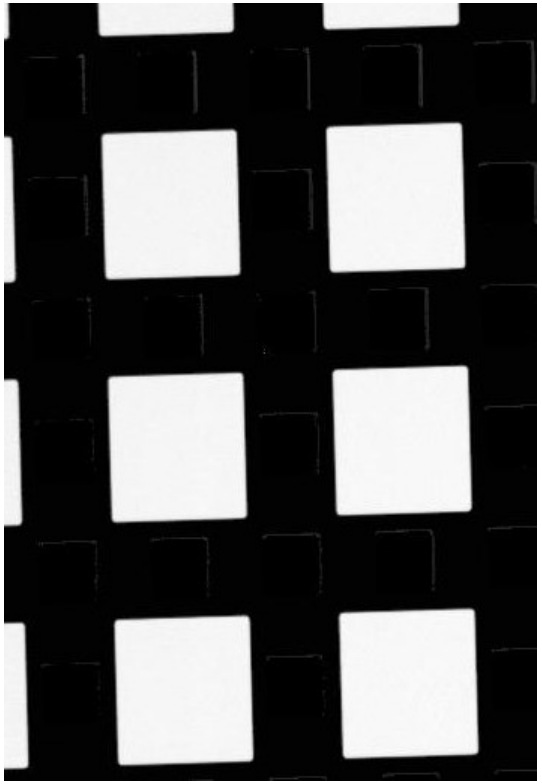




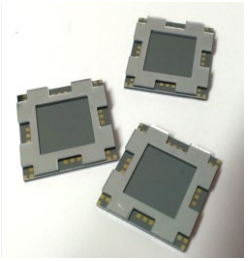
Interface C (W3-W2)

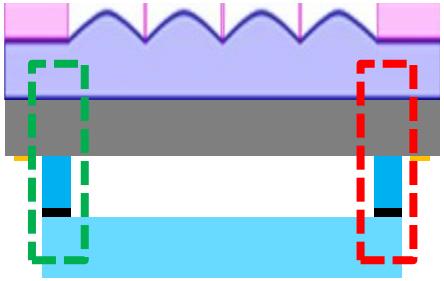


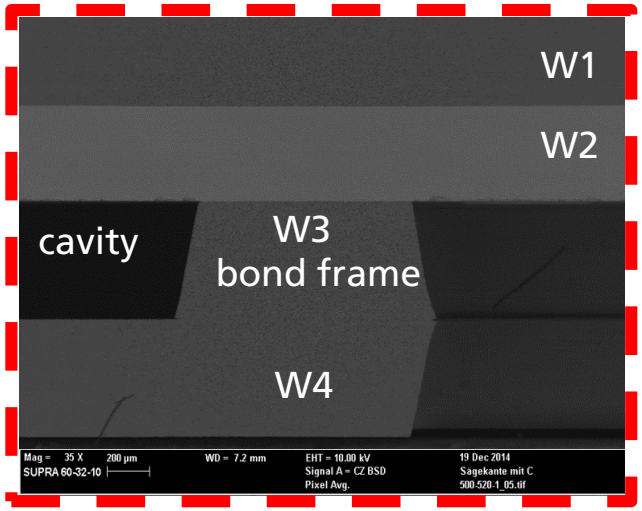
InterfaceD (W4-W3)

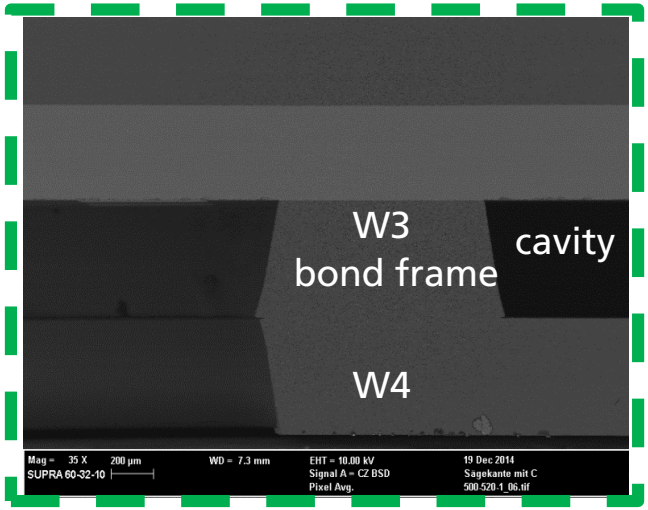


Demonstrator II: SEM images of bonded chips

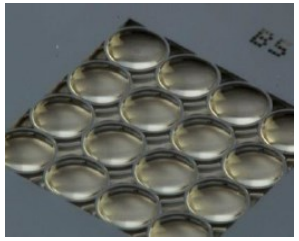


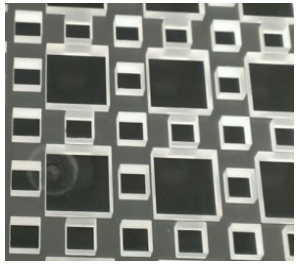


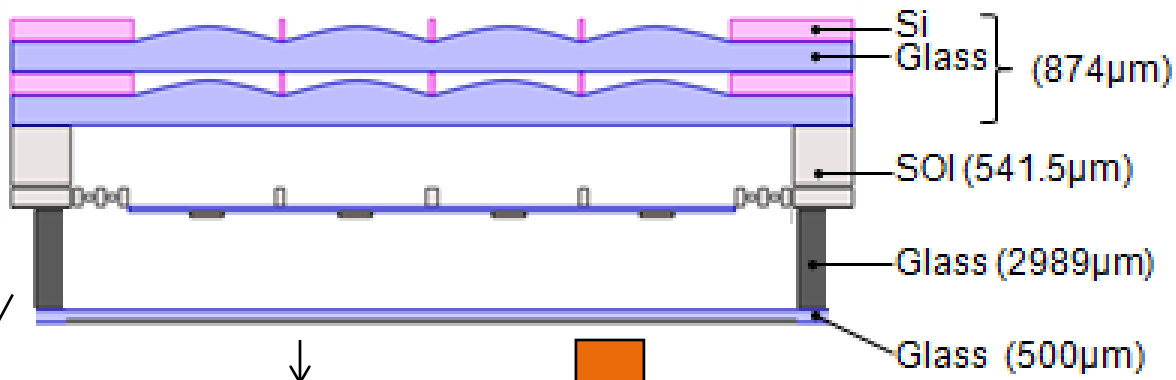




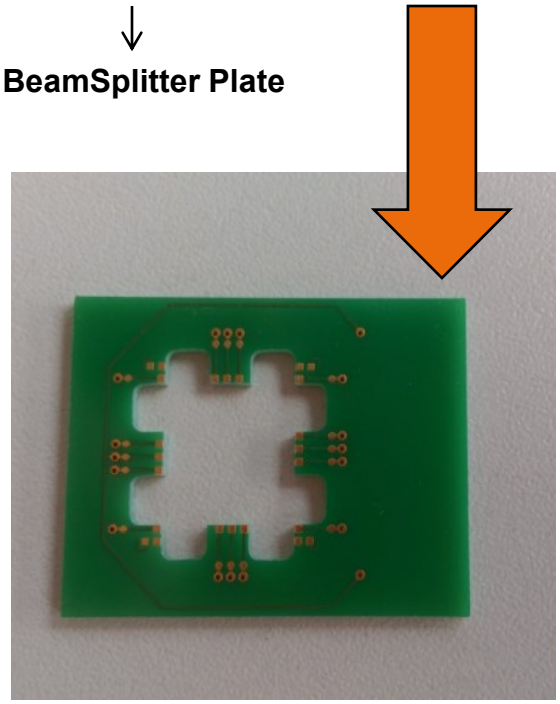
Assembly of Mirau µ-interferometer





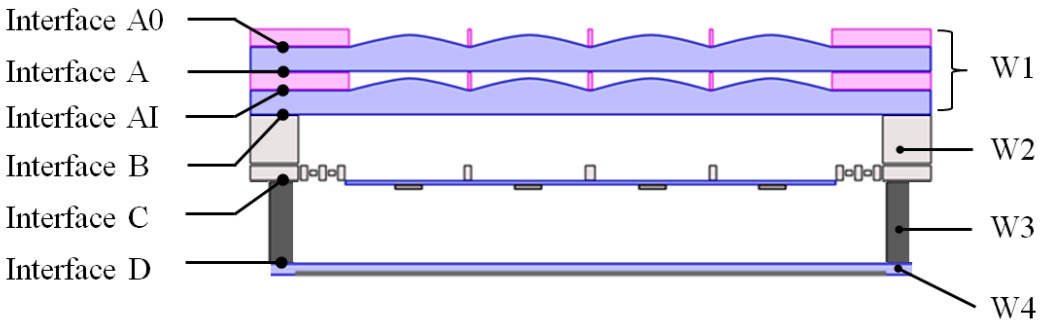


BeamSplitter Plate

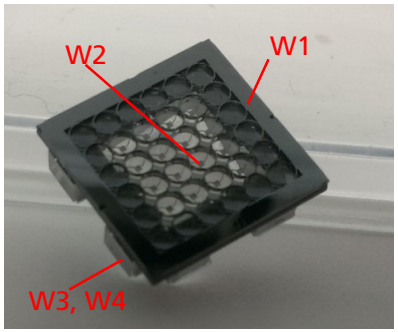


Mounted on PCB with contact pads

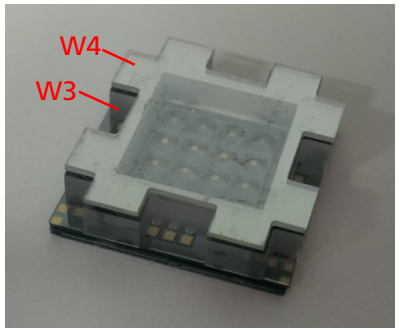
N-bonding process of a Mirau Stack at chip level



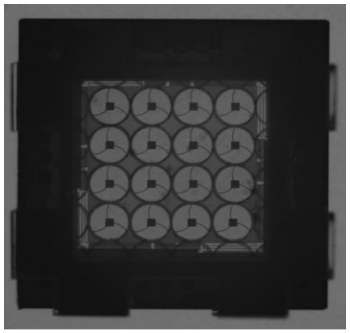
Interface	bonding step	bonding parameters
A0, A, A1	lense+lense	350°C. 900V
D	W3+W4	360˚C, 400V (W4 chipwithout TiO2 layer)
C	W2+ (W3/W4)	360˚C, 2000V
B	W1+(W2/W3/W4)	360˚C, 2000V
All anodic bonding		



front side



back side



back side Infrared camera

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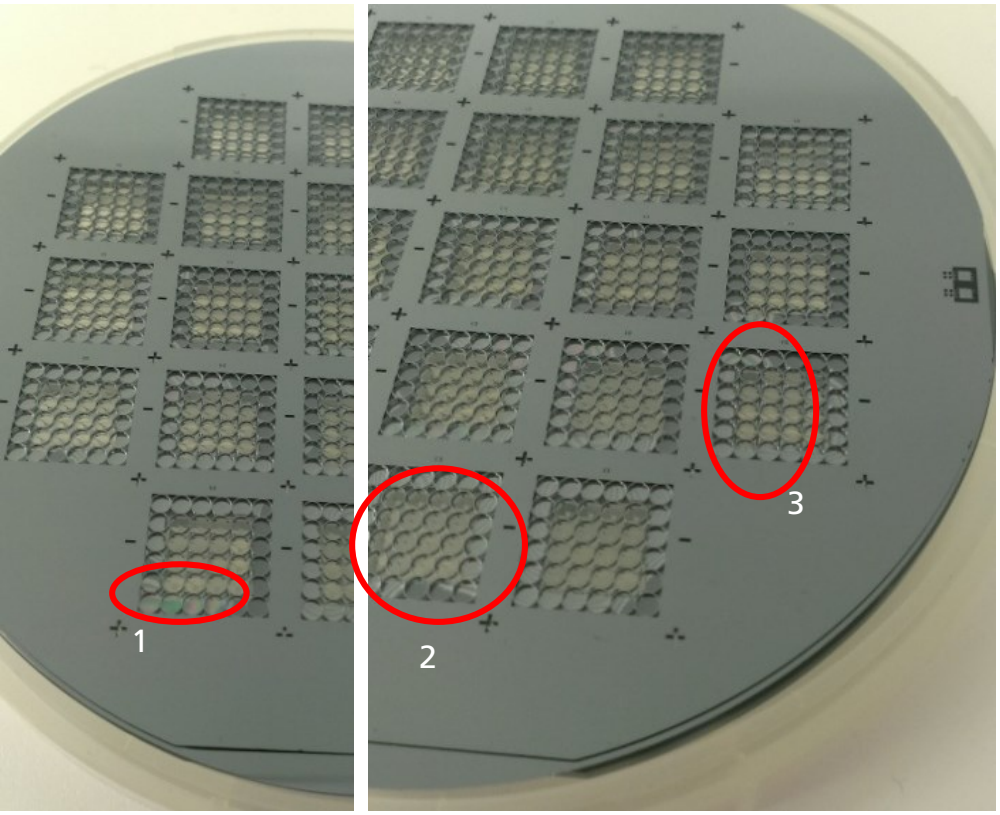
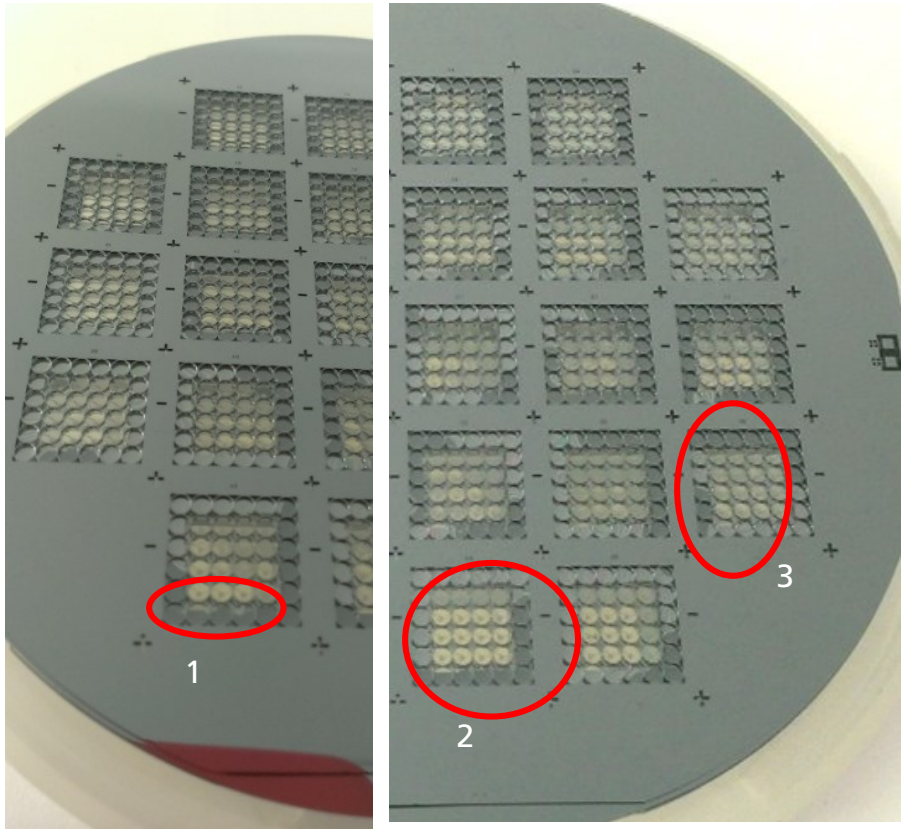
N-bonding process of a Mirau Stack at wafer level

After bonding at 1000V



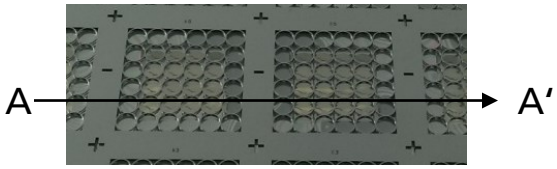
After bonding at 1100V



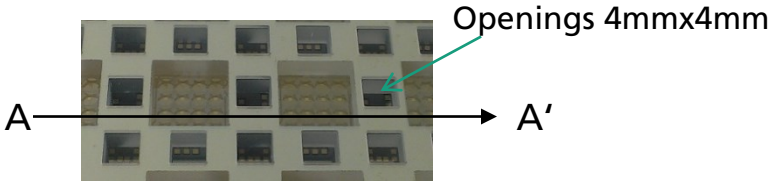
After bonding at 1100V: Increased bonded area (dark areas) but not significant

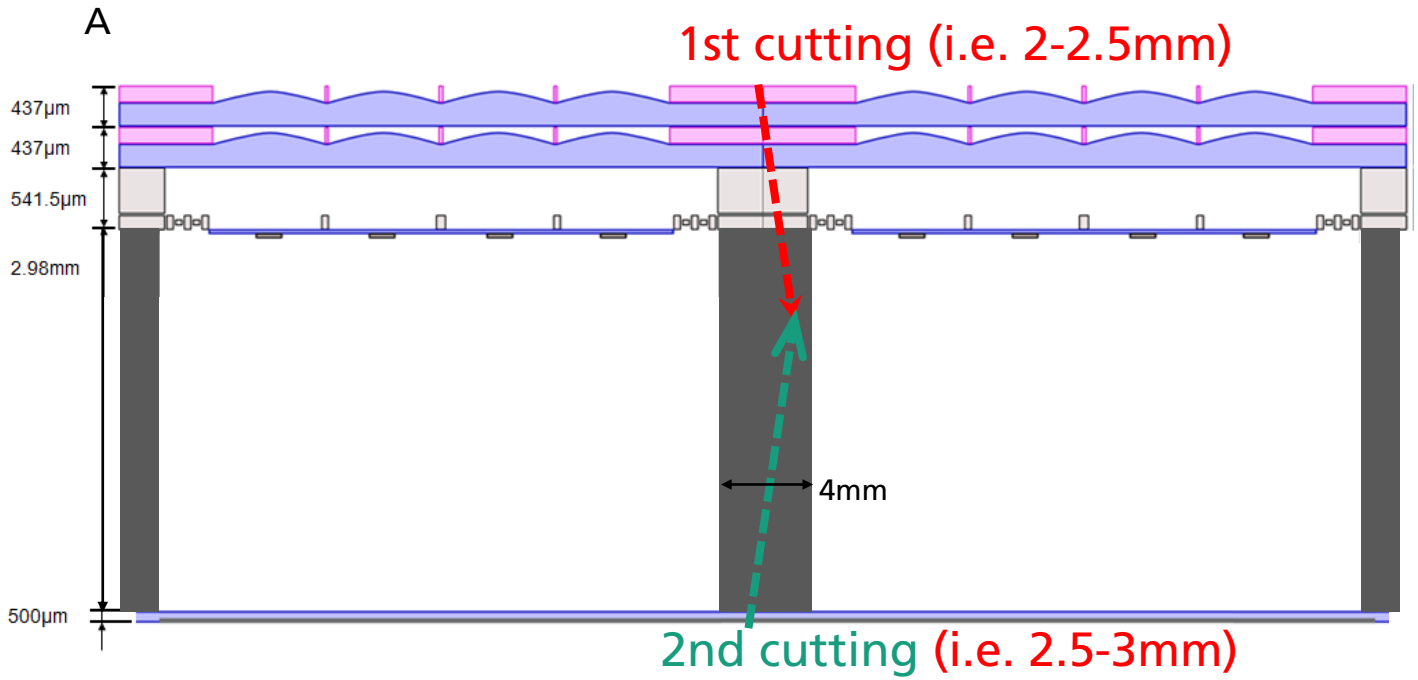
Laser dicing approach to get Mirau chips

front side



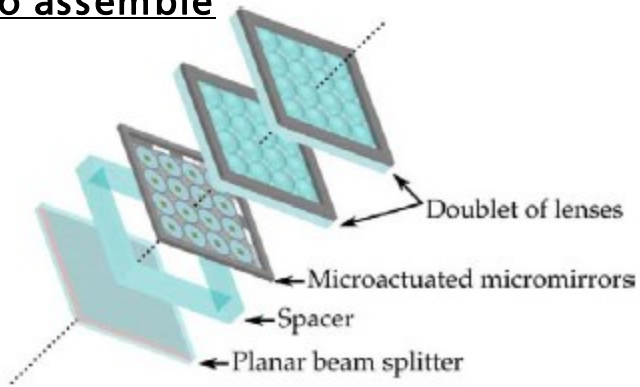
back side



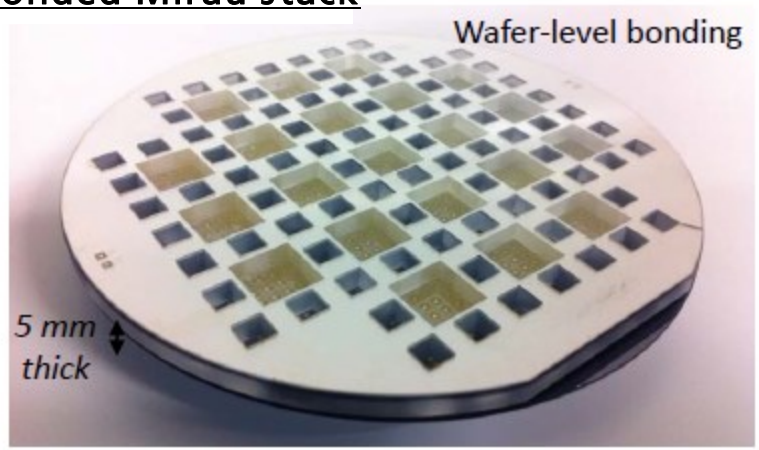


Assembled Mirau µ-interferometer

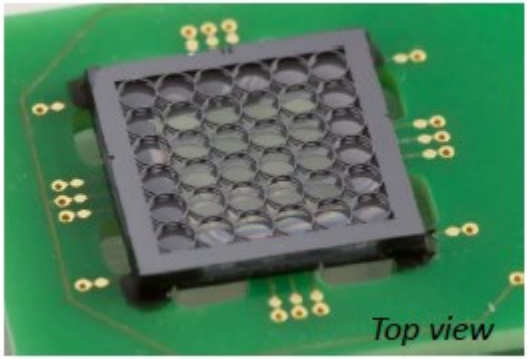
7 wafers to assemble

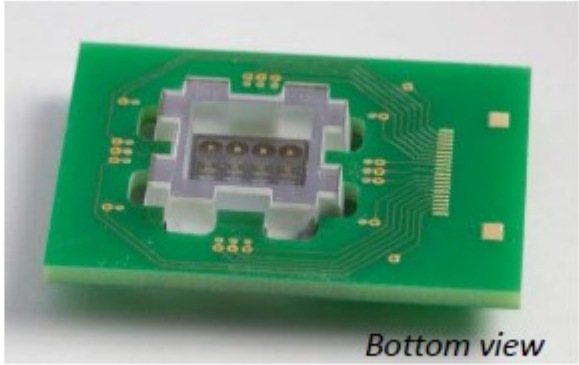


Bonded Mirau stack



Diced chips mounted on PCB





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Vertical integration of array-type miniature interferometers at wafer level by using multi-stack anodic bonding

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[a]Fraunhofer Institute for Electronic Nanosystems, Technologie Campus 3, 09126 Chemnitz, Germany; [b]Technische Universität Chemnitz, 09107 Chemnitz, Germany; [c]FEMTO-ST Institute, 15B, Avenue des Montboucons, F-25030 Besançon, France

ABSTRACT

In this work, vertical integration of miniaturized array-type Mirau interferometers at wafer level by using multi-stack anodic bonding is presented. Mirau interferometer is suitable for MEMS metrology and for medical imaging according to its vertical- lateral resolutions and working distances. Miniaturized Mirau interferometer can be a promising candidate as a key component of an optical coherence tomography (OCT) system. The miniaturized array-type interferometer consists of a microlens doublet, a Scanned MEMS Z scanner, a spacer for focus-adjustment and a beam splitter. Therefore, bonding technologies which are suitable for heterogeneous collective use of both optical and

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Conclusions

- A suitable design and technology have been demonstrated in order to vertically integrate optically functionalized wafers
- Demonstrators and Mirau interferometers have been successfully bonded both at chip level and at wafer level.
- Design of electrical connections for the Mirau interferometer which provides a simple, cost-effective process is proposed and realized.
- Mirau µ-interferometers are successfully assembled and fully characterized.
- The assembled Mirau µ-interferometers can be further integrated with other components of an OCT microsystem.

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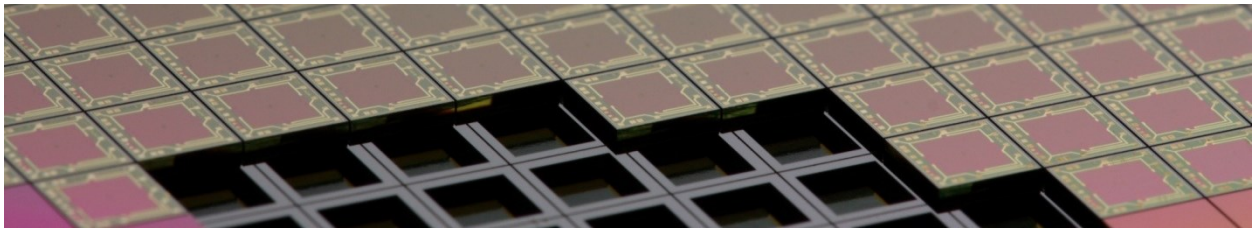
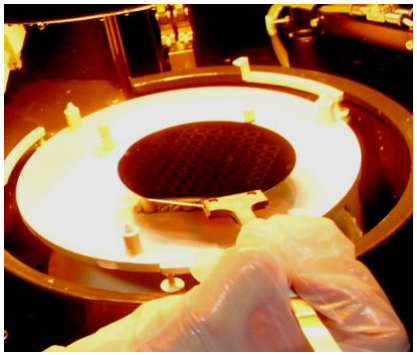
Thank you for your attention





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