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

Wei-Shan Wang\textsuperscript{a}, Maik Wiemer\textsuperscript{*a}, Joerg Froemel\textsuperscript{a}, Tom Enderlein\textsuperscript{a}, Thomas Gessner \textsuperscript{a}, Justine Lullin\textsuperscript{b}, Sylwester Bargiel\textsuperscript{b}, Nicolas Passilly\textsuperscript{b}, Jorge Albero\textsuperscript{b}, Christophe Gorecki\textsuperscript{b}

\textsuperscript{a}Fraunhofer Institute for Electronic Nanosystems, Germany
\textsuperscript{b}Department of MN2S, Institut FEMTO-ST, France
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 diagnosed 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 acceptance by the market
Mirau µ-interferometer: a key component of OCT microsystem which aims to image a total scan area of 8x8x0.5 mm³

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: a key component of OCT microsystem which aims to image a total scan area of 8x8x0.5 mm³

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

- Doublet of microlenses (W1)
- MOEMS Z scanner (W2)
- Spacer (W3)
- Beamsplitter (W4)
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

<table>
<thead>
<tr>
<th>Bonding</th>
<th>Temperature</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct</td>
<td>~1000°C</td>
<td>High surface requirement</td>
</tr>
<tr>
<td>Surface activated</td>
<td>&lt; 200°C</td>
<td>Plasma effect on devices</td>
</tr>
<tr>
<td>Au-Sn eutectic</td>
<td>~300°C</td>
<td>Intermediate material</td>
</tr>
<tr>
<td>Anodic</td>
<td>&lt;500°C</td>
<td>High surface requirement</td>
</tr>
<tr>
<td>Glass frit</td>
<td>&lt;450°C</td>
<td>Need larger area for bond frame</td>
</tr>
</tbody>
</table>
Packaging of Micro-Mirror devices

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

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

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

Optical transparency 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

**Mechanical/electrical through bumps**
- No additional metallization on W3
- Higher miniaturization possible
- Stronger spacer
- More complicated PCB

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**Openings on W1 and W2**

**Additional metallization on W3**

**More space needed**
Demonstrator I simulating a Mirau Stack

<table>
<thead>
<tr>
<th>Interface</th>
<th>bonding step</th>
<th>Alignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface A1</td>
<td>W1</td>
<td>+/- 8µm</td>
</tr>
<tr>
<td>Interface B</td>
<td>W2+W3</td>
<td>+/- 8µm</td>
</tr>
<tr>
<td>Interface C</td>
<td>W1 + W2/W3</td>
<td>+/- 16µm</td>
</tr>
<tr>
<td>Interface D</td>
<td>W1/W2/W3 + W4</td>
<td>+/- 16µm</td>
</tr>
<tr>
<td>Summary</td>
<td>All anodic bonding</td>
<td></td>
</tr>
</tbody>
</table>
Demonstrator II including a mocrolense wafer

To decrease bonding times of W2 as well as bonding temperature

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

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Demonstrator II: bond interfaces

- Interface A: Si-Glass lense
- Interface B: W1-W2
- Interface C (W3-W2)
- Interface D (W4-W3)

Scanning Acoustic Microscope pictures

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

<table>
<thead>
<tr>
<th>Interface</th>
<th>bonding step</th>
<th>bonding parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0, A, A1</td>
<td>lense+lense</td>
<td>350°C, 900V</td>
</tr>
<tr>
<td>D</td>
<td>W3+W4</td>
<td>360°C, 400V (W4 chip without TiO2 layer)</td>
</tr>
<tr>
<td>C</td>
<td>W2+ (W3/W4)</td>
<td>360°C, 2000V</td>
</tr>
<tr>
<td>B</td>
<td>W1+(W2/W3/W4)</td>
<td>360°C, 2000V</td>
</tr>
</tbody>
</table>

**All anodic bonding**

[Diagram of bonding process]

Front side back side

[Images of Mirau Stack at chip level]
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

1st cutting (i.e. 2-2.5mm)

2nd cutting (i.e. 2.5-3mm)

Openings 4mm x 4mm
Assembled Mirau µ-interferometer

7 wafers to assemble

Bonded Mirau stack

Diced chips mounted on PCB


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

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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

Contact

Wei-Shan Wang
Fraunhofer ENAS
Department System Packaging
wei-shan.wang@enas.fraunhofer.de
0049 (0) 371-45001-495

Technologie-Campus-3
09126 Chemnitz
Germany