Chip in the Tip ultra-compact cameras for endoscopic applications

Erik Beckert\textsuperscript{1},
Frank Wippermann\textsuperscript{1}, Sarah Walther\textsuperscript{1}, Thomas Burkhardt\textsuperscript{1,2}, Bernhard Messerschmidt\textsuperscript{3}, Franz Bechtold\textsuperscript{4}, Torsten Vahrenkamp\textsuperscript{5}, Ramona Eberhardt\textsuperscript{1}, Daniel Gäbler\textsuperscript{6}, Andreas Tünnermann\textsuperscript{1,2}

\textsuperscript{1}: Fraunhofer-Institute for Applied Optics and Precision Engineering, Jena, Germany
\textsuperscript{2}: Institute of Applied Physics, Friedrich Schiller University, Jena, Germany
\textsuperscript{3}: GRINTECH GmbH, Jena, Germany
\textsuperscript{4}: VIA electronic GmbH, Hermsdorf, Germany
\textsuperscript{5}: ficonTEC Service GmbH, Achim, Germany
\textsuperscript{6}: X-FAB Semiconductor Foundries AG, Erfurt, Germany
Chip in the Tip Mini Endoscope – Design

Optics

Optomechanics

CMOS-Imager and LTCC PCB

Specifications and Technology

Through Silicon Via & Freeform Dicing

LTCC PCB Design and Packaging

Optics Manufacturing and Assembly

SPDT Prototyping

Flip-Chip / Pick&Place Assembly

Characteristics

Summary
Chip in the Tip – Motivation

Miniaturized Video Endoscope

- best possible resolution
- Image Acquisition and Processing Capacity in the endoscope Head
- Wire or Wireless Connection to the Environment
- compact Designs, round
- flexible Layouts and Assembly
- cheap Manufacturing
- fast Prototyping
- Stable or disposable Systems
Chip in the Tip – Optical Designs

- Straight View
- 2.8 µm Pixel
- Nyquist 178 LP / mm
- FOV 75 ° and 110 °
- F-Number 4.6
- Object Distance 8 mm
- Front Plano-Asphere
- GRIN Lens with back side Aperture
- Back Sphere
Chip in the Tip – Optomechanical Design

- Stainless Steel Tube Ø 3 mm
- Objective Ø 2.8 mm
  - SPDT / Injection moulded Lenses
  - Back Sphere: Drop-on-Demand possible
- stacked Objective
- Imager Anisotropic Conductive Adhesive mounted on LTCC Printed Circuit Board
- LTCC PCB carries Clock
- Imager connected during Assembly & actively aligned
- external Illumination
VGA CMOS-Imager – Specifications

- >VGA\(^{(640\times480)}\) Resolution - 680x680
- Pixel Size 2.78 µm
- Image Circle Ø 2.1 mm
- Outer Ø 2.7 mm
- 50 Frames per Second
- On-Chip Pre-Processing
- 6 Connectors

...because the world is analog.
VGA CMOS-Imager – Through Silicon Via and FreeForm Dicing

- FreeForm Dicing - FFD
  - fully flexible chip shape
  - no unfunctional Si left
- Through Silicon Via - TSV
  - for 400 µm wafers
  - TSV lands on 60x60 µm² metal1 areas in CMOS Backend
  - Via filling by Cu electroplating
  - Backside pads and routing

...because the world is analog.
Ceramic Carrier – LTCC PCB

- Round LTCC Carrier
  - Ø 2.8 mm, 0.8 mm thick
  - 4 Layers DP951
  - Rerouting Front (Sensor) -> Back (Interface) with Oscillator SG-150 (20..50 MHz) and C-Integration
  - Out: Data +/-, 3.3 V, GND

- 4“ Multi-PCB Coupon
  - 49 PCB per Coupon
  - Pre-singulated by cutting / lasering
  - Final Singulation after Reflow by Breaking
Ceramic Carrier – LTCC PCB

Back (Component and Interface) Side

Front (Sensor) Side
LTCC PCB Packaging

- Two Stage Flip-Chip
  - Sensor: Solder Bumps 200 µm, 80Au20Sn on LTCC
  - 370°C / 100°C Sensor / LTCC Reflow
  - Components. Solder Bumps 400 µm SAC305
  - 240°C / 100°C Oscillator, C / LTCC
  - Reflow by FiconTec BL2000
Optics Manufacturing – Prototype Lenses SPDT

- **Single Point Diamond Turning** for Rapid Prototyping in Polymer
  - Material: ZEONEX
  - PV: <300 nm, rms ca. 50 nm
- **Single Point Diamond Turning** for Mould Manufacturing
  - Mould Material: electroplated NiP
  - Ultrasonic Sound enhanced SPDT -> Stainless Steel Moulds
  - Replication by Injection Moulding
Optics Assembly – Automated Pick&Place for Stacking

- Objective Stacking
  - passive Concentric Alignment
  - Decenter < 10 µm
  - Tip / Tilt < 1°

- active Alignment (Tip/Tilt/ Focus)
  - Objective <-> Imager-Assembly

- Imager pre-Assembly on LTCC

- Handling / Connector frame on LTCC

- Singulation @ predetermined break point

- automated in FlipChip Bonder BL2000 (ficonTEC)
Optics Assembly – Front Window Soldering

- Long term stable soldered Front Window
- Solderjet Bumping\(^1\) – overlapping discrete Solder Droplets
- Liquid Solder Application, no flux, local thermal Impact
- 300 μm Ø Spheres AuSn used
- Time ca. 1 min (Bumping Frequency 1 Hz, 10 Hz possible)
- Autoclave Cycles 5x @ 134 °C, 98 % rel. Humidity, 5 min
- Hermeticity before and after Autoclave Cycles: 4e\(^{-9}\) mbar*l*s\(^{-1}\)

\(^1\): Patented: DE102007002436 & WO03/006197
Front Window Soldering

First Step: Fixation

Second Step: Hermetic Sealing
Optics Evaluation – Modulation Transfer Function

- Method: Slanted Edge*, Goal\(\text{(Nyquist/2)}\): 90 LP / mm @ 30 % contrast
- FOV 75 °: > 100 LP / mm @ 30 % contrast
- FOV 110 °: > 100 LP / mm @ 30 % contrast

Optics Evaluation – Depth of Fokus

MTF @ -6 mm, FOV 75°

MTF @ +12 mm, FOV 75°

MTF @ -6 mm, FOV 110°

MTF @ +12 mm, FOV 110°

Goal: 60 LP / mm @ 20 % contrast
Optics Evaluation – Distortion

FOV 75 °
-18 % max.

FOV 110 °
-40 % max.
Summary

- SPDT manufactured Prototype Lenses
- Central GRINS lens for stacking
- FFD round CMOS-Sensor with TSV
- Pick& Place for simplified Assembly
- long term stable soldered Front Window
- automated mid-Volume Production

Flexible Integration
Acknowledgement

The work presented in this presentation is based on the project HoKa (miniaturized high resolution camera systems). Funding by the Thuringian Government and the European Regional Development Fund (ERDF) as well as project management by the Thueringer Aufbaubank (project number 2008 VF 0057) is gratefully acknowledged.

Thank you for your Attention.