On-chip MEMS for automated chip-to-chip assembly

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Photonics for data communication

- Photonic packages to enable massive data communication
- Complex packages, containing: Photonic Integrated Circuit (PIC), micro-optics, electrical components
- Integration is a key challenge
  Technology exists for assembly, however:
  - Labour intensive
  - Expensive

1st generation 40G package
Case: multi-chip photonic package

- Two PICs
- Multiple O-I/O
- Required precision for each O-I/O: $\pm 0.1\mu m$, control $T_{IP}, T_{OOP}, R_{PROP}$
Enabler: microfabrication and MEMS

• **Passive alignment**: geometric mating features

• **Active alignment**: use of MEMS
The concept

- Integrate an “assembly machine” into one of the photonic chips for fine alignment: on-chip MEMS
- Two-stage process

Step 1: pre-assembly of photonic chips on common carrier, flip chip bonding
The concept

- Integrate an “assembly machine” into one of the photonic chips for fine alignment: on-chip MEMS
- Two-stage process

**The potential:**
- Increased assembly automation, cost reduction
- Local alignment: high precision

Step 2: Fine alignment of flexible waveguide structures using on-chip MEMS

*MEMS = MicroElectroMechanical System*
On-chip functions

- Functions:
  - Flexible waveguide beams, coupled by cross-bar
  - Actuators
  - Waveguide beam locking

By chip assembly
By on-chip actuators
SiO$_2$ photonic MEMS

**Challenges**

- Functionality realised in TriPleX material platform:
  - **Fabrication**
    - Compressive stress in thick SiO$_2$
  - **Actuation range**
    - All relevant motion direction
    - CTE of SiO$_2$ (thermal actuators)
  - **Deformation**
    - Residual stress in multi-material layers
  - **Design integration**
    - All functions cooperating, space consumption
  - **Locking precision**
    - Maintain position

![TriPleX™ platform diagram](image)
Fabrication and results
Fabrication in TriPleX material platform

- Frontside release
  - Structuring of photonic layer (plasma etch)
  - Release by underetching Si (isotropic plasma etch)
Fabrication in TriPleX material platform

- Poor yield
  - $\text{SiO}_2$ under compressive stress
  - Clamped-clamped beam situations

Fabrication in TriPleX material platform

• Improved process: “Si-reinforced”
• 98% yield (single cantilevers)

Fabrication process for reliable structure release
Fabrication in TriPleX material platform

- Improved process: “Si-reinforced”
- 98% yield (single cantilevers)
Thermal bimorph actuators
Example structure
Post-fabrication deformation

![Graph and diagram showing vertical position vs. position over beam (mm) for waveguide beam, inner actuator beam, and outer actuator beam.]

Peters, Tichem, SPIE Photonics Europe, Brussels, 2016, doi 10.1117/12.2222512
Peters, Tichem, Journal paper under preparation
Waveguide motion

*Side view of bimorph actuator*
Motion measurements

(a) $\Delta y_{\text{center}}$ plotted as a function of voltage

Peters, Tichem, SPIE Photonics Europe, Brussels, 2016, doi 10.1117/12.2222512
Height compensation and actuation range using short loop bimorph actuators
Initial deflection

Bimorph actuators (short loop)

Chip150 (short-loop poly-Si):
$L_{ox}=650\mu m$, $L_h=150\mu m$

Double-layer membrane

Fully released structures

Waveguide beams

Crossbar

Wu, Tichem, SPIE Photonics West 2016, doi: 10.1117/12.2209499
Motion measurement

Chip150 (short-loop poly-Si):
$L_{ox}=650\mu m$, $L_h=150\mu m$

Laser vibrometer measurement
Amplitude: 4V,
Offset: 2V,
Frequency: 2Hz

Wu, Tichem, SPIE Photonics West 2016, doi: 10.1117/12.2209499
Conclusions

• Concept proposed for highly automated, high-precision, multi-port chip-to-chip alignment, exploiting MEMS

• Implementation of concept is challenged by thick ($\approx 16\mu m$) SiO$_2$ material, and requires smart designs:
  – Reliable fabrication is feasible with proper process design (make use of supportive Si) and chip design (prevent clamped-clamped beam situation)
  – Short-loop actuator design to use post-fabrication deformation for height compensation and have motion ranges in order of few $\mu m$

• Basic functions demonstrated, currently working on in-plane actuation, locking, optical coupling experiments and integration into overall concept
Towards a complete process

*EU FP7 PHASTFleX*

First proof of assembly
TriPleX chip w/o MEMS

Wörhoff et al, SPIE Photonics Europe, 2016
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