Passively aligned fiber-coupling of planar integrated waveguides

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- Research published:
Motivation

- Fiber coupling of integrated optical systems is important:
  - Communication over long distances
  - Coupling to sources
  - Interlinking of PLCs (Planar Lightwave Circuits)

- Properties
  - High integration density of PLCs → Fiber-Arrays
  - Facet-coupling of dielectric waveguides with low index-contrast is most efficient (in terms of IL, space consumption etc.)
  - Small surface area on the facets of the fibers and waveguide-boards limits the durability of a facet joint
State of the Art

- Active alignment of fiber-arrays and adhesive bonding
  - Apply glass-blocks to enlarge the bonding surface
  - Polishing the facet
  - Active alignment & bonding using and UV-curing adhesive
- Automation difficult & device specific (high volume)
  → Fiber-coupling is a significant cost contributor
**Approach**

- **Goal:** passively aligned multi-channel fiber coupling of PLCs
- **Silicon-element with V-Grooves**
  - V-Grooves as Fiber-Holder
  - V-Grooves as alignment feature
- **Coupling interface on PLC board**
  - Structured cladding
  - Core structures as alignment feature

Source: Kremmel et al., Opt. Eng. 56 (2) 2017
Coupling characteristics

- Lateral and angular displacement – coupling efficiency
  - Waveguide: 5µm x 5µm, Δn = 0.006

![Coupling Losses, lateral displacement](image1)

- Accuracy, accepting a displacement loss of 0.5dB:
  - Lateral: <1.5µm
  - Axial: <50µm
  - Angular: <1.2°
  - Losses by Mode-Mismatch: 0.18dB

![Coupling Losses, angular displacement](image2)
Silicon-Element

- Precise Etching of V-Grooves in Silicon using KOH
  - Slow etching \{111\}-Planes for high accuracy
  - 8 Grooves for fibers
  - 3 Grooves as alignment feature
  - Large bonding area: minimal angular deviation, adhesion

- Assembly
  - Adhesive bonding of the fibers
  - cut and polish the fibers using a wafer dicer
    → all facets in one plane, <30nm RMS
**Coupling Interface PLC**

- Waveguides with structured top-cladding
  - Structuring by using UV-LDI
- Alignment structures corresponding to alignment V-Grooves
  - Alignment features and waveguide-cores in the same process step
  - Maximum position accuracy

→ Assembly using UV-curing adhesive
Assembly I

- Application of the silicon fiber-ribbon onto the PLC-Board
  - Alignment structures fit to V-Grooves and provide precise lateral alignment
  - Axial alignment: facets act as stop

- Mounting using UV-curing adhesive
  - Adhesive as index-matching agent
Assembly II

- Microscopy analysis of the Assembly
  - Cross-sections to investigate alignment
Optical Characterization

- Measurement of the Coupling Loss
  - Compare passively coupled WGs and reference WGs

- Reference Measurement:
  - Measure light transmitted through WG

- Measurement passive coupling:
  - Measure light transmitted through WG & coupled into SM-Fiber
**Results**

\[ T_{\text{Ref}} = -1.69 \, \text{dB} \]

\[ T_{\text{Ribbon}} = -1.92 \, \text{dB} \]

\[ \rightarrow \text{Losses by SM-Coupling (CL)}: \quad 0.23 \, \text{dB} \]

\[ \text{Losses due to Misalignment}: \quad 0.05 \, \text{dB} \]

\[ \rightarrow \text{CL – Transition Loss}: 0.23\, \text{dB} - 0.18\, \text{dB} \]

\[ \text{Scattering Losses}: \quad 0.22 \, \text{dB} \]

\[ \rightarrow \text{Cut-Back Measurement} \]

\[ \rightarrow \text{Total Coupling Losses/Interface}: (0.45 +/- 0.20) \, \text{dB} \]

\[ \rightarrow \text{Transition Loss + Misalignment + Scattering} \]
Results II

- Climate Tests:
  - Thermal Cycling: -30 – 70°C, 10 times
    → Transmission remains unchanged on all channels
  
  - 85/85-Test for 168h:
    → Losses increase by 1.2dB in average
    → Reference Waveguides stable
    → SEM-Analysis of Cross-Sections: delamination of the adhesive in the gap between fiber and waveguide
Conclusions

- Passively aligned coupling of 8 SM-fibers to 8 SM-WGs has been demonstrated successfully
  - Achieved coupling losses are significantly lower than earlier reports
  - Simple assembly: no additional tools necessary (even by hand)
  - For climate tests → further optimization of assembly process

- Only standard MEMS resp. MOEMS fabrication and packaging processes have been applied
  - Si-etching in KOH
  - Adhesive bonding
  - Wafer dicing