Optical Free-Form Couplers for High-density Integrated Photonics (OFFCHIP)

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Solving the optical I/O bottleneck

Optical coupler requirements: **low loss, broadband, high-density & good alignment tolerance**
Free-form micro-optical reflective couplers

Elliptical reflector

- Couples focused light from one point to another

Parabolic reflector

- Transforms focused light into a collimated beam
Free-form micro-optical reflective couplers

A universal coupling platform

*J. Lightwave Technol.* **38**, 3358-3365 (2020)
Fiber-to-chip reflective coupler

Free-form reflector combines beam redirection, expansion, and shaping functions.

Optical fiber

Waveguide

Reflector

Fiber mode

Reflected beam
Chip-to-fiber reflective coupler: simulation

Coupling efficiency 95.3% (0.21 dB insertion loss)
Chip-to-fiber reflective coupler: simulation

Low loss (< 0.27 dB) for both polarizations across the entire telecom band

J. Lightwave Technol. 38, 3358-3365 (2020)
Chip-to-fiber reflective coupler: simulation

- ± 2.5 μm 1-dB alignment tolerance
- Compatible with passive alignment
## Performance benchmark

| Coupling scheme | Edge | Grating | OFFCHIP |
|-----------------|------|---------|---------|
|                 | Opt. Commun. 283, 3678 | OFC M2I.5 (2016) | This work |
| Insertion loss  | 0.4 dB | 0.36 dB | 0.21 dB |
| 1-dB bandwidth  | > 100 nm | 50 nm | > 400 nm |
| Alignment tolerance (1-dB) | 0.9 μm | 2.4 μm | 2.5 μm |
| Bandwidth density | Limited by fiber pitch | High (2-D array) | High (2-D array) |
| Testing method  | Die-level | Wafer-level | Wafer-level |

**Notes:**
- **Opt. Commun. 283, 3678**
- **OFC M2I.5 (2016)**
- **This work**
Chip-to-fiber reflective coupler: fabrication

➢ < ±160 nm alignment accuracy
➢ < 10 nm surface RMS roughness
Chip-to-fiber reflective coupler: fabrication

- Photonic device fabrication at AIM Photonics
- High-throughput two-photon-polymerization fabrication
- Fiber attachment

Writing time: 24 s per coupler; measured coupling loss: 0.9 dB
Chip-to-free-space coupler: optical trapping

- 3-D trapping of levitated particle
- Versatility in trap geometry design
- High efficiency: 10x lower trapping power
- Broadband operation

With F. Capasso et al.
TEA: comparison of testing and packaging process flow

- Photonic packaging processes nowadays can make up 20-70% of the total optical device/module costs.
- Comparison based on fully automated alignment, testing and packaging processes for high volume manufacturing (HVM) considerations.
- Optical coupling method also strongly affects the testing and known-good die (KGD) selection process.
TEA: comparison of estimated cost

- **Edge coupling** incurs high packaging cost:
  - Requires sub-mounts;
  - Difficulties in fiber alignment & attachment;
  - Inability of wafer level-testing.

- **Surface coupling methods**:
  - Wafer level testing reduces time by orders of magnitude;
  - Easy and mature fiber alignment & attachment;
  - Gratings are wavelength and polarization sensitive.

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**Grating**

- Die singulation
- Wafer level test. (KGD)

**OFFCHIP**

- Wafer level polymer coupler
- Die singulation
- Die on substrate/board attach.
Summary

OFFCHIP: a photonic packaging technology that is

- Completely wavelength-agnostic
- Low loss: < 0.3 dB
- Compatible with high-density wafer-scale testing & packaging
- Alignment tolerant
- Lower cost compared to edge coupling
- A universal coupling platform