Wavelength-independent coupler from fiber to an on-chip cavity, demonstrated over an 850nm span

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Importance of phase match

Efficient coupling

Identical velocities

\[ n_{\text{eff} 1}(\lambda) - n_{\text{eff} 2}(\lambda) = 0 \]

Different velocities

\[ n_{\text{eff} 1}(\lambda) - n_{\text{eff} 2}(\lambda) \neq 0 \]

Bent - Straight

\[ n_{\text{eff} 1}(\lambda) \neq n_{\text{eff} 2}(\lambda) \]
## History

<table>
<thead>
<tr>
<th>Straight – Bent</th>
<th>Bent – Corner</th>
<th>Need:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tapered fiber</td>
<td>Prism</td>
<td>1) Wavelength independent</td>
</tr>
<tr>
<td>Asymmetrical</td>
<td>(Wavelength dependant)</td>
<td>2) Fiber compatible</td>
</tr>
<tr>
<td>Fiber compatible,</td>
<td>Tunable to a <strong>broad</strong> wavelength span</td>
<td></td>
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<tr>
<td>Wavelength dependant.</td>
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</tbody>
</table>

- **Ulrich**, JOSA 60 1337 (1970)
- **Sarid**, APL 33 514 (1978)
Motivation

Motivation: Open current technology of ultra-high Q cavities to be fiber accessible for applications in a regime spanning from the extreme UV to the IR band.

One example: On-chip continuous visible emitter by third-harmonic generation.

- Need to couple in the IR pump (1500 nm) while coupling out visible signal (500 nm)

Can we combine symmetry with fiber coupler?

<table>
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<th>Past</th>
<th>Today</th>
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<tbody>
<tr>
<td><strong>Straight – Bent</strong></td>
<td><strong>Bent – Bent</strong></td>
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<tr>
<td>Tapered fiber</td>
<td>Bent tapered fiber</td>
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<tr>
<td>Asymmetrical</td>
<td>Symmetrical</td>
</tr>
<tr>
<td>Fiber compatible, Wavelength dependant.</td>
<td>Wavelength independent</td>
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</tbody>
</table>

*Carmon et al, Submitted to Optics Express (2007)*


- Ulrich, JOSA 60 1337 (1970)
- Sarid, APL 33 514 (1978)
- Gorodetsky, Opt Comm, 113 133 (1994)
Bend-coupler fabrication

• Pull an optical fiber above a flame

• Push and twist

• Pull, anneal
Experimental Setup

Symmetrical coupling (wavelength independent)

Diameter of a human hair

40 μm

5 μm

Cavity

Fiber
Experimental Results

Variable coupling distance

- Operating along a 850nm span
- Visible wavelength is more than twice shorter than the IR
- Q for both colors > 20 millions
Experimental results

Comparison with tapered fiber coupler

Tapered coupler functions properly at one wavelength while at the other wavelength we could measure no coupling at all.
Experiment
Fixed coupling distance

Simultaneous coupling of two wavelengths

Coupling distance scales with wavelength, this is why the short wavelength is under coupled while the long is over coupled.
Advantages of bent-bent coupler
(200-2000nm, fiber compatible)

- Good resistance for surface effects (e.g. roughness, contaminations) that degrade transmission
  - Mechanically stable
  - Thermally stable (Tapered fibers burn in vacuum)

- Bent-bent configuration is Fat:
  - Short coupling distance

- For a given velocity mismatch, the bent-bent configuration will acquire smaller phase-mismatch (better phase-match)

Evanescent wave

Bent-bent: the mode is grazing the interface only in a short and azimuthally-selective region
Disadvantages of bent coupler

Contains also high order modes

• Not a problem when coupling from fiber to cavity.
• Light coupled out of the cavity to high-order modes will be lost when entering the single mode fiber.

Possible solution:
• Thin single-mode bent coupler (and thin ring cavity)
Conclusion

For circular Cavities the bent–bent configuration

- Wavelength-independent (along an 850 nm span)
- Fiber compatible
- Facilitating applications spanning along the entire silica transparency span (200nm – 2000nm)

*The coupler mode is minimally grazing the surface*

- Resistance for surface contaminations and roughness.
  Cross-section area is 25 times larger than Straight-straight coupler implies proportionally better:
  - Mechanical strength
  - Power handling capability

For Photonic Crystals, thin films, waveguides etc:

Free space
Carmon et. al., Wavelength-independent coupler from fiber to an on-chip cavity, demonstrated over an 850nm span. submitter to Optics Express (2007)
Over coupling

Ideality better than 60% for the over-coupled regime and ideality better than 40% for the under-coupled region. The physical reason that ideality decreases with coupling distance is that high-order modes extend (evanescently) from the coupler to a greater distance which is longer than that of the fundamental mode.

Carmon et. al., Wavelength-independent coupler from fiber to an on-chip cavity, demonstrated over an 850nm span to Optics Express (2007)