6th ESA Round Table on Micro & Nano Technologies for Space Applications

Hollow Waveguide Optical PCB Technology for Micro-Optical Sensors

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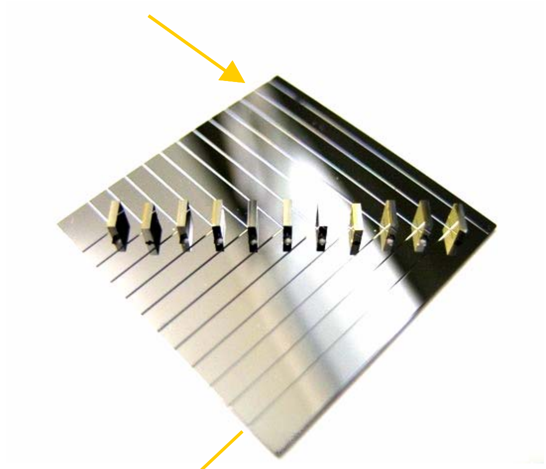

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ESTEC

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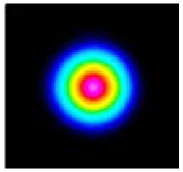

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ESA’s interests in relation to space instrumentation

- Optical and laser based systems play an increasingly important role in space missions. In such missions, key requirements are:

  - small size
  - low mass
  - robustness to optical misalignment
  - good optical efficiency
  - low cost

- An optical PCB concept could fulfil these requirements

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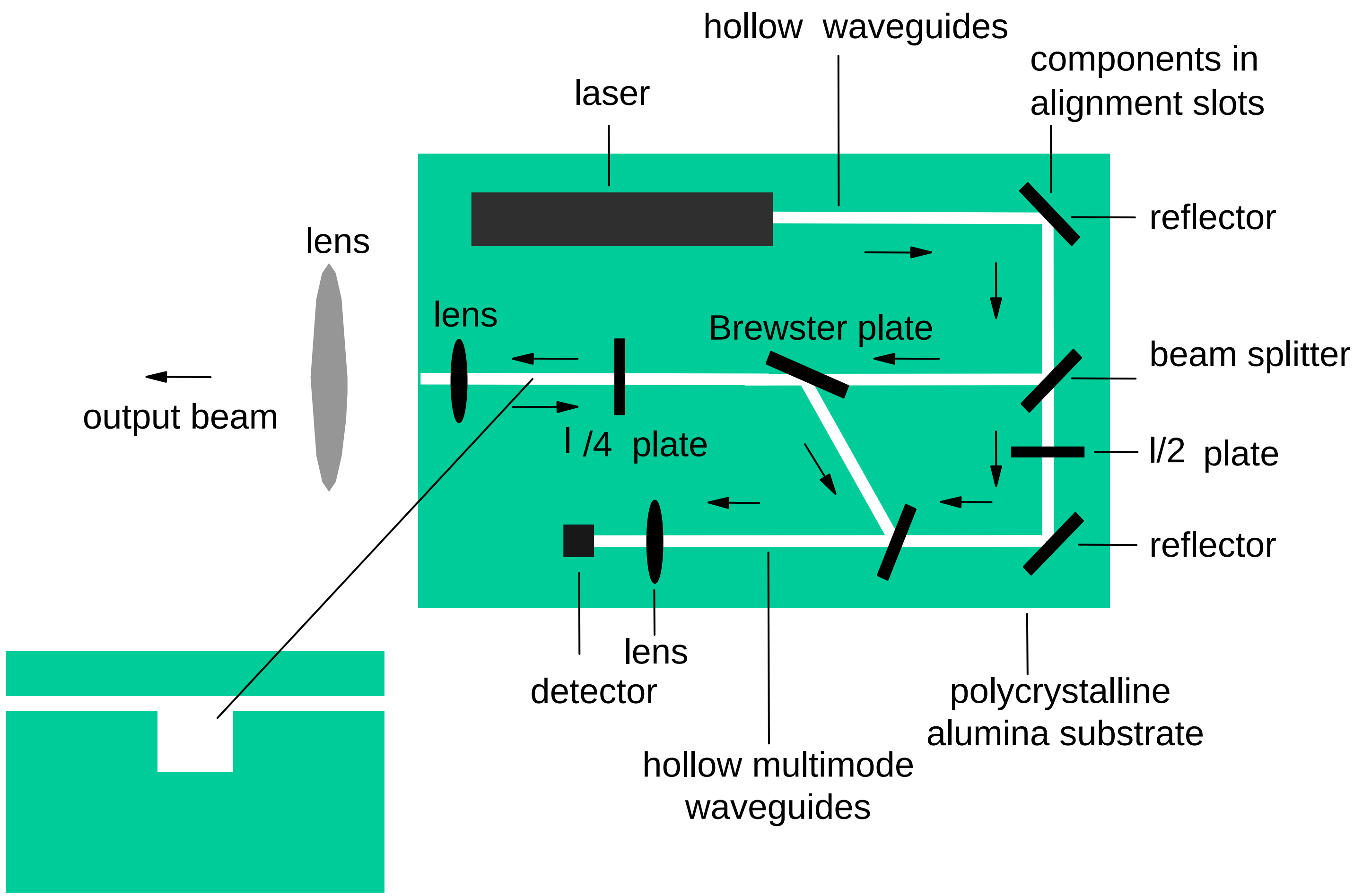
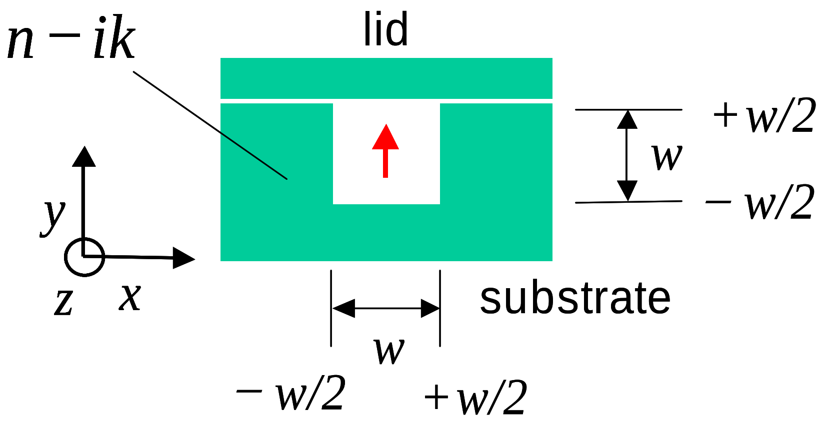
The hollow waveguide optical PCB concept

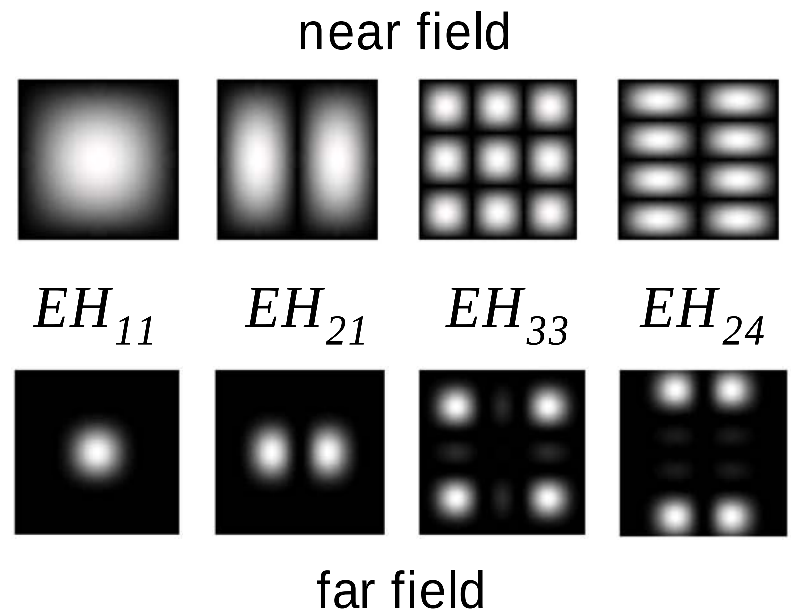


Advantages of hollow waveguide optical PCB concept

- Provides a fundamentally new approach to the manufacture of micro-optical systems
  - Inherently compact, rugged (optically robust) and low mass
  - Easy integration of any required discrete component
  - Easier angular alignment tolerances result in excellent optical performance
  - Optical guidance means small beam widths allowing increased packing density compared with free-space systems
  - The hollow core waveguides facilitate very broad waveband, high power transmission characteristics compared with solid core guides
  - Considerable potential for low cost mass manufacture

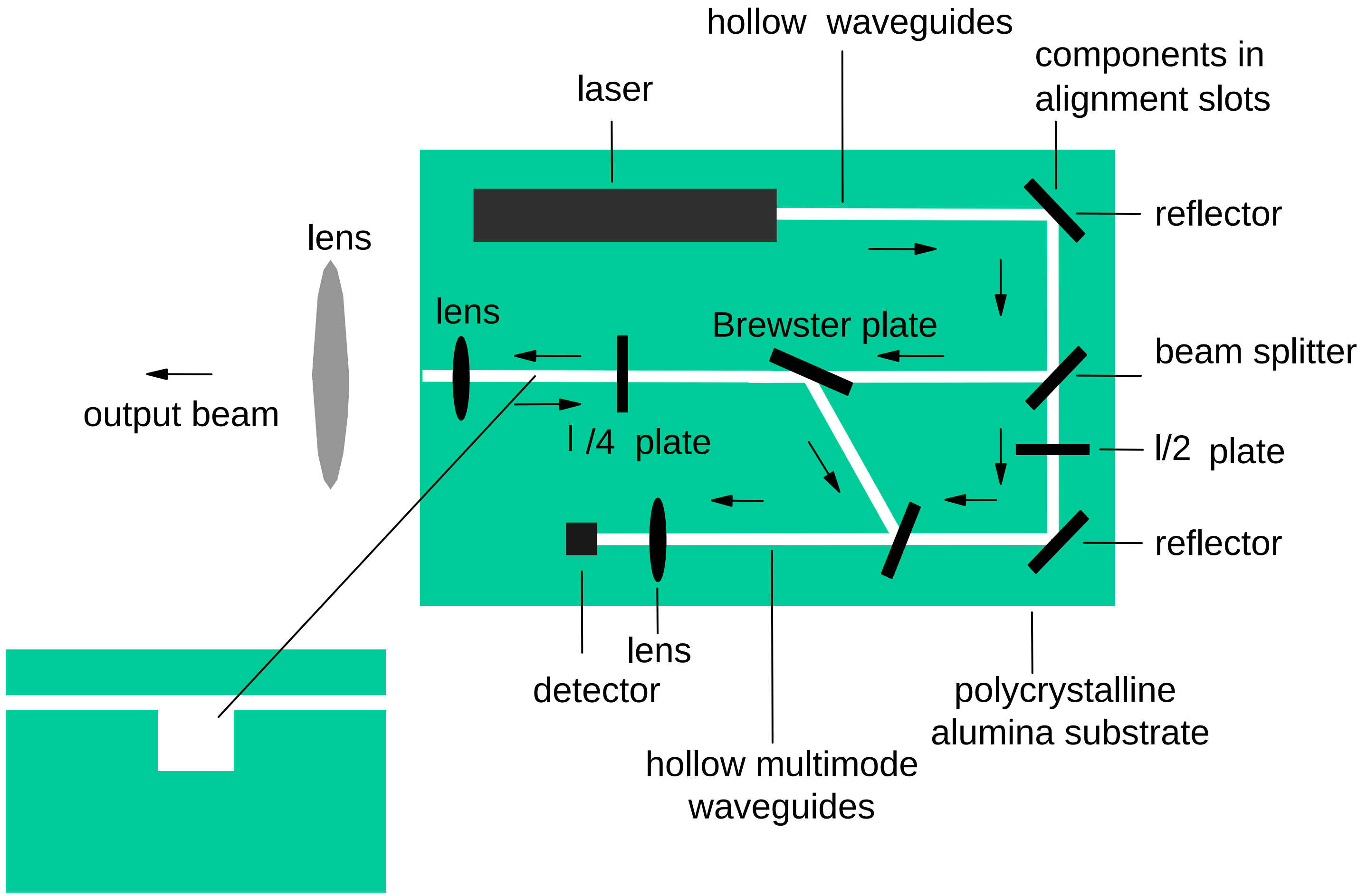
Hollow waveguide mode theory





$$T_{pq_{dB}} = -4.35\,\frac{\lambda^2}{w^3}\left[p^2\,Re\left(\frac{1}{\left\{(n-ik)^2-1\right\}^{1/2}}\right) + q^2\,Re\left(\frac{(n-ik)^2}{\left\{(n-ik)^2-1\right\}^{1/2}}\right)\right]$$

The hollow waveguide optical PCB concept

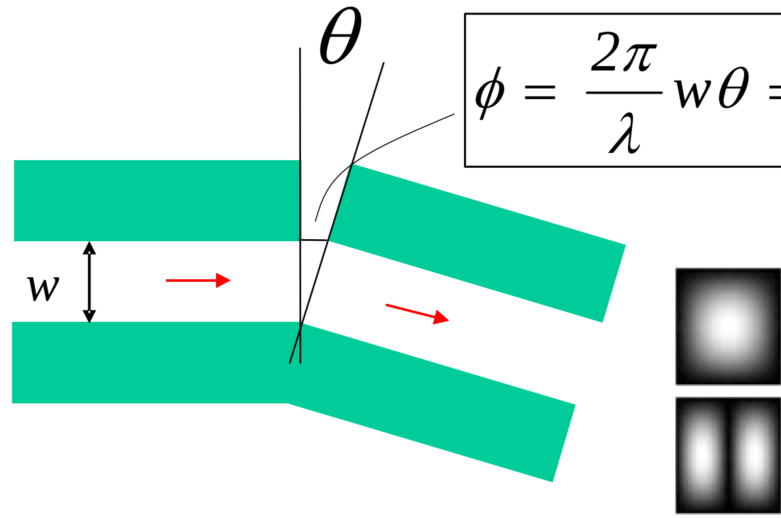


Definition of alignment criteria

angular alignment criteria

$$\theta \le \frac{\lambda}{5w}$$

equates to EH_{11} coupling ≥ 0.95

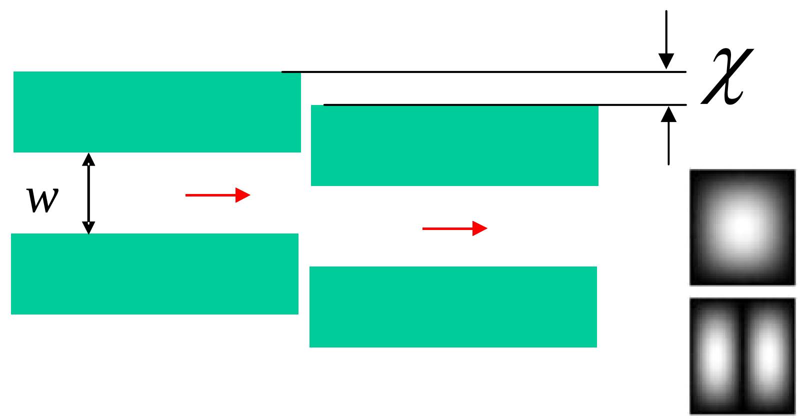


$$\phi = \frac{2\pi}{\lambda} w\theta = 2\pi\,\theta\frac{w}{\lambda}$$

lateral alignment criteria

$$\chi \le \frac{w}{15}$$

equates to EH_{11} coupling ≥ 0.95



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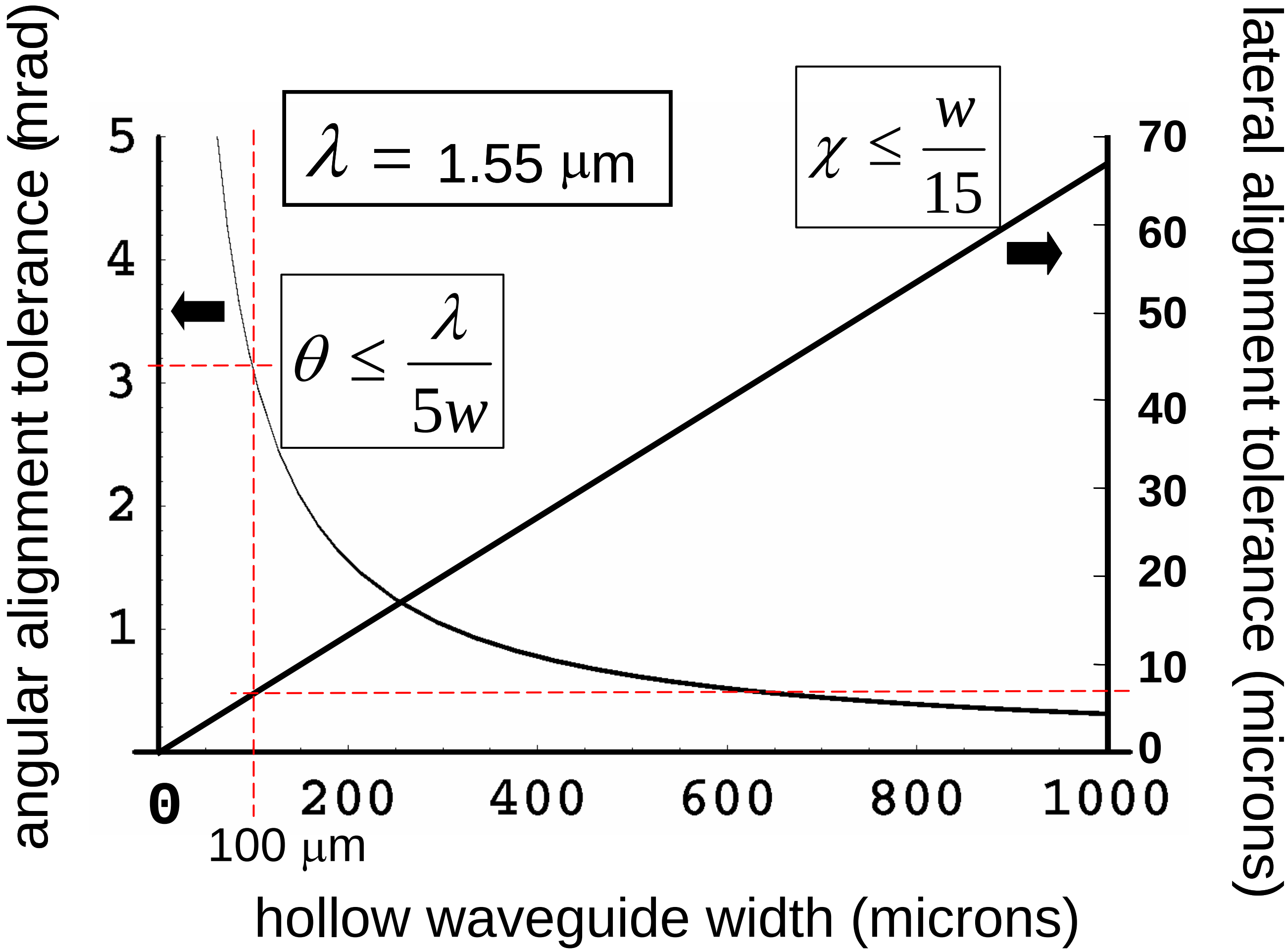
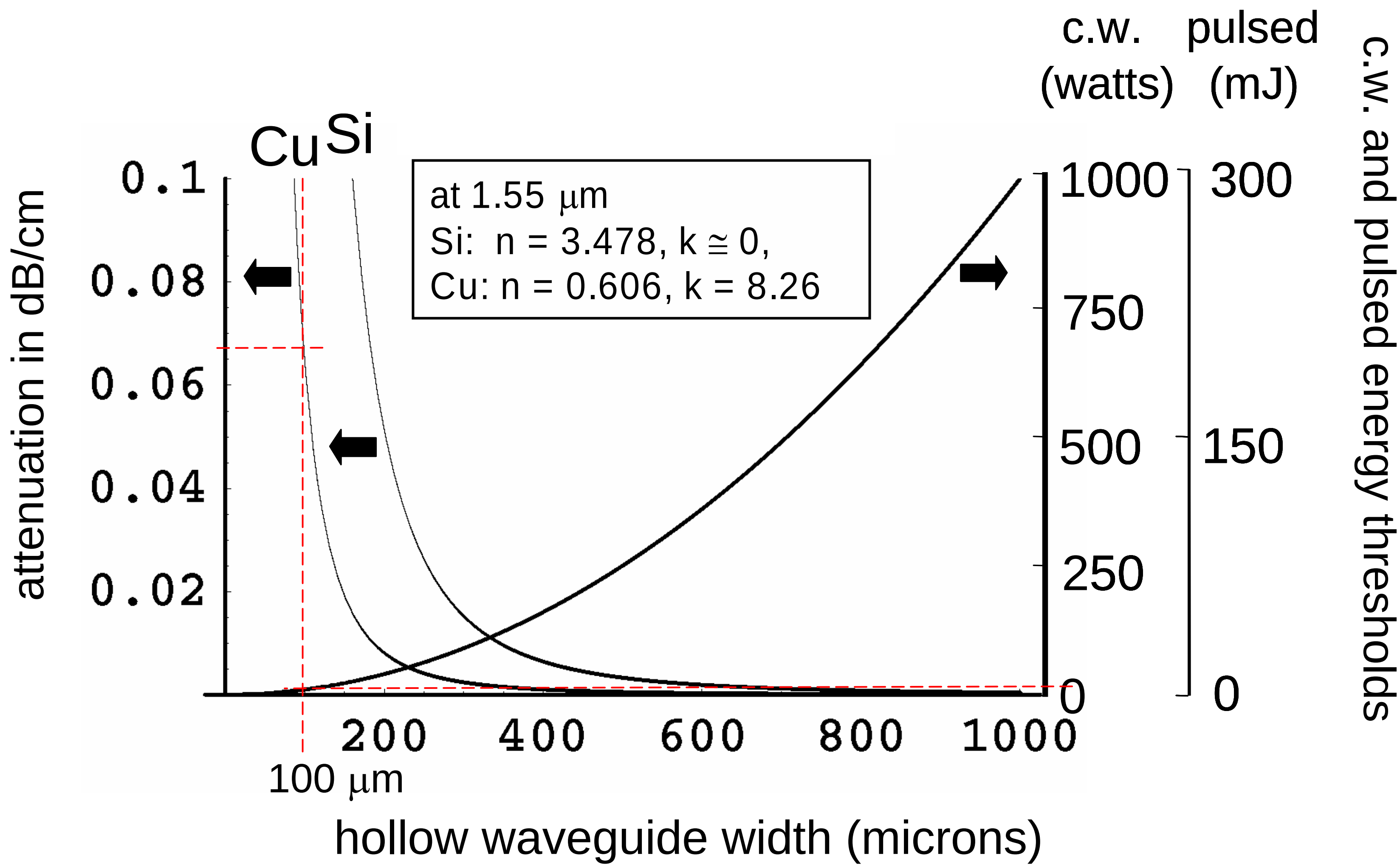
Angular and lateral alignment tolerances versus guide width



Attenuation and power handling versus guide width



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QinetiQ Malvern MEMS processing facility

Leading European provider of custom military & commercial MEMS solutions

- Experienced, integrated team of

  50 staff

Key Capabilities

- MEMS design and modelling
- CMOS Electronic design (PCB / MCM / ASIC)
- Microsystems with embedded processing
- Microstructure fabrication (ISO9001) Advanced characterisation and test

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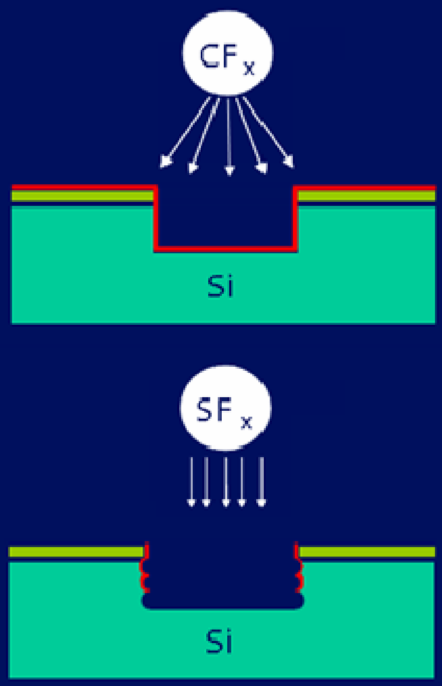
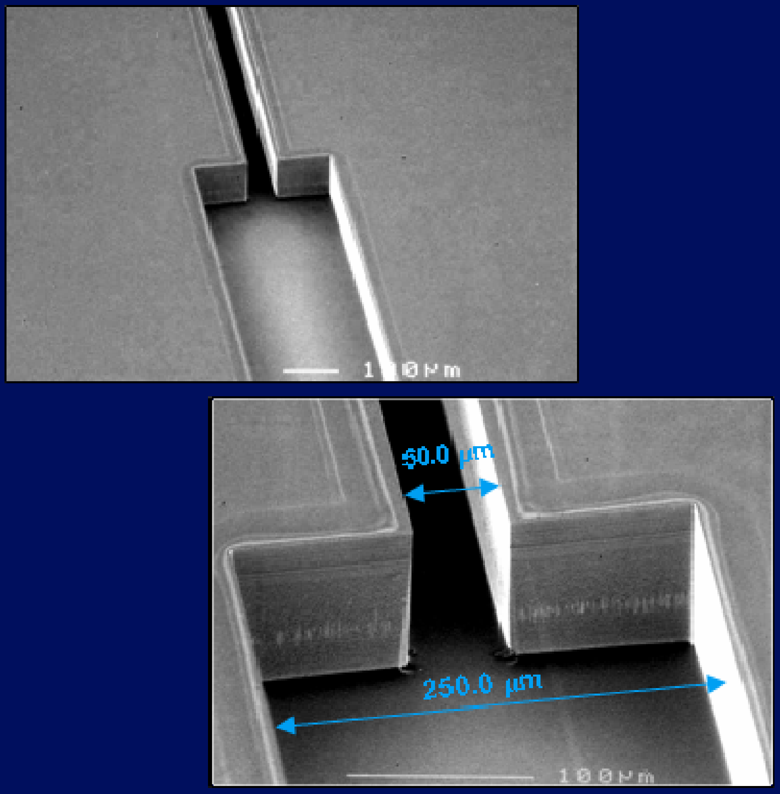
Hollow silicon waveguides for 1.55 μm micro-optical systems

DRIE Passivation & Etch Cycle





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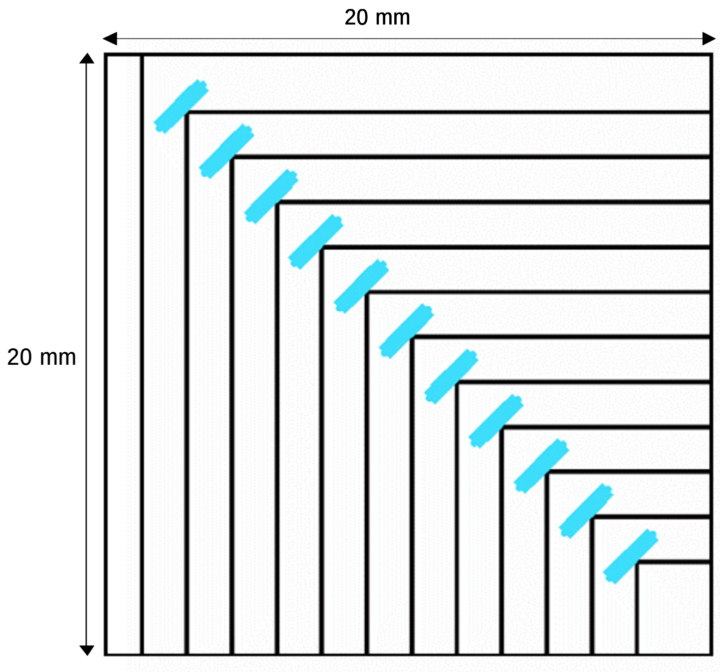
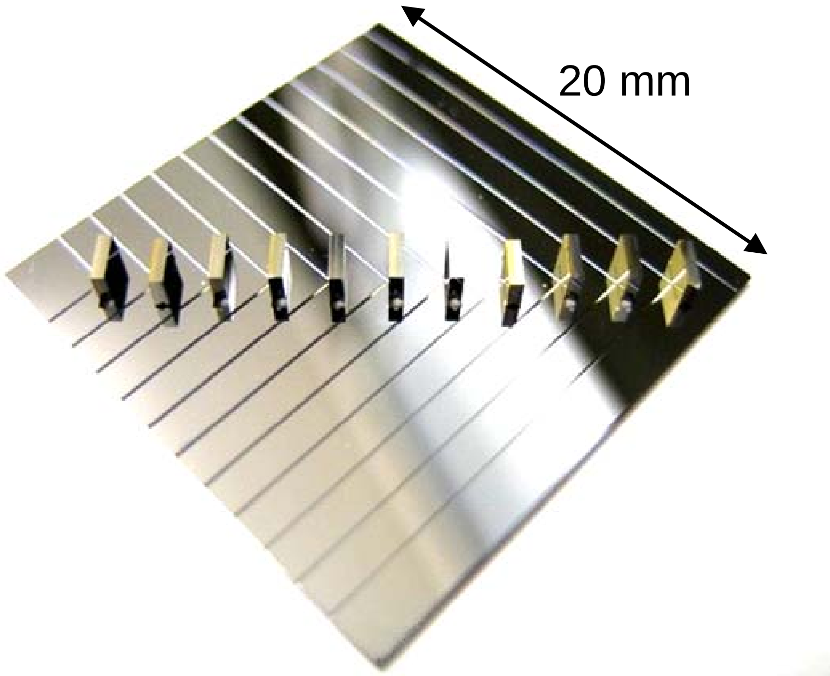
11-element 90° fold array based on precision alignment slots





Optical PCB test structure with eleven 2 x 2 x 0.5 mm integrated fully reflecting fold mirrors in conjunction with 125 μm wide hollow guides for assessing alignment reproducibility

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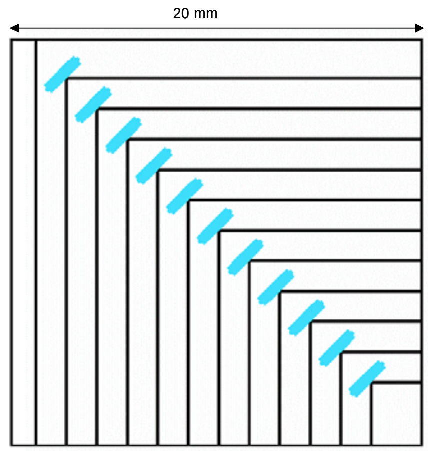
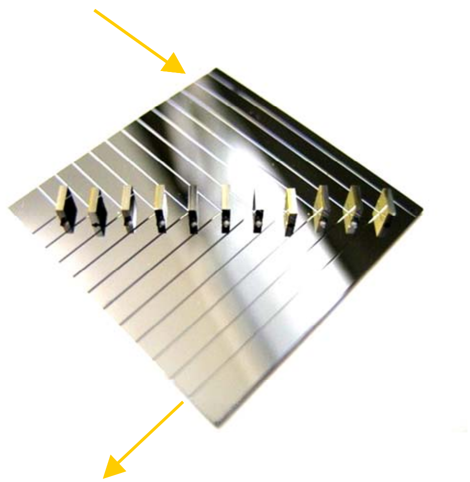
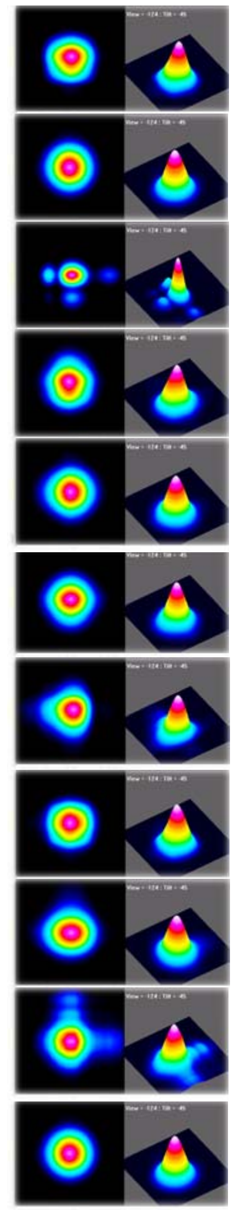
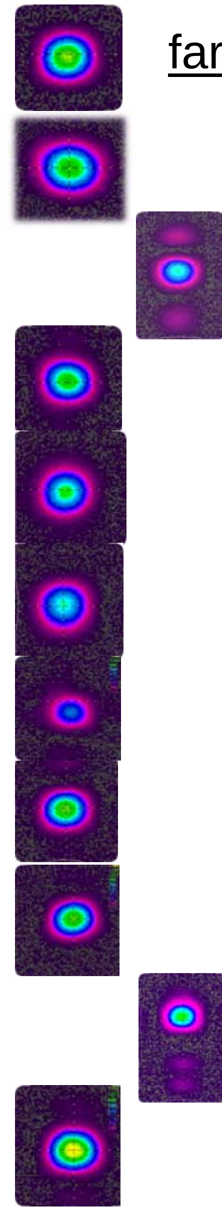


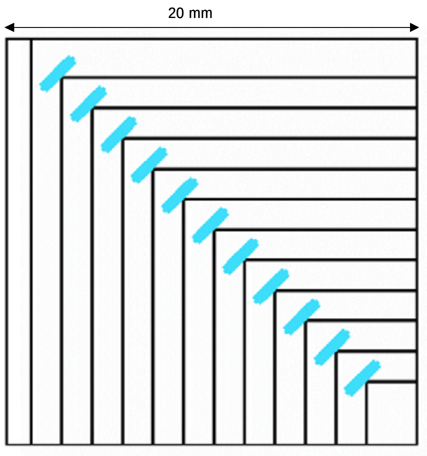


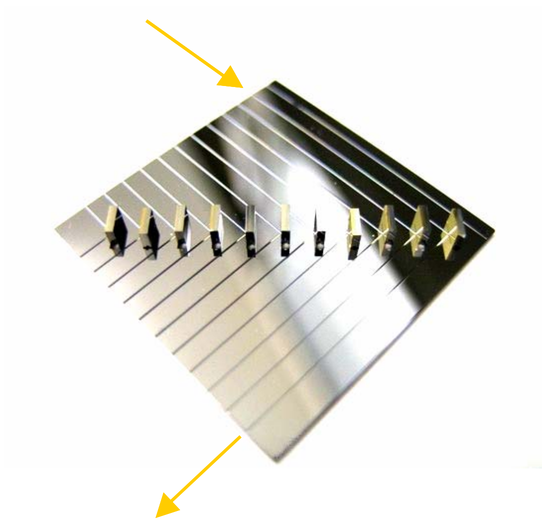
fold 1 near field far field
fold 2
fold 3
fold 4
fold 5
fold 6
fold 7
fold 8
fold 9
fold 10
fold 11

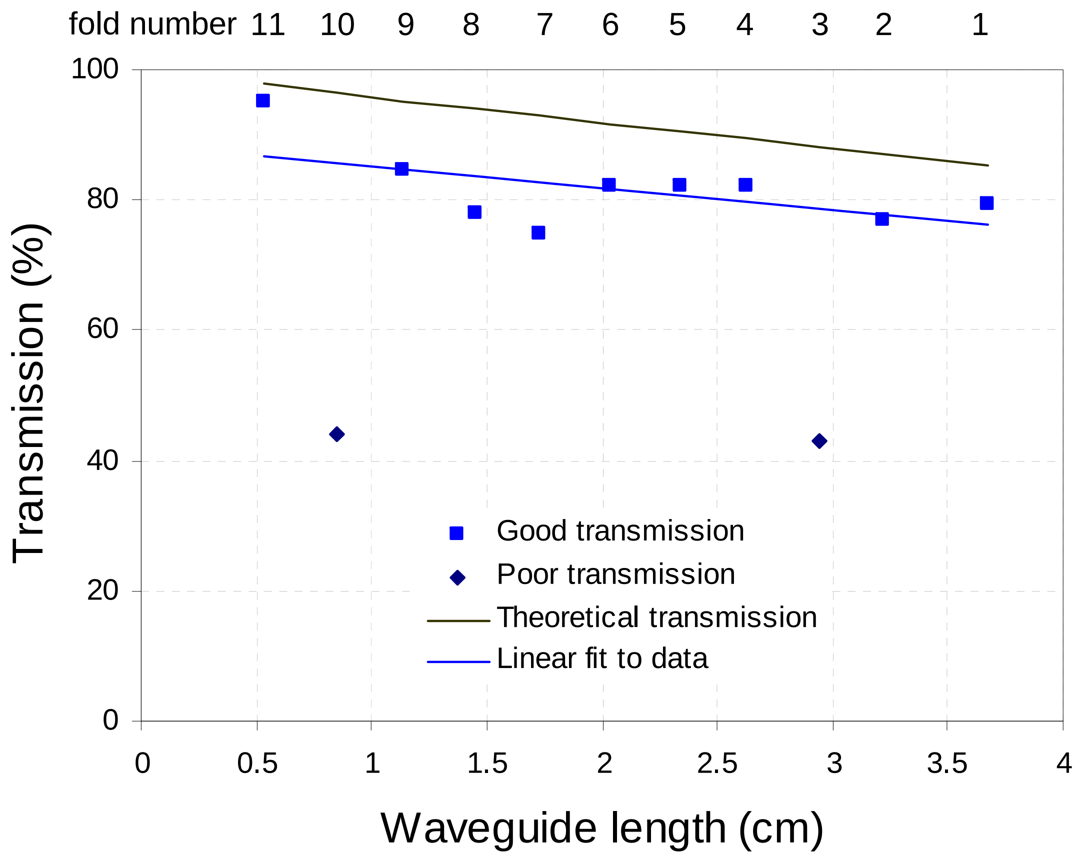




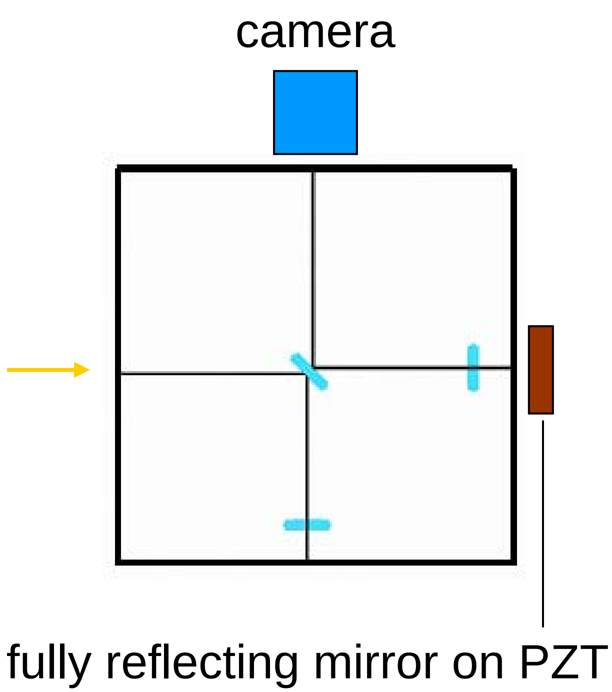
Measurements of attenuation as a function of overall guide length

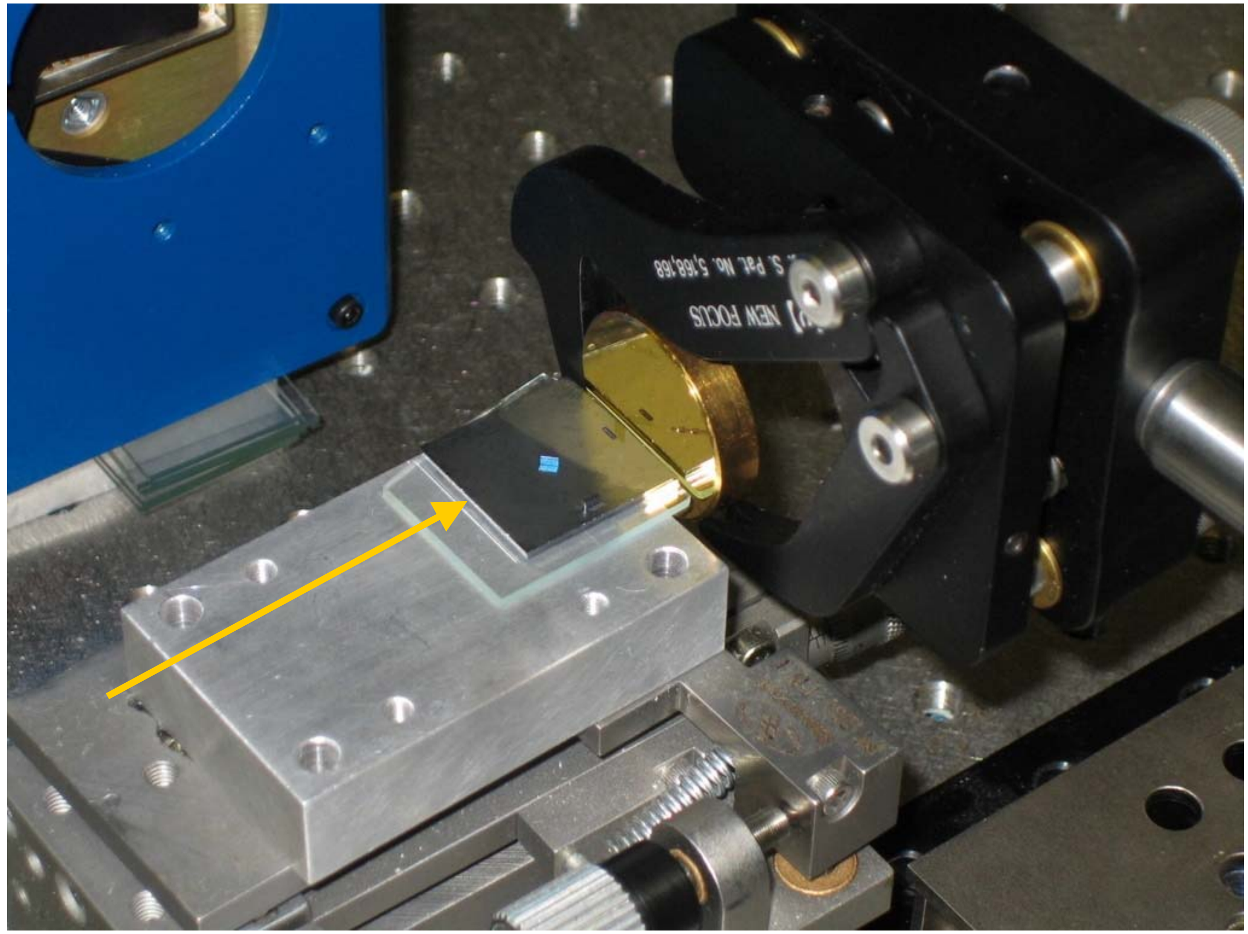






Hollow silicon waveguide Michelson interferometer





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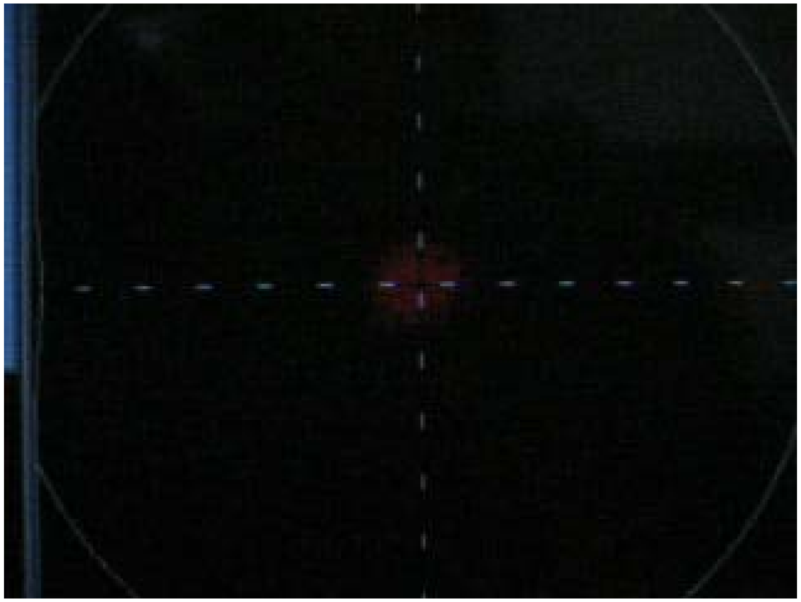
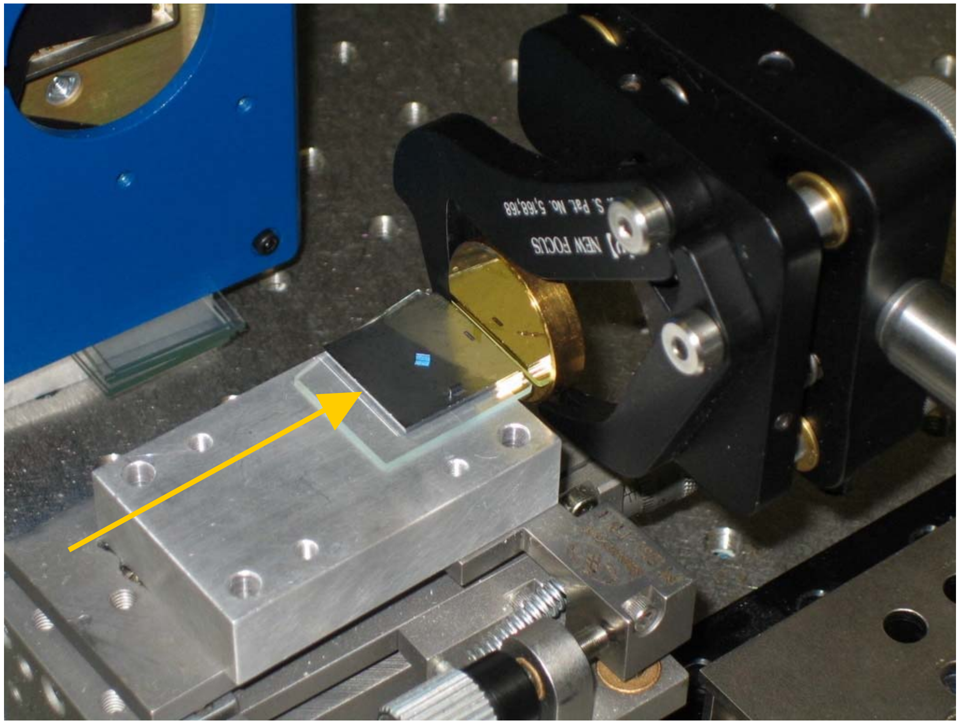
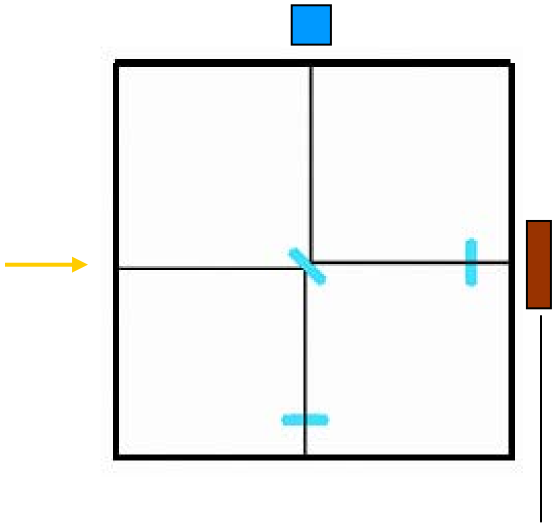
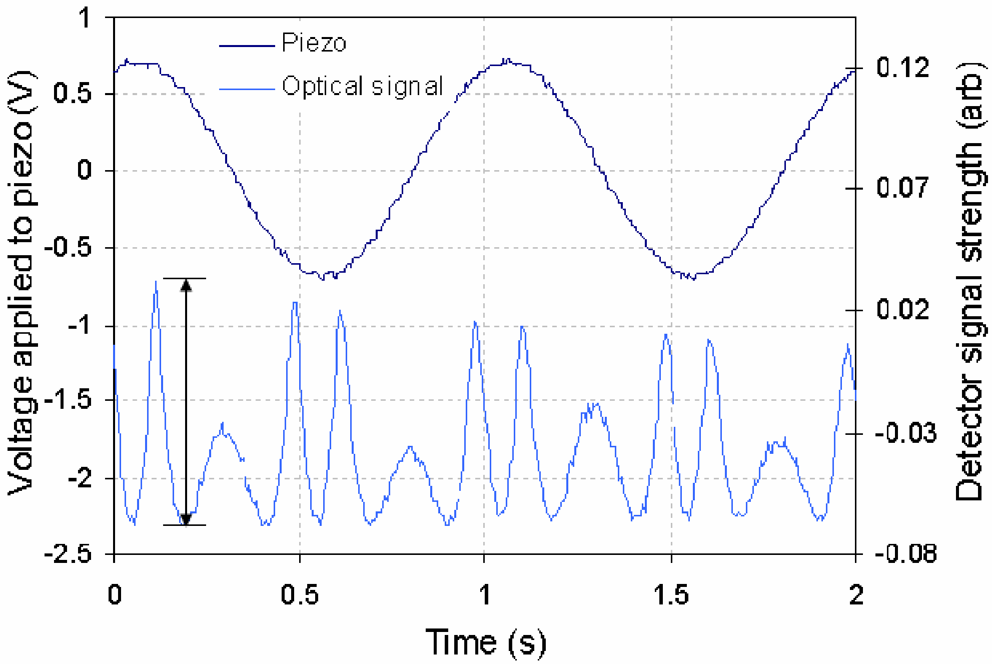
Demonstration of hollow silicon waveguide Michelson interferometer





Characteristics of Michelson interferometer test structure





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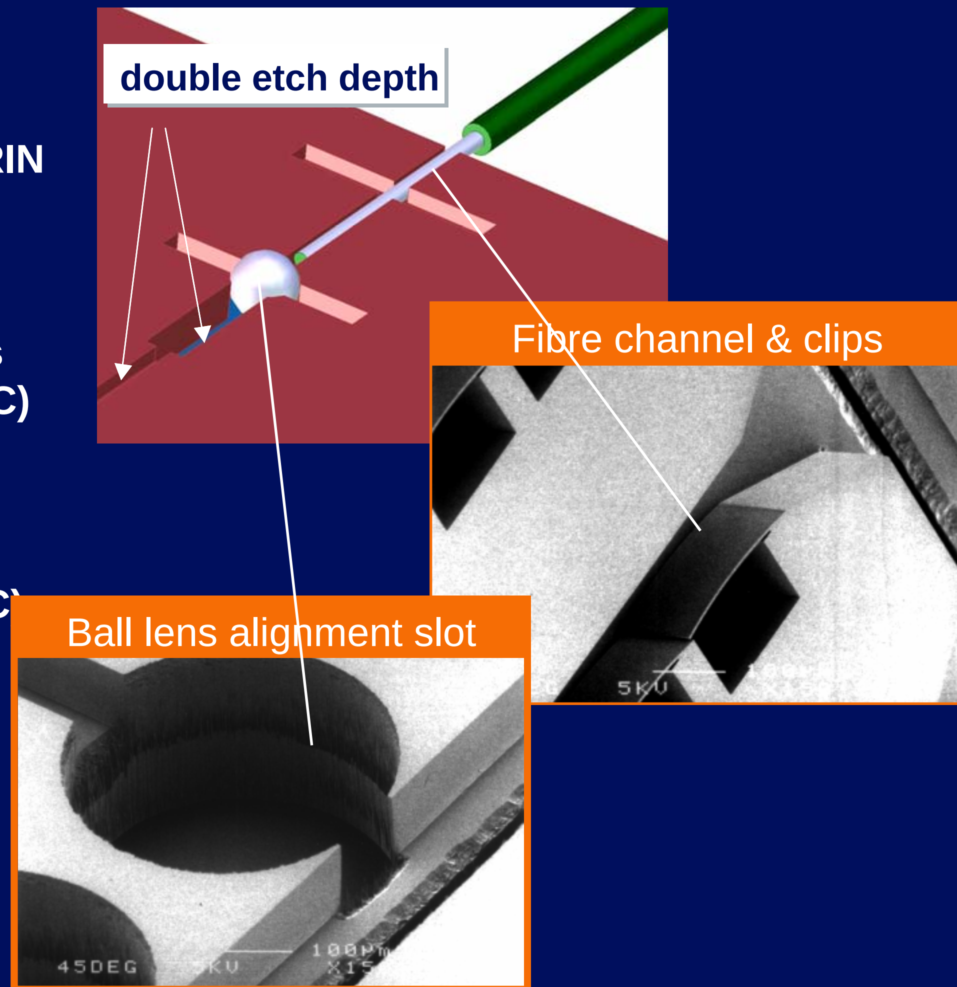
Hybrid integration of discrete components

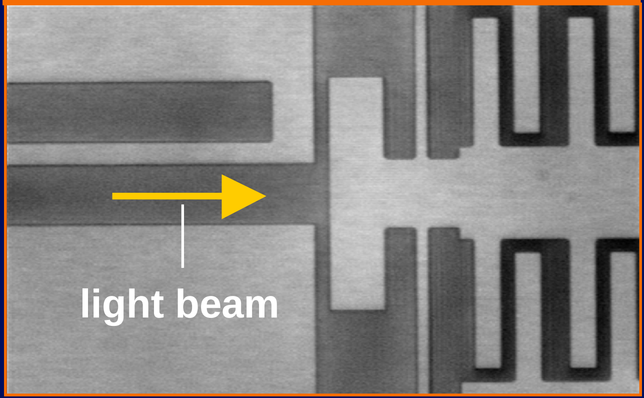
- Passive
  - Fibres
  - Lenses - ball/GRIN
  - Mirrors
  - Beam Splitters
  - Gratings
  - Optical isolators
  - TFF & AWG (PLC)
- Active
  - Lasers
  - Modulators (PLC)
  - Detectors
  - VOAs
  - SOAs



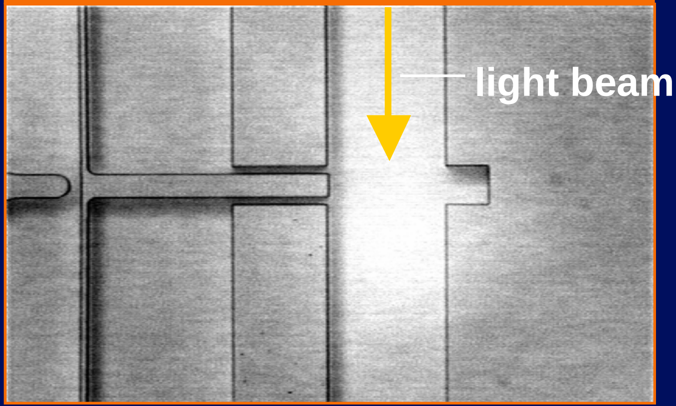
Monolithic integration of MEMS components

- Monolithic
  - Moveable mirrors
    - Phase shifters
    - Beam steering
  - VOA / Switch
    - Shutter-based
- Hybrid
  - Moveable Mirrors
  - Tuneable Filters
  - VOA / Switch
  - etc.

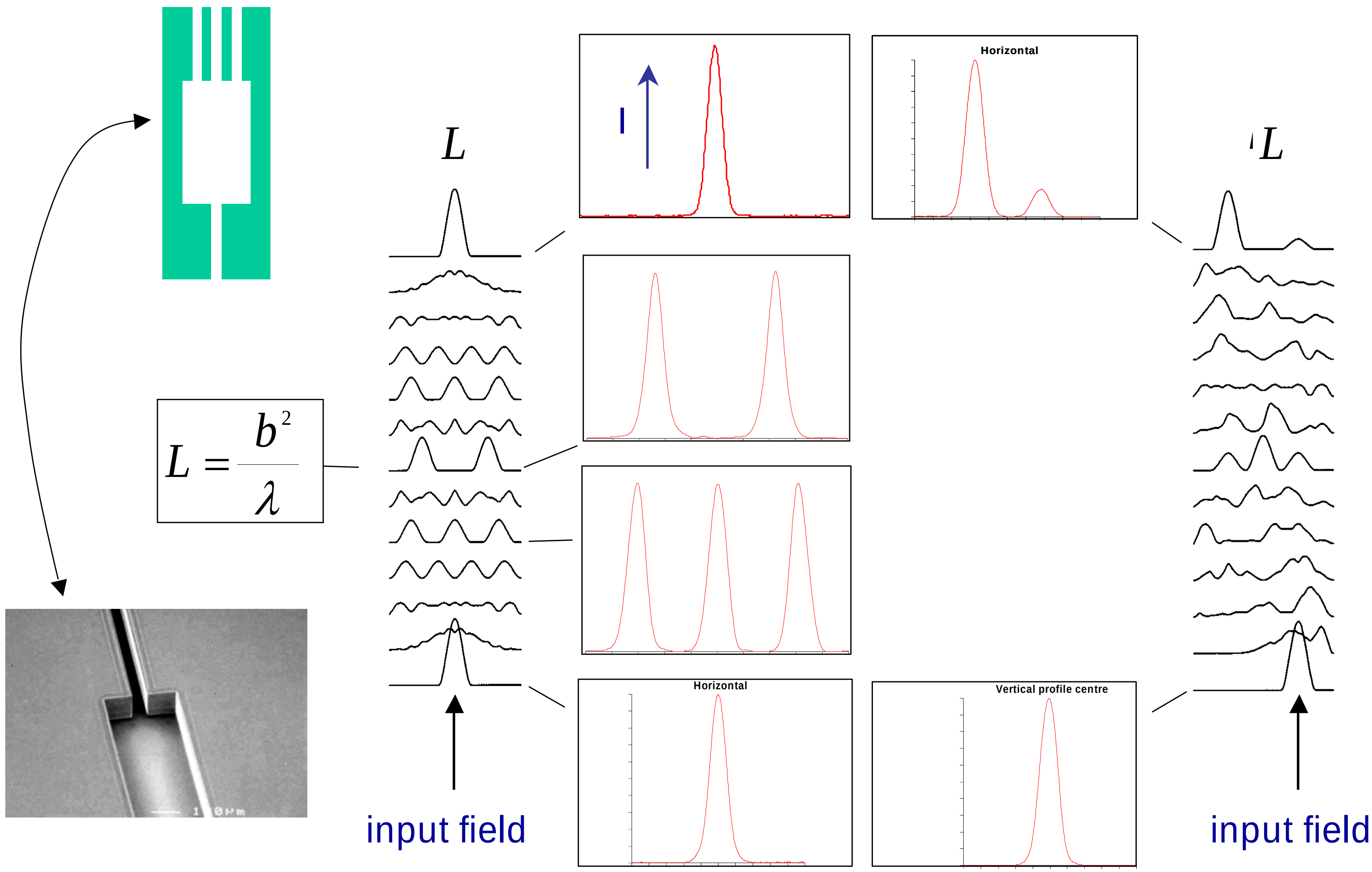
MEMS mirror phase shifter



VOA based on shutter in guide



Demonstration of multimode interference (MMI) splitters



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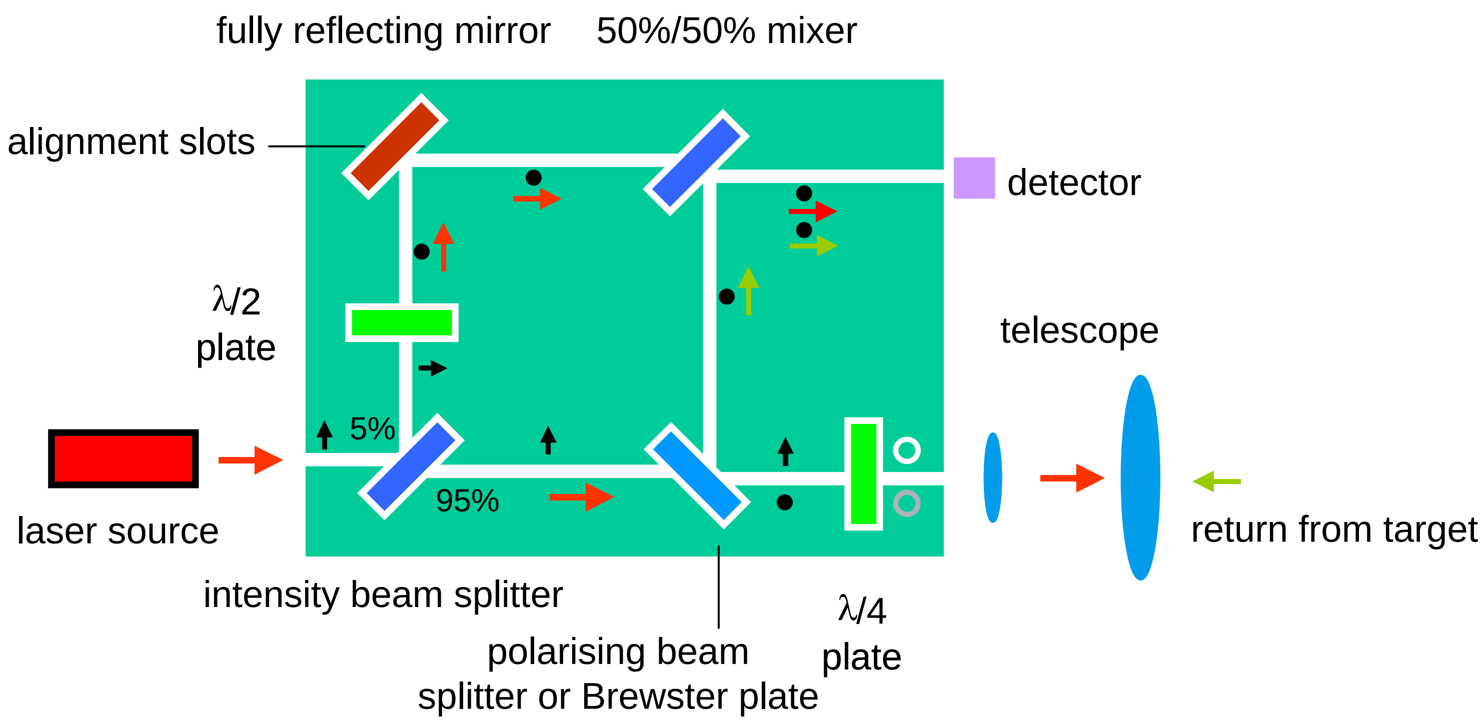
Proposed HWG 1.55 μm coherent lidar demonstrator



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Summary of hollow silicon waveguide optical PCB integration technology

- Ease integration of discrete components - no optical interface to bridge
- Broad waveband high power transmission characteristics
- No beam diffraction - small/fixed beam diameter
- Easier angular alignment tolerances c.f. free-space
- Easier lateral alignment tolerances c.f. solid-core guides
- Predicted attenuation coefficients < 0.01 dB/cm
- Integrated 45° fold mirrors provide good fundamental mode propagation fidelity in practice
- Hollow waveguide Michelson interferometer demonstrated in practice
- With some further development the concept appears set to provide us with compact, low mass, rugged, low cost micro-optical systems

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