Matthieu Duperron

Photonic Packaging Group

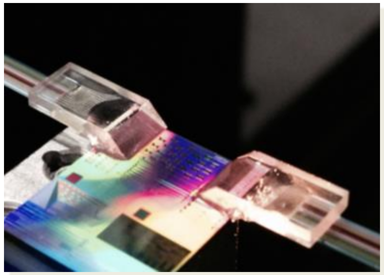
Tyndall National Institute

SPIE Photonic West - 1st February 2017

Hybrid Integration of Laser Source on Silicon Photonic Integrated Circuit for a Low-cost Interferometry Medical Device

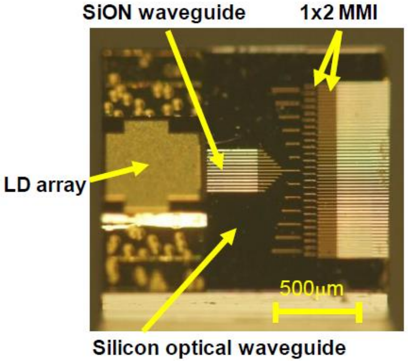
Introduction: Light Source for Si-PIC

- Photonic Integrated Circuits (PIC) offer integrated, low-cost solution for ICT, sensing and medical applications.



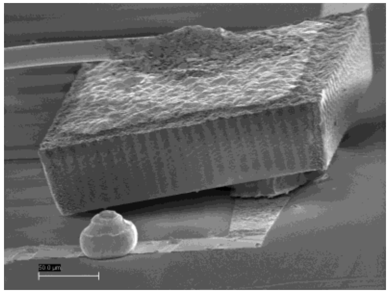
- Need for an "integrated" light source
  - Heterogeneous integration (III-V laser die bonding)
  - Hybrid integration (fully processed laser chip)

*Edge coupling **

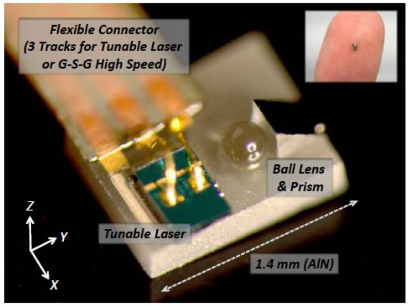


Grating couplers

*VCSEL ***



Micro-Optical Bench



- Edge emitting lasers chip
- Free space coupling

=> High level of customizability

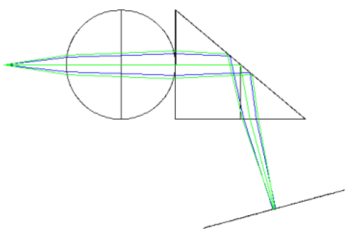
- Platform for biomedical applications:
  Power / Wavelength (value and spectral range) / Linewidth / Polarization control

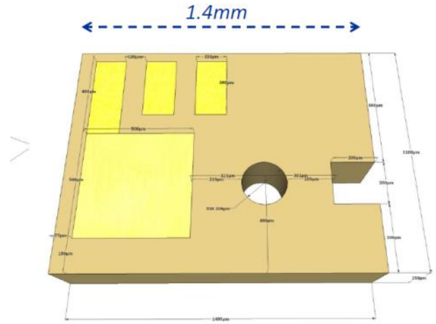
* T. Shimizu et al, Photonics Research 2(3), A19–A24 (2014)   ** P. O'Brien 10072_19

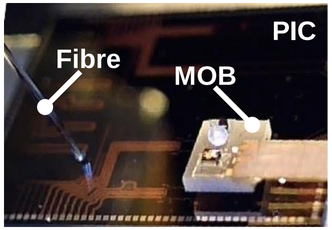
Introduction: MOB

- Optimal coupling with free-space optical components

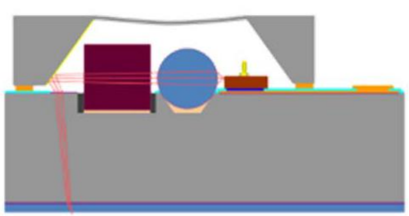
- Low-Cost Fabrication and alignment
  - Passive assembly of the components
  - Active assembly of the MOB on the PIC

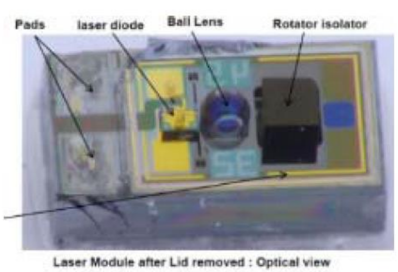






Luxtera (for high-speed interconnects)*





* P. De Dobbelaere et al, "Silicon-photonics-based optical transceivers for high-speed interconnect applications," in SPIE OPTO, 977503–977503, International Society for Optics and Photonics (2016).

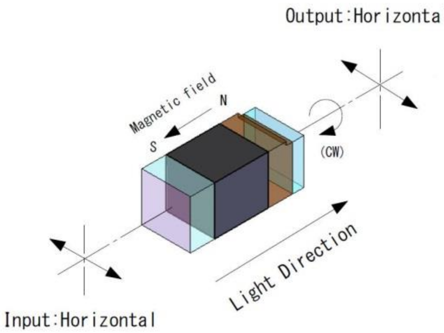
Introduction: Project Requirements

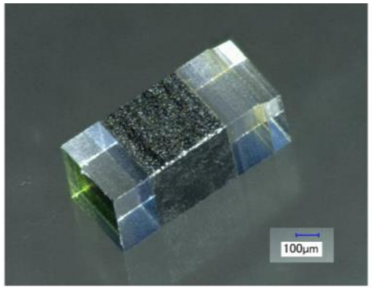
Early stage CARdio Vascular Disease Detection with Integrated Silicon Photonics

Demonstrate the concept of a mobile, low-cost device based on a silicon photonics integrated laser vibrometer .

Requirement for a 1550nm laser / Discrete mode / Linewidth 20MHz / Stabilization

- Discrete sub-mm isolator integration
  - >20dB isolation
  - Ensure high frequency stability
- Thermal management
  - AlN substrate (300W.m^{-1}.K^{-1})
  - Close integration of thermistor
  - Avoid low-frequency drifts
- Optimal optical coupling
  - High Power required: >10mW in the waveguide





Outline

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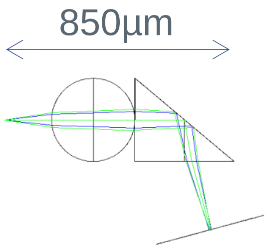
- Design:
  - Optical
  - Alignement tolerances study
  - Mechanical
- Assembly process
- Results:
  - Beam profile characterization
  - PIC alignment
  - Coupling

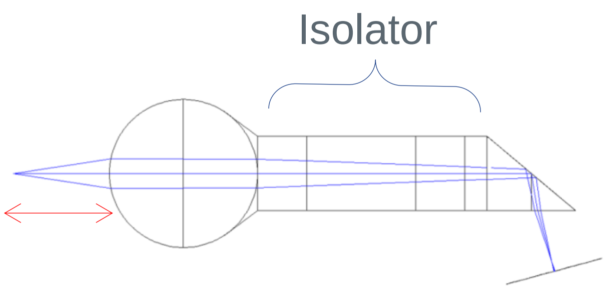
Optical Design

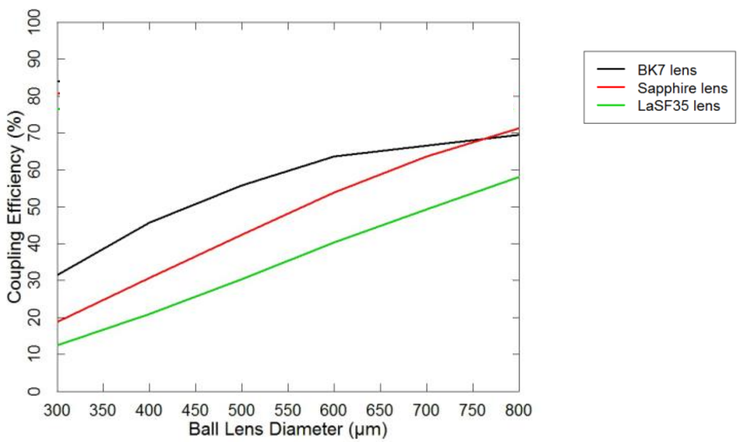
Challenges:

- Accommodate the additional 900µm length and keep the NA conversion
- Manage passive assembly

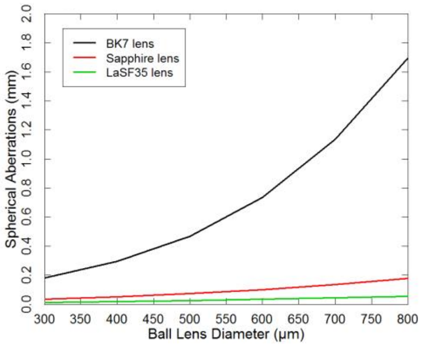


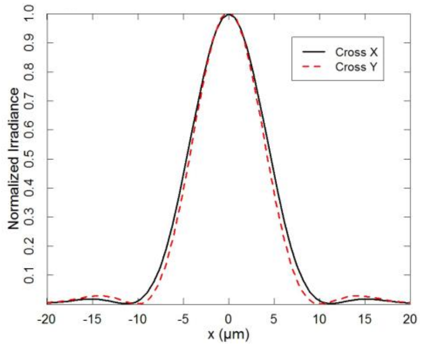
- 1 ball lens:





Towards NA conversion



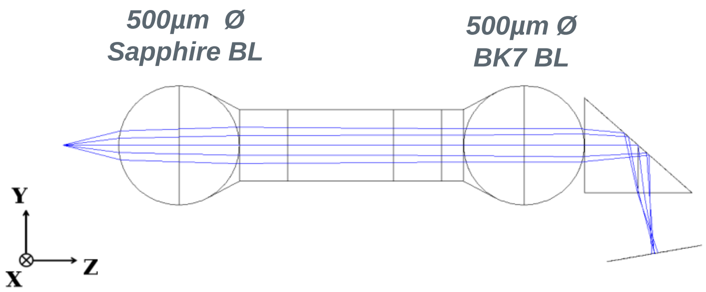


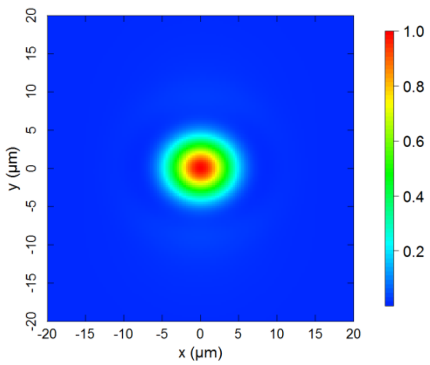
CE limited by:

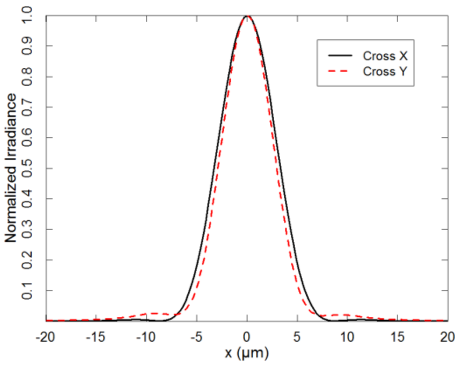
- Ball lens size
- Spherical aberrations

Optical Design

- 2 ball lenses:
  - Perfect NA conversion (i.e. beam spot size)
    CE_{rec}=96%
  - Little aberrations
  - Collimated beam in the isolator

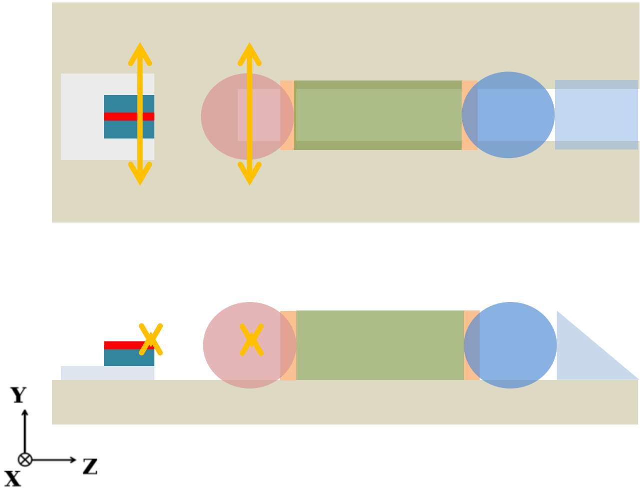






  - Relatively tolerant to NA changes
    NA 0.115/0.15 => CE_{rec}=96%
    NA 0.19/0.25 => CE_{rec}=77%
  - 2 lenses to align, more difficult?

Alignment Tolerances

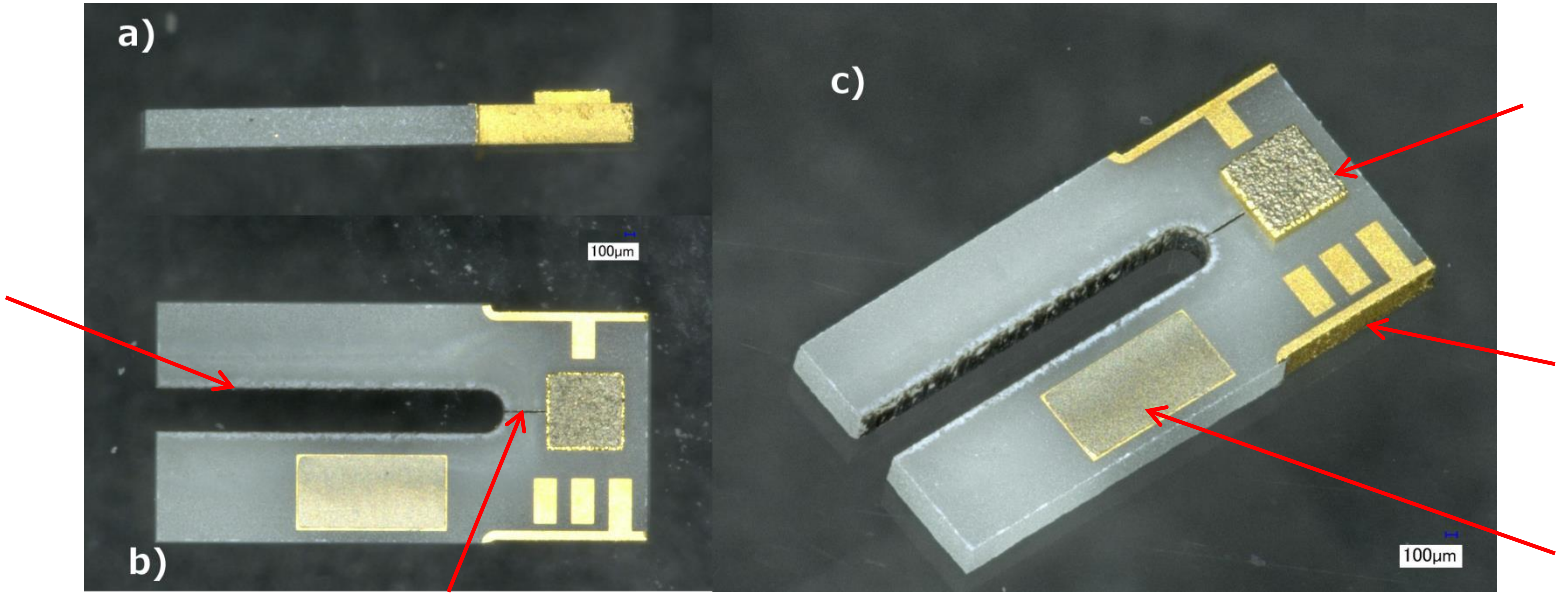


Misalignment	2 lenses MOB
Laser_DecenterX	±17µm
Laser_TiltY	±5°
Laser_DecenterY	±15µm
Laser_TiltX	±4°
BL1_DecenterX	±12µm
BL1_DecenterY	±11µm
BL2_DecenterX	>±30µm
BL2_DecenterY	>±30µm
FFL	±15µm
BFL	0-60µm

1dB losses misalignment tolerances

How are those alignment tolerances reached with a passive alignment process?

Bench Design

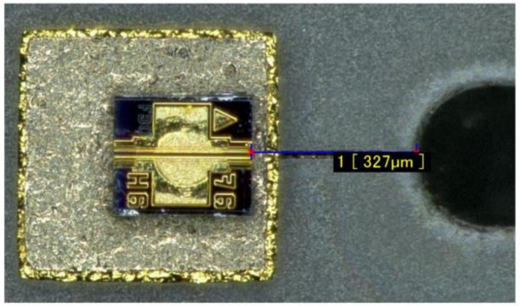


Features:

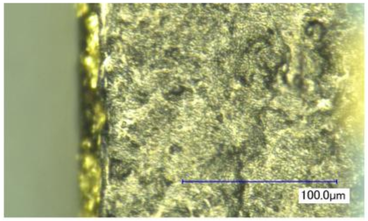
- Trench for passive alignment of the different components
  - 2 ball-lenses of the same diameter
- Alignment mark
  - For laser positioning
- Thick metallic pad for laser height accomodation
  - Optical Axis at 200um from the surface
- Side contacts
- Pad for thermistor

Assembly

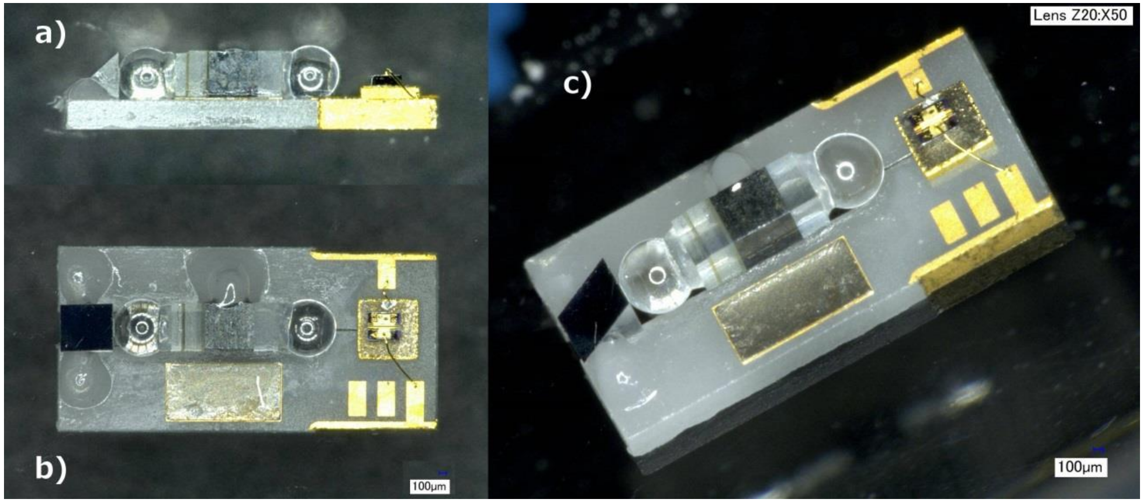
- Standard flip-chip of the laser die
  - Visual Alignment
  - AuSn reflow fixation
  - Position accuracy expected: ±5µm / ±1°



- Results:
  - Position accuracy obtained: ±15µm / ±5°
  - Roughness difficulty
  - Optimization in progress



- Optical assembly:
  - Manual positioning
  - Gluing with UV-cure epoxy



Beam profile characterization

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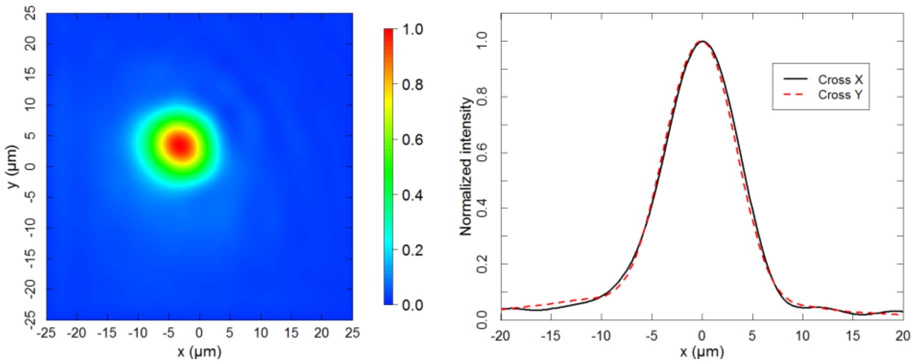
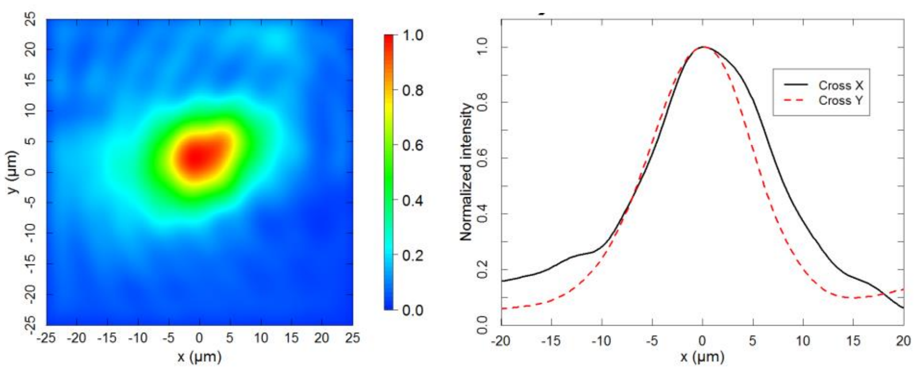
- Beam intensity scanned at the focusing plan



"Good" alignment

- 14µm-15µm fitted gaussian profile diameter
- Symmetric
- Low aberrations
- Slightly defocus

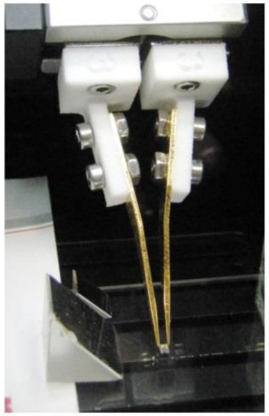


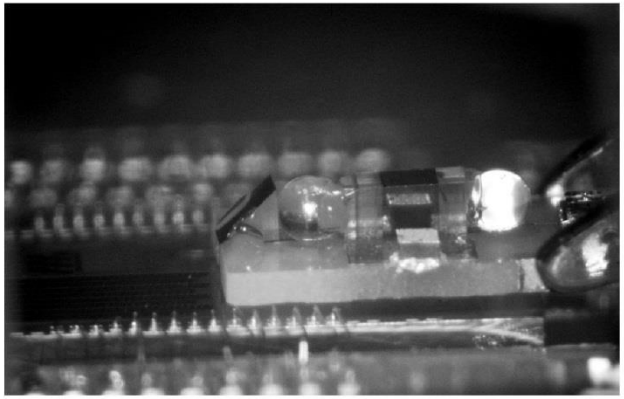
"Bad" alignment ***(laser shifted 30µm laterally)***

- 21µm-23µm fitted Gaussian profile diameter
- Astigmatism
- Diffraction patterns
- Strong defocus

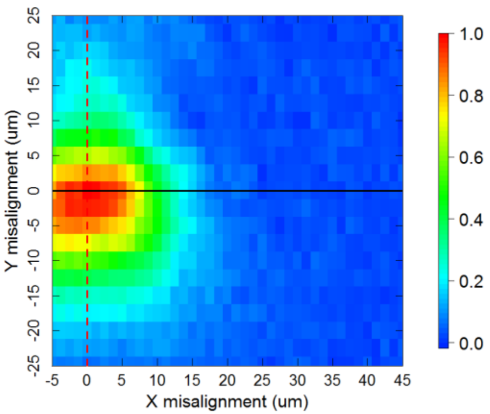
PIC alignment

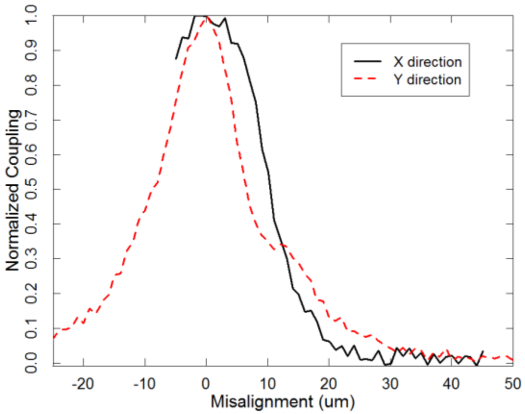
- Powering pick up tool:
  - 2 degrees of freedom optical alignment
  - Cost-effective process





- Expected alignment tolerances:

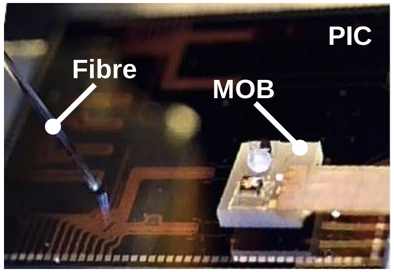




Coupling result: work in progress

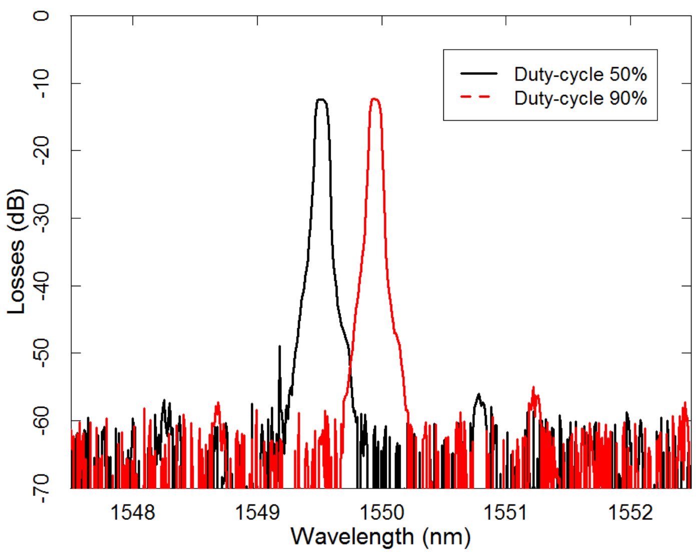
- Integration penalty measurement:

$$Losses = \frac{MOB_{spectrum}/Laser_{Power}}{Fiber_{spectrum}/SLD_{spectrum}}$$



- Discussion
  - Discrete Mode
  - Linewidth
  - Wavelength variation: 4°C shift

- Efficiency 12dB Losses
  - Standard package: coupling to fiber 4-5dB losses
  - Expected from perfect design 3dB
- Investigation:
  - Defocus 2-3dB
  - Isolator insertion losses
    - Additional surface reflection
  - DC measurement with thermal control required



Summary

- Platform for integration of fully processed laser chips
  - Thick pad and flip-chip process allows integration of most off-the-shelf edge emitting laser chips

- 2 ball-lenses optical design allows
  - maximized coupling efficiency
  - optimal integration of sub-millimetric isolator for high-frequency stabilization of the laser

- Low-cost assembly process
  - Passive assembly of the bench
  - 2 degrees of freedom active assembly

Next steps

- Optimize coupling efficiency
- Characterize laser stability
  - Optical isolation
  - Thermal management

Acknowledgments

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- *SIOS-Messtechnik GmbH*: Ralph Schüler
- *Medtronics*: Soren Aasmul

CardiS

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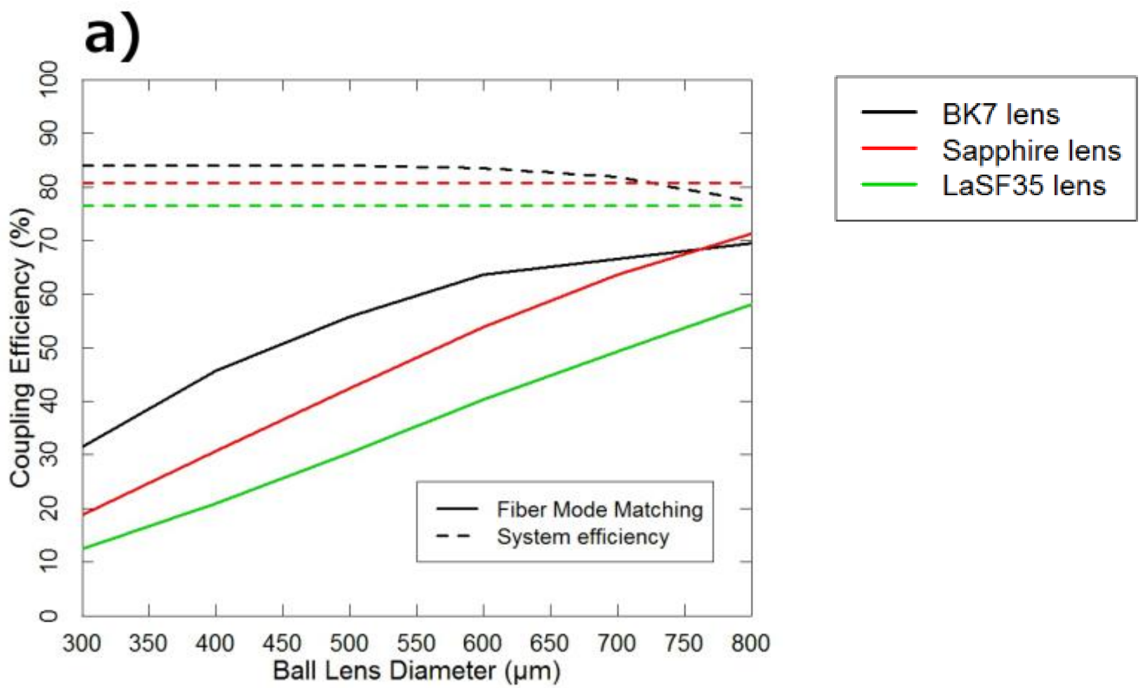
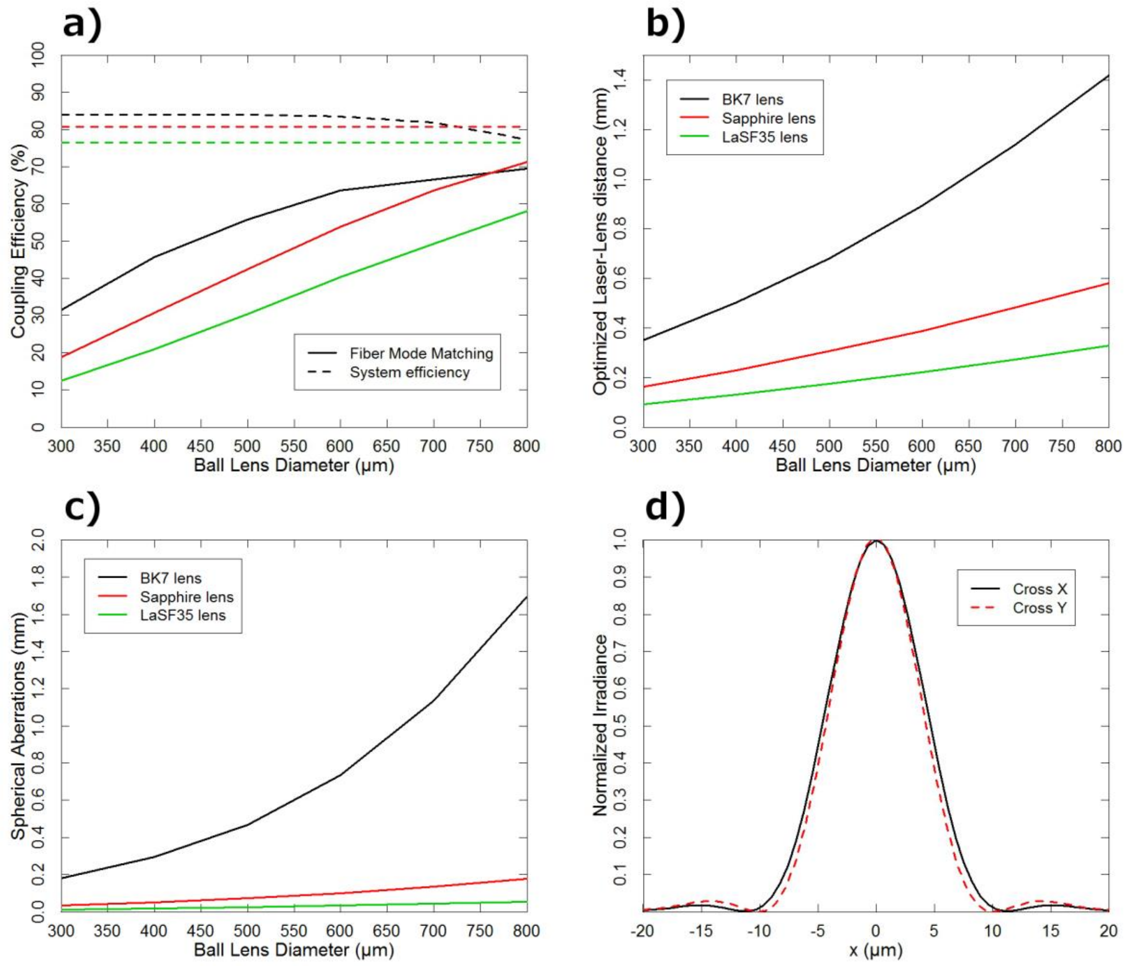
Tyndall National Institute,
Lee Maltings,
Dyke Parade,
Cork,
Ireland.
T12 R5CP

t: +353 21 490 4177
e: info@tyndall.ie
tyndall.ie


a)
Coupling Efficiency (%)
0
10
20
30
40
50
60
70
80
90
100
300
350
400
450
500
550
600
650
700
750
800
Ball Lens Diameter (µm)
Fiber Mode Matching
System efficiency
BK7 lens
Sapphire lens
LaSF35 lens


a)
Coupling Efficiency (%)
Ball Lens Diameter (µm)
Fiber Mode Matching
System efficiency
b)
Optimized Laser-Lens distance (mm)
Ball Lens Diameter (µm)
BK7 lens
Sapphire lens
LaSF35 lens
c)
Spherical Aberrations (mm)
Ball Lens Diameter (µm)
BK7 lens
Sapphire lens
LaSF35 lens
d)
Normalized Irradiance
x (µm)
Cross X
Cross Y