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Photonic skins for pressure, shear and strain sensing

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Overview

- **Introduction**
  - Composite structures: need for monitoring
  - Photonic Skins for Optical Sensing
- **Technology**
  - Flexible Ultra-thin OptoElectronic package
  - Polymer transducer interface
- **Applications**
  - Interference based pressure sensor
  - Intensity based shear sensor
  - Wavelength based strain sensor
- **Conclusions**

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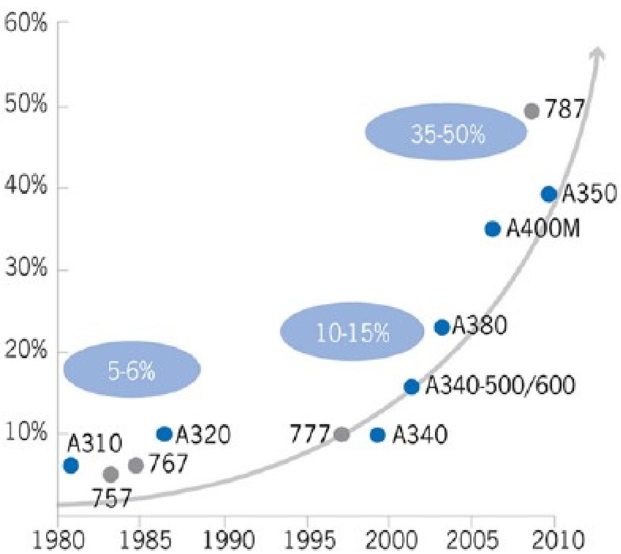
Introduction

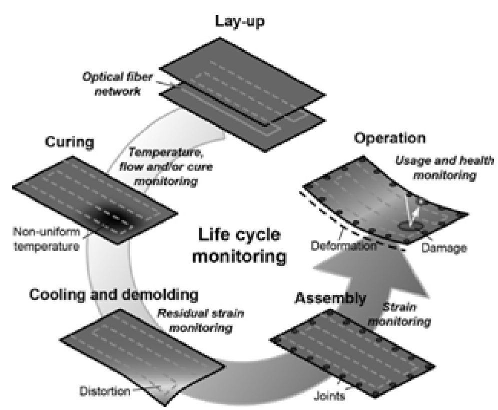
- **Increasing use of composite materials**
- **Enhance *performance*, *reliability*, *safety***
- **Minimize life cycle *cost***

multifunctional materials with sensing capabilities

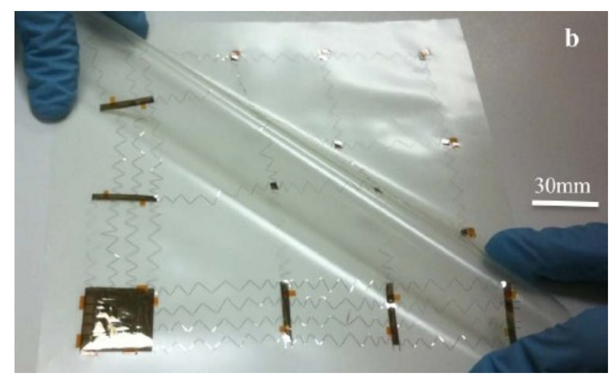
Aircraft composite content over time



Source: Hexcel Corp.,Aerostrategy



S. Minakuchi



Stanford University

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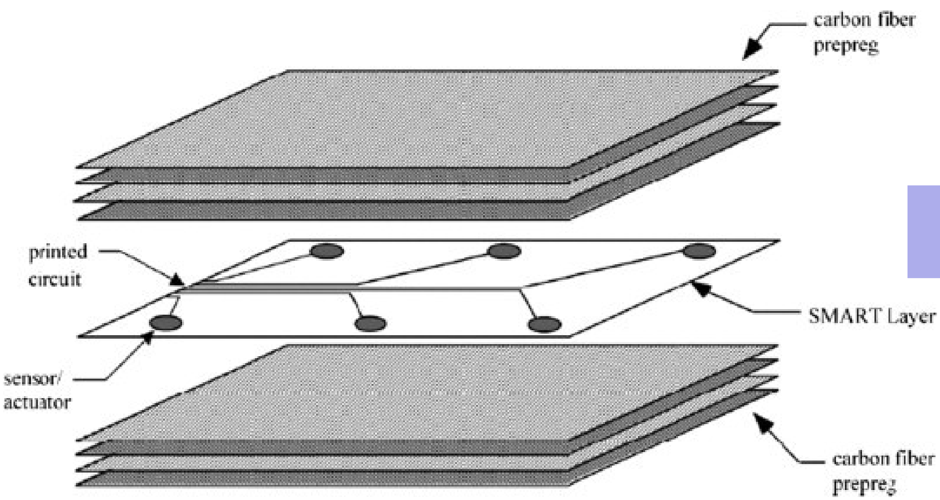
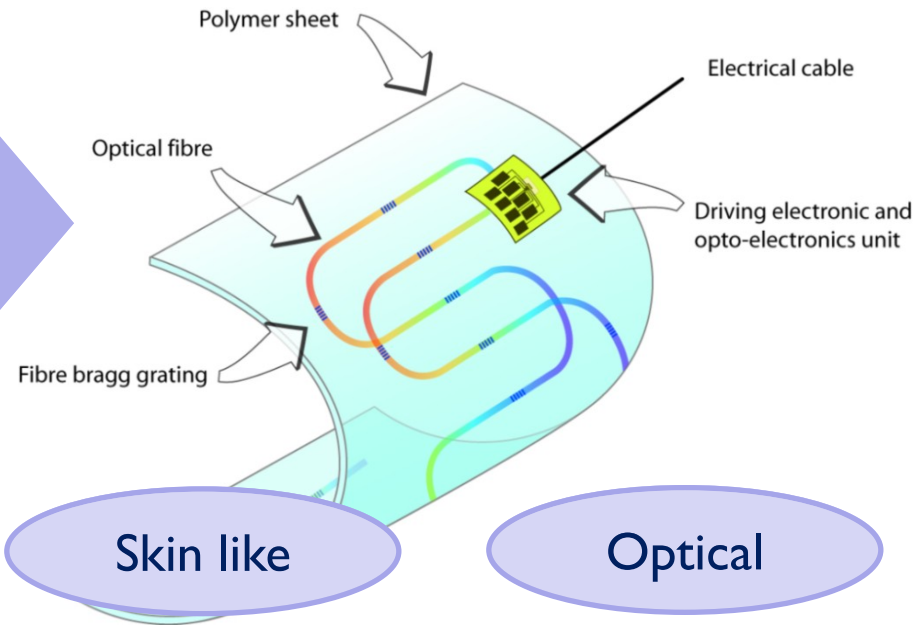
Introduction

- **Sensing systems to measure pressure, shear stress, axial/transverse strain**
  - Integrated
  - Cost effective
  - Compact

Challenges
→ Multiplexed
→ Distributed
→ Inert



Stanford-Multi-Actuator-Receiver-Transduction layer concept



Skin like

Optical

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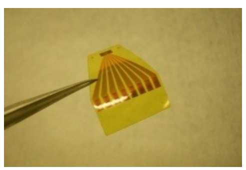
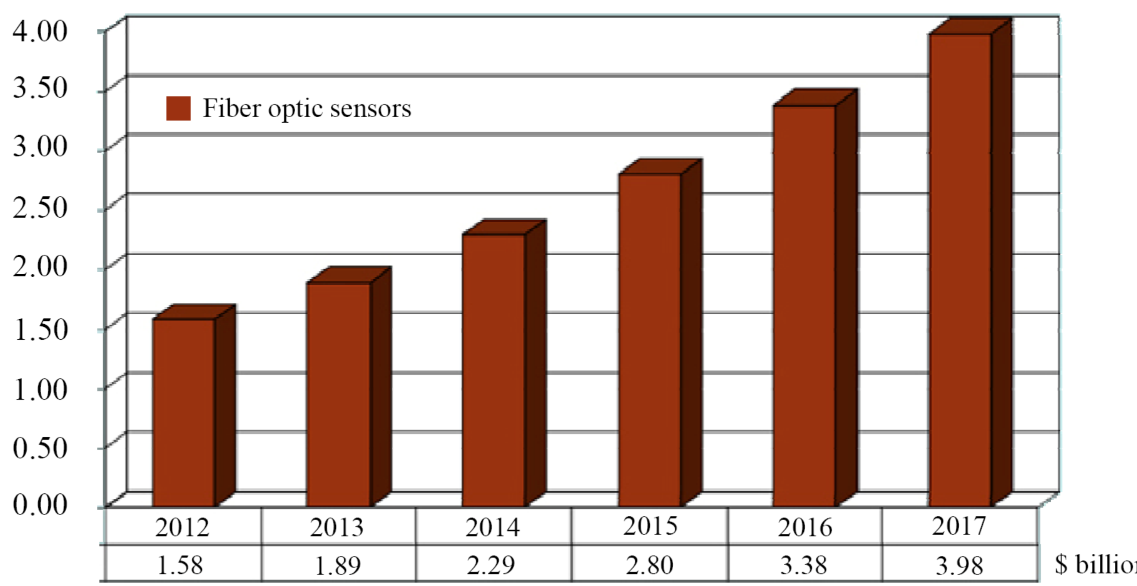
Introduction

- **A Photonic Skin is a flexible optical sensing foil**
  - in which all necessary optical sensing elements can be integrated
  - that can be wrapped around, embedded in, attached or anchored to irregularly shaped or moving objects





Emerging market
Example: Fiber Optic Sensor Revenue, expected growth 2012-2017
[Source: optics.org and ElectroniCast Consultants].

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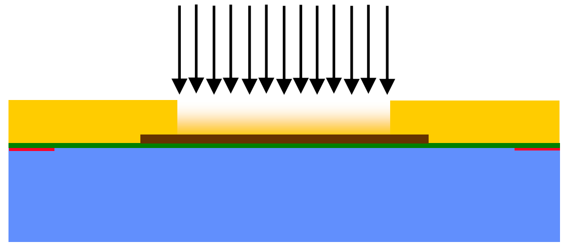
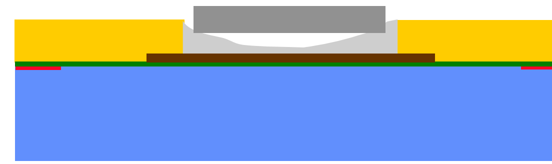
Technology

Flexible ultra-thin OE package: process

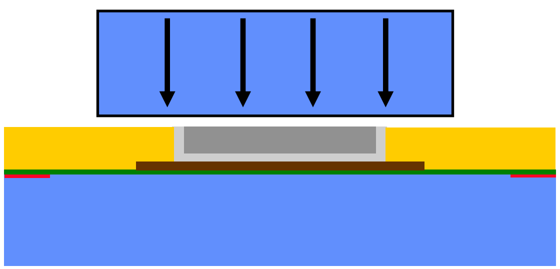
Polymer layer deposition on rigid glass carrier



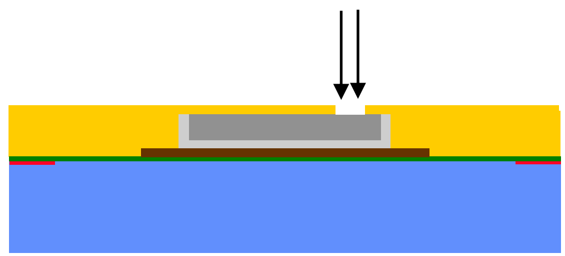
Laser patterning cavity



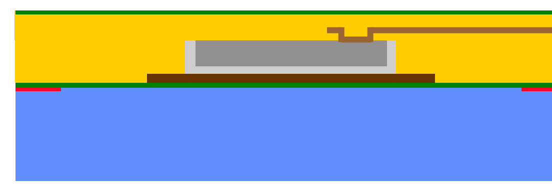
Face-up chip placement and fixation



Chip leveling inside cavity



Laser blind via drilling to chip contacts



Electrical contacting, polymer layer deposition and release from glass carrier

"Ultrathin Optoelectronic Device Packaging in Flexible Carriers",
E. Bosman, B. Van Hoe et al., IEEE Journal of Selected Topics in Quantumelectronics, 2011
"Two axis optoelectronic tactile shear stress sensor", J. Missinne, B.Van Hoe et al., Sensors and Actuators A, 2012

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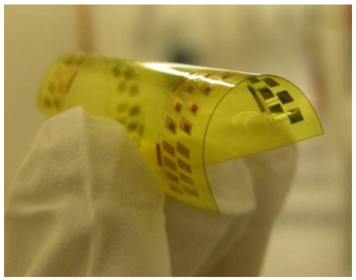
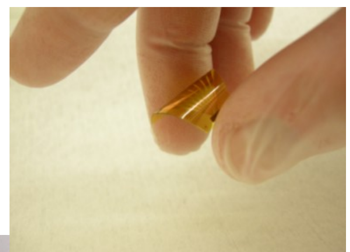
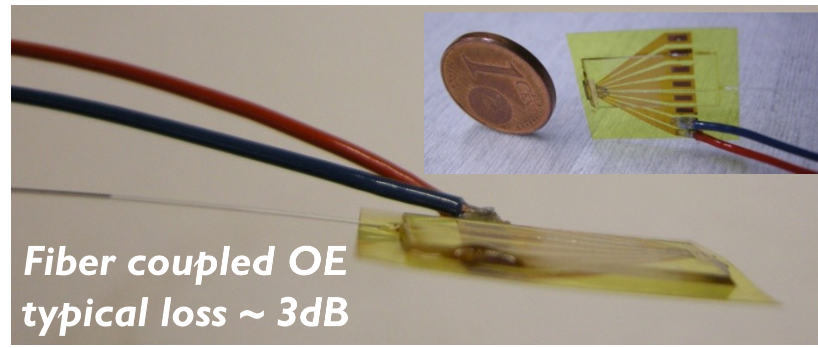
Technology

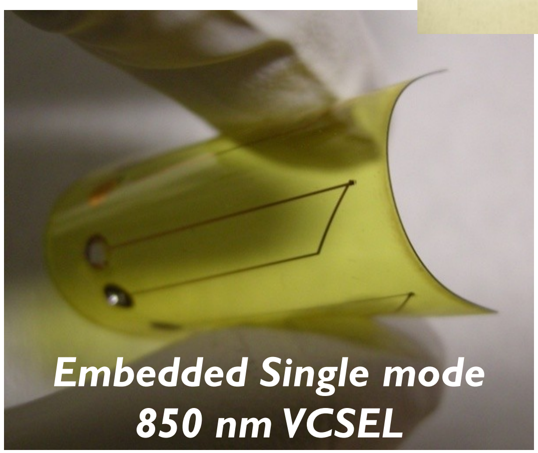
Flexible ultra-thin OE package



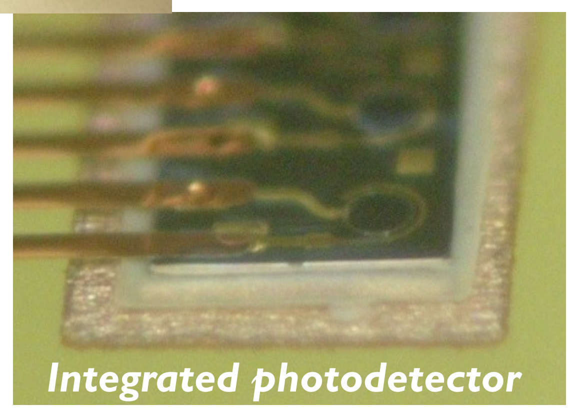




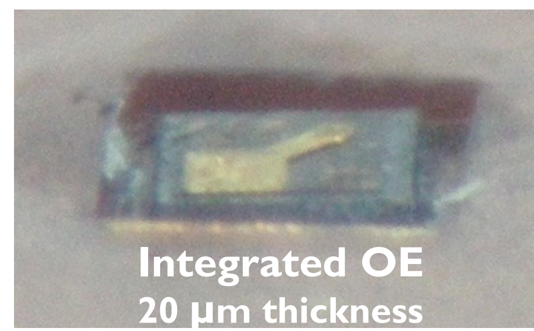
Fiber coupled OE
typical loss ~ 3dB



Embedded Single mode
850 nm VCSEL



Integrated photodetector



Integrated OE
20 µm thickness

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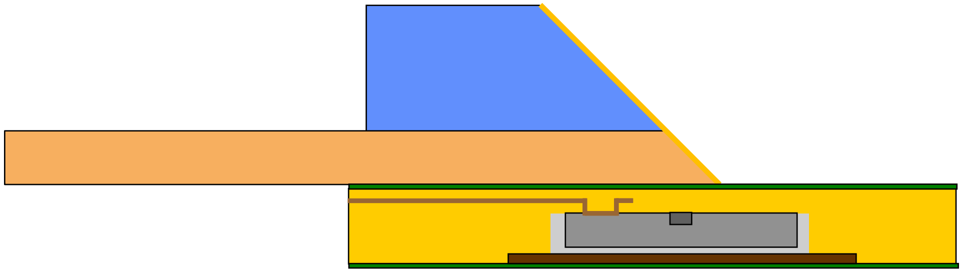
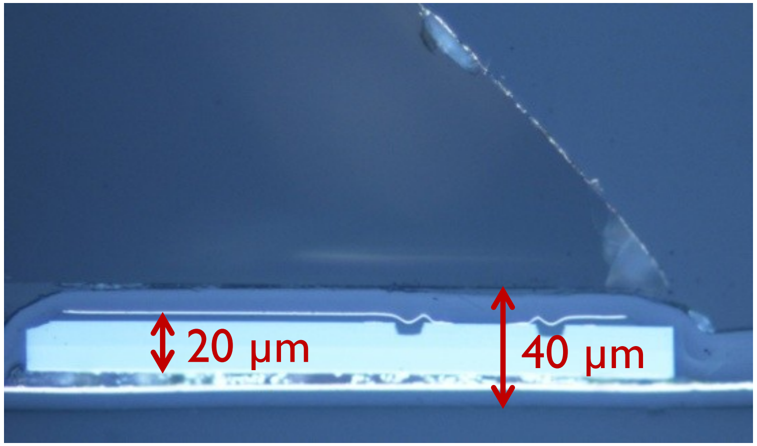
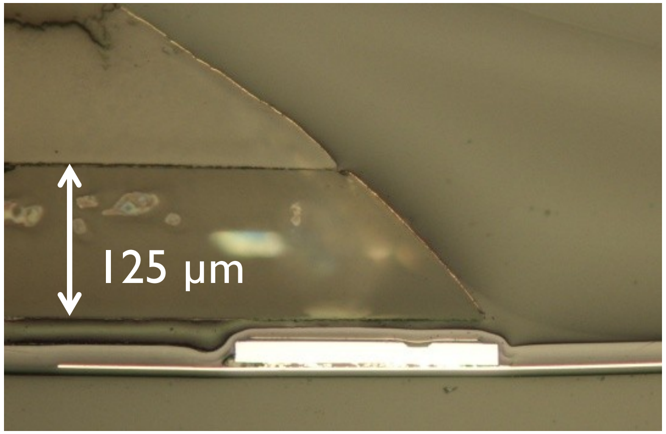
Technology

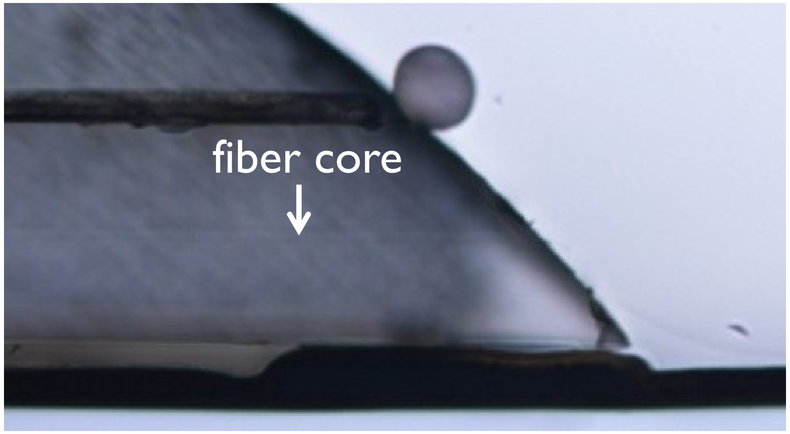
Fiber coupling flexible ultra-thin OE package



Active alignment of ultra-thin optical package and fiber with 45° micromirror







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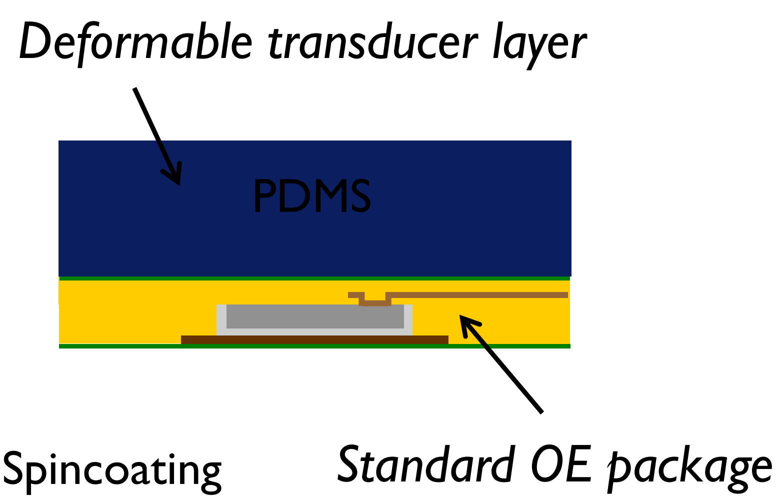
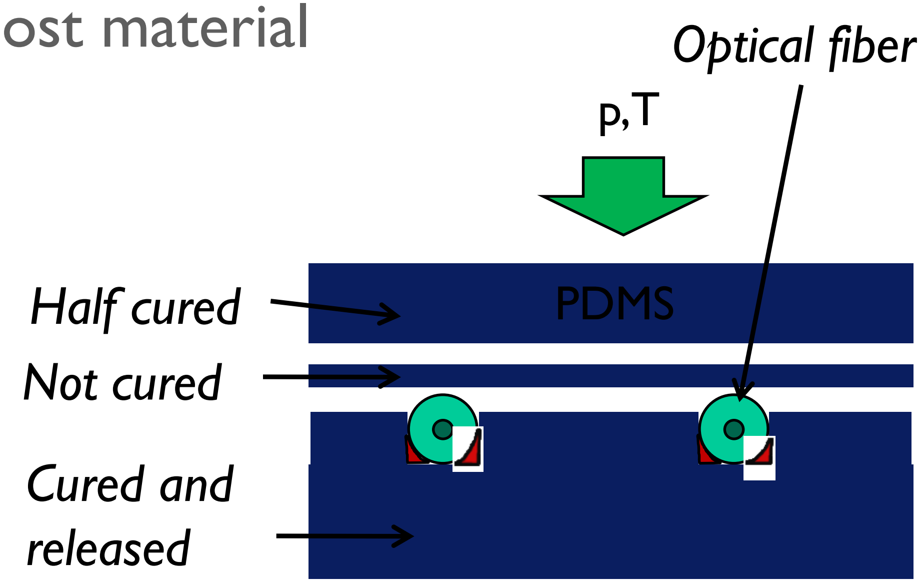
Technology

Polymer transducer interface

- Applying stretchable PDMS material
  - On ultra-thin OE package
  - As stretchable host material



- Spincoating
- Casting



- Moulding
- Soft-litho transfer

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Technology

Polymer transducer interface

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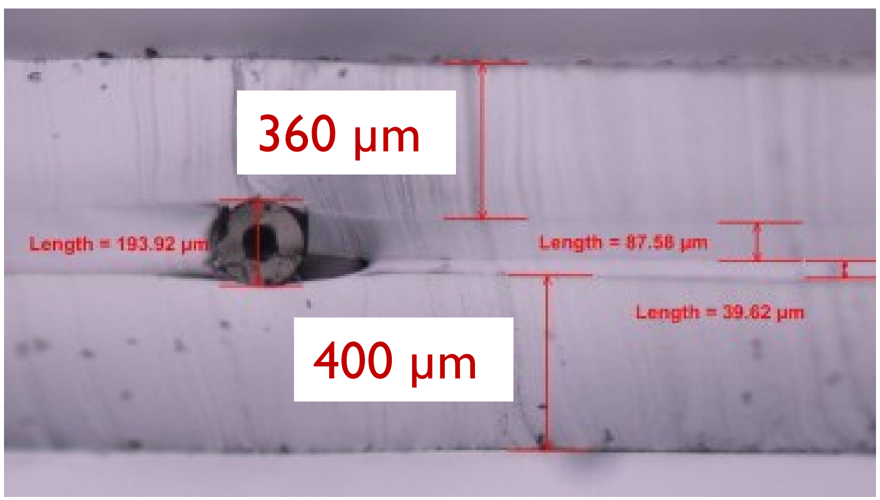

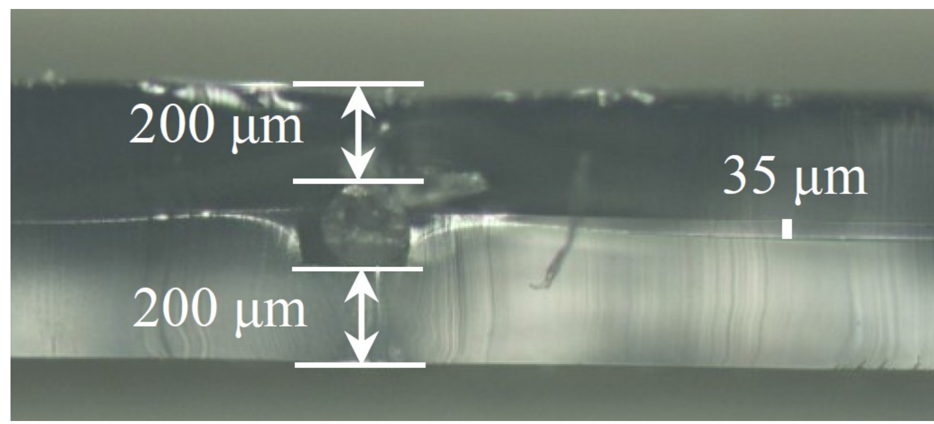

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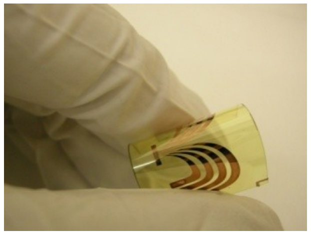
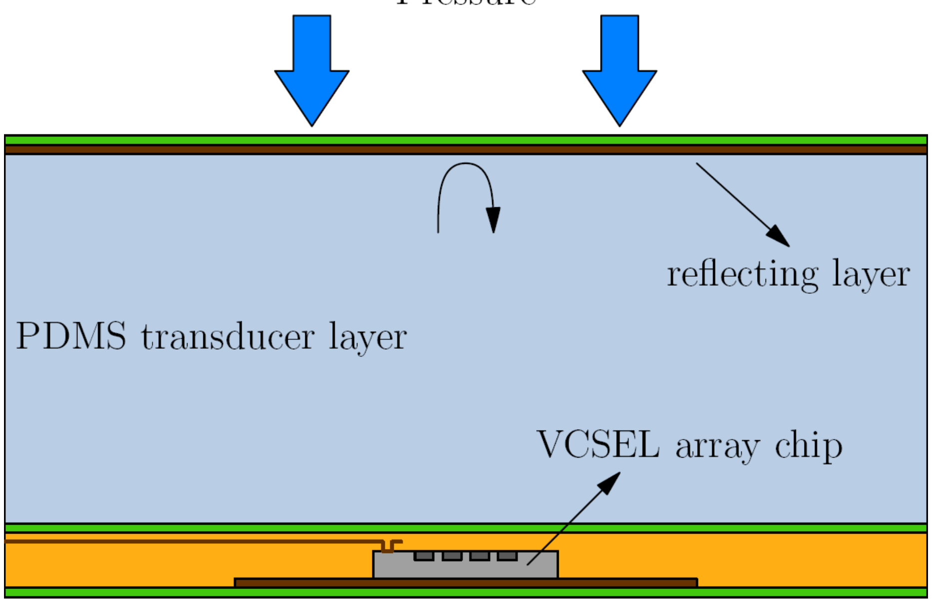
Applications

Interference-based pressure sensor

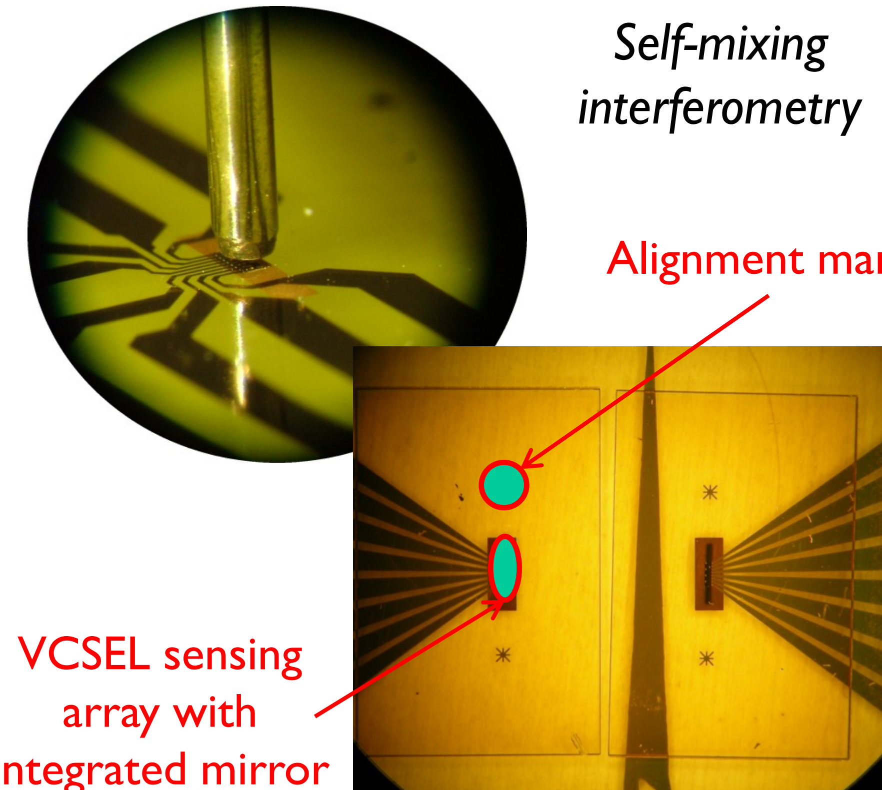
- Displacement measurement





Ultra thin flexible VCSEL package

Self-mixing interferometry



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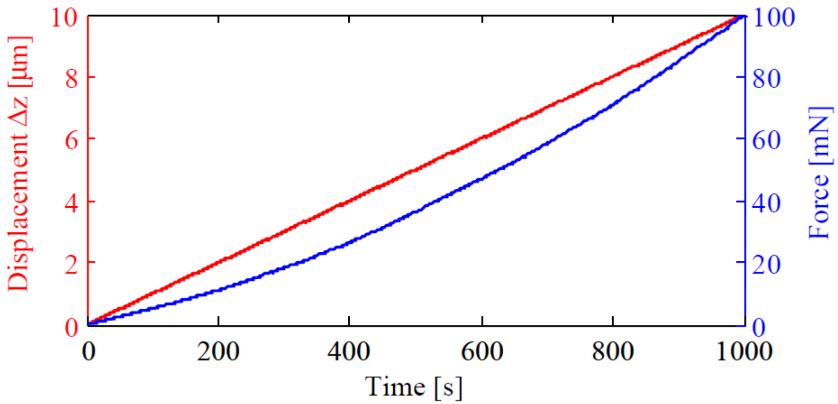
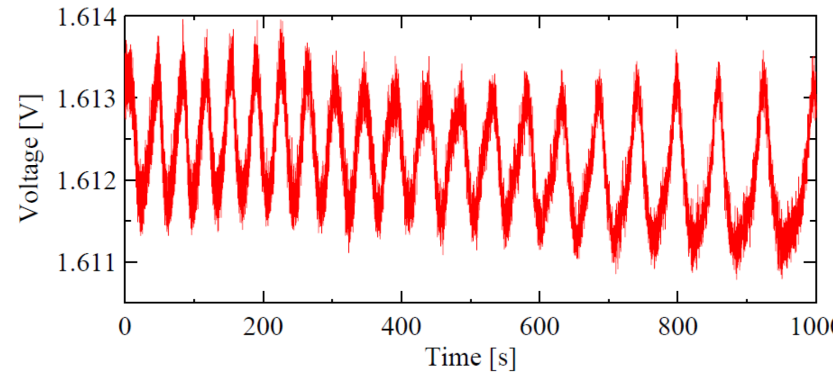
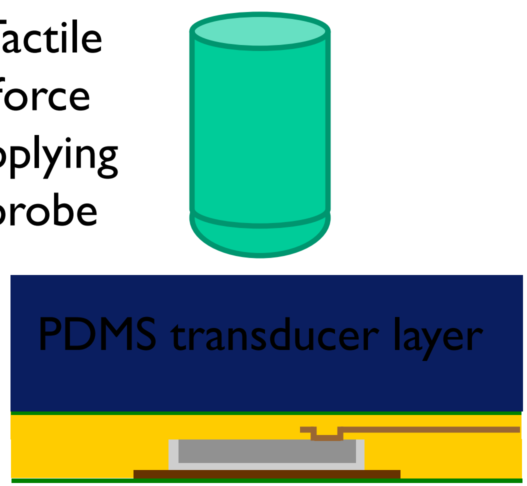
Applications

Interference-based pressure sensor

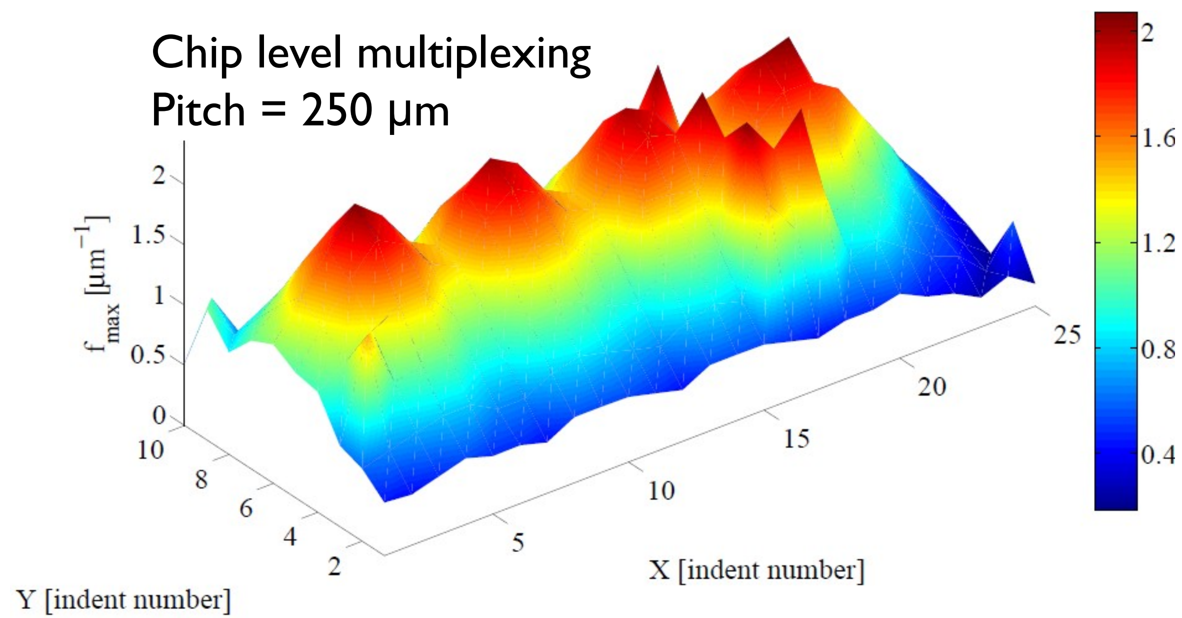




Tactile force applying probe



Chip level multiplexing
Pitch = 250 µm



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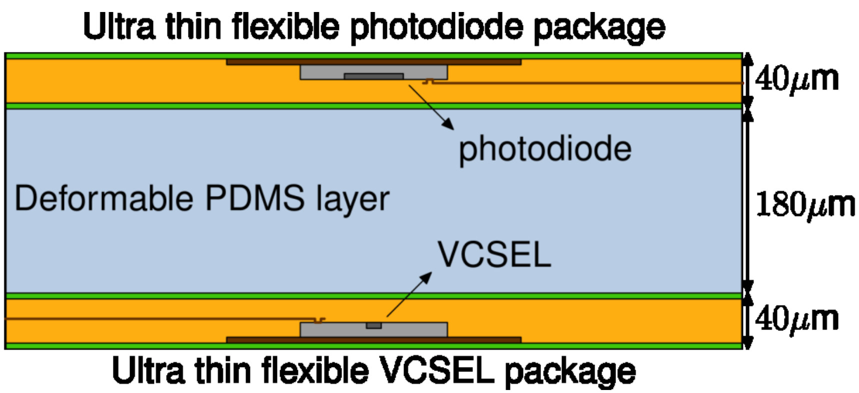
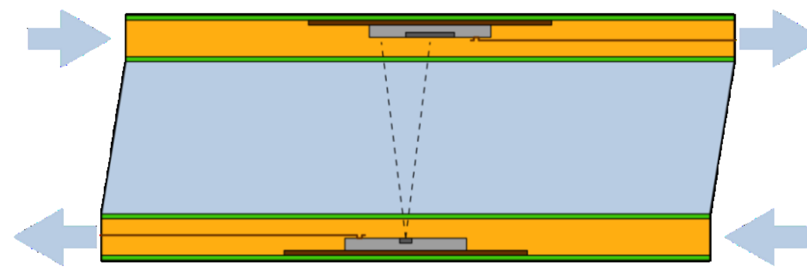
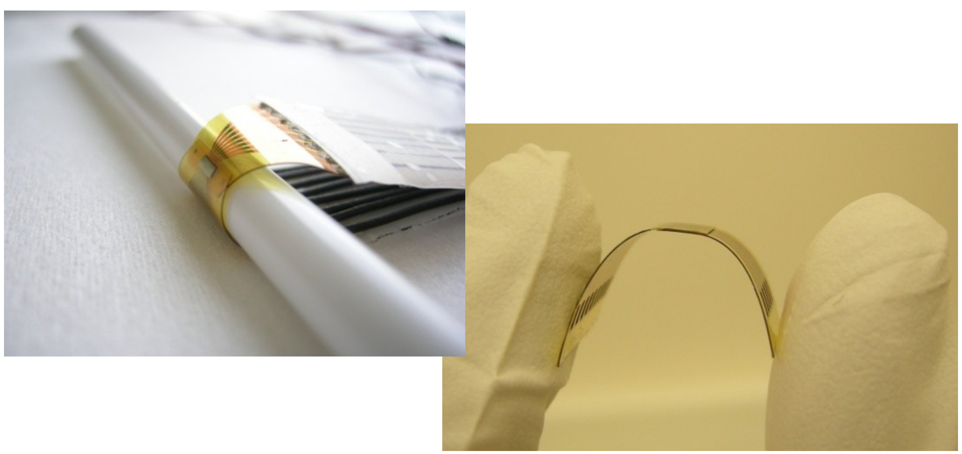
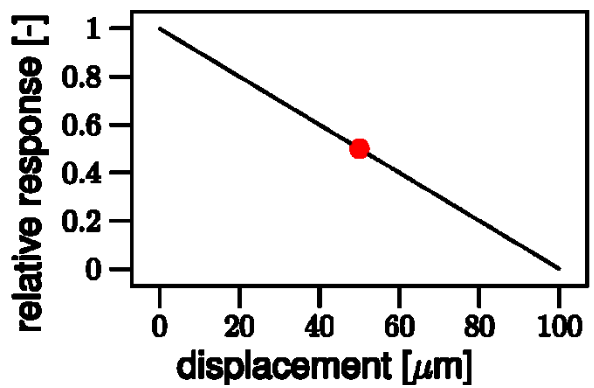
Applications

Intensity-based shear sensor









Changing coupling behavior

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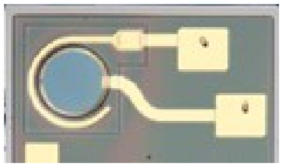
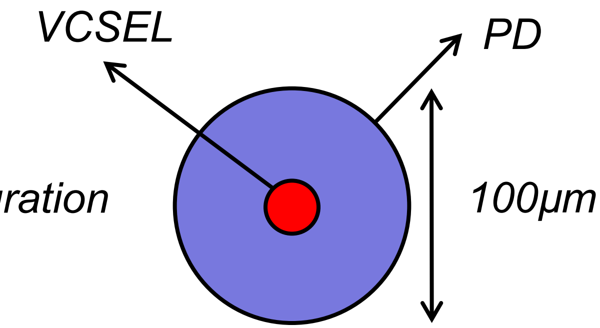
Applications

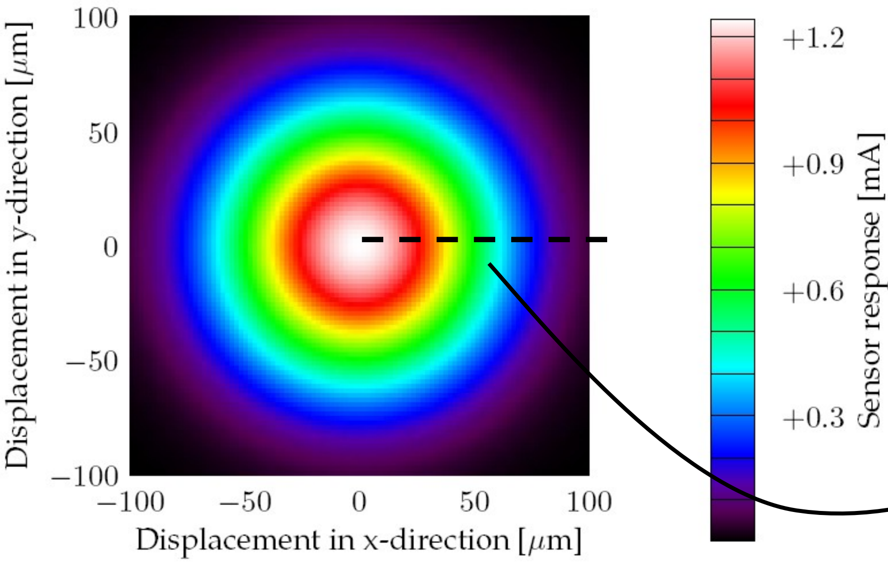
Intensity-based shear sensor

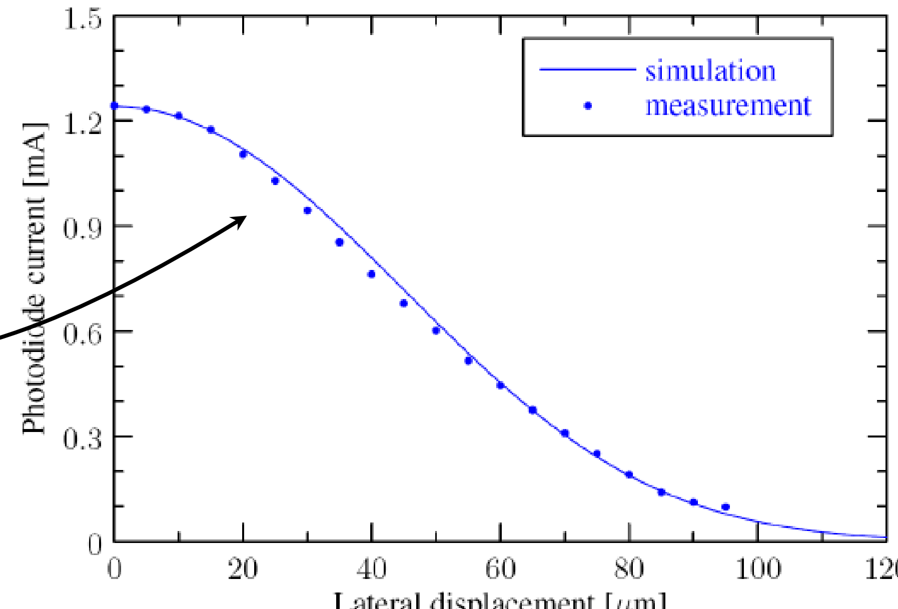


- Circular photodiode



(0,0) → initial position





Cross-section in 1 direction

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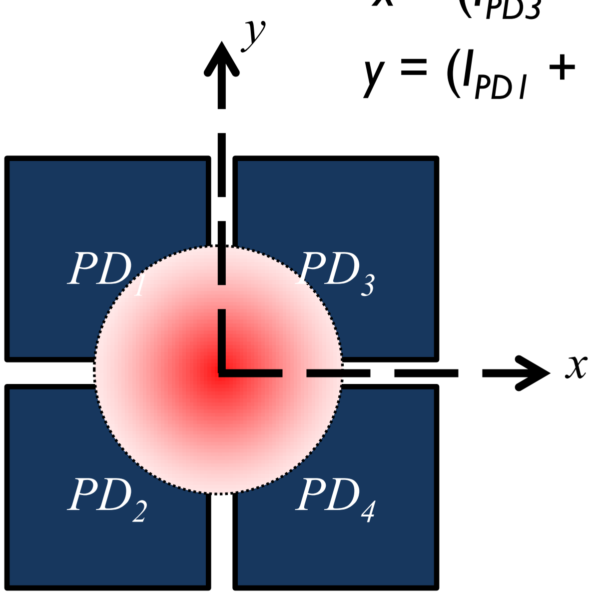
Applications

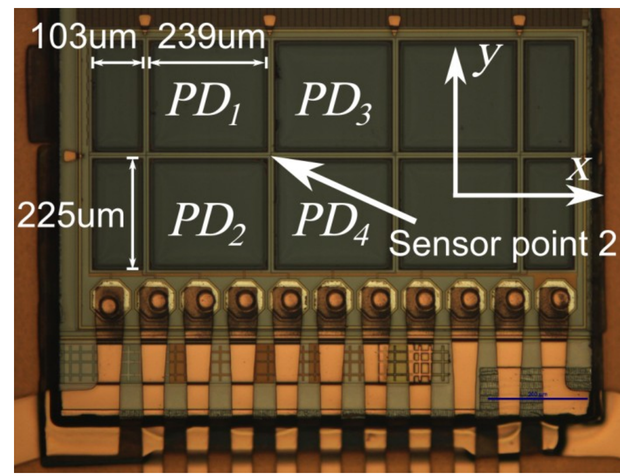
Intensity-based shear sensor

- Square segmented photodiode



$$x = (I_{PD3} + I_{PD4} - I_{PD1} - I_{PD2}) / I_{tot}$$

$$y = (I_{PD1} + I_{PD3} - I_{PD2} - I_{PD4}) / I_{tot}$$



Segmented photodiode developed at EMCE, TUWien, prof. Zimmermann.

- (x,y) sensing
- reduced external influences affecting all segments equally

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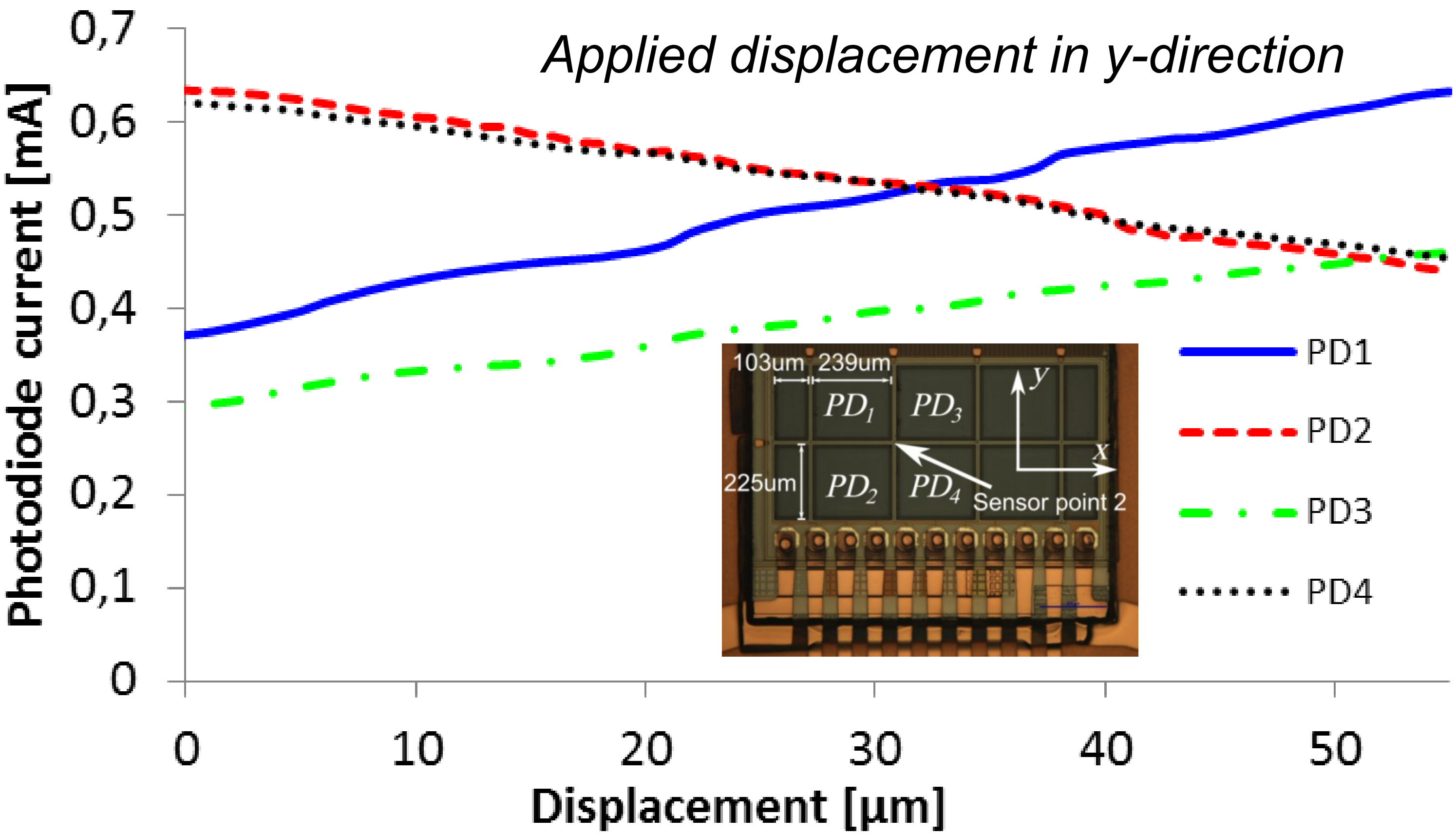
Applications

Intensity-based shear sensor



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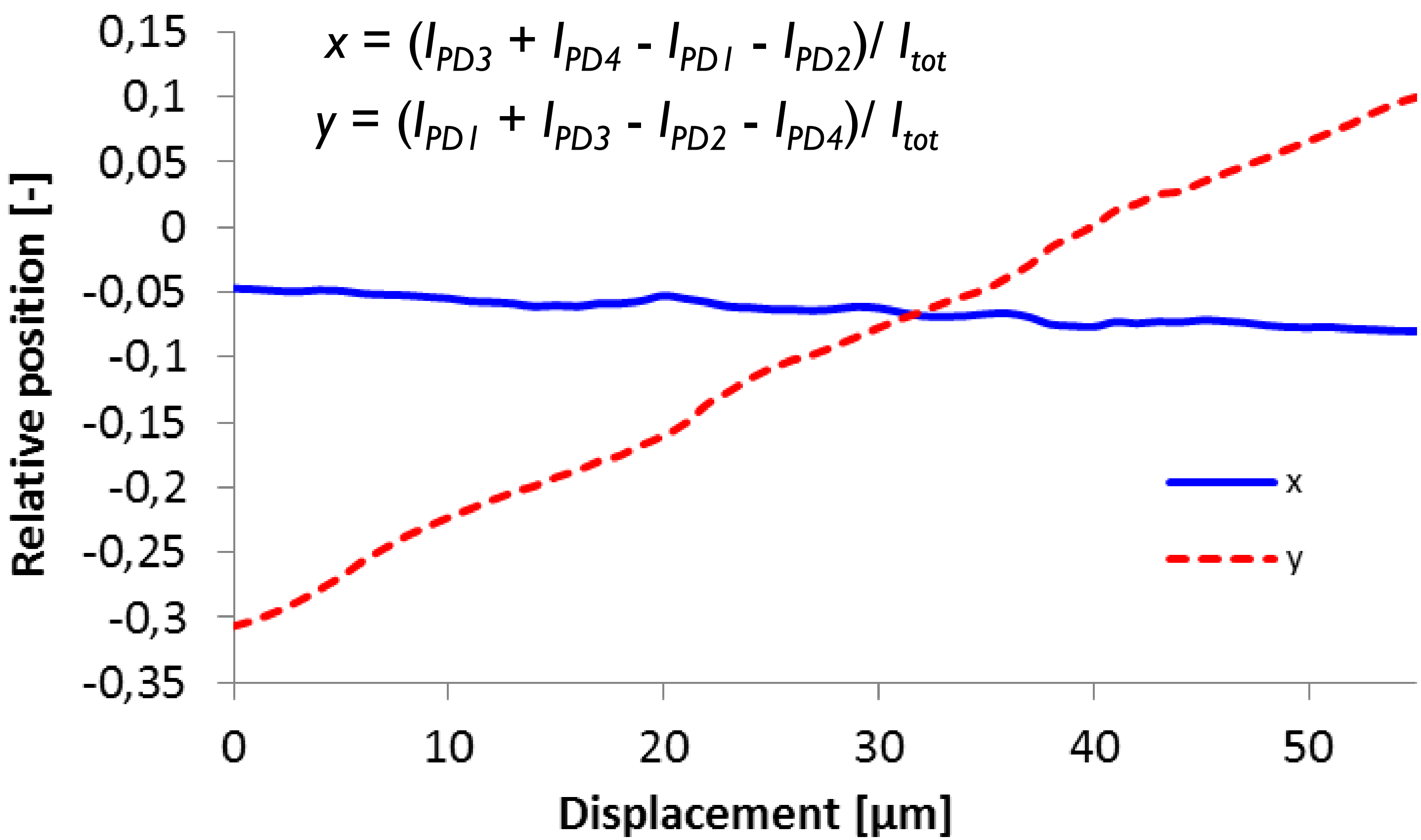
Applications

Intensity-based shear sensor



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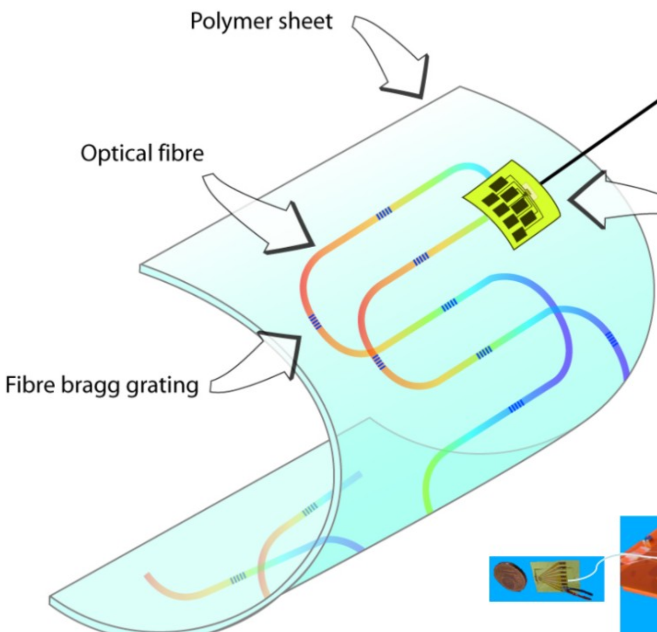
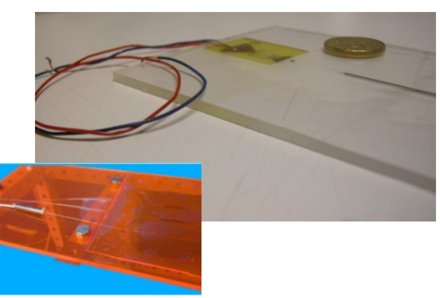
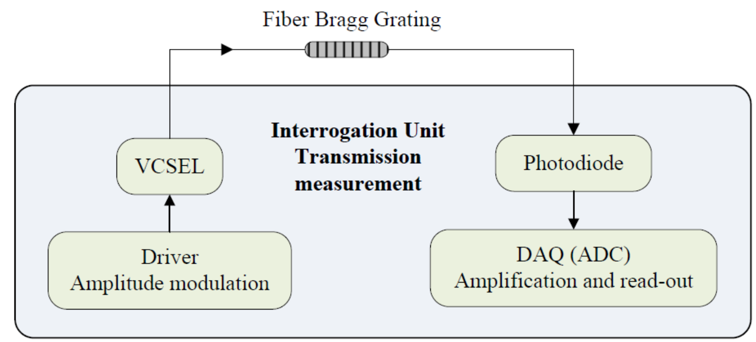
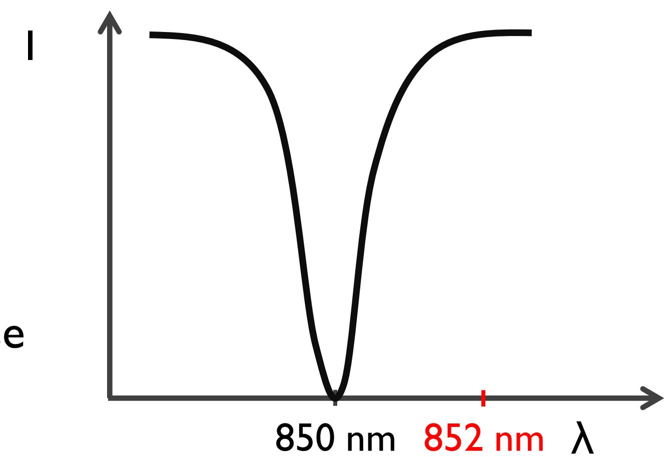
Applications

Wavelength-based strain sensor









FlexStretch optical sensing systems with integrated read-out

Axial or transverse strain

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Applications

Wavelength-based strain sensor

Single mode VCSEL source

External parameters ε, p, T

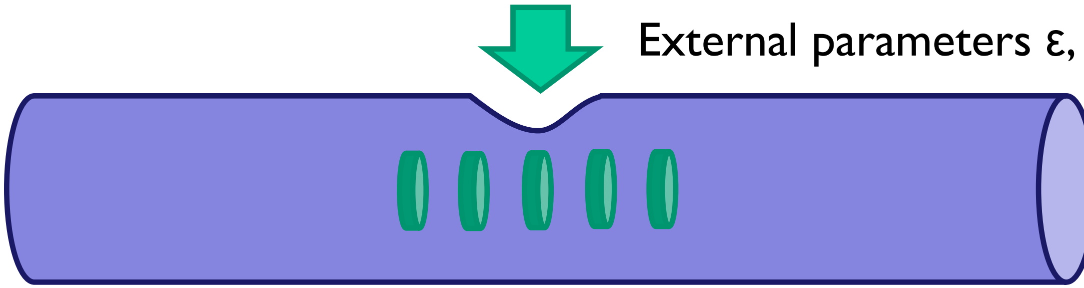
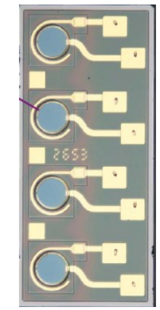


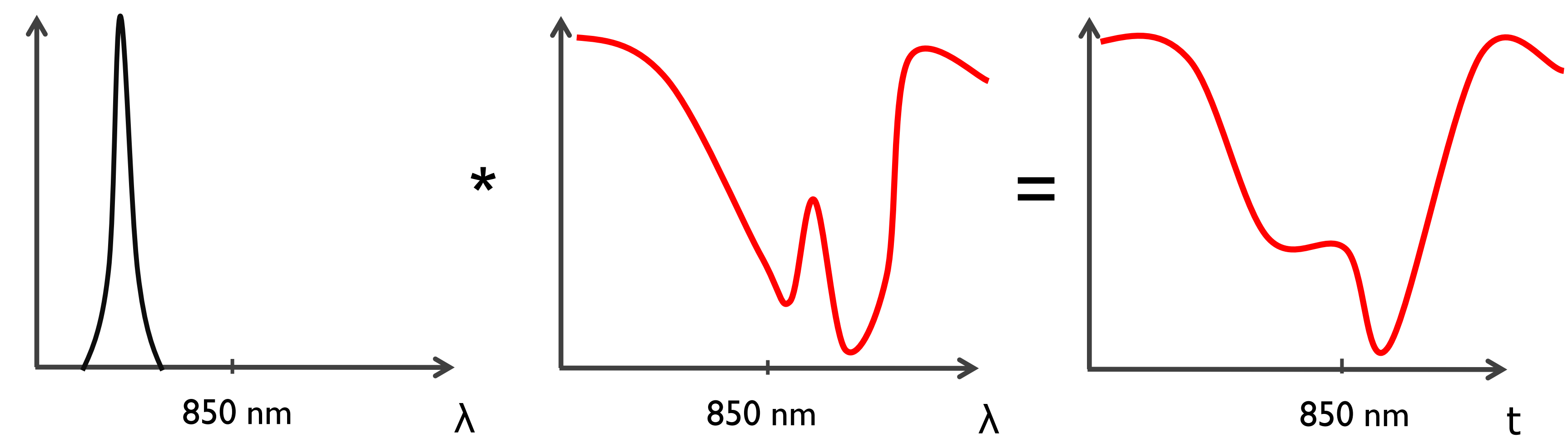
Photo-detector



VCSEL

Grating filter characteristic

PD current



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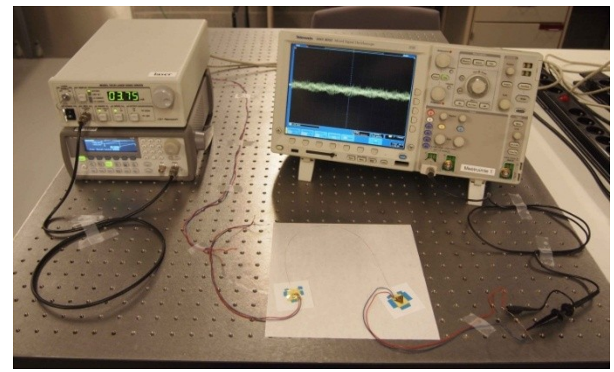
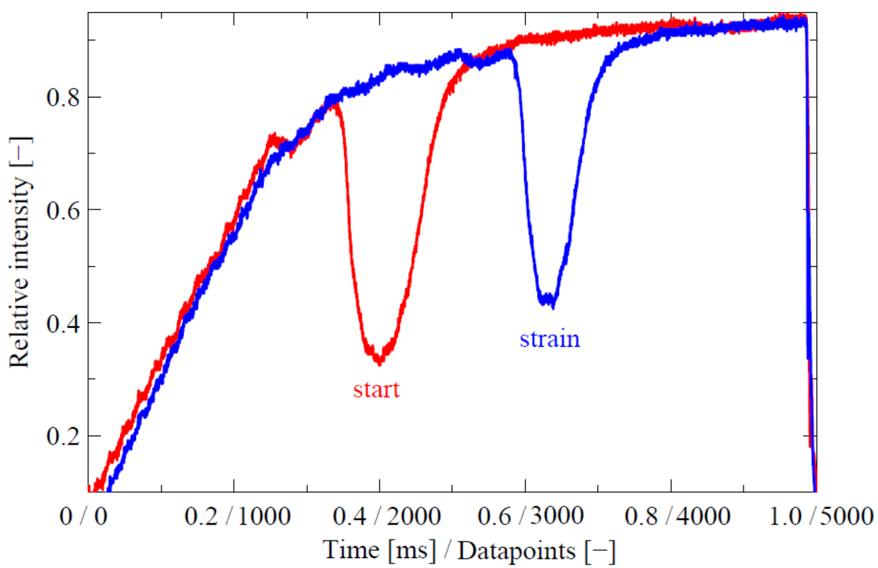
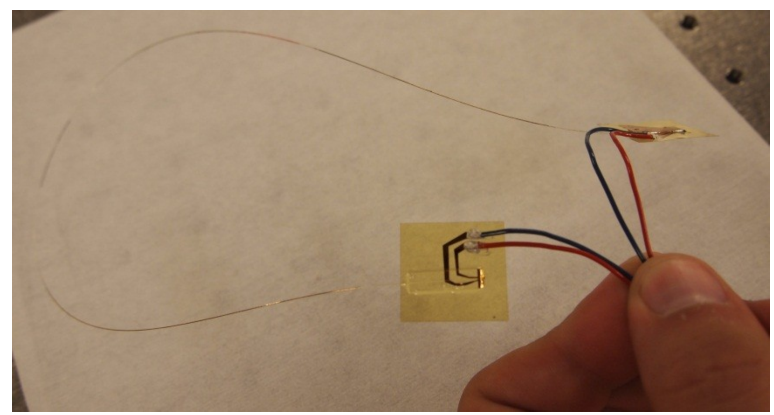
Applications

Wavelength-based strain sensor

- Single-mode system
- Overall loss: 7 dB
- Ultra-compact







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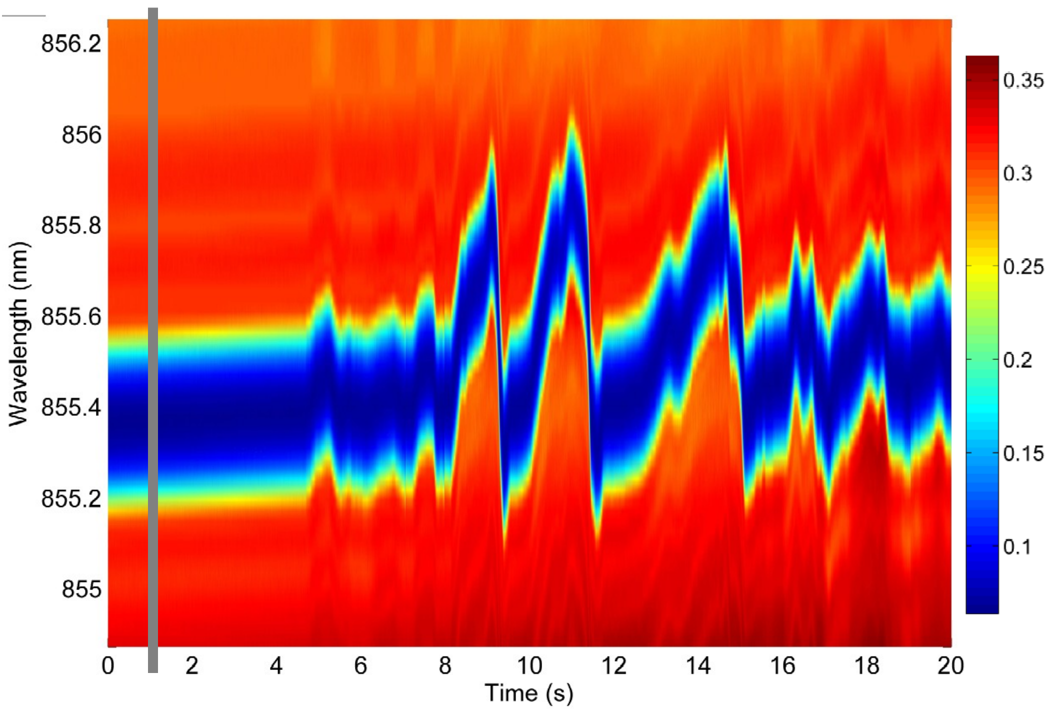
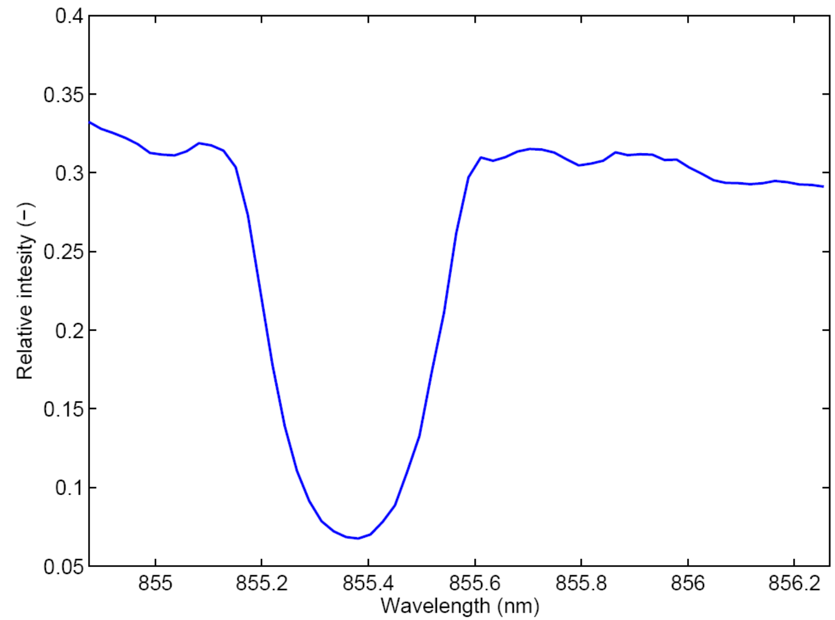
Applications

Wavelength-based strain sensor



Up to 20 kHz



t = 11s

t = 1s

Manual straining and releasing up to 0.5 mstrain

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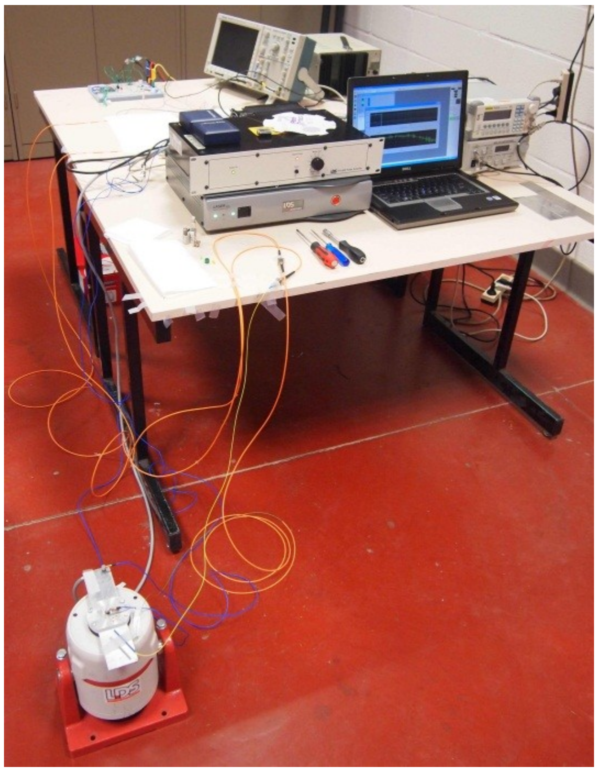
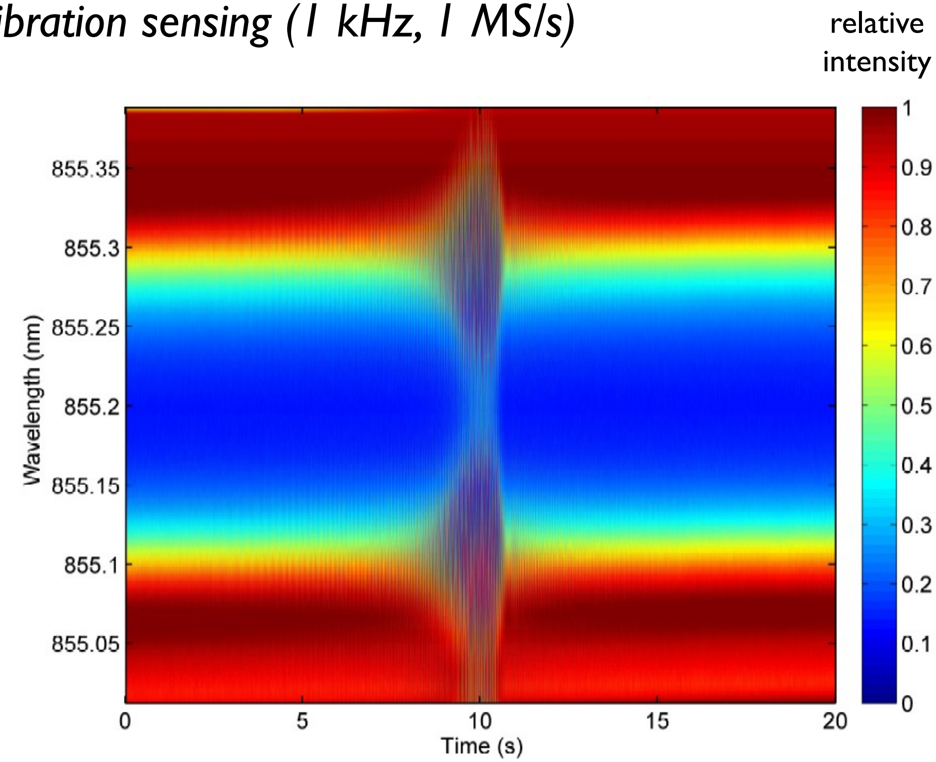
Applications

Wavelength-based strain sensor



Electrodynamic shaker (1 kHz, 1 MS/s)
Vibration sensing (1 kHz, 1 MS/s)



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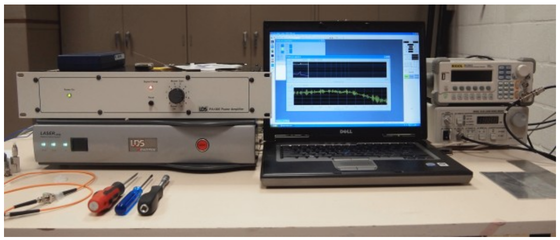
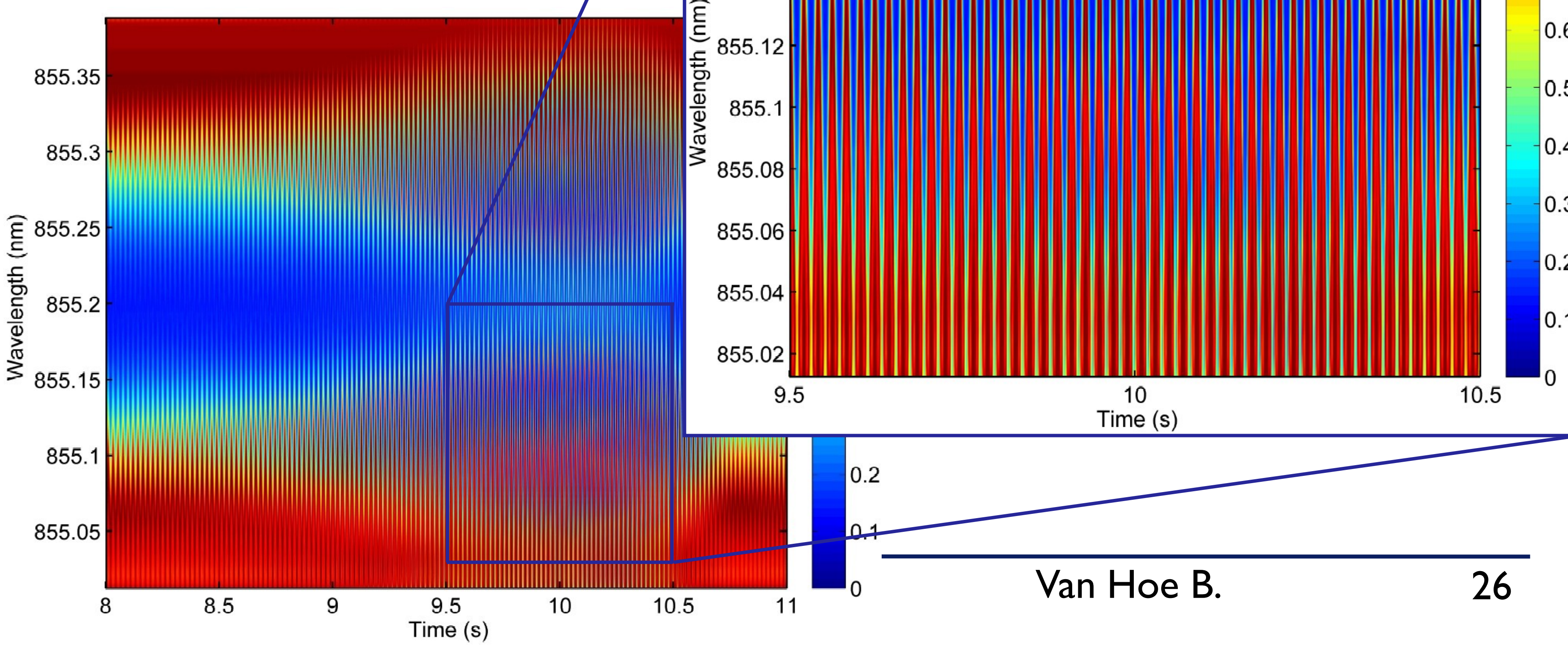
Wavelength-based strain sensor





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  - Interference based pressure sensor
  - Intensity based shear sensor
  - Wavelength based strain sensor
- **Conclusions**

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Conclusions

- **Optical sensors**
  - Miniaturization through integration
  - Thin and flexible: unobtrusive
  - Multiplexing: (quasi-) distributed sensing
- **Combine different sensors in one photonic skin**
- **Towards polymer waveguide sensors**
  - Sensitivity, planar technoloy
  - Cfr. Demo

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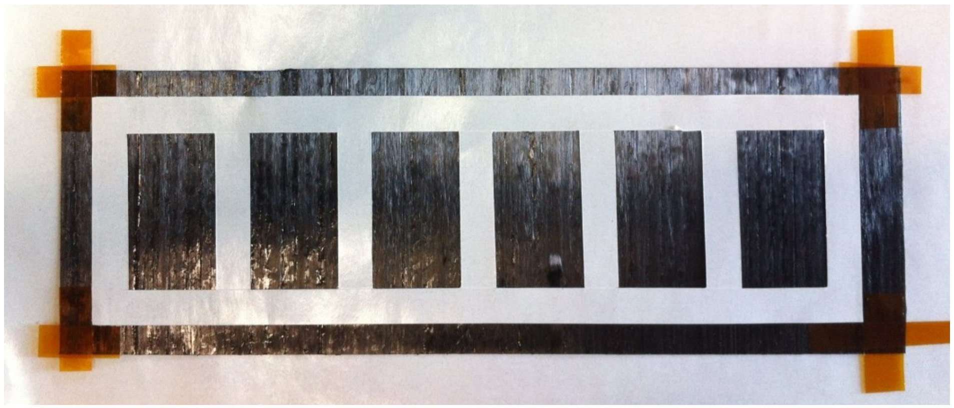
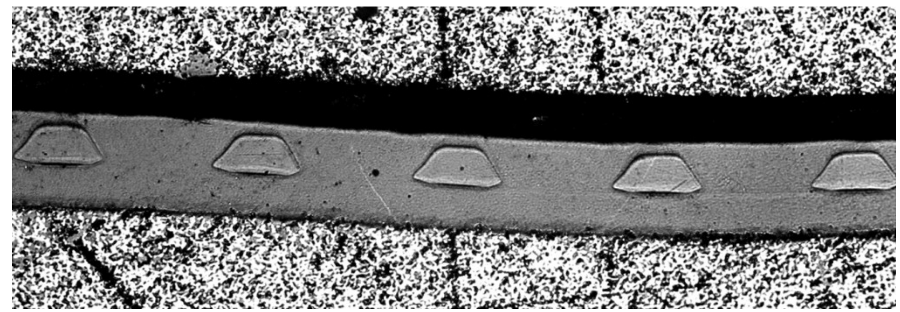
Conclusions

- **Composite integration of sensing layer**





Material → prepreg M10/T300, 0.3 mm layer thickness
Lay-up → 4 layers oriented at 0° (aligned with the PWG length direction)
Manufacturing process → autoclave cycle p_{max} 7 bar, T_{max} 120°C, post curing

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Acknowledgments

Self Sensing Composites

IWT – SBO project

Photonic Skins For Optical Sensing

EC – FP7 project

Optical team – Centre for Microsystems Technology (CMST) affiliated with Ghent University and Imec

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Photonic skins for pressure, shear and strain sensing

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