

Optical Fiber Sensors and Networks –

Will They Further Brighten Our Future?

Communications
Signal
Processing

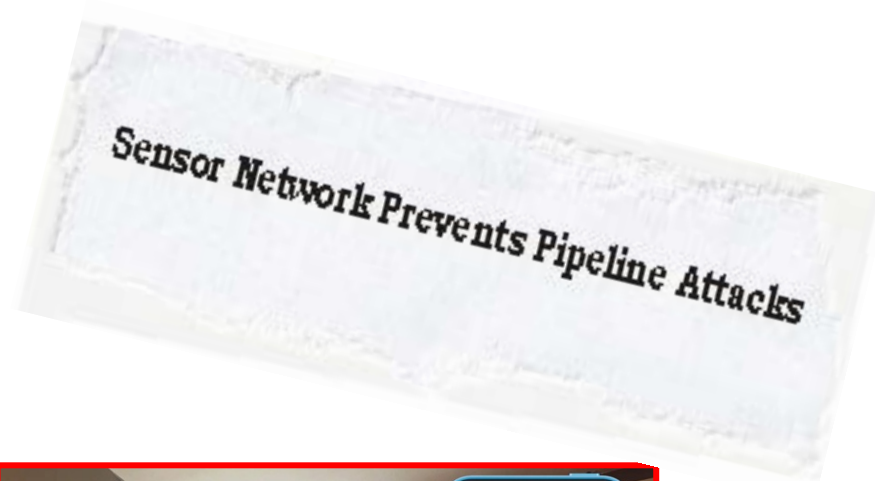


Prof. Dr.-Eng. habil. Steffen Lochmann

**HOCHSCHULE
WISMAR**
UNIVERSITY OF
TECHNOLOGY,
AND
BUSINESS
DESIGN



Alternative, but Justified News:



/He

/Na

/Optromix Inc./

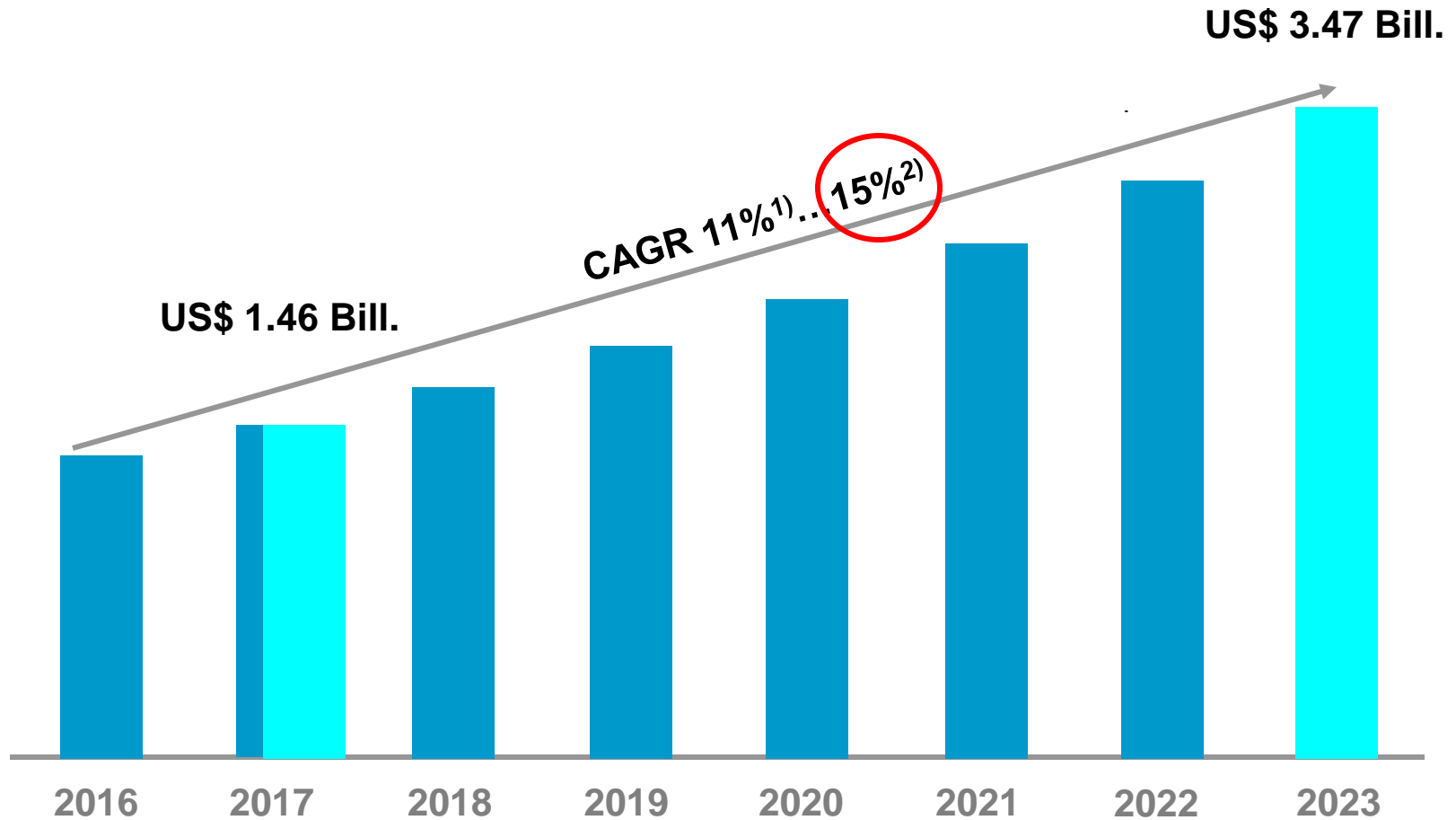


Outline

- 1. Market**
- 2. Driving Forces and Restrictions**
- 3. Advanced Implementation Examples**
- 4. Concluding Remarks**



Global Fiber Optic Sensor Market

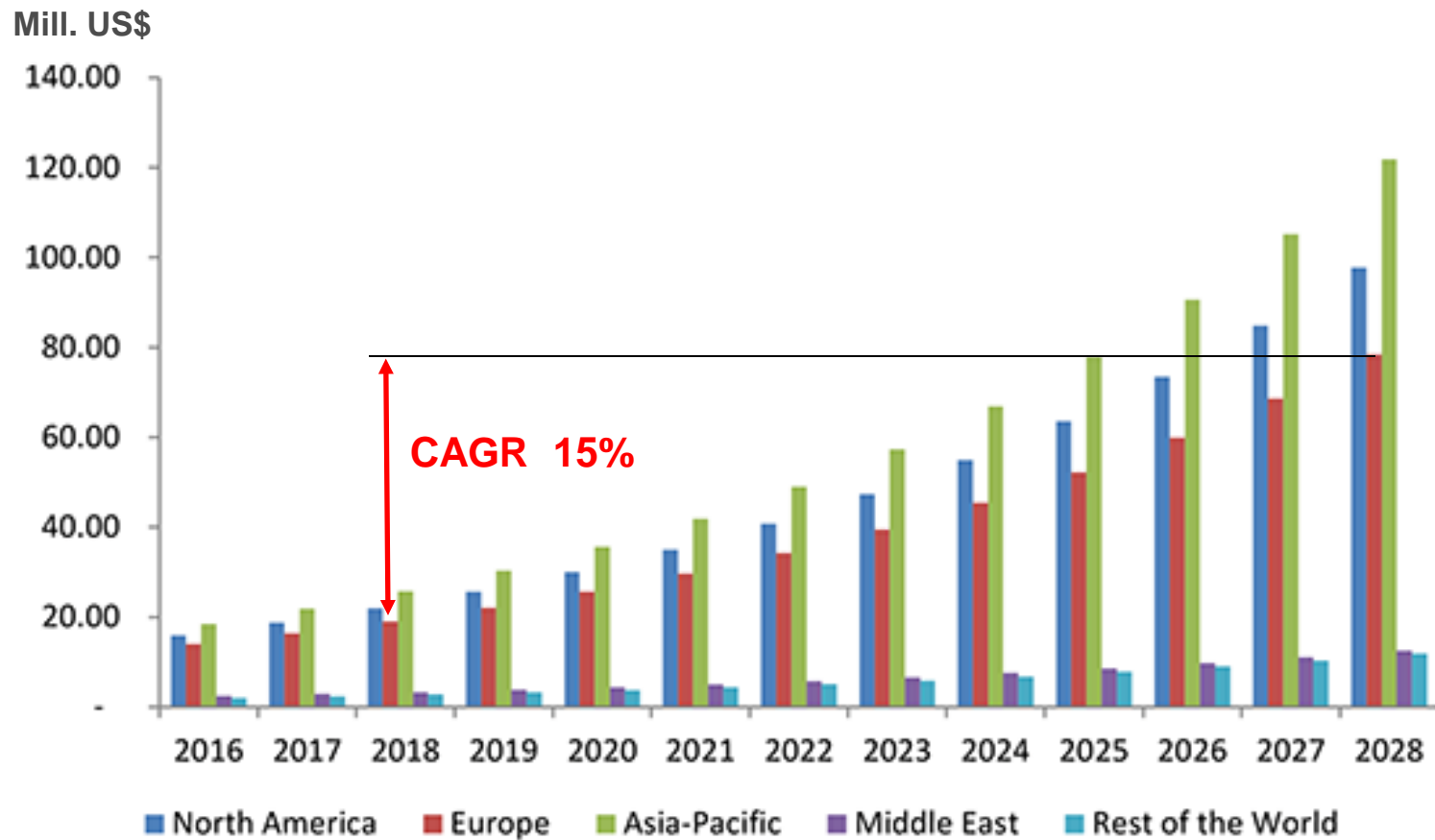


1) WantStats Research And Media Pvt. Ltd.

2) MarketsandMarkets Research Pvt. Ltd.



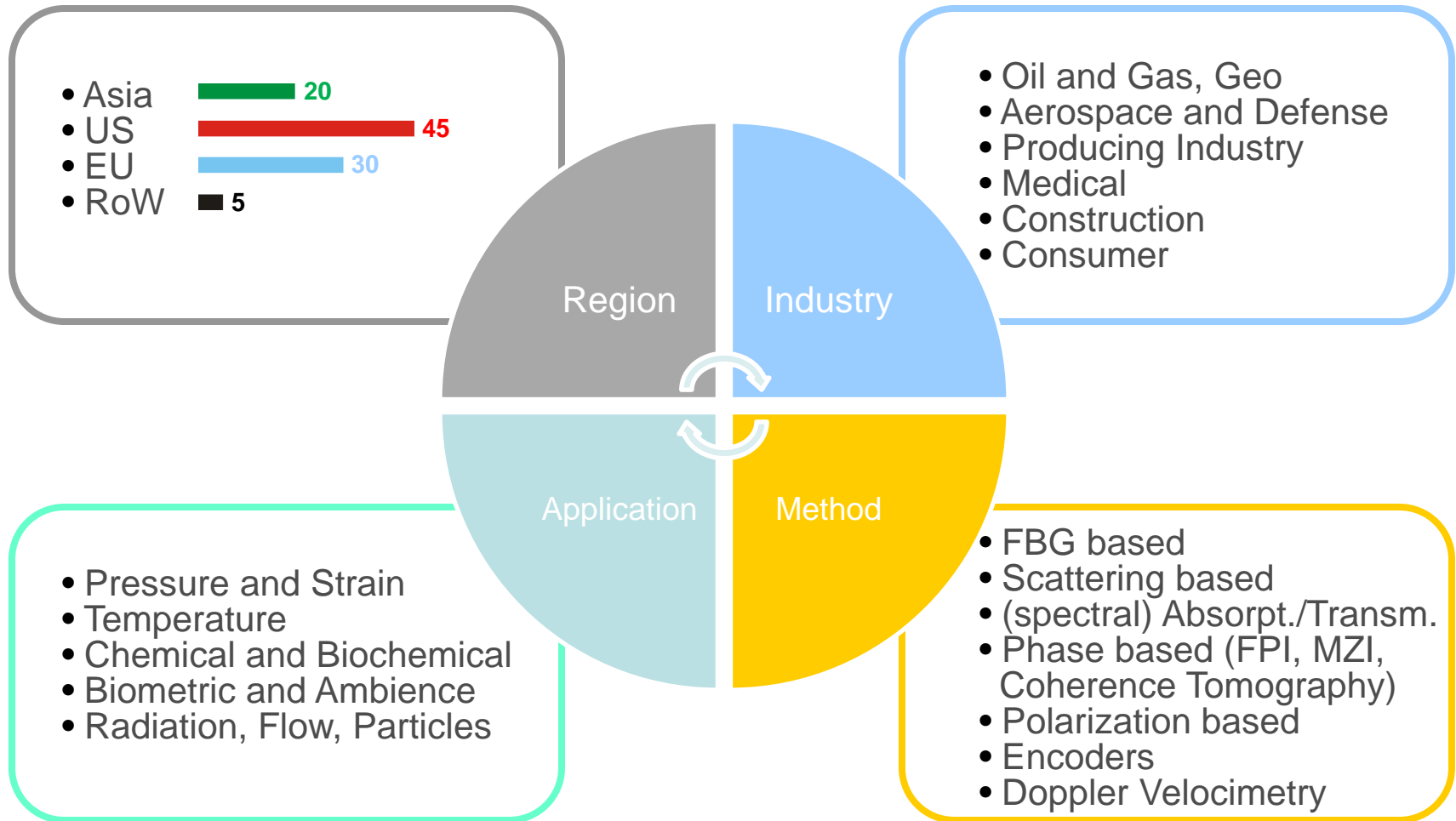
Distributed Fiber Optic Sensing Market



/Visiongain Limited/

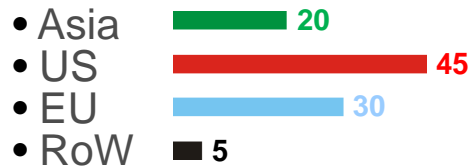


Fiber Optic Sensor Market Segments





Major Drivers



- Oil and Gas, Geo
- Aerospace and Defense
- Producing Industry
- Medical
- Construction
- Consumer

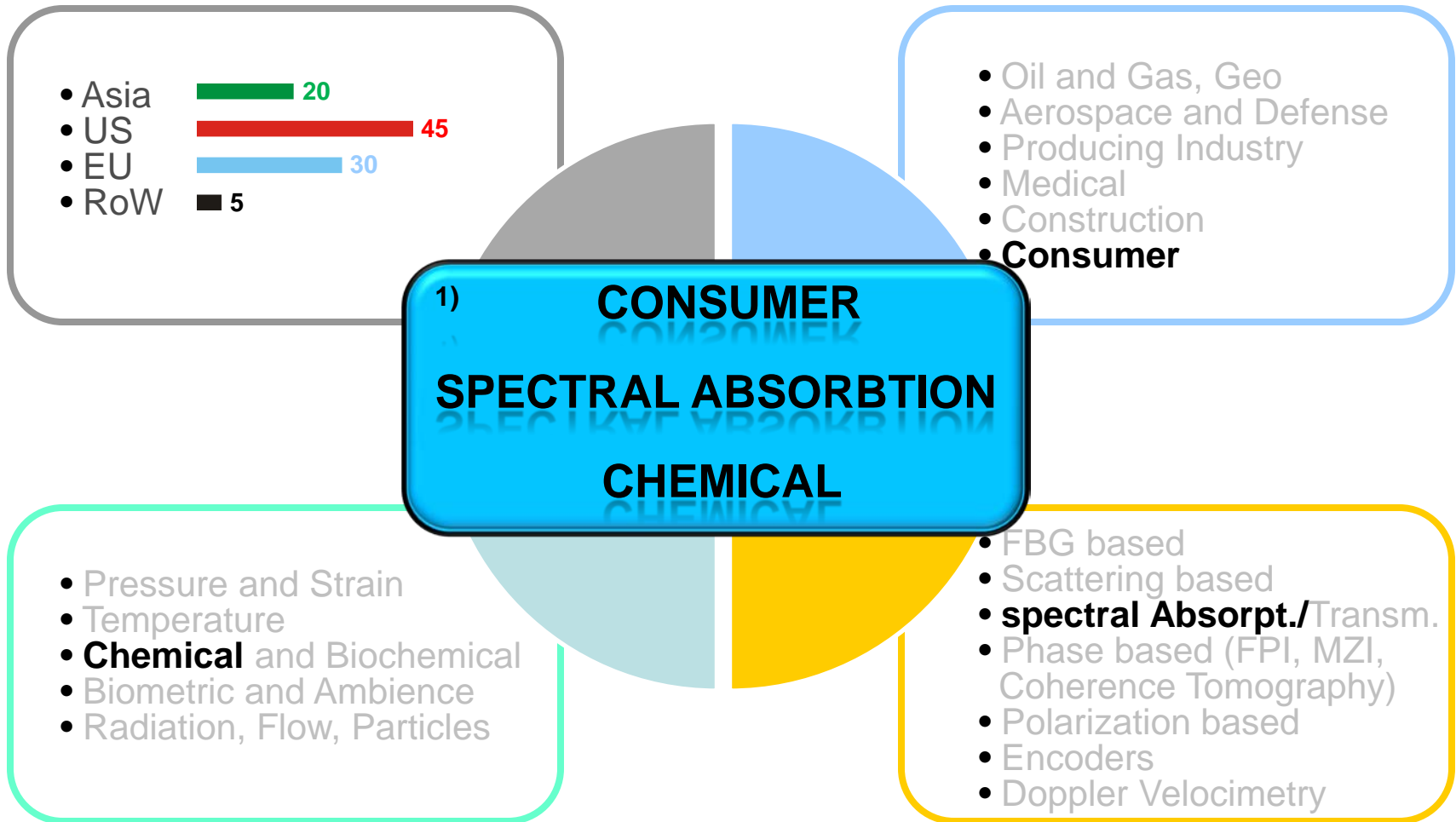
- **Constant new technology developments**
- **Ever increasing need for high quality field data**
- **Suitable for harsh environment**

- Pressure and Strain
- Temperature
- Chemical and Biochemical
- Biometric and Ambience
- Radiation, Flow, Particles

- FBG based
- Scattering based
- (spectral) Absorpt./Transm.
- Phase based (FPI, MZI, Coherence Tomography)
- Polarization based
- Encoders
- Doppler Velocimetry

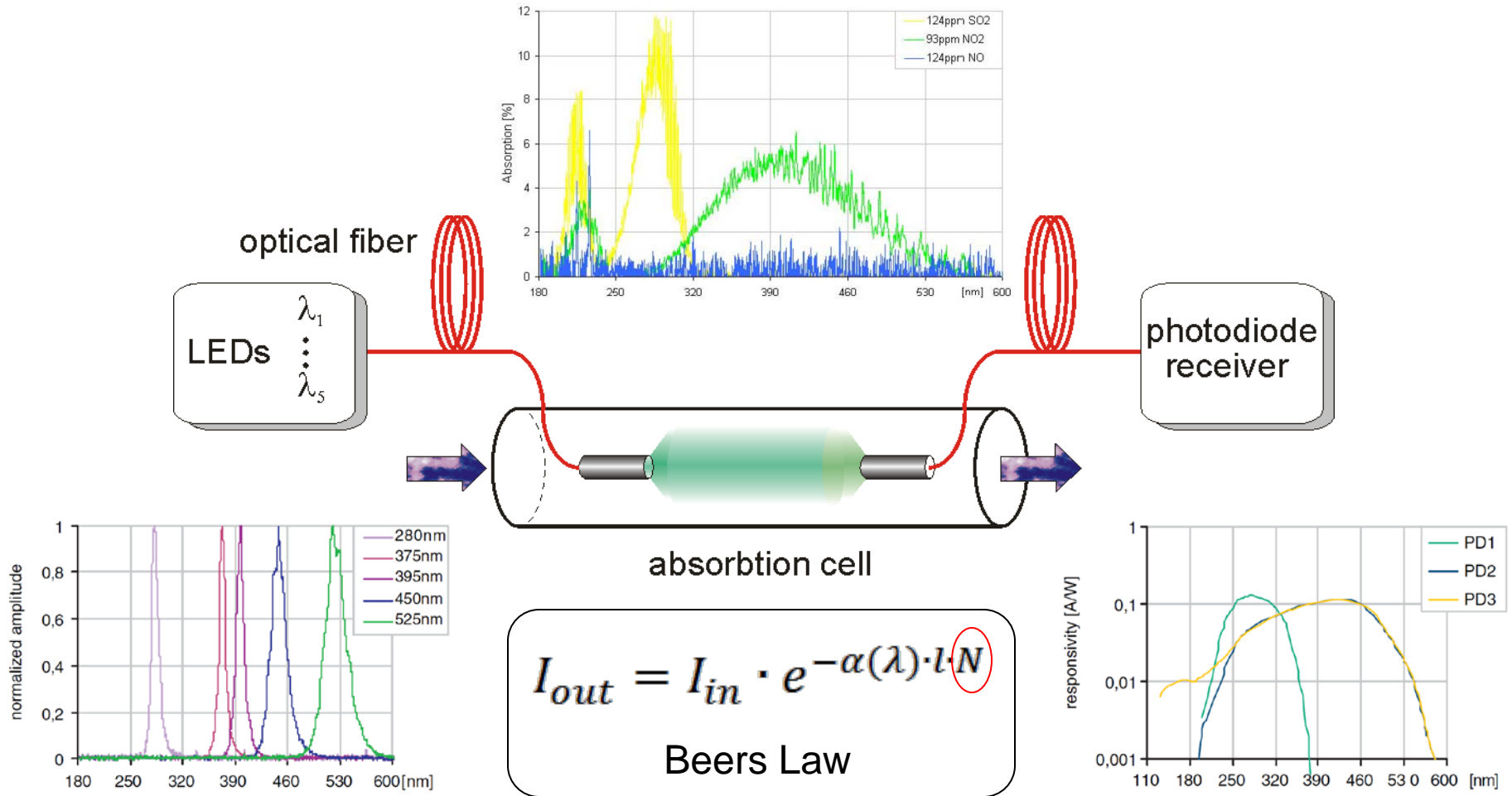


Fiber Optic Sensor Market Segments



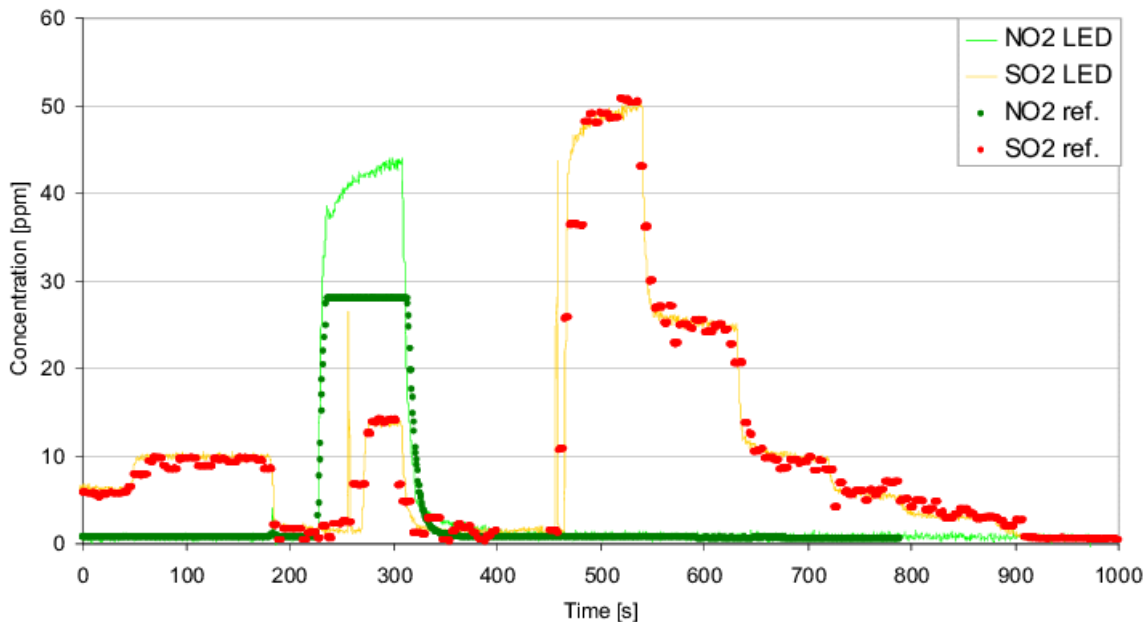


1 EMI-insensitive Multi-Gas Sensors





1 EMI-insensitive Multi-Gas Sensors

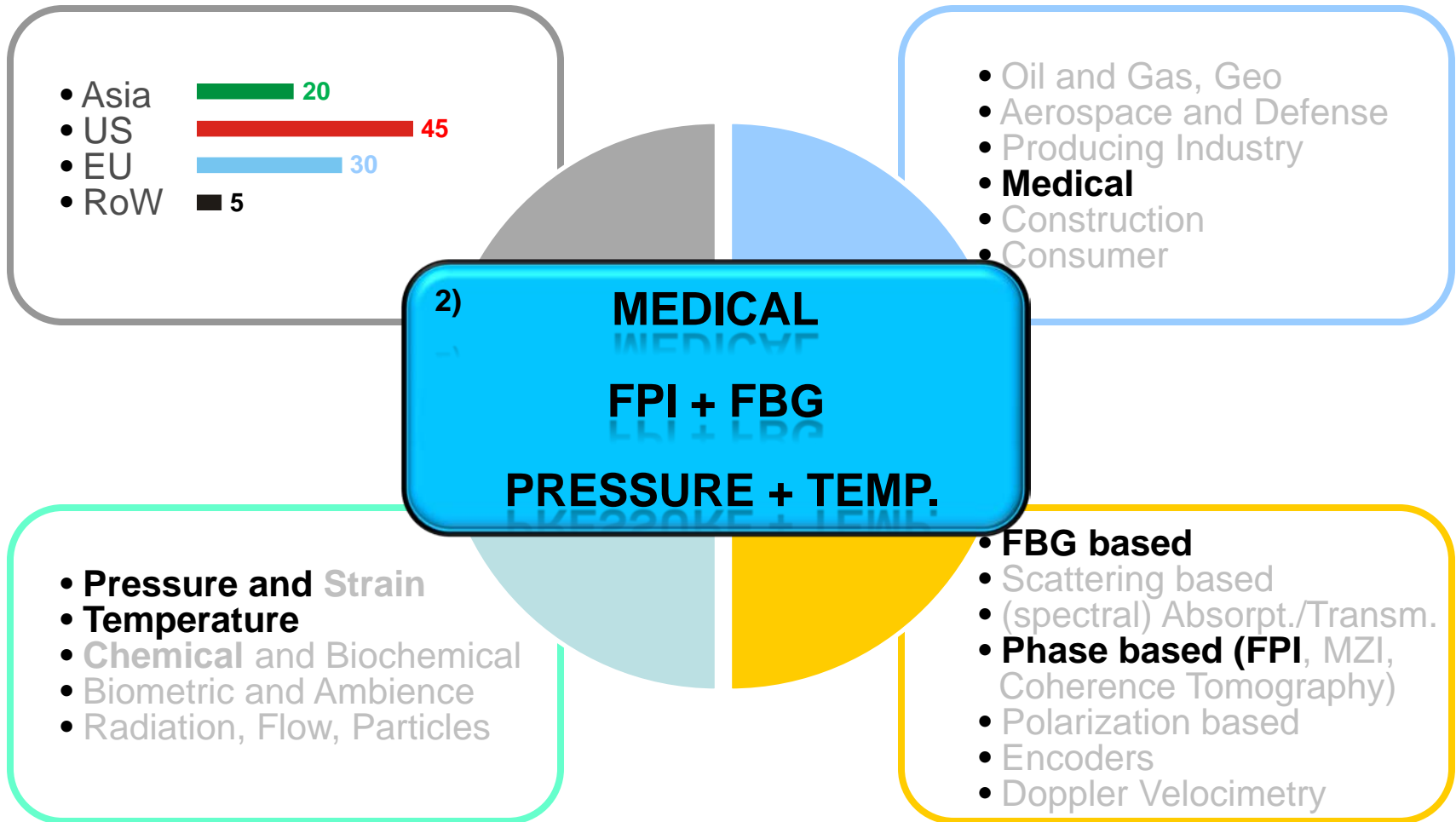


LED-based NO₂ and SO₂ measurement using a reflection probe sensor (cell dimension 4 cm) at 100 ms acquisition time

/Degner et al,
University of Rostock/



Fiber Optic Sensor Market Segments





2 Miniature Medical Pressure Sensor

Pressure measurement needed in:

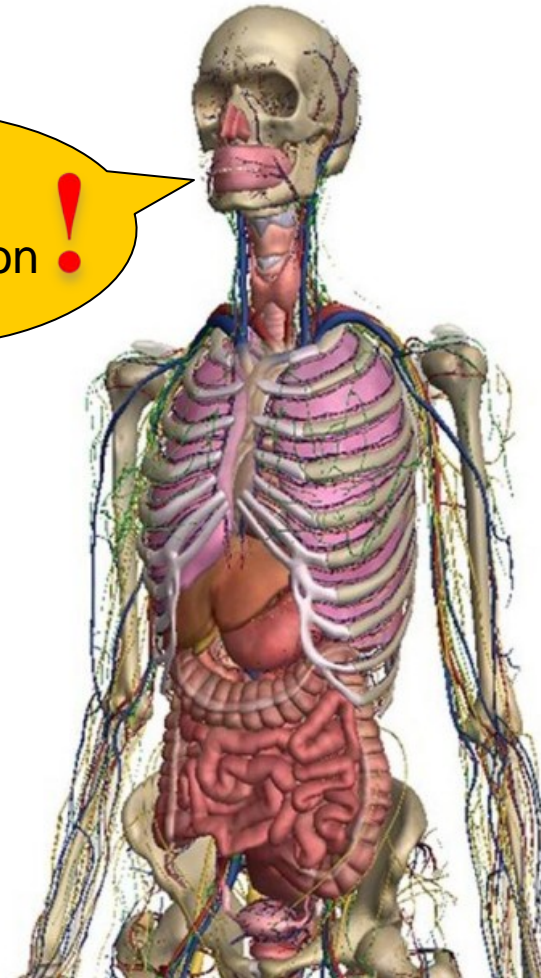
- Brain
- Eye
- Ear

- Lung
- Heart/Vessels

- Liver
- Kidney
- Stomac
- Colon
- Bladder

- Muscles

Sensor
miniaturization !





2 Miniature Medical Pressure Sensor

Pressure measurement needed in:

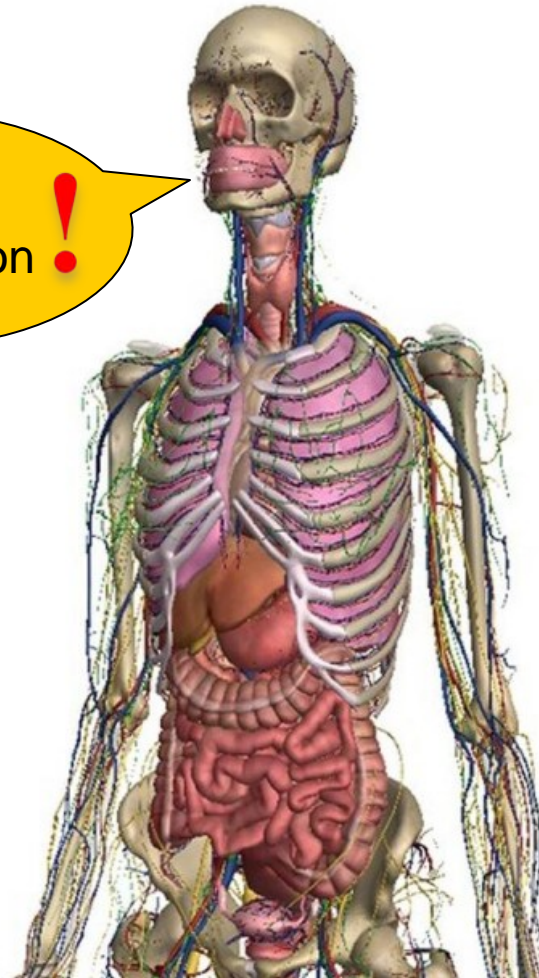
- Brain
- Eye
- Ear

- Lung
- Heart/Vessels

- Liver
- Kidney
- Stomac
- Colon
- Bladder

- Muscles

Sensor miniaturization !





2 Miniature Medical Pressure Sensor

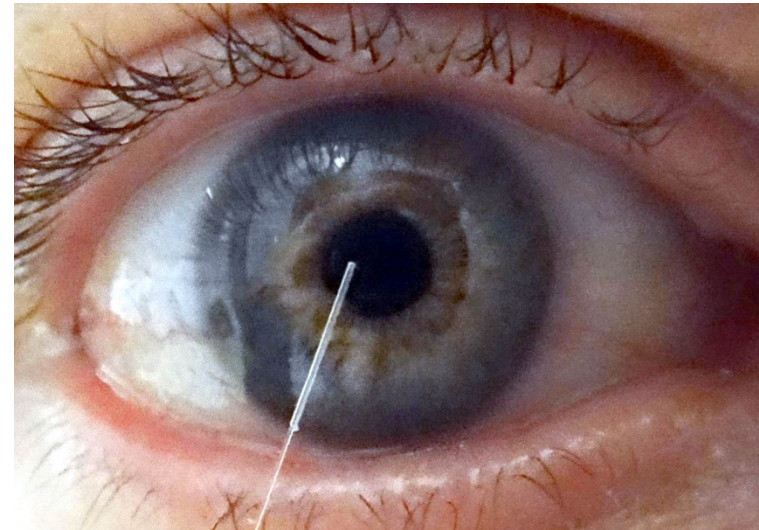
Pressure measurement needed in:

- Brain
- **Eye**
- **Ear**

- Lung
- Heart/Vessels

- Liver
- Kidney
- Stomac
- Colon
- **Bladder**

- Muscles



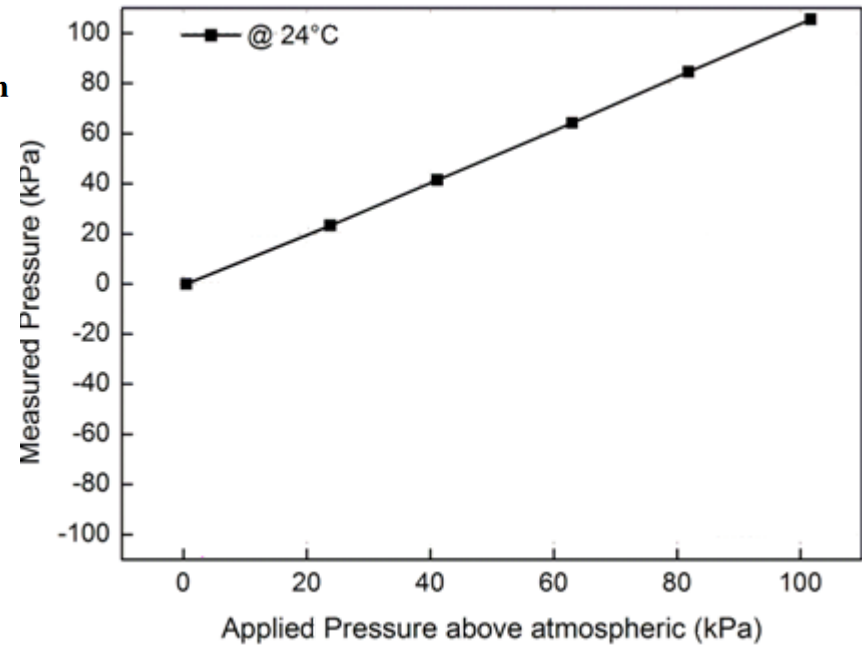
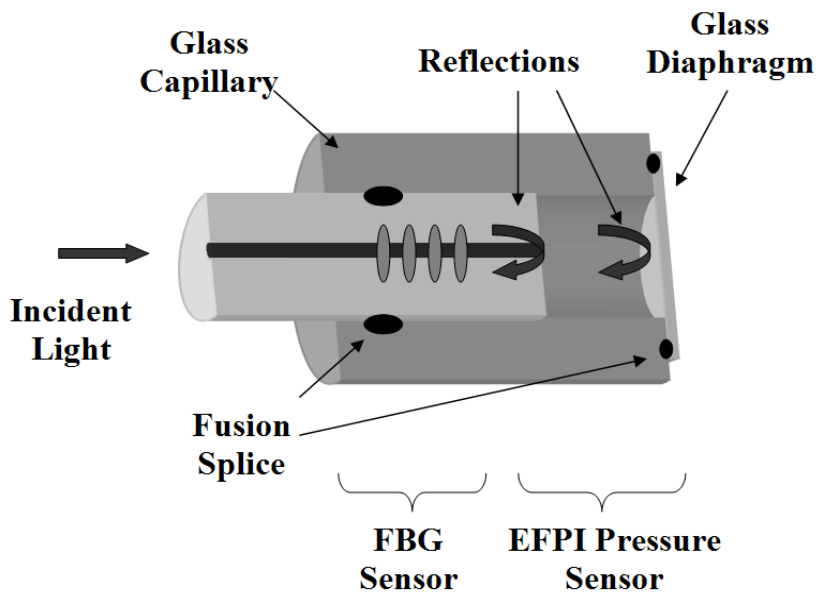
- **Small size**
- **Bio-compatible**





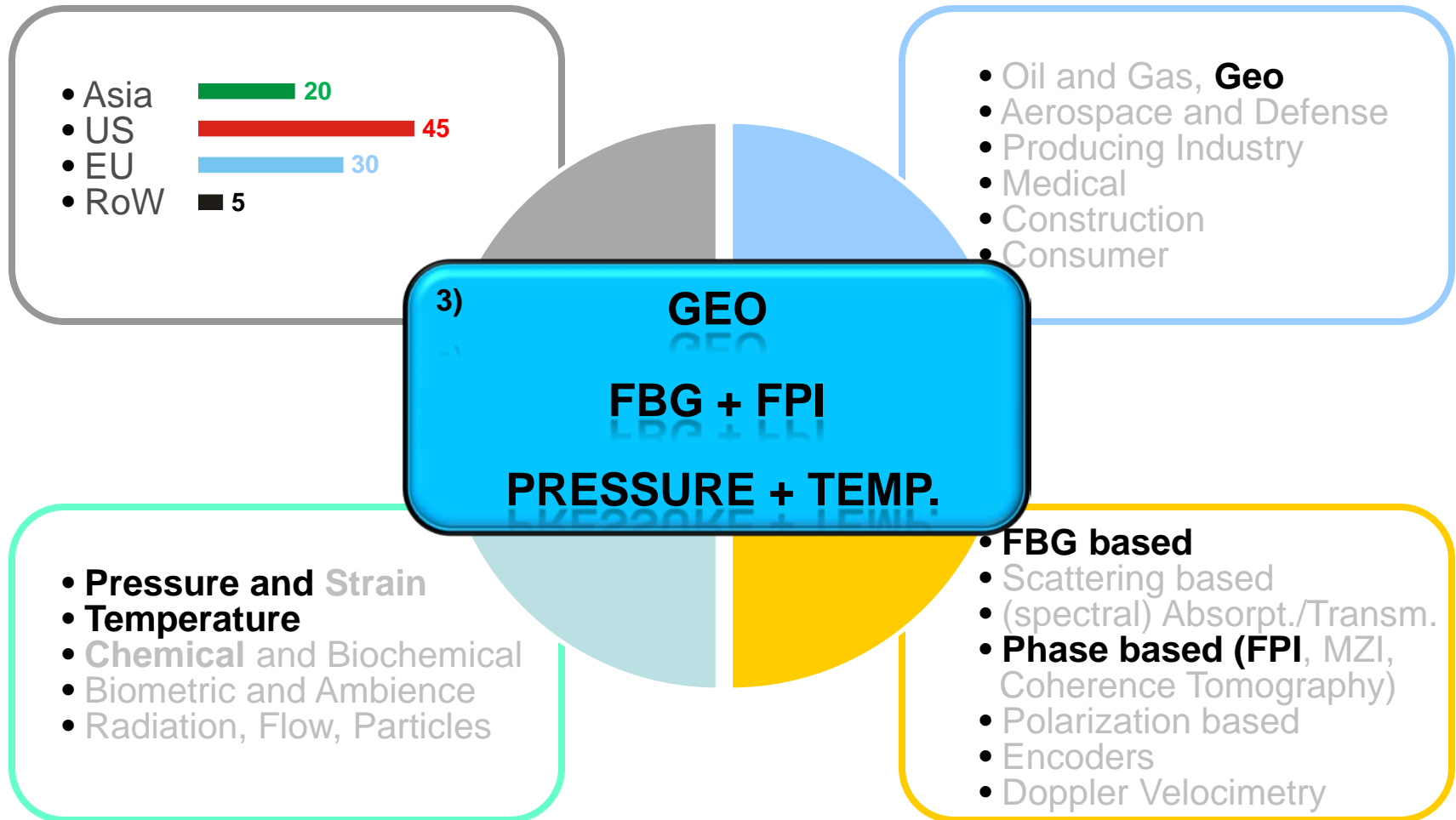
2 Miniature Medical Pressure Sensor

Fiber Bragg Grating / External Fabry Perot Interferometer (FBG/EFPI)





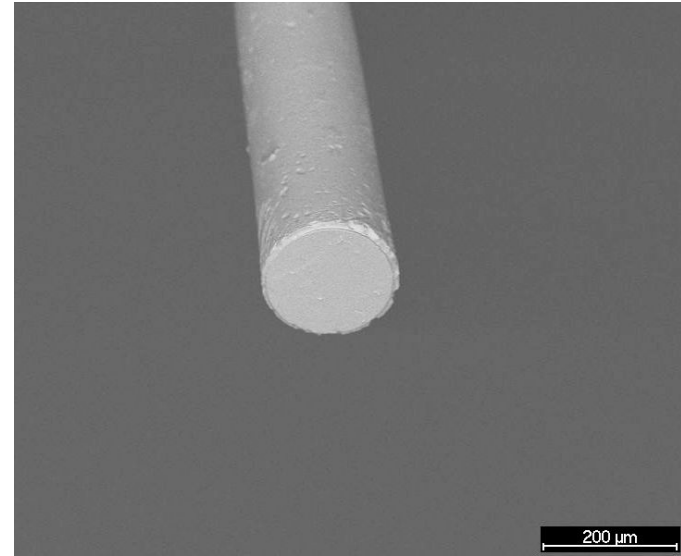
Fiber Optic Sensor Market Segments





3 Miniature Pressure and Temperature Sensor

for **Pore Pressure Measurement** within the pore space of rock



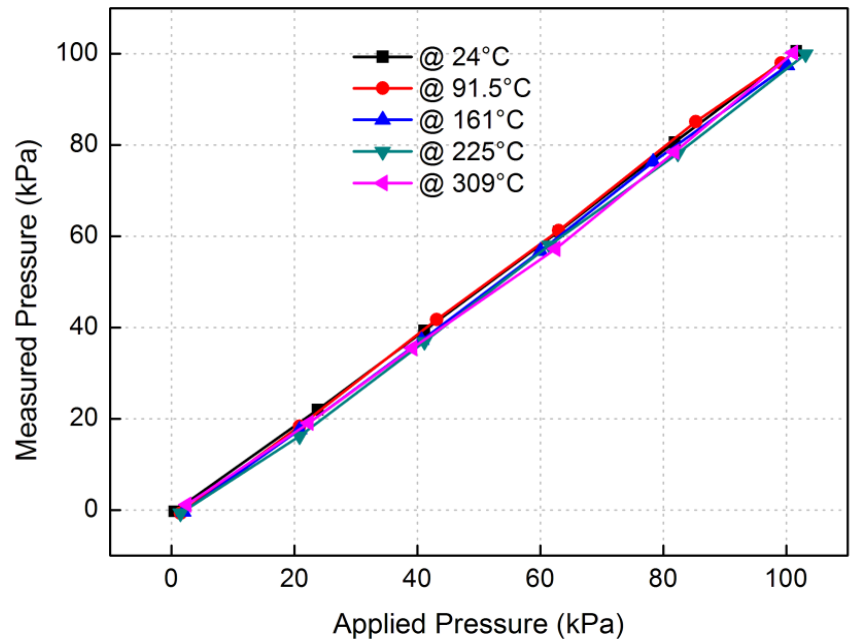
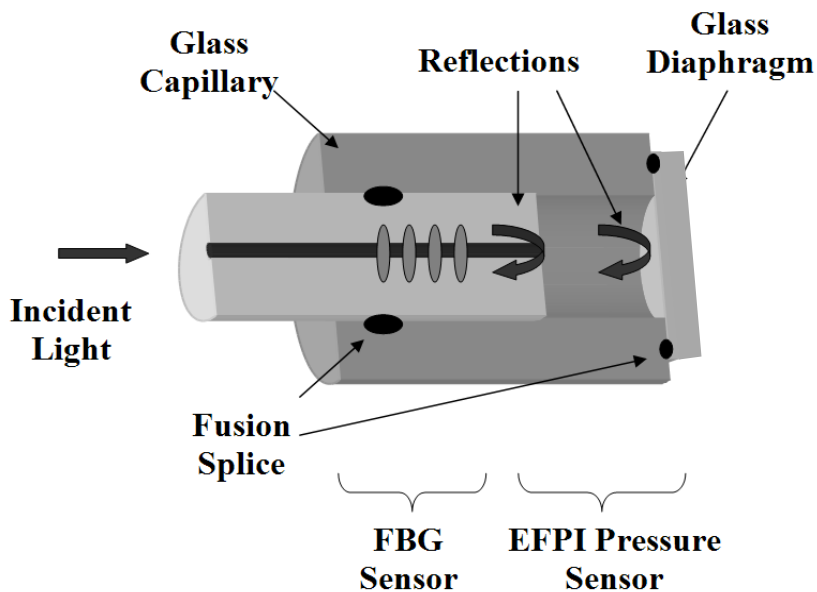
- Small size
- High pressure
- Harsh temperature





3 Miniature Pressure and Temperature Sensor

for Pore Pressure Measurement *within* the pore space of rock

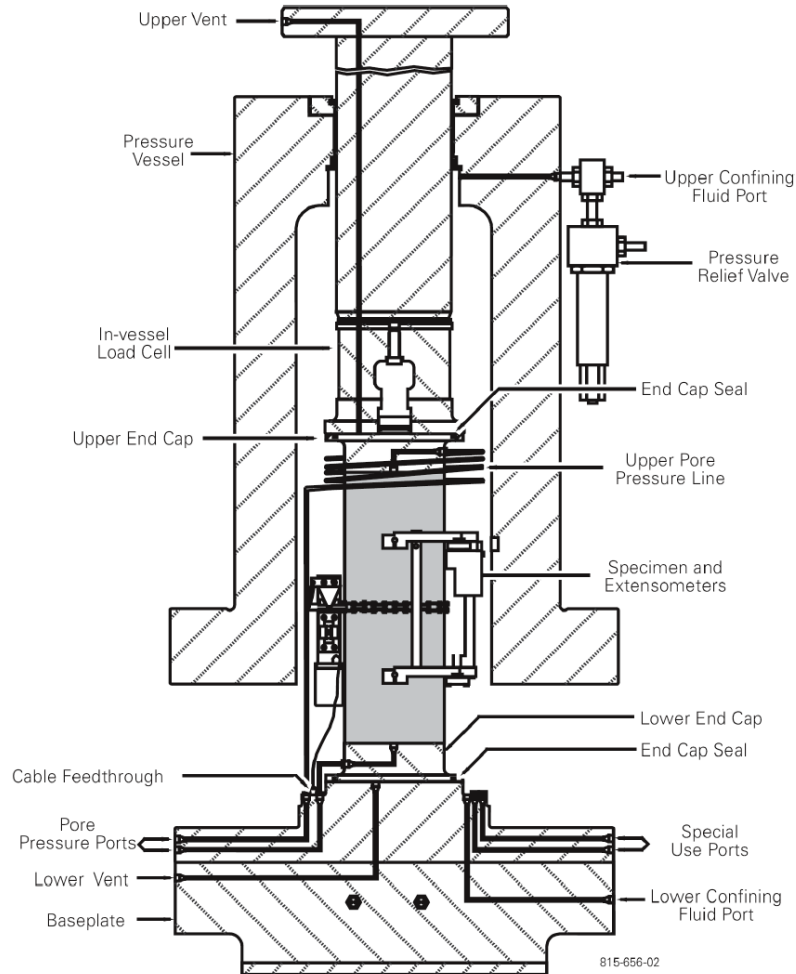


➔ Adjustment of cavity length and membran thickness

➔ Temperature Compensation

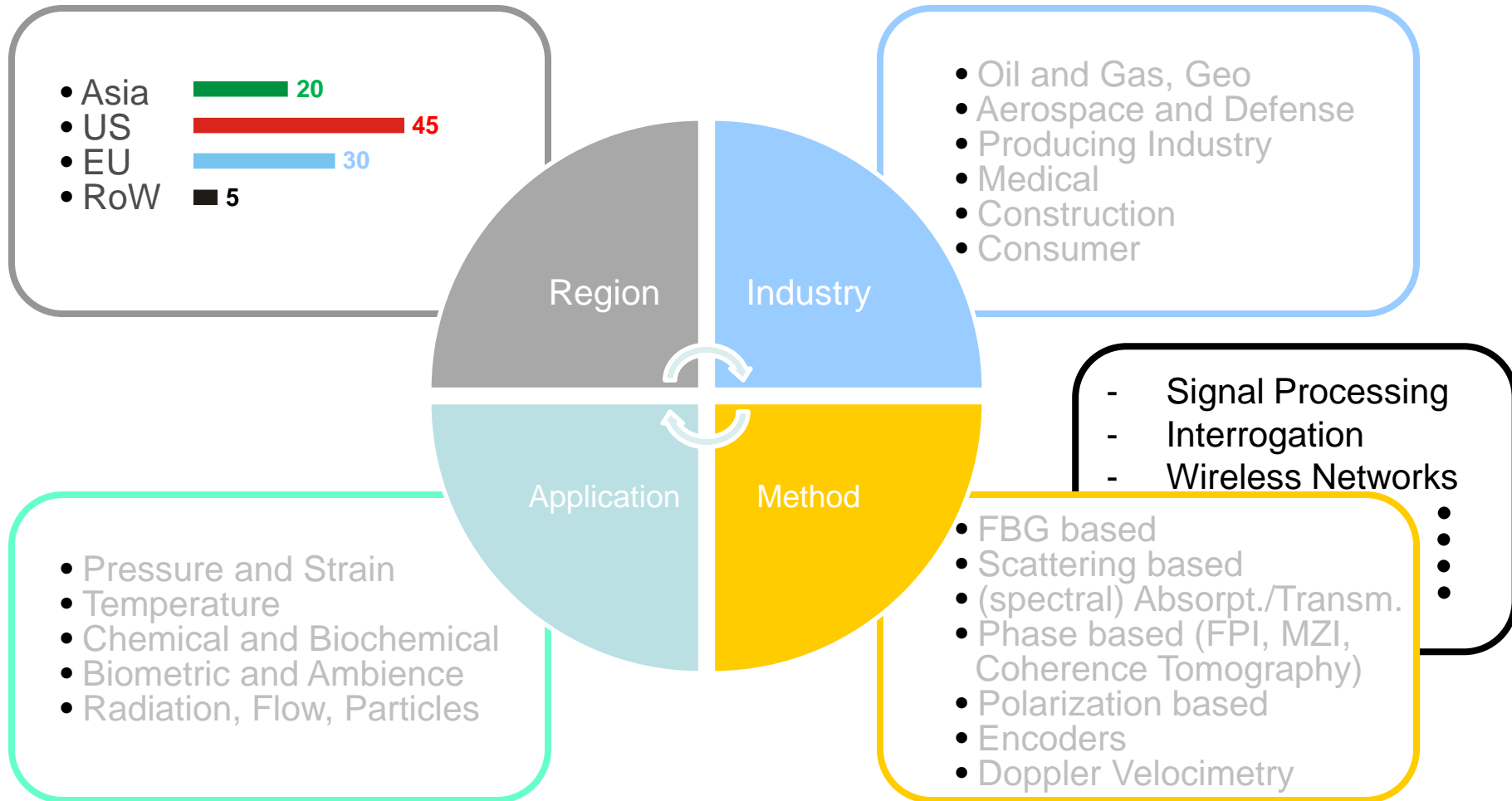


3 Miniature Pressure and Temperature Sensor



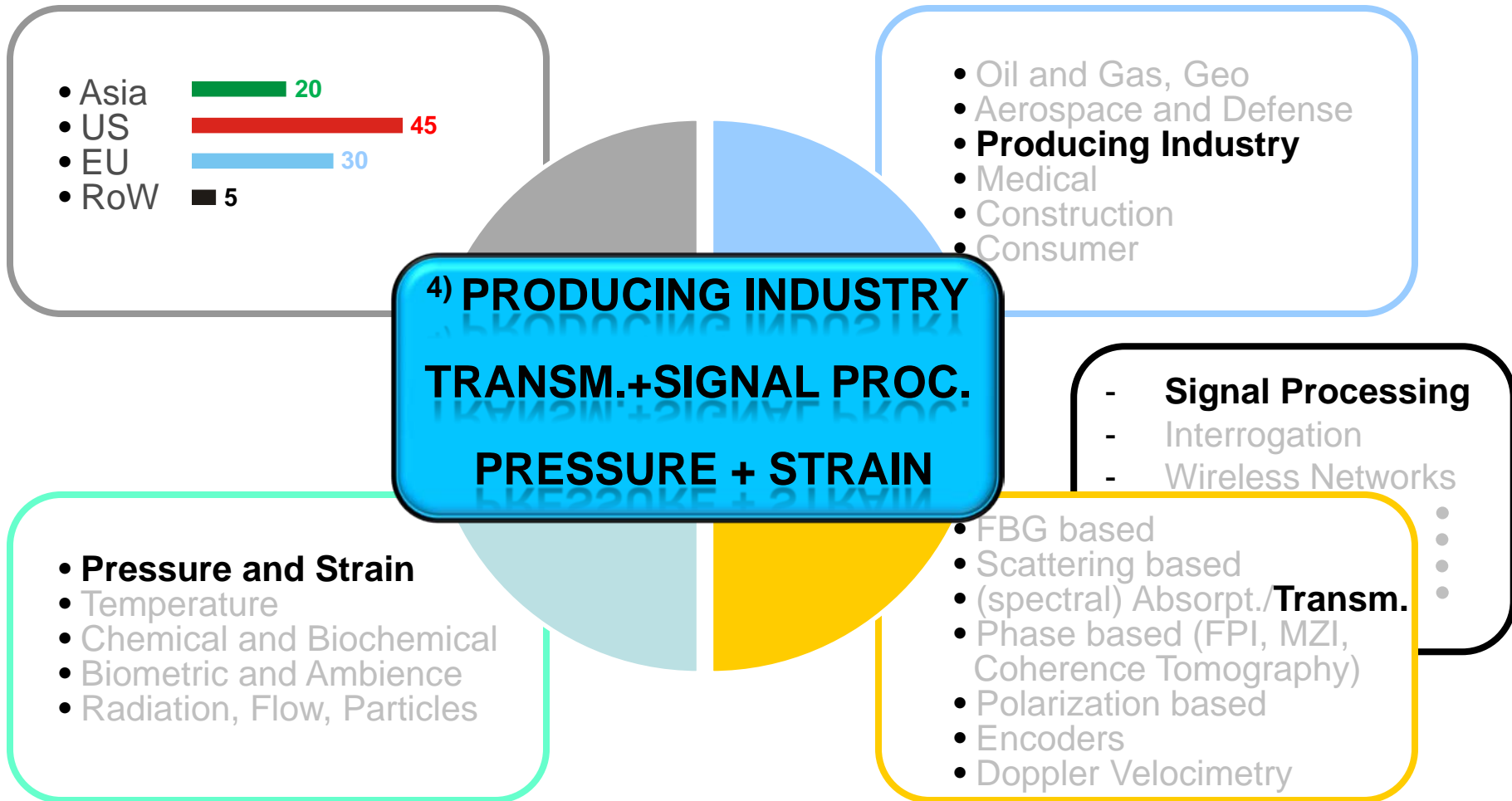


Fiber Optic Sensor Market Segments





Fiber Optic Sensor Market Segments





4 Signal Processing Improves Microbender

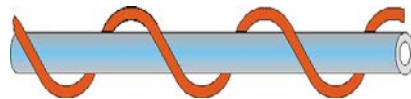
Low cost sensor for

- Acceleration Measurement



/fos4X GmbH/

- Safety Bumper

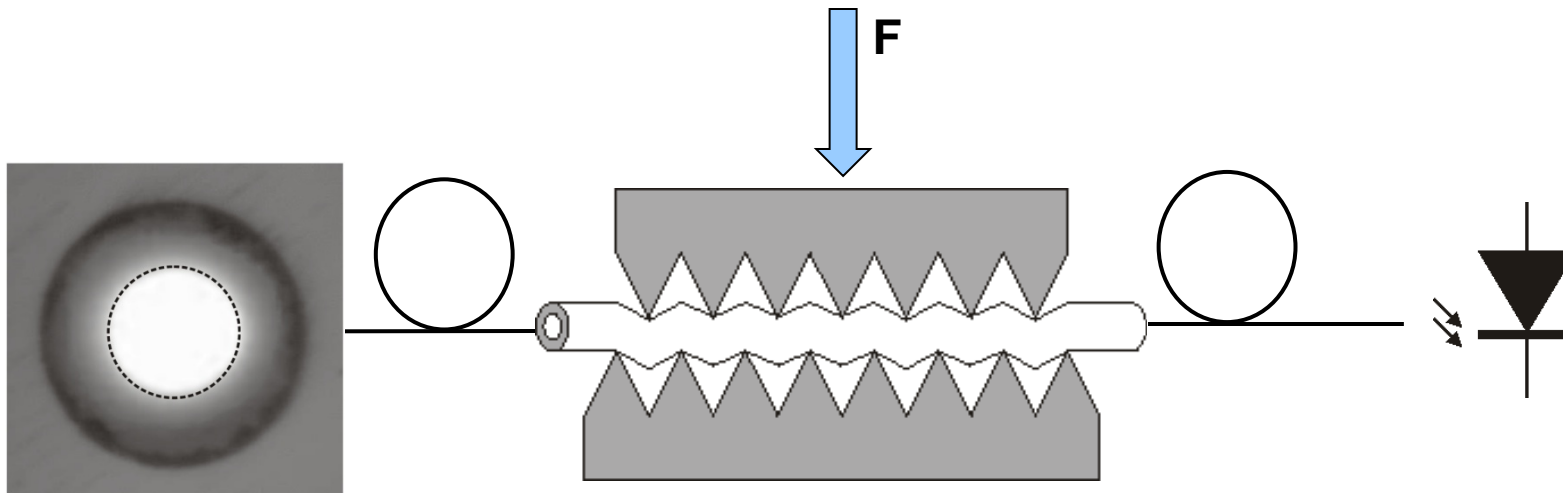


/HergaLite/

-
-
-



4 Signal Processing Improves Microbender

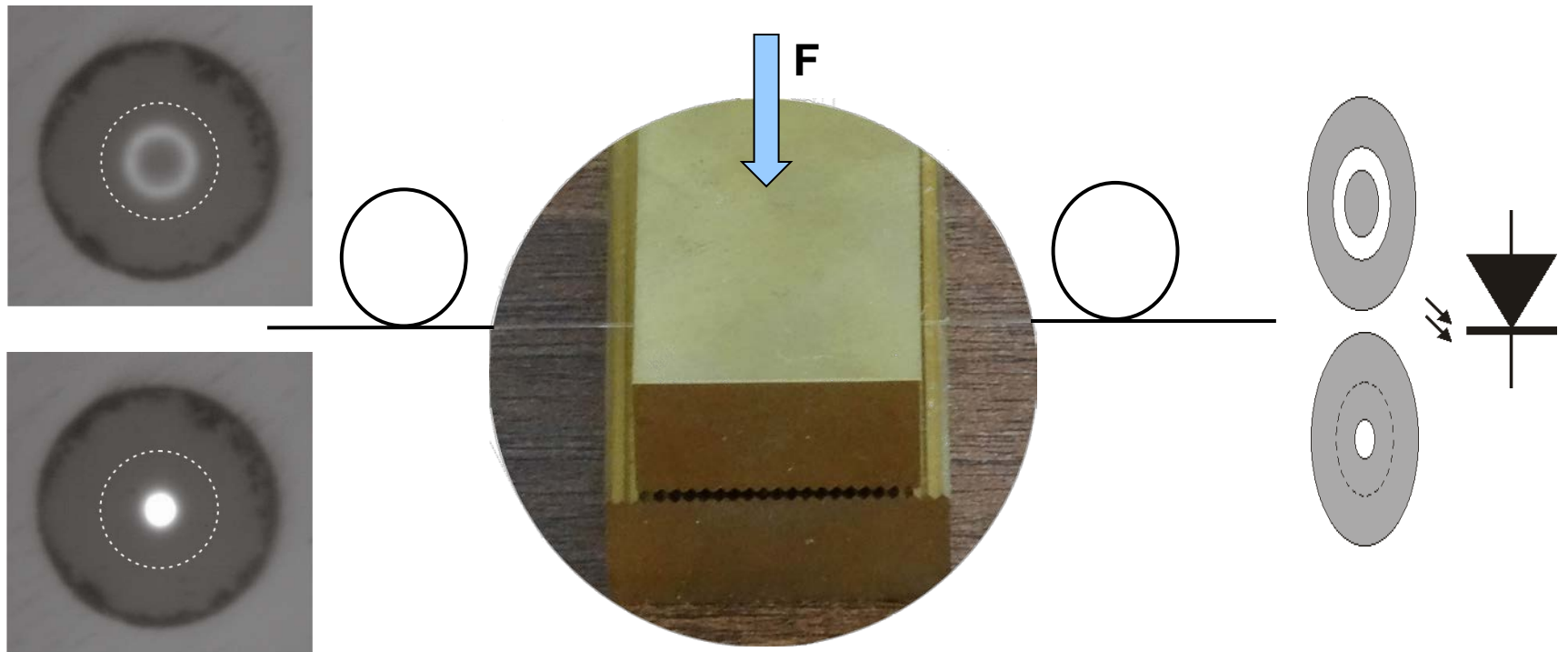


a) Steady state illumination conditions

 Simple power measurement



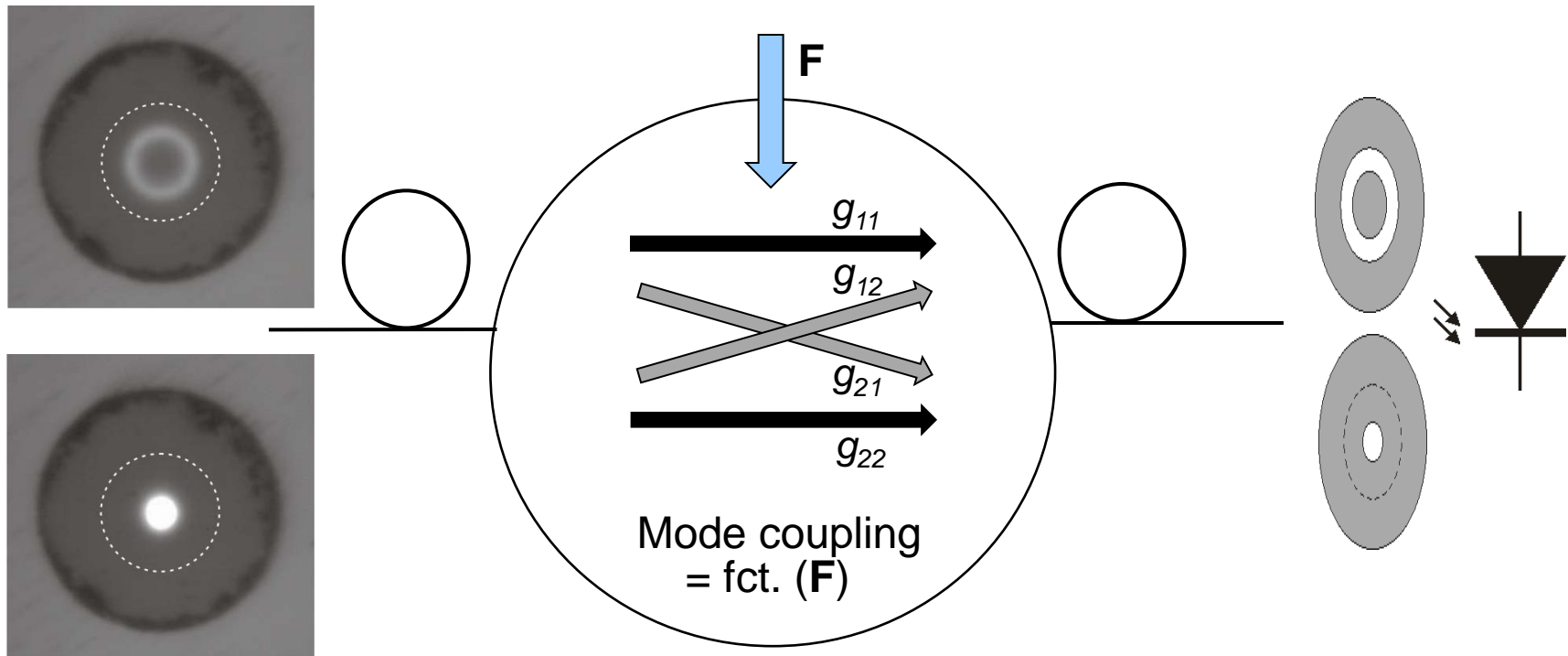
4 Signal Processing Improves Microbender



- a) Steady state illumination conditions
- b) Selective mode group excitation



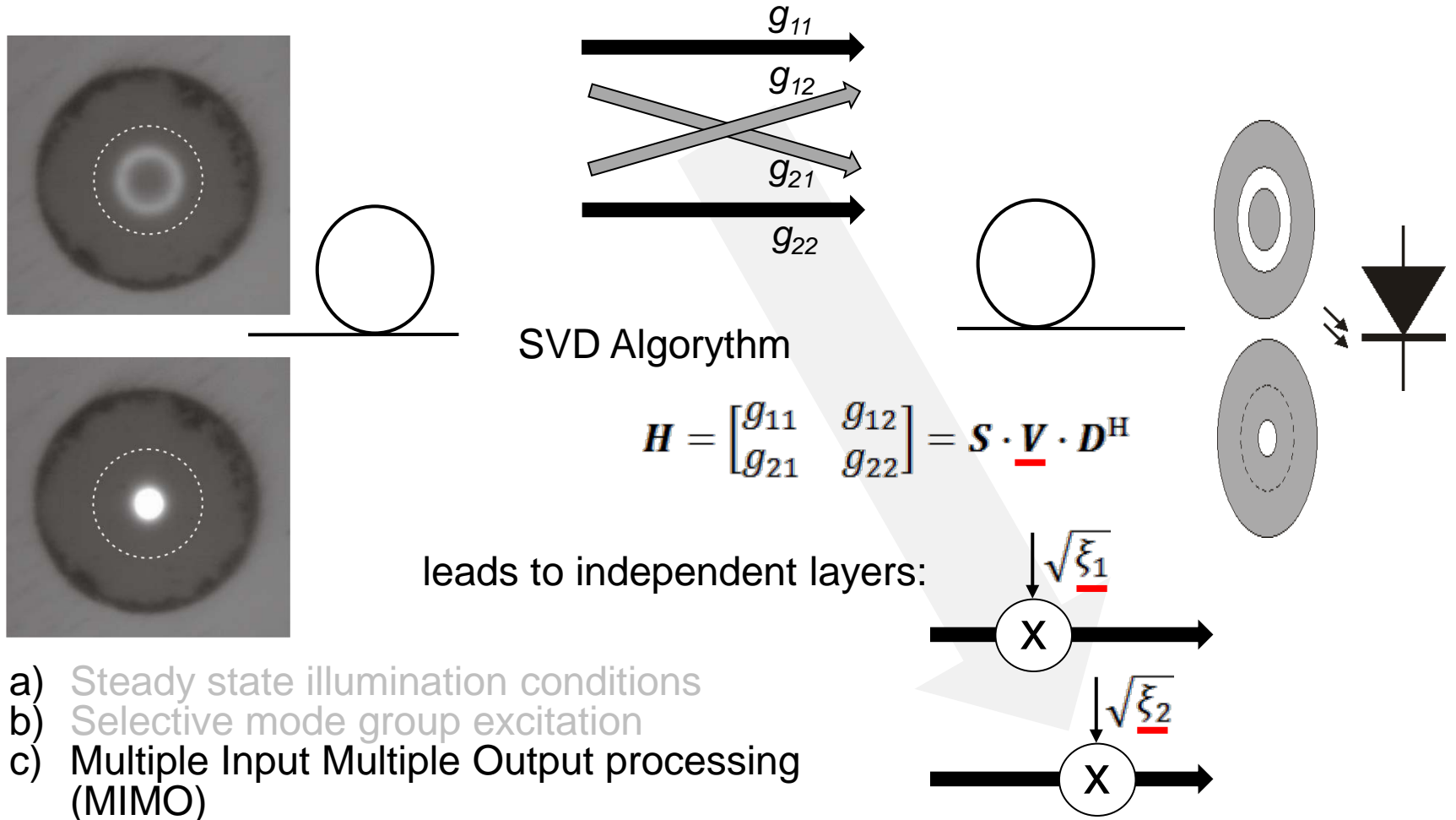
4 Signal Processing Improves Microbender



- a) Steady state illumination conditions
- b) Selective mode group excitation
- c) Multiple Input Multiple Output processing (MIMO)

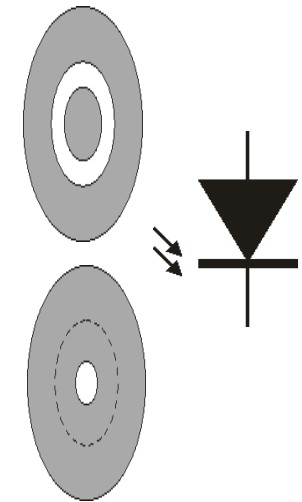
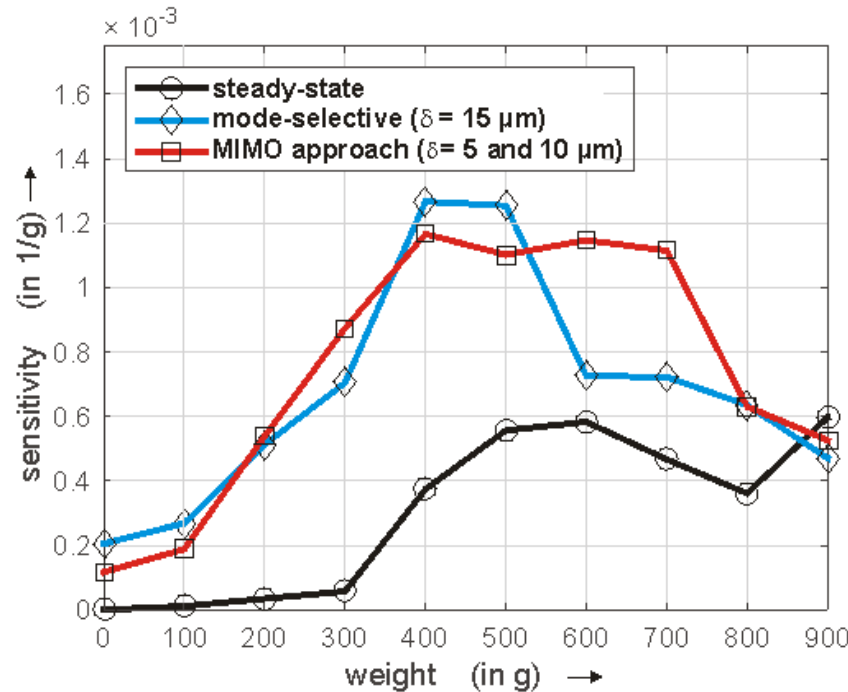
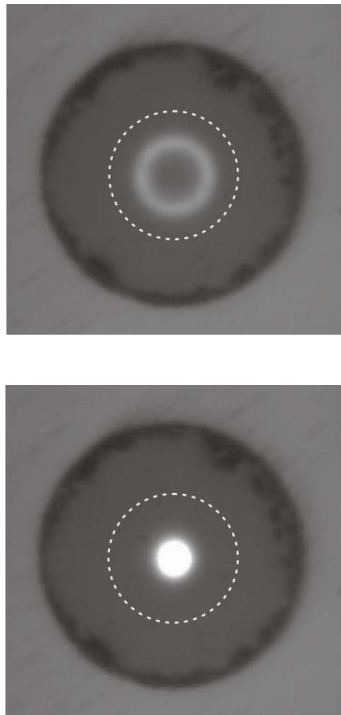


4 Signal Processing Improves Microbender





4 Signal Processing Improves Microbender



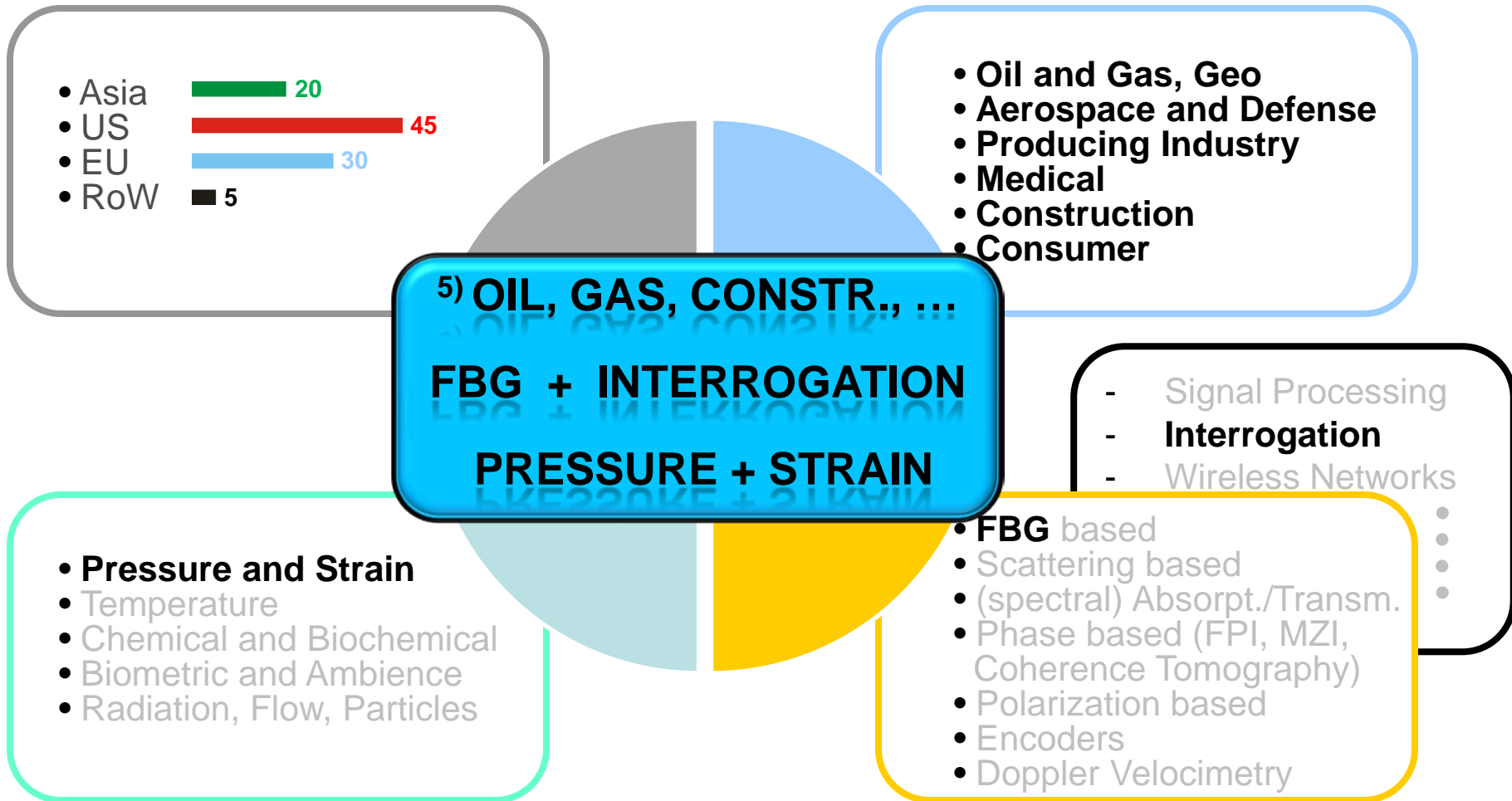
- a) Steady state illumination conditions
- b) Selective mode group excitation
- c) Multiple Input Multiple Output processing (MIMO)



High sensitivity paired with wide measurement range

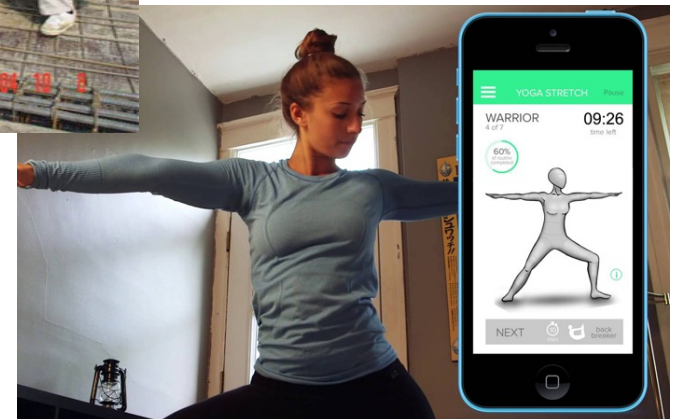
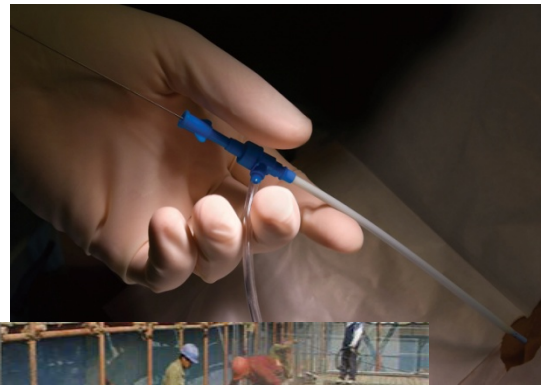


Fiber Optic Sensor Market Segments





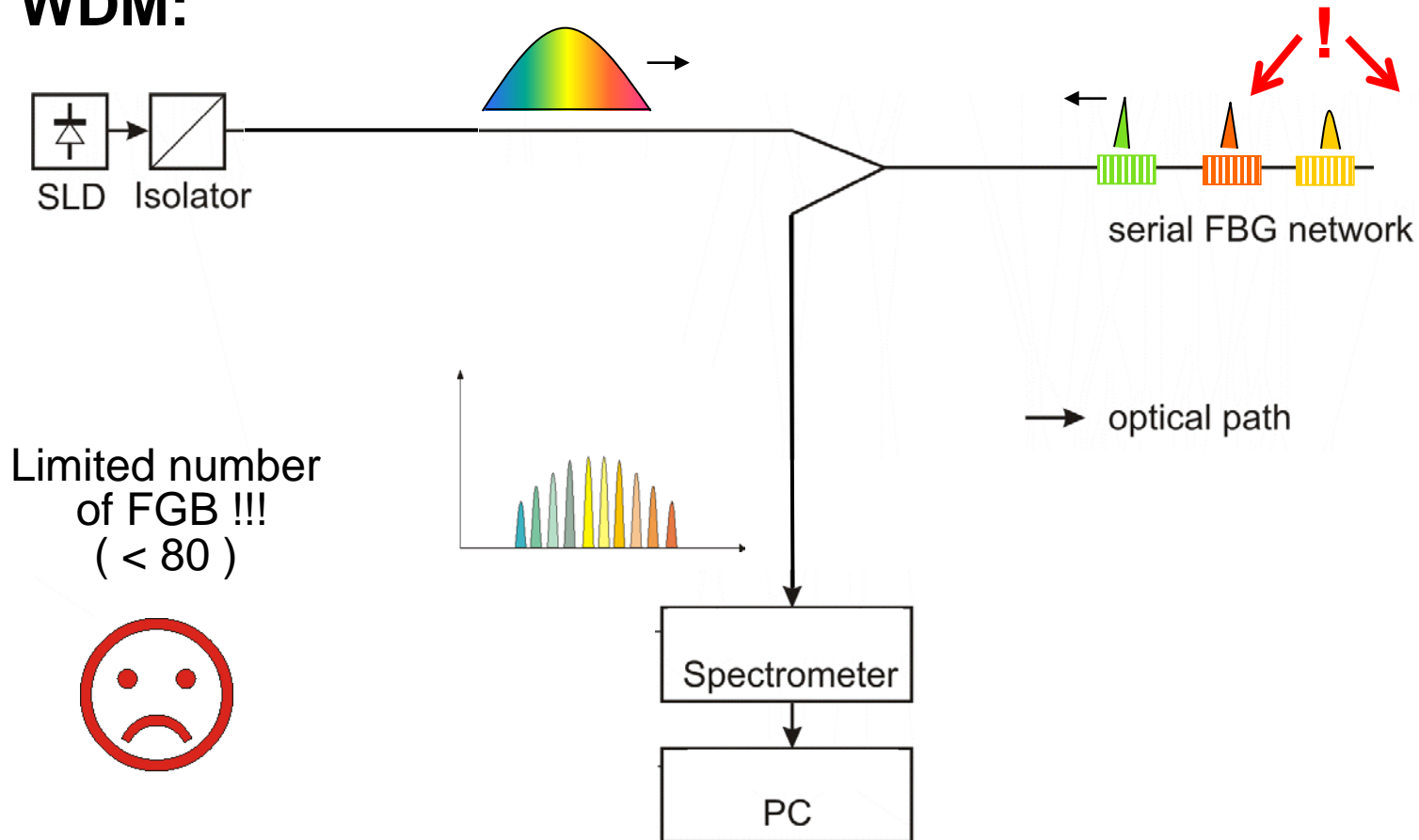
5 Interrogation of Massive FBG Networks





5 Interrogation of Massive FBG Networks

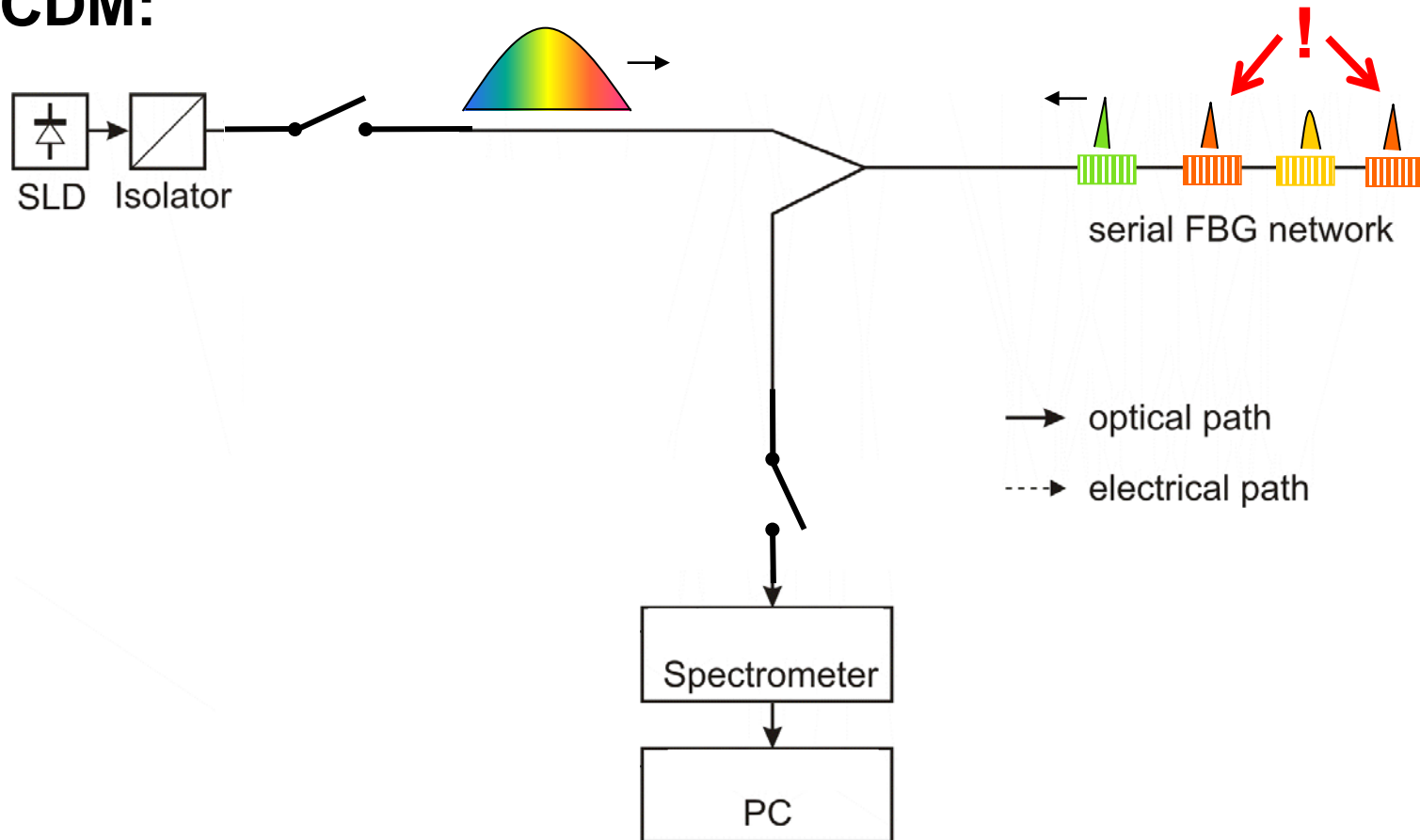
WDM:





5 Interrogation of Massive FBG Networks

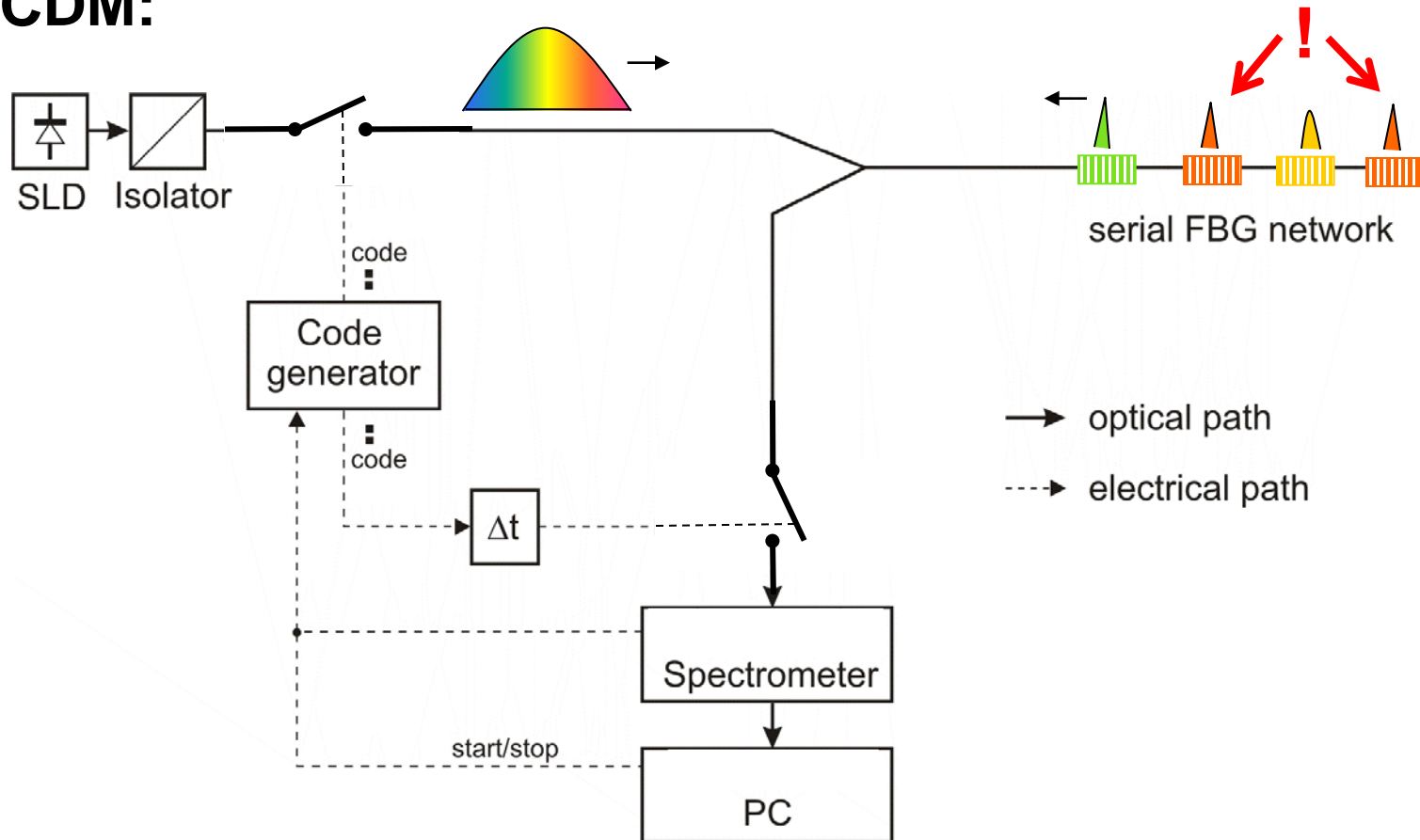
CDM:





5 Interrogation of Massive FBG Networks

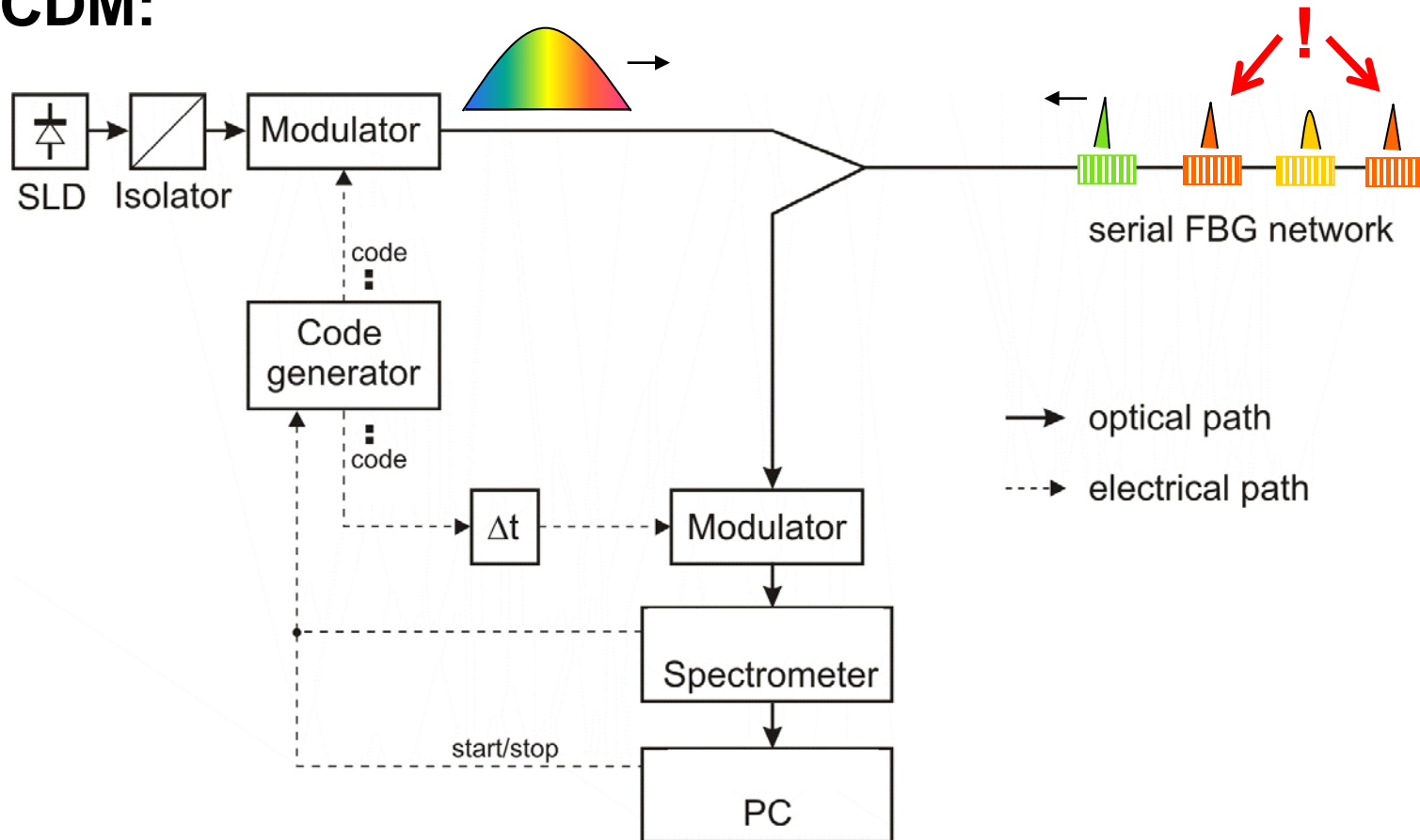
CDM:





5 Interrogation of Massive FBG Networks

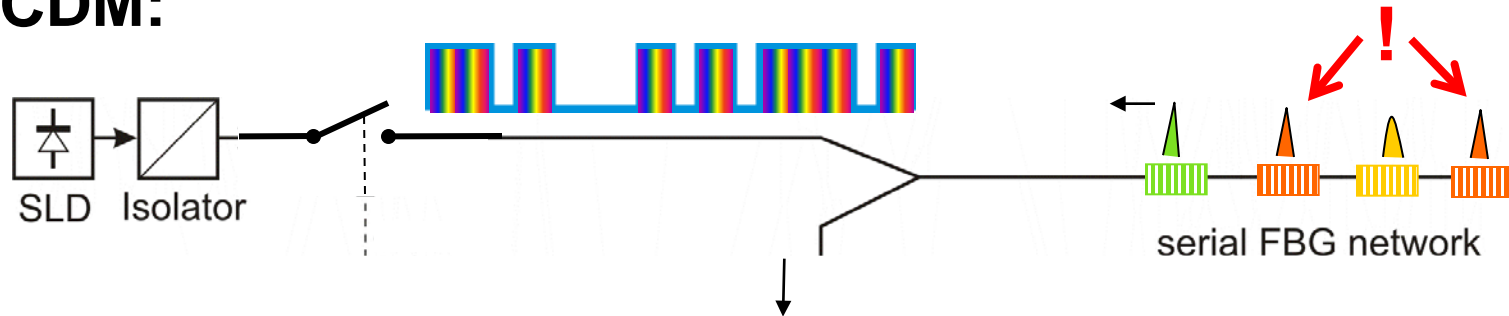
CDM:





5 Interrogation of Massive FBG Networks

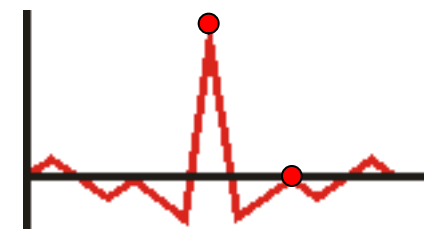
CDM:



$$\int_0^T code \cdot s_{FBG2} = 16$$

out of sync :

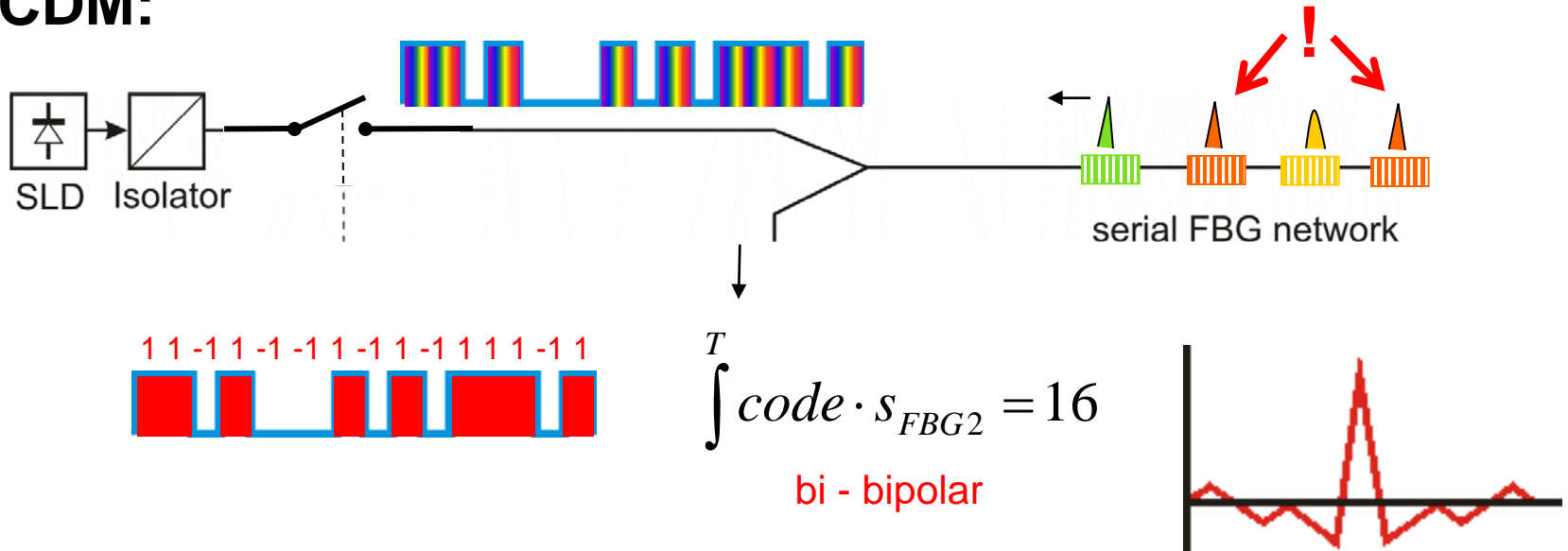
$$\int_0^T code \cdot s_{FBG4} = 0$$





5 Interrogation of Massive FBG Networks

CDM:

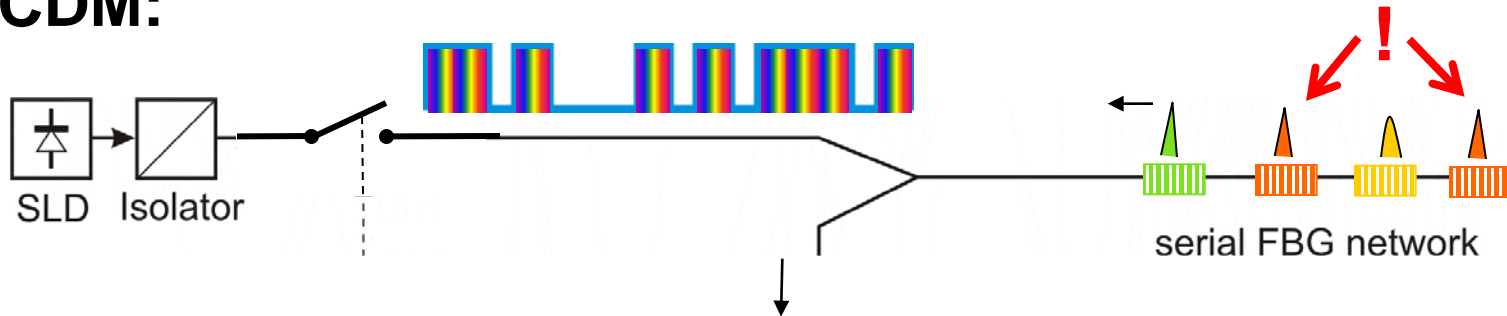


1 1 0 1 0 0 1 0 1 0 1 1 1 0 1



5 Interrogation of Massive FBG Networks

CDM:



$$\int^T code \cdot s_{FBG2} = 16$$

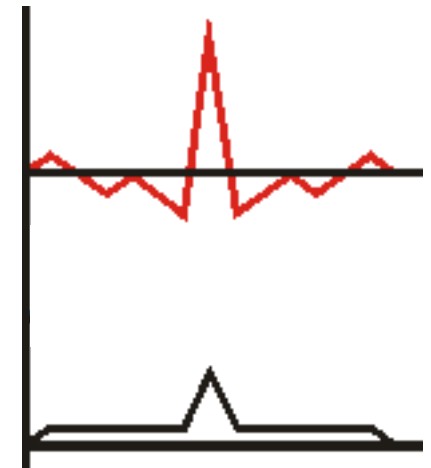
bi - bipolar

1 1 0 1 0 0 1 0 1 0 1 1 1 0 1 x 1 1 -1 1 -1 -1 1 -1 1 -1 1 1 -1 1

uni - bipolar

= 8

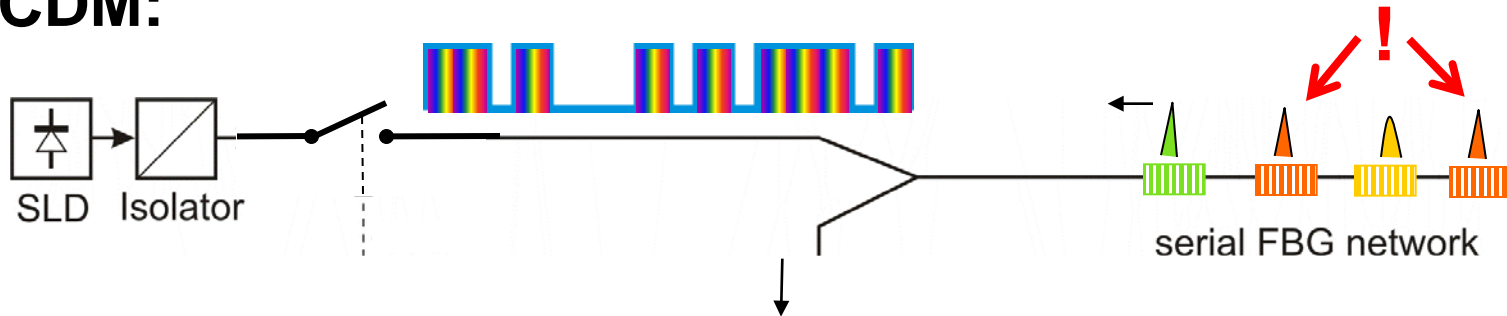
uni - unipolar





5 Interrogation of Massive FBG Networks

CDM:



$$\int^T code \cdot s_{FBG2} = 16$$

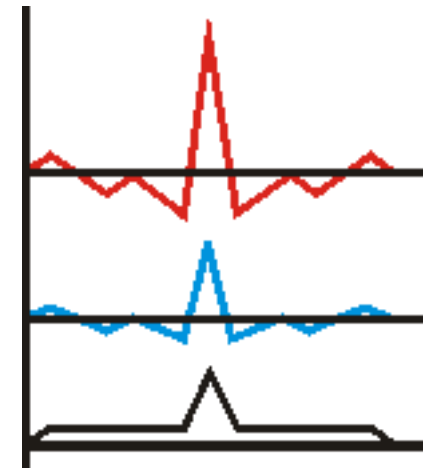
bi - bipolar

$$110100101011101 \times 11-11-1-11-11-1111-11$$

uni - bipolar

= 8

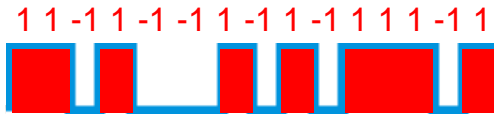
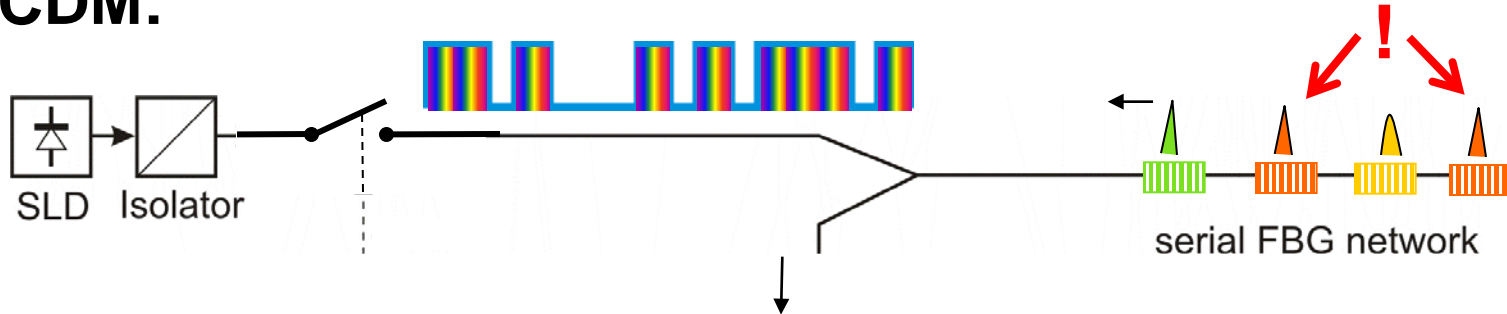
uni - unipolar





5 Interrogation of Massive FBG Networks

CDM:



bi - bipolar

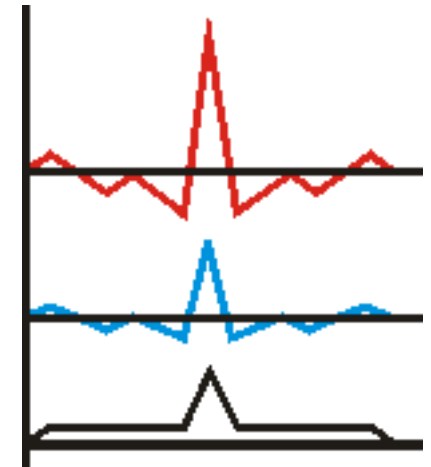
$$\begin{array}{r}
 110100101011101 \\
 -001011010100010 \\
 \hline
 = 11-11-1-11-11-1111-11
 \end{array}$$



uni - bipolar

Sequence Inverse Keying (SIK)

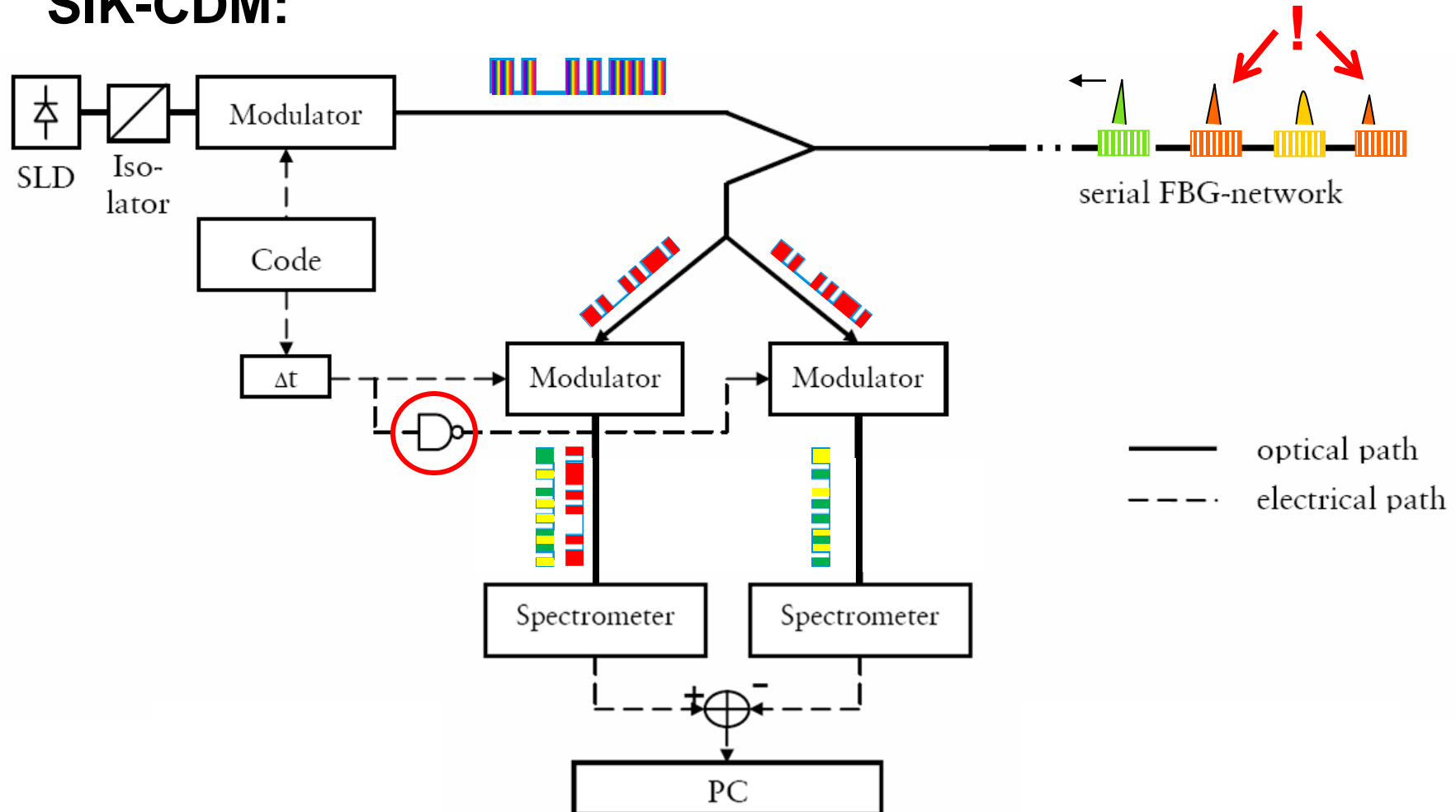
uni - unipolar





5 Interrogation of Massive FBG Networks

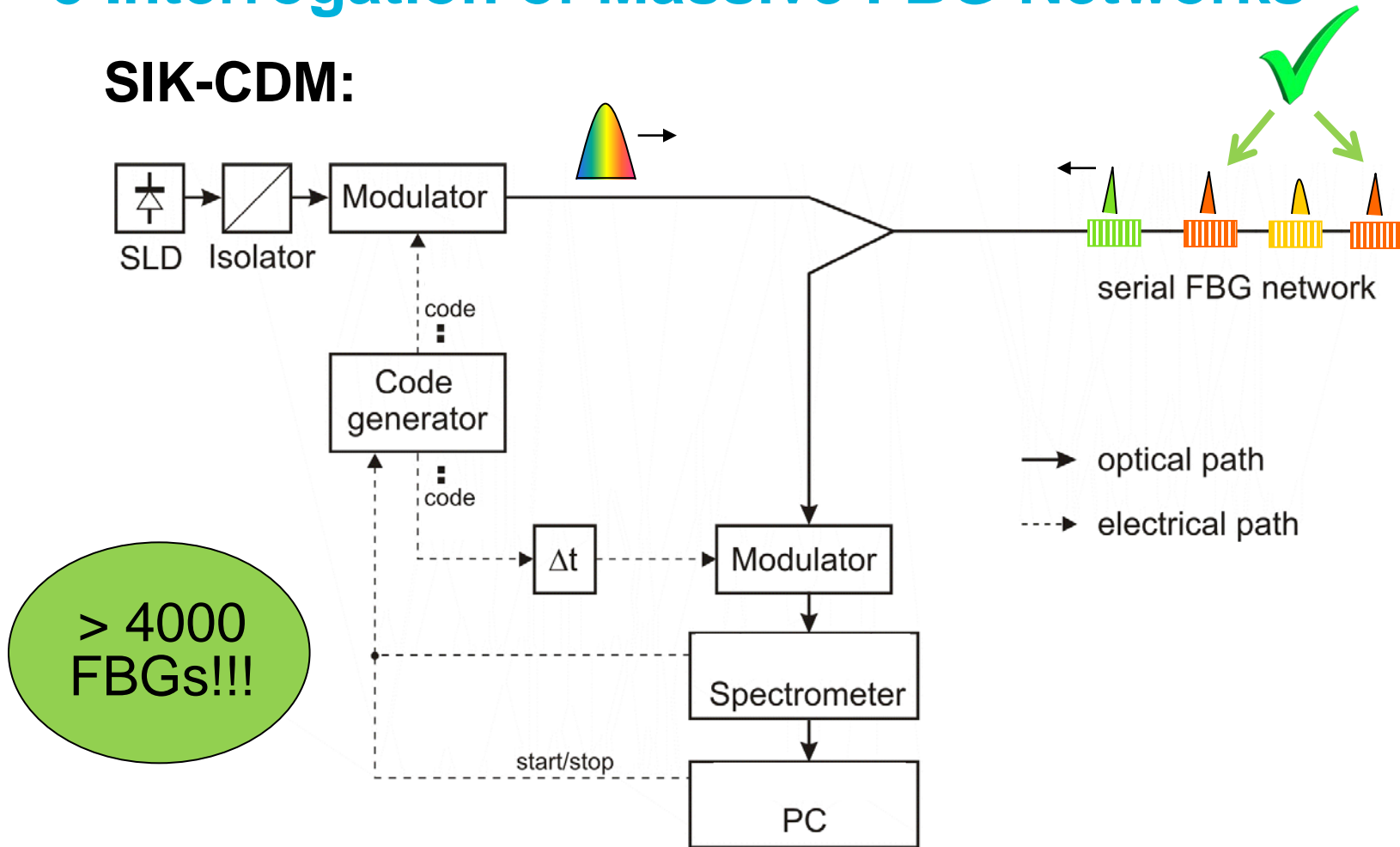
SIK-CDM:





5 Interrogation of Massive FBG Networks

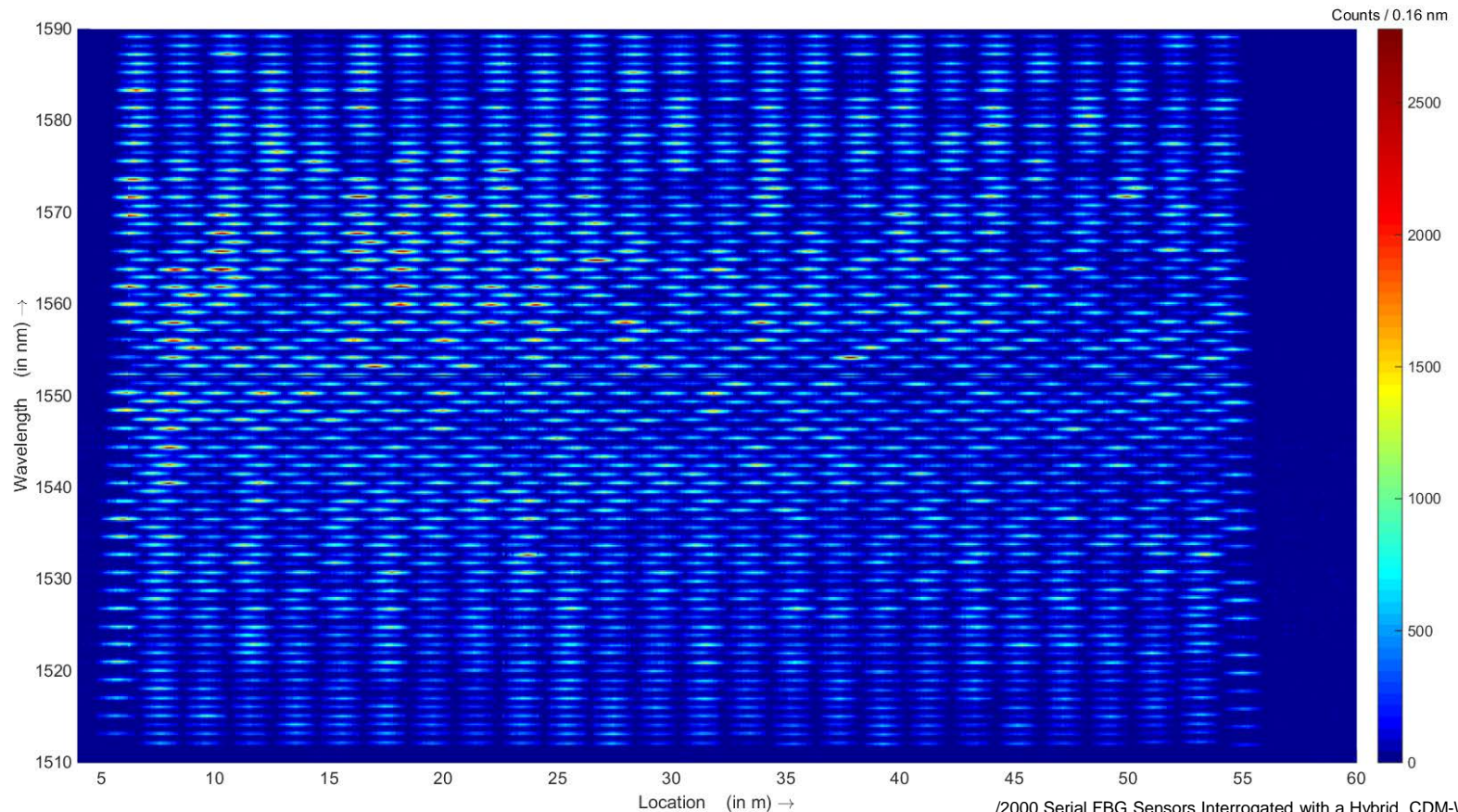
SIK-CDM:





5 Interrogation of Massive FBG Networks

SIK-CDM: 25 x 80 serial FBGs



/2000 Serial FBG Sensors Interrogated with a Hybrid CDM-WDM Scheme, in Journal of Lightwave Technology 2020/



Conclusion or what we have learned 😊

The robust and vibrant fiber optic sensor market is based on

- the penetration of all major application/user segments
- the need for more high quality data, even from harsh environments
- constant new technology and data processing developments



Acknowledgment

Sensor Developments by



In Cooperation with



**CENTRO
RICERCHE
FIAT**

**Universität
Rostock**



FBGS

Tailored Fiber Optic Sensing
Components & Solutions



**UNIVERSITY
of
LIMERICK**

OLLSCOIL LUIMNIGH

GFZ

Helmholtz Centre
POTSDAM

fiberware
www.fiberware.de