Faculty of Electronics, Telecom and Info Technology

Lecture 11

Optoelectronic Sensors with Industrial Applications

Wearable sensors: optical approach

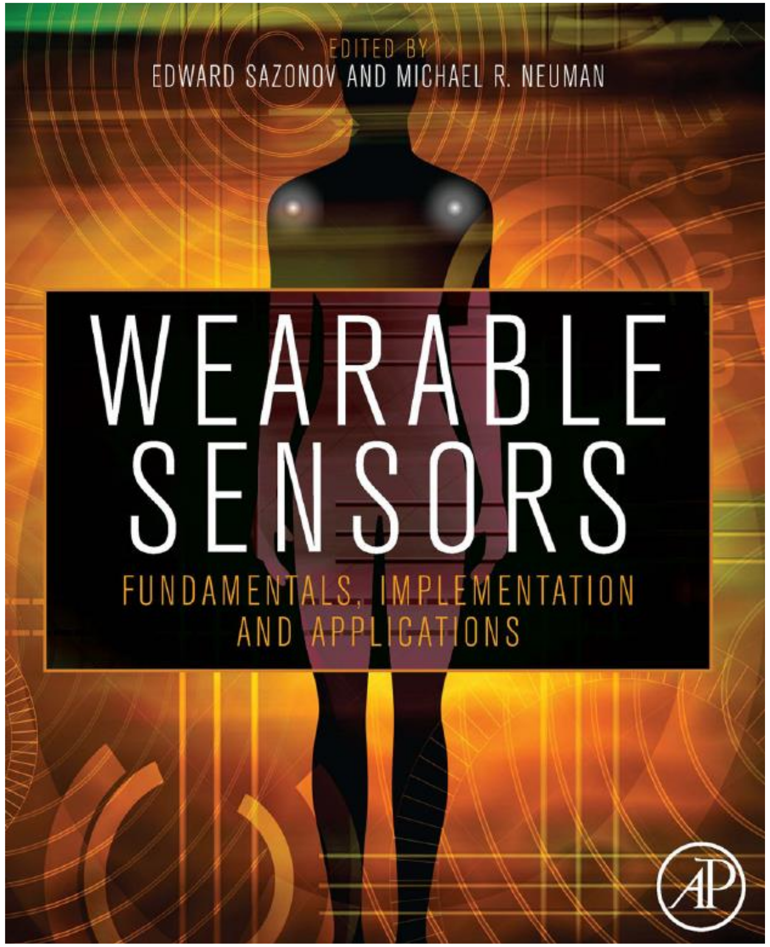
Associate prof Ramona Galatus
Basis of Electronics Department

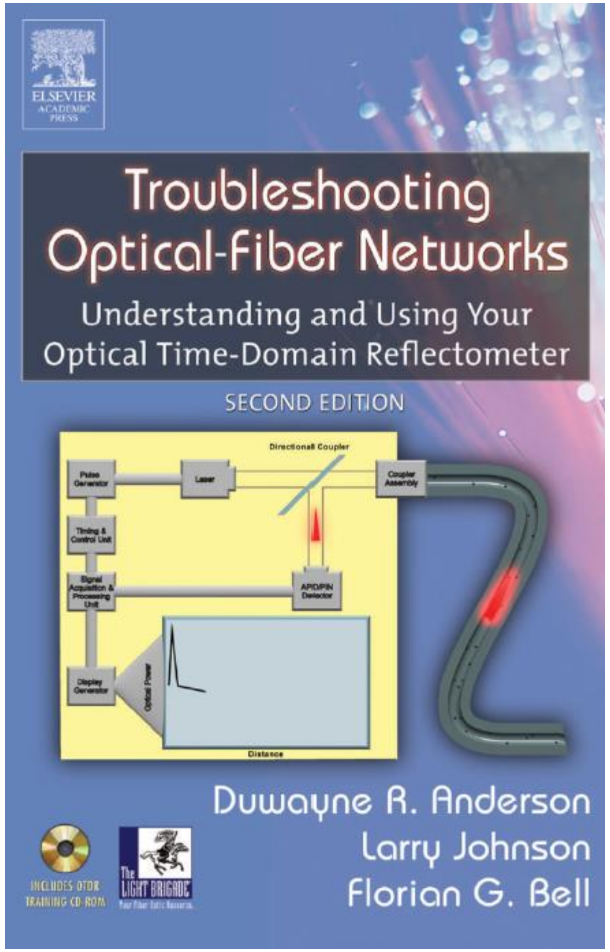
Outline: Applications

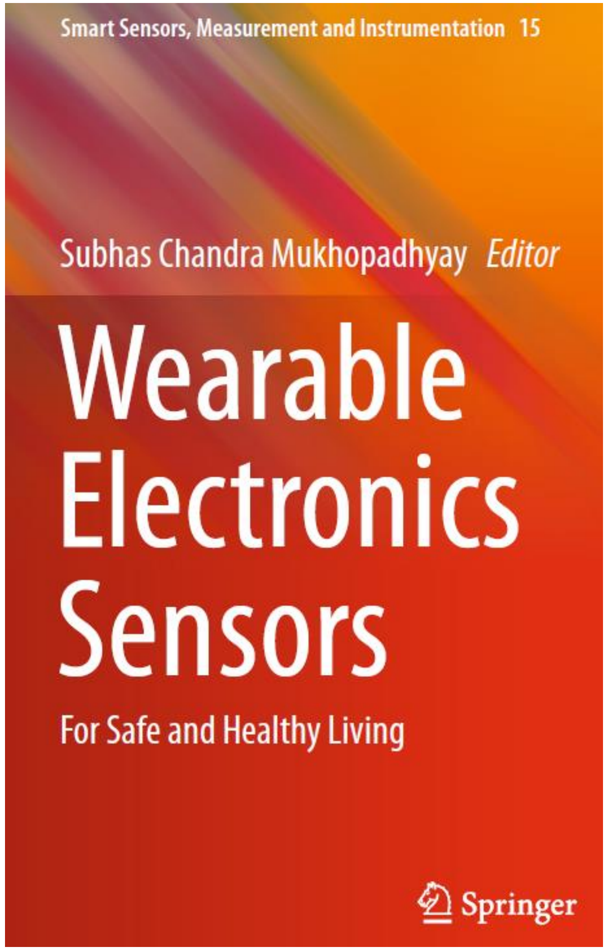
- Part 1 – Wearable sensors
  - Wearable (human body parameters) versus portable sensors (other real world parameters)
  - Wearable sensors: optical approach
- Part 2 - Portable example: OTDR measurements

References

https://www.fierceelectronics.com/







Wearable devices concept

- “wearable devices” focuses on various aspects of sensor technology, ranging from physiological monitoring, inertial, bio and chemical sensors, to optical and heat flow sensors.
- Low-cost/affordable and non-invasive
- Smartphone Sensors: Heart Rate, NFC, GPS, Altimeter, Accelerometer, Gyroscope, Ambient Light, Microphone
- A wearable device is essentially a tiny computer with sensing, processing, storage and communications capabilities.
- Many wearable devices also include interfaces and actuation capabilities that provide feedback to the user.
- The concept of a wearable device is not new, but the area is experiencing a rapid growth in popularity nowadays
- Handheld mobile phones are extremely popular descendants of mobile phone technology originally developed for use in vehicles

In spite of the clear advances in sensing technologies and high number of laboratory prototype sensors that appear every year, only a small fraction of these sensors reach commercialization.

Apart from the complexity of the receptor design, the main reason for this is the incompatibility of the sensor platform with the real-world application.

Sensors exposed to real-life scenarios are subjected to many environmental effects that can affect **stability, reproducibility, and sensitivity**.

Effective sampling methods are crucial to avoid contamination and ensure controlled delivery to the active sensor surface. For example, a chemical sensor analyzing a body fluid such as sweat, blood, or tears must collect and deliver a sample to the sensor’s active surface, whereupon a binding event happens and a signal is generated.

Other issues relate to **system integration, sensor miniaturization, and low-power sensor interface circuitry design**. One possible route toward the development of new and improved chemical sensing technologies is the emergence of nanoscience, related new nanostructured materials and multi-functional polymers. It is therefore not surprising that the last decade has witnessed rapid development in the field of chemical and biochemical sensors in parallel with the development of new materials. Several chemical and biochemical wearable sensors have been developed in recent years, and they include **pH sensors for sweat, sensors for several electrolytes (sodium, chloride, potassium) in sweat, the oximeter sensor, and others; however, most of them require further optimization and assessment in clinical trials before exploitation and routine use can occur.**

DETECTION LIMIT

Blood pressure

HeartGuide™ Wearable Blood Pressure Monitor

https://www.wareable.com/health-and-wellbeing/the-best-connected-home-blood-pressure-monitors

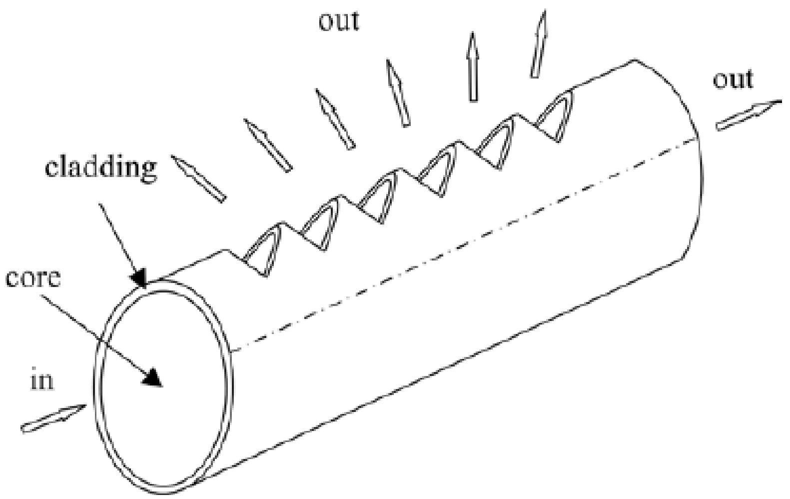
https://www.wearable-technologies.com/2020/03/vitrack-cuffless-wearable-for-continuous-non-invasive-blood-pressure-monitoring/

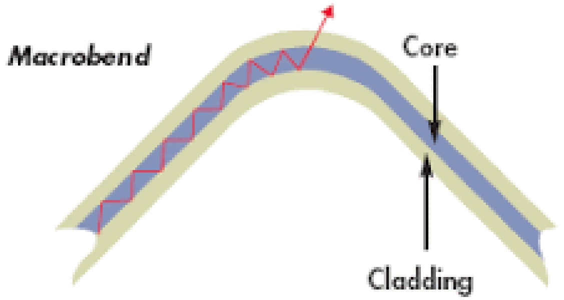
Wearable optical sensors

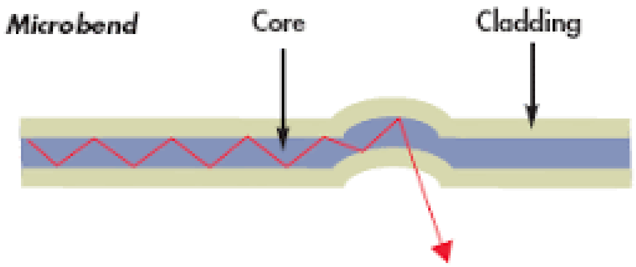
- Pulse oximetry apps are now available based on wearable Bluetooth-enabled optical sensors on mobile phones, and research into colorimetric sensing is increasing.
- The smartphone may become part of a wearable sensor system serving as the detection element, and also for data management and communications.
- An example of the smartphone being used for colorimetric analysis is presented by Oncescu et al., in which **sweat and saliva pH** measurements are taken using **pH-sensitive paper** inserted into a smartphone accessory [*V. Oncescu, D. O'Dell, D. Erickson, Smartphone based health accessory for colorimetric detection of biomarkers in sweat and saliva, Lab Chip vol. 13 (2013) 32323238*].
- An example of the data management capability of smartphones is the iBGStar by **Sanofi Diabetes**, which allows users to track and manage their blood glucose levels by linking to an iPhone. Through mobile communications, this information can be shared by email, websites, or text messages to facilitate a movement toward remote management of personal health.

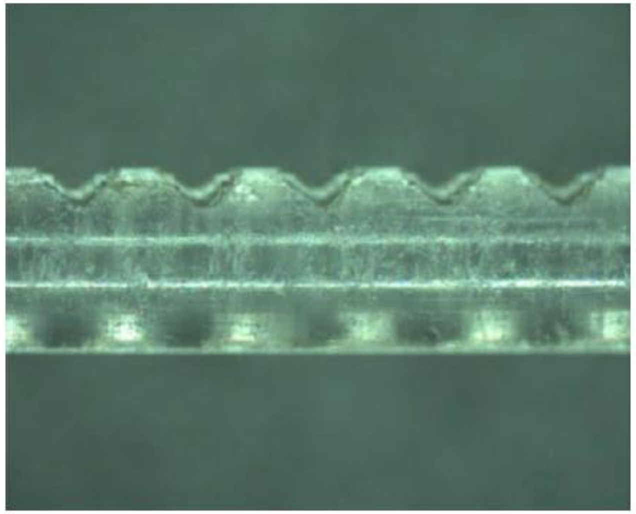
1. Human joint

- Bending effect
- To increase the sensitivity the bending loss is increased by using fiber strips









Human joint-implementation

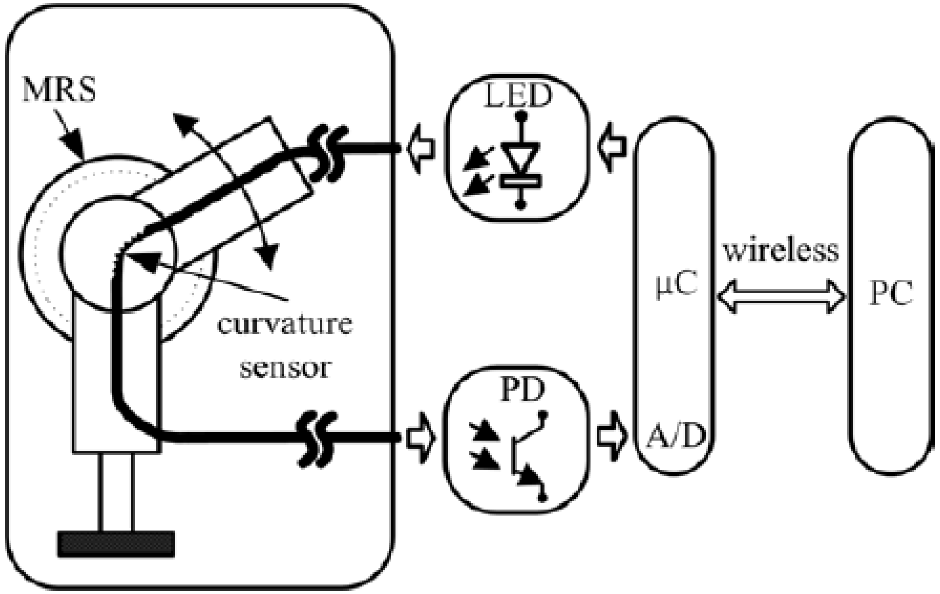


Fig. 3. Block diagram of the laboratory experimental setup for human joint movements monitoring based on the curvature sensor: MRS – manual rotation stage, PD – photodarlington, LED – light emitting diode, µC – microcontroller, A/D – analog to digital converter.

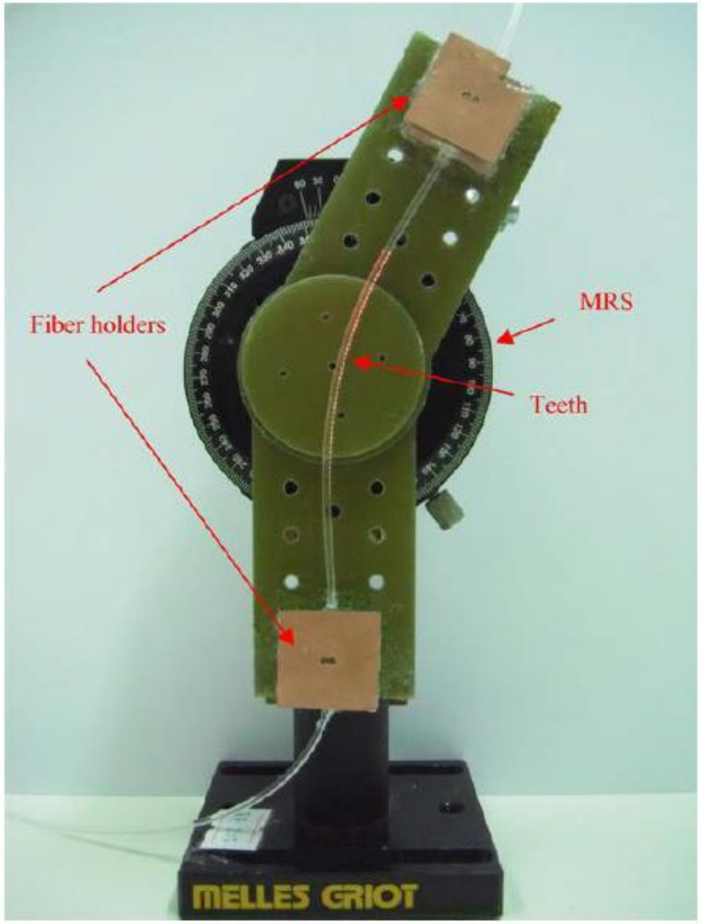


Fig. 4. Photograph of the curvature sensor used in laboratory measurements.

- Stupar, D.Z., Bajic, J.S., Manojlovic, L.M., Slankamenac, M.P., Joza, A.V., Zivanov, M.B.: Wearable low-cost system for human joint movements monitoring based on fiber-optic curvature sensor. IEEE Sensors Journal 12(12), 3424–3431 (2012)

Calibration of the sensor

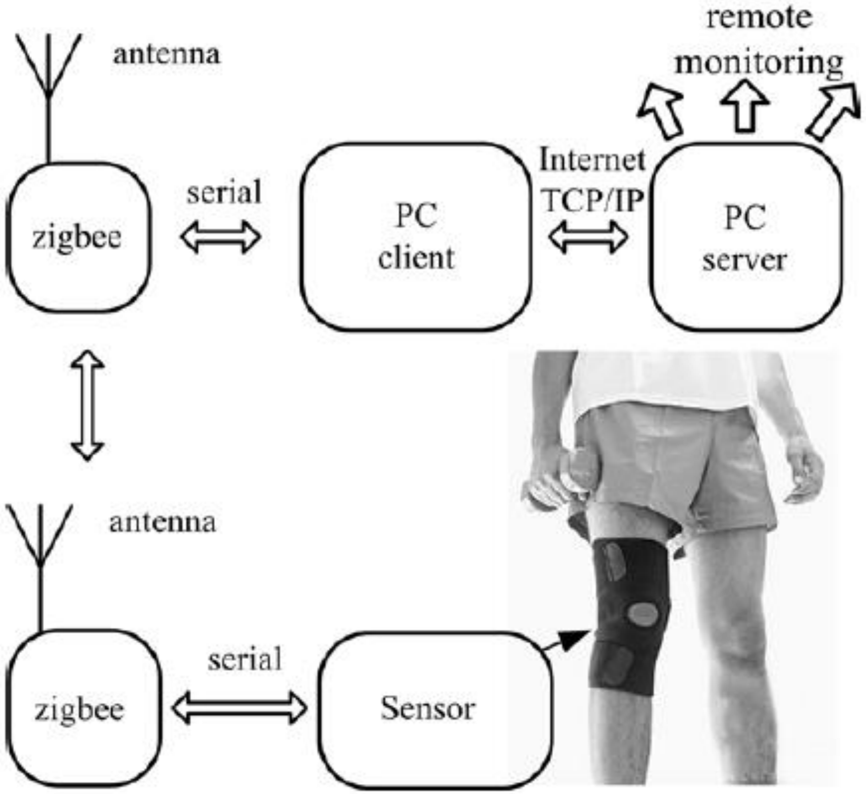


Fig. 6. Photograph of the produced wearable fiber-optic sensor mounted on the knee joint brace. The curvature sensor is sewn on the knee joint brace. The electronics is placed in the box (it is opened in this photograph), which is attached to the belt.

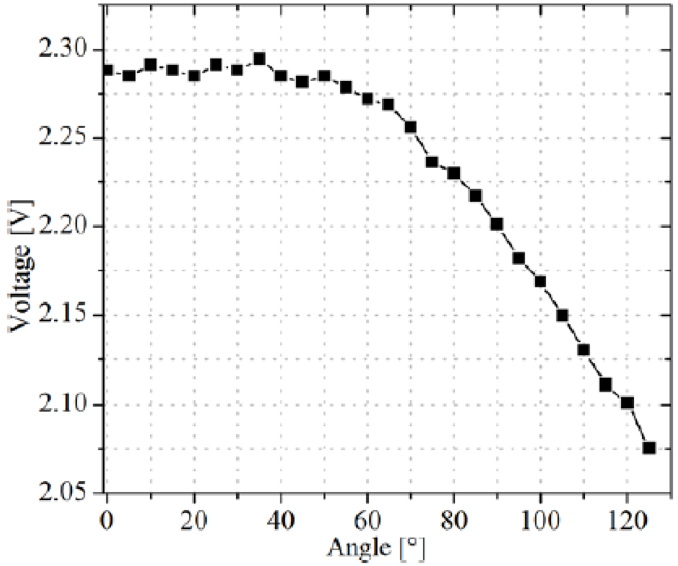


Fig. 8. POF bending characteristic. POF is bent in the range of 0° – 125°.

2. Colorimetric sensing

- One way of combining sensing with a **textile fluidic** system is to use **colorimetric methods**.
- Progress in the development of micro-fluidic devices based on multifilament threads and textiles for **clinical diagnostic** and **environmental sensing**.
- Low-cost/affordable and non-invasive
- pH, glucose, wide range of analytes, other biomarkers in case of chemical analysis
- A colorimetric approach to pH measurement in sweat using pH sensitive dyes and surface mount LEDs and photodiodes has been developed by the Adaptive Sensors Group at Dublin City University
- readily integrated into **clothing** like T-shirts through the knitting of chemical-sensitive yarns within the fabric
- further explored the concept of thread micro-fluidics, showing the possibility of performing multiplexed colorimetric analysis through the use of a single thread sewn through a wearable adhesive plaster. This has the potential for sensing a wide range of analytes, such as **proteins, ketones, and nitrates.**

2. Sweat pH optical sensor –operating principle

K.T. Lau, W.S. Yerzunis, R.L. Shepard, D. Diamond, Quantitative colourmetric analysis of dye mixtures using an optical photometer based on LED array, Sens. Actuat. B Chem. 114 (2006) 819–825.

A **colorimetric** approach was used for sweat pH measurement.

Colorimetric sensors involve a color change at the active sensor surface, which can then be measured using optical techniques.

This involved using a **pH sensitive dye** which changes colour depending on the pH of the sweat.

This colour change was detected by diffuse reflectance measurement using an **emitter-detector LED technique**

Human sweat typically varies from pH 5–7 [A.I.S. Department of Sports Nutrition, How much do athletes sweat? Data Sheet (2004) 1–5].

Bromocresol purple (BCP, p*K*a = 6.2) is suitable for the required range of measurement and is fabricated directly onto the fabric channel by co-immobilising the dye with tetraoctyl ammonium bromide.

To obtain quantitative pH measurements a paired emitter-detector dual LED configuration was used. The detector LED is reverse biased at a specific voltage. The photocurrent generated upon incident light then discharges the LED at a rate that is proportional to the intensity of light reaching the detector

Simple threshold detection/timer routine is realised and data is transmitted wirelessly

First step: Dye mixture analysis

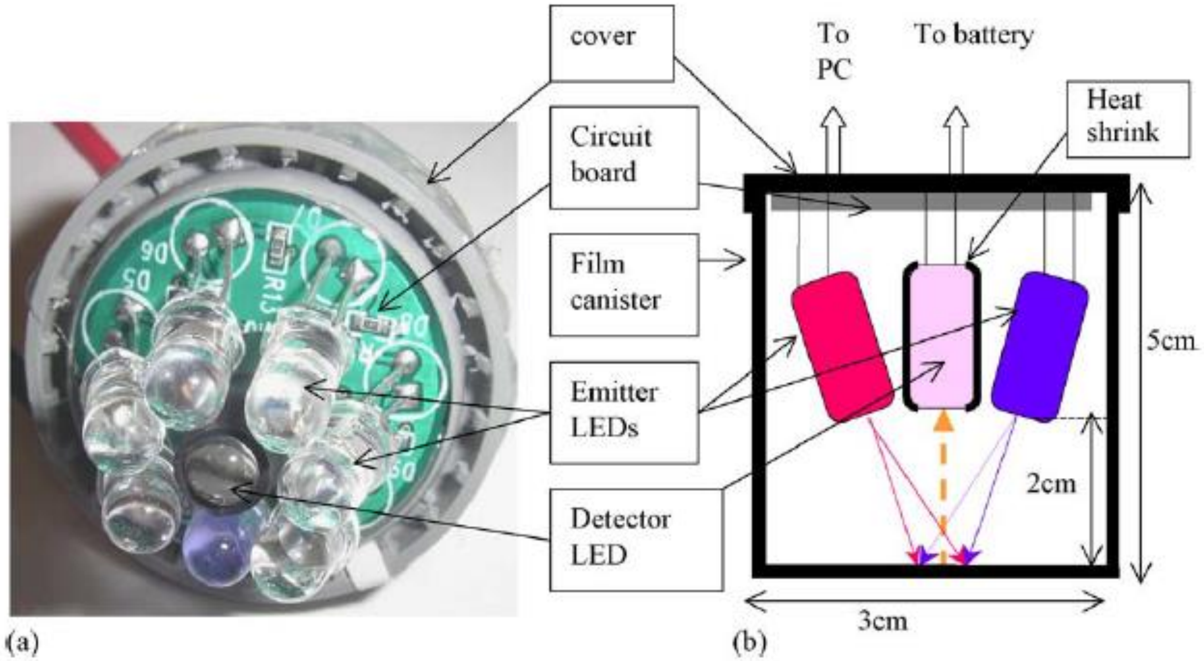


Fig. 1. A picture of the disco photometer (a) and a sketch of the disco photometer to illustrate the light detection pathway (

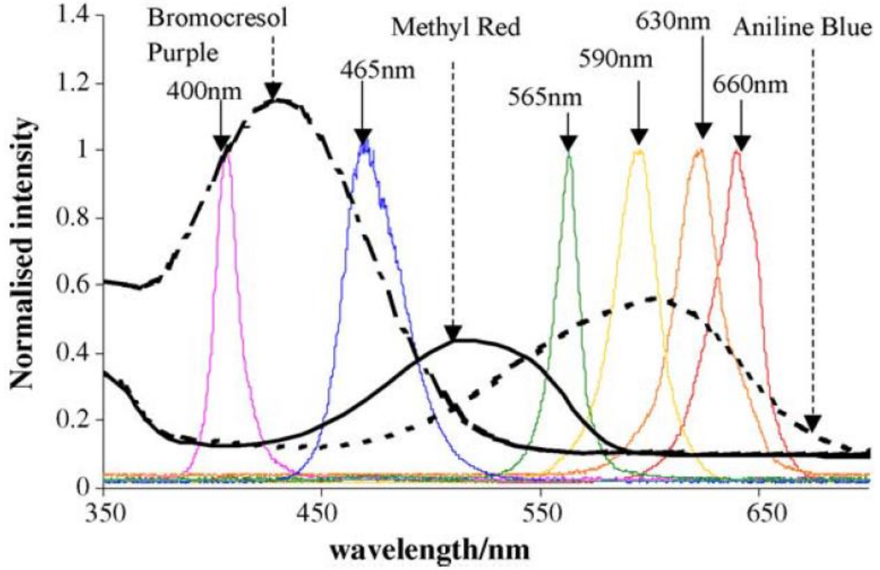


Fig. 2. Emission spectra of the LED light sources used in the photometer and the UV–vis absorption spectra of bromocresol purple (BCP), aniline blue (AB) and methyl red (MR) obtained from the original dye stock solutions made up with 0.1 M HCl.

Second step: Sweat pH optical sensor-configuration

Dictionar: s**ubstanta hidrofoba**, acel obiect este protejat de picaturile de apa, in jurul lui creandu-se o bula protectoare

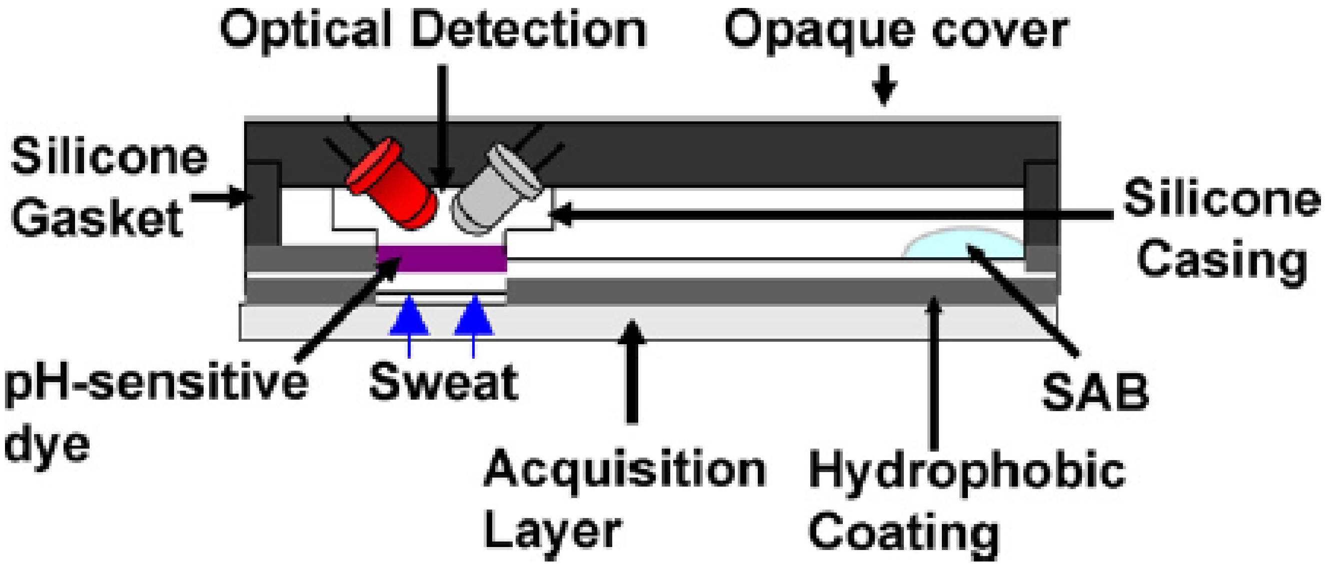


Fig. 3. Illustration of pH sensor and optical detection system.

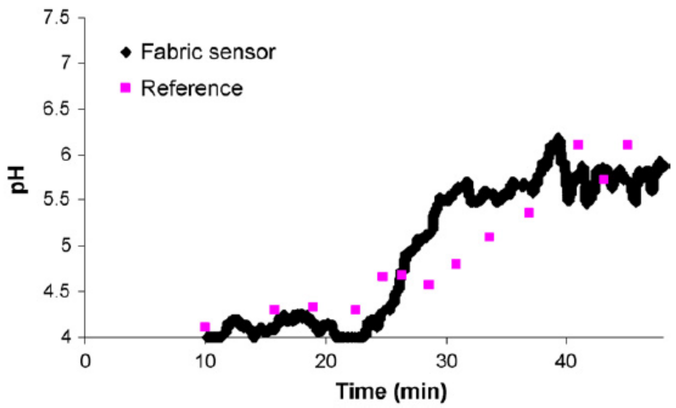


Fig. 8. pH values recorded during on-body trial.

Morris, D., Coyle, S., Wu, Y., Lau, K.T., Wallace, G., Diamond, D.: Bio-sensing textile based patch with integrated optical detection system for sweat monitoring. Sensors and Actuators B: Chemical 139(1), 231–236 (2009)

Sweat collecting fluid handling platform

The design of the sweat collecting fluid handling platform is based on using fabrics with inherent **moisture wicking properties**.

It **collects the sweat** from the skin surface and wicks the sample through a predefined channel to the sensing area.

It was determined that **sports materials**, which are used to move sweat from the wearer's skin to the surface of the fabric where it can evaporate are ideal candidates for this application.

Such material can be purchased in specialist sports stores and are generally composed of a polyester/lycra® blend.

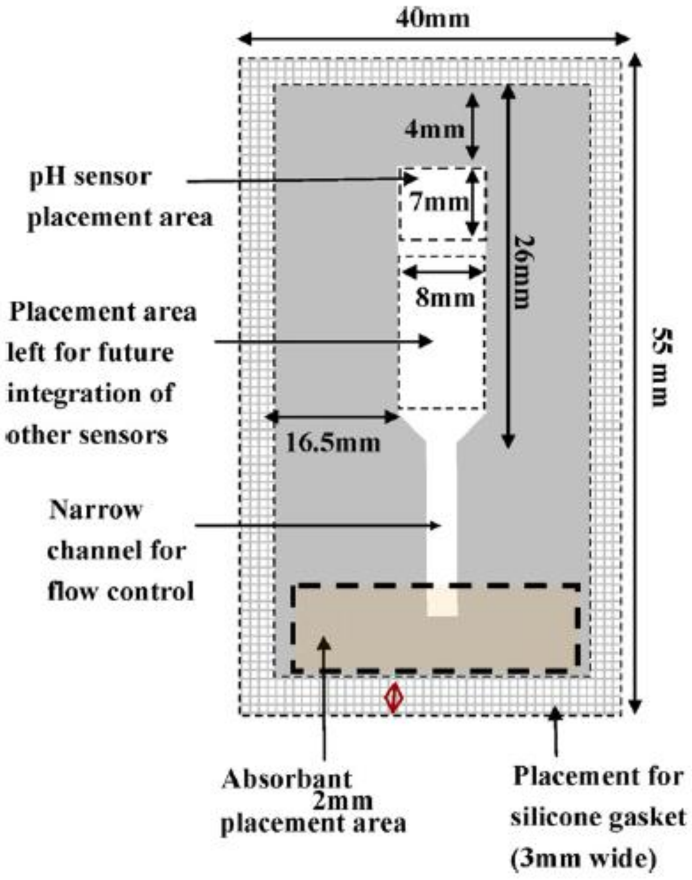


Fig. 2. Layout of fluid handling system and position of pH sensor.

3. Glucose

R. Badugu, J.R. Lakowicz, C.D. Geddes, A Glucose Sensing Contact Lens: A Non-Invasive Technique for continuous Physiological Glucose Monitoring, J. Fluores vol. 13 (2003) 371374

- A wearable colorimetric biosensor within a contact lens has been developed to detect glucose levels in tears.
- the use of disposable contact lenses embedded with boronic acid-based fluorophores ->colorimetric detection of glucose.
- The contact lens changes color according to the amount of glucose in tears, and is monitored by the wearer by simply looking into a mirror and comparing the color to a precalibrated color strip

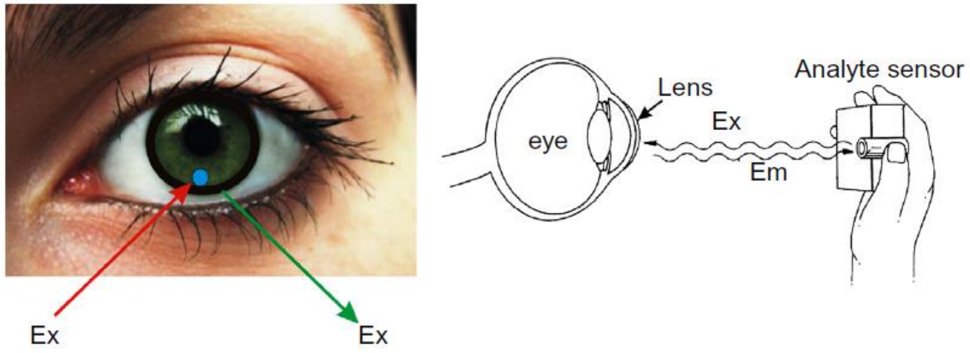


FIGURE 6 Continuous tear glucose monitoring using bored doped contact lenses (left). The hand held device works by flashing a light into the eye (Ex) and measuring the emission (Em) intensity. Schematic representation of the tear glucose-sensing device (right). *Adapted from [37].*

4. Heart bate

TECHNICAL UNIVERSITY OF CLUJ-NAPOCA ROMANIA

- The heartbeat trend is also important information to understand health conditions.
- In general, there are two types of heartbeat sensors: an optical measurement and a mechanical deformation measurement.
- Optical heart rate sensors work via pulse oximetry, a measurement technique that takes advantage of the fact that

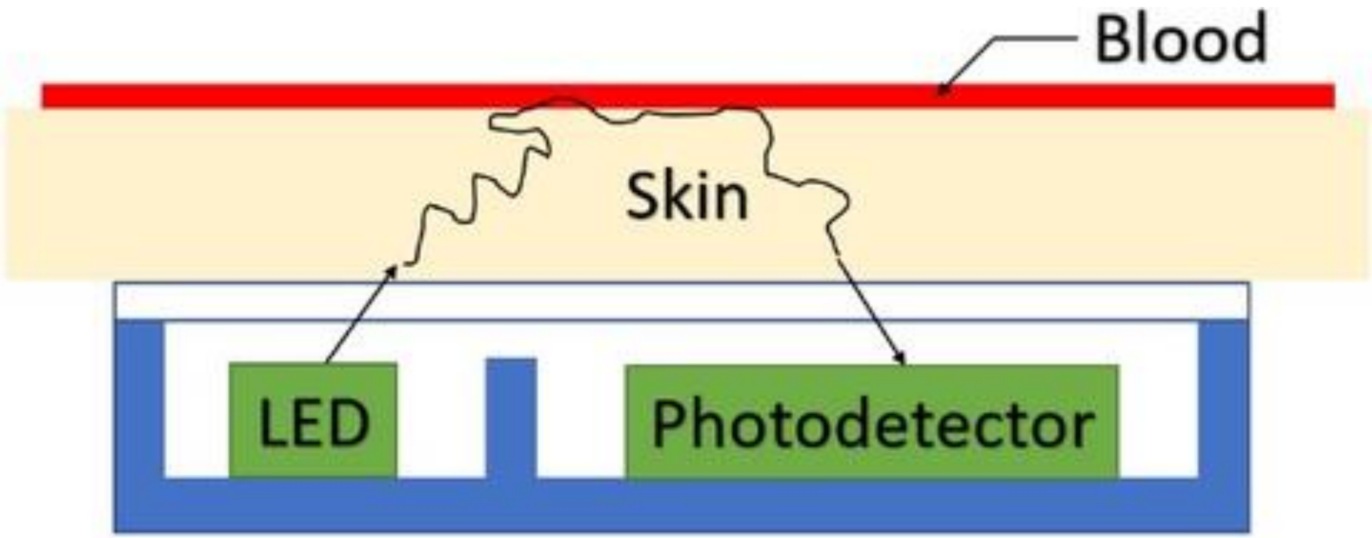
-**oxygenated and de-oxygenated hemoglobin have different optical properties**.

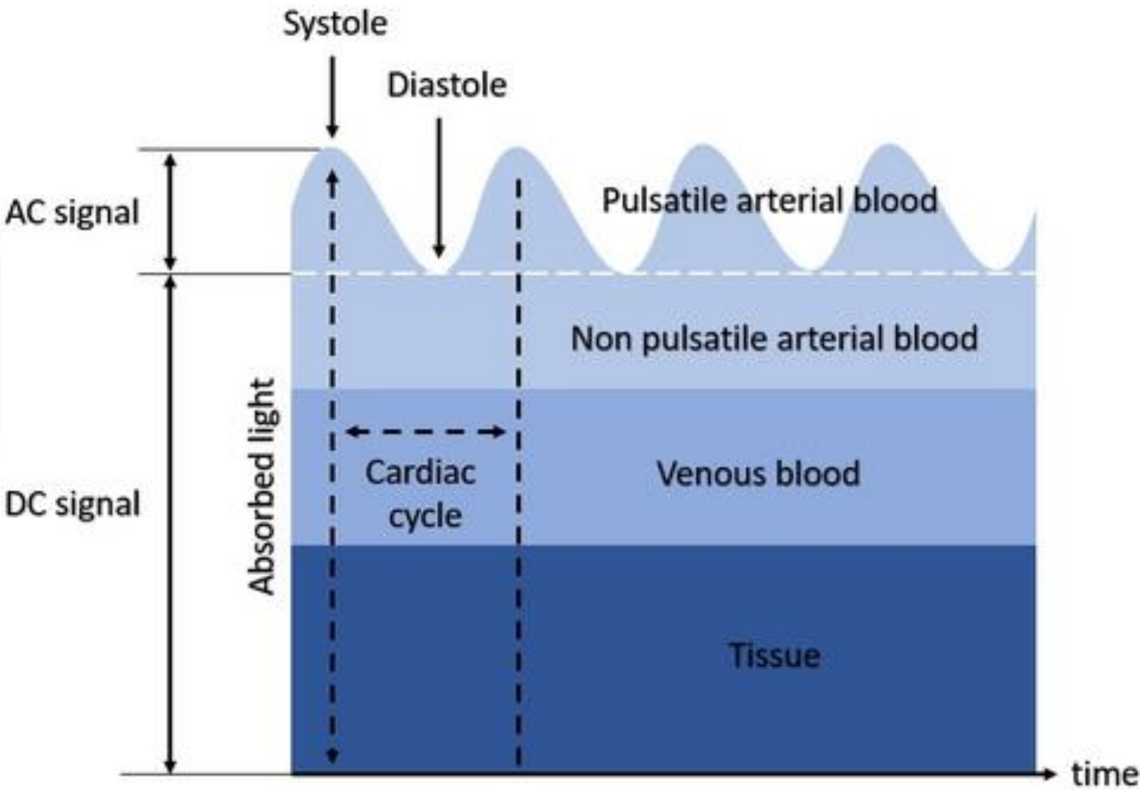
- with every heartbeat, there is a spike in arterial (oxygenated) blood, which is detected as a change in the **absorbance and/or reflectance of red and/or infrared light.**

Photoplethysmography

- The principle on which optical sensors measure heart rate is called photoplethysmography (PPG). As the heart pumps, the volume of blood transported in the arteries changes.
- More blood flows through the arteries when the heart expels blood (systolic phase) and less blood flows when the heart draws blood in (diastolic phase).
- When the blood volume changes between systolic and diastolic heart beats, it results in a change in the optical absorption coefficient of the arterial layer.
- By optically illuminating the tissue and measuring the transmitted light, the absorption change due to the blood volume change can be determined and the heart-rate pulsatile signal can be recovered.

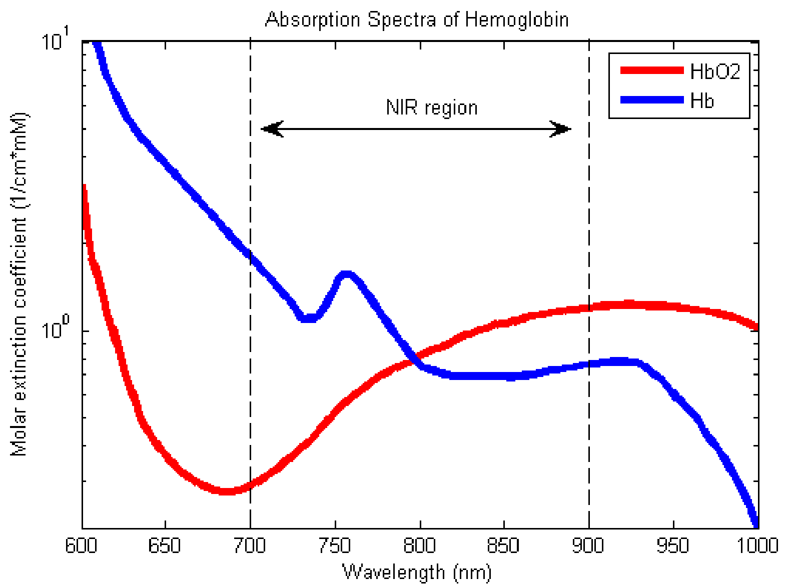
Sensor operation principle

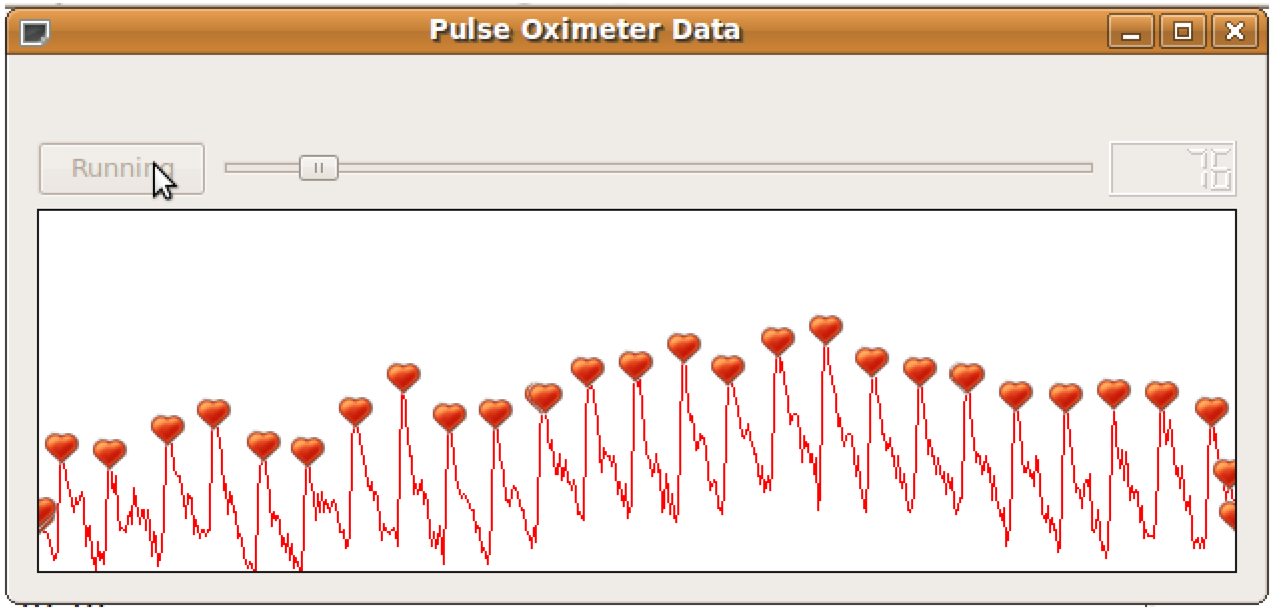




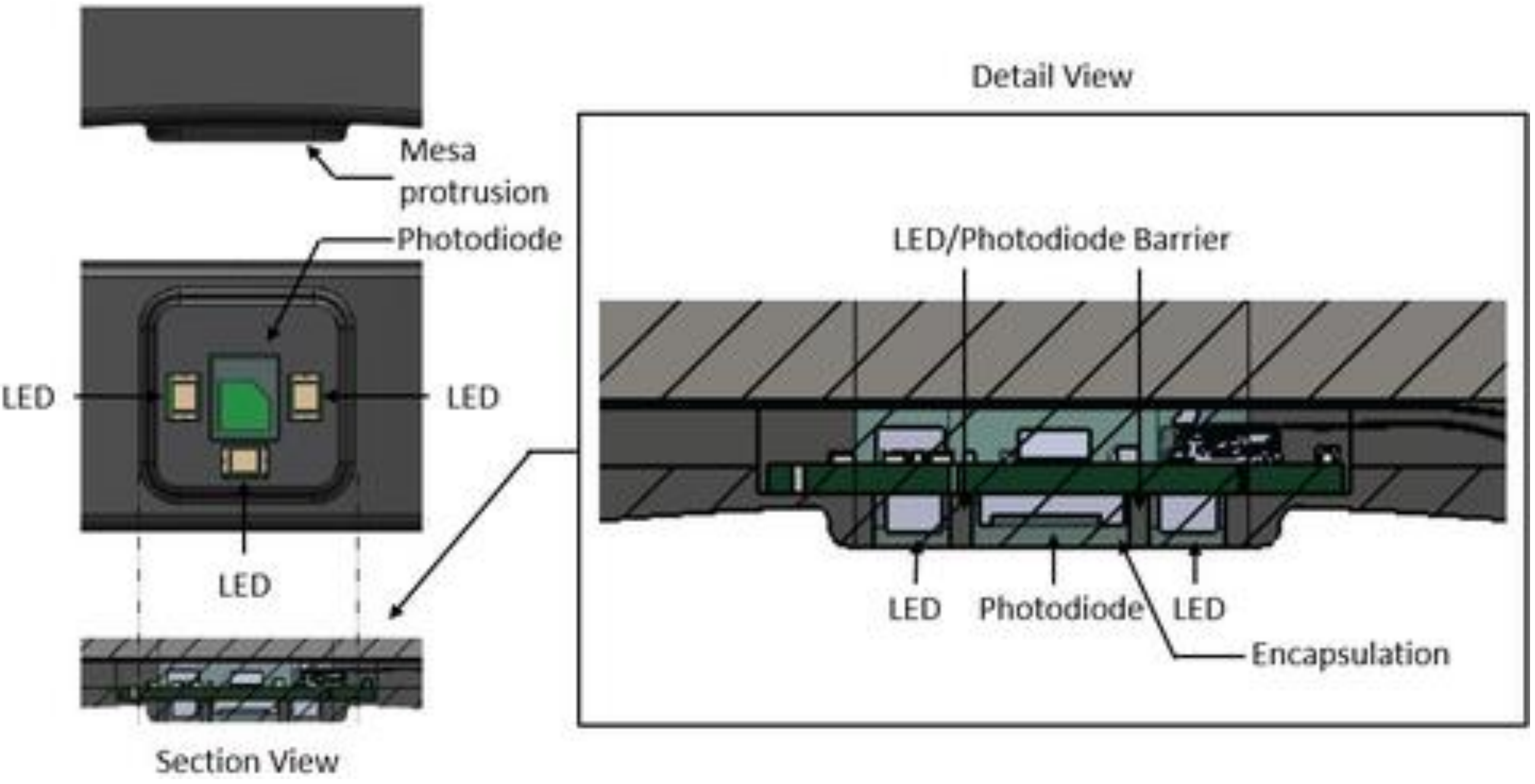
https://www.fierceelectronics.com/components/opto-mechanical-integration-heart-rate-monitors-wearable-wrist-devices

- Most optical heart rate monitors in smartphones or wearable devices are fairly rudimentary as compared to clinical oximeters.
- They consist of a red LED and an optical detector which measures the reflectance of the red light from your skin (or more specifically, the blood under your skin).
- The reflectance is a bit different during a **heartbeat versus between heartbeats**, so the detector will see a periodic signal for the duration of the measurement from which the heart rate is extracted.





Wearable device



Optomechanical Design Considerations
maximize both
-the signal received by the sensor and
-the signal-to-noise parameter.

The latter can be increased by maximizing the signal that has penetrated deep enough into the skin to detect a PPG signal while minimizing crosstalk, which is the signal on the sensor from sources other than the PPG signal.

J. G. Webster, "Design of Pulse Oximeters", Series in Medical Physics and Biomedical Engineering, Taylor & Francis, New York, USA, 1997.

Clinical implementation – an example

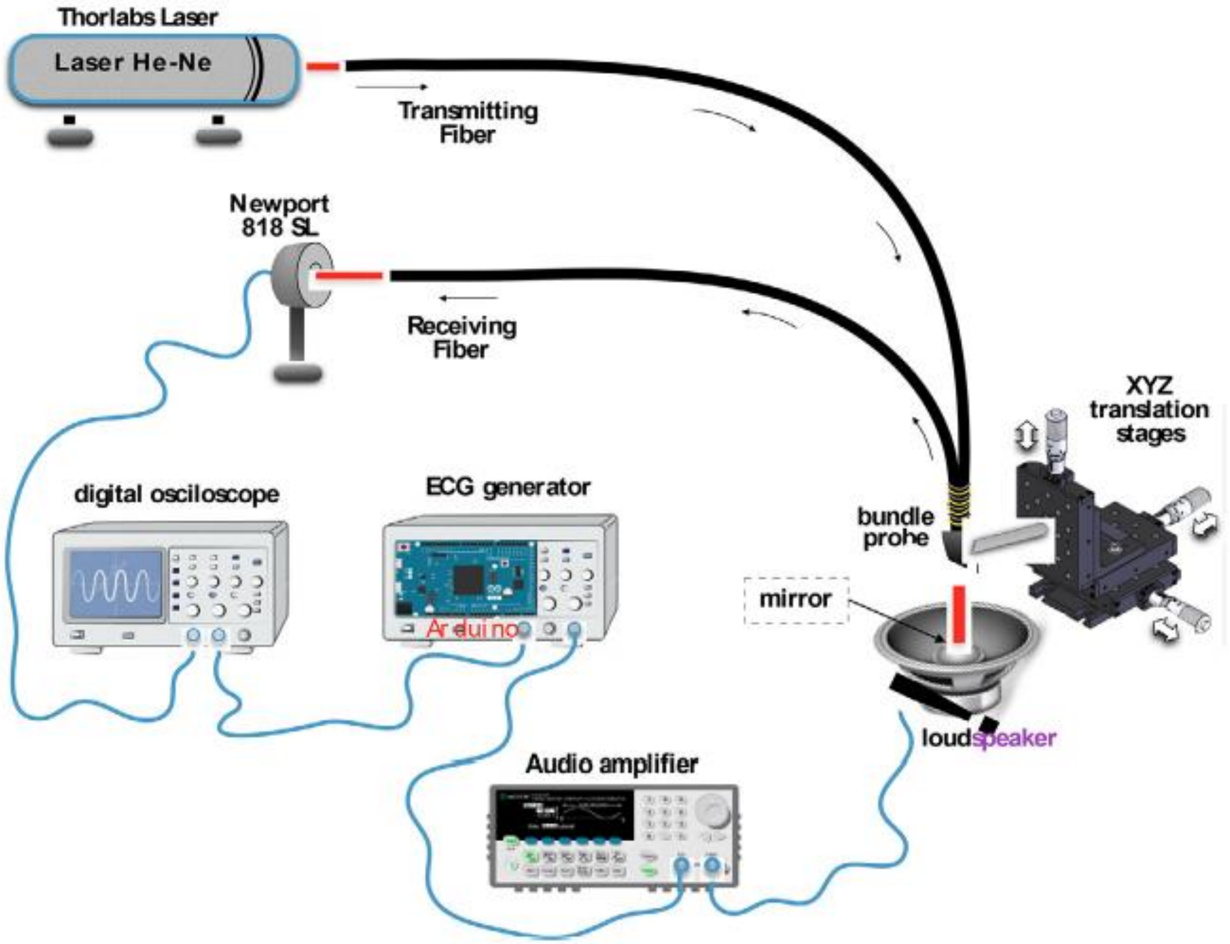
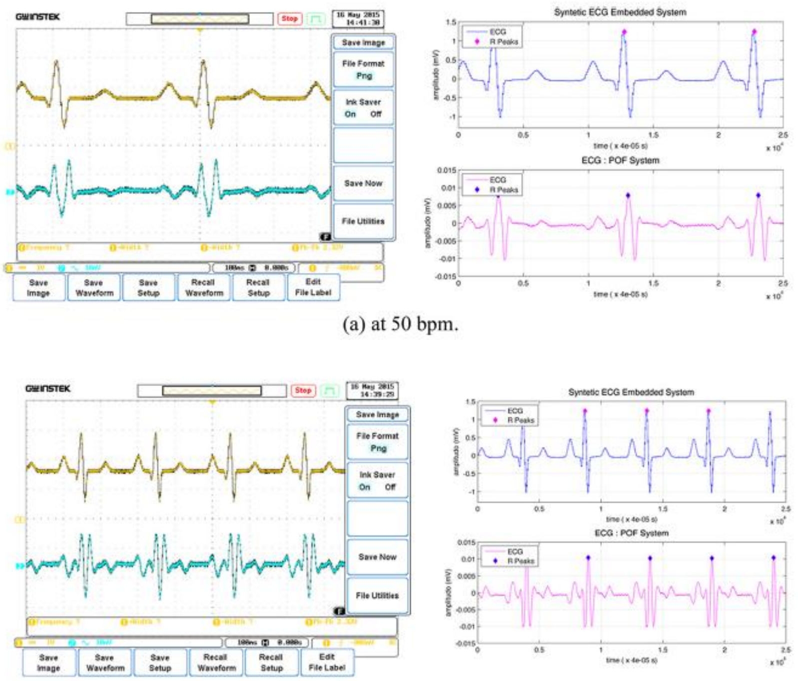


Fig. 1. Experimental setup of fiber optic sensor for heart rate detection.



(a) at 50 bpm.

(b) at 300 bpm

Fig. 3. Comparison heart rate signal from generator and sensor output at different frequencies (a) 50 bpm and (b) 300 bpm.

Fiber optic sensor for heart rate detection Y.G. Yhun Yhuwana, R. Apsari, M. Yasin∗, Optik, 2017

3. Smart Shirt

- uses optical fibers to detect bullet wounds (rani) in addition to monitoring the vital signs of the soldier during combat conditions.
- The wearable motherboard can be tailored to be a head cap so that the gamer's brain activity can be tracked by recording the electroencephalogram (EEG). Thus, the wearable motherboard is an effective meta-wearable and the structure has the look and feel of traditional textiles with the fabric serving as a confortable information infrastructure.
- when sensors for vital signs such as heart rate, electrocardiogram, and body temperature are plugged in, the wearer's physical condition is monitored.

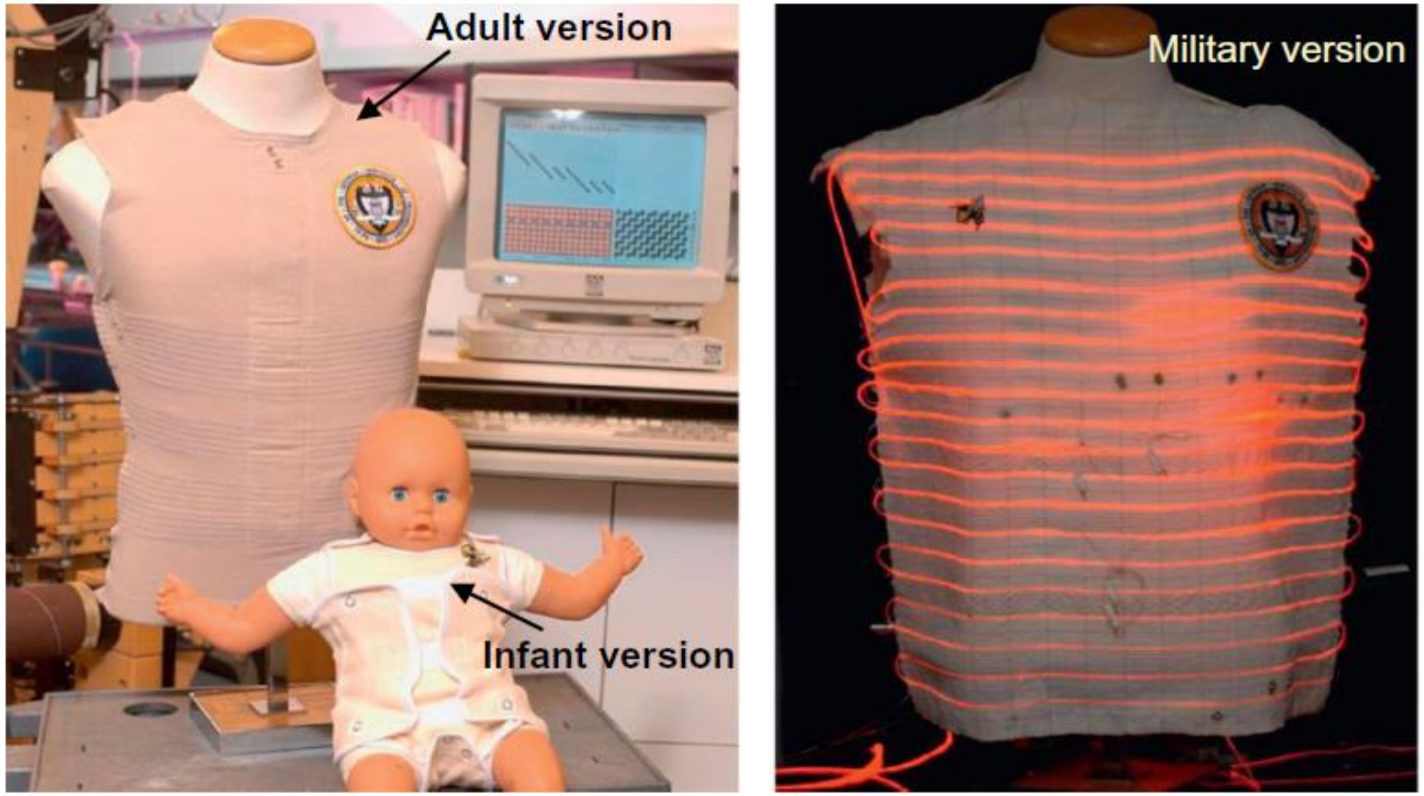


FIGURE 7 The wearable motherboard: adult, baby, and military versions.

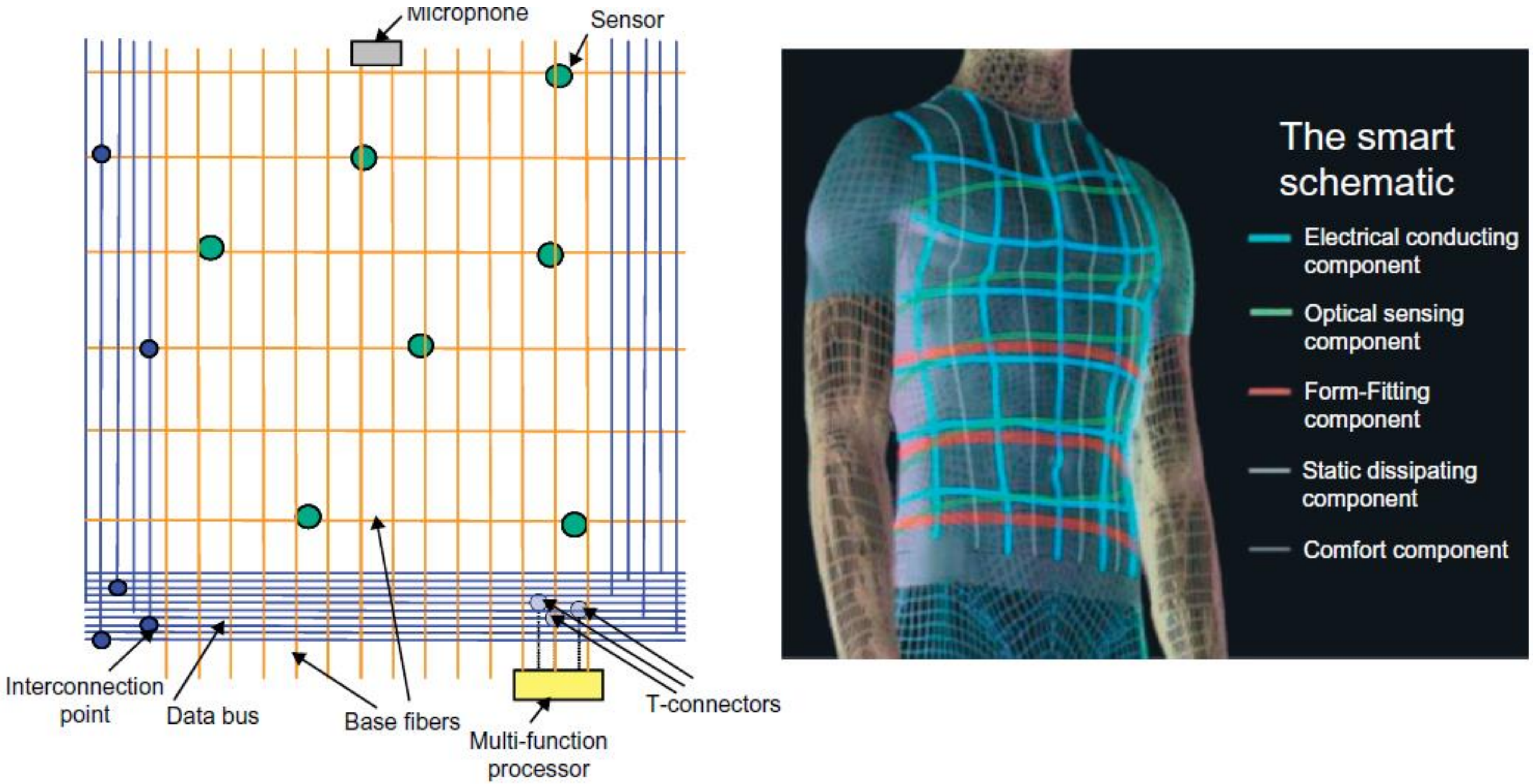
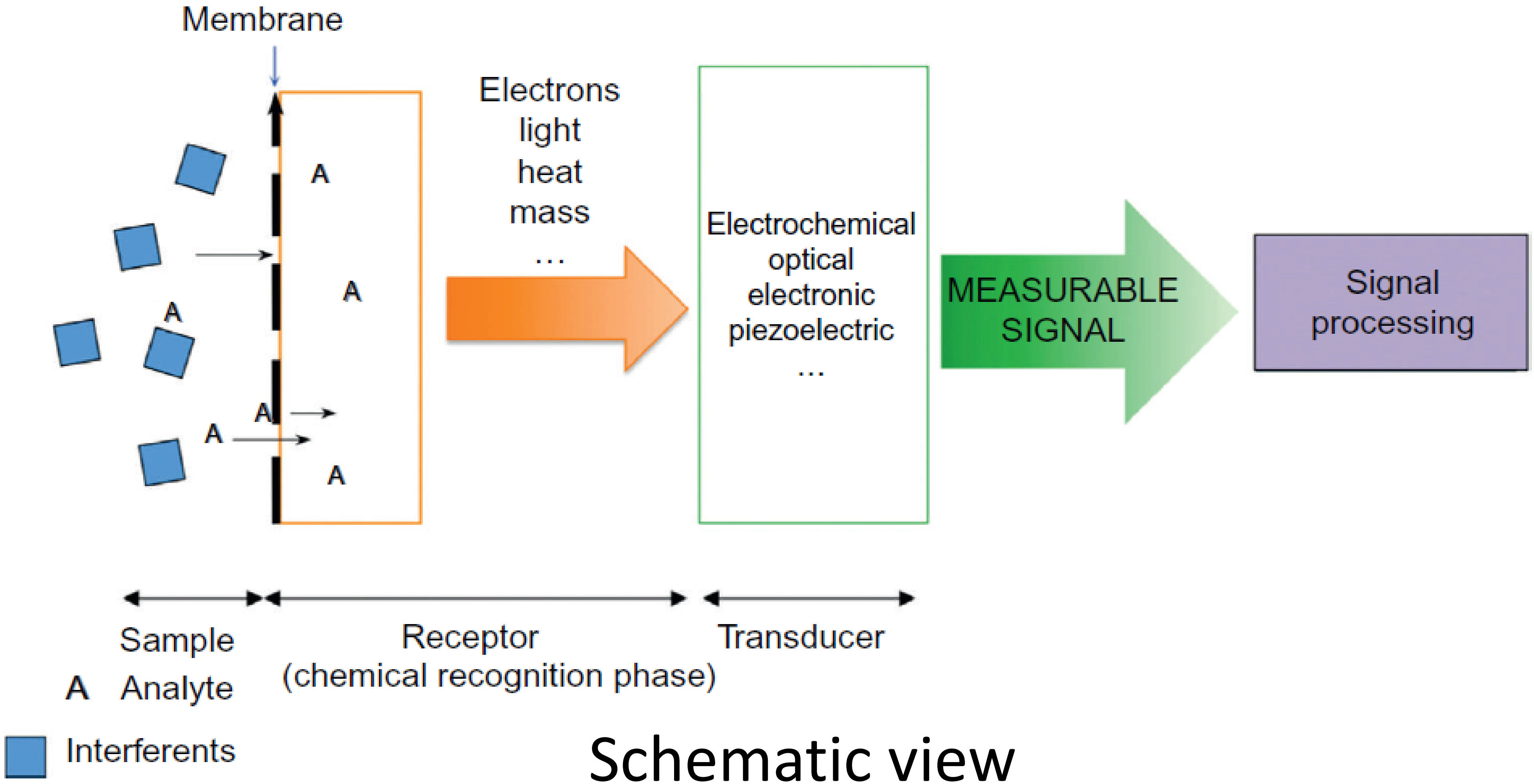


FIGURE 8 Wearable motherboard architecture.

Head-Mounted Wearable Computer

- Safe in explosive environment

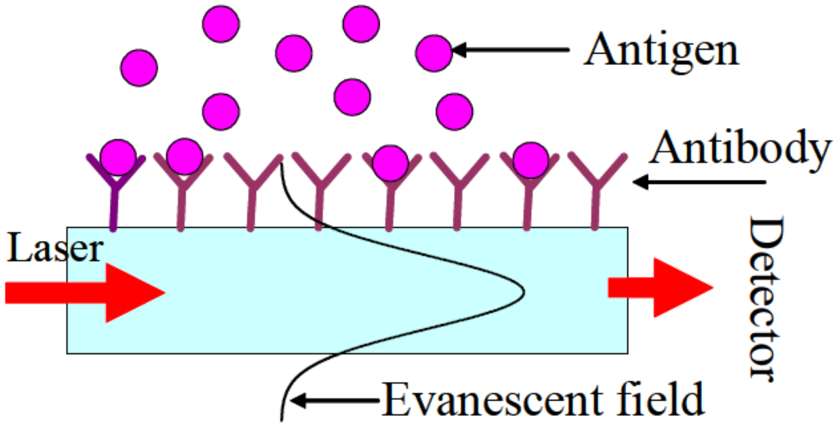
4. Chemical sensors



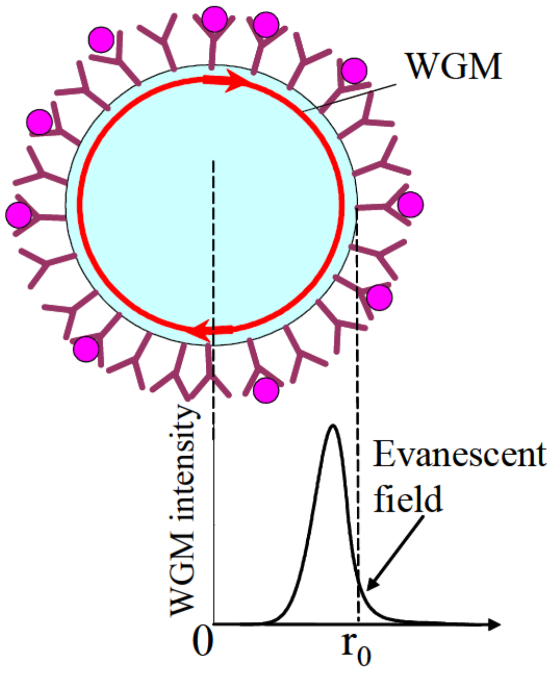
Schematic view

A. Lobnik, M. Turel, ˇS. Korent Urek, Optical Chemical Sensors:Design and Applications, Advances in Chemical Sensors, InTech, 2012.

Optical resonators sensors



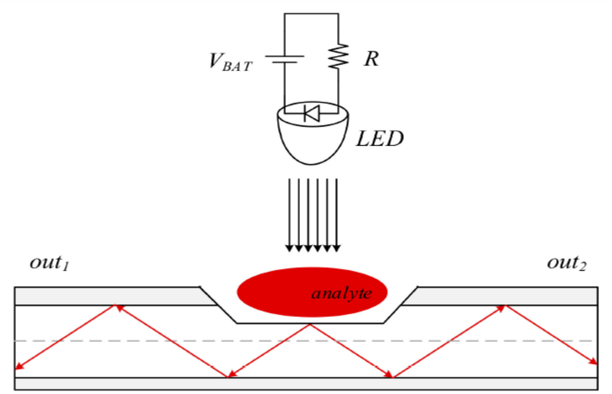
An optical biosensor based on a straight waveguide

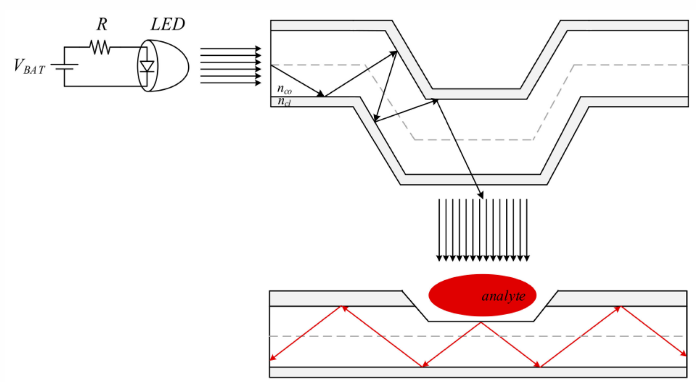


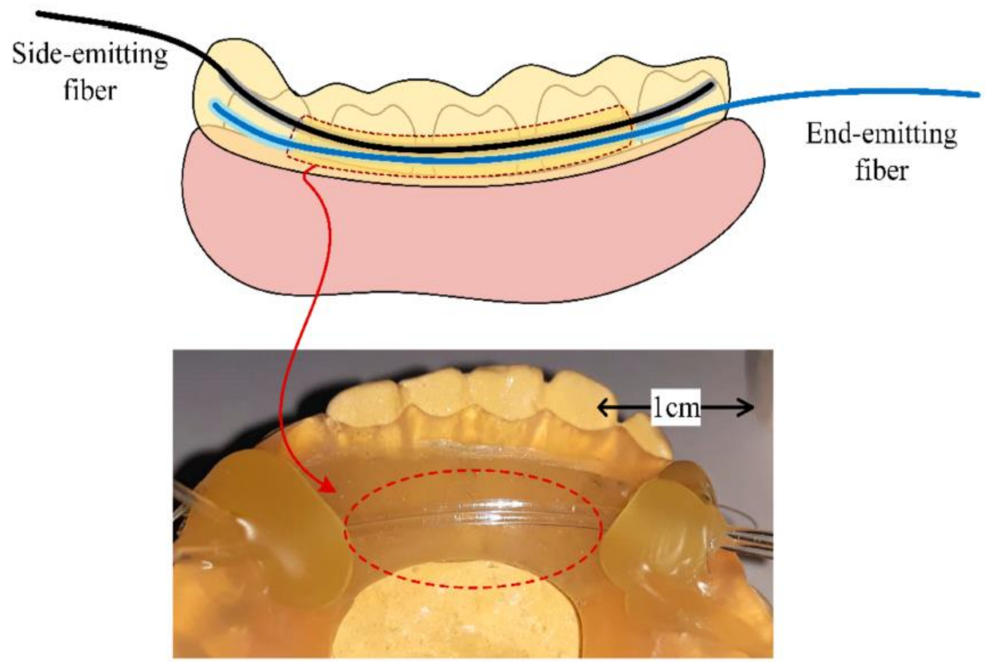
An optical ring resonator in which the Whispering Gallery Mode circulates along its surface

Operation principle: interference with the body

- The transducer translates the chemical information about the sample into a useful analytical signal.
- The transduction element may be electrochemical, optical, electronic, or piezoelectric
- In recent years, novel chemical and biochemical sensors have been developed by scientific groups all over the world.





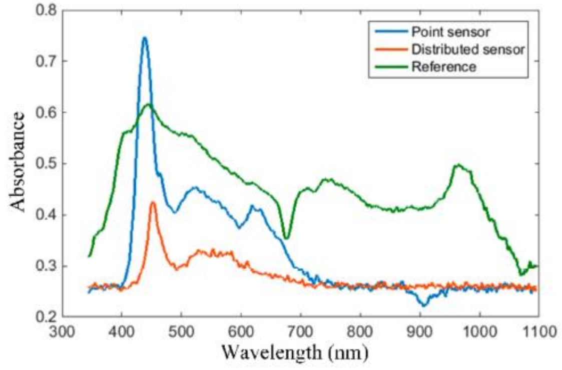


DETECTION LIMIT - CALIBRATION

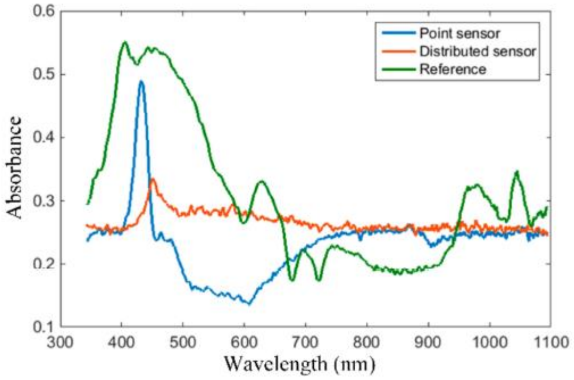
Farago, P.; Babt, an, A.M.; Galatus, R.; Groza, R.; Roman, N.M.; Feurdean, C.N.; Ilea, A. A Side-Polished Fluorescent Fiber Sensor for the Detection of Blood in the Saliva. In IFMBE Proceedings, Proceedings of the 6th International Conference on Advancements of Medicine and Health Care through Technology, Cluj Napoca, Romania, 17–20 October 2018; Vlad, S., Roman, N., Eds.; Springer: Singapore, 2019; Volume 71

(**a**)

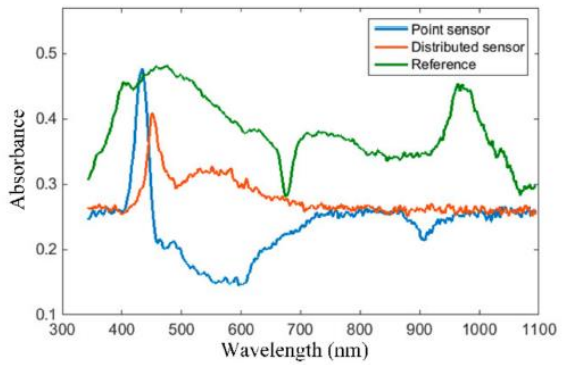
(**b**)


Point sensor
Distributed sensor
Reference
Absorbance
Wavelength (nm)

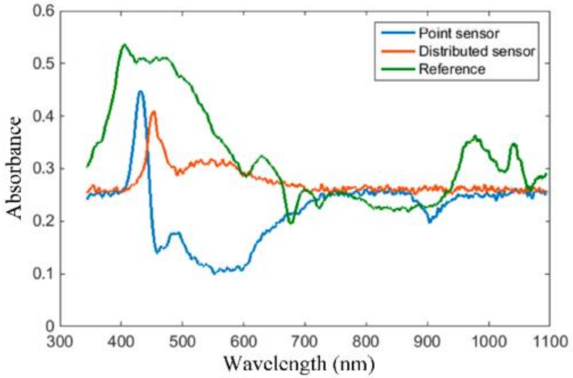
(**a**)


Point sensor
Distributed sensor
Reference
Absorbance
Wavelength (nm)

(**b**)

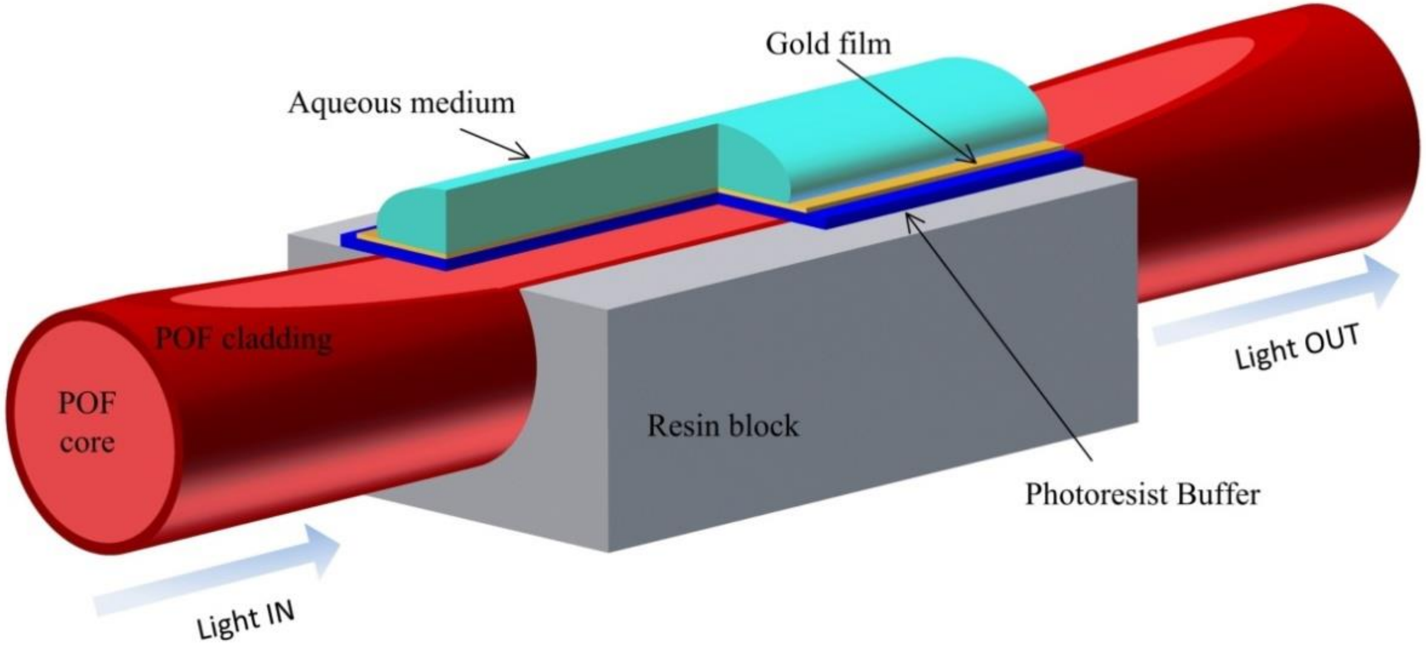

Point sensor
Distributed sensor
Reference
Absorbance
Wavelength (nm)

(**c**)


Point sensor
Distributed sensor
Reference
Absorbance
Wavelength (nm)

(**d**)

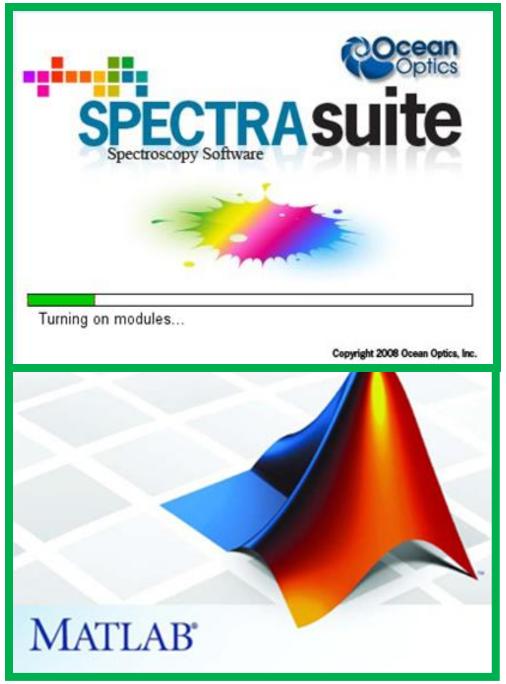
A simple optical platform: SPR in POF



POFs are especially advantageous due to their excellent flexibility, easy manipulation, great numerical aperture, large diameter, and the fact that plastic is able to withstand smaller bend radii than glass!

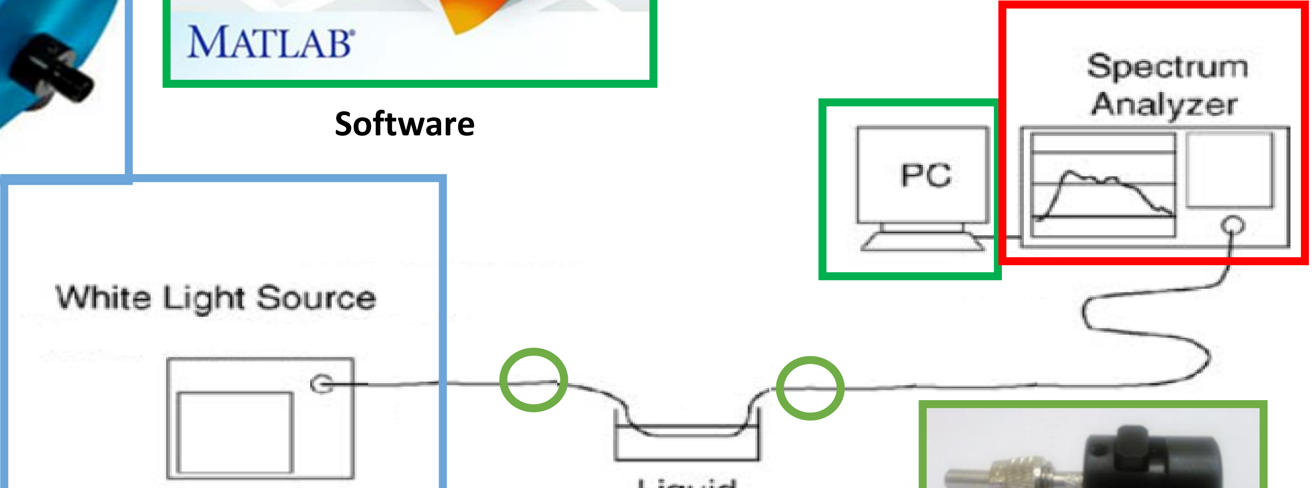
Experimental set-up

White Light Source
(360 ÷ 2000 nm)



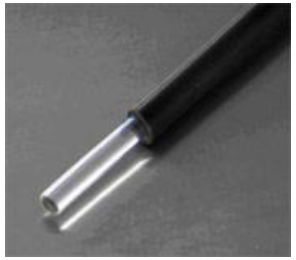
Software

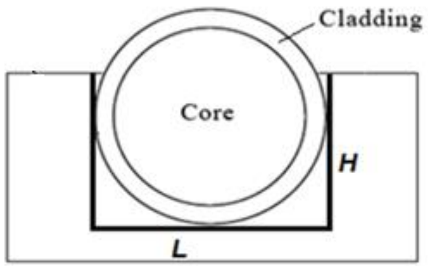
Spectrum analyzer
(200 ÷ 850 nm)

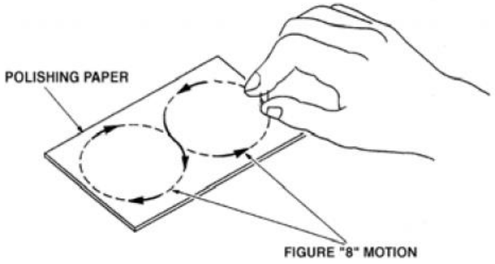


SMA connectors

A simple optical platform: SPR in POF

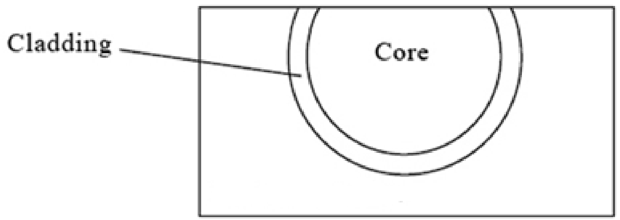


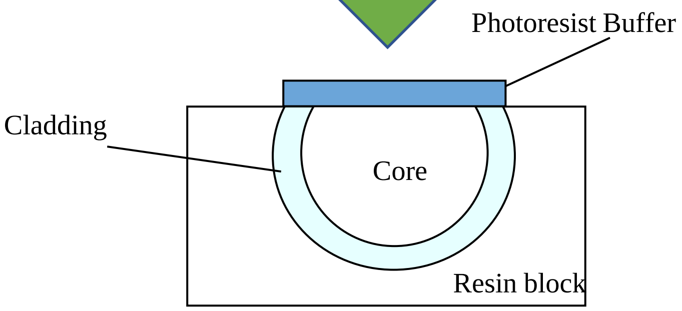


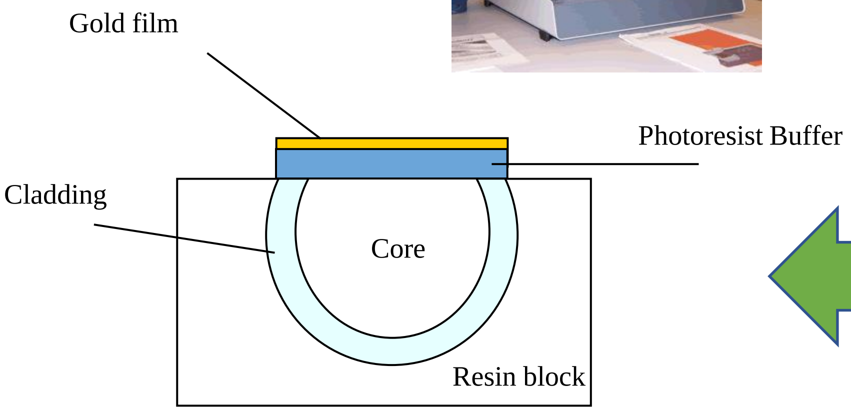


Spin coater

Sputter coater

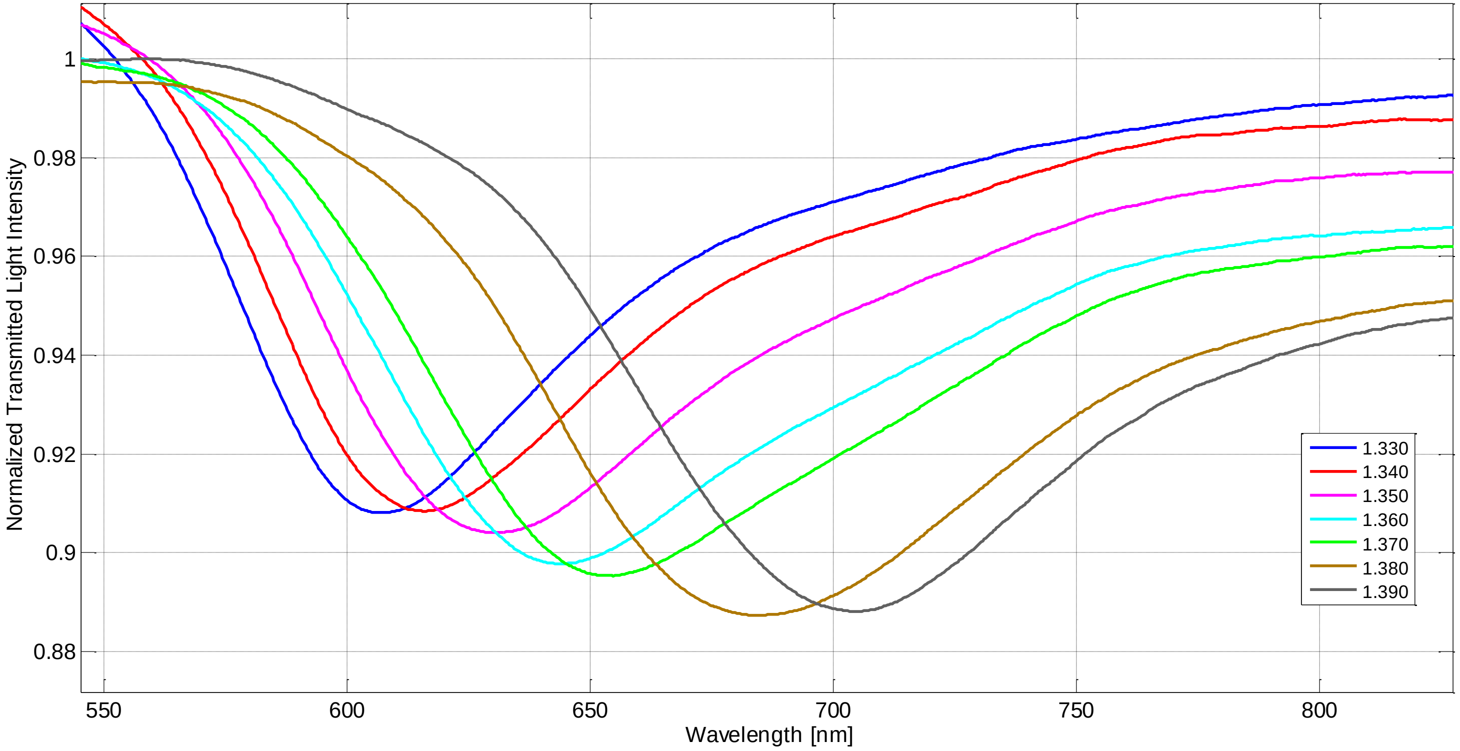






Optical platform for biosensor implementation

Basic platform characteristics

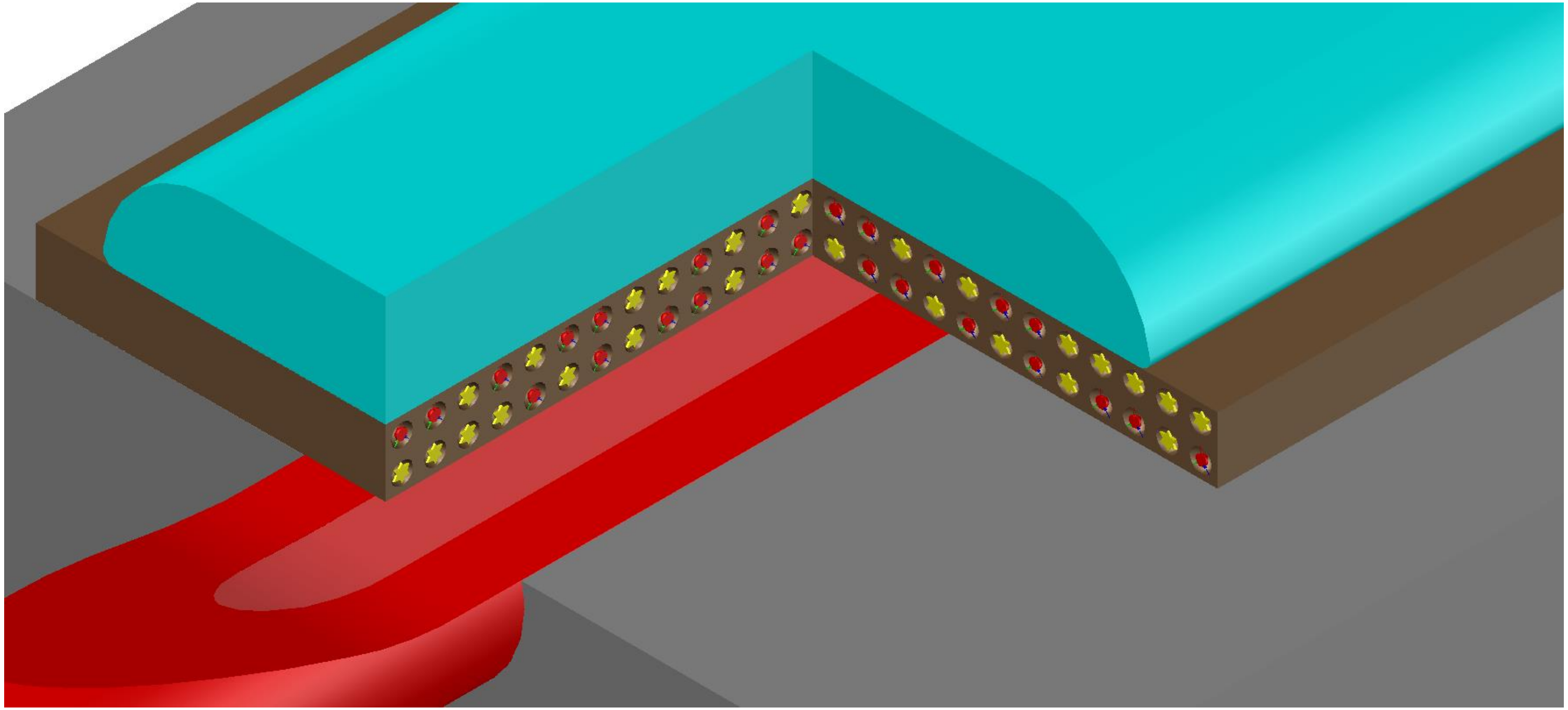


S = 10 ^{3} ÷ 10 ^{4} [nm/RIU]

NEXT TIME:

Different chemical sensing layer

MIP with Gold Nano-Stars (GNS): Excitation of Localized Surface Plasmon Resonance (LSPR)



Plamonic sensors

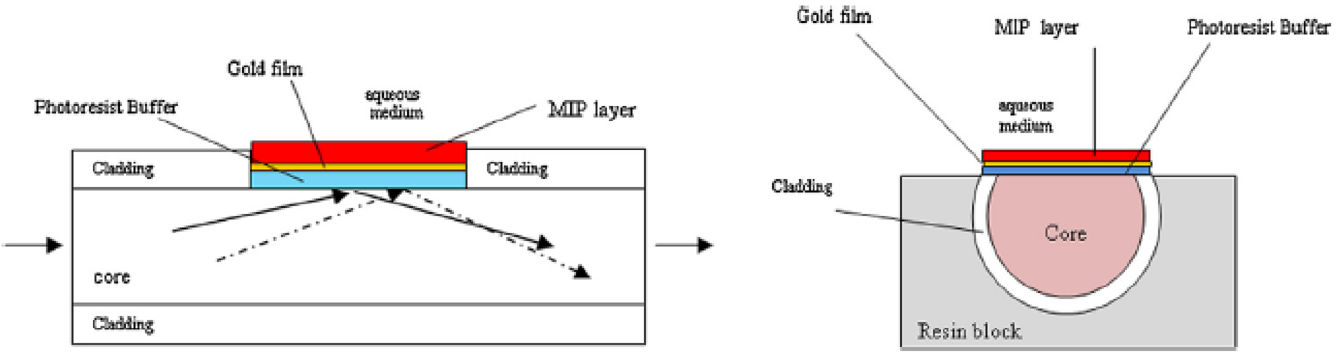
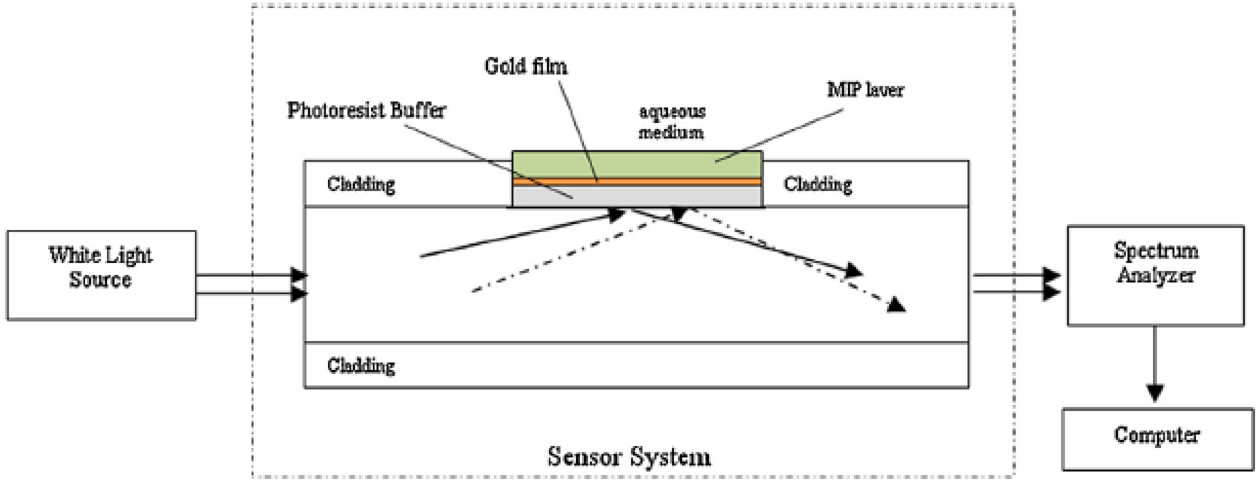


Fig. 1. Section of the optical chemical sensor with detail of sensor geometry.



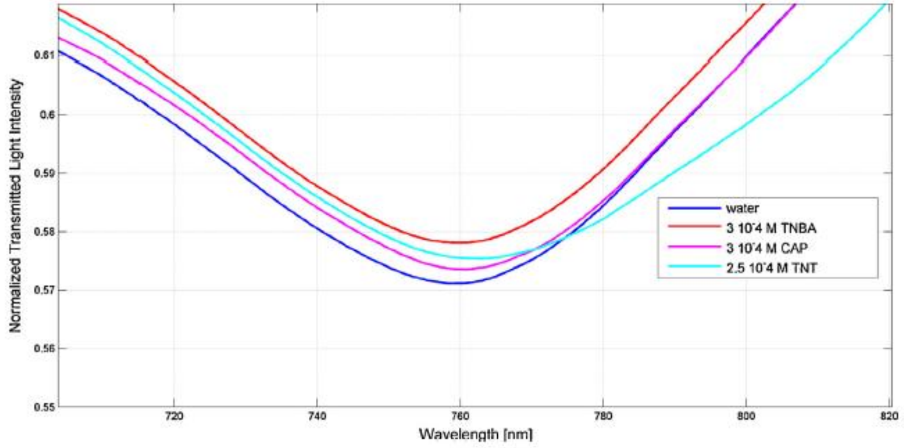


Fig. 2. Sensor system and experimental setup.

Sensors based on surface plasmon resonance in a plastic optical fiber for the detection of trinitrotoluene N. Cennamoa, G. D'Agostino b**, R. Galatus** c, L. Bibbòa, M. Pesavento b,∗∗, L. Zeni a,d,∗, Sensors and Acuators: B Chemical, 2013

Part 2 – portable devices or integrated devices

Example 1: Integrated devices - Light barrier

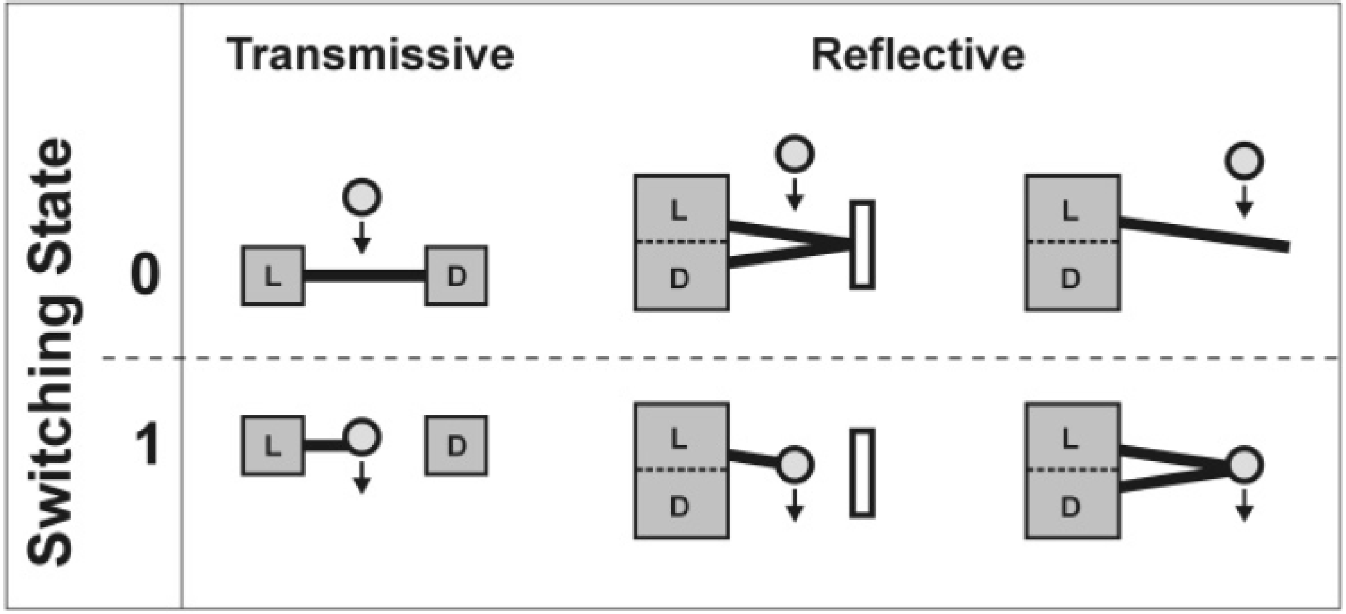


Figure 2.4 Light barrier designs. L: light source, D: detector. Left: transmission-type, right: reflexion-type.

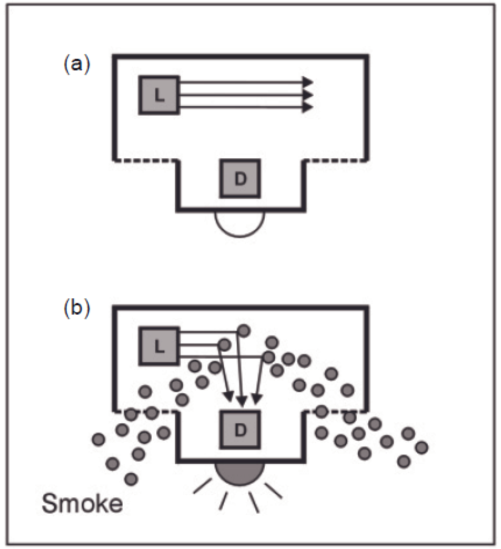


Figure 2.5 Smoke detector. L: light source, D: detector. (a) with clean air, (b) with smoke.

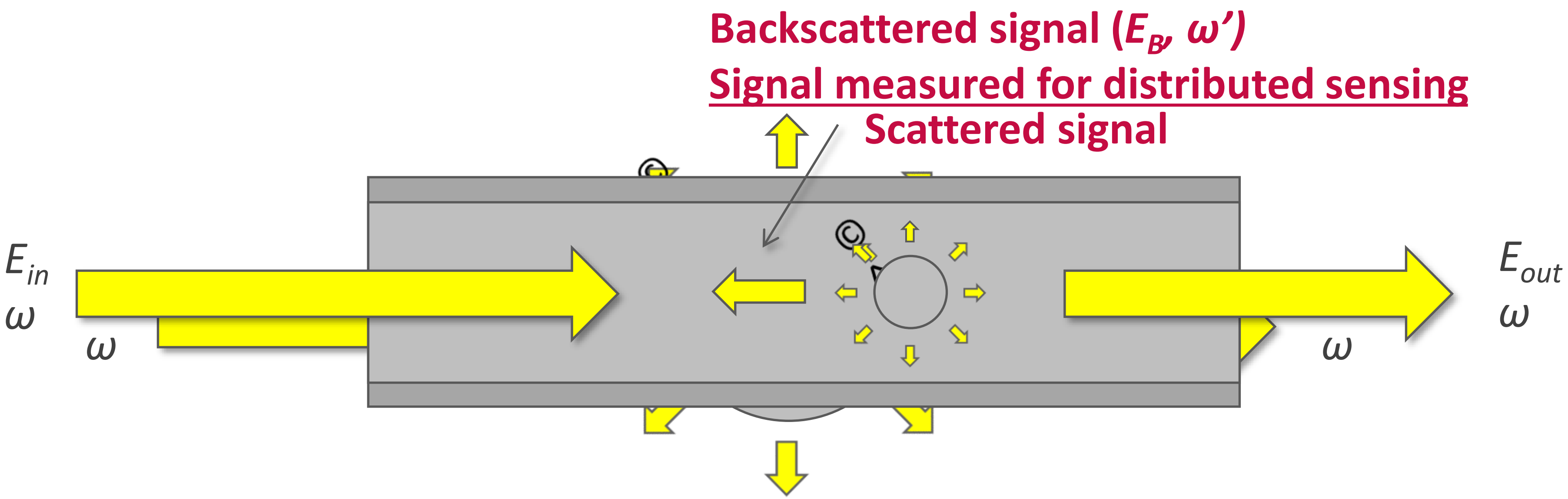
Example 2: OTDR

Figure 13.6. Portable OTDR for making measurements in the field. (Model FTB-400, photo provided courtesy of EXFO; www.exfo.com.)

The presentation is based on 3M training course

The content of this talk ranges from physical concepts to applications

The scattering effects are the physical phenomenon that will be **detected/quantified/treated** by every sensing systems presented in the applications.



First objective: description of the basic physical principle of scatterings in optical fibres (Rayleigh, Brillouin, Raman)

The content of this talk ranges from physical concepts to <u>applications</u>

Rayleigh

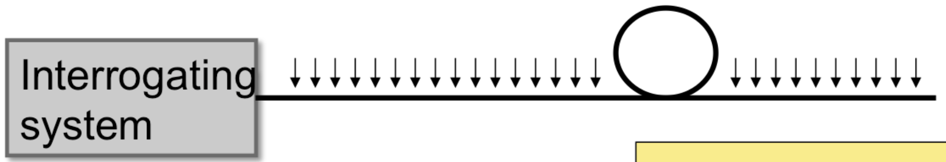
- Monitoring for telecommunication or SENSING purposes (OTDR)
- φ-OTDR (Phase-OTDR) for intrusion and vibration sensing

Brillouin

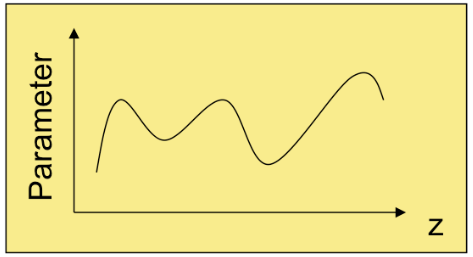
Brillouin reflectometer for temperature and strain sensing

Raman

Temperature sensing



<u>Distributed measurement</u>

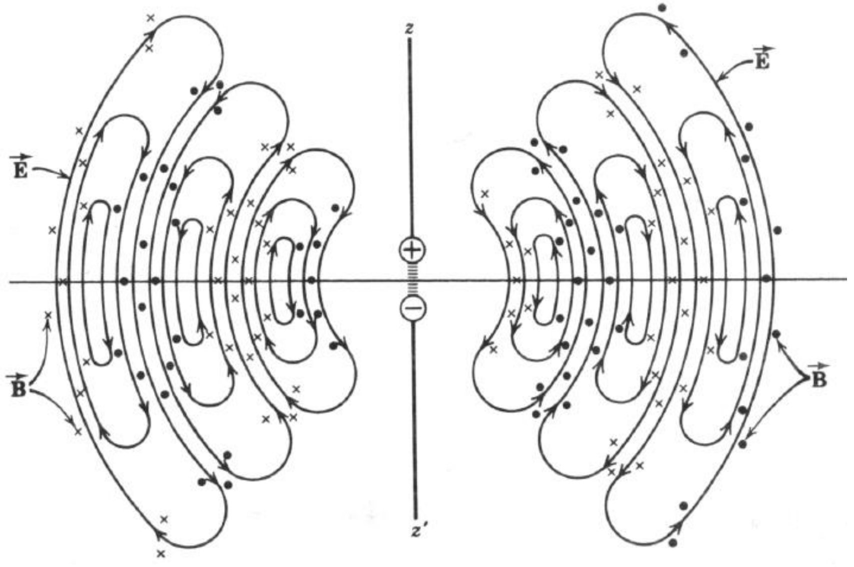


Second objective: **introduction to measurement using scattering effects**

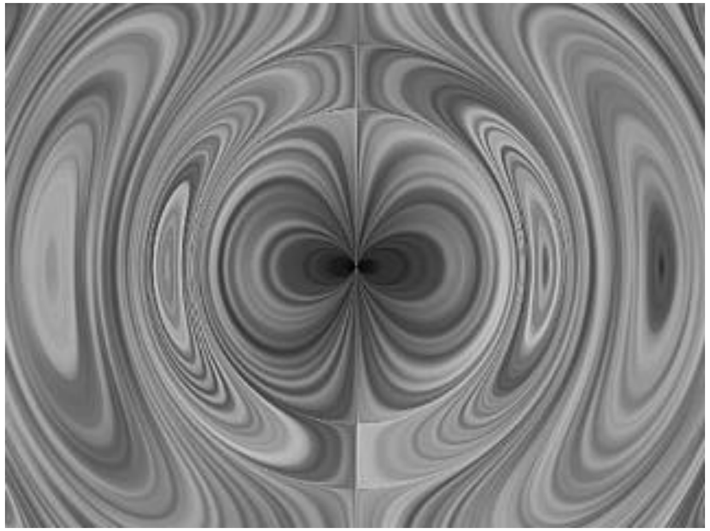
Scattering results from light-matter interactions

→ A monochromatic electromagnetic wave interacts with the medium particles by **stimulating the atomic electrons to oscillate**

→ The electrons radiate in the manner of **elementary electric dipoles**



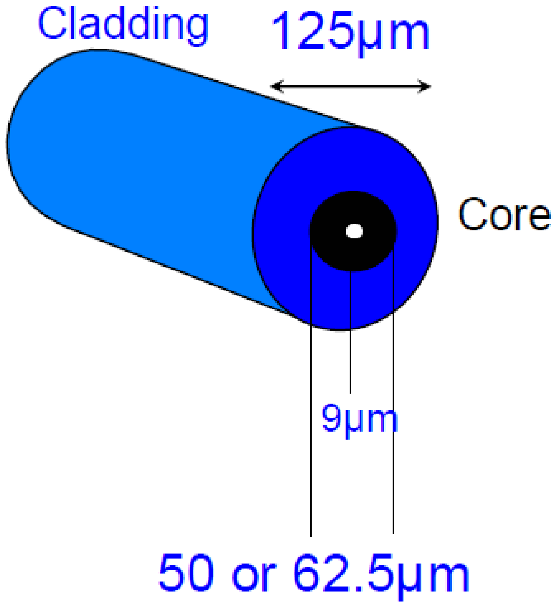
From R. Resnick and D. Hallyday, Ondes, optique et physique moderne, Editions ERP, 1980



From http://www.vis.uni-stuttgart.de/ufac/dipole/

Review

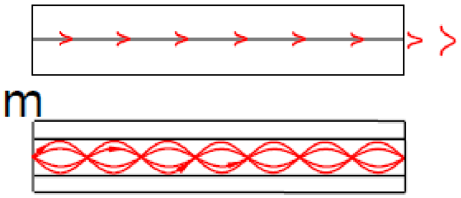
Fiber Fundamentals



Fiber types

-9/125µm Single mode

-50/125µm and 62.5/125µm multimode



Trends

-Lower attenuation and dispersion

-Lower cost per ft.

-More fibers per cable: From 8 to 288

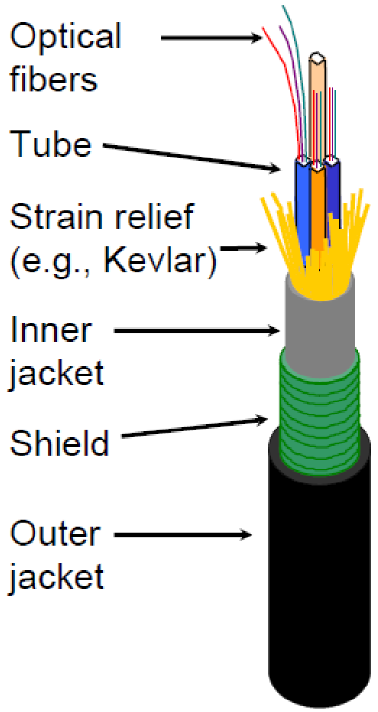
Cables

Cables

- Mechanical design: *Indoor, outdoor, or submarine installation*

- Typical attenuation:

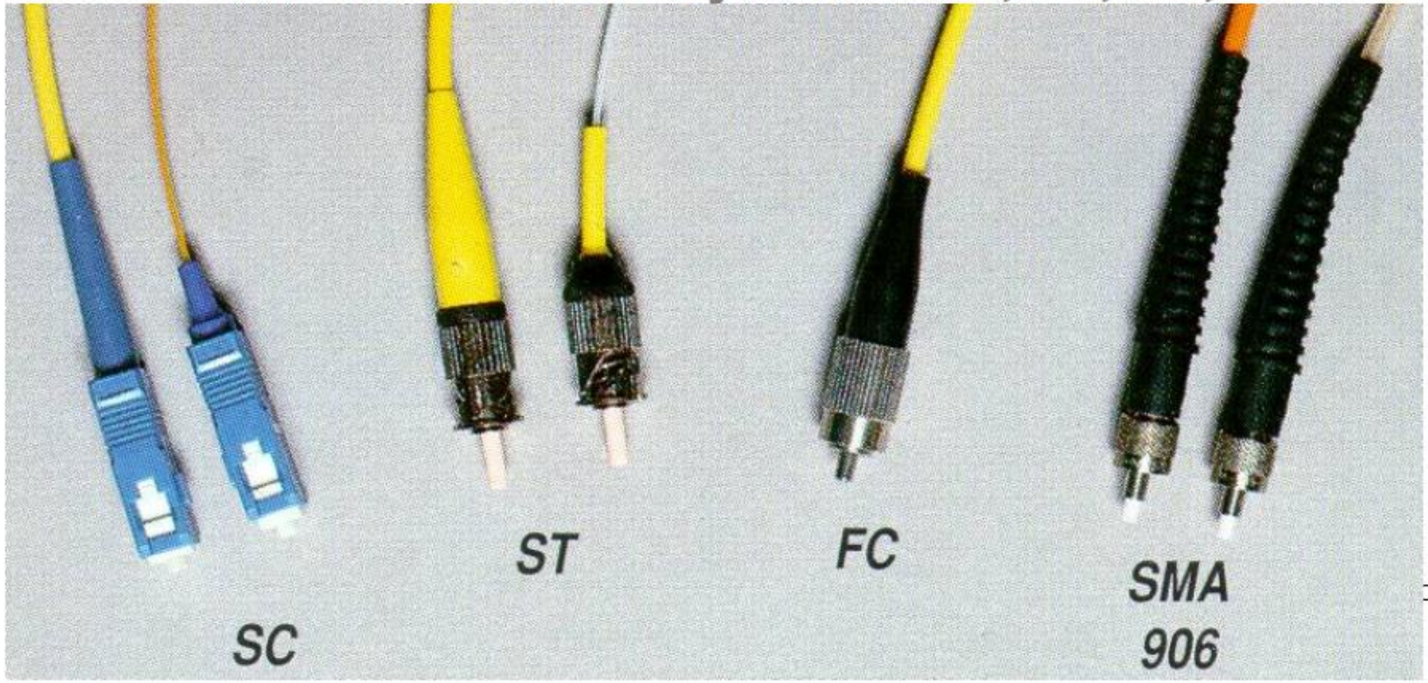
  0.2 - 0.25 dB/km @ 1550 nm, SM
  0.3 - 0.4 dB/km @ 1310 nm, SM
  0.5 - 0.7 dB/km @ 1300 nm, MM
  2.2 - 3.0 dB/km @ 850 nm, MM



Common connector types

Connector Types

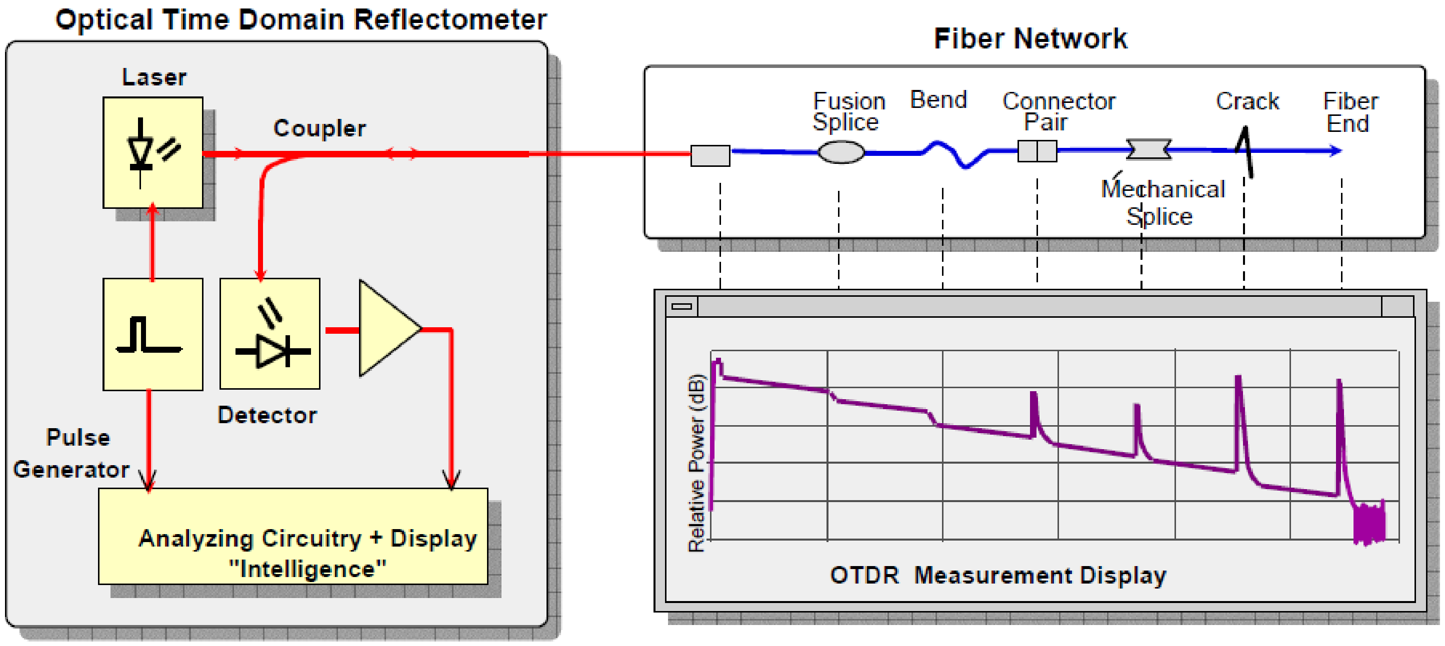
- **Fiber end polishing: *straight or angled***
- **Common mechanical styles: *FC/PC, ST, SC, DIN***



Gould
ptics

OTDR measurement principle

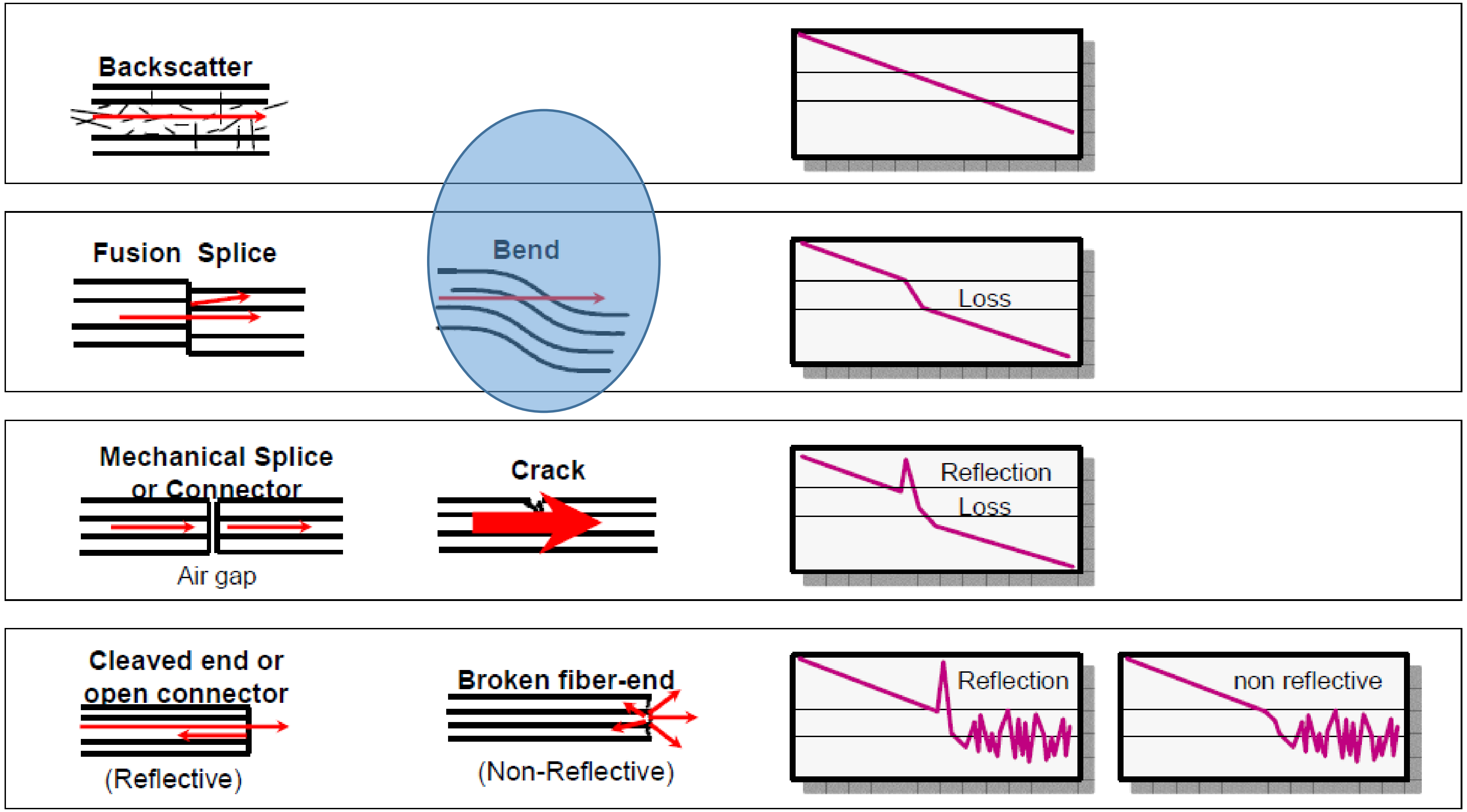
What is an OTDR?



http://www.automation.ro/damfu/rezultate-publice.html

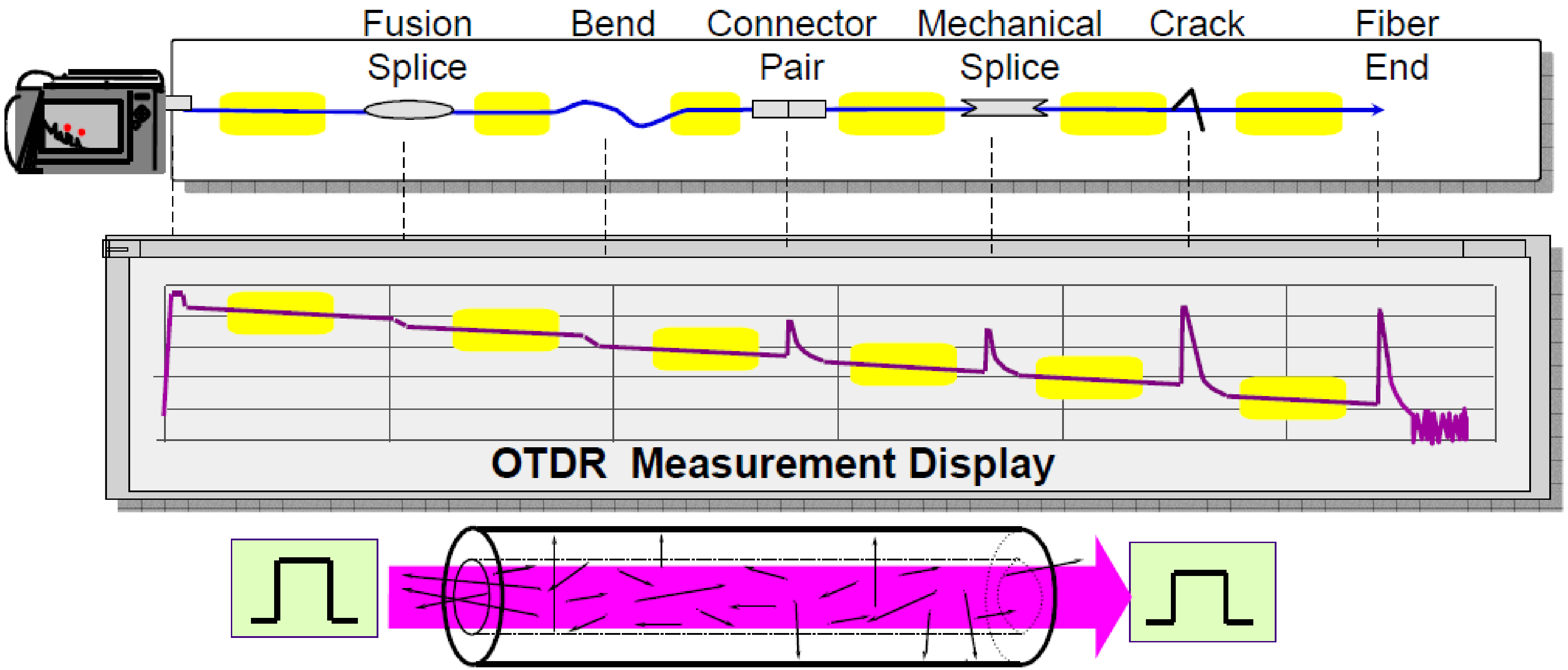
OTDR events

Fiber events and their trace representation



Backscattering

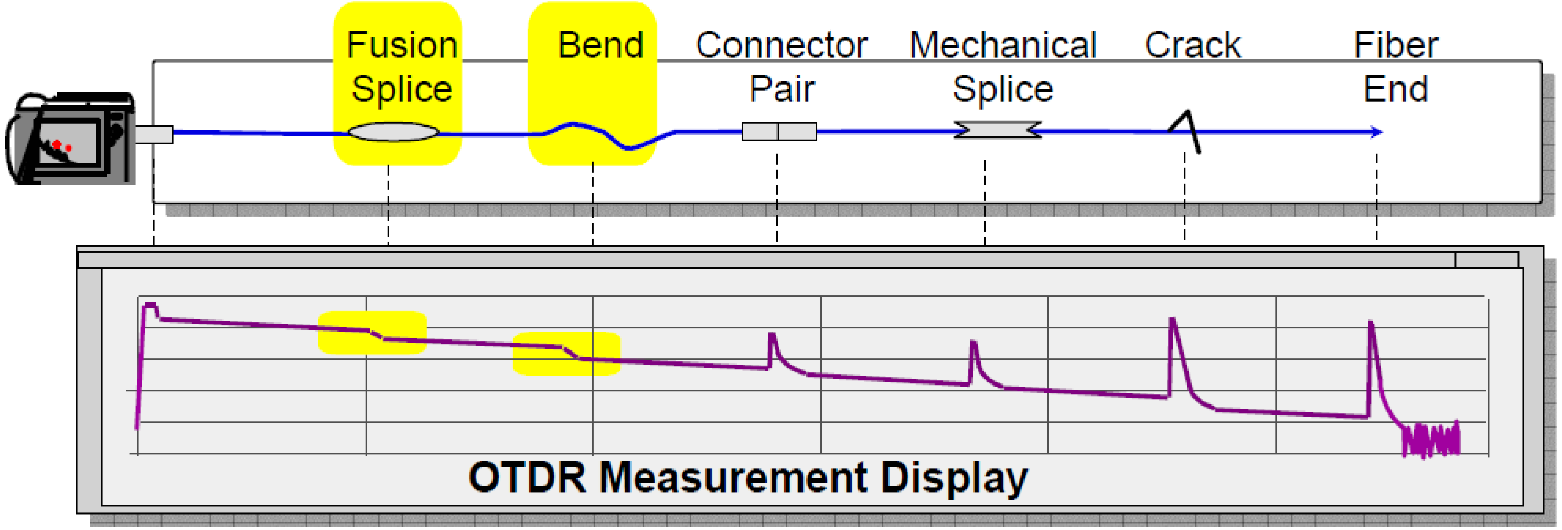
Backscatter



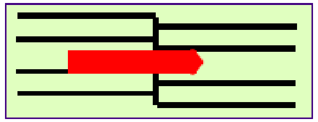
Backscatter is the small part of the Raleigh scattering which returns to the OTDR.

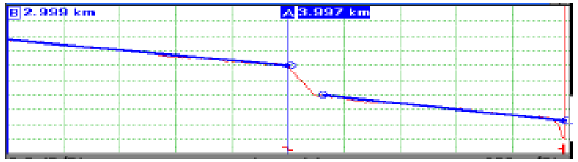
Non-reflective events

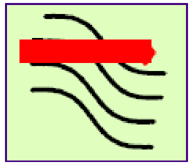
Non-Reflective Events



Fusion Splice





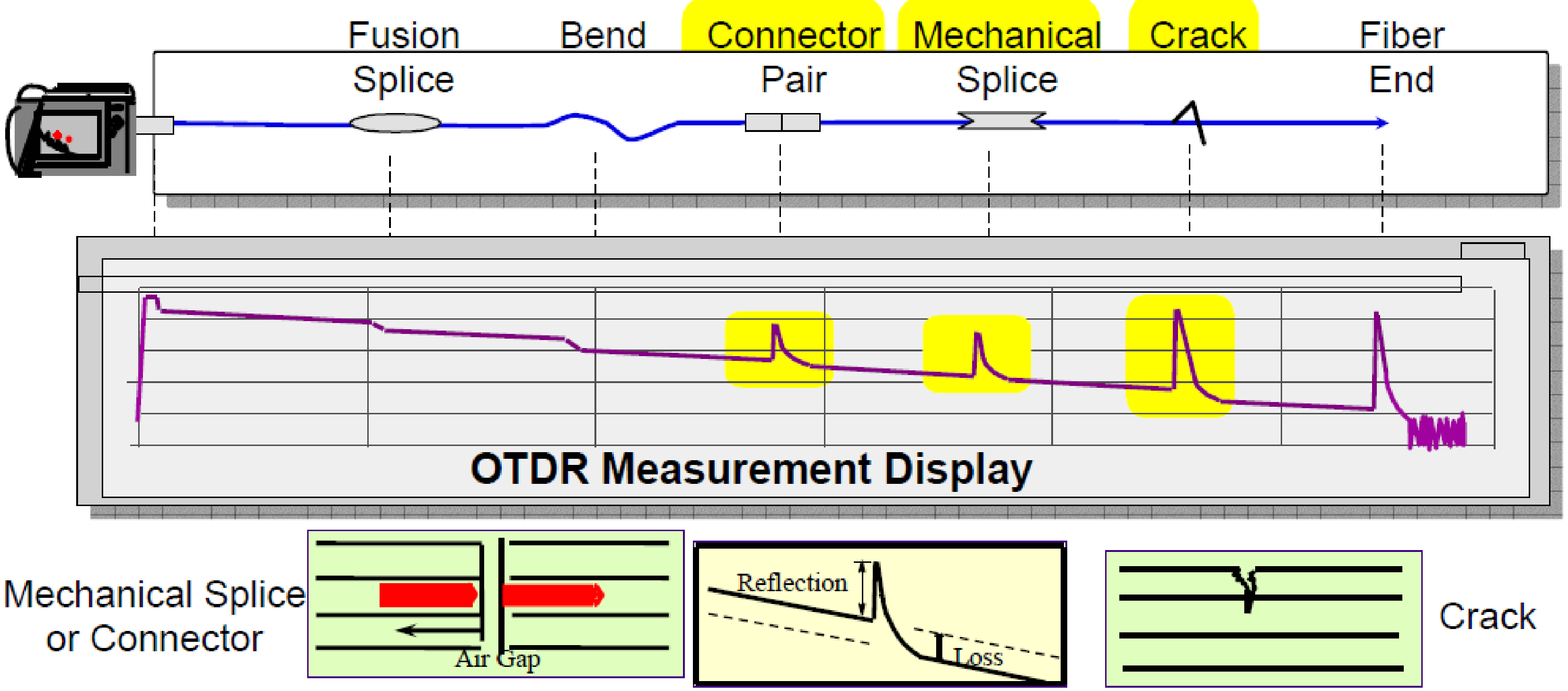


Bend

Fusion splices and bends cause loss, but no reflection. Their signatures are similar on an OTDR display.

Reflective events

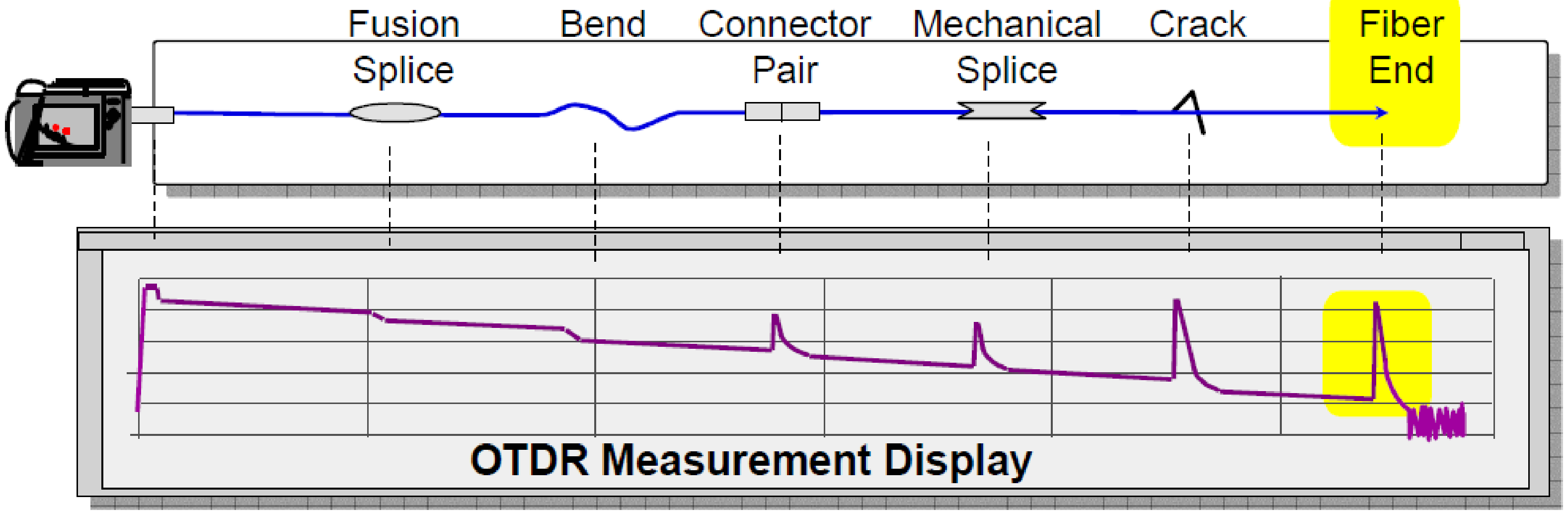
Reflective Events

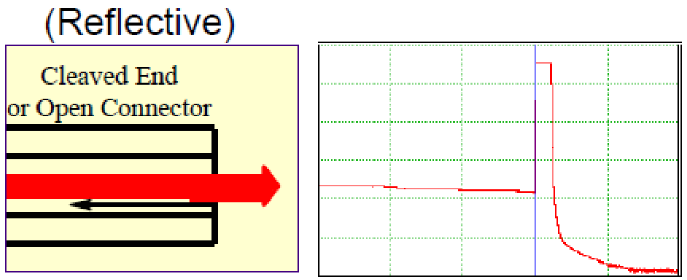


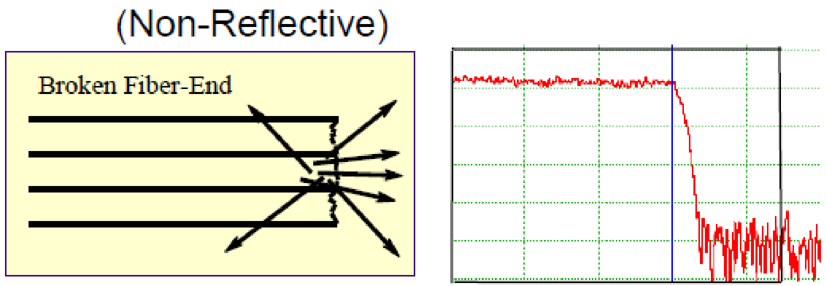
Mechanical splices, connectors and cracks cause both reflections and loss. Their signatures are similar on an OTDR display.

Fiber end

Fiber-End

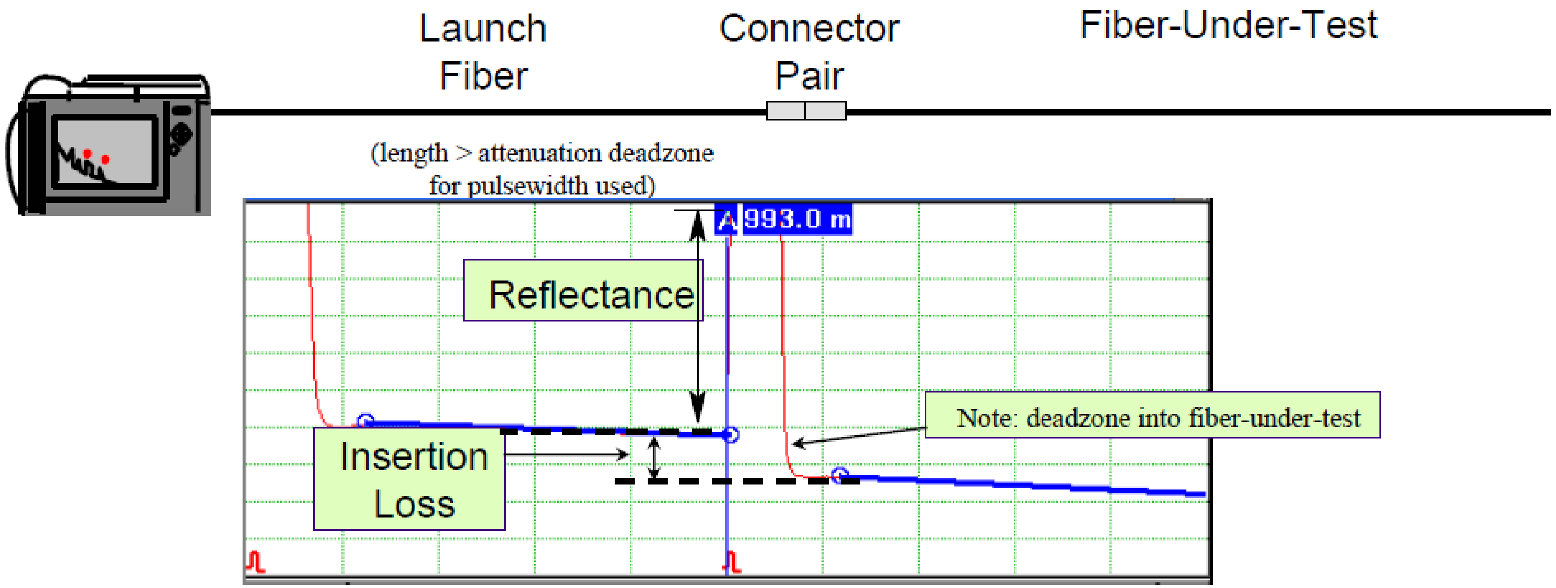






Insertion Loss

Measuring Insertion Loss and Reflectance of the First Connector



An external or connectorized launch fiber can be used so that the first connector's insertion loss and reflectance can be measured.

Conclusions

- State of the art in wearable sensors
- Portable sensors measurement, using OTDR