Microfluidic devices with selectable optical pathlength for quality control of alcoholic solutions

Elisabetta BODO and Valentina BELLO

Laboratory of ElectroOptics

Department of Electrical, Computer and Biomedical Engineering

University of Pavia, Pavia, Italy

ECSA-8

The 8th International Electronic Conference on Sensors and Applications

01–15 NOVEMBER 2021 | ONLINE

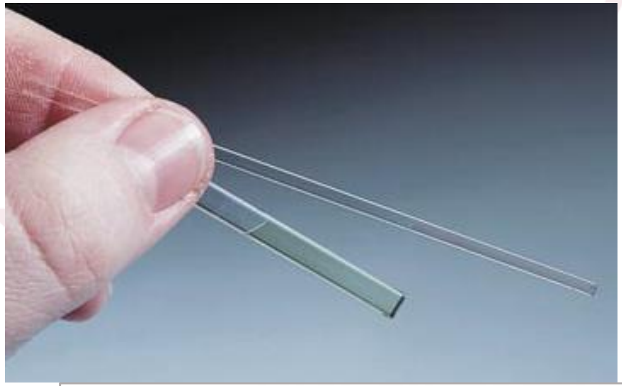
(Student Session)

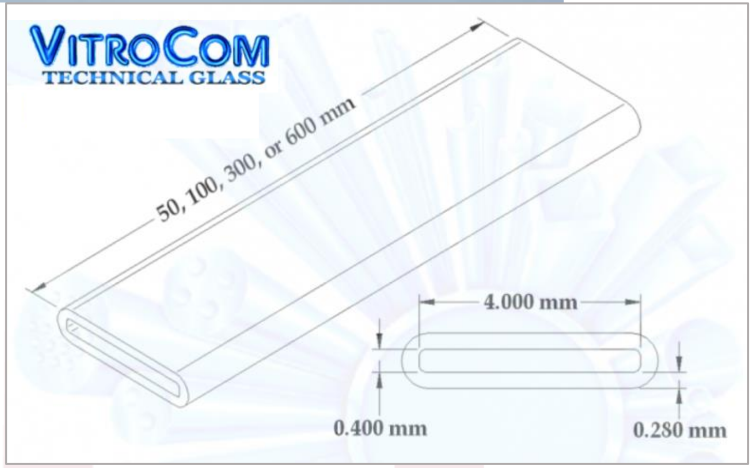
UNIVERSITÀ DI PAVIA

Goal of the work

DEVELOPMENT OF A MICRO-OPTO-FLUIDIC PLATFORM BASED ON RECTANGULAR GLASS MICRO-CAPILLARIES WITH INTEGRATED REFLECTORS FOR THE IDENTIFICATION OF FLUIDS EXPLOITING THEIR ABSORPTION PROPERTIES

ECSA-8





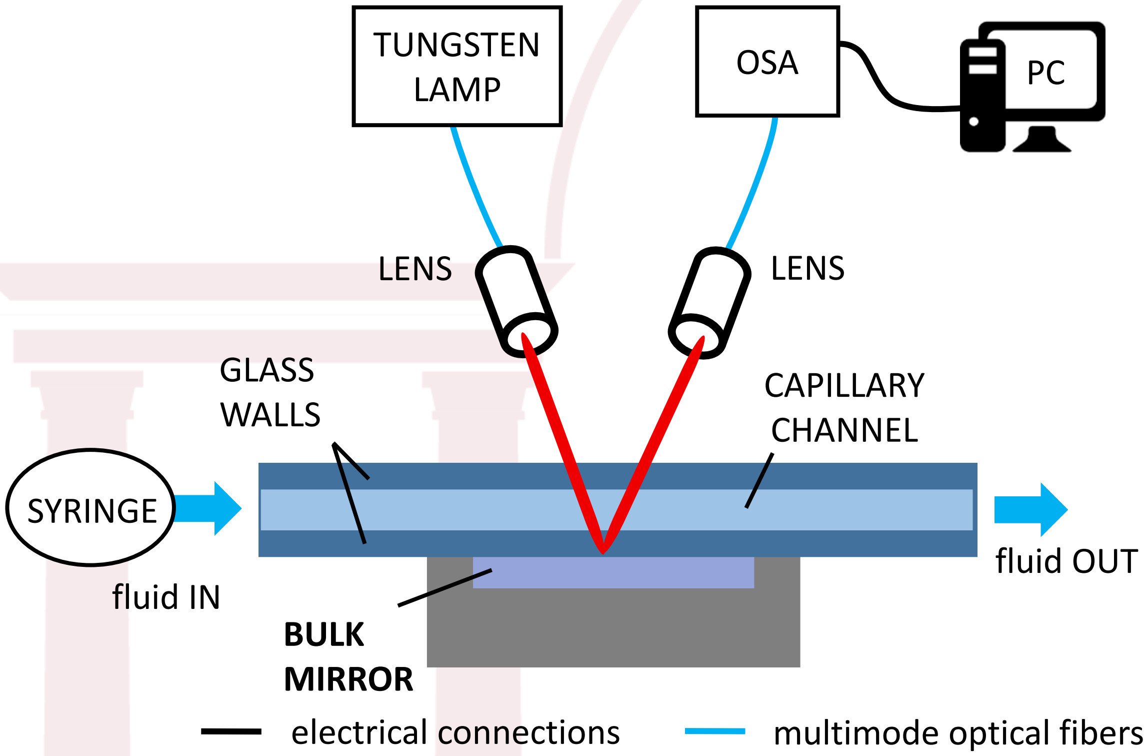
Features of rectangular glass micro-capillaries:

- Low-cost devices, commercially available in several formats
- Composition: borosilicate glass BK7. Refractive index: 1.5 @ 1550 nm
- Biocompatible material → suitable for analyses on biological fluids
- Analysis of ultra-low volumes (µL or nL) of fluids
- Suitable for contactless, remote and non-invasive optical investigation
- Reduction of light scattering typical with round section capillaries

UNIVERSITÀ DI PAVIA

Micro-opto-fluidic setup – Previous work

In a previous work, we exploited micro-capillaries laid onto a bulk mirror for testing the absorption features of pure fluid sample in the Near Infra-Red (NIR) wavelength region*

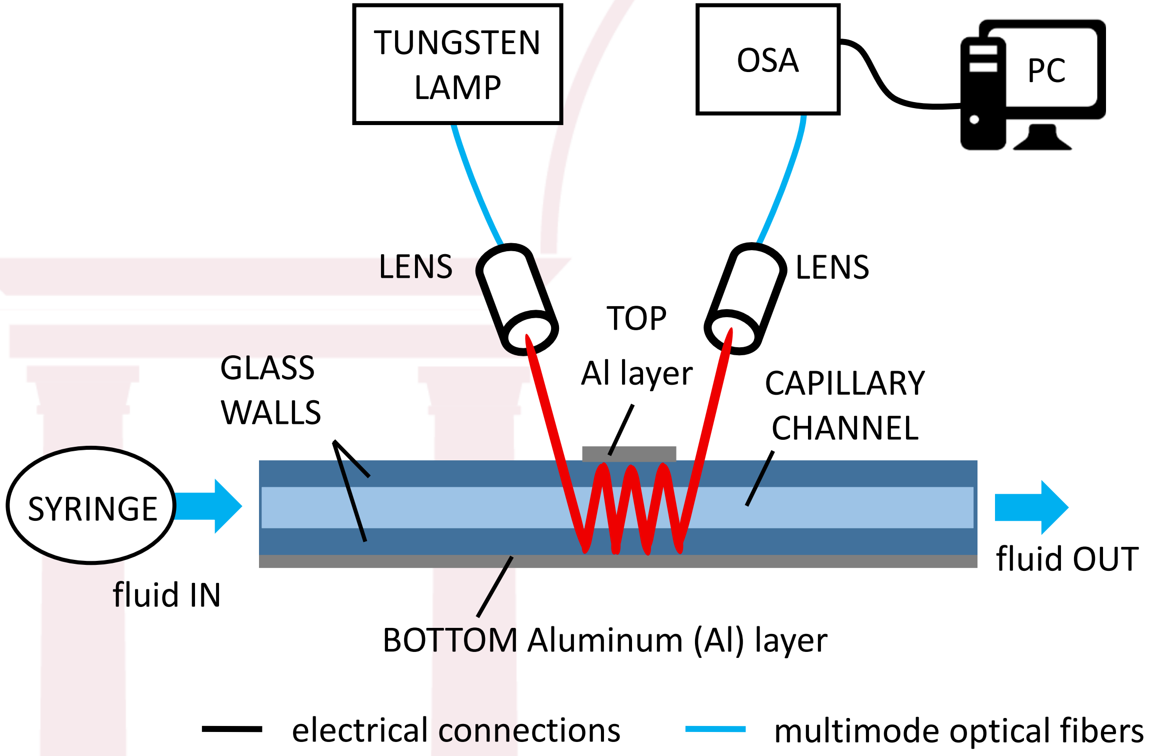


- Light crosses the capillary only twice
- The results were promising, **BUT** the structure was difficult to handle and not suitable for implementing sensing platform
- Sensitivity is limited

* Bello, V. and Bodo, E. **A NIR-spectroscopy-based approach for detection of fluids in rectangular glass micro-capillaries**. *Engineering Proceedings* **2020**, *2*, 43 DOI: 10.3390/ecsa-7-08250

Micro-opto-fluidic setup – This work

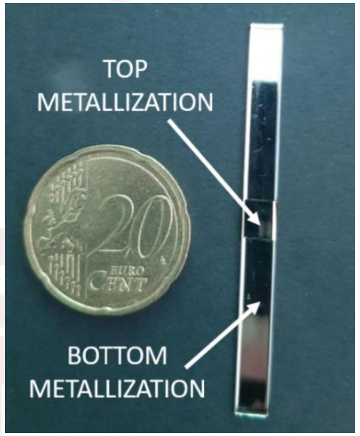
ECSA-8



Hence, in this work

We exploited a micro-capillary provided with **integrated external reflectors**

- Compact micro-device
- Simple and low-cost technology
- Selectable pathlength#
- Light can cross the capillary multiple times → sensitivity is enhanced
- Suitable for sensing purpose (pure substances and mixtures)



Bello, V., Bodo, E. and Merlo, S. **Near infrared absorption spectroscopy in microfluidic devices with selectable pathlength**, *IEEE/OSA Journal of Lightwave Technology* **2021**, *39*, 4193-4200 DOI: 10.1109/JLT.2020.3040488

Theoretical model

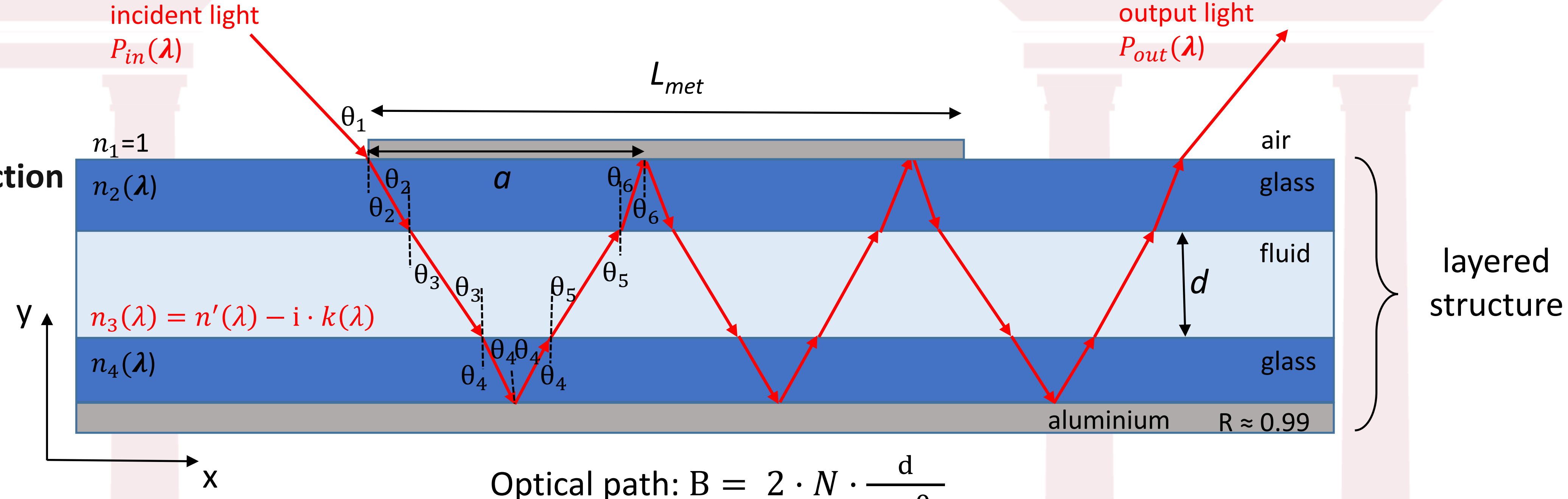
MATLAB

Beer-Lambert law → $T_{abs}(\lambda) = e^{-\alpha(\lambda)\cdot B}$ $\alpha(\lambda) = \frac{4\cdot\pi\cdot k(\lambda)}{\lambda}$

Snell law and Fresnel formulas → transmission coefficient for the power at each interface

$$T_{sample}(\lambda) = \frac{P_{out,sample}(\lambda)}{P_{in}(\lambda)}$$

Longitudinal section of the glass rectangular capillary



Optical path: $B = 2 \cdot N \cdot \frac{d}{\cos\theta_3}$

Number of bounces: $N = \frac{L_{met}}{a}$

In the scheme: $N = 3$

ECSA-8

UNIVERSITÀ DI PAVIA

Theoretical model – Results

With the multiple bounce configuration the sensitivity increases.
It allows to observe more details of the transmitted power spectra.

Law of additivity of absorbances

$$n_{3,mixture} = n_i \cdot p_i + n_j \cdot p_j$$

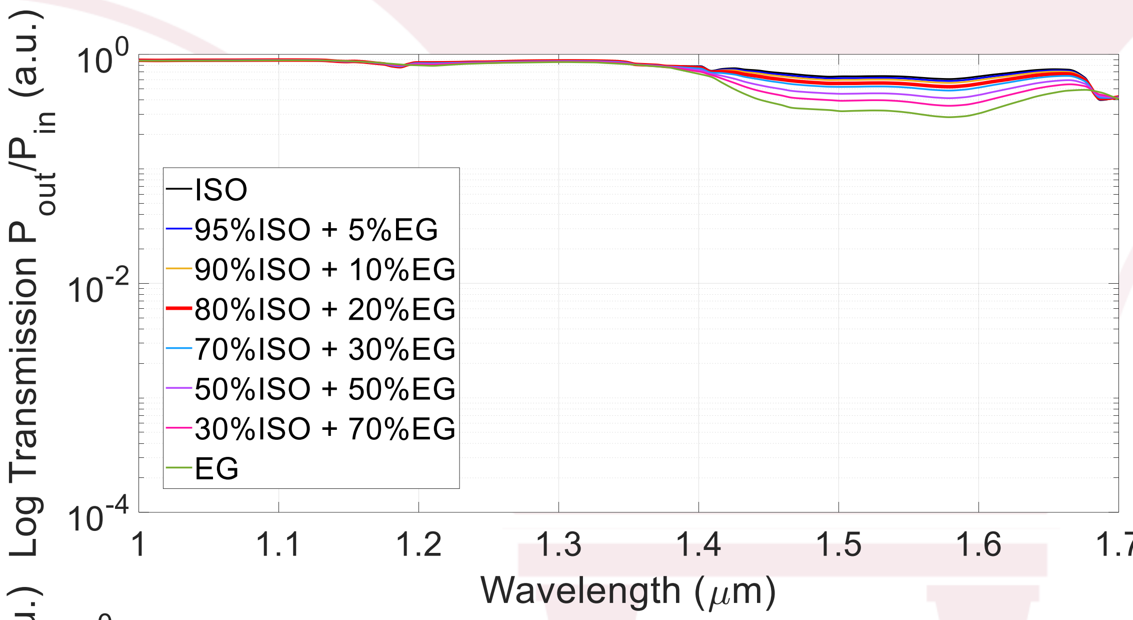
$n_{i,j}$ = real part of the refractive indices

$p_{i,j}$ = fractional volume concentrations

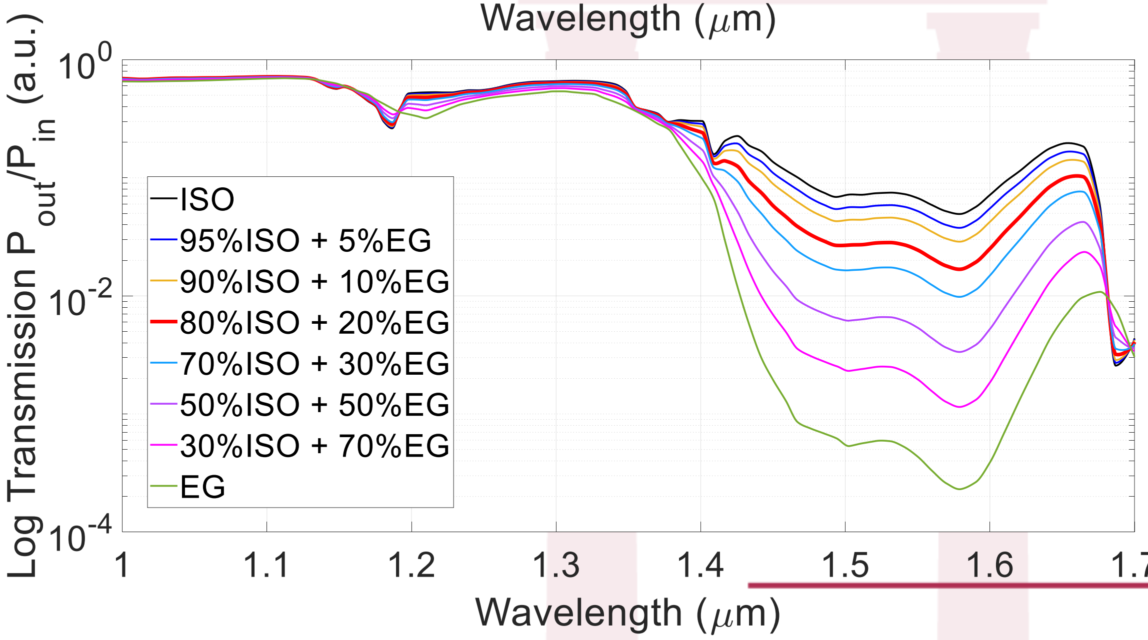
$A_{i,j}$ = absorbance of the fluids contained in the mixture

$$A_{mixture} = A_i \cdot p_i + A_j \cdot p_j$$

$$T_{mixture}(\lambda) = \frac{1}{10^{A_{mixture}(\lambda)}}$$



1 bounce



Multiple (7) bounces

NOTE: same y-axis for direct comparison

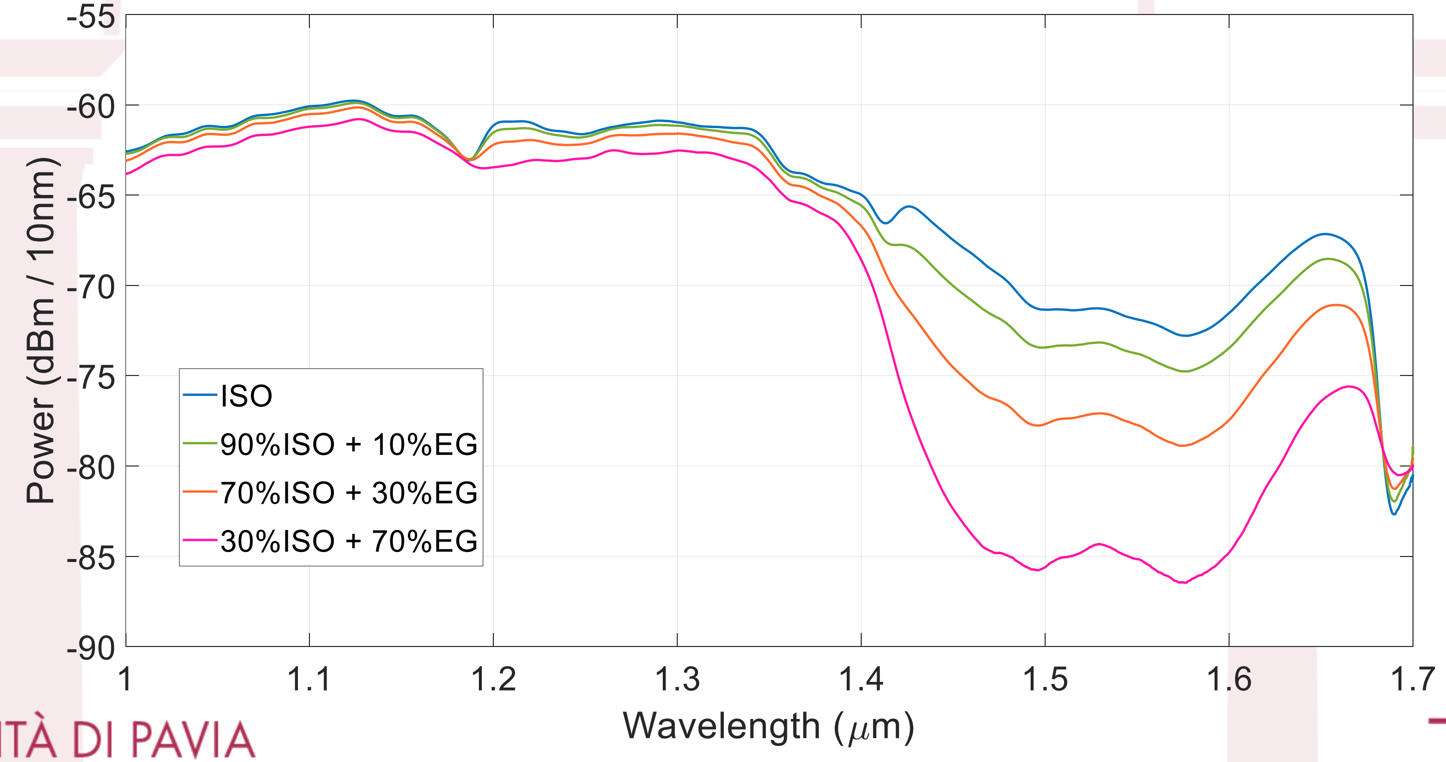
UNIVERSITÀ DI PAVIA

ECSA-8

Spectral analysis

Experimental measurements were carried out by filling the channel with **mixtures** of ethylene glycol (EG) and isopropanol (ISO) in different volume concentrations.

For increasing ethylene glycol concentration, the transmitted power between 1.4 µm and 1.6 µm decreases since ethylene glycol does exhibit two absorption bands around 1.46 µm and 1.57 µm



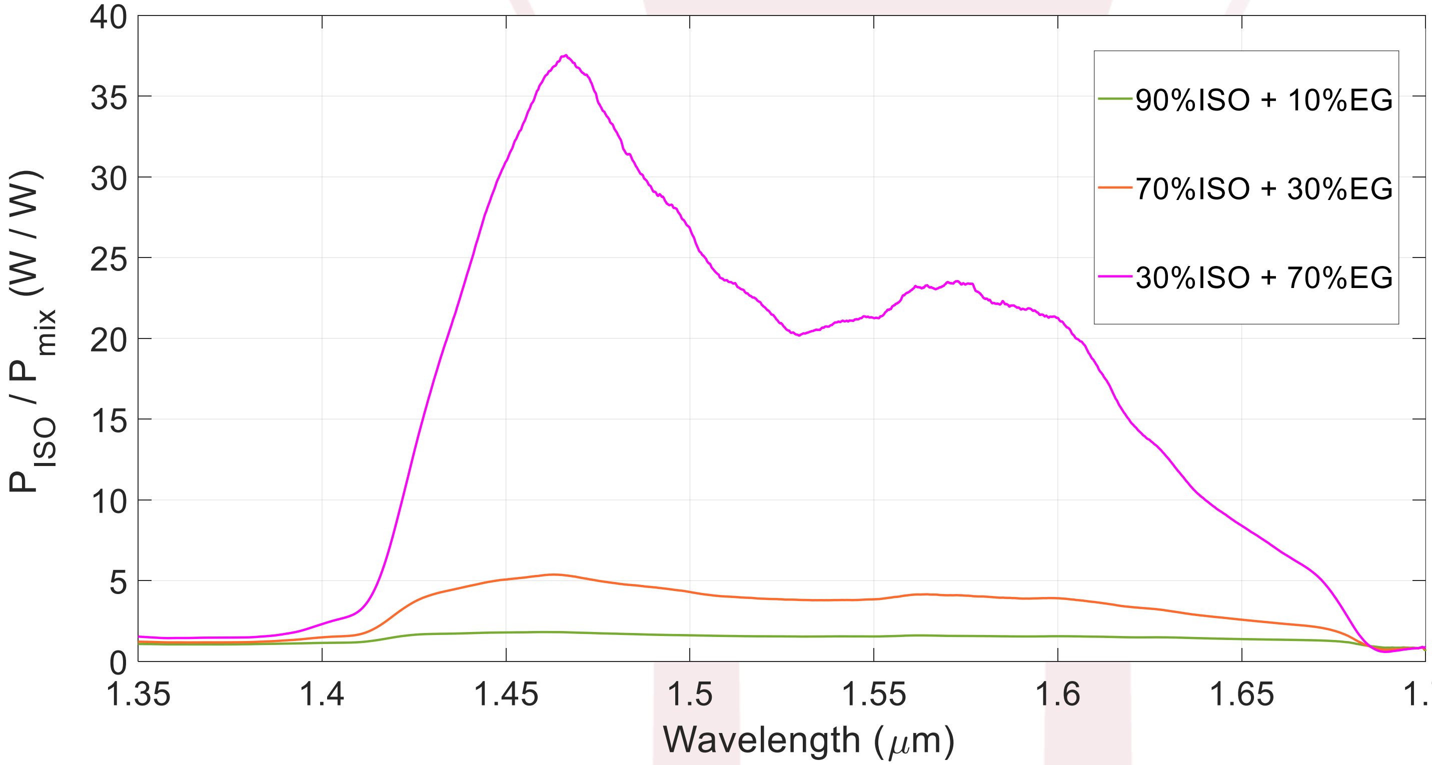
Implementation of the optical sensor based on amplitude detection

Extraction of
ethylene glycol content:

$$\frac{P_{ISO}}{P_{mix}}$$

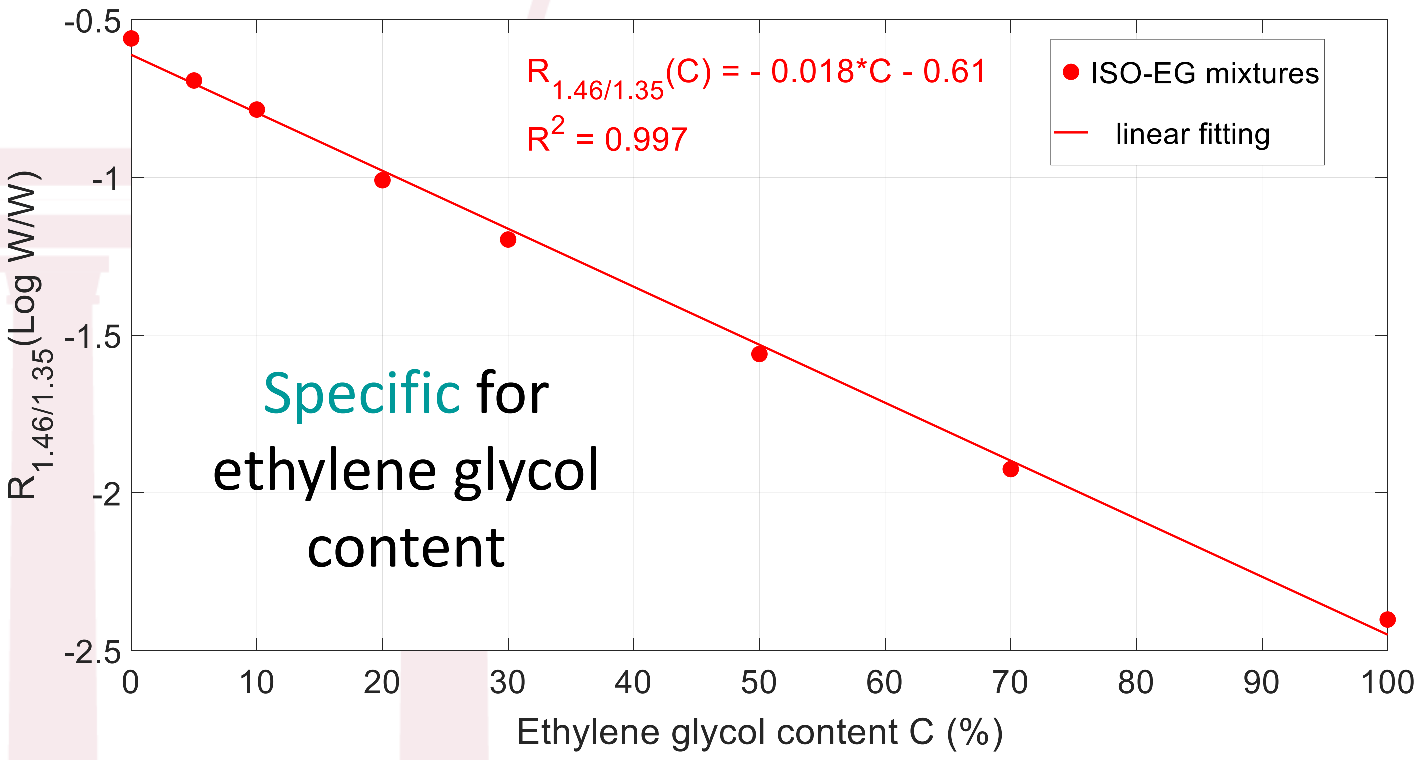
Reference fluid

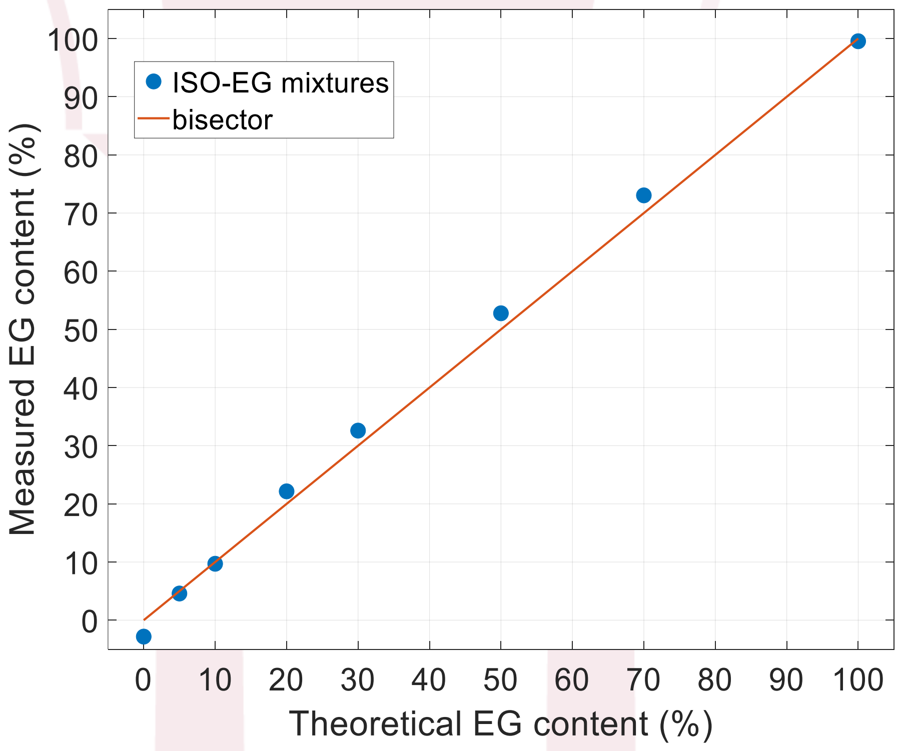
Ethylene glycol-isopropanol mixture



Implementation of the optical sensor based on amplitude detection

Responsivity $R_{1.46/1.35} = Log\left(\frac{P_{out}(1.46\ \mu m)}{P_{out}(1.35\ \mu m)}\right)$ → experimental calibration curve





Conclusions

In this work, we have reported a smart and compact **micro-opto-fluidic platform** based on **rectangular** glass **micro-capillaries** for detection of fluids based on their **spectroscopic features**.

The micro-capillary is provided with **integrated reflectors** and light emitted by a **tungsten lamp** crosses the channel containing the sample multiple times.

Mixtures of isopropanol and ethylene glycol at different concentrations were **distinguished** thanks to their absorption profiles.

We have identified the two-wavelength ratio as **responsivity parameter** of the sensor: the **specificity** for ethylene glycol content detection has been verified.


UNIVERSITÀ
DI PAVIA
THANK YOU FOR
YOUR KIND ATTENTION!
The authors wish to thank
Prof. SABINA MERLO
for her guidance and fruitful suggestions.
Pavia, Lombardy, Italy