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Optical glass fiber tips for photonic micro-sensor systems

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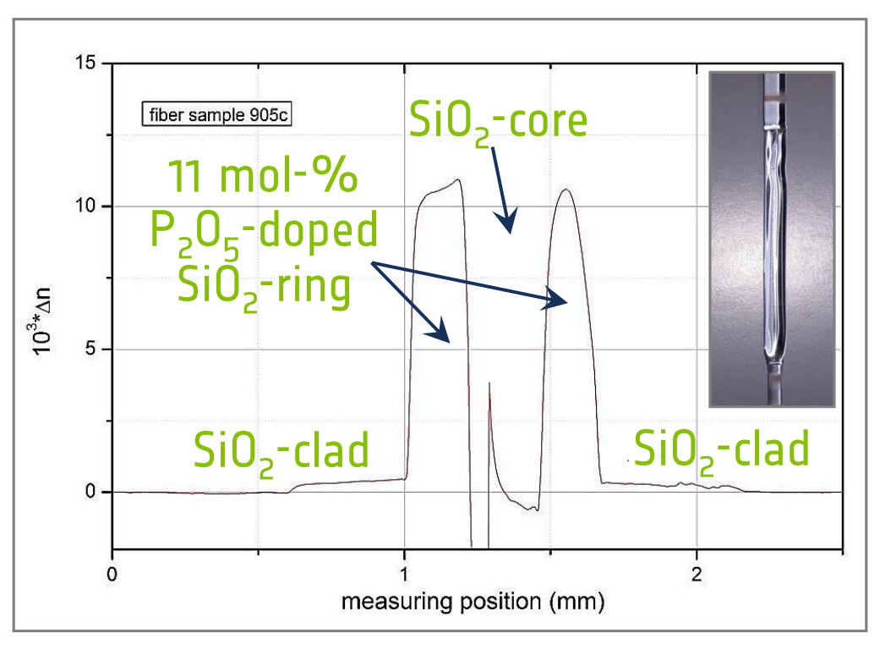
Introduction

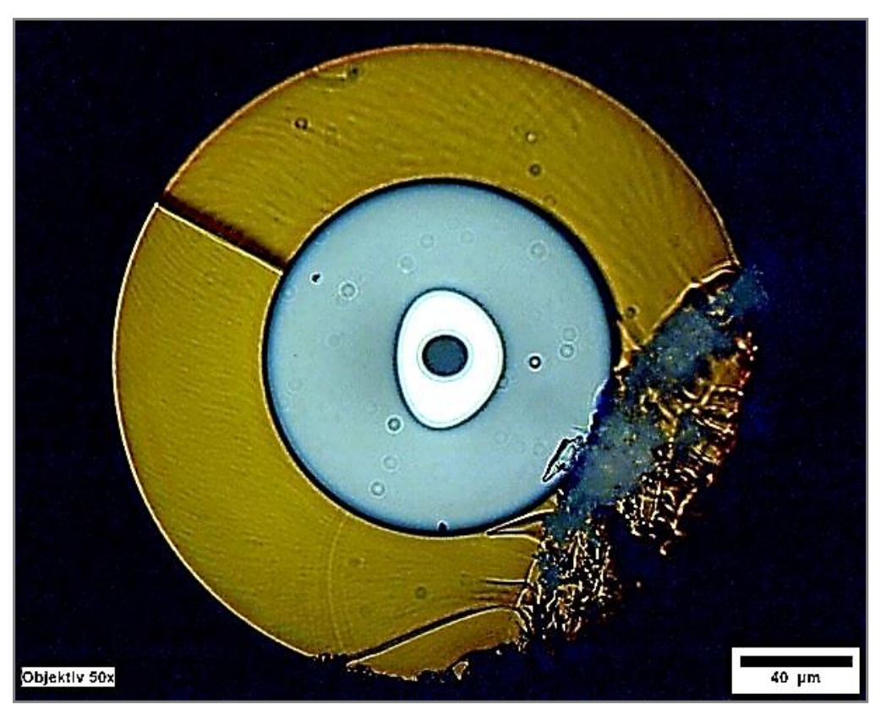
The application potential of sub-structured fiber tips in optical sensor technology and photonic microsystems is high. The miniaturization of sensor systems and the technical implementation using optical fibers allow novel sensor designs with improved properties and extended functionality. The post-processing of specifically doped or undoped silica fibers by chemical etching or focused ion beam etching (FIB) are promising methods in order to form complex photonic microstructures at the end or on the inside of glass fibers in the form of tips or cavities. The profiling of fiber tips was achieved through different etching rates that depend on the type of treatment and the doping characteristic of the fiber. Based on etch-structured microcavities with embedded fiber tips high-sensitivity Fabry-Perot temperature sensors were prepared and subjected to temperature variations both in air and water. An ultra-high sensitive strain sensor is proposed, too. The sensing head, based on the post-processing of a fiber Bragg grating, is used to perform passive strain measurements. Both wavelength and full width half maximum dependences with the applied strain. Furthermore, a novel fluid sensor concept consisting of a 5-hole microstructured fiber, FIB-inscribed with microfluidic canals is introduced.

Microcavity tip temperature sensor

Preform and fiber preparation [1]



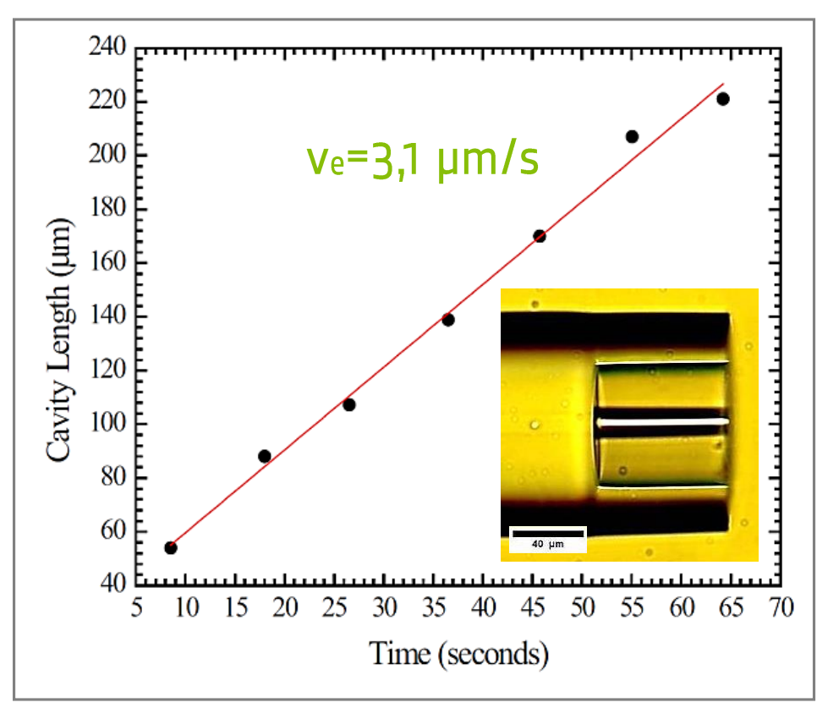
Refractive index profile and doping characteristics of a P_2O_5-doped MCVD-preform.
Ø=10 mm
l=165 mm



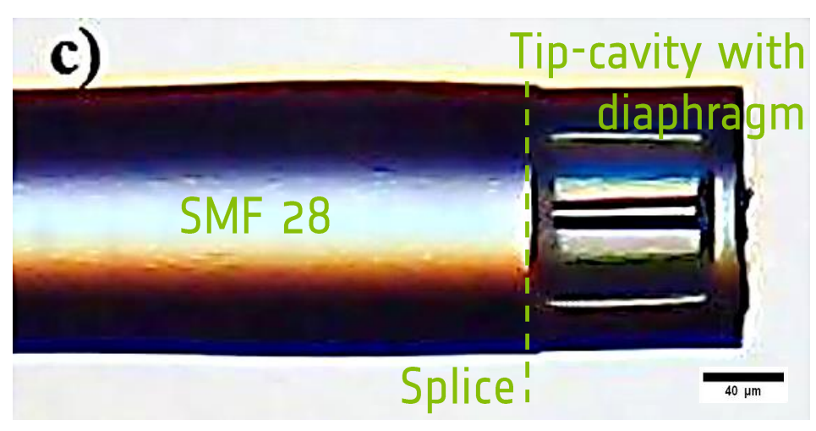
Glass fiber with a large SiO_2-core surrounded by a P_2O_5-doped etching layer.
$Ø_{coat}$=230 µm
$Ø_{fiber}$=125 µm
$Ø_{core}$=18 µm
$Ø_{ring}$=45 µm

Fiber tip formation [2]

Etching treatment:
ultrasonic wet etching in 40% HF (l) ⇒ v_e=11 mm/h

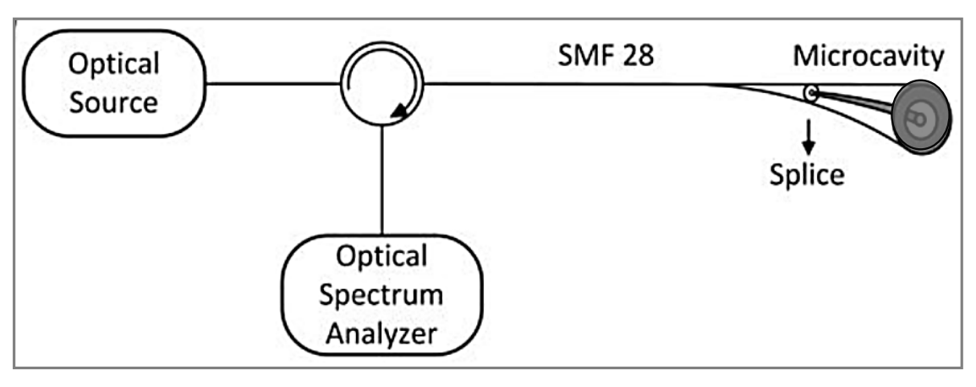


Linear cavity formation.

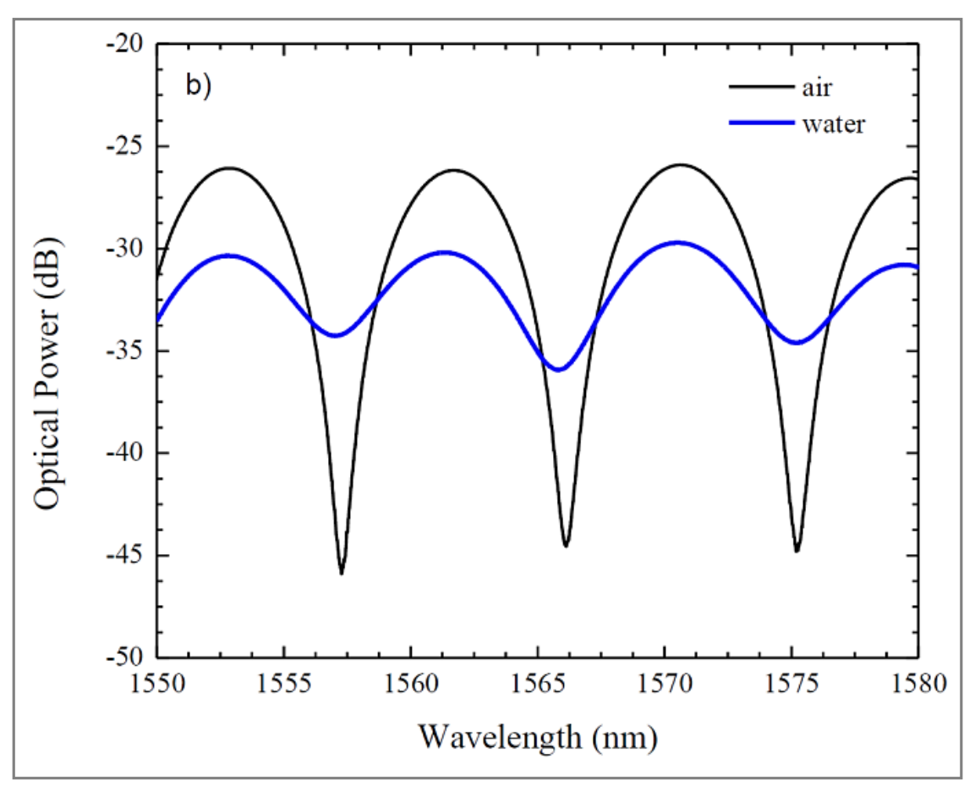


Micro-cavity sensor head.

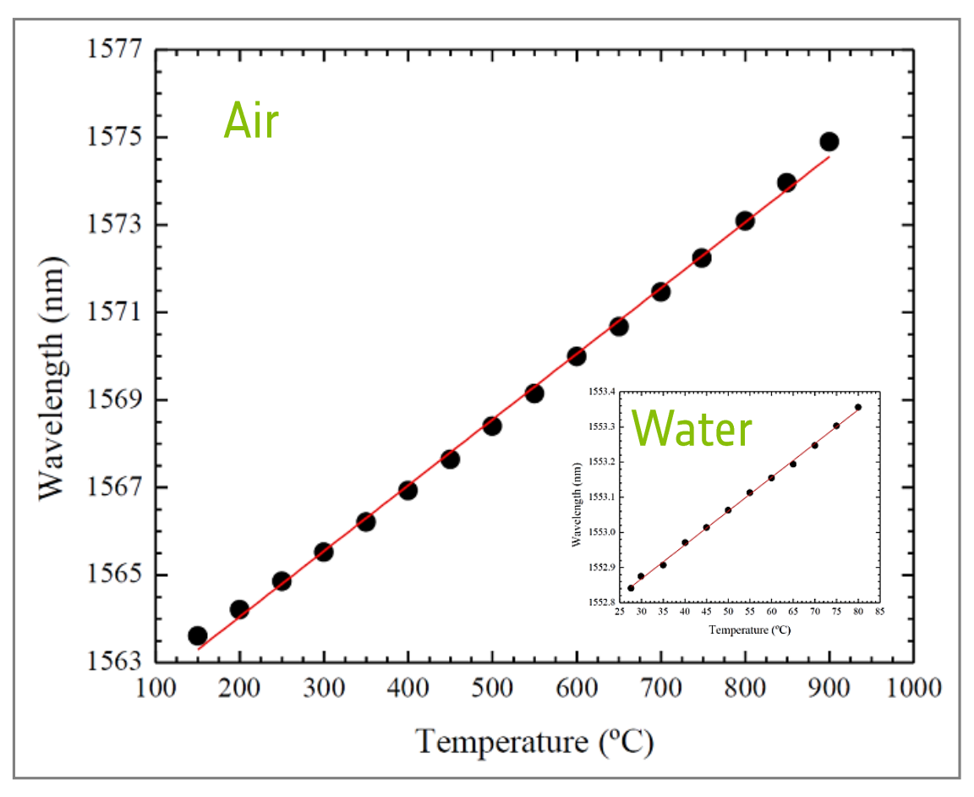
Sensor experiments [3]



Temperature measuring setup.
Fabry-Pērot cavity:
l=80 µm, $Ø_{core}$=8 µm, l_{dia}=10 µm



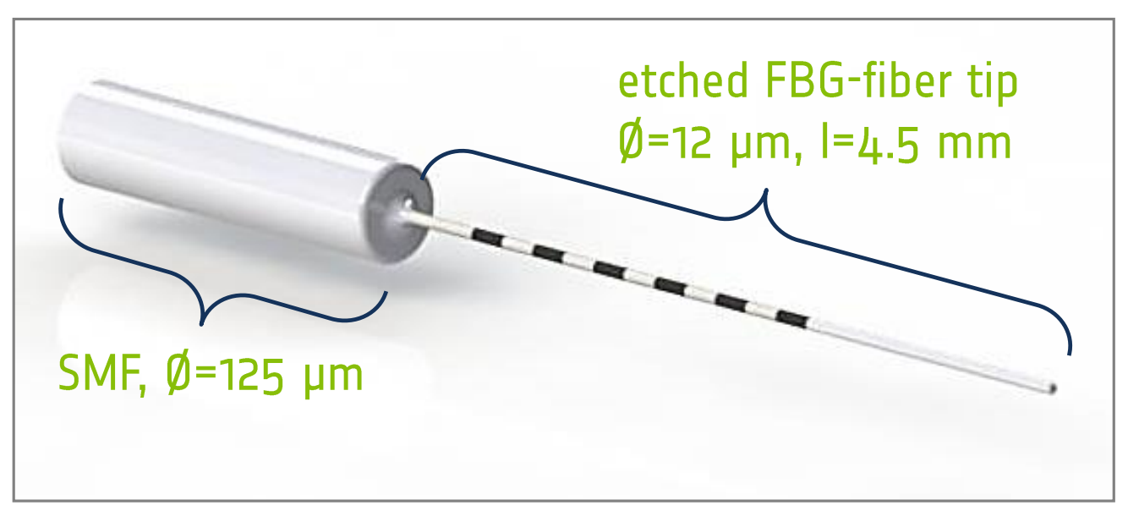
Sensing head reflection spectra
⇒ two-wave FP interferometer.



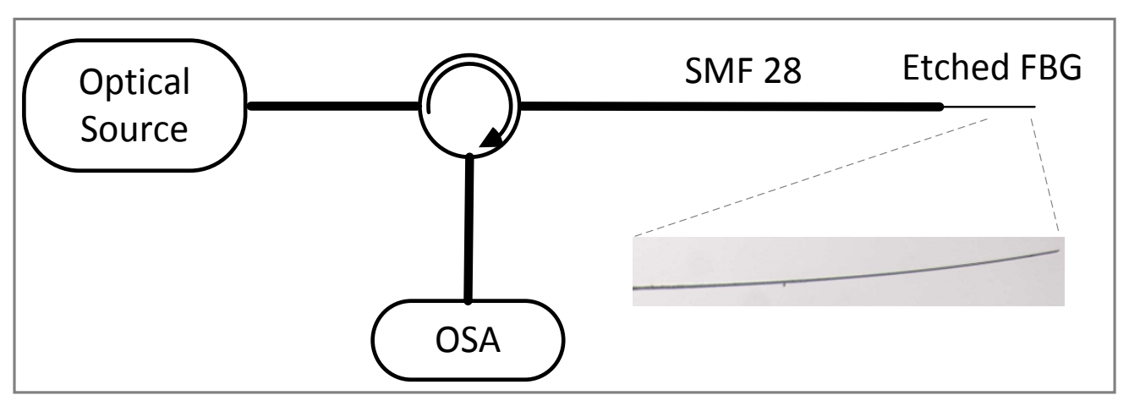
Linear temperature sensitivity:
15 pm/K (air), 10 pm/K (water)

A tip temperature sensor based on a Fabry-Pērot (FP) microcavity was developed by HF-etching of a double-clad fiber. The fiber presented an inner cladding composed by phosphorous-doped silica, which showed a higher refractive index than the pure silica core. During etching the inner cladding was removed and the fiber started to guide light in the suspended silica core, until it reaches a diaphragm. A FP-microcavity was formed and the sensing head showed a linear temperature response both in air and water over a wide range of temperature.

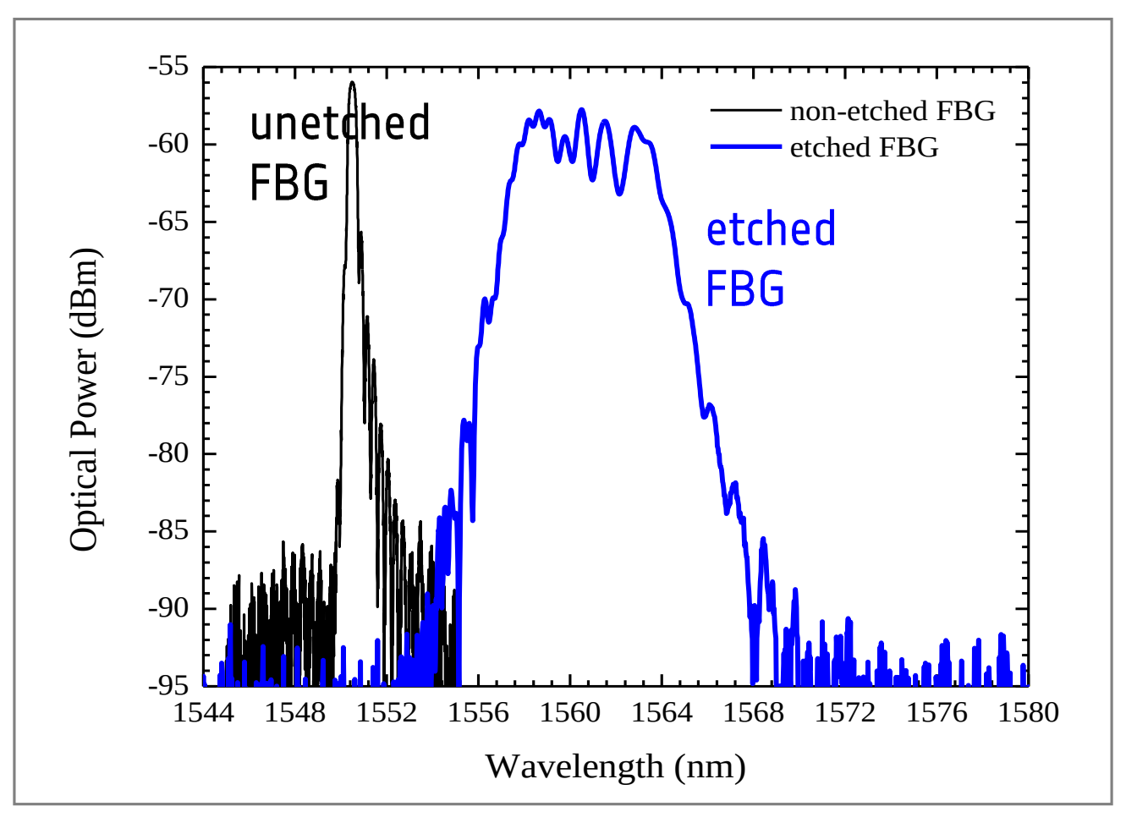
Ultra-high sensitive strain sensor



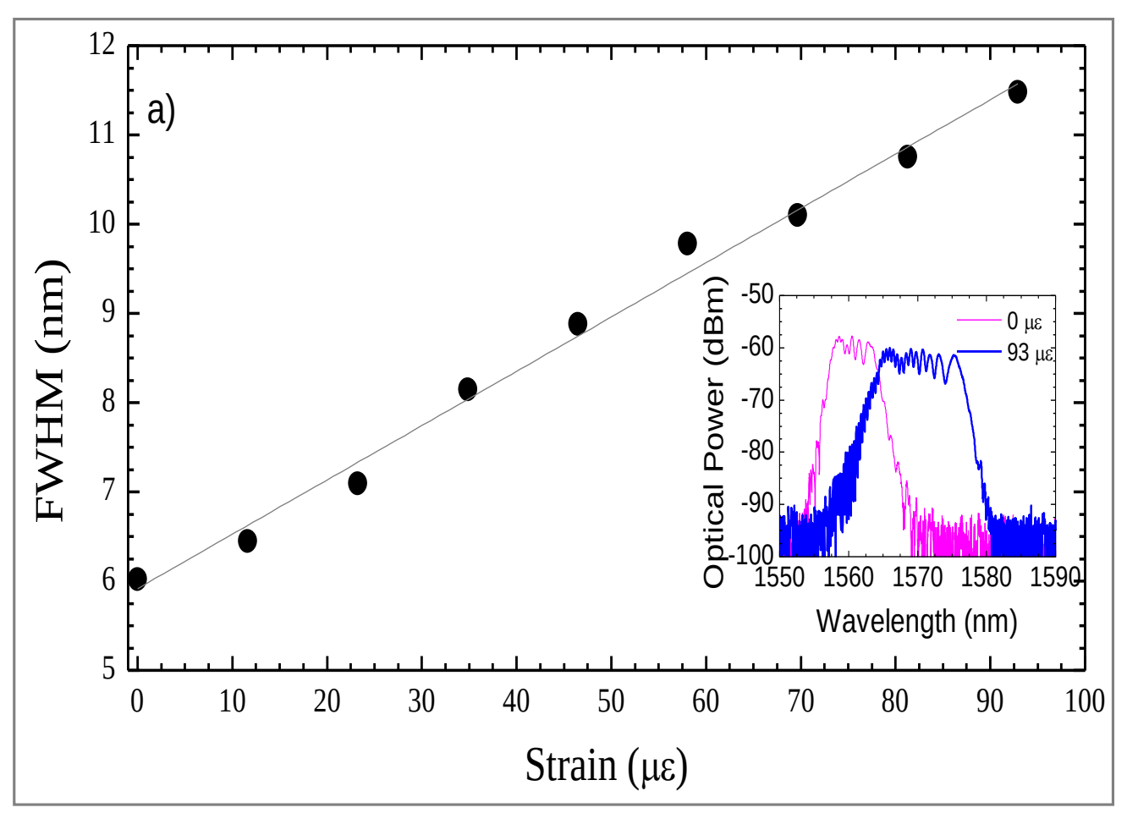
Sensor tip after FBG inscription, splicing to SMF and HF-etching.



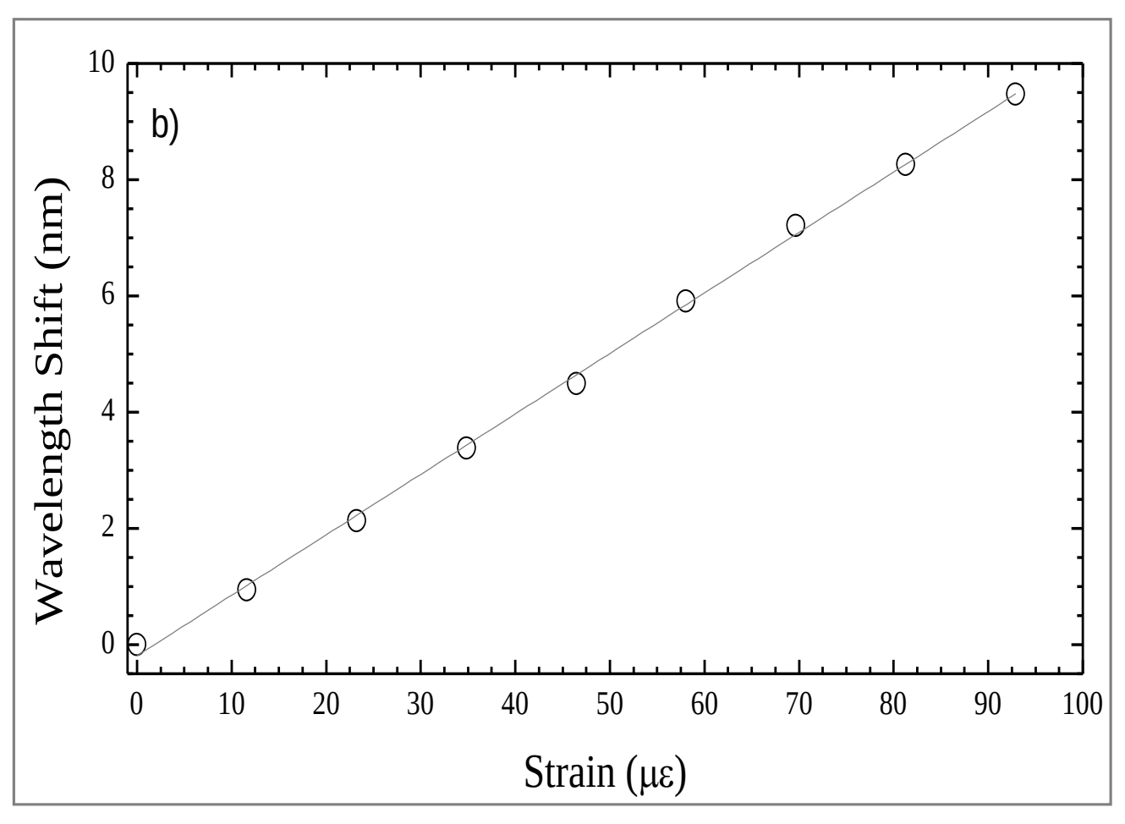
Strain measuring setup.
Strain application by translation stage.



Spectra of unetched and etched FBGs
⇒ Bragg-λ shift and FWHM broadening.



FWHM broadening with applied strain
⇒ linear sensitivity of 62 pm/$\mu\varepsilon$.



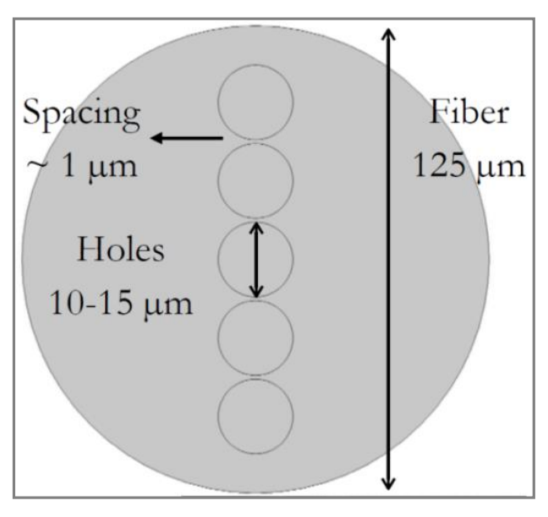
Bragg-λ shift with applied strain
⇒ linear sensitivity of 104 pm/$\mu\varepsilon$.

Highly sensitive strain sensors based on etch-processed fiber Bragg gratings (FBGs) were prepared [4]. A 3 mm long FBG was written in a photosensitive fiber and spliced to a single mode fiber (SMF). The FBG fiber section was etched in 40% HF (l) to form a tip-shaped sensor head. In strain measurements both a linear Bragg peak broadening (FWHM) and wavelength shift with high sensitivity were observed. Depending on temperature only the Bragg wavelength shifted ⇒ simultaneous strain and temperature measurements are possible.

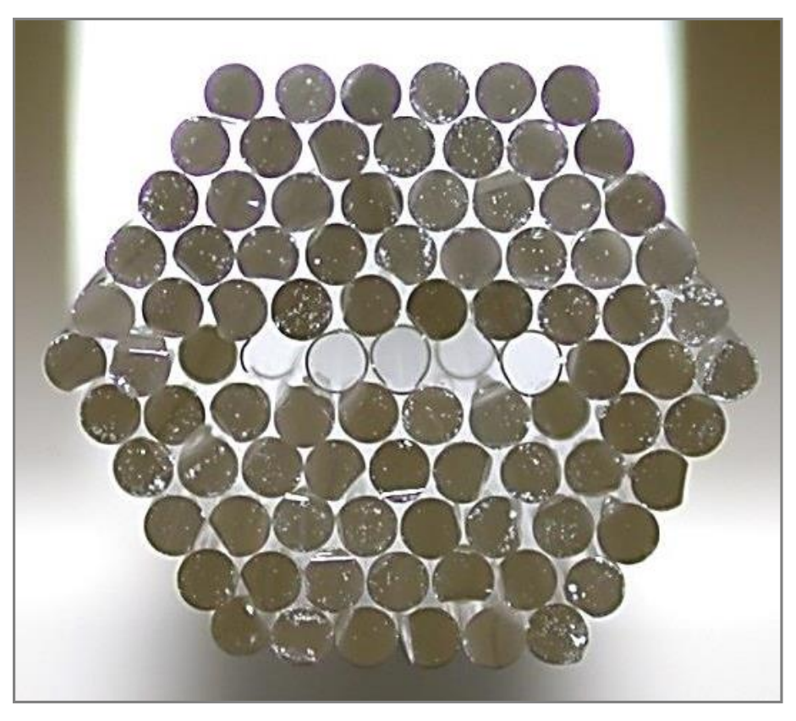
MOF fluid sensor

Fiber preparation by stack-and-draw technique

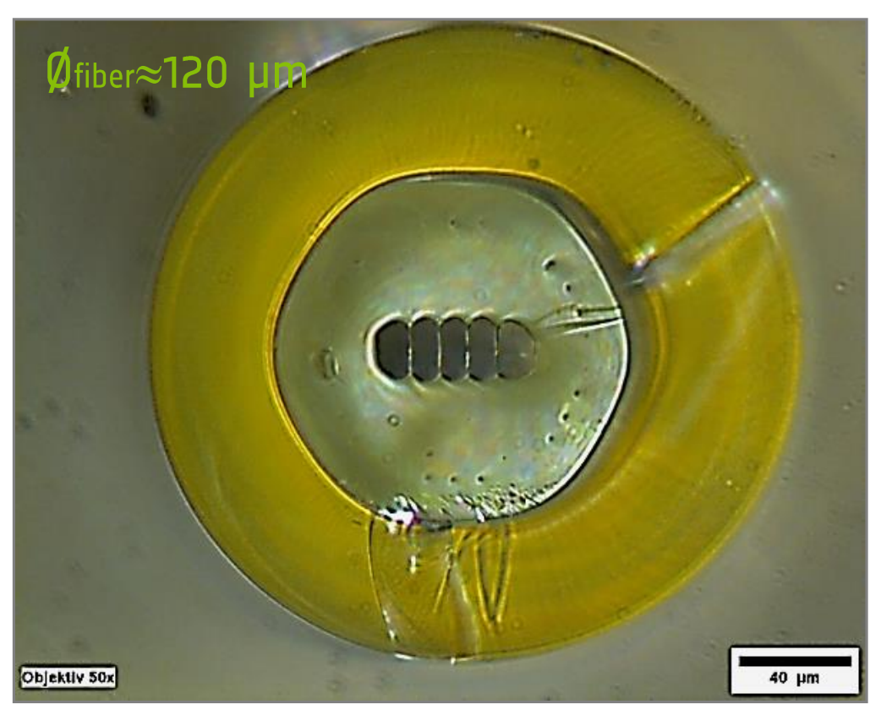
- *Objective: MOF for fluid sensing*
  - *Interaction through guided light propagation*
  - *Refractive index sensing*
  - *Interferometry*



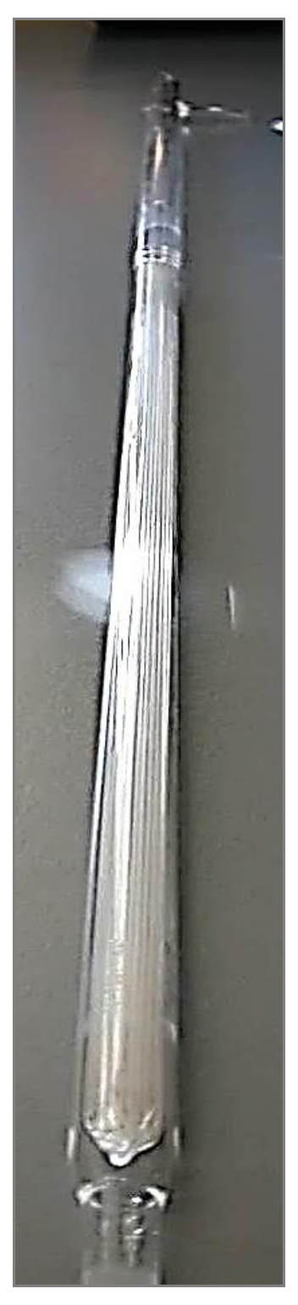
Proposal of a 5-hole fiber (MOF) to build an in-line fluid sensing element.



Arranging of glass rods and capillaries to preform bundle.

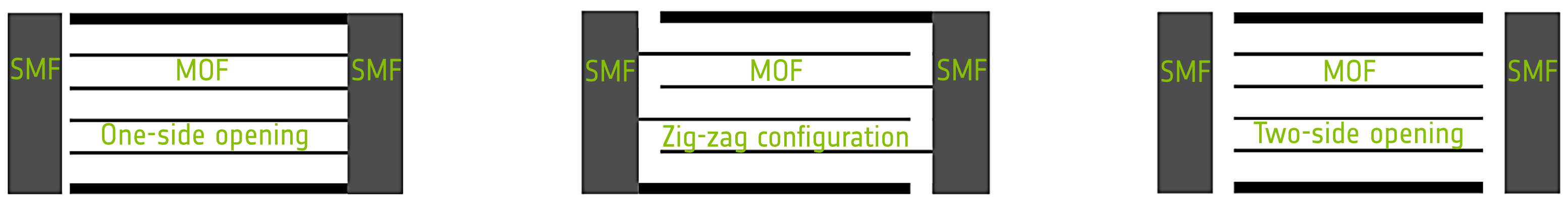


Cross section of a drawn 5-hole fiber. Fiber is coated with a polymer layer.

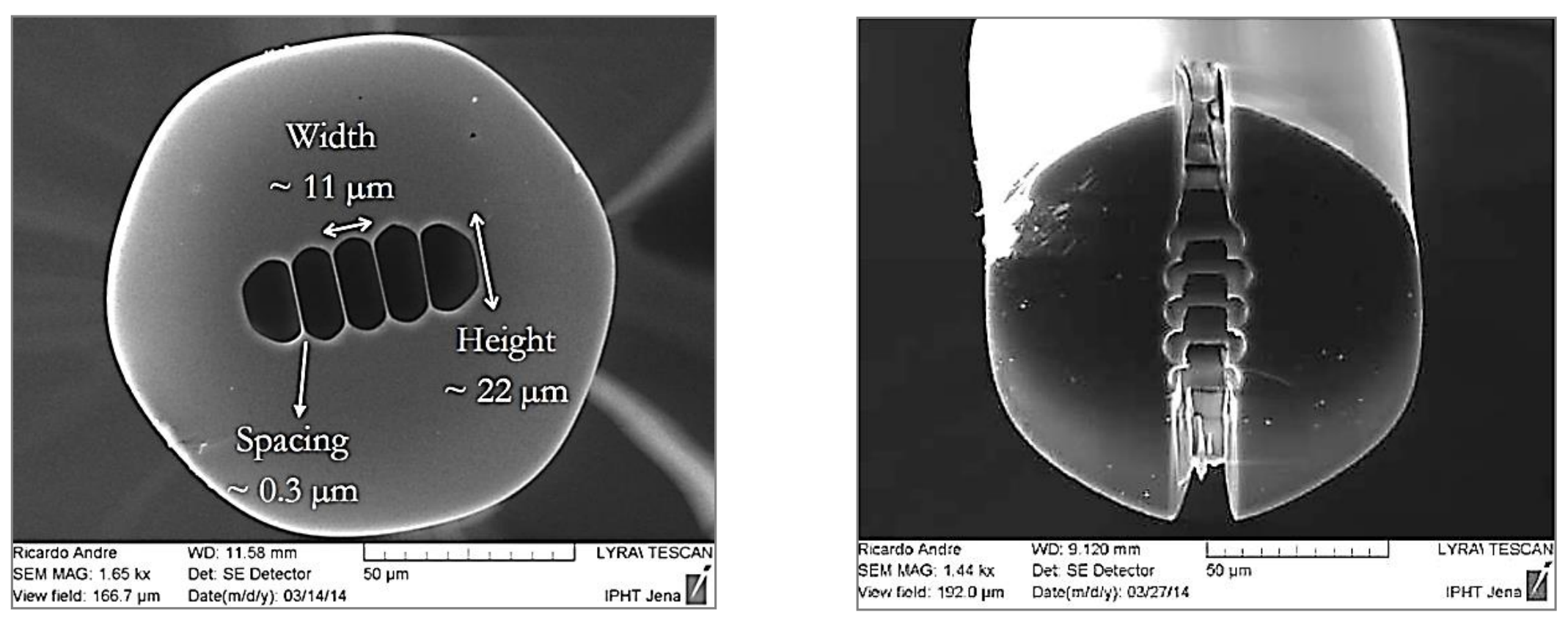


Overcladded preform.

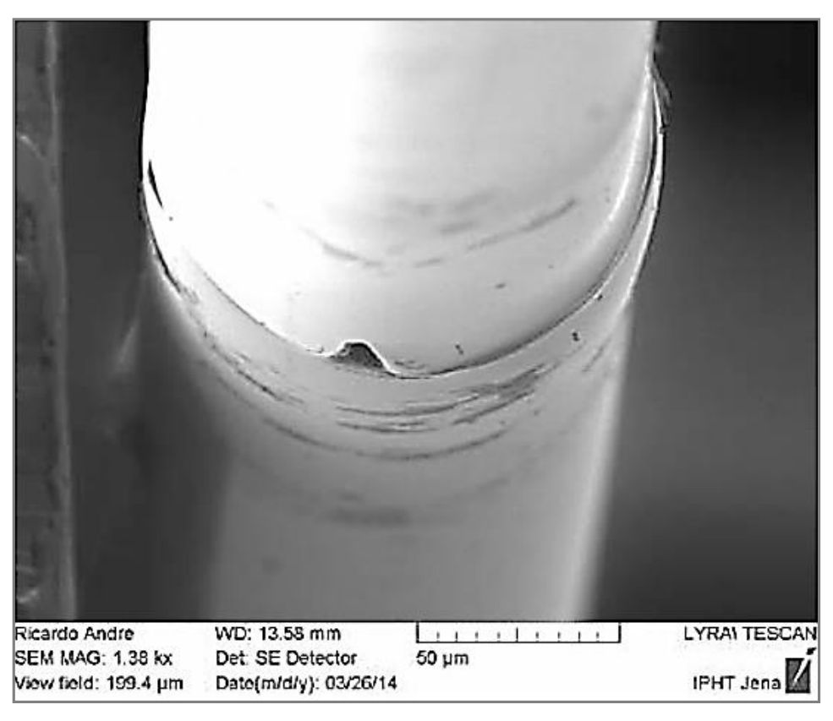
FIB inscription of microfluidic canals



Possible longitudinal profiles of an in-line MOF sensing element, fusion spliced to SMFs. For flow of liquid samples microfluidic connection canals inside and to the exterior must be created.



2 steps FIB process: 1.) outer canal milling with fiber-FIB parallel alignment; 2.) inner wall milling with small fiber-FIB angle.



Intact microfluidic canals after SMF-MOF splicing.

The proposed in-line fluid sensor consists of a post-processed 5-hole microstructured fiber (MOF) segment, fusion-spliced to single-mode fibers (SMFs). A macrostructured preform was stacked by arranging of glass rods and capillaries in a jacket tube and drawn to the 5-hole fiber. To allow the flow of liquids through the hole-structure microfluidic connection canals were created using the focused ion beam etching (FIB). Filling experiments with liquids were successful – in future work, the capability of the sensing head for fluid sensing will investigate.

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