Two-photon 3D printed Fabry-Perot cavity combined with a femtosecond fiber Bragg grating on a single fiber for simultaneous sensing of pressure and temperature at high temperatures

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Abstract

The advent of additive manufacturing particularly **Two-Photon Polymerization (2PP)** has enabled new ways of creating optical sensors by **printing directly on the fiber.** This technique has opened new possibilities in the architecture of optical fiber sensors though most of them rely on the use of polymer based resin as the material of choice which cannot withstand high temperature.

In this abstract we worked on:

- **Silica based printed sensors** through the use of Solmer resin which is resistant to **high temperature**, similarly to the work of El Aadad Halima *and al. (Mater. Today Adv., 2024)*.
- Combining different sensor manufacturing techniques by using high temperature resistant (>1000°C) **Fiber Bragg Grating (FBG)** (inscribed with point-by-point (PbP) technique and a fs-laser, for more information see poster by M. Sosa-Marti Th-6.7) and **2PP printing of a Fabry Perot (FP) cavity on the same optical fiber.**

This results in the creation of a **combined pressure and temperature sensor** which can withstand high temperatures **up to 600°C.**

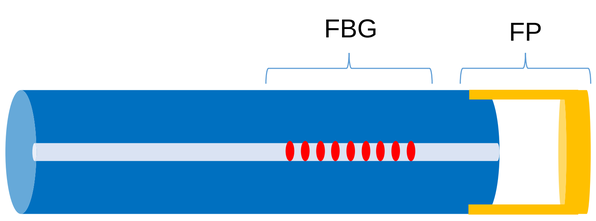
3D printing process on fiber's tip

PbP inscription of FBG → Fiber is cleaved near the FBG → 3D modeling of the FP cavity and slicing → 3D printing on the fiber's tip → Rinsing → Debinding and sintering at 800°C → Characterizations of the combined FBG-FP sensor

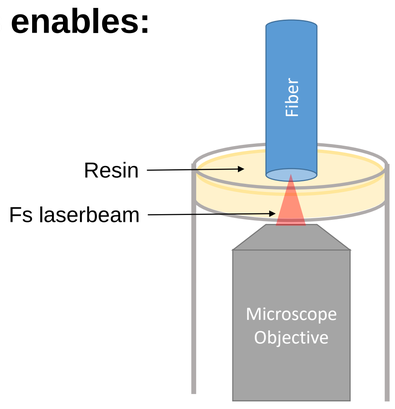
Manufacturing process of a dual FBG and silica based FP sensor

Two-photon polymerization printing process enables:

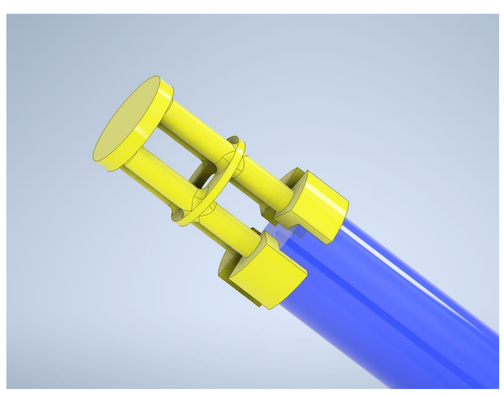
- to print details down to 100 nm
- the use of lab-made resins: Solmer
- the creation of novel sensor architectures
- to print directly on the optical fiber end



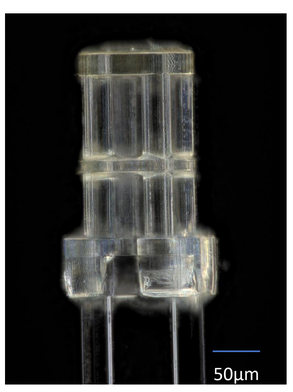
Schematic representation of the sensor



Schematic of the 3D printing process on the UpNano NanoOne 250



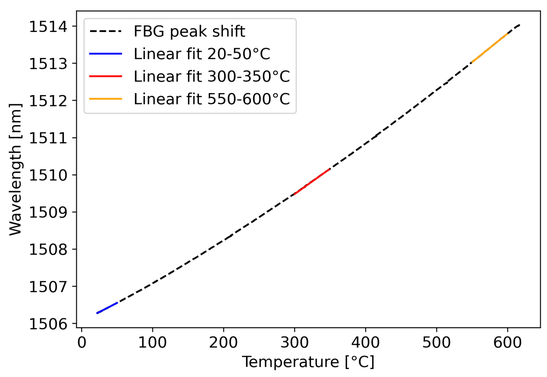
3D Model

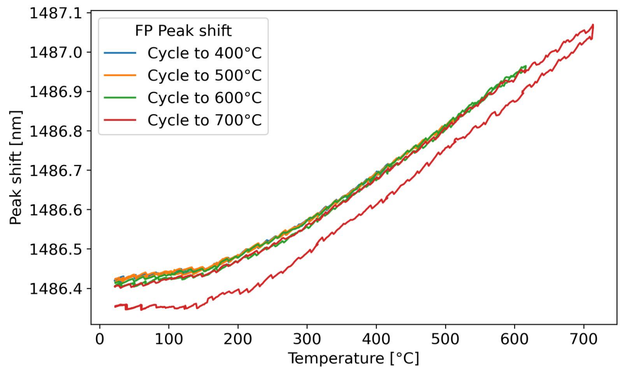


3D printed FP on the fiber end

3D printed FP on the fiber's tip after debinding and sintering

Temperature sensitivity

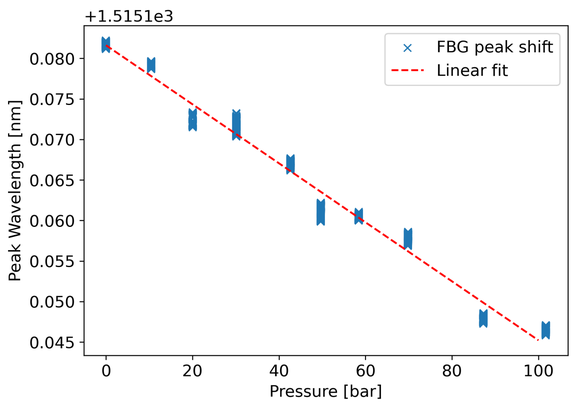


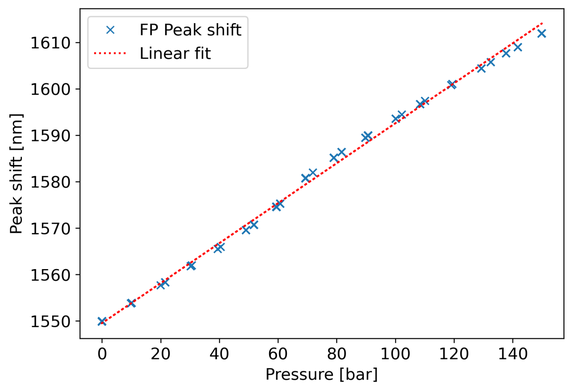


- Heating cycles from 400°C to 700°C in steps of 100°C
- A hysteresis appears when heating above 600°C for the FP
- High sensitivity of the FBG to temperature
- Low sensitivity of the FP cavity to temperature
- For precise temperature measurements a polynomial law should be used A. Lerner *et al. (Opt. Las. Tech., 2024)*

Temperature range	FBG sensitivity [pm/°C]	FP sensitivity [pm/°C]
20°C to 50°C	9.8	0.15
300°C to 350°C	13.7	1.29
550°C to 650°C	15.4	1.37

Pressure sensitivity

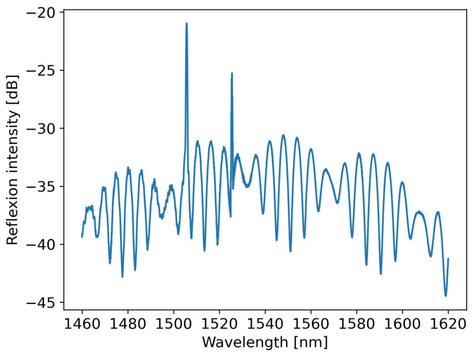




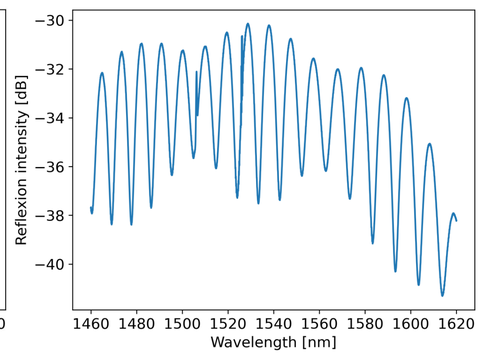
- Linear response to pressure from the FBG and the FP
- High sensitivity from the FP cavity to pressure changes (430 pm/bar)
- Low sensitivity from the FBG to pressure changes (-0,36 pm/bar)
- 3 orders of magnitude difference in terms of sensitivity

Conclusions

- We were able to combine two sensor manufacturing methods on the same fiber: PbP FBG inscription and 2PP printing
- The partial thermal erasure of the micro-void FBG seems excessive compared to our own results on this kind of grating. Studies are ongoing to understand this phenomenon
- This enabled us to create a combined sensor exhibiting properties allowing for simultaneous measurement of pressure and temperature:
  - FBG for temperature sensing since it has low pressure sensitivity
  - FP for pressure sensing since it has a low temperature sensitivity
- The use of a Solmer based resin resulting in a silica based nano-printed object allows this sensor to be used within high temperature environment up to 600°C



Signal before debinding and sintering



Signal after debinding and sintering

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