Fiber optic sensors based on strongly coupled multicore fiber

Axel Schülzgen,[1,*] Amy Van Newkirk,[1] Jose Enrique Antonio-Lopez,[1] Rodrigo Amezcua Correa,[1] Joseba Zubia,[2] and Joel Villatoro[2,3]

[1]*CREOL, College of Optics and Photonics, University of Central Florida, Orlando, FL 32816, USA*
[2]*Department of Communications Engineering, Escuela de Ingeniería de Bilbao, University of the Basque Country, E-48013 Bilbao, Spain*
[3]*Fundación Centro de Tecnologías Aeronáuticas (CTA), Miñano, Spain*
[*]*Corresponding author: axel@creol.ucf.edu*

Abstract: We report on the use of a multi-core fiber (MCF) for accurate sensing of temperature, strain, bending, and vibrations in real-world environments and under harsh conditions including temperatures up to 1000 ºC.

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1. Introduction

Optical fiber sensing is a viable technology to monitor important physical parameter in many application fields. Such a sensor monitors changes in phase, intensity, or wavelength of the guided light as the fiber is subjected to different environments. Fiber optic sensors can be divided into two main categories, distributed and discrete (or point) sensors. The former require sophisticated interrogation systems and are suitable to monitor environments over long distances, on the order of tens of kilometers [1,2]. Point sensors are simpler and are used in applications that require the monitoring at specific locations [3,4].

Amongst the point sensors, fiber Bragg gratings (FBGs) are most common and, based on FBGs high performance point monitoring sensors have been developed [5-7]. For example, FBG sensors are widely applied to monitor the integrity and health of civil infrastructures [8,9]. Some drawbacks of FBG strain sensors include their degradation at temperatures above a few hundred degrees Celsius the need for interrogation systems with high spectral resolution. To overcome these limitations many research groups around the world are placing emphasis on the use of specialty optical fibers (SOFs) including photonic crystal fibers and multi-core fibers with isolated cores, to name but a few. However, the lack of SOF components and the incompatibility of most SOFs with widely available and cost effective telecommunications fibers make SOF sensors often complex and impractical. perhaps for this reason, the majority of SOF based sensors have been tested only in conventional laboratory environments and most of their potential remains untouched.

In this presentation, we report on an approach to build compact, simple and accurate fiber optic point sensors based on particular SOFs, namely multi-core fibers (MCFs) with strongly coupled cores. Our MCF based sensor designs are optimized for operation at optical communication wavelengths providing compatibility with readily available fibers and fiber optic components. The sensing principle is based on the excitation and interference of supermodes inside MCF segments. To fabricate our interferometric MCF point sensors a short segment of MCF is inserted between two single mode fibers (SMFs) using a conventional fusion splicing. Any environmental change causes drastic changes to the supermode interference, and results in easy-to-detect changes in the transmission spectra through the SMF-MCF-SMF sensor. In particular, sensors based on 7-core fibers demonstrate great potential since the selective excitation and successive interference of only two supermodes leads to highly predictable interference patterns and the devices fabrication is rather simple and very reproducible, see Fig. 1. Very similar devices can be designed to measure temperature, strain, bending, and vibrations [10-16].

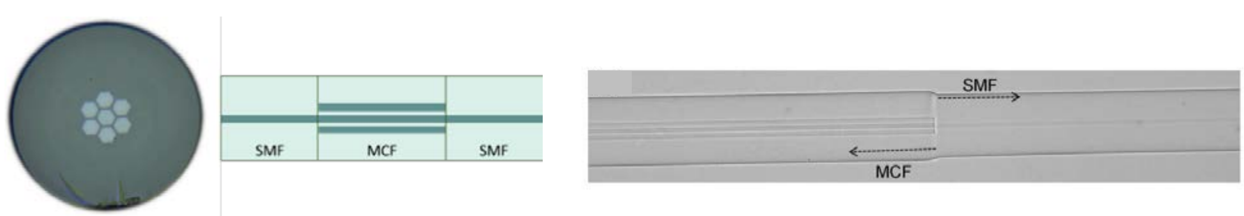

Fig. 1. Left: Facet image of a typical 7-core fiber used for point sensing, Center: Schematic of and SMF-MCF-SMS device structure. Right: microscope image of 7-core fiber to SMF junction [13].

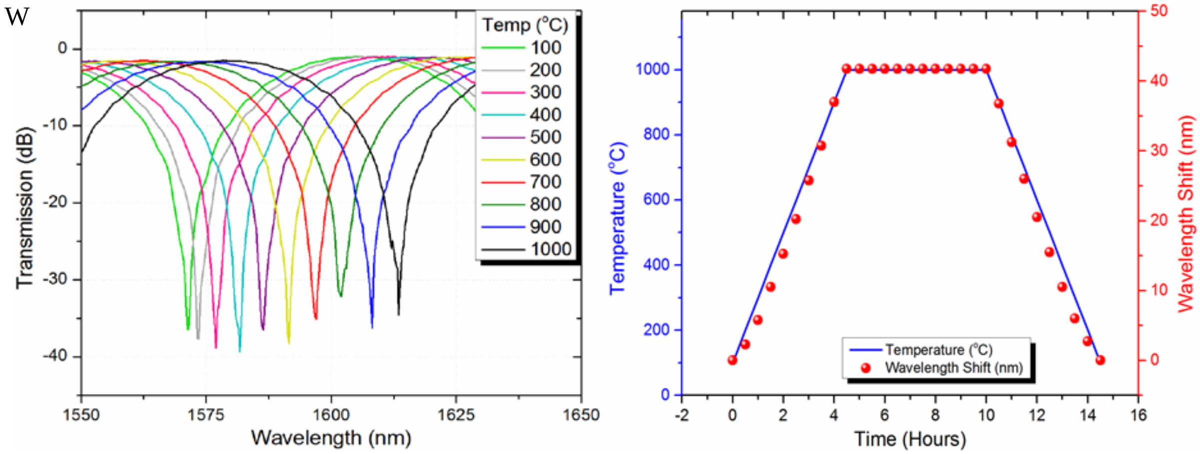

Fig. 2. Left: Transmission spectra through a sensor with 2 cm of 7-core fiber as function of temperature. Right: Time evolution of the wavelength shift of the MCF sensor (red dots) during a long cycle of temperature variations (blue line) [10].

2. Sensor performances

Fig. 3 shows the spectral response of the MCF sensor for 100 °C increments changed in 30 minutes intervals. As expected, the wavelength of the deep notch shifts to longer wavelengths as the temperature is increased. Between room temperature and 1000 °C the transmission minimum shifts a total of 43.5 nm, from 1469 nm to 1613.5 nm. The insertion loss of the MCF device and the fringe visibility were obtained as 1 dB and 37 dB, respectively, which outperforms most of the sensors based on interference effects reported so far. In particular, when compared to FBG based sensors, the ability to perform at temperatures up to for rather long periods of time is a clear benefit for many applications.

That our MCF based sensors are suitable for real-world applications is demonstrated in Fig. 3. A SMF-MCF-SMF sensor was packaged and used to measure strain in a crossbeam of the Vizcaya Bridge (a UNESCO World Heritage Site) during a period of three months. During these experiments our sensor data were referenced against a commercial strain gauges and FBG sensors as shown in the bottom part of the Fig. 3. Our results suggest that the strain sensors here proposed can compete in performance with such devices.

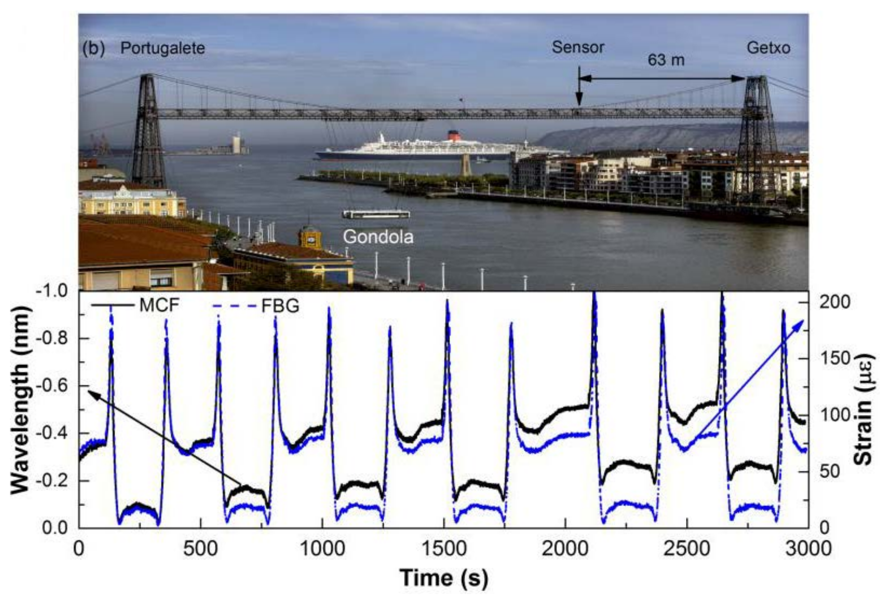

Fig. 3. Top: Photograph of the Vizcaya Bridge highlighting the positions of the sensors and the hanging gondola. Bottom: Strain induced wavelength shift of the interference pattern of our MCF sensor (left scale, black curve) and the strain measured by a commercial FBG sensor (right scale, blue line) at the same location of the crossbeam of the bridge while the gondola moved from Portugalete to Getxo and back.

4. Conclusion

In conclusion, we reported on fiber optic sensing based on the interference of supermodes in a MCF with strongly coupled cores. The interferometers reported here consist of short segments of MCF, inserted, via standard fusion splicing, between two SMFs. The fabrication of the SMF-MCF-SMF structure is fast, reproducible and inexpensive and is carried out with hardware widely used in the telecommunications industry.

We demonstrate that our sensors perform well when compared with commercial FBG based sensors. Due to the robustness of the sensing fiber optic structure our MCF based sensors outperform in particular FBG based sensors in harsh environments such as elevated temperatures up to 1000 °C. Perhaps even more important, we show that our sensor devices can be applied in real-world environments over extended periods of time by monitoring strain in bridge over several months. Our results suggest that fiber optic point sensors based on MCF can compete in performance with conventional devices and have great potential for commercial applications.

5. References

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