Simple Multi-core Optical Fiber Accelerometer

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Abstract: We report on a compact accelerometer built with strongly coupled multi-core optical fiber. The device was placed in cantilever position. An ultra-miniature seismic mass was used to tune the device sensitivity and operating frequency range.

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1. Introduction

Accelerometers have a wide variety of applications. They are used to monitor vibrations patterns of machines, turbines, or civil infrastructures (buildings, tunnels, etc.), and even the physical activity of a person. In each of these applications, the frequency range and amplitude of the vibrations, and the environmental conditions are different. Thus, there is a myriad variety of accelerometers. In environments where electromagnetic interference is present, accelerometers based on optical fibers are a viable, or the only alternative. An additional advantage of fiber optic accelerometers (FOA) is the possibility of interrogating them over ultra-long distances. FOAs have reached high level of maturity. Currently, several companies commercial different models of FOAs.

Optical fibers are insensitive to acceleration (vibrations). Therefore, to devise a FOA, a mechanical system is necessary to modify some properties of the guided light when the optical fiber experiences vibrations. A common approach consists of attaching a segment of an optical fiber to a metal cantilever [1,2]. In the presence of vibrations, the cantilever oscillates and strains, or bends periodically the optical fiber. Strain or bending in an optical fiber can be detected with fiber Bragg gratings (FBG) [3,4], interferometric methods [1], or by intensity changes [2].

In this work, we introduce a simple and compact multi-core fiber accelerometer. Our device is built by fusion splicing a few centimeters of strongly coupled multi-core fiber (MCF) to a standard single mode fiber (SMF). In the MCF segment, two super-modes are excited and interfere with each other [5-7]. Such super-mode interference is highly sensitive to bending, hence to acceleration. The MCF interferometer was packaged with a cylindrical glass capillary. An ultraminiature test mass (~0.03 g) attached at the end of the capillary was used to tune the resonance frequency of the accelerometer. Our sensor was calibrated at various frequencies and amplitudes in a shaker. As a reference, a commercial electronic accelerometer was used.

2. Results and Discussion

The MCF used to build our devices has seven strongly coupled cores made of Ge-doped silica; the cladding of the fiber is made of pure silica [5-7]. The cross section of such a MCF is shown Fig. 1(a). The architecture of the sensor is shown in Fig. 1(b). To make such a structure, the MCF is fusion spliced to a SMF. The aforementioned MCF and the SMF are mode matched, thus, the coupling between both fibers is highly efficient and the insertion loss of the SMF-MCF structure is minimal. After the splicing process, the MCF is cleaved with a conventional fiber cleaver. Thus, the MCF end serves as a low reflectivity mirror. The length of the MCF segment was approximately 16 mm.

The SMF-MCF structure, shown in Fig. 1(b), is a super-mode interferometer [5-7]. Due to the axial symmetry of the structure and the excitation with the fundamental SMF mode, only two super-modes are excited in the MCF. The two super-modes propagate in the MCF and interference with each other. Therefore, a series of maxima and minima (interference pattern) can be observed when one analyzes the reflected light from the SMF-MCF structure [5-7].

As bare fibers are delicate, a proper protection (packaging) is necessary to implement a functional device. In our case, the SMF-MCF structure was protected by a proper segment of polyimide-coated flexible silica capillary tube with inner/outer diameter of 150/360 μm. To make a cantilever, the capillary tube was secured inside a small box fabricated using a 3D printer. The clamping point of the MCF interferometer is shown in Fig. 1(c). In this manner, the cantilever was free to oscillate. To enhance the sensitivity of our device and to tune the resonance frequency of the accelerometer, without altering its dimensions, we used a fiber optic ceramic ferrule attached at the end of the capillary as a seismic mass. To calibrate our packaged sensor we put it on a shaker which was driven by a function generator, see Fig. 1(d). As a reference, we used an electronic accelerometer.

We devised an accelerometer to operate at low frequencies, as those found in seismic events. An interferometer

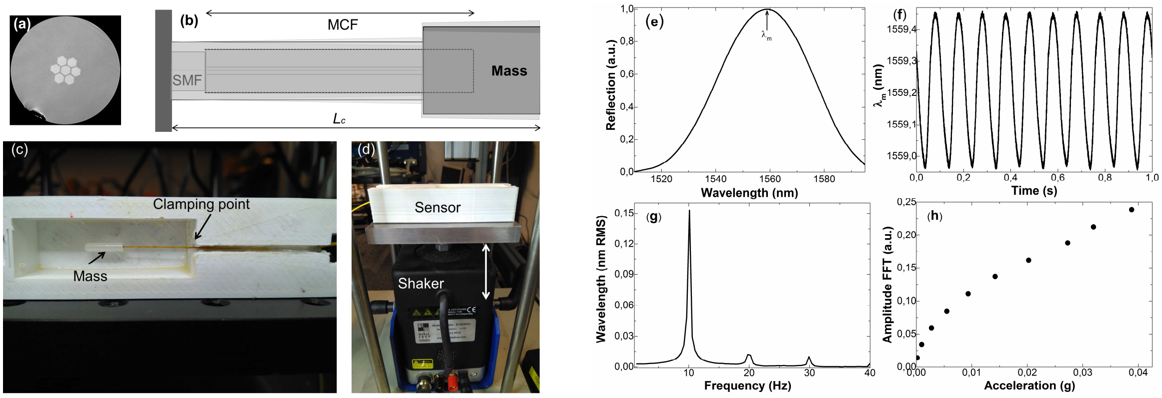

Fig. 1. (a) Cross section of the MCF. (b) Sketch of the MCF interferometer. The dotted line represents the segment of MCF. L_c is the length of the cantilever. (c) Photograph of the testing set up. The arrow indicates the direction of vibration. (d) Photograph of the sensor. (e) Reflection spectrum of an interferometer fabricated with 16 mm of MCF. λ_m is the position of the absolute maximum. (f) Position of λ_m as a function of time when the shaker was oscillating at 10 Hz. (g) Fast Fourier transform (FFT) of the graph (f). (h) Amplitude of the FFT as a function of acceleration. In all cases, the frequency was 10 Hz.

was fabricated with 16 mm of MCF. The measured reflection spectrum of the device is shown in Fig. 1(e). The position of the absolute maximum of the interference pattern is denoted by λ_m. Under vibrations induced by the shaker, the position of λ_m changes cyclically. Figure 1(f) shows the position of λ_m as a function of time when the shaker was oscillating at 10 Hz. By means of the fast Fourier transform (FFT), the frequency and amplitude of the oscillations can be determined, see Fig. 1(g). The amplitude of the FFT as a function of acceleration is shown in Fig. 1(h). In all cases, the frequency was 10 Hz. It is important to point out that the acceleration was measured with the reference accelerometer mentioned above. The testing of our accelerometer at other frequencies, between 5 and 50 Hz, and at different accelerations are being investigated. The results will be presented at the conference.

3. Conclusions

In conclusion, we have proposed and demonstrated a simple multicore optical fiber accelerometer. The device is fabricated by fusion splicing a short segment of strongly coupled MCF to telecommunication optical fiber. The fabrication of the sensor is highly reproducible. As conventional fiber cleaving and splicing equipment are required, the fabrication process is cost effective. To interrogate our devices, we monitor the light reflected back from the cleaved MCF facet. The MCF interferometer was packaged and placed in cantilever position. The performance of the accelerometer here proposed was studied at different frequencies and amplitudes in a shaker driven by a function generator. As a reference, we used a well-calibrated electronic accelerometer. We found that the device reported here is suitable to monitor low-frequency vibrations as those found in seismic events or in critical civil infrastructures. The performance of the accelerometer can be optimized for different frequency ranges. A seismic mass with a suitable weight in combination with a proper length of the MCF segment is just required.

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References

[1] X. Wu, X. Wang, S. Li, S. Huang, Q. Ge, and B. Yu, "Cantilever fiber-optic accelerometer based on modal interferometer," IEEE Photon. Technol. Lett. **27**, 1632-1635 (2015).
[2] J. Li, G. Y. Wang, J. N. Sun, R. R. J. Maier, W. N. Macpherson, D. P. Hand, F. Z. Dong, "Micro-machined optical fiber side-cantilevers for acceleration measurement," IEEE Photon. Technol. Lett. **29**, 1836-1839 (2017).
[3] N. Gutiérrez, P. Galvín, F. Lasagni, "Low weight additive manufacturing FBG accelerometer: Design, characterization and testing," Measurement, **117**, 295-303 (2018).
[4] X. Qiao, Z. Shao, W. Bao, and Q. Rong, "Fiber Bragg grating sensors for the oil industry," Sensors **17**, art. 429, (2017).
[5] J. E. Antonio-Lopez, Z. S. Eznaveh, P. LiKamWa, A. Schülzgen and R. Amezcua-Correa, "Multicore fiber sensor for high-temperature applications up to 1000°C," Opt. Lett. **39**, 4309-4312 (2014).
[6] J. Villatoro, A. Van Newkirk, J. E. Antonio-Lopez, J. Zubia, A. Schülzgen, and R. Amezcua-Correa, "Ultrasensitive vector bending sensor based on multicore optical fiber," Opt. Lett. **41**, 832-835 (2016).
[7] J. Villatoro, E. Antonio-Lopez, A. Schülzgen, and R. Amezcua-Correa, "Miniature multicore optical fiber vibration sensor," Opt. Lett. **42**, 2022-2025 (2017).