Packaged Multi-core Fiber Interferometric Vibration Sensor

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Abstract: We report on a packaged interferometer built with strongly-coupled multi-core optical fiber (MCF) for vibration sensing. A miniature test mass (~0.01 g) induces cyclic bending to the MCF which results in periodic shifts of the interference pattern.

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1. Introduction

Vibrations sensors (also called accelerometers) have a myriad of applications. They allow monitoring or studying, for example, seismic events or the health status of machines and civil infrastructures (bridges, buildings, etc.). The environmental conditions, the frequency range and amplitude of vibrations are different in each application. Thus, there exists a variety of vibration sensors. Those based on optical fibers are an alternative to well-established electronic and non-optical vibration sensors and have important advantages. The latter include immunity to electromagnetic interference, long distance interrogation, and flexibility, amongst others. Due to such advantages, optical fiber vibration sensors have reached high level of maturity and are commercially available [1,2]. Since optical fibers are insensitive to vibrations, an intermediate mechanism is necessary to alter the guided light when vibrations reach the optical fiber. A common approach is to use a test mass attached to the optical fiber. In the presence of vibrations the test mass will move periodically and this oscillation induces periodic strain in the optical fiber. Strain in turn modifies the phase or amplitude of the guided light. Such changes of the guided light can be easily detected with fiber Bragg gratings (FBG) or interferometers [1-4].

In this work, we propose and demonstrate a fiber optic vibration sensor based on super-mode interference. Our sensor consists of a short segment of strongly coupled multi-core fiber (MCF) spliced at the distal end of a conventional 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 vibrations. A test mass of ~0.01 g attached at the end of the sensor induces cyclic bending to the MCF segment resulting in a periodic shift of the interference pattern. The sensor was packaged inside a cylindrical glass capillary with additional protection provided by a metallic tube that was finally mounted inside a small box. The sensor proposed here is suitable to monitor low frequencies.

2. Results and Discussion

Figure 1(a) and (b) show, respectively, the cross section of the MCF used to build the device and an illustration of the sensor architecture. The MCF consists of seven coupled cores made of germanium doped silica embedded in a pure silica cladding [5]. The junction of the SMF and the MCF was carried out with a fusion splicer (Fujikura 100P+). As the MCF and the SMF are mode matched, the coupling between both fibers is highly efficient and the insertion loss of the SMF-MCF structure is minimal (0.1 dB). Once the SMF and MCF are fusion spliced, the MCF is cleaved perpendicular to the light propagation axis. Thus, the cleaved end of the MCF serves as a low reflectivity mirror. The length of the MCF segment was approximately 18 mm.

The SMF-MCF structure, shown in Fig. 1(b), is a super-mode interferometer [5-7]. The MCF supports seven super-modes [5,7]; however, due to the axial symmetry of the SMF-MCF structure and the excitation with the fundamental mode of the SMF, only two super-modes are excited in the MCF. The two super-modes propagate at different phase velocity, thus they accumulate a phase difference as they propagate along the segment of MCF. Therefore, if light from a broadband source is launched to the SMF-MCF structure and the reflected light is analyzed with a spectrometer, a series of maxima and minima (interference pattern) can be observed [5-7].

Immediately after the SMF to MCF splicing, the structure was protected by a glass capillary (from Polymicro) with inner/outer diameter of 150/360 μm. A test mass of 0.01 g was attached at the end of the capillary. A metallic tube was additionally used to secure the glass capillary. The metallic tube was packaged inside a small box, where the end of the metallic tube was the clamping point of the MCF interferometer, see Fig. 1(c). In this manner, the test

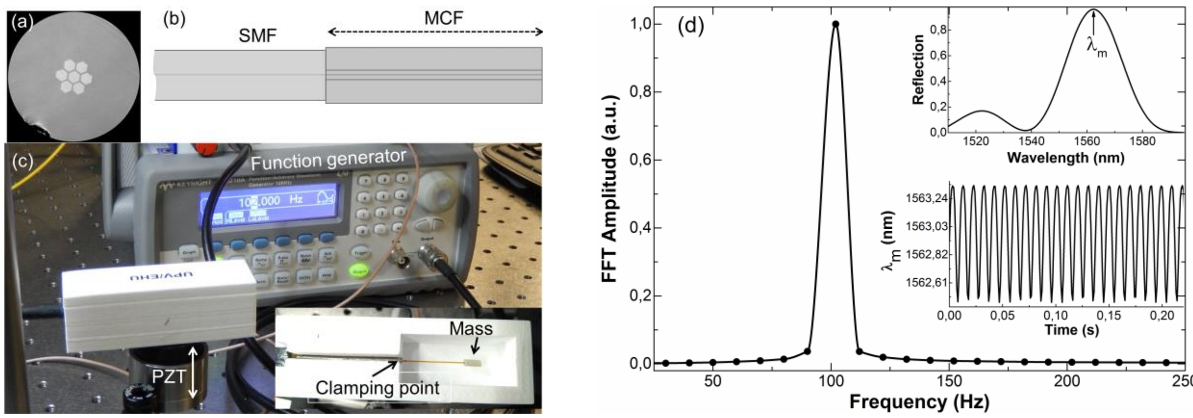

Fig. 1. (a) Cross section of the MCF. (b) Sketch of the MCF interferometer. (c) Photograph of the testing set up. PZT is piezo-electric transducer. The arrow indicates the direction of vibration. The photograph of the inset shows details of the sensor. (d) Experimental amplitude-frequency response of our device. The inset plots show the reflection spectrum of an 18 mm-long device (top) and the shift of the interference pattern as a function of time (bottom) when the sensor was oscillating at 102 Hz. λ_m is the maximum of the interference pattern, FFT is fast Fourier transform.

mass was free to oscillate. Our MCF interferometer was shielded inside the small box that was fabricated using a 3D printer. To test our packaged sensor we put it on a piezo-electric transducer (PZT) which was driven by a function generator.

The measured spectrum of light reflected from the cleaved MCF facet is shown in the inset of Fig. 1(d). λ_m is the position of the absolute maximum of the interference pattern. Under vibrations induced by the PZT, the position of λ_m oscillates as shown in the other inset of Fig. 1(d). The frequency of oscillations is determined by means of the fast Fourier transform (FFT) of the λ_m vs time graph. We tested the response of our sensor at frequencies between 30 and 240 Hz. The results are shown in Fig. 1(d). The highest point in the figure, at about 100 Hz, corresponds to the resonance frequency (F_r) of the device. If the test mass is heavier, or if the length of the cantilever is longer, F_r is lower. Thus, we believe that our sensor can be configured to monitor different vibration frequencies.

3. Conclusions

In conclusion, we have proposed and demonstrated a new type of fiber optic vibration sensor. The device consists of a short segment of MCF directly spliced to a telecommunication optical SMF. The device operates in reflection mode measuring light reflected back from the cleaved MCF facet. The fabrication of the sensor requires standard fiber cleaving a splicing equipment and is reproducible. The interrogation of the sensor involves a broadband optical source, conventional fiber couplers, and a miniature spectrometer. The MCF interferometer was packaged and its performance was studied. It was demonstrated that the sensor reported here is suitable to monitor low-frequency vibrations as those found in civil infrastructures or seismic events. The performance of the sensor can be optimized for specific frequency ranges by choosing a test mass with a suitable weight and selecting a specific length of the MCF segment.

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