Fiber Cavity Ring-down for Strain Sensing Using an OTDR

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***Abstract*—This work presents a fiber CRD configuration for the measurement of strain. An Optical Time-Domain Reflectometer was used to send impulses down into the fiber loop cavity, inside of which a chirped fiber Bragg grating was placed to act as a strain sensing element. This technique could provide strain results with both conventional CRD-based configuration and the OTDR.**

Keywords*—Cavity ring down; OTDR; optical fiber sensors; strain.

I. INTRODUCTION

Cavity ring down (CRD) spectroscopy is a highly sensitive spectroscopic technique that measures changes in the decay rate of an optical resonator and it has been in the past few decades a strong subject of research [1]. Although typically implemented in a mirror-based cavity in bulk optics, the CRD is commonly applied to real-time chemical analysis but it is also an effective method for determining the loss in an optical fiber-based loop resonator [2,3].

The appearance of the fiber-optic based CRD, which uses a fiber loop as resonant cavity, emerged as a potential alternative to the usual CRD for spectroscopy; and quickly suggested a range of new applications, including distributed monitoring over a large physical area or even remote sensing. In fact, in the last few years, this technique has been implemented in the measurement of different physical parameters, namely: strain [4-5], pressure [6], temperature [7], refractive index [8-10] and biochemical sensing [11-15].

In this work, a fiber CRD configuration using an Optical Time Domain Reflectometer (OTDR) optical modulated source is presented for the measurement of strain. The sensing head, which is placed inside the fiber loop cavity, is based on a chirped fiber Bragg grating (FBG) and acts as a strain sensing element. The strain results were attained with both conventional CRD-based configuration and the OTDR.

II. EXPERIMENTAL RESULTS

The experimental setup of the proposed CRD chirped-FBG system is presented in Fig. 1. The cavity is composed of two standard (2 × 1) 1:99 optical fiber couplers, a fiber loop with ~1560 m (SMF 28) and a chirped-FBG. A commercial OTDR (Yokogawa AQ7270) is used to send impulses (1 μs at 1550 nm) down into the fiber cavity, instead of the usual laser and modulator setup [16]. The train of pulses is coupled via 1% arm of the input optical coupler, rings around inside the fiber loop and is coupled out via 1 % arm of the output coupler; the amplitude of the output pulses decay temporally due to the total existing losses in the fiber loop (fiber loss, fiber couplers insertion losses, chirped-FBG transmission attenuation), passes through a photodetector (gain of 40 dB) and is monitored in an oscilloscope. The chirped-FBG placed inside the fiber loop cavity is centered at 1573 nm and it has ca. 4nm width. The proposed technique allows dual interrogation of the chirped-FBG incorporated in a conventional CRD topology. The output signal is read (1) through the oscilloscope or (2) by the OTDR. In the first case, the output signal of the OTDR is used only as optical modulated source [17].

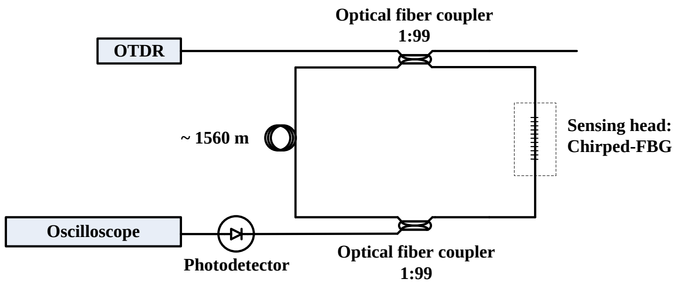

Fig. 1. Experimental setup of the proposed CRD chirped-FBG. The signal is introduced inside the fiber cavity by means of an OTDR and monitored via a photodetector and an oscilloscope.

To perform strain measurements, the chirped FBG was fixed at two points that were 200 mm apart, and submitted to specific strain values by means of a translation stage (via sequential 20 μm displacements). When strain was applied to the chirped-FBG, two distinct output responses could be observed either in the oscilloscope or in the OTDR – see subsections *A* and *B*, respectively.

In overall, the output signal response is strongly dependent of the wavelength position of the FBG with respect to the OTDR laser source. Usually, the optical sources used in the OTDR are multimode lasers centered at 1550 nm. In this case the FBG in interrogated in transmission (recall Figure 1). If the chirped-FBG is placed at lower wavelengths, the output signal is expected to decrease with increasing strain. On the other hand, if the FBG is placed at wavelengths higher than 1550 nm

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(in this case, the FBG is centered at 1570 nm) the output signal is expected to increase with applied strain. The following subsections present the results attained by interrogating the chirped-FBG with the conventional CRD configuration and the OTDR.

A. Conventional CRD interrogation

The decay curve from one cavity ring-down decay is illustrated in Fig. 2. The obtained output signal corresponds to a typical loop ring-down waveform of the conventional CRD.

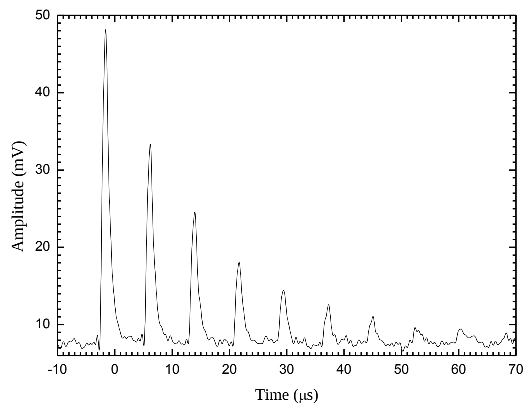

Fig. 2. Cavity ring-down decay with a chirped-FBG inside the fiber loop.

In this case, the time of a single round trip is ca. 7.7 μs and is strongly dependent of the cavity length. An exponential fit was performed and a ring-down time of ca. 23 μs was attained. This value depends strongly on the losses originated by the length of the loop, splices and insertion losses of the fiber couplers.

Fig. 3 shows the cavity ring-down decay with increasing strain applied to the chirped-FBG. As expected, the amplitude of the output signal response increases with increasing strain since the FBG is placed at a wavelength higher than 1550 nm, i.e. the central wavelength of the multimode laser of the OTDR.

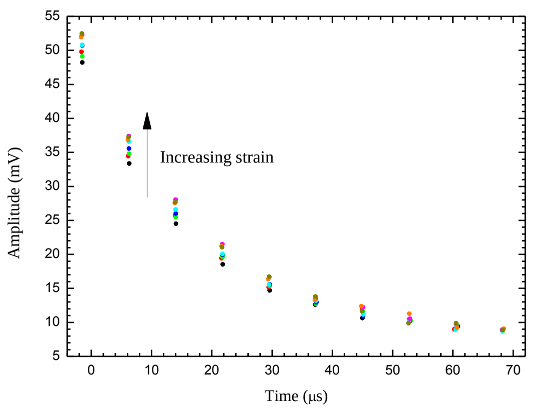

Fig. 3. Cavity ring-down decay with increasing strain applied to the chirped-FBG.

In Fig. 4 it is depicted the CRD response to applied strain. A linear response was obtained due to the strain feature of the chirped-FBG (linear response $d\lambda/d\varepsilon$) and a sensitivity of 1.34 ns/$\mu\varepsilon$ was obtained. In this case, an increase of the ring-down time is observed because the spectral response of the FBG is superimposed with the spectral response of the optical source. When is subjected to the strain the transmission spectrum of FBG fades of in the spectrum of the optical source.

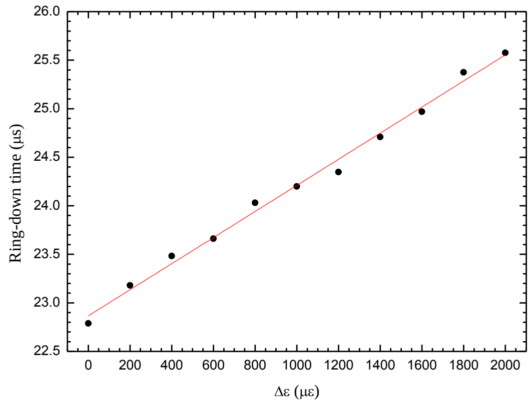

Fig. 4. Cavitiy ring-down time versus applied strain to the chirped-FBG.

B. OTDR interrogation

Fig. 5 presents the OTDR pulse intensity decay that is back-reflected by the chirped-FBG inside the fiber loop. One can observe at the beginning signal saturation that may be avoided by placing a few meters of fiber (SMF28) between the OTDR and the ring cavity. Afterwards, the amplitude of the signal decays due to the several round trips of the pulse inside the cavity, as expected.

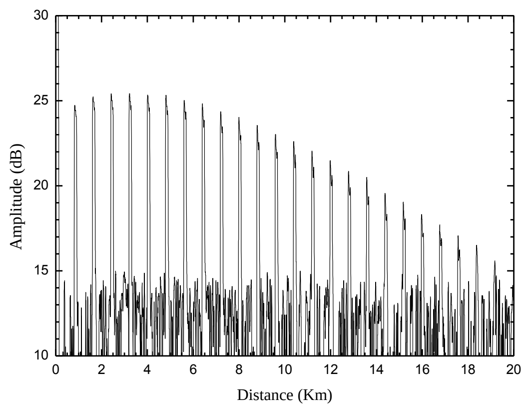

Fig. 5. OTDR waveform of the pulse intensity decay of the chirped-FBG inside the fiber loop.

The OTDR may also be a viable interrogation method as depicted in Fig. 6. The amplitude of the signal increases when the chirped-FBG is submitted to strain. Although is this case a ring-down time of only 62 μs was achieved.

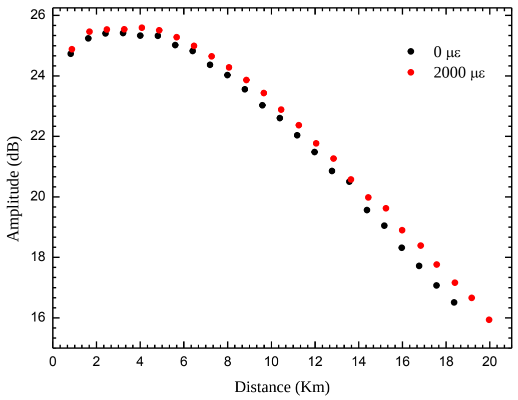

Fig. 6. Pulse intensity decay with increasing strain applied to the chirped-FBG and interrogated by the OTDR.

III. Conclusions

A fiber-based CRD configuration using an OTDR as optical modulated source was presented in this work for the measurement of strain. A chirped-FBG was placed inside the fiber loop cavity and acted as a strain sensing device. Strain results could be attained with both conventional CRD-based configuration and the OTDR. Although measurements acquired with the photodetector and oscilloscope provided a better a ring-down time response (ca. 23 µs) when compared to the one achieved with the OTDR (62 µs), it was possible to prove the viability of using the OTDR as an interrogation method combined with the CRD configuration. Using the conventional CRD configuration it was possible to obtain a linear response to strain applied in the range 0-2000 με, at the wavelength of 1570 nm. Using the chirped-FBG, a sensitivity of 1.34 ns/με was obtained. In overall, the proposed configuration is simpler than the conventional CRD, that uses the laser and modulator setup, provides dual interrogation method and the OTDR also enables remote sensing.

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