PHOTONIC SENSORS / Vol. 6, No. 4, 2016: 324–327

Fiber Cavity Ring Down and Gain Amplification Effect

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Abstract: The effect of an erbium-doped fiber amplifier (EDFA) placed inside the fiber ring of a cavity ring down (CRD) configuration is studied. The limitations and advantages of this configuration are discussed, and the study of the ring-down time as a function of the current applied and gain to the EDFA is also presented. In this case, the power fluctuations in the output signal are strongly dependent on the cavity ring-down time with the EDFA gain.

Keywords: Cavity ring down; EDFA; multimode laser; optical fibers.

Citation: Susana SILVA, Regina MAGALHÃES, Rosa Ana PÉREZ-HERRERA, Manuel LOPEZ-AMO, M. B. MARQUES, and O. FRAZÃO, "Fiber Cavity Ring Down and Gain Amplification Effect," *Photonic Sensors*, 2016, 6(4): 324–327.

1. Introduction

Over the past thirty years, cavity ring down (CRD) spectroscopy has been a strong subject of research. In fact, the CRD scheme was firstly developed for quantifying high-reflectivity mirrors that were difficult to characterize by other means [1, 2]. A few years later, the CRD technique gained popularity due to its ability of measuring absorption in real time, with highly sensitivity, using pulsed light sources [3]. Nowadays, CRD spectroscopy is widely used for chemical and molecular analysis in real time [4]. This technology quickly gave rise to the development of fiber optic-based CRD schemes, where a fiber loop is used as resonant cavity [5]. Although its focus is in optical spectroscopy, the CRD technique has also been used to the measurement of physical parameters, such as strain [6], pressure [7], temperature [8], refractive index [9], and biochemical sensing [10].

A common drawback of the CRD systems is an almost 100% coupling loss when light is coupled into the cavity, either using reflective layers ($R >$ 99.9%) or optical fiber couplers with high splitting ratios (99:1) in the case of fiber loop configurations. One example to overcome this issue was the use of an erbium-doped fiber amplifier (EDFA) for loss compensation, allowing the use of open-path micro-optic cells, increasing the ring-down time of the system [11]. The study of signal amplification by placing an EDFA inside a fiber ring configuration was also reported [12]. Recently, a fiber-based CRD technique that used a large core multimode fiber-cavity design based on highly reflective gold coatings was demonstrated [13].

In this work, it is demonstrated the effect of using an EDFA for signal amplification inside the fiber ring of a cavity ring-down configuration. The

Received: 22 December 2015 / Revised: 28 July 2016

DOI: 10.1007/s13320-016-0309-9
Article type: Regular

study of the ring-down time as a function of the current applied to the EDFA is presented. The limitations caused by the EDFA placed inside the fiber ring are discussed, and the advantages are also presented.

2. Experimental results

The experimental setup of the proposed CRD system with amplification is presented in Fig. 1. The configuration is composed by a modulated multimode laser source, two standard (2×1) 1:99 optical fiber couplers, a fiber loop with a length of ~1 km (SMF 28), an EDFA, a photodetector (Thorlabs PDA 10CS-EC, 70 dB maximum gain), and an oscilloscope (Tektronix TDS1002C-EDU).

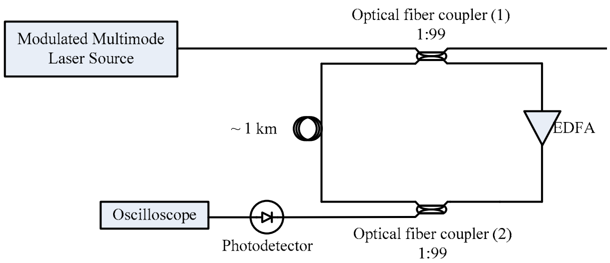

Fig. 1 Experimental setup of the proposed CRD with amplification performed inside the fiber loop by means of an EDFA (the signal is introduced inside the fiber cavity using a modulated multimode laser source and monitored via a photodetector and an oscilloscope).

The modulated multimode laser source is used to send impulses (1 s at 1550 nm) down into the fiber loop—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 decays with time due to the total existing losses in the fiber loop (fiber loss, fiber couplers insertion losses), passes through a photodetector (gain of 40 dB), and is monitored in an oscilloscope. The EDFA is made in house, has 2 m of an erbium-doped fiber (losses of 14 dB/m @ 980 nm), and it is inserted in the fiber loop for signal amplification of the CRD configuration.

Figure 2 shows the spectral response of the multimode laser source with and without amplification, when interrogated by an optical spectrum analyzer. One can observe that the implementation of the EDFA (gain of 10 dB) in the CRD setup increases 10-fold the amplitude of the optical power signal of the multimode laser source. The spectral response of the multimode laser changes because the EDFA gain has a high gain for shorter wavelength in the region presented in Fig. 2.

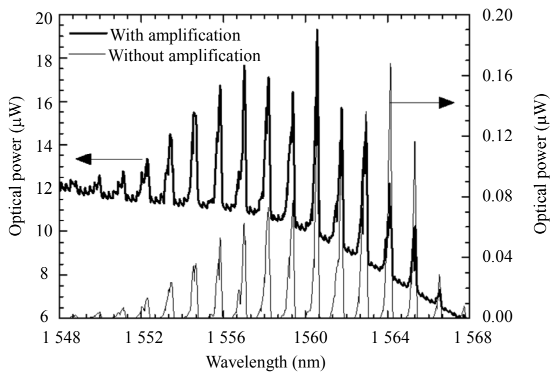

Fig. 2 Optical spectrum of the multimode laser source with (bold line) and without (line) amplification.

Figure 3(a) presents the typical CRD decay waveform, when the maximum current is applied to the EDFA, namely, 56.0 mA. This corresponds to a ring-down time of 82.7 s with the light traveling 60 times inside the fiber loop. The several CRD traces as a function of current applied to the EDFA are depicted in Fig. 3(b). The minimum current used to observe the first decaying signal is 45.1 mA, with a ring-down time of 11.04 s; when applying a current of 52.0 mA, it shows an amplitude signal and ring-down time similar to the one already reported with a decay time response of 31.8 s [14].

It is important to notice that the CRD setup without the EDFA allows reading the output signal with a ring-down time of 32 s when light travels 25 times inside the fiber loop [14]. In this case, the gain of the EDFA compensates its own losses. In the current range of (52.0–56.0) mA, the EDFA gain eliminates losses of the fiber ring itself, such as splices, fiber connectors, and others. For currents above 56 mA, losses are totally eliminated, and lasing is observed. From the results presented in

Fig. (3b), it is possible to obtain the exponential fit for each waveform, and the ring-down time is determined, as shown in Fig. 4.

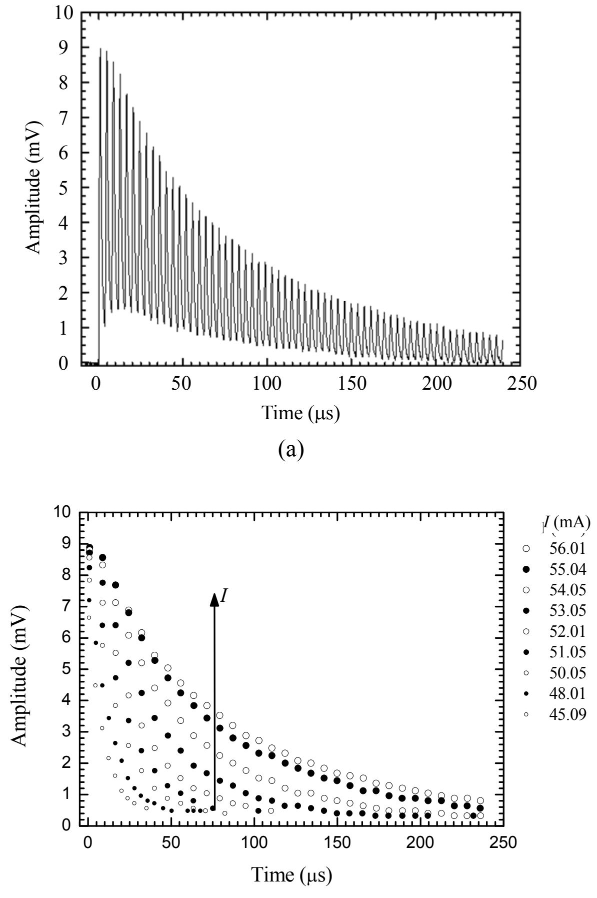

Fig. 3 CRD trace obtained for: (a) maximum current applied to the EDFA (56.01 mA) and (b) for different currents applied to the EDFA.

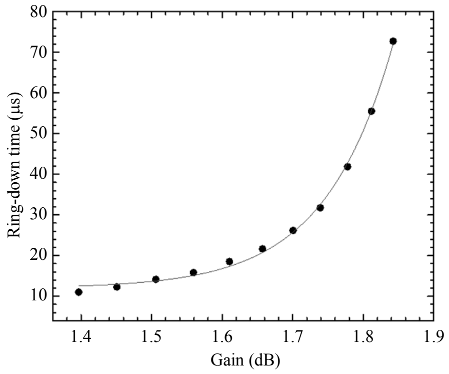

Fig. 4 Ring-down time versus gain of the CRD signal.

Figure 4 presents the relationship between the ring-down time and the gain of the CRD signal. A small variation of the ring-down time is observed for gain signals below 1.65 dB. Therefore, in the case of any power instability of the EDFA will be negligible in this region. Ranging from 1.65 dB, the ring-down time is actually obtained due to the amplification of the CRD amplitude signal inside the cavity loop, where signal saturation may be observed. In this range, any small variation of the EDFA gain will change significantly the ring-down time. The EDFA may be used in these conditions requiring however high power stability. The ring-down time obtained with the proposed configuration is strongly dependent on the EDFA gain due to its location inside the fiber ring, which in turn influences the output power when read by the photodetector. This is a limitation when placing an EDFA or any other kind of amplification system inside the fiber ring of a CRD configuration. On the other hand, an advantage of the proposed configuration is that the EDFA placed inside the fiber ring allows to work in a larger dynamic range (with power stabilization) when compared with the conventional CRD configuration.

3. Conclusions

This work presents the study of implementing an EDFA inside the fiber ring of a cavity ring-down configuration for signal amplification. The fiber CRD configuration uses a modulated multimode laser source, and signal amplification is performed in the gain range [1.40–1.86] dB. The limitation of using such configuration is that the CRD output signal becomes dependent on the EDFA input power and, consequently, so as the ring-down time achievable in the gain range studied. In this case, the immunity of power fluctuations to the input power is eliminated when it is inserted an EDFA in the ring cavity. An advantage is that a larger dynamic range may be obtained when compared with the conventional CRD configuration.

Acknowledgment

This work was supported by Project "CORAL – Sustainable Ocean Exploitation: Tools and Sensors, NORTE-01-0145-FEDER-000036, financed by the North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, and through the European Regional Development Fund (ERDF). S.S. received a Pos-Doc fellowship (ref. SFRH/BPD/92418/2013) also funded by FCT – Portuguese national funding agency for science, research and technology.

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