Acoustic Sensor Based on Depressed Cladding Erbium Doped Fiber Ring Laser


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ABSTRACT

This work describes a new type of acoustic sensor based on depressed cladding erbium doped fiber (DC-EDF) ring laser. Due to the fiber amplification based on bending characteristics developed for S-Band uses, this sensor has high sensitivity, broad dynamic range and wide bandwidth. It can be used to monitor parameters such as frequency, vibration and acoustics. We describe the sensor characterization in S band in frequencies from 5 Hz to 50 kHz.

Keywords: Erbium doped fiber ring laser, fiber bending sensor, fiber loop sensor, depressed cladding erbium doped fiber, S band.

1. INTRODUCTION

Depressed erbium doped fiber (DC-EDF) was developed a few years ago in order to obtain optical amplification in S-Band (1480 - 1525 nm) and to be used in Dense Wavelength Division Multiplexing (DWDM) channel expansion [1]-[2]. It has been pointed out that the behavior of DC-EDF is very sensitive to the bending radius, which is used to filter out the C-Band amplified spontaneous emission (ASE) generated by erbium doped fiber, thus enabling S-Band optical amplification. In [2] is described a method to tune the gain of a double-pass amplifier using DC-EDF fiber using an adjustable elliptical coil.

Besides the DC-EDF uses in optical amplifiers, other application that has been studied for DC-EDF is for ring laser. Some research works have studied this type of laser and its mechanism of tunability [3]-[4]. Other ones [5-6] describe ring lasers and its mechanism of tunability based on uses of standard erbium doped fiber. In such cases, the characteristics of ring lasers were not explored for sensing purposes.

This paper describes a new type of acoustic sensing system based on DC-EDF ring laser. We described a DC-EDF acoustic sensing system and its characterization in S band (1495 to 1515) nm in a frequency range from 5 Hz to 50 kHz. Our purpose is to explore the bending/lasing mechanism of DC-EDF in order to obtain a highly sensitive sensing system which can be used in many areas of interest, such as, electric energy and civil engineering.

2. S-BAND FIBER SENSING SYSTEM AND EXPERIMENTAL SET-UP

The operation principle of the proposed fiber sensing system is based on the DC-EDF, which can also be referred to as dual-clad or “W-profile” erbium doped fiber. It has been demonstrated that the ASE of erbium-doped fibers can be suppressed in the C-Band, to take advantage of the S-Band amplification, due to the fundamental mode cutoff of DC-EDF [1]. The design of a DC-EDF has the cutoff wavelength at about 1525 nm, distributed loss > 200 dB for C-Band, and distributed loss in the S-Band much less than the gain. Distributed fiber loss or the distributed fiber gain at S-Band depends on fiber bending to suppress the C-Band ASE in a certain bending radius which is generally smaller than 50 mm.

The basic configuration of the sensing system is depicted in Figure 1(a)). An optical splitter (90/10%) was used at the sensing system output to obtain a sample of laser light (10% port) and to connect the counter-propagating ASE power generated by the near end DC-EDF (90% port) in to the far end of DC-EDF. The laser stability and tunability were achieved by using one isolator and one tunable optical filter in the feedback loop, respectively. The DC-EDF was pumped by a co-propagating pump scheme using one 980 nm laser. In the sensing system output (10 % port) we utilized
an optical spectrum analyzer (OSA) or an optical receiver Rx (photodetector (PD) plus trans-impedance amplifier (TIA)), followed by one audio amplifier and an oscilloscope.

The DC-EDF used employs an Er–La–Al-doped core, and the 980 nm pump absorption is 7.6 dB/m. The C-Band bending loss exceeds 10 dB/m for a 30 mm coil radius. Based on previous amplification experiments [2] we choose the DC-EDF length of 12 m wound in a 50 mm radius. The 980 nm pumping power in the DC-EDF fiber input was 50 mW.

The Figure 2(a) shows the S band ring laser output power and the Figure 2(b) some ring laser spectral lines. The spectral operation below 1495 nm was not possible due to limitation of tuning range of the optical filter and above 1517 nm was also not possible due to cutting of the fundamental mode of DC-EDF.

The characterization of the sensing system was done using one acoustic transducer, which mechanically excited the DC-EDF fiber (Figure 1(b)). The electrical signal connected to the acoustic transducer was supplied by one signal generator and amplified by one electrical amplifier. One calibrated Hall sensor was coupled to the acoustic transducer followed by one amplifier and the oscilloscope in order to measure the mechanical displacement of the DC-EDF radius caused by acoustic transducer.

Fig.1 - (a) Basic configuration for DC-EDF sensing system experimental set-up, and (b) details of fixing DC-EDF fiber loop in the acoustic transducer.

Fig.2 - (a) output power of the ring laser and (b) some examples of spectral lines of the ring laser.

3. RESULTS

In order to perform the acoustic characterization, the fiber loop was oriented in a vertical position (see Figure 1(b)) and it was fixed in two points using adhesive tapes. The DC-EDF fiber was first mechanically excited in 100 Hz by the acoustic transducer in different radius variations (ΔR) ranging from 17 to 727 µm in order to search for the sensor linearity. Figure 3 shows the linear behavior of the peak-to-peak voltage measured by the optical receiver Rx for four
different tuned wavelengths versus the DC-EDF radius variation. As we can observe in Figure 3 the linearity of the sensing system is very good mainly for wavelengths of 1495 and 1505 nm.

![Graph showing peak-to-peak voltage measured by the optical receiver Rx for four different tuned frequencies versus the DC-EDF radius variation.](http://proceedings.spiedigitallibrary.org/)

Fig. 3. Peak-to-peak voltage measured by the optical receiver Rx for four different tuned frequencies versus the DC-EDF radius variation.

Next the DC-EDF fiber was mechanically excited from 5 Hz to 50 kHz by the acoustic transducer for one fixed value of EDF radius variation $\Delta R = 4 \mu m$. We used this radius variation in order to get the highest frequency as possible reproduced by the acoustic transducer. Fig. 4 shows the spectral performance of the sensing system for the wavelengths of 1495 and 1510 nm. The spectral behavior is certainly no flat, but the sensitivity is very good from low to high frequencies.

![Spectral performance graph](http://proceedings.spiedigitallibrary.org/)

Fig. 4. Spectral performance of the sensing system from 5 Hz to 50 kHz for $\Delta R = 4 \mu m$.

Figure 4 shows the formation of resonance peaks in the sensor signal. This behavior can be understood using a simplified model of string resonance. The sensor resonance has dependence with some fiber loop parameters, such as applied strain, length, radius, points of fixing (acoustic nodes) and fiber material constants [7]. When the fiber loop is tensioned by the acoustic transducer, the transverse waves propagate to the fixing end point, where they are reflected undergoing constructive interference and leading to the resonance frequencies. Figures 5(a) to (e) show examples of waveforms collected by the oscilloscope for DC-EDF sensor from 5 Hz to 50 kHz, 1495 nm, $\Delta R = 4 \mu m$ and Figure 5(f) shows an example of waveform collected by Hall sensor for 5 kHz. As we can observe the waveforms are undistorted except for 50
kHz, because of the filtering employed to minimize the ASE noise which is created in the lasing process. Because of the limitations of the acoustic transducer, the measurements could not extend above 50 kHz. Since the sensing system can detect ultrasonic frequencies (>20 kHz) it is possible to use it in many interesting applications, such as, partial discharge detection in power transformers and hydrogenerators. In low frequencies, the sensing system can also be used to detect vibrations in large structures such as bridges and dams.

![Time waveforms of the sensing system from (a) 5 Hz, (b) 50 Hz, (c) 500 Hz, (d) 5 kHz, (e) 50 kHz and (f) 5 kHz (Hall sensor) for 1495 nm and ΔR = 4 μm.](image)

**Fig. 5.** Time waveforms of the sensing system from (a) 5 Hz, (b) 50 Hz, (c) 500 Hz, (d) 5 kHz, (e) 50 kHz and (f) 5 kHz (Hall sensor) for 1495 nm and ΔR = 4 μm.

4. **CONCLUSIONS**

This work described a new type of bending sensing system based on depressed cladding erbium doped fiber ring laser. It can be used to monitor static parameters such as force, pressure, displacement and dynamic parameters used in acoustics and vibration. We described the sensing system characterization from 1495 and 1515 nm in frequencies from 5 Hz to 50 kHz, and it showed good performance. Due to its large bandwidth and high sensitivity we believe that it can be used in electric energy and civil engineering opening applications in many areas of interest.

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**REFERENCES**