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Performance investigation of semiconductor optical amplifier and raman amplifier as an optical sensors

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In this paper, a new idea is presented to sense the vibrations and temperature using semiconductor optical amplifier (SOA) and Raman amplifier, respectively. The SOA is used because of its compact size, on chip embedability and cost effectiveness. On the other hand, the Raman amplifiers can be used as a distributed amplifier which provides distributed sensing along with the transmission fiber. We have observed the variation of received output power (for SOA -38 to -4 dBm, -44 to -8 dBm, -49 to -13 dBm at different amplifier length such as 100µm, 200µm, 300µm, respectively and for Raman amplifier 15.7 to -40.25dBm, 11.7 to -50.01dBm, 9.1 to -55dBm at different amplifiers length 100km, 200km, 300km, respectively) with respect to the vibrations and temperature.

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1. Introduction

In recent years, optical fibers have been increasingly used in many fields for their huge advantages such as increase system capacity, large bandwidth, low loss, long distance etc. [1]. The optical fiber is the technique which can be used in various applications, such as, optical communication, optical amplifiers, optical couplers, optical sensors etc. Optical sensor is the efficient way to monitor any physical quantity (i.e. strain, temperature, corrosion, humidity etc.) with fast and cost effective solution [2-4]. A precisely distributed optical sensor is estimated to make known temperature, strain and vibration information from any point along an optical fiber through light scattering phenomena. It has been required to find the method that would allow the key structural parameters to be determined at any point along an optical fiber with an appropriate sensitivity and spatial resolution, and yet within acceptable time limits for vibration or dynamic strain detection. Fortunately, due to the huge hard work of researchers from the fiber sensor community over the last 20 years, the performances of distributed strain or temperature sensors are satisfactory used for many applications that require large areas of coverage with high location accuracy, especially for distributed sensors based on Brillouin scattering, the strain resolution is a few micro-meters over one meter (micro-strain) and the temperature resolution can be less than 1 °C [5-7]. The usual communication fibers can be set in structures such as bridges, buildings, dams, power generators, airplanes and other civil works, to report their internal status.

The most widely used fiber optic sensing (FOS) is fiber Bragg grating (FBG) [8]. However, the main disadvantages of employing FBGs as strain and temperature sensors have a high intrinsic temperature cross-sensitivity [9-11]. In literature, various techniques have been investigated to measure the strain, temperature, humidity and vibration [8, 9-13].

Zhou et al. [2] proposed an FBG sensor and fiber reinforced polymer (FRP) for 3D structural strain monitoring. The efficient results have been found by removing the errors after optimizing the structure of optical sensor. It was reported that the proposed scheme can be used for 3D strain measurement and can eventually be employed in many applications including monitoring the strain field.

Bai et al. [12] designed an FBG sensor network which was further used to monitor the heath of civil structures. It was reported that the proposed design gives the best results as compared to traditional strain measurement. Fuxin et al. [13] presented an experimental investigation on humidity measurements by using an FBG with multi-layer polyimide coating. The RH range covered was 30.80% with sensitivity 2 pm/%. Zhang et al. [14] investigated the response time of humidity sensors based on optical FBG. It was reported that the range of humidity was 30-90% RH with sensitivity 3.6pm% RH and response time 7 minutes were covered. Jung et al. [15] demonstrated an FBG with erbium doped fiber amplifier (EDFA), which can be simultaneously measured the strain and temperature. The parameters of FBG and EDFA were optimized at different bragg wavelengths and amplifier lengths (or pumping powers), respectively. It was reported that, the performance of strain and temperature can observe by monitoring the transmission dip shift and subtracting the temperature effect from it.

Nishino et al. [16] proposed a waveguide vibrations measurements sensor for sensing the force or displacement in syntactic foams (hollow particle filled lightweight composites). It was reported that, when the force was applied on the proposed fiber optical loop sensor (FOLS) then the radius of fiber loop changed, which causes transmission power losses and it can easily measured by the optical spectrum analyzer. The generator and shaker were also included in the system setup and shows that the FOLS can detect vibrations up to 100 Hz in frequency. Foroozmehr et al. [17] proposed FBG for structural health monitoring. They described the design, fabrication, and calibration of novel dual parameter FBG sensor to simultaneous measured the strain and temperature. The proposed sensor was used to measure the strain and temperature (up to $2\times10^{-3}\mu\epsilon$ and 50^{o} C, respectively).

Unfortunately, these investigations are based on the monitor the civil structures in the presence of FBG sensor. But FBG also have some disadvantage such as difficult to design, hard to implement, expensive etc. Till now, no investigations have done on optical amplifiers like optical sensors, as these the cheaper than FBG. In previous studies, the semiconductor optical amplifiers (SOAs) are used as pre-amplifier, post-amplifier, inline amplifier, wavelength converter, logic gates but the SOA is still to investigate as optical sensors [18- 23]. In this paper, we have extended the previous work by measuring the vibration and temperature using the low cost SOA and Raman amplifier.

After the introduction, section II explains the setup of the system, in section III results and discussion are described and finally, section IV summarizes the conclusions.

2. System setup

The block diagram of proposed setup based on SOA and Raman amplifier is shown in Fig. 1 and 2, respectively. Here SOA and Raman are used as optical sensors to measure vibration and temperature, respectively. The continuous wave laser tuned at 1550nm is used as optical source with input power of -5dBm.

Table 1. Various parameter of SOA.

Sr. no.	Name of parameter	Value
1	Attenuation	0.2 dB/km
2	Effective interaction area	72 μm^2
3	Raman gain reference pump	1000nm
4	Rayleigh back scattering	5×10^{-5} km^{-1}
5	Upper pump reference	1450nm

Table 2. Various Parameter of Raman amplifiers.

Sr. no.	Name of parameter	Value
1	Attenuation	0.2dB/km
2	Effective interaction area	72 μm^2
3	Raman gain reference pump	1000nm
4	Rayleigh back scattering	5×10^{-5} km^{-1}
5	Upper pump reference	1450nm

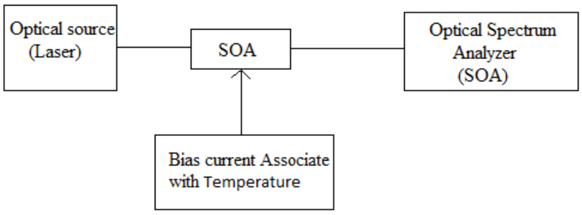


Fig. 1. Semiconductor Optical Amplifier as a Sensor

In this investigation, we have assumed that the vibrations values are associated with the SOA bias current, means if the vibration value increases then the associated bias current will also increases. The electronic circuitry can be used to implement this condition. The various parameters of SOA are described in Table 1. Another proposed system, as shown in Fig. 2, where Raman amplifier is considered as a sensor with co-propagating pump. The various parameters of Raman amplifier are described in Table 2. We have exposed the Raman amplifier temperature with vibrations, means if the vibration value increases then the associated temperature will also increases. Optical spectrum analyzer is used to analyze the optical spectrum and optical power after optical sensor.

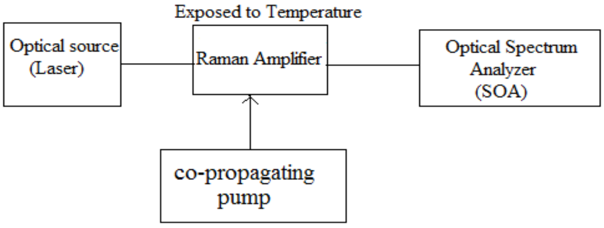


Fig. 2. Raman Amplifier as an Optical Sensor

3. Result and discussion

First, the SOA amplifier is investigated as an optical sensor to measure the vibration. We have varying the bias current from 5 to 100 mA at different amplifier length such as 100, 200 and 300 micro-meter to attain the result. Fig. 3 shows the graphical representation of the received optical power as a function of bias current. It can be observed that, the received optical power is directly propositional to bias current which is associated with vibrations.

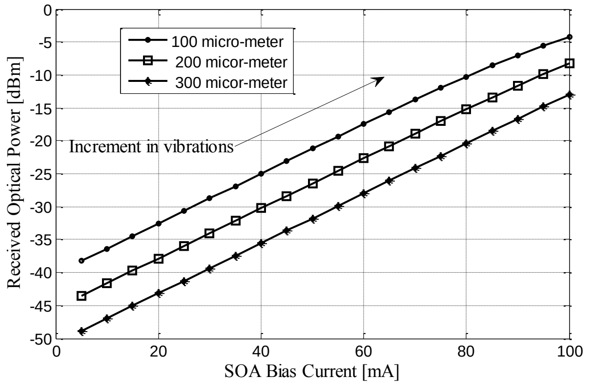
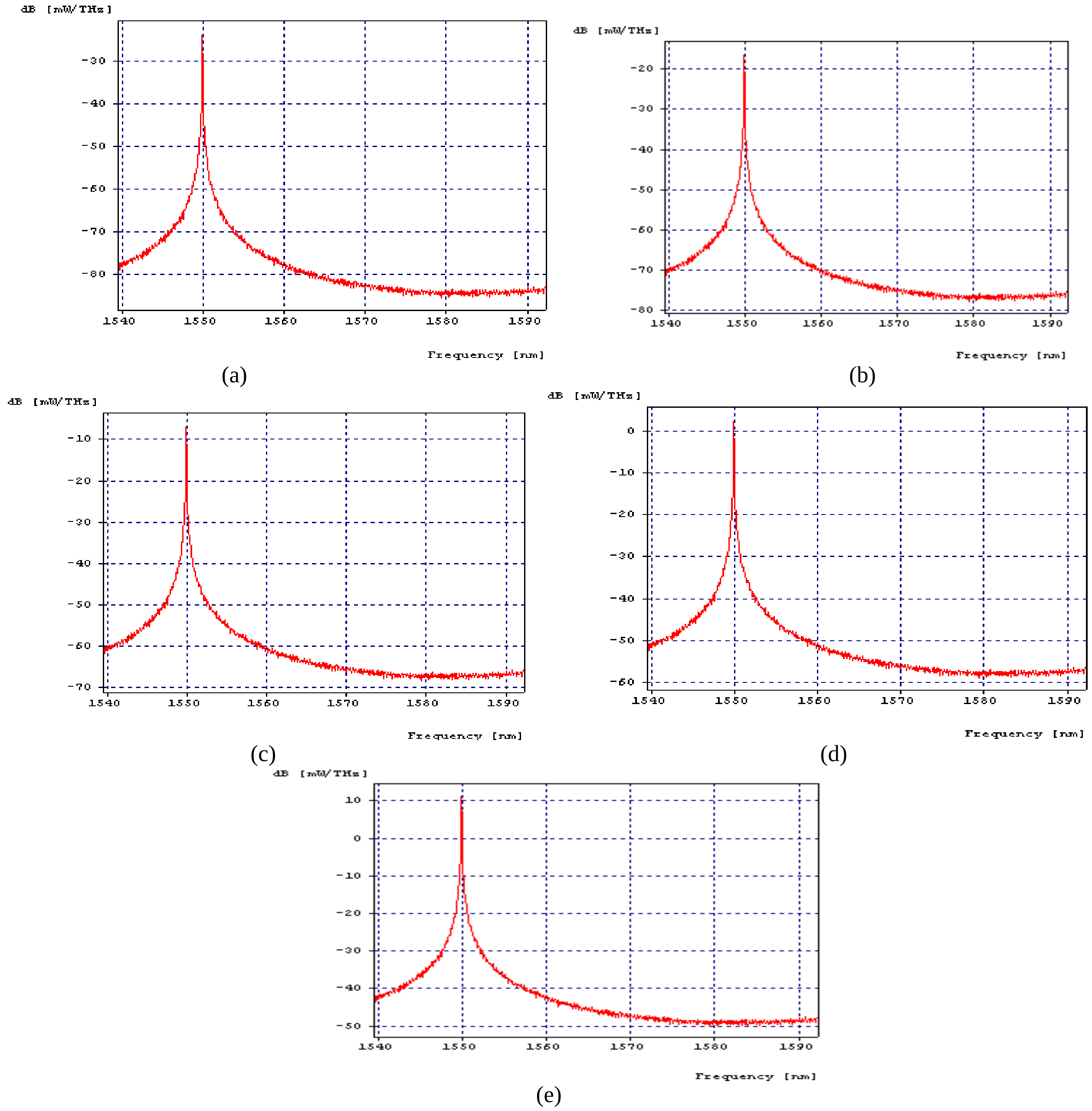


Fig. 3. Variations of Received output power as a function of SOA bias current for different amplifier length

As shown in Fig. 4, the optical spectrum is observed at the different bias current such as 5, 25, 50, 75 and 100 mA while the length of amplifier is set to 200 micrometer.

In Fig. 2 Raman amplifier is used to measure the temperature. The surrounding temperature is varying from 20 to 500 K and further the response of Raman amplifiers has been checked (in the term of optical power) with different fiber lengths. After observation we can understand that the received optical power is inversely propositional to the temperature exposed to Raman amplifier.



(a)

(b)

(c)

(d)

(e)

Fig. 4. Optical spectrum after SOA at bias current of: (a) 5mA, (b) 25mA, (c) 50mA, (d) 75mA (e) 100mA

Fig. 5 shows the graphical representation of received optical power as a function of temperature exposed to Raman amplifier, at different amplifier length. It can be observed that, when the temperature is increases from 5 k to 500 k then the output power of Raman amplifier decreases over 15.7dBm to -40.25dBm, 11.7dBm to -50.015dBm and 9.1dBm to -55dBm for 100km, 200km, and 300km of Raman amplifier length, respectively.

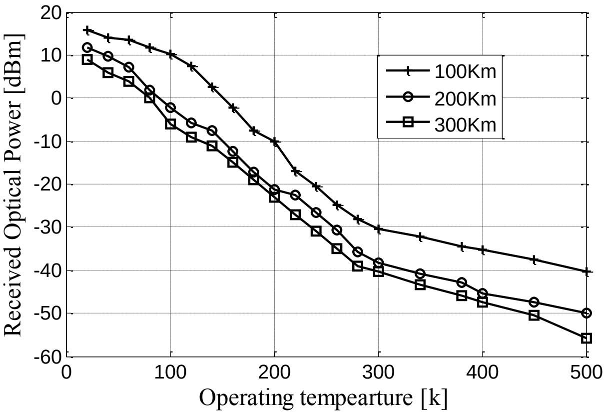


Fig. 5. Variations of Received optical power as a function of Raman Operating temperature for different Raman amplifier length.

4. Conclusion

This paper presents a consistent optical fiber SOA and Raman as a sensor to measure the vibrations and temperature, respectively. By detecting changes in the received optical power and optical spectrum, it is observed that the amplifier as sensor can be used for measuring localized temperature, vibrations, and strain over optical fiber link. In the case of Raman amplifier it is observed that, when the temperature is increases from 5 k to 500 k then the output power of Raman amplifier decreases over 15.7dBm to -40.25dBm, 11.7dBm to -50.015dBm and 9.1dBm to -55dBm for 100km, 200km, and 300km of Raman amplifier length, respectively. On the other hand, in the case of SOA the received power is vary from -38 to -4 dBm, -44 to -8 dBm, -49 to -13 dBm at different amplifier length such as 100µm, 200µm, 300µm, respectively.

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