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Fiber-fault monitoring technique for passive optical networks based on fiber Bragg gratings and semiconductor optical amplifier

Chien-Hung Yeh [a,*], Sien Chi [b,c,1]

[a] *Transmission System Department, Computer and Communications Research Laboratories, Industrial Technology Research Institute, Rm. 223, Bldg. 14, 195, Sec. 4, Chung Hsing Road, Chutung, Hsinchu 310, Taiwan*
[b] *Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 300, Taiwan*
[c] *Department of Electrical Engineering, Yuan Ze University, Chung-Li 320, Taiwan*

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Abstract

A novel monitoring method for in-service fault indemnification in passive optical networks (PONs) is proposed and demonstrated experimentally. The proposed monitoring technique is based on fiber Bragg grating (FBG) sensors and fiber laser scheme, and a semiconductor optical amplifier (SOA) is used to serve as a gain medium. By detecting the number of the wavelength lasing, the fiber-fault can be monitored without affecting the in-service channels. Moreover, the strain behavior on the FBGs has also been discussed.

Keywords: Fiber-fault monitoring; FBG; SOA; Fiber laser

1. Introduction

Passive optical networks (PONs) are the major role in alleviating the last mile bottleneck for next generation broadband optical access network. For the enormous communication capacity of the fiber link, any service outage due to fiber cut will lead to tremendous loss in business. Therefore, a simple and effective monitoring configuration is highly desirable for timely fault identification along the fiber link. Moreover, the monitoring should be performed constantly while other channels are still in service to maximize the link utilization. In a tree-structured PON, fiber failure detection by an

* Corresponding author. Tel.: +886 939 442785; fax: +886 3 5828187.
E-mail addresses: depew@itri.org.tw, depew.eo89g@nctu.edu.tw (C.-H. Yeh).
1 Fellow, OSA.

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optical time domain reflectometer (OTDR) is not suitable because the Rayleigh back-scattered light from different branches cannot be distinguished at the OTDR. To overcome this drawback, several methods based on multi-wavelength OTDR [1,2], and reflection of optical amplifier's residual amplified spontaneous emission (ASE) [3,4], have been proposed.

However, fiber Bragg gratings (FGBs) are the passive sensors due to their feasibility of multi-point sensing [5], high signal-to-noise ratio (SNR). Using FBG and EDFA for the branched fiber-fault has also been reported [4]. Recently, FBG sensor systems based on fiber laser structures have been studied due to their high output power and SNR [6–9]. Since the fiber schemes have high SNRs compared to those of the passive structures, the homogeneous broadening of erbium ions will limit the number of lasing modes that are generally less than four and the lasing modes have unstably power fluctuates due to the gain competition. To solve this drawback, an optical tunable filter was used for scanning the lasing light [4,10], and the scanning speed limits the dynamic range of the sensor.

In this study, we experimentally propose and investigate an all-optical FBG-based fiber-fault monitoring technique in PONs by a fiber laser scheme, using a semiconductor optical amplifier (SOA) as a gain medium for dominating the effect of inhomogeneous broadening to overcome the lasing mode limitation. In addition, the strain effect on the FBGs has also been discussed.

2. Experimental scheme

Fig. 1 shows the proposed fiber laser sensor configuration for the fiber-fault monitoring for tree-structure PON. The monitoring configuration composes of an SOA, an optical reflector, a 3 dB optical coupler, an optical reflector (OR), a 1×8 optical splitter, and eight FBGs as the sensor heads. In the experiments, the eight FBGs used have different central wavelengths and reflectivities. The central wavelength and reflectivity of the FGB_1–FBG_8 are 1534.56 nm and 74.7%, 1539.58 nm and 81.8%, 1548.31 nm and 91.8%, 1552.6 nm and 87.7%, 1556.06 nm and 93.9%, 1557.97 nm and 94%, 1562.19 nm and 87.7%, and 1565.65 nm and 83.8%, respectively. The FBGs have similar 3 dB bandwidths of 0.4 nm. The OR has 100% reflectivity. The 3 dB bandwidth of the SOA is 40 nm from 1485 to

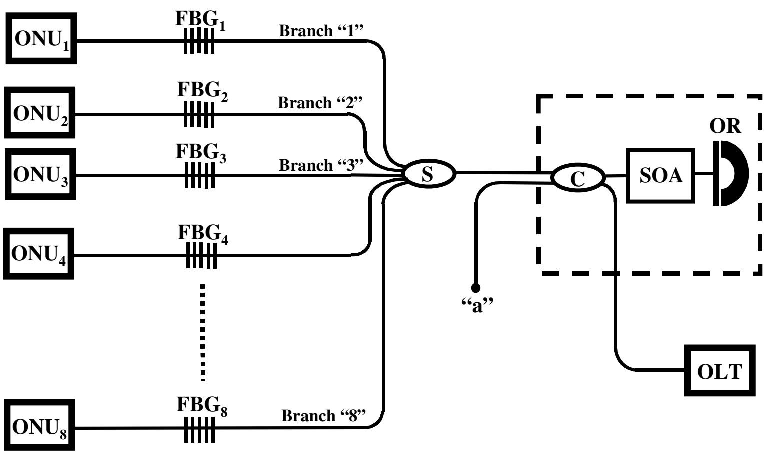

Fig. 1. The proposed fiber laser sensor configuration for the fiber-fault monitoring for tree-structure PON.

1535 nm, and the pumping bias current is operated at 200 mA. In the proposed scheme, an FBG of distinct center reflection wavelength is placed in front of an optical network unit (ONU) as the branch identifier. And the FBGs are employed to as the optical filters of reflection type, thus the wavelengths of lasing modes are equal to those FBGs used. For the EDF laser case, not all of the FBGs do produce the lasing modes because of the gain profile of the erbium ions and the dominant homogeneous broadening to induce a few modes. Due to the inhomogeneous broadening effect of the SOA, it is possible to generate multiple lasing wavelengths. In our experiments, a distance from an FBG to the optical coupler is about 5 m long, and the total insertion loss is nearly 7 dB. Then, eight lasing modes are equal to the number of the FBGs used. However, the reflectivities of FBGs, and properly cavity length will govern the optical output power and SNR of the lasing wavelengths. If the central wavelength separations of the FBGs were smaller than that of the present case and the gain medium can be suitably adjusted, the number of the lasing modes would be increased. In practical application of the conventional PON systems, the wavelength of 1490 nm is allocated for downstream channel from an optical line terminator (OLT) and the 1310 nm is for upstream data service from each ONU. Therefore, the identified wavelengths from FBGs have can be used to the upstream monitoring channels. As shown in Fig. 1, the number of lasing wavelength for the proposed laser scheme to monitor the branched fiber-fault in the tree-structure PON can be observed at the point "a" by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

3. Results and discussion

Fig. 2 shows the output wavelength spectra of the proposed fiber laser scheme for optical fiber-fault monitoring at the point "a" in the PON of eight branches without any fiber branch broken or cut. The inset of Fig. 2 is the ASE spectrum of an SOA. Fig. 2 indicates the maximum and minimum output power of 3.4 and −8.1 dBm over the wavelength operation range. All of the lasing wavelengths from the FBG_1 to FBG_8 are stable according to the shown results. The minimum SNR of all FBGs is above 23 dB for the readability on the monitoring scheme to each branch. And the maximum variation of the output power and SNR is nearly 11.5 and 10 dB between each FBG.

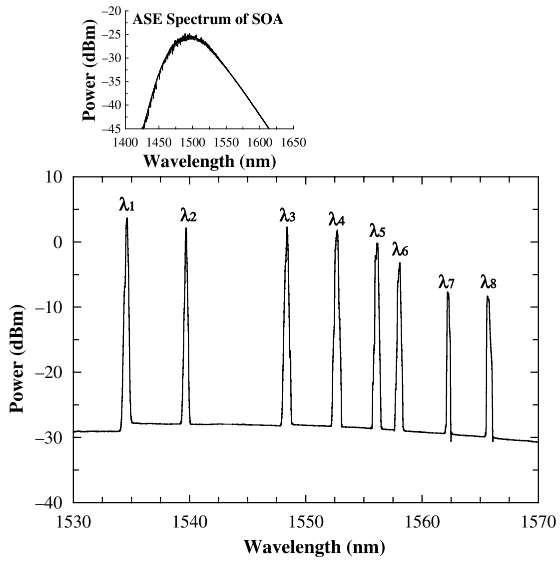

Fig. 2. The output wavelength spectra of the proposed fiber laser scheme for optical fiber-fault monitoring at the point "a" in PON system of eight branches without any fiber branch broken or cut. The inset of this figure is the ASE spectrum of an SOA.

To simulate the fault identification process, Fig. 3 shows the optical output spectra of the

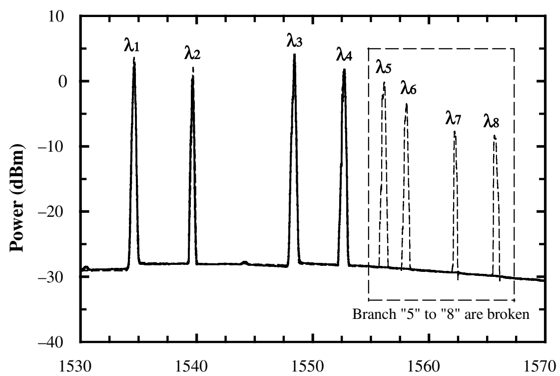

Fig. 3. The optical output spectra of the proposed monitoring configuration when the fibers of breach "5"–"8" are broken or cut by the external force applied.

proposed fiber branch monitoring when the fiber breach "5"–"8" are broken or cut by the external force applied. The solid line indicates the normally operation from branch "1" to "4", and the dotted line shows the fiber-fault behavior when the passive branch "5"–"8" are disconnected, as seen in Fig. 3. Therefore, by monitoring the number of lasing wavelength of the proposed laser scheme can be detected the branch faults.

Under the PON scheme, the laser scheme can also be served as a FBG sensor system.The FBG was placed on a mount and subjected to two-point pulling for the induced strains of 0–2000 με. The maximum strain variation on the FBG depends on the induced strains of 2000 με. Fig. 4(a) shows the strain versus the lasing wavelength observed at the "a" position, when the different strain variation was applied on FBG_2 ($\lambda_2 = 1539.58$ nm). The shift variation of the central wavelength is ~2.2 nm as the maximum strain variation on the FBG. Therefore, the experimental results are not influenced by the partial homogeneous broadening effect of the SOA [11] because the output power and SNR are similar than that of without strain effect, as shown in Fig. 4(b).

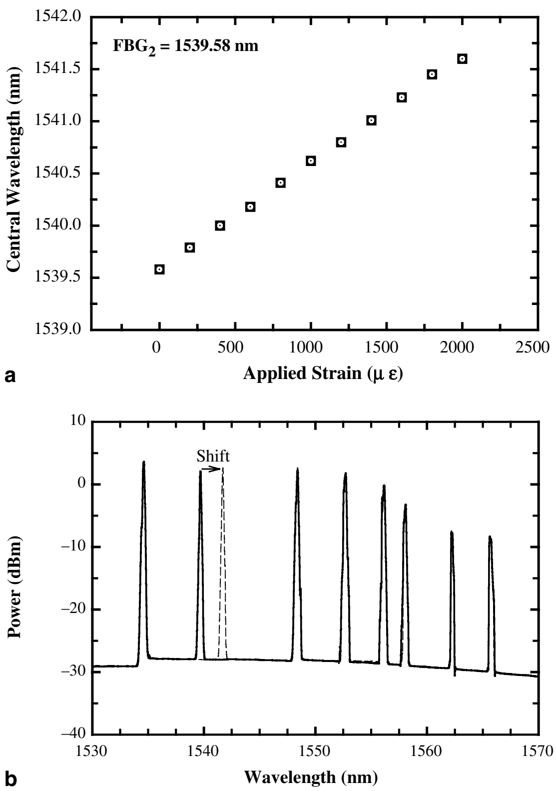

Fig. 4. The strain versus the lasing wavelength when the different strain was applied on FBG_2 ($\lambda_2 = 1539.58$ nm) observed at the "a" position.

4. Conclusion

A novel monitoring method for in-service fault indemnification in PON is proposed and demonstrated experimentally. The proposed monitoring technique is based on the FBG sensors and fiber laser scheme, and a semiconductor optical amplifier (SOA) is used to serve as a gain medium. By monitoring the number of the wavelength lasing, the optical fiber-fault of the branches can be detected without affecting the in-service channels.

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