The International Journal of Engineering and Science (IJES)
|| Volume || 7 || Issue || 9 Ver.III || Pages || PP 26-33|| 2018 ||
ISSN (e): 2319 – 1813 ISSN (p): 23-19 – 1805

Opticalfiber Micro-Bending Sensor System: Fabrication And Characterization

Marwan Hafeedhyounus
Department of Physics, college of education, Mosul University

--***ABSTRACT***--
In this study, an optical fiber micro-bending pressure sensor system is fabricated and investigated. This system consistsof two parts: a multimode optical fiber, which is a sensor part, and the OTDR device, which is an analyzer of the optical signal that propagateinside the optical fiber. The multimode optical fiberis fabricated using etching chemical method.The clad of the fiber with 1 cm length is etched by hydrofluoric acid. The sensing systemis used to detect small changes in the pressure thatis produced from the linear displacement of the two plats of the Mode Scrambler. The relationship between the applied pressure and the losses in the OTDR trace is calculated during the monitoring process. The results show that removing the jacket and the clad of the optical fiber, leads to increase the sensitivity of the sesor. The highest sensitivity of sensing system is 168.4 dB/cm after etching cladding of fiber, while the lowest sensitivity is 131.4 dB and 97.6 dB for the clad and the jacket, respectively. In addition, the multimode optical fiber with the core only offers better sensitivity to the small changes in the applied pressure compared with the multimode optical fiber with the core and the jacket.

Date of Submission: 06-09-2018 Date of acceptance: 22-09-2018

I. INTRODUCTION

Since the end of the last century and the beginning of this century, scientists have been able to diagnose and discuss various issues to develop and manufacture devices of small size, low cost, good efficiency and high responsibility. These numerous studies have led to the emergence of optical fibers. Optical fibers are light in weight, small in size, high flexible, easy to handle and not affected by the electromagnetic field. Optical fiber also has no harmful side that effects on the environment because using the light to carry the information instead of electricity. The optical fibers can transmit light signals for long-distances without any significant losses. These advantages have led to the emergence of fiber optic sensor technology [1-4].

Using optical fibersas sensors have been extensively applied in various applications such as, in plant fuel stations and oil pipelines [5-8]. In addition, many different optical fiber sensorsare invented and fabricated, such as pressure sensors [9], temperature sensors [10], FBG sensors [11], SPR sensors [12, 13], and microwave bending sensors [14] -15]. All of these species of sensors have a single working principle in which optical fiber works as a sensing part to sensitize the surrounding medium. In addition, fiber optic sensors have been used in many different fields such as, the medical field [16], the architecture of building structures and wells [17-18].

The optical fiber sensor system consists of three main parts: an optical source, which generates the pulse light, an optical fiber that acts as an sensor, and the optical detector that receives the light pulses coming from the source. When light is transferred from the source to the sensing part in the fiber, the properties of light (intensity, wavelength and phase) is changing which leads to change the light signal that falling on the detector, and this can be used in the control process [19, 20].

There has recently been growing interest in the development of optical fiber sensors for micro-bending, where many researchers have manufactured and adapted these types of sensors in various fields [21-24]. Most of these studies used OTDR technology to describe the response of optical fiber sensors. OTDR technology is one of the most important techniqueswhuch used in optical fiber safety test. It is also used in calculating fiber length, attenuation and losses along the fiber. Additionally, the applied pressure produces a curvature at specific pointalong of optical fiber, which leads to increase the losses in the power of the optical signal, and this can be accurately measured by using the OTDR device[25-30].

This research is aim to build a micro-bending optical fiber sensors system. The system consists two parts,the first part is the multimode optical fiber that acts as a micro-banding sensor due to the applied pressure and the second part, represents the OTDR device, which is used as an analyzer for the optical signal transmitted within the fiber.

II. PRINCIPLEOF OPTICAL TIME DOMAIN REFLECTOMETER (OTDR)

The principle of OTDR device is based on the reflected light in an optical fiber. The optical fiber is connected to the OTDR device from one side only and the other side (the far end) of the fiber remains free in the air as shown in Figure 1. The OTDR consists of the Light source, Photo-detector, Coupler and Signal processing. This device used to measure the attenuation ofreflected light in the fiber. In addition, the OTDR device is used to determine the losses at the mechanical connectors, the splicing parts as well as the identification of all other defect points along the fiber. Also, theOTDR displays the attenuation trace including all events resulting from defects as shown in Figure 2 [31-34].

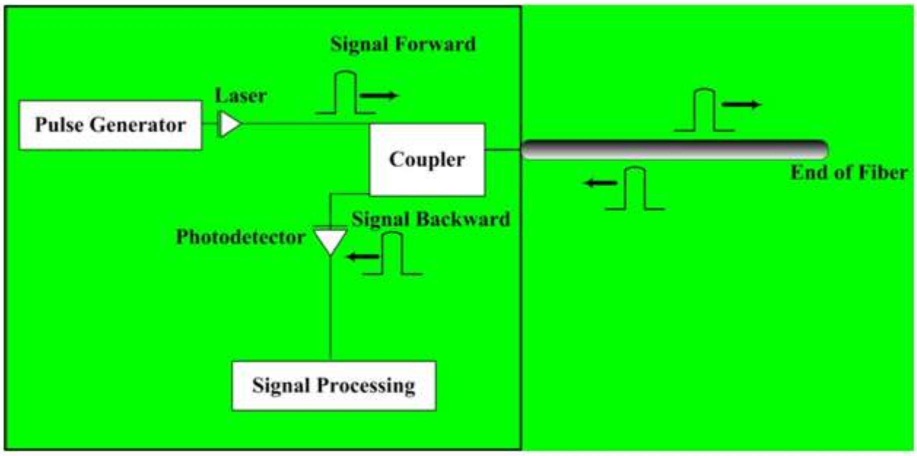

Figure 1. Basic components of the OTDR device

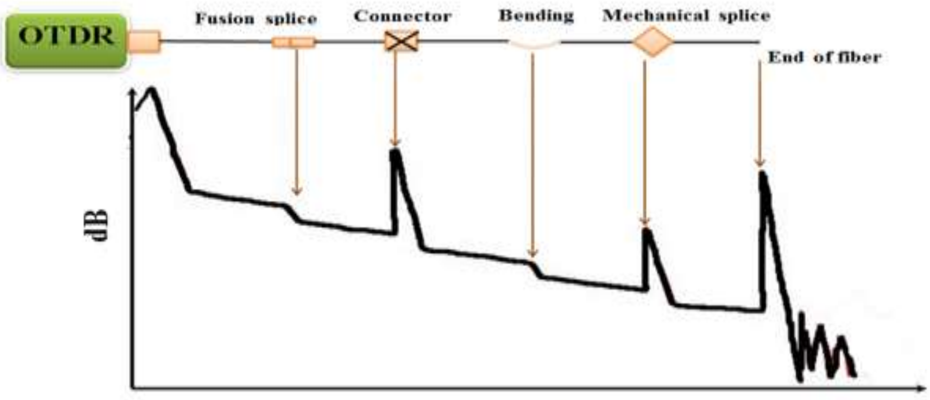

Figure 2. Curved attenuation of the OTDR device

III. FABRICATION OF OPTICAL FIBER SENSOR

In the proposed sensing system, a multimode optical fiber (MMF) with a refractive index of 1.456 and a length of 60 m is used as the micro-bending pressure sensor. The optical fiber consists of a core and a clad with a diameter of 50 µm and 125 µm, respectively. This type of fiber is characterized by the carry a large amount of light compared to the single mode fiber (SMF), which leads to increasing the amount of reflected light or incoming light to the detector of the OTDR device.

The sensing part is fabricated by etching 1 cm of the clad from the fiber using the chemical etching method. First, before the etching process and to make sure that the fiber is free from any impurities, the fiber is cleaned by acetone, alcohol and then washing by distilled water respectively. This process is followed by removing all impurities using special paper tissues to clear and dry the optical fibers. Second, the optical fiber is fixed on a U-shaped plastic holder, and then it is immersed inside the hydrofluoric acid bath (49% HF). HF acid has the properties of reaction with silica, which is used to dissolve this material while not interacting with the plastic material. In addition, the claddingof the fiber is completely removed within 20 minutes inside the HF acid. Figure 3 shows the image of optical fiber before and after the etching using an electron microscope. It can be seen that the cladding of optical fiber has been completely removed without any damage to the core surface.

Note that, this reduced the diameter of fiber from 125 μm to 50 μm, with a smooth surface of core that is free from any unwanted roughness which may effecton the sensitivity of the optical fiber.

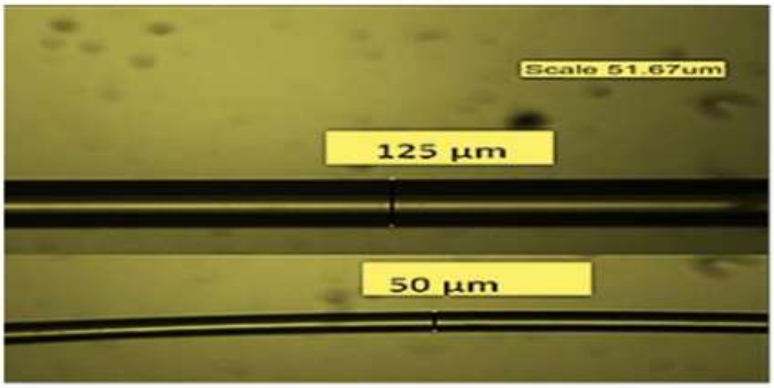

Figure 3. Optical fiber diameter before and after the etching

IV. MICRO-BENDING SENSOR SYSTEMSET UP

Figure 4a shows the Mode Scrambler tool used in this research to generate the micro- bending at the sensing part of the optical fiber.This tool produces periodic deformation on the fiber due to the resulting pressure. It consists of a pair of plats with teeth in each plate made of stainless steel. Also, one of the plates is fixed which cannot be moved, while the second platis movable part forward or backward using a knob. In addition, the control knob is in the form of a circle divided from 0^o to 360^o. Its used to increase or decreases the pressure at the sensing part placed between two plates. When the control knob move in angular displacement, it leads to linear displacement in the movable plate. Additionally , the Mode Scrambler can be used to convert the angular displacement to linear displacement in the movable plate, and this process leads to increases or decrease the distance between the two plates according to the direction of the control knob. The relationship between the angular displacement and linear displacement is calculated using the traveling microscope as shown in Figure 4b.

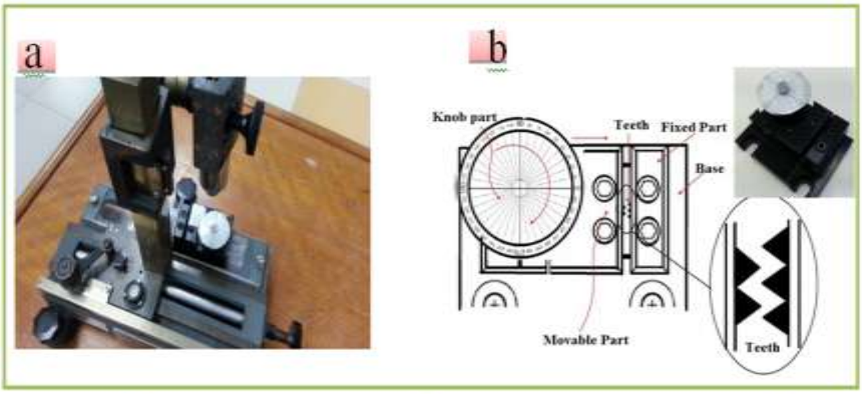

Figure 4. (a) the traveling optical microscope(b) Illustration the parts of the Mode Scrambler

Figure 5 shows the optical fiber micro-bending sensor system after placing the fiber between the two plates of the Mode Scrambler at sensing parte. In such case, the disturbance can be observed at the sensing part of fiber (zoom-in) between the teeth of two plates. When the applied pressureisincreasingon the fiberdue to the teeth of plates, the intensity of the transmitted light inside the fiberis change. Thus, the attenuation spectrum in OTDR trace will alsochange and this leads to give theinformation of small change in the applied pressure on the sensing part.

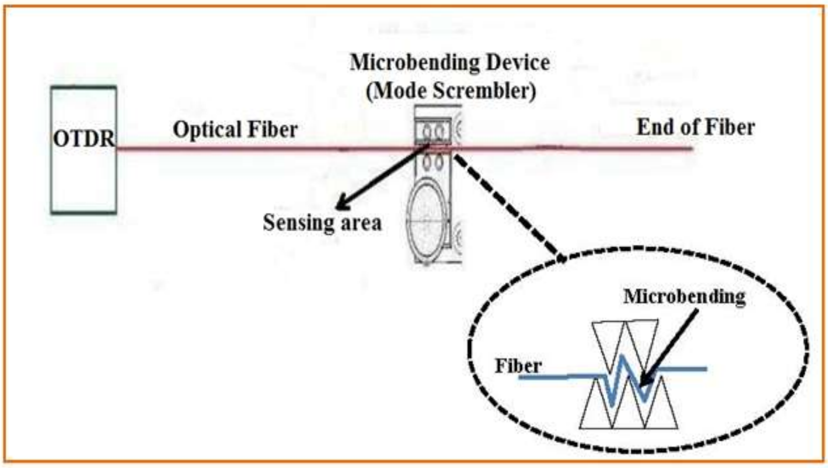

Figure 5. Illustrate the optical fiber sensor micro-bending system after placing the fiber between the plates of Mode Scrambler

V. RESULTS AND DISCUSSION

5.1. Calculate the relationship between the angle displacement and the linear displacement of the Mode Scrambler

Table 1 shows the relationship between angular displacements (θ^o) and the linear displacement (d μm) in the micro-bending device(Mode Scrambler). This relationship is calculated of both cases (increase and decrease)by placed the ModeScrambler on the travelling microscope. The distance between the two plates (linear displacement) is obtainedby changing theknob(see Figure 4).

Table 1. The relationship between the angular displacement and the linear displacement

	Increasing		Decreasing	
No.	Linear displacement (d μm)	Angular displacement (θ°)	Linear displacement (d μm)	Angular displacement (θ°)
1	0	0	0	0
2	21	30	21	30
3	42	60	42	60
4	60	90	60	90
5	84	120	84	120
6	105	150	105	150
7	126	180	126	180
8	147	210	147	210
9	166	240	166	240

As can see from Table 1, the value of the linear displacement increaseswhen the angle displacement isfrom $\theta^o = 0^o$ to $\theta^o = 240^o$ with increment step equal to 30^o. Also, when the angle displacement is decreased, the linear displacementdecreases for same values of θ^o. Figure 6 shows the relationship of increasing and decreasingbetween the angular displacement and the linear displacement. The result shows there is well linear relation ofangular displacement and linear displacement. In addition,the equation of the linear line fitting is given by $Y = 0.69X – 0.22$, where Y indicates the linear displacementand X indicates angular displacement. The R-square value for the linear line fitting is 0.9996, which indicates very good linearity. It should be noted that the values shown in Table 1 were used to determine the changes in the micro-bending (applied pressure) at the sensing part.

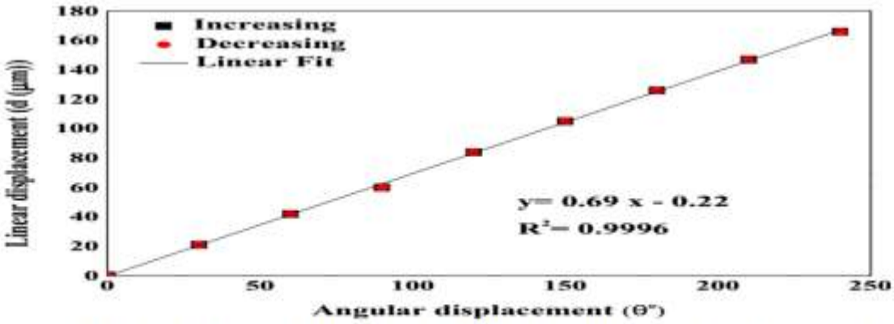

Figure 6. Linear fitting of the linear displacement as a function of increase and decrease of angle displacement

Determine the sensitivity of the optical fiber sensor system

The sensitivity of the sensing systemis defined as a changing of the losses in the OTDR trace due to the applied pressure at a sensing partof the optical fiber. Figure 7 a, 7 b and 7 c show the typical OTDRtraces after applied pressure at sensing part with jacket, clad and core respectively. The OTDR traces were determinedusing the YOKOGAWA OTDR VIEWER program. In these traces, the initial value of the angle displacement is equal to $\theta = 30^{o}$ which equates of 21 µmof a linear displacement (see Table 1).As can be seen in Figure 7, the step dropin the OTDR trace was increased after removed the jacket and clad of optical fiber.Consequently, the loss in the OTDR trace also increased due to the increased in the step drop. The results show that the highest loss was found to be 3.162 dB and this related to the sensing part after removing both of jacket and clad from the fiber (Figure 7 c). The lowest loss is equal to1.645 dBand 2.261 dBof sensing part with jacket and clad respectively (Figure 7 a and b).

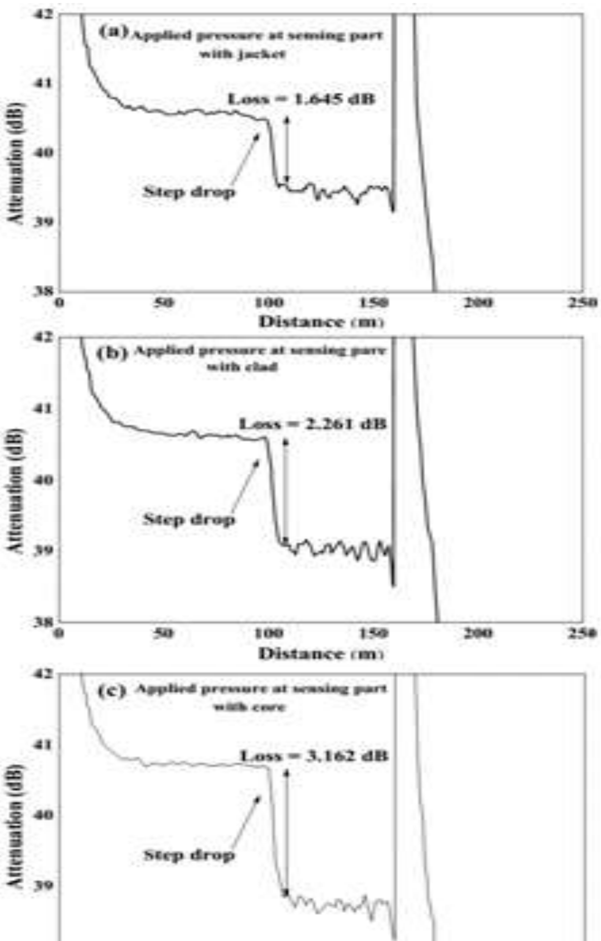

Figure 7. The typical OTDR tracesafter applying pressure at the sensing part with jacket, clad and core,(θ = 30o).

The comparison of OTDR traces of the optical fiber with jacket, clad and core is shown in Figure 8.

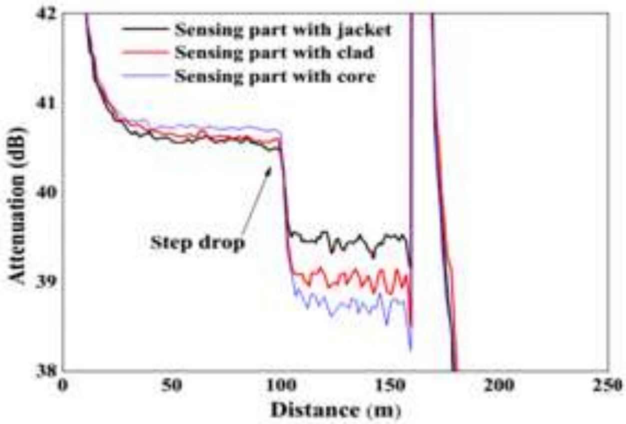

Figure 8. The comparison of OTDR traces of sensing part with jacket, clad and core, (θ = 30o)

The experiments were performed of different values of the angular displacement (θ=30^o – θ=240^o) with increment step of θ=30^o. And the reading of the corresponding losses from the OTDR traces were measured. Figure 9 shows the linear displacement versus the losses from the OTDR traces of sensing part with jacket, clad and core. The losses recorded using OTDR trace were found to be proportional linearly to the linear displacement. The results were further analyzed to obtain the sensitivity of optical fiber sensor. The sensitivity was estimated to be 168.4 dB/cm, 131.4 dB/cm and97.6 dB/cmof the sensor with jacket, clad and core respectively.It can see from Figure 9 that the sensitivity of the sensor with core only is larger than the sensitivity of the sensor with jacket and clad.This is because the bare core of the sensor was in direct contact with the applied pressure which induced changes in optical behavior leading to loss more of light and thus the response increases.Overall, the results show that the optical fiber sensor system includes the multimode fiber sensor and OTDR has potential for pressure monitoring, and they are able to localize the change in the applied pressure at unclad part of optical fiber.

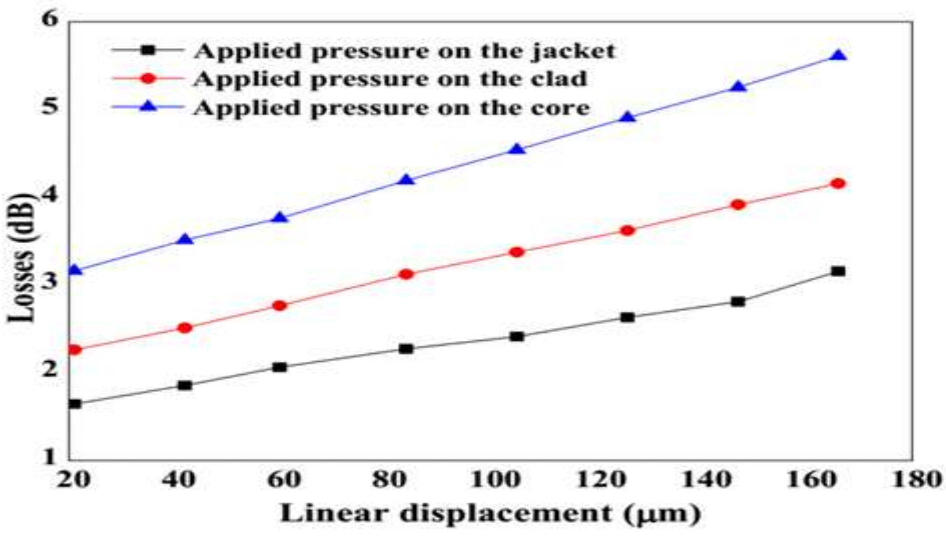

Figure 9. The losses of the OTDR trace versus the linear displacement (applied pressure) of sensor with jacket, clad and core.

VI. CONCLUSION

In this work, an optical fiber micro-bending sensor system based OTDR and multimode optical fiber was presented. The chemical etching method was used to remove 1 cm of cladding from the optical fiber. The experiment was performed to test the ability ofsensing system to localize the pressure produced from the teeth of two plates of Mode Scramblerat sensing part. The losses (step drop) from the OTDR trace at the sensing part were affected via applied pressure. The results indicated that the responseof the sensing part was enhance after etchingprocess compare to sensing response with jacket and cladding.The maximum sensitivity of sensing system was equal to168.4 dB/cm of sensing part after etching process,while the minimum sensitivities were equal131.4 dB/cm and97.6 dB/cmof sensing part with jacket and clad respectively.Due to a good linearity between the applied pressure and the losses produced from the step drop in the OTR trace, the proposed sensing system can be implemented for practical pressure measurement.

ACKNOWLEDGMENT

Thisworkis supported staff at the Physics department, college of education, Mosul University for providing research facilities required tocomplete this study.

REFERENCES

[1]. Hui, Chen, Michael, Buric, Paul, R. Ohodnicki, Jinichiro, Nakano, Bo, Liu, & Benjamin, T. Chorpening. (2018). Review and perspective: Sapphire optical fiber cladding development for harsh environment sensing. Applied Physics Reviews, 5(1), 011102.
[2]. Lee, Byoungho. (2003). Review of the present status of optical fiber sensors. Optical Fiber Technology, 9(2), 57-79.
[3]. Yariv, Amnon, and PochiYeh. "Photonics: optical electronics in modern communications (the oxford series in electrical and computer engineering)." Oxford University 22 (2006): 24-66.
[4]. Webb, D. J. 2002. Optical-Fiber Sensors: An Overview. MRS Bulletin. 27(5): 365-369.
[5]. Zhao, C., Ye, L., Yu, X., and Ge, J. 2012. Continuous Fuel Level Sensor Based On Spiral Side-Emitting Optical Fiber. J. Control Sci. Eng. 4(2): 21-27.
[6]. Buerck, J., Roth, S., Kraemer, K., and Mathieu, H. 2003. OTDR Fiber-Optical Chemical Sensor System For Detection And Location Of Hydrocarbon Leakage. Journal of Hazardous Materials. 102(1):13-28.
[7]. Black, P. 1992. A Review of Pipeline Leak Detection Technology. Springer Netherlands.
[8]. Tow, Kenny Hey, et al. "Exploring the Use of Native Spider Silk as an Optical Fiber for Chemical Sensing." Journal of Lightwave Technology 36.4 (2018): 1138-1144.
[9]. Wang, Xue, et al. "An MEMS optical fiber pressure sensor fabricated by Au-Au thermal-compression bonding." 2017 International Conference on Optical Instruments and Technology: Advanced Optical Sensors and Applications. Vol. 10618. International Society for Optics and Photonics, 2018.
[10]. Herrera, Christian, et al. "Use of a fiber optic distributed temperature sensing system for thermal response testing of ground-coupled heat exchangers." Geothermics 71 (2018): 331-338.
[11]. Min, Rui, et al. "Fast inscription of long period gratings in microstructured polymer optical fibers." IEEE Sensors Journal18.5 (2018): 1919-1923.
[12]. Zhao, Yong, et al. "Smart Hydrogel-based Optical Fiber SPR Sensor for pH Measurements." Sensors and Actuators B: Chemical (2018).
[13]. Qian, Siyu, et al. "Boronic acid functionalized fiber-optic SPR sensors for high sensitivity glycoprotein detection." Sensors and Actuators B: Chemical (2018).
[14]. Arcas, Ariadny da S., et al. "Surface plasmon resonance and bending loss-based u-shaped plastic optical fiber biosensors." Sensors 18.2 (2018): 648.
[15]. Berthold, John W. "Historical review of microbend fiber-optic sensors." Journal of lightwave technology 13.7 (1995): 1193-1199.
[16]. Peterson, John I., and Gerald G. Vurek. "Fiber-optic sensors for biomedical applications." Science 224.4645 (1984): 123-127.
[17]. Udd, Eric, and William B. SpillmanJr, eds. Fiber optic sensors: an introduction for engineers and scientists. John Wiley & Sons, 2011.
[18]. Wheeler, Lisa N., et al. "Measurement of distributed dynamic rail strains using a Rayleigh backscatter based fiber optic sensor: Lab and field evaluation." Transportation Geotechnics14 (2018): 70-80.
[19]. Webb, D. J. "Optical-fiber sensors: an overview." Mrs Bulletin27.5 (2002): 365-369.
[20]. Grattan, K. T. V., and T. Sun. "Fiber optic sensor technology: an overview." Sensors and Actuators A: Physical 82.1-3 (2000): 40-61.
[21]. Chen, W. P., et al. "Multimode fiber tip Fabry-Perot cavity for highly sensitive pressure measurement." Scientific reports 7.1 (2017): 368-374.
[22]. Berthold, John W. "Historical review of microbend fiber-optic sensors." Journal of lightwave technology 13.7 (1995): 1193-1199.
[23]. Luo, Fei, et al. "A fiber optic microbend sensor for distributed sensing application in the structural strain monitoring." Sensors and Actuators A: Physical 75.1 (1999): 41-44.
[24]. Qiu, Jianchun, et al. "Optical fiber sensor experimental research based on the theory of bending loss applied to monitoring differential settlement at the earth-rock junction." Journal of Sensors 2015 (2015), 1:14.
[25]. Satar, NJ Muhd, NS Abdul Rahim, and M. K. Abd-Rahman. "Displacement Sensor for Structural Monitoring Using Optical Time-Domain Reflectometer." AIP Conference Proceedings. Vol. 1150. No. 1. AIP, 2009.
[26]. Bravo, Mikel, Montserrat Fernandez Vallejo, and Manuel Lopez-Amo. "Hybrid OTDR-fiber laser system for remote sensor multiplexing." IEEE Sensors Journal 12.1 (2012): 174-178.
[27]. Lhaten, RoslyAdbRahman. "Investigation on the Sensitivity of Optical Fiber Sensors, for Pressure Sensing, based on the OTDR Technique." Global Journal of Computer Science and Technology (2014).
[28]. Spirin, V. V., et al. "Fiber laser for application in phase sensitive optical time domain reflectometry." Fiber Lasers XV: Technology and Systems. Vol. 10512. International Society for Optics and Photonics, 2018.
[29]. Kong, Yong, et al. "Research on the ϕ-OTDR fiber sensor sensitive for all of the distance." Optics Communications 407 (2018): 148-152.
[30]. Huang, Zejia, et al. "Distributed measurement of axes misaligned splicing and multi-stress in polarization-maintaining fiber based on polarization-OTDR." Optics Communications423 (2018): 96-99.
[31]. Khermosh, Lior, Christopher Michael Look, and TiberiuGalambos. "Passive optical network (PON) in-band optical time domain reflectometer (OTDR)." U.S. Patent No. 8,406,620. 26 Mar. 2013.
[32]. Qin, Zengguang, et al. "High sensitivity distributed vibration sensor based on polarization-maintaining configurations of phase-OTDR." IEEE Photonics Technology Letters 23.15 (2011): 1091-1093.

[33]. Zhang, Ziyi, and XiaoyiBao. "Distributed optical fiber vibration sensor based on spectrum analysis of Polarization-OTDR system." Optics express 16.14 (2008): 10240-10247.
[34]. Wegmuller, Mark, François Scholder, and Nicolas Gisin. "Photon-counting OTDR for local birefringence and fault analysis in the metro environment." Journal of lightwave technology 22.2 (2004): 390-400.
[35]. Binu, S., VP MahadevanPillai, and N. Chandrasekaran. "OTDR based fiber optic microbend sensor for distributed sensing applications in structural pressure monitoring." Journal of Optics 35.1 (2006): 36-44.
[36]. Lhaten, RoslyAdbRahman. "Investigation on the Sensitivity of Optical Fiber Sensors, for Pressure Sensing, based on the OTDR Technique." Global Journal of Computer Science and Technology (2014).

Marwan Hafeedhyounus "Opticalfiber Micro-Bending Sensor System: Fabrication And Characterization "The International Journal of Engineering and Science (IJES),), 7.9 (2018): 26-33