Indian Journal of Science and Technology, *Vol 9(19), DOI: 10.17485/ijst/2016/v9i19/88556, May 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Multiple Bends Coated Intensity based Plastic Optical Fiber Sensor to Detect Liquid Level

Kunthi Aristiani and Heru Kuswanto*

Physics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Yogyakarta,
Jl. Colombo 1 Yogyakarta, Indonesia;
herukus61@uny.ac.id, kunthi.aristiani30@gmail.com

Abstract

Objectives: This study aims to obtain a sensitive liquid level sensor by using Plastic Optical Fiber (POF). **Methods/Analysis**: The sensor head is obtained by removing part of the jacket. This section is bent with a diameter of 2 cm. To determine differences in the sensitivity, the sensor head is also coated with aluminum or copper. In a fiber composed of four/five bends. He-Ne laser light inserted into the fiber optic. Output intensity is measured by a power meter. **Findings**: The diameter and the number of bends in the POF affects the intensity of the output, since the incident angle core becomes smaller than the critical angle so that not all of the light to be refracted toward the cladding. The coating on the cladding affects the intensity of the output of POF due to differences in the reflectance of the coating material. Coating affects the performance of the sensor. Aluminum coating on the fiber with four bends provide better sensitivity sensor. **Applications/Improvements:** This sensor can be used to monitor liquid levels. The number of bends and coating with aluminum on the sensor increases sensitivity.

Keywords: Aluminum, Copper, Level, POF, Sensor

1. Introduction

Fiber optic sensor technology has become a major part in optoelectronics and fiber-optic communications industry. Many of the components associated with this industry are often developed for applications of fiber optic sensors. The study of sensor optical fiber that has existed among them, level sensors petrol[1], liquid levels[2,3,15], the level of the liquid in a volumetric flasks as applications in industry[4], strain measurement[5], the humidity sensor in storage chemical[6,7], and temperature sensors[8,17].

Fiber optic sensor used a modified behavior of light waves. Methods for modifying can be done against the amplitude (intensity), frequency, and phase. Amplitude modification has the advantage of being easy to be processed[8–13]. This method is a simple method. Intensity changes occurred due to the leakage caused by the optical fiber subjected to pressure, temperature[17] changes, bending[18–20] or other physical treatment[16]. Modulating the intensity of the most widely developed can be conducted through a wave absorption in the core-cladding interface by modifying the optical fiber cladding. Intensity modulated optical fiber sensor (amplitude) by measuring the optical power or absorption that occurs both inside and outside the fiber optics. The advantage of the method of measuring intensity modulated is ease of implementation, quality and simplicity in signal processing. This modulation may occur outside (extrinsic)[11,14,17] or inside (intrinsic)[6,17] optical fiber.

This research examined the sensitivity of changes in the intensity of the POF sensor which has multiple bends. Sensitivity was also assessed for part sensing coated by aluminum and copper. In this study shown aluminum coated sensor increases the sensitivity.

**Author for correspondence*

2. Calculation of Leakage Losses in POF Bent

The numerical aperture of an optical fiber is useful to know the parameters that measure the ability of an optical fiber in collecting or trapping light. The value of the refractive index of core and cladding can be used to calculate the numerical aperture value by using the equation (1).

$$NA = \sqrt{(n_c ore^2 - n_c ladding^2)} = \sqrt{(1{,}49^2 -_1{,}41^2)} = 0{,}48 \quad (1)$$

Acceptance angle also indicates the range of values for an incident angle of light entering the optical fiber, which is still possible to be propagating in the core until it reaches the output end, then there should be a clear relationship between the numerical aperture and acceptance angle, as both the magnitude of this measure are two things that are basically the same. The formula used to determine the angle of acceptance as in equation (2).

$$\text{Acceptanceangle} = \arcsin\ (NA) = \arcsin\ (0.48)\ = 28.8^0 \quad (2)$$

Selection of the incident angle of 25^0 from the air core to be done so that light can be reflected back into the core (first medium) when the optical fiber is straight. The reflectance of the first bend can be used as input for the next bend is shown in Figure 1.

By using Snell's law can be determined angle values to allow light into the core

$$n_1 sin\theta_1 = n_2 sin\theta_2 ; n_{air} sin\theta_{air} = n_{core} sin\theta_{core} ; 1.0 sin 25^0$$
$$= 1.49 sin\theta_2 ;\ \theta_2 = 16.48^0 \quad (3)$$

The light will enter the core and keep moving until arriving at the boundary between the core and cladding, as shown in Figure 2.

Normal line of POF in straight position is perpendicular to the boundary. Figure 3 shows the normal line (old and new) to form a right triangle. In every triangle, the sum of the angular is 180^0. When subtracting the value

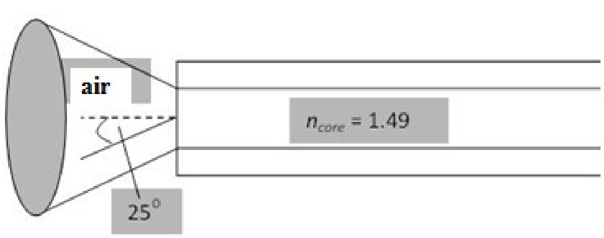

Figure 1. Selection of angle in the range of acceptance angle

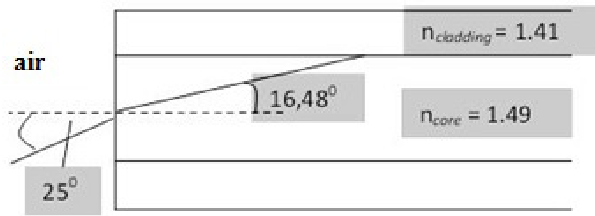

Figure 2. Light inserted into the core of POF.

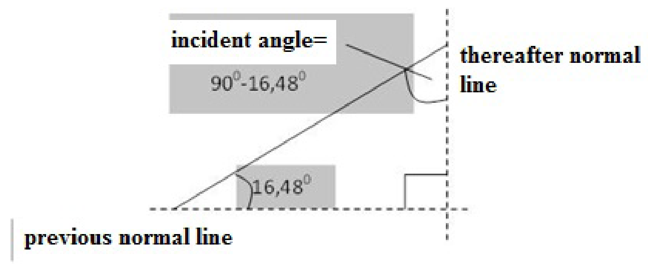

Figure 3. The normal lines are changed due to the bend of POF.

angle right angle corner 90^0 with a value of 16.48^0, it will get the value of the angle of incidence:

$$90^0 - 16.48^0 = 73.52^0$$

Next is to determine whether the light with the incident angle of 73.52^0 will be reflected back by the core-cladding boundary, or light can penetrate into the cladding. In order to determine this, first determine the magnitude of the critical angle at the boundary core and cladding. Equation 4 can be used to calculate the magnitude of the critical angle.

$$\theta_{crit} = \arcsin \frac{n_2}{n_1} = \arcsin \frac{1.41}{1.49} = 71.14^0 \quad (4)$$

Due to the angle of incidence greater than , then the light will be reflected back by the boundary into the first medium (core) as shown in Figure 4.

The incident angle to the plane of the bend is (θ_{core}) of 73.52^0. The bend is considered as a semicircle, with a diameter of 2 cm (distance between the cladding to the cladding) as shown in Figure 5.

By using a protractor, it can also be obtained angle comes from the core to the cladding of the normal line is 32^0. In making the normal line, first draw a tangent. Therefore normal lines are no longer in a vertical position. That is a nature of a tangent that intersects the circle

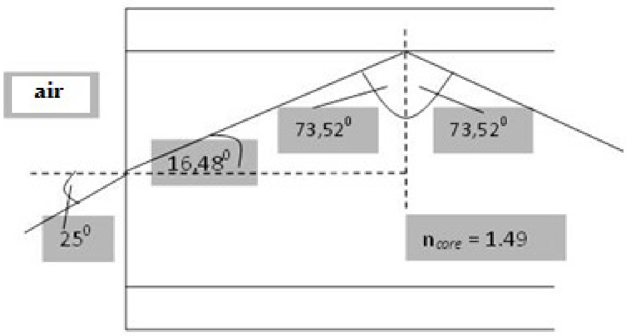

Figure 4. Reflection of light in the core.

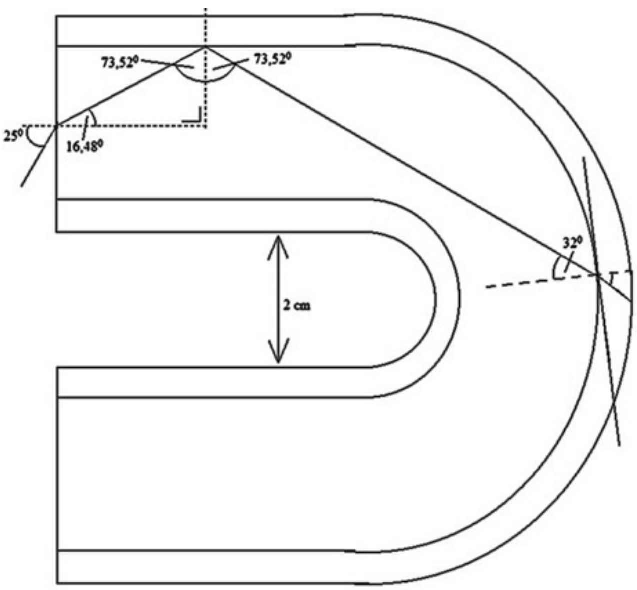

Figure 5. Propagation of light in the bend plane of core to cladding of POF.

at one point and is perpendicular to the radius of the circle.

If the light on a material with a different refractive index, there will be two things, the portion of the light is reflected and some of the light will be passed to the second medium. The magnitude of reflection on the core can be calculated using Fresnel Equation (5) and (6)

$$R = \left[\frac{n_1\cos\theta_1 - \sqrt{n_2^2 - n_1^2\sin^2\theta_1}}{n_1\cos\theta_1 + \sqrt{n_2^2 - n_1^2\sin^2\theta_1}}\right]^2 \quad (5)$$

$$= \left[\frac{1.49\cos 32^0 - \sqrt{1.41^2 - 1.49^2\sin 32^0}}{1.49\cos 32^0 + \sqrt{1.41^2 - 1.49^2\sin 32^0}}\right]^2 = 0.15\%$$

$$R_{\|} = \left[\frac{n_2\cos\theta_1 - \frac{n_1}{n_2}\sqrt{n_2^2 - n_1^2\sin^2\theta_1}}{n_2\cos\theta_1 + \frac{n_1}{n_2}\sqrt{n_2^2 - n_1^2\sin^2\theta_1}}\right]^2$$

$$= \left[\frac{1.41\cos 32^0 - \frac{1.49}{1.41}\sqrt{1.41^2 - 1.49^2\sin 32^0}}{1.41\cos 32^0 + \frac{1.49}{1.41}\sqrt{1.41^2 - 1.49^2\sin 32^0}}\right]^2 = 0.025\% \quad (6)$$

For one the bend with the angle of incidence (air to the core) of 25^0, then the value of the reflection coefficient perpendicular to the image plane (R_) 0.15% and parallel to the image plane (R‖) is 0.025%. It has also carried out the calculations for the other angles come from core to cladding; if the angle of incidence of core to cladding is getting smaller it will result in the reflection coefficient becomes smaller.

3. Methods

Optical fiber used in this study is a plastic optical fiber-type SH-4001-1.3. Optical fiber consists of a core, cladding and buffer. Core material used is polymethyl-methacrylate resin with a diameter of 980 µm and a cladding material used is a fluorinated polymer with a diameter of 1000 µm. The refractive index of core and cladding are 1.49 and 1.41, respectively[21]. The sensor is made by stripping the POF jacket. The length of POF jackets are stripped of 4 to 5 cm. One POF can contain 4 to 5 stripped places. Stripped part is then coated with copper or aluminum. The sensor is formed by bending the fiber section that is stripped, without or with layers. Bend diameter is 2 cm. Figure 6 shows one sensor designs are studied.

Figure 7 presents the experimental setup in this study. Sensors prepared inserted into the glass beaker. He-Ne Laser light inserted into the fiber optic. Optical power output of POF detected using Optical Power Meter. Put in a beaker of water slowly until the entire sensor is submerged. Measurements were taken at each increase in water level.

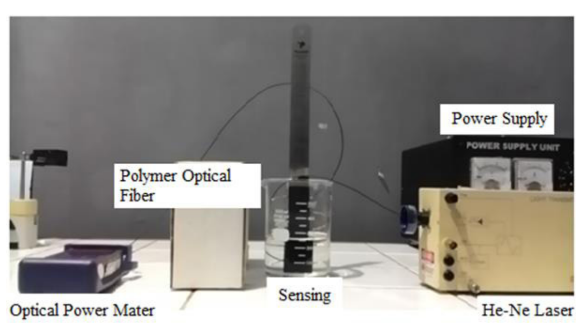

Figure 6. Experimental setup.

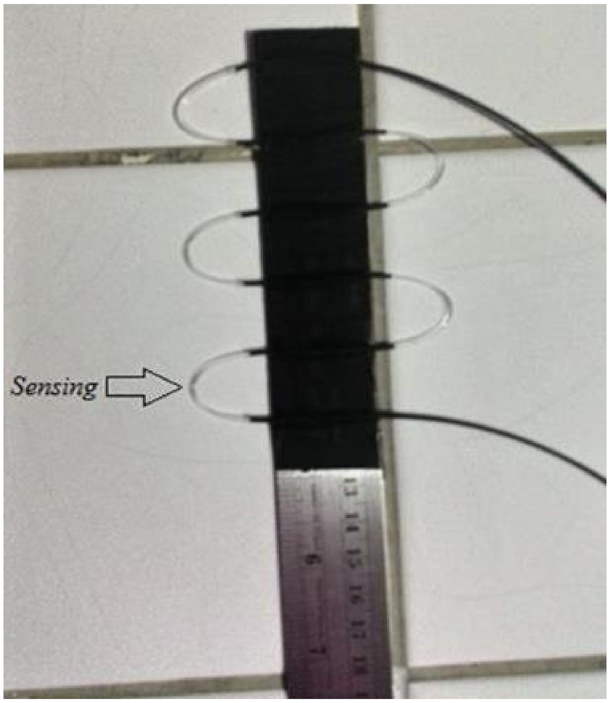

Figure 7. POF Sensor design.

4. Results and Discussions

Figure 8 shows the difference in power changes to the number of bends and the different of length sensing. Values shown are the normalized value. Normalization is done to the highest power value for each variation. Four variations of the configuration of the sensor showed a decrease in power as a function of the liquid level is almost similar. The slopes of the decline in the level of fluid which is less than 6 cm in four types of sensors are nearly coincident. The slopes of the decline in the level of fluid which is less than 6 cm in four types of sensors are nearly coincident. At 7 cm fluid level the slope is changed, especially for sensors with four bends with a length of 4 cm sensing. The slope changes quite sharply. Therefore sensors with four bends can be a good candidate compared with five bends sensor.

The characteristics of copper coated sensors are shown in Figure 9. In contrast to the sensor without a coating, the declines of four configurations do not coincide. For four-bend sensor, a 5 cm of length sensing decline sharper than of 4 cm. Two sensors with five bends have the same slope up to 6 cm liquid level. Afterwards the two split. Sensors with a length of 5 cm decreased more sharply. From these results, the copper coated sensors with four bends and 5 cm of length sensing is a good candidate as compared to other configurations.

Figure 10 displays a decrease in power as a function of liquid level of aluminum coated sensor. The slope of four sensors configuration are different. Two of five bends sensors both coincide since the beginning. However, the slope decline in the four-bend sensors separate from the

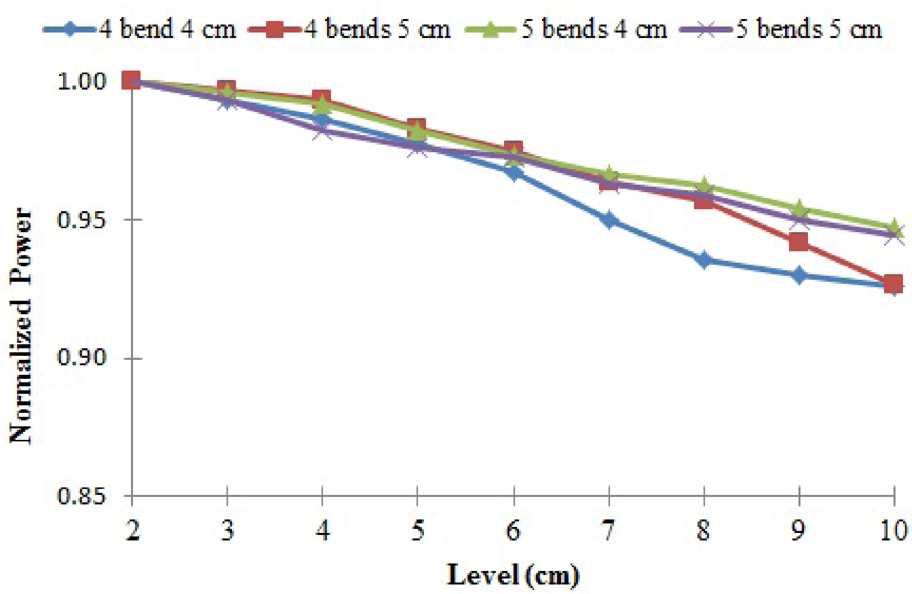

Figure 8. Differences in decreased power to the number of bends and the length the sensing in sensor without coating.

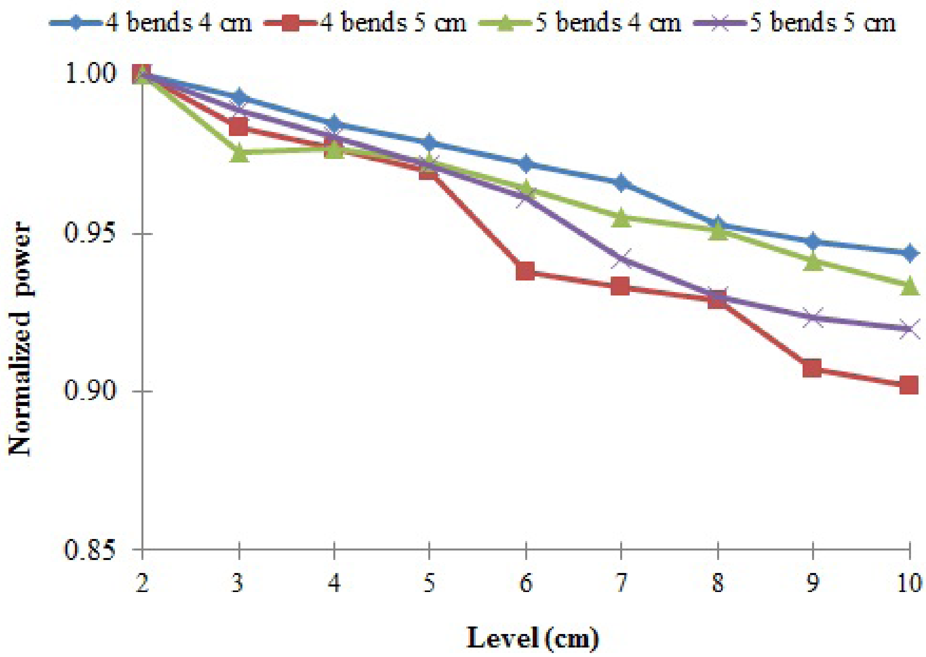

Figure 9. Differences in decreased power to the number of bends and the length the sensing in copper coated sensor.

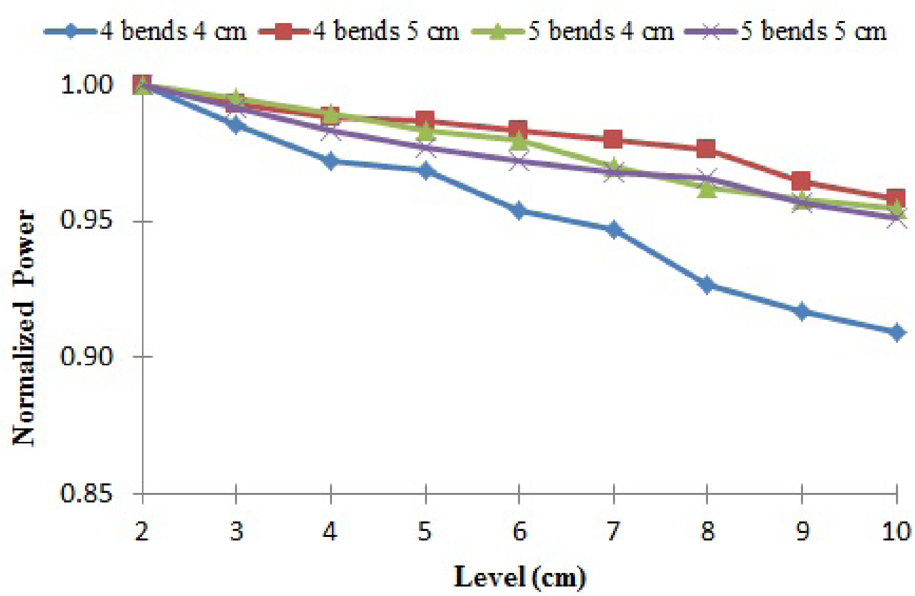

Figure10. Differences in decreased power to the number of bends and the length the sensing in aluminum coated sensor.

outset. Sensors four bends with a length of 4 cm sensing has a sharper decline than the other configurations. In contrast to the four bend sensor with a length of 5 cm sensing small sloped or flat.

Which configuration that has good sensitivity and high linearity? Figure 11 compares the decreased of power due the increase of liquid level for three types of sensors with four bends and the length sensing 4 cm. The third

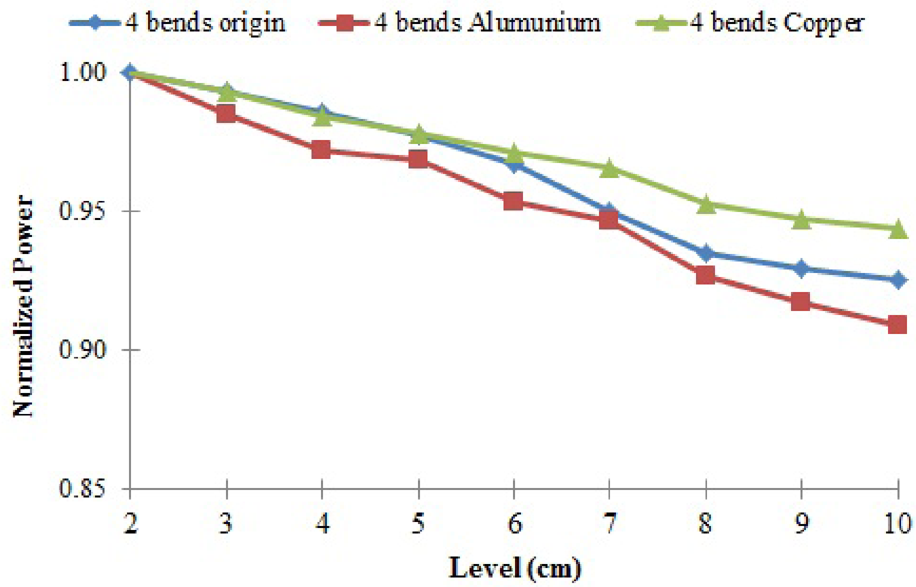

Figure 11. Comparison of transmission on fiber optic sensor without coating, aluminum and copper coated.

Table 1. The comparison of the linearity of sensors

Type the sensing	Sensing without coating	Sensing with copper coating	Sensing with aluminum coating
4 bends with 4 cm sensing	0.99 ± 0,02	0,99 ± 0,09	0,99 ± 0,02
4 bends with 5 cm sensing	0,98 ± 0,02	0,99 ± 0,03	0,97 ± 0,02
5 bends with4 cm sensing	0,99 ± 0,08	0,99 ± 0,01	0,99 ± 0,08
5 bends with 5 cm sensing	0,99 ± 0,07	0,99 ± 0,02	0,99 ± 0,01

type of sensor has a linearity which is almost the same as shown in Table 1. However, sensors with aluminum coating showed more steeply decline in the beginning, up to the level of 8 cm. After this point all three showed traces similarities.

5. Conclusion

The diameter and the number of bends in the POF affect the intensity of the output, since the incident angle core becomes smaller than the critical angle so that not all of the light to be refracted toward the cladding. The coating on the cladding affects the intensity of the output of POF due to differences in the reflectance of the coating material. Best sensitivity is obtained from sensor with 4 bends which has a length of 5 cm aluminum coated.

6. References

1. Montero DS, Vazquez C. Polymer optical fiber intensity-based sensor for liquid-level measurements in volumetric flasks for industrial application. ISRN Sensor Networks. 2012; 2012:7.
2. Sameer MC, Nicolas A, Jaeger F. Optical fiber-based liquid level sensor. Journal Optical Engineering. 2007; 46(11):114401–7
3. Antonio-Lopez JE, Sanchez-Mondragon JJ, May-Arrioja DA. Fiber-optic sensor for liquid level measurement. Optical Letters. 2011; 36(17):3425–7.
4. Mamun A, Ahmed N, Ahamed NA, Rahman SAM, Ahmad B, Sundaraj K. Use of wireless sensor and microcontroller to develop water-level monitoring system. Indian Journal of Science and Technology. 2014 Jan; 7(9):1321–6.
5. Harith Z, Irawati N, Batumalay M, Rafaie HA, Yun G, Harun SW, Nor RM, Ahmad H. Relative humidity sensor

employing optical fibers coated with ZnO nanostructures. Indian Journal of Science and Technology. 2015 Dec; 8(35):1–5.

6. Montero DS, Vazquez C, Mollers I, Arrue J, Jager D. A self-referencing intensity based polymer optical fiber sensor for liquid detection. Sensors. 2009; 9(8):6446–55.
7. Chang X, Li M, Han X. Recent development and applications of polymer optical fiber sensors for strain measurement. Frontiers of Optoelectronics China. 2009; 2(4):362.
8. Arrue J, Zubia J, Fuster G, Kalymnios D. Light power behavior when bending plastic optical fibres. IEE Proceedings Optoelectronics. 1998; 145(6):313–8.
9. Bilro L, Alberto N, Pinto JL, Nogueira R. Optical sensors based on plastic fibers. Sensors. 2012; 12(9):12184–207.
10. Chen YC, Chen LW, Chen PC. Combined effects of bending and elongation on polymer optical fiber losses. Opt Letters. 2005; 30(3):230–2.
11. Chen YC, Kuang JH, Chen LW, Chuang HC. Effect of plastic strain energy density on polymer optical fiber power losses. Opt Letters. 2006; 31(7):879–81.
12. Chen YC, Chen PC, Kuang JH. Effect of elongation deformation on power losses in polymer optical fibers. Appl Opt. 2006; 45(26):6668–74.
13. Chen YC. Power Losses in bent and elongated polymer optical fiber. Appl Opt. 2007; 46(21):4570–78.
14. Lomer M, Arrue J, Jauregui C, Aiestaran P, Zubia J, López-Higuera JM. Lateral polishing of bends in plastic optical fibres applied to a multipoint liquid-level measurement sensor. Sensors and Actuators A: Physical. 2007; 137(1):68–73.
15. Lomer M, Quintela A, Lopez-Amo M, Zubia J, Lopez-Higuera JM. A quasi-distributed level sensor based on a bent side-polished plastic optical fibre cable. Measurement. Science and Technology. 2007; 18(7):2261–7.
16. Annepu VNV, Rao AB. Overall noise analysis for transisition edge sensor at optical and infra-red wavelengths. Indian Journal of Science and Technology. 2015 Dec; 8(35):1–5.
17. Moraleda AT, Vazquez C, Zubia J, Arrue J. A temperature sensor-based on a polymer optical fibre macro-bend. Sensors. 2013; 13(10):13076–89.
18. Lu WH, Chen LW, Xie WF, Chen YC. A sensing element based on a bent and elongated grooved optical fiber. Sensors. 2012; 12(6):7485–95.
19. Kuang JH, Chen PC, Chen YC. Plastic optical fiber displacement sensor based on dual cycling bending. Sensors. 2010; 10(11):10198–10.
20. Zhao J, Bao T, Kundu T. Wide range fiber displacement sensor based on bending loss. Journal of Sensors. 2016; 2016:5.
21. Industrial Fiber Optics. 2015 Jul. Availabe from: http://i-fiberoptics.com/fiber-detail.php?id=13