Macrobending Multimode Plastic Optical Fiber Coated with PANI-PVA Composite as a pH Sensor

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Abstract: The pH measurement is essential in medicine, industry, and research, and each requires measuring instruments with different sensitivities. Measuring the pH of a solution, in principle, measures hydrogen ions in the solution. In this study, a pH sensor was designed and fabricated using macrobending multimode optical fiber. The optical fiber cladding was peeled off and replaced with a PANI-PVA (polyaniline-polyvinyl alcohol) composite layer, bent with a 2.0 and 2.5 cm diameter. The results showed that the pH sensor could measure the solution's pH linearly in the range of pH = 2 to 8. Macrobending optical fibers with 2.5 and 2.0 cm diameters have sensitivities of -7.7736 a.u./pH and -1.257 a.u./pH, respectively. Macrobending optical fiber with a diameter of 2.5 cm is more sensitive than macrobending optical fiber with a diameter of 2.0 cm but less precise.

Keywords: pH sensor; PANI-PVA; fiber optics plastic; macrobending

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http://dx.doi.org/10.12962/j24604682.v20i2.18883

I. INTRODUCTION

Optical fiber is widely used in communication systems as a medium for transmitting light. In its development, in addition to being used in communication systems, optical fiber is widely used as a sensor, among others as a gas sensor [1], humidity [2], NaCl concentration [3], and salinity [4]. Sensors based on optical fiber have several advantages, including high sensitivity and not being affected by electric and magnetic fields [5]. Generally, fiber optic cables consist of 3 main parts: coating, cladding, and core, as shown in Fig. 1(a). The coating is a plastic layer that protects the optical fiber from damage; cladding is a sheath of the core, which has a lower refractive index than the core. At the same time, the core is where light or rays propagate.

Light can propagate in optical fiber because light experiences total internal reflection at the boundary between the core and the sheath. In its propagation, light experiences a decrease in power (loss) due to absorption by the scattering fiber material and bending. Bending loss is one of several sources of optical fiber losses. Based on its type, as shown in Fig. 1(b), bending losses are divided into 2, namely macrobending and microbending [6]. Macrobending losses occur when the light or rays passing through the optical fiber are bent with a radius wider than the diameter of the optical fiber, causing power losses [7]. Macrobending losses occur due to uneven surfaces (in the micro order) and imperfect material coating processes.

However, this bending phenomenon can also be used as a sensor. Light waves propagating in the fiber core will be distorted if the fiber is bent. The speed of light propagating on the inside of the curve is almost slower than on the outside to maintain the shape of the wavefront. This means that the refractive index value of the fiber core in that section is smaller than when the fiber is straight. The smaller the radius of curvature, the closer the value is to the refractive index value of the cladding so that more light comes out of the fiber core, or the more significant the loss [8]. he application of plastic optical fibers as sensors is mostly done by modifying the fiber cladding. Febrielviyanti has replaced the plastic fiber cladding with a TiO_2-SiO_2 layer to measure environmental humidity [9], Khanikar uses a PANI-PVA coating [10], Chauhan uses a PANI/ZnO composite [11], and Mendez uses silica sol-gel to measure the pH of the solution [12].

The pH of a solution is an important parameter in the world of medicine, industry, and research. Each field requires measuring instruments with different sensitivities. Khanikar has made a pH sensor with optical fiber coated with PANI-PVA, with a straight-shaped sensing element design [10]. he sensor that has been successfully created can measure the pH of a solution in the range of pH = 2 to pH = 9. The quantity measured by the sensor is the output intensity. The experimental results show that the output intensity decreases as the pH value of the solution increases. Likewise, Chauhan uses a PANI/ZnO composite as a pH sensor with straight fiber optics [11]. Meanwhile, Mihai uses a PANI/PVA composite as a pH sensor with a sensing element in the form of a membrane [13]. As is generally known, polyaniline (PANI) as a conductive polymer material has unique characteristics, namely that it can undergo a change in electrical properties from an insulator (non-conductive) state to a conductor (or semiconductor) based on the level of protonation of the polyaniline material. As electrical properties (conductivity) change, optical properties (refractive index and absorptivity) also change based on protonation conditions and changes in chemical structure [14].

Polyvinyl alcohol (PVA) is a hydrophilic polymer that is smooth, yellowish-white in color, and odorless. It is a water-soluble polymer, non-toxic, has good miscibility, and has elas-

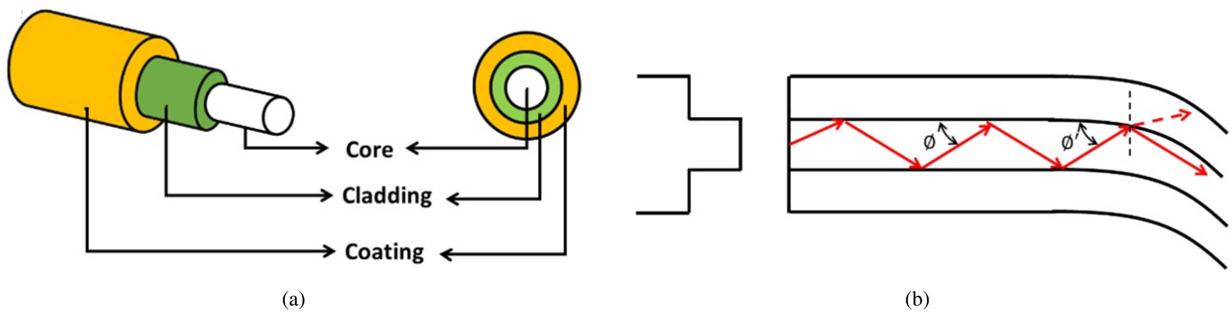

FIG. 1: (a) Optical fiber structure, (b) Macrobending fiber.

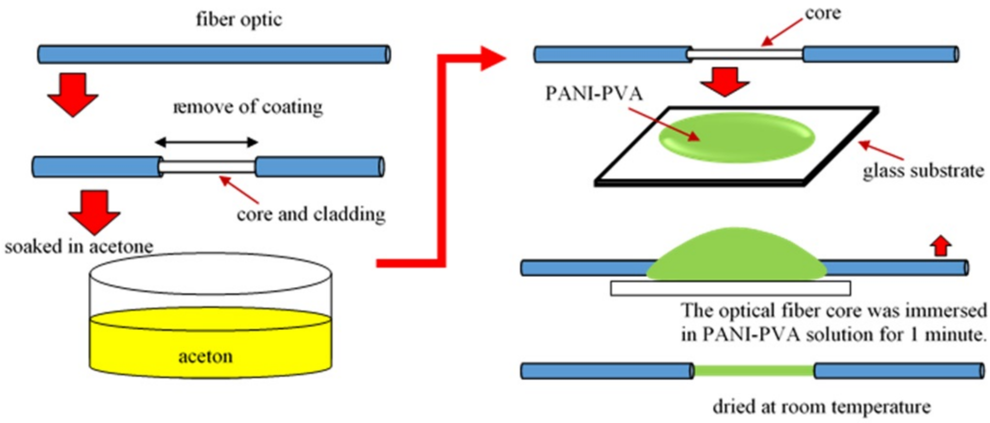

FIG. 2: Coating process using PANI-PVA.

tic properties. If PVA is in the form of a dry solid, granules, or powder, it has a good film form, is non-corrosive, soft and adhesive, and has good tensile strength [15]. Mendez fabricated the pH sensor using U-bending plastic fiber optics with a layer of silica sol-gel [12]. U-bending on the pH sensor sensing element can increase sensitivity and resolution compared to the straight fiber sensing element design. In this research, a pH sensor was fabricated using plastic optical fiber whose cladding layer was replaced with a PANI-PVA layer. The shape of the sensing element is U-bending.

II. METHODOLOGY

A. Materials

The PANI-PVA composite was synthesized using aniline (Merck), HCl (SAP), ammonium peroxydisulfate (APS) (Smart Lab), and polyvinyl alcohol (PVA) (Merck). Meanwhile, the optical fiber used in this research is a multimode plastic optical fiber with type FD-620-10. which has a diameter of 2.8 mm. The fiber coating is black, while the cladding and core are transparent. Overall, fiber type FD-620-10 is made of plastic.

B. Synthesis of PANI-PVA composite

The first step in this research was making a PANI-PVA composite solution. The PANI-PVA composite consists of three parts: a PVA solution (2.73 gr PVA in 50 ml distilled water), an aniline-HCl solution (2 ml aniline mixed in 50 ml HCl), and an ammonium peroxy disulfate solution (6 g APS mixed in 50 ml distilled water). The three solutions were mixed with the help of a magnetic stirrer and heated at 80°C with continuous stirring until mixed homogeneously (6 hours).

C. Preparation of sensing probe

Optical fiber that has been cut to a length of 1 m, the middle part is peeled to a length of 2 cm (variations of 3 and 4 cm are adjusted to the size of the radius of the sensing element). The part of the fiber core with its cladding peeled is coated with PANI-PVA. PANI-PVA coating is carried out by thickening the solution in glass preparation and then heating it. After the PANI-PVA solution thickens, the optical fiber whose cladding has been stripped is dipped into the PANI-PVA solution until the core is coated with the PANI-PVA solution. The PANI-PVA coating process can be seen in Fig. 2.

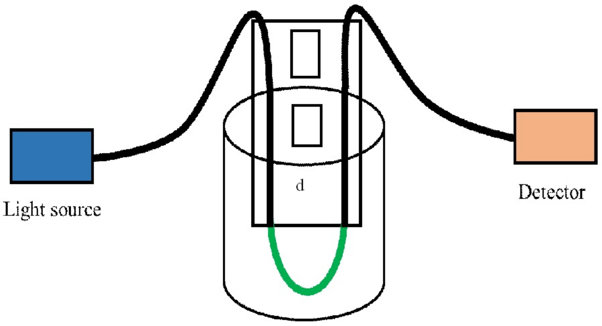

FIG. 3: Equipment set up.

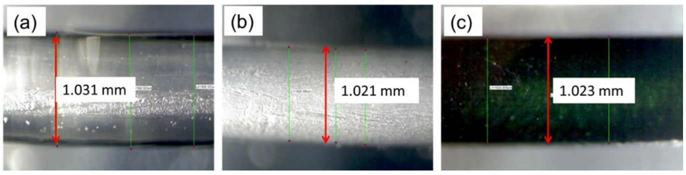

FIG. 4: (a) fiber before sanding; (b) fiber after sanding; (c) fiber after PANI-PVA coating.

D. Experiment set-up

The next stage is testing the fiber optic sensor. Testing is done by connecting the end of the fiber optic to a laser source as a light source, and the other end is connected to a detector, as shown in Fig. 3. After both ends are connected, the fiber optic is then dipped into a measuring cup containing a pH solution, and measurements are taken. The data obtained is the intensity of the laser output that can be emitted by the fiber optic coated with PANI-PVA. Testing is carried out on solutions with a pH of 10 to 2. Variations in the pH of the solution are made by dripping pH up or down into the aquades until a specific pH value of the solution is obtained, which is measured using a pH meter.

The intensity of the output light on the optical fiber itself cannot be affected by the pH of a solution, so it is necessary to apply a coating as a substitute for cladding with a material sensitive to changes in the refractive index. In this study, the material used was PANI-PVA with a strip length that produced a curvature with a diameter of 2.0 and 2.5 cm. The refractive index value of the PANI-PVA coating changes according to the pH value of the solution, thus affecting the intensity of the output light. The light source and detector on this pH sensor use BF5R-D1-N, which emits light with a wavelength of 660 nm.

III. RESULTS AND DISCUSSION

The thickness of fiber cladding can be calculated by comparing the diameters shown in the Fig. 4. It was found that the thickness of the cladding was 0.01 mm and the thickness of the PANI-PVA layer as a substitute for cladding was 0.002 mm. Figure 6 shows the detector output intensity after the pH sensor sensing element is immersed in varying pH values of the solution for two different microbending diameters. The figure shows a decrease in the intensity value as a function of increasing the pH value of the solution.

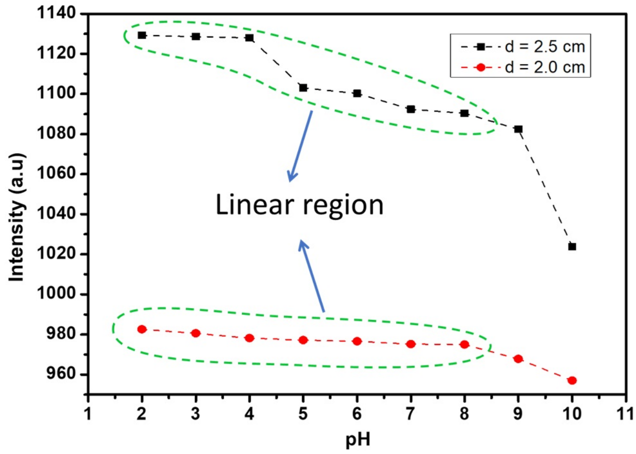

FIG. 5: Output light intensity in macrobending of optical fibers with 2.0 and 2.5 cm diameters.

Fig. 5 shows that the higher the pH of the solution, the smaller the intensity transmitted in the fiber. This is due to the influence of light absorption of the PANI-PVA material coated on the core of the optical fiber. The higher the pH value, the more basic the solution (OH-), so the concentration of free electrons is more significant. Atoms with negative valence ions have more free electrons, whereas free electrons can absorb photon energy [16]. This is based on the experiment's results: the higher the pH value, the lower the output light intensity. The difference in the bend radius of the curvature affects the amount of light intensity lost due to fiber bending. It can be seen in Figure 6 that the bend diameter of 2.5 cm transmits more light compared to the bend diameter of 2 cm, which means that the loss of intensity due to bending is less. In general, fibers given bending treatment will experience bend loss, a loss caused by bending. This is consistent with previously reported studies showing that bend diameters below 10 mm cause significant power losses. For example, studies have shown that small-radius bends, ranging from 5.5 to 19.5 mm, result in substantial bend loss increases due to geometric changes and stress-induced refractive index variations [17, 18].

Fig. 5 shows that the working area of the sensor system is in the pH range of 2 to 8, as indicated by the linearity of the output intensity to changes in pH. While above pH 8, there is a significant change, so this system can detect changes well in pH changes from 2 to 8. The results of detecting changes in solution pH show that bending with a diameter of 2.0 has a better level of linearity than bending with a diameter of 2.5 cm. At a diameter of 2.0 cm, it has an R^2 of around 0.922, while at a diameter of 2.5, it is 0.871, as shown in Fig. 6, which shows increasing precision in detecting pH changes. Macrobending optical fibers with diameters of 2.5 and 2.0 cm have a sensitivity indicated by the slope of the linear fitting

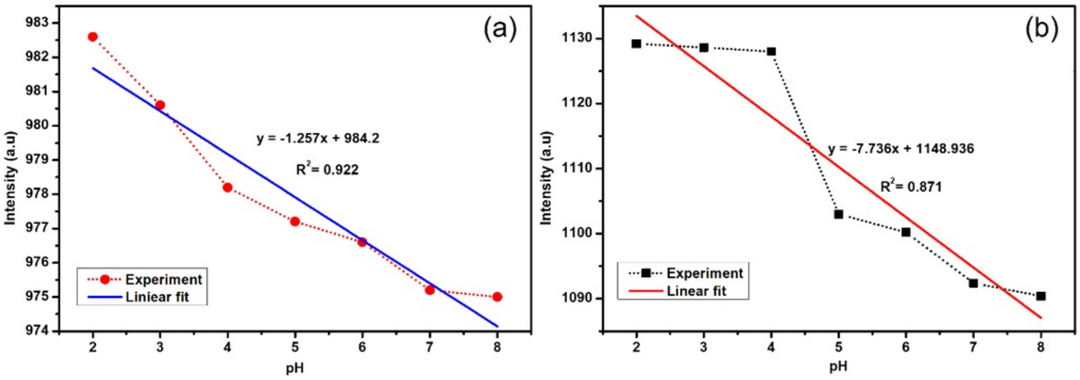

FIG. 6: Output light intensity data (a) d = 2.0 cm, and d =2.5 cm.

graph of -7.7736 a.u./pH and -1.257 a.u./pH, respectively, so macrobending with a diameter of 2.5 cm is more sensitive than a diameter of 2.0 cm but less precise.

IV. CONCLUSION

Based on the research results, it can be concluded that the pH sensor using macrobending plastic optical fibre with cladding in the form of a PANI-PVA layer has been successfully fabricated. Macrobending optical fibers with 2.5 and 2.0 cm diameters have sensitivities of -7.7736 a.u./pH and -1.257 a.u./pH, respectively. Macrobending optical fiber with a diameter of 2.5 cm is more sensitive than macrobending optical fiber with a diameter of 2.0 cm but less precise.

Acknowledgments

The research was funded by Directorate of Research and Community Service (DRPM), departmental fund scheme contract number 2319/PKS/ITS/2023. The author would like to thank DRPM ITS for this support.

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