Fabricate Optical Microfiber by Using Flame Brushing Technique and Coated with Polymer Polyaniline for Sensing Application

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Abstract. Adiabaticity is one of the essential criteria in producing good fabricated tapered fibers. Good tapered fibers can be use in sensor application such as humidity sensor, temperature sensor and refractive index sensor. In this paper, good tapering silica fiber is produced by using flame brushing technique and then, the microfiber is coated with polymer Polyaniline (PAni) to sense different type of alcohols with different concentrations. The outcome of this experiment gives excellent repeatability in the detection of alcohol sensing with a sensitivity of 0.1332 μW/% and a resolution of 3.764%. In conclusion, conducting polymer coated optical microfiber sensor for alcohol detection with low cost, effective and simple set-up was successfully achieved in this study.

1. Introduction
Recently, tapered fibers have attracted more researchers around the globe to focus in the optical sensor area due to its extensively outstanding performances and powerful in numerous sensing applications [1]. Fiber optics sensor is immune to the electromagnetic interference which make more desirable in sensing applications. Fiber optic sensing has been in market demands for quite some time alongside with the rapid growth in micro and nanotechnology nowadays. The tapered fiber is called microfiber when the diameter is in range of micrometer (µm) and called nanofiber when the diameter of the tapered fiber is below 1 µm [2]. The small in diameter made the fiber optics more sensitive, highly responsive, large dynamic range, low loss of attenuation, tight optical confinement and strong evanescent fields [3-7]. With such characteristics, it makes the tapered optical fiber an ideal application in remote sensing such as in humidity [8,9], refractive index sensing [10-12], vapour sensing, biomedicines, chemical analysis, environmental engineering and in an automotive industry [3].

Due to the smaller in diameter of the microfiber, the evanescent field surrounding the area is large and make it sensitive to the ambient changes. The evanescent part will have effect on the propagating mode inside the core and the output transmission power of this sensor changes with its optical properties, depending on the ambient medium or solutions. Therefore, with the modification of the optical fiber cladding it brings many attractive advantages due to its fast responsive, high sensitivity and larger integration with other fiber systems.
Conducting polymer polyaniline (PAni) as a cladding optical fiber sensor result in quick and large responses to chemical solutions. The advantages of using the polymer is due to easy fabrication, excellent stability, low power consumption, rapid and reversible adsorption [13]. To add, PAni characteristics is independent on detecting air humidity and temperature compared to traditional sensing material such as metal oxide which is highly dependent on detecting environment. Thus, polymer PAni make more favourable use as sensing applications compare with traditional material. Chiam et al. demonstrated polymer PAni coated optical microfiber in detection of alcohols. The outcome of this study gives red shift in the output spectrum with increasing steric effect. The presence of PAni result in an increasing of dihedral angle and band gap energy [14].

Both microfiber and nanofiber (MNF) are usually manufactured from the regular sized optical fiber by heating and stretching it [2]. The process of reducing the diameter of the fiber is called fabrication technique. There are many techniques to fabricate MNF. The most commonly use to fabricate microfiber is flame brushing technique because of their uniformity to maintain heat source, controlling the flame movement, stretching the fiber length and speed [15]. Flame brushing technique gives many advantages as it will determine the adiabatic criterion and to produce good quality of tapered fibers.

In this study, an optical microfiber is fabricated by using flame brushing technique and the microfiber produced is coated with polymer Polyaniline (PAni) to sense different type of alcohols with different concentrations. The polymer PAni is coated onto the tapered fiber by using drop coating method. The coated microfiber is sensitive to selective chemical or biological species. Thus, good is sensing applications.

2. Fabrication of microfiber

Fabrication process of microfiber is where the core diameter of the structured fiber is reduced by heating and stretching the single-mode fiber (SMF). The smallest diameter of the tapered fiber is called waist and between the waist and the unstretched SMF is transition regions. Transition regions is where the diameter of the core and cladding are decrease exponentially to range micrometer or nanometer, depending on how long the stretching of the SMF took place. When there is changing of size in the core and cladding diameter along the transition regions, the field distribution of waveguide will vary. Due to the rate of diameter change, the propagating wave may experience energy transfer from the fundamental mode to some closest few higher order modes. Most of the time loss will be appear in the system. To minimize the excess loss, adiabatic criteria should be taken into consideration throughout the tapering process [15].

3. Experimental Method

The experiment is started with the preparation of the optical fiber by connecting the fiber with the pigtails. The preparation of the optical fiber includes stripping, cleaving and splicing. 0.01 dB transmission loss has achieved in the splicing process. The experiment is continued with the fabrication of the microfiber by using (a) flame brushing technique and conducting (b) coated polymer Polyaniline for alcohol detection.

3.1 Flame Brushing Technique

Figure 1, shows a schematic diagram for fabrication of tapered fiber by using flame brushing technique. There are two stepper motors, one motor controller board, and two fiber holders on a linear stage, a sliding stage with an oxy-butane torch being fixed to it. The control board acts as a brain of the system which will give instruction to the stepper motors such as speed, moving direction and controlling the stages position. The two fiber holders are on a linear stage and one of them were controlled by precision stepper motors. One of the clamps will hold the fiber while the other one that have stepper motor will stretch the fiber during the tapering process. The linear stage travels at slow speed in order to have low loss and smooth process of the tapered fiber. At this time, the other motorized stage which acts as a brushing flame which will heats and brush the uncoated segment of
the fiber. The torch is on sliding stage and move at a very high speed than a linear stage. The reason is to provide uniform heat along the tapered fiber. The flame is produced from oxygen and butane or called oxy-butane torch. The flame also plays an important role in tapering process. To obtain good flame, the convection air flow from the flame need to be kept at an acceptably low level and the temperature of the flame need to be high in order to heat enough and soften the silica fiber. The distance between burner’s tip and silica fiber also need to be concern in order to prevent excessive heat that can break the tapered fiber during the fabrication process. The length of the tapered fiber is successfully fabricated at 3 cm.

![Flame Brushing Machine](image)

**Figure 1.** Flame Brushing Machine.

### 3.2 Coated Polymer Polyaniline

After successfully fabricate microfiber by using flame brushing technique, the microfiber is then coated with polymer Polyaniline (PAni) by using drop coating method. 3 drops of PAni solution is drop onto microfiber with interval of 10 seconds each and the structure is left to dry for 30 minutes. Figure 2 shows the coated PAni microfiber at a diameter of 4 µm. Figure 3 shows the optical set-up for microfiber sensor coated with PAni solution to sense different type of alcohols such as Methanol, Ethanol and Propanol with different concentrations. In the experiment, the sensing device is located between the light source, amplified spontaneous emission (ASE) and output wave, optical spectrum analyser (OSA). Weighing dish is placed below the tapered coated fiber for sensing different kind of solutions. The coated PAni microfiber was immersed by different kind of alcohols for sensing application and their outcome was analysed and recorded by OSA. Figure 4 shows a picture of the experiment in this project where the end of the fiber is connected to OSA and ASE.
Figure 2. Microscopic image of microfiber coated with Polyaniline.

Figure 3. Experiment setup for conducting PANi coated optical microfiber sensor.

Figure 4. Picture of the overall experiment assembled in the laboratory.
4. Result and Discussion

Figure 5(a) shows the transmission power of different alcohols with different concentrations. The uncoated microfiber was immersed in alcohol solutions. Based on the plotted graph, Propanol have the highest transmission power for all the concentrations compared to Ethanol and Methanol. As the concentration of propanol increases from 100 ppm to 500 ppm, the output spectra reduce from 797.1 µW to 761.7 µW. The uncoated microfiber sensor give a sensitivity of 0.0327 µW/% with a linearity of 95.56 % and a limit detection of 13.76 %. Whereas in figure 5(b) the graph is plotted for coated microfiber with polymer PAni and the graph illustrated that as the concentration of propanol increases from 100 ppm to 500 ppm, the output spectra reduce from 375.3 µW to 320.38 µW. The coated microfiber sensor give a sensitivity of 0.126 µW/% with a linearity of 96.54 % and a limit detection of 5.723 %. As the number of carbon atoms in the alkyl group of alcohol increasing the transmission power also increasing. However, the increasing of concentration of the solvent reduces the transmission power. The pattern is repeatability by different concentration of alcohols.

![Graph Uncoated](image1)
![Graph Coating](image2)

Figure 5. Power spectrum in detection of various kind of alcohols at different concentrations (a) uncoated microfiber and (b) coated microfiber with Polymer PAni.
Figure 6 shows the output spectra of the transmitted light from the microfiber with and without coating of Polyaniline. As illustrated in the figure, without coating of PAni in the tapered fiber the spectrum output power is -23.60 dBm and after the coating of PAni the spectrum output power decrease to -49.63 dBm. The transmitted light intensity drops by around 26 dBm at 1532 nm after the microfiber is coated with the polymer. This indicate that by coating polymer PAni to the microfiber make the fiber more sensitive to the surrounding because there is difference in the refractive index of the inner cladding. The evanescent fields surrounding the coated fiber and air is high which is very sensitive to the index change when there is presence of other medium or solution around the tapered area. The resonant peaks in the transmission spectrum will change with the variation in the refractive index of the environment. Microfiber becomes more sensitive when coated with polymer Polyaniline. Hence, the increasing in the sensitivity gives a good sensing properties.

![Before and after coating with PANI](image)

**Figure 6.** Output spectra of the microfiber before and after coating of PAni.

Figure 7 shows the spectral output response of coated polymer PAni microfiber in Methanol with different concentrations. As illustrated in the figure, different concentrations of alcohols have different transmission power due to their different refractive index of the solution. The refractive index increases with the increment of the alcohol concentrations. Higher concentration allows a strong enhancement of the evanescent field intensity and a great reduction in the transmitted power of the microfiber due to enhanced interactions between the evanescent field and the alcohol solution. Therefore, more leakage from the light that propagates inside the tapered region to the surrounding, which result in decreasing of output power. Thus, when the concentrations of methanol increase from 100 ppm to 400 ppm the output voltage drops from -55.97 dBm to -60.37 dBm.
Figure 7. Transmission power (dBm) reduced when the concentration of methanol increasing.

In Figure 8, the graph has been plotted for transmission power of coating PAni in different alcohol between Methanol, Ethanol and Propanol. 100 ppm concentration of each alcohols is taken to compare their transmission spectrum. Methanol has the highest transmission power of -55.28 dBm, whereas Propanol has the lowest transmission power of -62.07 dBm. It is observed that with the increasing of carbon atoms in the alkyl group of alcohol molecules, it increases the reduction in the transmitted power because of the strong interactions between the evanescent field and the alcohol solutions. Furthermore, with the increasing of carbon atoms in the alkyl group also increases the refractive index and lead to increases in reduction in the transmitted power. With different kind of alcohol, the output power will differ from one another and results in capability to sense different kind of alcohols.

Figure 8. Different type of alcohols lead to different output spectra (dBm).
The overall performance of the refractive index sensor is summarized in Table 1. The microfiber coated with PANi display a higher sensitivity than the uncoated microfiber when the alcohol solutions is immersed. The microfiber coated with PANi shows a sensitivity of 0.1332 μW/% with a linearity of 97.52% when it immersed with Methanol. Its limit of detection is calculated at 5.6%. As for the uncoated microfiber with Methanol solution, the sensitivity display 0.0794 μW/% with a linearity of 90.43%. The detection limit is 9.08%. With the comparison between coated and uncoated microfiber, the coated microfiber has low limit of detection compared to with uncoated microfiber. The lower limit of detection gives higher system efficiency and performance. To conclude, based on the Table 1, coated PANi microfiber provides more sensitivity in term of sensing applications.

Table 1. Performance characteristic.

|                  | Uncoated Microfiber | Coated Microfiber |
|------------------|---------------------|-------------------|
| Sensitivity (μW/%) | 0.0794              | 0.1332            |
|                  | 0.0327              | 0.126             |
| Linearity (%)     | 90.43               | 97.52             |
|                  | 95.56               | 96.54             |
| Standard Deviation (μW) | 0.721              | 0.746             |
|                  | 0.450               | 0.721             |
| Limit of Detection (%) | 9.08               | 5.60              |
|                  | 13.76               | 5.72              |

5. Conclusion
A simple refractive index sensor is proposed and demonstrated using a tapered silica optical fiber coated with a polymer composite for measurement of different kind of alcohols with various concentrations. The microfiber is fabricated by using flame brushing technique with tapering length of 3 cm. The microfiber coated with polymer PANi gives a sensitivity of 0.1332 μW/% with a linearity more than 97.52%. The presence of coated polymer give more sensitivity to the system due to the effective refractive index of the deposited coated that allows more light to be transmitted through the tapered fiber. Therefore, the proposed sensor provides outstanding advantages such as low cost, simple, and effective setup for sensing applications. This refractive index sensor is very convenience in monitoring and controlling the quality of alcohol concentration in the food processing and medical industry.

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