J. of the Korean Sensors Society
Vol. 13, No. 2 (2004) pp. 96 – 100

Fabrication of Optical Fiber Gas Sensor with Polyaniline Clad

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Abstract

Optical fiber sensors have been used to detect small amounts of chemical species. In this work, a new thin polymer-clad fiber sensor is developed. Polyaniline is chemically synthesized and thin clad layers of the polymer are easily deposited on optical fiber by dip-coating technique. The optical property of polyaniline as a sensing material is analyzed by UV-Vis-NIR. The light source is stabilized He-Ne laser at 635 nm wavelength with 1 mW power. The light power transmitted through the optical fiber is measured with a spectrophotometer. By selecting a fixed incident angle, variation of transmitted light intensity through the optical fiber can be detected as gas molecules absorbed in the polyaniline clad layer. Among the various gases, the fabricated optical fiber sensor shows good sensitivity to NH_3 gas. The optical fiber sensors was shown more improved properties than polymer based sensors which measure conductivity changes.

Key Words : optical fiber sensor, polyaniline(PANi), NH_3 gas

1. Introduction

Recently, considerable efforts have been directed to the development of optical fiber based chemical sensors[1-4]. In these sensors, optical properties of sensing layers such as absorption, reflectance, and scattering of light are changing as the sensing layers interact with the gas species. The light is guided via optical fiber in measuring instruments. Employing these sensors enable the performance of real-time chemical detection of noxious gases. Until now, sensing layers are mostly metal oxide types such as SnO_2 and Fe_2O_3. The response of metal oxide to gases originates from variation of conductance in surface states. The major disadvantages of using such oxide materials include the dependence on detecting environments.

However, the methods employing optical properties have many advantages over conventional ones, such as environmental interference immunity, low weight and small size, etc[5]. The other advantage of these optical fiber sensors is the possibility of performing remote detection in a hostile environment and achieving continuous monitoring of chemical parameters in industrial and chemical processing.

In this paper, the suggested method is the detection of modulated signal caused by variation of reflecting coefficient[6]. This reflecting coefficient is varied by adsorption of gas molecule in polyaniline (PANi) surface. For the purpose of fabricating optical fiber sensor, the chemically polymerized PANi is deposited on stripped clad.

2. Experimental

2.1. Polymer-clad Optical Fiber Sensor

A detecting method of gases using optical technique can be coupled with a conducting polymer which has unique optical property. The sensing layer is composed of chemically polymerized PANi. The chemical polymerization process of PANi is described as follows. Ammonium persulfate (APS, Kanto Chemical Co. Inc.) as an oxidant and dodecylbenzene sulfonic acid (DBSA, Kanto Chemical Co. Inc.) as a dopant are used as received. A 0.15 mol of DBSA and a 0.3 mol of aniline are dissolved in 500 ml of distilled water by vigorously stirring. A 0.06 mol of APS in 100 m*l* of distilled water is slowly added to the above solution at 0°C. Reaction is carried out for 24 hours and terminated by pouring methanol. The resultant PANi powder is washed

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(Received : February 3, 2004, Accepted : February 21, 2004)

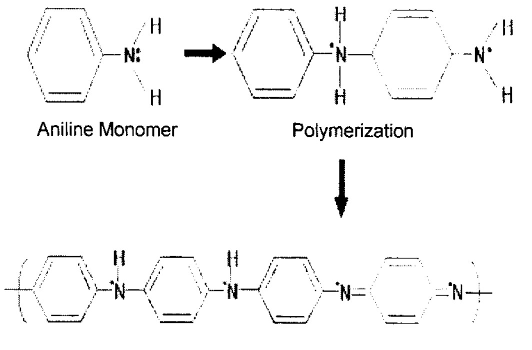

Fig. 1. The growth mechanism of polyaniline.

sequentially with the distilled water, methanol and acetone several times, followed by filtering and drying in a vacuum oven at 25°C for 12 hours. The obtained powder (0.1 g) is completely dissolved by ultrasonification in 5 m*l* of chloroform with additional 0.2 g of DBSA. PANi gel is prepared for sensing material. Among the PANi structures, our study is only connected with emeraldine-base structure.

Fig. 1 shows the growth mechanism of PANi utilized in the optical sensor. Although the emeraldine-base PANi is much less conductive than its salt, it can absorb visible light at significantly lower energy level that required for the $\pi \rightarrow \pi^*$ transition[7].

Therefore the light wavelength selected in this study is compatible to UV and visible wavelength which is used for conventional optic fiber sensor.

A small length of the fiber (600 μm core diameter, multi-mode) is mechanically stripped and then immersed in a sulphochromic mixture in order to remove the clad[2]. With dip coating method, the stripped section of the optical fiber is easily coated by PANi gel solution instead of cladding on optical fiber[8]. Subsequently, the fiber is dried at 70°C for 24 hours for the purpose of improving film durability.

2.2. Experimental Set-up

The measurement is completed with an optical source to generate the signal and an optical detector to measure the modulated signal.

Fig. 2 shows the experimental set-up to characterize the PANi-clad optical fiber sensor. The fiber is illuminated by an incident laser beam at an oblique angle (about 75°). The light source is a stabilized He-Ne laser at 635 nm wavelength with 1 mW power.

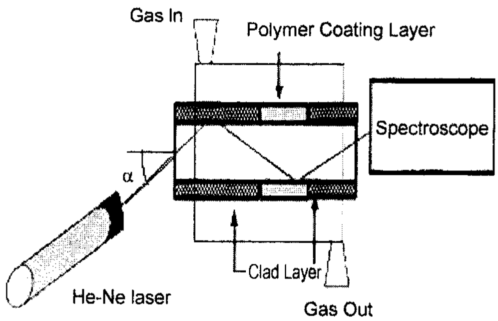

Fig. 2. The measuring equipment schematic.

The light power transmitted through the fiber is measured with a spectrophotometer. The energy of the transmitted light depends upon the difference of the refractive indices between the core and the clad. If the gas molecules are adsorbed onto the coated polymer surface, its refractive index would vary with concentration of gas species.

3. Results and Discussion

We used chemically polymerized PANi film is used for sensing material because of its easily deposition and high sensitivity. The fabricated film was analyzed to study its surface morphology. Fig. 3 shows the scanning probe microscope (SPM) and scanning electron microscope (SEM) picture of PANi films.

As shown in Fig. 3, the surface of the chemically polymerized film appears smooth form. It is reasoned that the polymer chains of chemically synthesized polymer lie down in the parallel direction of the substrate. It is known that polymer becomes conductive due to the formation of bipolaron along the polymer backbone. Thus, the chemically polymerized film has more bipolaron on the surface and higher sensitivity than those prepared by other polymerized methods. Therefore, chemically polymerized films have good sensitivity due to a lot of absorption sites on the surface.

Fig. 4 shows AFM pictures of PANi films in an air and a NH_3 1,000 ppm concentration. This figure illustrates thickness change of PANi film. The volume of the film is proportional to thickness change. When gas molecules are adsorbed at the PANi film surface, the interactions takes place between gas and film and then a repulsive force is generated between PANi chains. This force induces a swelling of PANi film and changes the

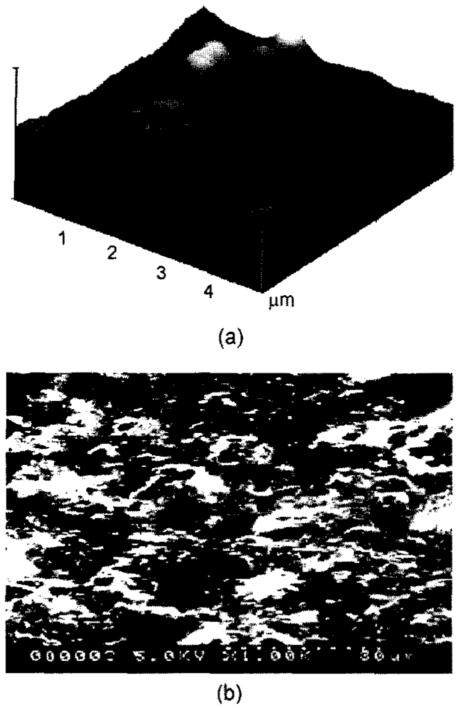

Fig. 3. The SPM and SEM pictures of chemically polymerized PANi film.

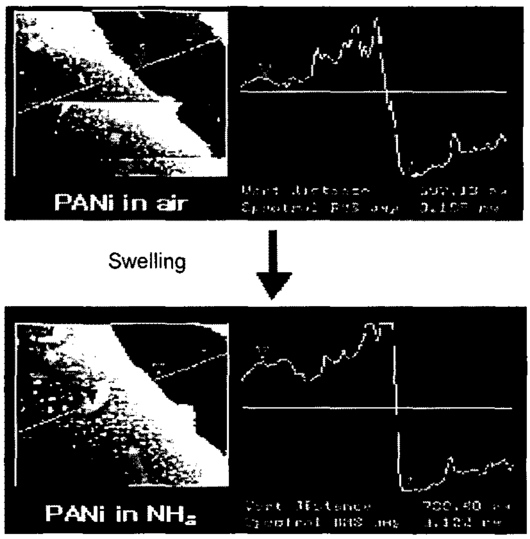

Fig. 4. The AFM results of PANi film in air and in NH_3 atmosphere.

volume of the film. This phenomenon is explained by the change of absorption coefficient. This phenomenon is used to introduce our optical sensing system.

The fabricated PANi films are deposited onto the

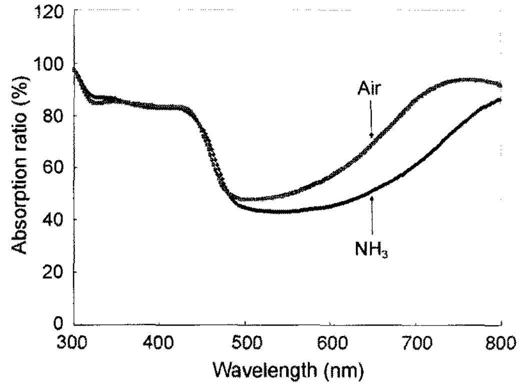

Fig. 5. UV-Vis-NIR spectra of PANi with and without NH_3 gas on glass.

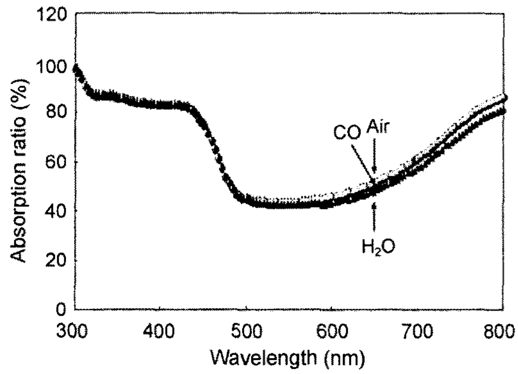

Fig. 6. UV-Vis-NIR spectra of PANi with CO gas (100 ppm) and water vapor (70 %).

glass in order to investigate optical property of films. The properties of films are measured by UV-Vis-NIR spectrophotometer. Fig. 5 shows that the absorption ratio decreases when the PANi is exposed to NH_3 in the wavelength range of 500 – 800 nm. In 650 nm, the absorption ratio decreased about 20 %. Owing to this variation at 650 nm, the fabricated optical sensing system has adequate selection that is composed with He-Ne laser as a light source.

Fig. 6 shows the absorption ratios for two different gases. In this figure, curves show a little change in the absorption ratio. The fabricated optical fiber sensor has selectivity to CO and water vapor.

Fig. 7 shows the transmittance of the optical fiber sensor for different concentrations of NH_3. The length and the polymer-clad width of optical fiber are 10 and 5 cm, respectively.

The experiment is performed at a wavelength of 650 nm. When NH_3 concentration increases from 25

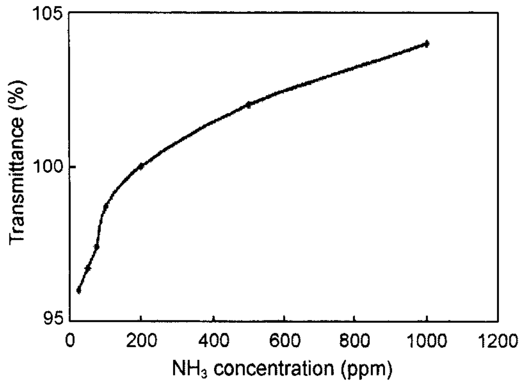

Fig. 7. The transmittance spectra of polymer-clad fiber sensor to various NH_3 concentrations.

ppm to 1,000 ppm, he light transmittance is increased about 8 %.

4. Conclusion

A polymer-clad optical fiber sensor has been fabricated. The PANi is deposited on the clad of commercial optic fiber. The behavior of sensor has been studied for various concentrations of NH_3. Conclusively, the optical fiber sensor with a PANi layer demonstrates a good sensitivity, selectivity, low cost and easy implementation. In the further, this sensor will have a reliable multiplexing into either a telecommunication or sensor network to make this sensor suitable for use in the chemical and clinical industries.

Acknowledgements

This work was supported by National Research Lab Program & Confrontation to Chemical and Biological Terror from Ministry of Science in Korea

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