Non-invasive Transcutaneous pCO₂ Gas Monitoring System for Arterial Blood Gas Analysis

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Abstract

Monitoring the carbon dioxide concentration in arterial blood is vital for the evaluation and prevention of pulmonary disease. Yet, domestic pure arterial blood carbon dioxide sensor technologies are not being developed, instead all sensors are imported. In this paper, we develop a real time monitoring system for arterial blood partial pressure of carbon dioxide(pCO₂) gas from the wrist by using a carbon micro-heater. The micro-heater was fabricated with a thickness of 0.3 μ m in order to collect the carbon dioxide under the skin. The micro-heater has been designed to perform temperature compensation in order to prevent damage to the skin. Two clinical trials of the system were undertaken. As a result, we demonstrated that a portable, transcutaneous carbon dioxide analysis(TcpCO₂) device produced domestically is possible. In addition, this system reduced the analysis time significantly. Carbon films could reduce the unit price of these sensors by replacing the gold film used in foreign models. Also, we developed a real time monitoring system which can be used with optical biosensors for medical diagnostics as well as gas sensors for environmental monitoring.

Keywords : pCO₂, Transcutaneous, Noninvasive

1. INTRODUCTION

Transcutaneous oxygen and carbon dioxide partial pressure measurements at birth is a well established procedure, and in recent years these measurements have been used to look at the state of tissue perfusion in patients with severe shock as an indicator of the appropriate treatment. Chronic obstructive disease(COPD) accounts for currently the fourth cause of mortality with through the world .It is predicted to increase even more in the future. Chronic obstructive pulmonary disease(COPD) is expected to become the world's fifth largest disease. The National Institute of Health(NIH) and the World Health Organization(WHO) make up the Global Initiative for Chronic Obstructive Lung Disease(GOLD) work towards the prevention, treatment and reduction of the disease.

Analysis and monitoring of carbon dioxide in the body is for essential for preventing lung disease. Analysis of the

carbon dioxide in the body is conducted from the expiratory system with non-invasive methods while arterial analysis uses invasive methods.

In emergencies where patients need non-invasive analysis, the measurement of the pCO₂ is inferred from the end-tidal partial pressure of carbon dioxide, EtCO₂, analysis. This, however, does not exactly reflect the pCO₂ and is very troublesome because patients must breathe through a catheter.

In the case of arterial blood analysis the long analysis time and the invasive catheter risks secondary infection.

In recent years, non-invasive monitoring technology has advanced greatly. Therefore, we are able to measure the concentration of pO₂ and pCO₂, of patients in continuous, real-time. However, Korea relies on imports for this technology. Therefore there is a need to develop domestic technology. The currently imported products make use of gold film as the contact conductive material with the skin. This has the disadvantage of increasing each unit's price.

Today, the physical and chemical characterization as well as various applications of carbon are being studied.

Through this research it has become possible to for carbon pure solution to be coated as a thin film. Thus, in this study, a micro-heater using the conductivity of carbon which is portable and can detect the concentration of carbon dioxide from tissue under the skin in real time has been produced.

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2. DESIGN

The principles used in the signal processing unit are as follows: The output value of CO₂ can be exactly determined because CO₂ absorbs infrared in the wavelength region of 4.26 μm as shown in Fig. 1.

Fig. 1. Infrared absorption spectrum of CO₂(4.26 μm).

Infrared filaments(IRL 715, Perkin Elmer, USA) were used for the detection of CO₂. They emit stable light in the 2 μm ~ 4.4 μm band and are highly reliable with high-output representation. The system used in the detector(LHi 807TC, Heimann, Germany) is a pyroelectric sensor, which has been used in various fields, and dramatically improves the optical response of the thermistor. It was attached to an optical filter of 4.26 μm to detect only the signals in front of the sensor i.e. under the skin. Output signals are highly dependent on the pulse frequency of the light part as the pyroelectric sensor is affected by the charge and discharges of spontaneous polarizations according to the input pulse frequency. However, the full output is not represented because of the shorter pulse frequency. Fig. 2 shows the characteristics of the pyroelectric sensor according to the pulse frequency of the lamp.

As you can see in Fig. 3, excellent response characteristics are seen when the pulse frequency of the light source is low. In this study, the frequency of the light was set at 1.2 Hz. The radiation efficiency in this configuration, with the output shown in Fig. 3, is 65 %.

Signal processing including the filter, amplifier and rectification circuit was configured to detect tiny signals through an optical detector.

Fig. 2. Characteristic graph of pyroelectric infrared sensor.

Fig. 3. Output radiation efficiency against frequency modulation.

The light drive unit was designed and built to adjust the light power source by considering the sensitivity of the sensor and the input pulse frequency. The analog unit design and manufacture was carried out while looking at the sensor signal amplifier, noise and thermal noise suppression[9].

Output signal amplification was designed to be easily amplified and rectified because very small changes in gas concentrations are measured in the output of the infrared sensor.

The amplified signal is input to the proper AC output channel value. Finally, the output value according to various parameters can be obtained. The microprocessor for measuring in real-time converts this to a DC output value.

Carbon(carbon; C) was used for measuring pCO₂ at the surface of the skin. Its characteristics are based on the higher organization solubility and diffusion of carbon dioxide through the skin .

The Ag and carbon layer with a thickness of 0.3 μm was coated on a PET film by screen printing. The micro-heater was completed after an insulator coating was applied and the device was heated for 20 minutes at 80 °C.

(a)

(b)

Fig. 4. The process of carbon micro-heater.

Fig. 3 shows the output radiation efficiency of the frequency-modulated sensor. Fig. 4 show the fabrication process of the carbon micro-heater

3. RESULTS AND DISCUSSIONS

Fig. 5 shows a graph of the the long-term stability of the system obtained after injection for 20 days of carbon dioxide at 10000 ppm and 20000 ppm. We knows that the long-term stability was in the area of 0.2 V and 0.42 V, respectively.

Temperature calibration graphs and switching characteristics are shown in Figs 6 and 7.

Fig. 6 shows the electrical switching characteristics of the fabricated micro-heater. The units achieved a normal temperature range and were able to maintain that range

approximately 10 seconds after the power supply was switched on. We confirmed that the unit has quick return characteristics, it takes 60 seconds from the power supply being turned off before returning to its initial temperature. Quick response and return characteristics have the advantages that measurement time is reduced.

Fig. 5. Graph the long-term stability of the system.

In addition, that can be characterized that is possible to heating surface and flexibility is good for the external voltage is applied. Surface heating of a new concept can be said for far-infrared emission is able to easy and no electromagnetic wave has almost.

Fig. 6. Switching characteristics of micro-heater.

Fig. 7 shows a graph of the temperature before and after temperature-compensation in the micro-heater.

The carbon micro-heater system was designed to operate at 40 °C ~ 50 °C with DC 12 V at 60 mA .

Trials were run to measure the carbon dioxide emitted in actual skin using the fabricated carbon micro-heater gas system(TCpCO₂). The first experiment measured the voltage by putting 5 % carbon dioxide in the carbon micro-heater. The second experiment measured the voltage values of dioxide concentrations through a comparison with test device.

Fig. 7. Graph before and after temperature-compensated of micro-heater.

Experiment is progressed in a manner with conducting on a five healthy people through their wrists at a constant temperature of $42^{\circ}\text{C} \sim 43^{\circ}\text{C}$. The unit was attached to the place on the wrist with the most densely packed capillary blood vessels. The wrist of the subject was warmed using skin-mounted micro-heaters to a constant temperature of $42^{\circ}\text{C} \sim 43^{\circ}\text{C}$. The measurement began after about two to three minutes to allow pores to extend to facilitate the emissions of carbon dioxide.

Fig. 8 shows the measured voltage after injecting 5 % carbon dioxide into the carbon micro-heater. This is equivalent to a 15000 ppm concentration of carbon dioxide in terms of the translated voltage value.

Fig. 9 shows that the results of the experiment involving warming the wrists of five people. It shows the subjects had 3000 ppm ~ 5000 ppm of carbon in their blood after the voltage values were converted. These results match those obtained for partial pressure of carbon based on Henry's Law and Bunsen's coefficients [7, 9].

4. CONCLUSIONS

Optical and electrochemical methods are used to transcutaneously measure carbon dioxide. At the moment, Korea is imports these devices from abroad.

In the case of optical methods the system prices are high due to the use of gold film as a membrane for detection in excessively large and unreliable sensors. Electro-chemical methods have been developed and researched but have problems in terms of structural complexity, technical difficulties, and the difficulty in regulating the membrane film.

The system(TCpCO₂) developed in this study gives a way to analyze the concentration of CO₂ in arterial blood

optically. This system, by using a carbon micro-heater with NDIR, can detect the amount of carbon dioxide distributed under the palm using non-invasive methods .

Fig. 8. Voltage characteristics of transcutaneous system by using carbon micro heater.

Fig. 9. Response by using the carbon micro-heater.

The system is monitored on a LCD by looking at the change in voltage we can find the carbon dioxide concentration.

Thus, changes in the concentration of carbon dioxide can be detected in real time. In addition, this shows that measurement of transcutaneous CO₂ can be made using domestic technology.

In the future, it is in the national interest to commercialize this product. The development of micro-heaters using carbon shows that gold detecting membranes can be replaced with other substances in existing commercial products.

We believe that this system can be applied in many areas such as biotechnology and environmental sectors. In particular in the medical sector this technology can be used in intensive care, diagnosis and treatment by estimating the concentration of CO₂ and also be used for early diagnosis of lung diseases.

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