A Novel Instrumentation Circuit for Electrochemical Measurements

Li-Te Yin ¹, Hung-Yu Wang ²*, Yang-Chiu Lin ² and Wen-Chung Huang ³

¹ Department of Optometry, Chung Hwa University of Medical Technology, Tainan 717, Taiwan; E-Mail: leaderyin@gmail.com
² Department of Electronic Engineering, National Kaohsiung University of Applied Science, Kaohsiung 807, Taiwan; E-Mail: jackyc_lin@compal.com
³ General Education Center, Chung Hwa University of Medical Technology, Tainan 717, Taiwan; E-Mail: tom709@kimo.com

* Author to whom correspondence should be addressed; E-Mail: hywang@cc.kuas.edu.tw; Tel.: +886-7-381-4526 (ext. 5640); Fax: +886-7-381-1182.

Received: 27 April 2012; in revised form: 9 June 2012 / Accepted: 9 July 2012 / Published: 17 July 2012

Abstract: In this paper, a novel signal processing circuit which can be used for the measurement of H⁺ ion and urea concentration is presented. A potentiometric method is used to detect the concentrations of H⁺ ions and urea by using H⁺ ion-selective electrodes and urea electrodes, respectively. The experimental data shows that this measuring structure has a linear pH response for the concentration range within pH 2 and 12, and the dynamic range for urea concentration measurement is in the range of 0.25 to 64 mg/dL. The designed instrumentation circuit possesses a calibration function and it can be applied to different sensing electrodes for electrochemical analysis. It possesses the advantageous properties of being multi-purpose, easy calibration and low cost.

Keywords: instrumentation; biosensor; electrochemical measurement; multi-purpose

1. Introduction

The prototype of biosensors was first proposed by Clark and Lyon in 1962 [1]. The analytical method of detecting organisms actually exploits the molecular recognition between enzyme and acceptor. This concept involves placement of an enzyme in close proximity to an electrode surface, where the
enzyme is able to catalyze a reaction. The analysis is based on the measurements of the consumption of an elective reactant (O₂) and the production of an electroactive product (H₂O₂) [2]. The sensing mechanism of the biosensor is dependent on the biological specificity of the enzyme-catalyzed reaction and the selectivity of the ion-selective electrode, and hence, the characteristics of the biosensor are strongly related to the selectivity of the ion-selective electrodes. The enzyme electrode is a miniature chemical transducer which functions by combining an electrochemical procedure with immobilized enzyme activity. In 1967, Updike and Hicks used glucose oxidase immobilized on a gel to measure the concentration of glucose in biological solutions and in tissues in vitro [3]. From this moment on, many researches devoted to the development of biosensors, such as the O₂, H₂O₂, H₂, H⁺, NH₃, CO₂ electrodes and ion-sensitive field effect transistor (ISFET) [4]. An ISFET can be considered as a special type of the MOSFET without a metal or polysilicon gate, with the gate coated with a hydrogen ion-sensitive layer [5]. The gate of ISFET is directly exposed to the buffered solution to detect the concentration of hydrogen ion. The extended gate field effect transistor (EGFET) is another sensing structure which isolates the FET from the chemical environment.

Biosensors mainly composed of two parts. The first part is the sensing element which receives the input signal for the biological sensor. It can be the organism molecules, tissue or molecular recognition elements of individual cells. The other part is the electronic circuit which processes the quantified electronic signals from sensing element and outputs the processing result [6]. Therefore, the way to get accurate biological information quickly from sensing element and its processing circuit receive much attention of researchers [7,8]. Electrochemical sensors are widely utilized in many applications, such as disease diagnosis, food inspection and environmental monitoring, because of their fast reaction, high selectivity, high sensitivity, and simplicity [9].

In this study, based on the potentiometric method, an electronic instrumentation circuit is designed to detect the concentrations of H⁺ ions and urea by using H⁺ ion-selective electrodes and urea electrodes. The system performance for the H⁺ ions concentration detection can achieve the same accuracy as the commercial pH meter. The urea concentration detection using urea biosensors based on the measurement of H⁺ ion concentration possesses the dynamic range between 0.25 and 64 mg/dL. The workability of the sensing system is verified by measurement results.

2. Realization of Sensing Configuration

In this study, the used direct potential method is based on the measurement of potentials of electrode and the analysis of activity concentrations of ions employing the Nernst equation. The method usually uses indicating electrodes with ion-selective function. There are slight structural differences between the electrodes used and their general structure is shown in Figure 1. The SnO₂/ITO/PET pH electrode in Figure 1 is based on a separated structure [10]. The SnO₂ thin film is deposited at a thickness of 200 nm using sputtering [11]. Figure 2 shows the practical electrode connected with a coaxial wire to increase the immunity to external noise. For the measurement of the concentrations of H⁺ ions, the pH sensing area acting as working electrode (WE) and Ag/AgCl reference electrode (RE) were dipped into buffer solution and connected to the input terminals A and B of the designed instrumentation, as shown in Figure 3. Figure 3 also shows the proposed potential system structure used for the concentration measurement of hydrogen ion. The circuit mainly consists
of an 8-bit microprocessor chip module (P89C51RB2HBA, Philips), an analog to digital converter (ADC), a liquid crystal display module (LCM) and a precision voltage amplifier. The voltage amplifier is implemented by an instrumentation amplifier (IA) to make good use of its characteristics of low-noise, high input impedance, low output impedance and tunable gain of the instrumentation amplifier. The commercially available pH meter usually set the zero potential which corresponds to pH 7. One unit change of pH value corresponds to the voltage change of about 59.1 mV. In theory, pH 14 to pH 0 will have the voltage from −413.7 mV to +413.7 mV.

For the proposed system in Figure 3, the ADC (ADS7841, Texas Instruments) is a single-supply chip, and the input voltage range of analog channel is a positive voltage between 0 V to 5 V. Thus the low-offset voltage and input bias current, high linearity and low gain error IA (LT1167, Linear Technology) with positive reference potential bias is used to construct the instrument, as shown in Figure 4. The positive reference potential bias can be obtained with a level-shift circuit. To calibrate the system and maximize the measurement range, the designed instrument has default setting that the output voltage of the IA for potential 2.5 V which corresponds to pH 7 of the buffer solution and code 2048 of ADC.

Figure 1. Electrode structure of ion-contact type.

![Figure 1](image1.png)

Figure 2. Practical pH electrode connected with a coaxial wire.

![Figure 2](image2.png)
Figure 3. The system structure for potential measurement.

Figure 4. Instrumentation amplifier circuit.

The 12-bit ADC (ADS7841) is operated with a supply voltage of 5 V. Due to its input voltage range of 0 to 5 V, the minimum voltage step can be $5/212 = 1.2207$ mV. The default setting is that the change of per unit of pH value corresponds to 59.1 mV potential change, but this value is settable for our system. Therefore, the accuracy of measured pH value can achieve the resolution of about one digit after decimal point. It is enough for the measurement of general chemical laboratory. Figure 5 shows the internal program operation flow chart for P89C51 chip. For the operation procedure in Figure 5, the measured value is obtained using the output code of the ADC multiply by minimum voltage step (1.2207 mV). The pH value corresponding to its measured voltage value can be derived according to the procedure in Figure 5. An adjustable delay time is added to stabilize the displayed output values on LCM since the output codes of ADC (with conversion rate of 200 ksample/s) is refreshed too frequently. Then the measured value is checked and displayed on LCM.

According to the Nernst equation, it can be found that the measured voltage of a solution will be different at different temperatures. Therefore, the designed instrument has adjustable setting functions. That is, it has default setting that the 2.5 V output voltage of the IA corresponds to the measured voltage of calibrated solution of pH 7 and code 2048 of ADC. However, this corresponding code of
Acknowledgments

This work has been supported by the National Science Council, Taiwan (Grant Nos NSC 101-2221-E-151-074 and NSC 100-2221-E-151-065). Many thanks are due to the reviewers for their useful comments.

References


© 2012 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution license (http://creativecommons.org/licenses/by/3.0/).