DOI 10.5162/IMCS2018/EC3.2

Miniaturization of Electrochemical Sensors

Sohrab Mansouri
Instrumentation Laboratory, 180 Hartwell Rd, Bedford MA 01730 USA
smansouri@ilww.com

Abstract

This article briefly describes the design and integration of miniaturized electrochemical sensors that meet stringent performance requirements for clinical applications. Advantages of using plastic substrates for combining sensor fabrication with fluidic packaging is elaborated. Utilization of shared external reference and counter electrodes for both potentiometric and amperometric measurements provided simple and uniform sensor configurations, allowing ease of fabrication and improved reliability. Further enhancement in reliability is achieved from functional testing of all fabricated sensors, prior to assembly in disposable cartridges.

Key words: Electrochemical sensors, Miniaturization, Plastic substrates, Clinical applications, Enhanced reliability.

Introduction

Advancements in technology and manufacturing methods have allowed for fabrication of disposable miniaturized sensors with low cost and ease-of-use. Thin film on silicon and thick film on ceramics technologies have been the primary methods for fabrication of miniaturized sensors. These substrate materials provide good mechanical and chemical resistance properties and allow for creation of conductive, dielectric and resistive motives for planar sensor fabrication. However, inadequate adhesion of polymeric sensing films to such substrates is a major challenge in constructing reliable sensors. Several methodologies have been adopted to overcome the adhesion issue, such as bonding an outer polymer encapsulant over the ceramic (US patent 5858452 to SenDex Medical) or employing a compression gasket over the sensor membrane (US patent 5284568 to DuPont). The drawback of these methodologies is the added complexity to the design and fabrication of the sensors. Other sources of design complexity are the configuration of multiple amperometric sensors on one substrate with individual reference and counter electrodes, and requirements for electrical isolation among sensors. Another challenge is assuring high reliability at the point of use due to prevailing quality control procedures based on random sampling from production lots, which may not be adequate to meet quality demands.

In this article, application of an alternative sensor substrate and methodologies for simplifying the sensor design and testing for enhancing reliability are elaborated.

Principle and Design of Sensors

The electrochemical sensors are classified as potentiometric and amperometric. The construction of miniaturized sensors requires a different approach to the internal filling solutions of the macro-electrodes. This is achieved by deposition of an aqueous solution, containing a hydrogel and salt, on the internal reference electrode, typically a silver/silver chloride-coated pin. For the enzymatic sensors, the pin is platinum and the hydrogel solution contains an enzyme, specific to the metabolite of interest, and a crosslinking reagent for enhancing enzyme stability. An outer polymeric film is solvent-casted over the hydrogel film to complete the sensor construction.

Thermoplastic polymers provide suitable substrates for sensor fabrication due to their capacity for solvent bonding with the polymeric membranes and ability to be molded into fluidic channels with the sensors. A molded plastic substrate called “sensor card” in the GEM® Premier™ line of blood gas analyzers (Instrumentation Laboratory) is an example of such an application. The sensor card schematics and a magnified image of sensors are illustrated in Figure 1. The individual sensors are formed from layers of polymer films, bonded to the substrate. The polymeric films are dissolved in suitable solvents and dispensed in preformed wells in the sensor card. A metallic contact under each sensor is connected to the back of the substrate to form electrical contact with the instrument. A metallic plate with adhesive backing is sealed over the sensor card to form a flow channel over the sensors.

DOI 10.5162/IMCS2018/EC3.2

A key design feature in the sensor card is the uniform configuration across all electrochemical sensors. This design uniformity has been achieved through application of a common external reference and a common counter electrode, negating the need for electrical isolation across sensors.

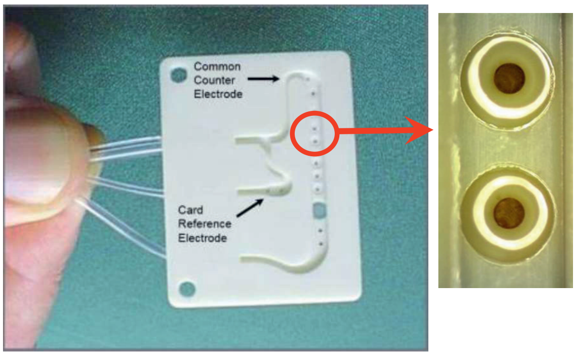

Figure 1. Schematics of a sensor card and two magnified sensors in a fluidic channel.

The potentiometric sensors for pH and electrolyte sensors are based on the principle of ion-selective electrodes (ISE). They are composed of plasticize polyvinyl chloride and an internal hydrogel salt layer over an internal Ag/AgCl reference electrode. The membrane potential is measured against the card reference electrode. The construction of the pCO_2 sensor is similar to the pH except with an internal hydrogel with bicarbonate salt. The *p*CO_2 in the sample comes to equilibrium with the internal solution, causing a change in the internal pH. The generated potential versus the pH sensor is correlated with the logarithm of pCO_2 partial pressure in the sample. The differential pCO_2 methodology allows the sensor to become uniform in configuration to other ISEs.

All amperometric sensors have simplified and uniform configuration due to the sharing of reference and counter electrodes. The oxygen sensor has a small platinum electrode poised at a negative potential, with respect to the card reference electrode. The current flow between the platinum and the common counter electrode is proportional to the oxygen partial pressure. The platinum wire is sealed inside a glass disk and glued to the sensor card. A gas-permeable membrane protects the platinum electrode from blood contaminants. Because this design is immune from silver dendrite formation (a common problem shortening sensor use-life in traditional oxygen electrodes), the use of external reference and counter electrodes improves sensor reliability.

The enzymatic sensors, such as the glucose and lactate, have platinum electrodes poised at a positive potential to the card reference electrode. Measurement is accomplished by enzymatic oxidation reaction of the metabolite and the detection of hydrogen peroxide product. The current flow between the platinum and the common electrode is proportional to the metabolite concentration. The sensor is constructed of a three-layer composite membrane, consisting of an inner layer for rejecting interferences, an enzyme for oxidation reaction and an outer layer for controlling metabolite diffusion into the enzyme layer. The inner interference rejection membrane is formed *in-situ* by electropolymerizing a monomer present in one of the cartridge regents (US patent 6872297 to Instrumentation Laboratory).

The main reference electrode in the sensor card is composed of Ag/Ag+ with an open liquid junction. Each time a sample is pumped into the sensor chamber, fresh reference solution containing Ag+ flows into the reference chamber, across a silver pin and contact with the sample solution through a small fluid path near exit section of the sensor chamber (see Figure 1). This configuration provides a fast, stable and reliable reference potential and independent of sample composition.

Quality Assurance

Sensor reliability is assured by wet testing of all manufactured sensor cards in automated computer-controlled testing systems. The procedure involves sensor hydration with buffered solutions, calibration, and measurement with a test solution. After the test completion, sensor cards are washed and purged with dry air. The sensor card test is possible due to the superior adhesion of the polymeric membranes to the plastic substrate, allowing hydration and drying with no deterioration in sensor performance.

Conclusions

Use of multi-parameter analysis by miniaturized chemical sensors in clinical applications is wide spread due to ease of use and avoidance of time-consuming maintenance. Such applications mandate careful sensor design and testing to assure reliability at the point of use. We have developed a simple and uniform sensor configuration adaptable for measuring various analytes with high reliability in GEM Premier Systems.