A Conductivity Probe for Determination of the Carbon Dioxide Tension at the Oxygenator Exhaust Outlet during Extracorporeal Membrane Oxygenation (ECMO)

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A veno-venous extracorporeal membrane oxygenation (ECMO) is a mature clinical treatment for an acute respiratory distress syndrome (ARDS). ECMO is applied to patients with severe lung failure. It can be understood as an artificial lung realizing oxygenation and carbon dioxide elimination. During a veno-venous ECMO venous blood is pumped through a membrane oxygenator before the oxygenated blood flows back into the patient’s vein [1]. There is a need for reliable, accurate and instant determinations of the arterial blood CO₂ tension (pₐCO₂) to guarantee a physiological therapy. The current state of the art is the manual collection of blood samples followed by a separate determination of pₐCO₂ by means of a blood gas analyzer. This approach delays the optimal regulation of the system and suffers from many unwanted manual steps [2]. A well known method for an indirect determination of the pₐCO₂ is the analysis of the partial pressure of CO₂ (pCO₂) in the exhaust gas outlet from the membrane oxygenator [3].

The common technique to measure the pₐCO₂ in blood samples is the use of Severinghaus-type electrochemical carbon dioxide sensors. In this potentiometric sensor the separation of the sample
from the internal electrolyte of the sensor is ensured by the implementation of a polymer membrane. This membrane is permeable to CO₂ gas but not to ions and water. In the internal electrolyte the pCO₂ determines the pH, which is measured by means of an integrated pH electrode [4].

A new concept for the determination of pCO₂ in the exhausted gas volume was studied. The electrochemical detection is based on a commercial thin-film microelectrode as illustrated in figure 1. Interdigitated platinum electrodes are structured on a 750 µm Pyrex substrate (10 x 6 mm), in detail 15 pairs of 10 µm width, separated by gaps of 10 µm, form the interdigital structure. Furthermore, there are two large electrodes, which could be used as reference and auxiliary electrodes. The whole chip is protected by a SU-8 layer. The key idea of the present sensor concept is, to have a membraneless device which measures the pCO₂ dependent conductivity in a thin film of water in direct contact with the gas phase. There is no need for a separating membrane as the measured medium in the oxygenator exhaust gas analysis consists only of oxygen, carbon dioxide and water vapor. The fact to have a sensor without any membrane is promising in terms of attractive response characteristics.

An impedance-phase analyzer was utilized for the investigation of the electrochemical characteristics of the sensor. Impedance spectra were measured to study the frequency behavior of the electrochemical sensor. It was found that an optimal measuring frequency is in the range of 10 kHz for the conductivity range of interest (2 – 20 µS/cm) [5]. The sensor was mounted into various of flow cells with different geometries and materials. The performance was characterized using the gas test bench. For preliminary studies the microelectrode was completely immersed into the electrolyte solution. Signal stability and reproducibility, calibration curves and response
characteristics were studied. The effect of film thickness on the sensor characteristics was investigated.

References


Figures

Figure 1: Photographs of the platinum thin-film sensor. (a) General chip layout. (b) Enlarged view of the interdigitated structure.