DEMOX—a Miniature Non-invasive Optical Oxygen Sensor

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An innovative oxygen reader has been developed to determine oxygen concentration rapidly, efficiently and non-invasively. Originally developed to monitor dissolved oxygen in real time in cell and tissue cultures, the DEMOX optical reader is a versatile device that enables oxygen measurements for many different applications such as medical air monitoring, food and beverage process control or water quality.

Molecular oxygen is a prerequisite for almost all life. Since respiration is vital for cells, tissues and organs, measurement and control of oxygen levels is of particular importance in the life sciences. Traditionally, oxygen concentration has been measured electrochemically, while more recently, optical sensors have become more widely used. The working principle of these optical sensors is based on selective quenching of fluorescent dyes in the presence of oxygen. One of the major advantages of optical oxygen sensing is that oxygen concentration can be determined relatively non-invasively. An additional advantage is that oxygen is not consumed by the sensing process.

For several years, CSEM has followed a multi-disciplinary approach to the development of effective sensing solutions for gaseous and dissolved oxygen by combining chemistry, optical and electronics integration, signal processing, packaging and life applications. Currently, the miniaturization of sensors together with their readers is a critical factor of success in many application fields.

CSEM's optical oxygen sensors are based on the functionalization of thin mesoporous silica-based films with selective dye indicators such as ruthenium complexes. Thanks to their high porosity and surface area, the mesoporous sensing films have both a high optical density and fast response times. The sensing films can easily be produced using large-area industrial techniques. They are biocompatible, can be sterilized by autoclaving, and can be fixed to the inner surfaces of transparent disposable plastics, glassware or bioreactors. The only requirement is an optical access to sensing films in contact with the sample, and the oxygen concentration can be measured non-invasively through the wall of the container while avoiding any contamination of the sample (Figure 1).

Figure 1: Fluorescent oxygen sensor in a tissue culture flask.

An extra compact reader called DEMOX has been designed and produced in a format very similar to a microscope objective (Figure 2a). It can be directly mounted on the inverted microscopes used routinely in biology (Figure 2b). The microscope facilitates alignment between sensor and reader while ensuring a stable and constant optical environment for reliability.

The quantitative determination of oxygen concentration is based on a frequency-domain lifetime measurement. The sensing films are excited by a blue square-modulated LED and the emitted fluorescence has a similar waveform but is phase-shifted with respect to the excitation curve. The amplitude of the phase-shift is directly dependent on the concentration of oxygen. The optimum measuring range for the sensors is from 0% to 21% oxygen with an accuracy of ±0.13% at 1% oxygen and ±0.48% at 10% oxygen. The precision is ±0.07% oxygen. The response time in gaseous environment is around two seconds.

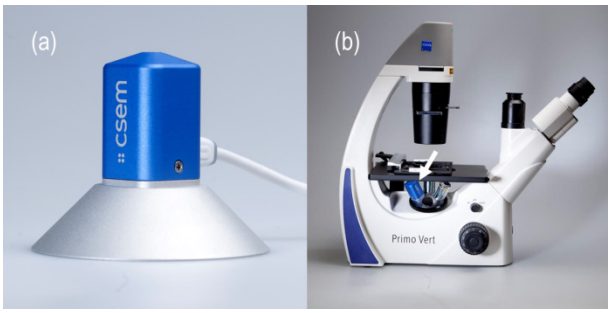

Figure 2: DEMOX reader on its support (a) and mounted on an inverted microscope (b).

The DEMOX reader has been developed to monitor oxygen in real time in cell cultures (Figure 3), but it enables oxygen measurements in many other contexts such as biotechnology, pharmaceutics or environmental research. It can be used, for example, for the quality control of air and water, and for the process control of food or beverages, as well as for diagnosis in applied and basic research. A clear advantage of this "objective-like" device is its compatibility with most commercial microscopes that are regularly used in biology.

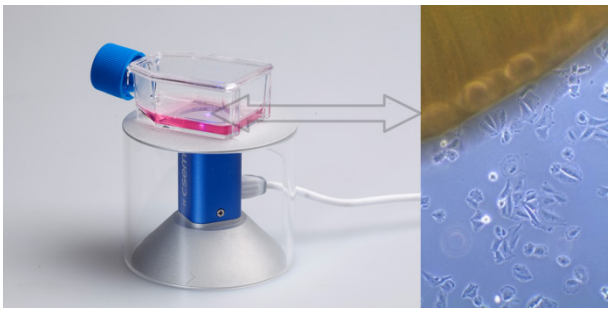

Figure 3: Oxygen control in a human osteosarcoma cell culture.

The combination of this new miniature reader with inexpensive sensing materials provides an innovative oxygen meter that opens new applications in health and environmental monitoring. The solution is highly customisable in terms of power supply, wireless communication or e-reading on mobile devices.

The Demox oxygen sensor was awarded the BioInnovation-Eclosion prize 2015.