Integration of New Sol-gel Films into Miniaturized Optical CO_2 Sensors for Air Quality Monitoring

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We present the development of a new CO_2 sensor, combining groundbreaking sol-gel thin films nanotechnologies with state-of-the-art optical detection. These smart gas sensors provide the necessary data for an energy-saving ventilation and air-conditioning in industrial and public buildings.

Carbon dioxide is a natural part of air. It is also the most important indicator of indoor air quality. A person working in an office exhales about 20 liters per hour of this odorless and tasteless gas. In the current regulation on air quality DIN EN 1946-2, a CO_2 limit of 1500 ppm is specified as the maximum permissible value. High CO_2 concentrations affect the performances of people and can lead to fatigue and headaches.

Sensors play a vital role in establishing the state of our environment and monitoring changes due to human activities. Conventional CO_2 analysis is usually carried out using infrared spectroscopy, using the strong absorbance of CO_2 at 4.26 µm. Unfortunately, this method presents significant drawbacks, such as the bulky and expensive nature of the equipment used and its susceptibility to humidity. In addition, the miniaturization of sensors into wearable devices entails sensors being small, cost-effective, reliable, and with a low energy consumption. Sensors based on change of luminescence in the presence of a specific molecule are promising candidates complying with these specifications since the change of luminescence can be measured by compact optical readers.

In this frame, the technology on which optical CO_2 sensors are based corresponds typically to the encapsulation of a pH indicator dye in an inert nanoporous sol-gel matrix. The sensing mechanism is based on a local change in pH upon reaction with a quaternary ammonium base selective for CO_2. This event is monitored with a pH indicator dye that can be luminescent or colored.

CSEM has developed innovative sol-gel based sensitive layers enabling the optical detection of volatile or dissolved analytes with enhanced performances [1]. To overcome the disadvantages of optical sensors based either on microporous or meso-, and macroporous sensitive layers embedding photosensitive dyes, the host film is made of a double matrix, a microporous sol-gel network encapsulating the active species, which is embedded into a mesoporous coating. These hierarchically nanostructured films are deposited on various substrates such as steel, glass, and flexible plastic sheets. The hierarchical nanostructure enhances the performances of the sensitive layers, *e.g.* higher optical signal, improved sensitivity, robustness, mechanical resistance, transparency, and selectivity, and a faster response.

Several pH indicator dyes, matrix chemistries, and printing process parameters have been screened to limit the impact of humidity and temperature, and to extend the lifetime of the probed patches (Figure 1).

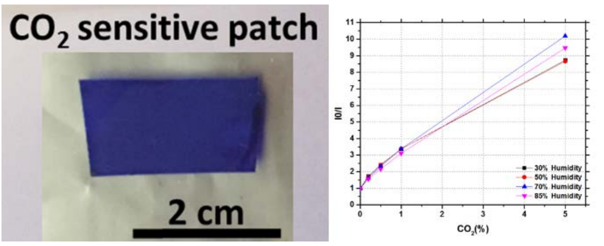

Figure 1: (Left) Picture of CO_2 sensing patches; (Right) Stern-Volmer curves of CO_2 sensitivity showing the low impact of humidity.

A miniaturized optical device for the detection of CO_2 is currently under development for air quality monitoring in buildings (Figure 2). A disposable and low cost sensitive patch is interrogated in a closed module containing LEDs, lenses, and photodetectors. Data processing based on artificial neural networks has been designed to limit the signal deviation (<0.05%). Once integrated into a system comprising humidity and temperature sensors, the device has a low detection limit (yet down to 1 ppm) enabling the monitoring of air quality. Moreover, it can also be used in combination with conductimetric sensors to ensure accurate calibration at 0 ppm.

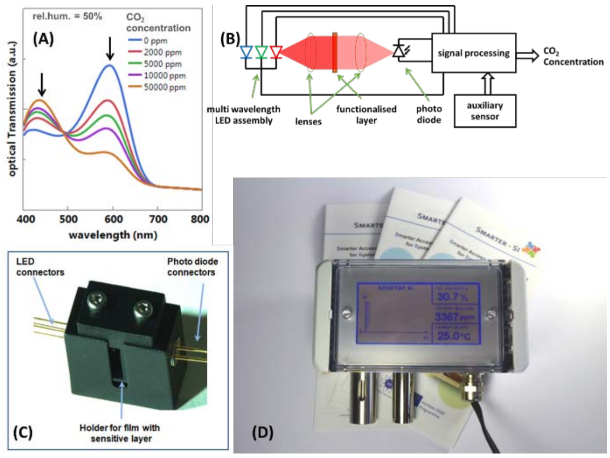

Figure 2: (A) Absorbance spectra of m-cresol purple dye functionalized sensitive patches at different CO_2 concentrations; (B) Working scheme of the optical reader; (C) picture of the reading module; (D) Picture of the sensor demonstrator for indoor air quality monitoring.

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[1] E. Scolan, B. Wenger, R. Pugin (2015), "Optical Sensor for detecting a chemical species", EP patent application EP15201731.5.