LIGHT-ADDRESSABLE POTENTIOMETRIC SENSOR AS SEMICONDUCTOR-BASED SENSOR PLATFORM FOR (BIO-) CHEMICAL SENSING

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1. Introduction

The light-addressable potentiometric sensor (LAPS) belongs to the class of field-effect-based sensor devices. Derived from early investigations on ion-selective field-effect transistors (ISFETs) [1], researchers first developed the electrolyte-insulator-semiconductor (EIS) capacitance to investigate the complex electrochemical- and surface mechanisms of the ISFET-gate region [2-4]. This was a consequential step, and followed the same way as the traditional development of MOSFETs (metal-oxide semiconductor field-effect transistor) and MOS (metal-oxide semiconductor) capacitances [5-8]. Due to the relatively simple manufacturing process and simple encapsulation, at the same time (bio-) chemical sensor development started to use EIS structures as an individual sensor platform [9-12].

Besides the traditional capacitance vs. voltage (C/V) measurements, which are mainly used for the characterization of MOS and EIS capacitances, the scanned light pulse technique (SLPT) was introduced by Engström et al. in 1983 [13]. This technique utilizes a light source to illuminate a local area of, e.g., a MOS structure. Thus, a local photoeffect-induced current can be measured that only depends on the local properties and energy states of the illuminated region of the MOS structure. In 1988, Hafeman et al. combined this SLPT method in combination with EIS structures to develop the light-addressable potentiometric sensor (LAPS) [14, 15]. Such a sensor is capable to measure the surface potential of the electrolyte-transducer interface with a lateral resolution by means of a change of the photocurrent. Hence, the surface potential itself depends on the chemical interactions between the transducer surface and the electrolyte solution (test sample).

Fig. 1 depicts the principal set-up of such a LAPS system.

The presented work will discuss, after a short summary of the theoretical principles, the trends and developments of LAPS-based measurements devices, followed by new developments and future possible tasks and challenges.

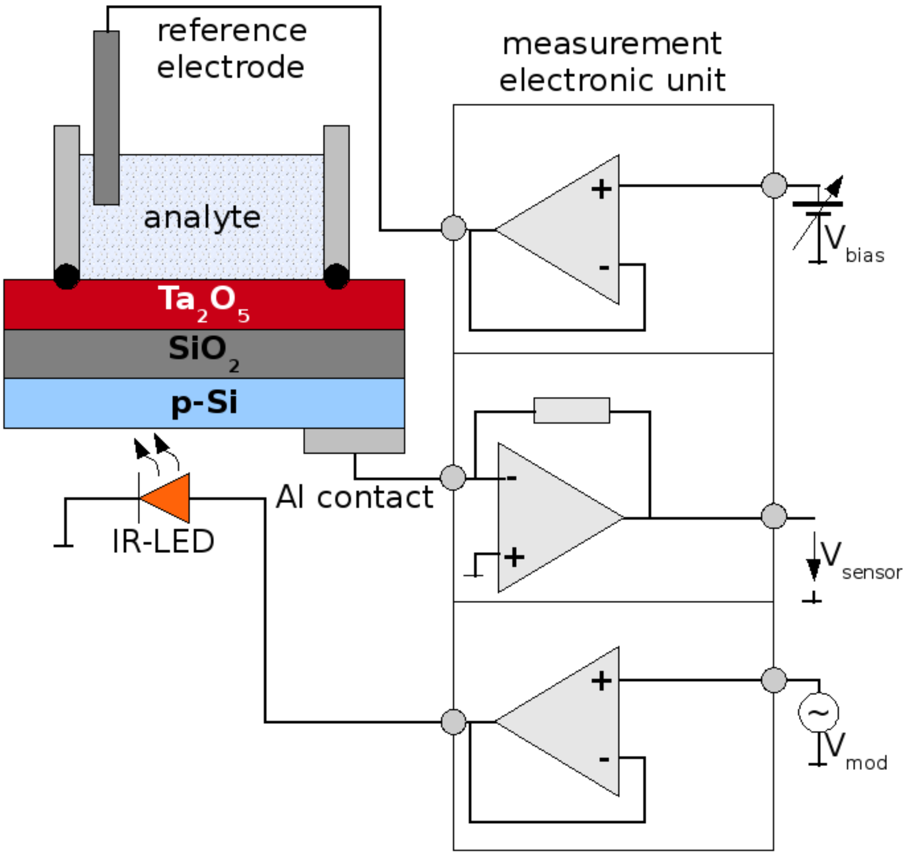

Fig. 1. Schematic representation of a light-addressable potentiometric sensor (LAPS) set-up.

2. Experimental and results

A LAPS sensor is utilized to measure a position-dependent photocurrent with the help of a light beam. By depositing a chemically and/or biologically sensitive surface on the top of a semiconductor-insulator structure, the photocurrent is related to the specific chemical parameter in the analyte. A bias voltage is applied to create a depletion layer at the insulator-semiconductor interface by the electric field. The sensitive surface arouses in interaction with the specific analyte an additional potential, which varies the width of the depletion layer. Depending on the position of the modulated light source used, the variation of the photocurrent serves as a resulting position-defined sensor signal. The measurement of this local photocurrent allows (in contrast to conventional EIS sensors) the measurement of chemical interactions of a certain region of the sensor surface.

Within the last years, different kinds of LAPS configurations have been developed in our laboratory in collaboration with partner universities. Table 1 gives a summary of these investigations and experimental set-ups. Figure 2 depicts the different LAPS-based measurement set-ups that were developed by the authors recently. Starting from an initial LAPS set-up capable to address 4 measurement spots (upper left), the system was scaled up towards 16 measurement spots (upper right), and finally a LAPS card set-up for 16 measurement spots, with embedded LAPS chip on a plastic carry and a reader unit was designed (bottom left).

Table 1. LAPS-based sensor platform for (bio-)chemical sensing.

Experimental set-up	Transducer layer	Ion/analyte	Sensor parameters	Reference
4 x pen-shape LAPS	PVC + ionophores	Ca^{2+}, K^+, Li^+	57mV/dec. (K^+ Li^+), 27 mV/dec. (Ca^{2+})	[16-18]
16 x pen-shape LAPS	Si3N4, Ta_2O_5	pH	54.2 ± 0.5 mV/dec. (Si_3N_4), 56.0 ± 0.2 mV/dec. (Ta_2O_5)	[19,20]
LAPS card	Ta_2O_5, $CdSAgIAs_2S_3$, metabolic activity of CHO[1] cells	pH, Cd^{2+}, acidification rate[2]	54.1 ± 0.5 mV/dec. (Ta_2O_5), 24.5 mV/dec. (Cd^{2+}), 0.1 pH/min acidification rate	[21,22]

[1]Chinese hamster ovary (CHO-K1, DSMZ no.: ACC 110)
[2]pH shift due to the metabolic conversion of glucose to lactic acid.

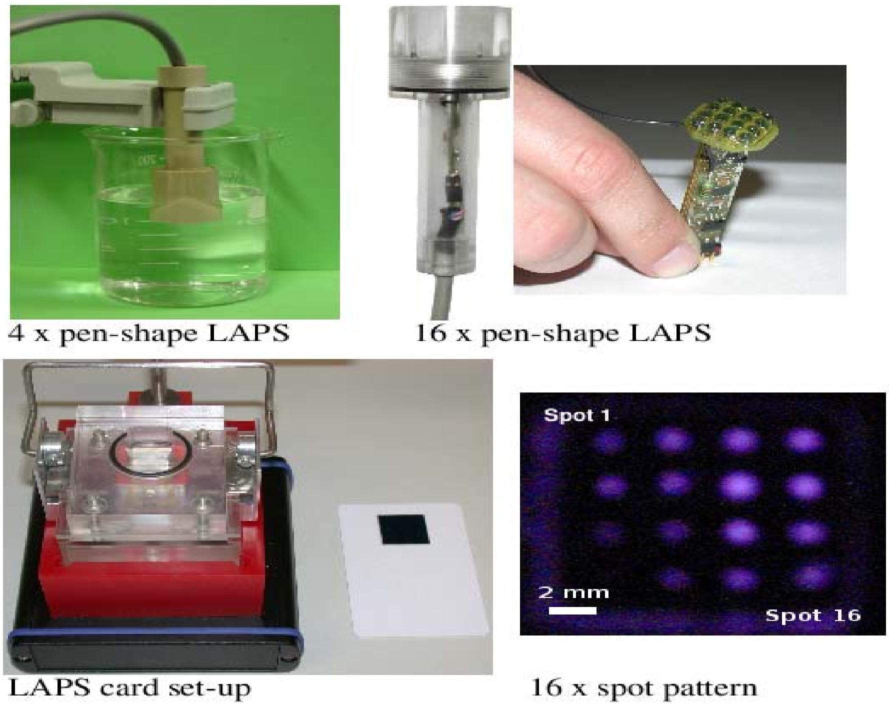

Fig. 2. Different LAPS set-ups: 4 x pen-shape LAPS (2002/2003), 16 x pen-shape LAPS (2004/2005), LAPS card set-up (2005/2006).

3. Conclusions

The LAPS-based set-ups show a good stability and reliability as well as an easy handling. These results underline the wide possible application range for the LAPS as a reliable sensor platform. The small size and integrated measurement electronic allows the utilization of these set-ups for different purposes, not only for laboratory applications. Further investigation will therefore focus on industry-compatible LAPS-based systems.

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