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Light-addressable potentiometric sensors and light-addressable electrodes as a combined sensor-and-manipulator microsystem with high flexibility

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Abstract

This work describes the novel combination of the light-addressable electrode (LAE) and the light-addressable potentiometric sensor (LAPS) into a microsystem set-up. Both the LAE as well as the LAPS shares the principle of addressing the active spot by means of a light beam. This enables both systems to manipulate resp. to detect an analyte with a high spatial resolution. Hence, combining both principles into a single set-up enables the active stimulation e.g., by means of electrolysis and a simultaneous observation e.g., the response of an entrapped biological cell by detection of extracellular pH changes. The work will describe the principles of both technologies and the necessary steps to integrate them into a single set-up. Furthermore, examples of application and operation of such systems will be presented.

Light-addressable potentiometric sensor; LAPS; light-addressable electrode; LAE; chemical sensor; biosensor

1. Introduction

The light-addressable potentiometric sensor (LAPS) is a field-effect-based chemical sensor consisting of a semiconductor substrate, an insulator layer and a transducer layer (see Figure 1a). The sensor is embedded in a measurement cell providing a direct contact to the analyte solution. The structure is

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electrically contacted by a single metal pad at the rear-side and by a reference electrode placed in the analyte solution. LAPS utilizes a modulated light beam to generate a photocurrent. The amplitude of the external photocurrent depends on the surface charge of the biased sensor structure. Depending on the utilized transducer layer, different analytes can be detected [1-3]. By recording both the position of the light beam and the amplitude of the photocurrent one can generate images of the concentration distribution above the sensor surface. Recently, the authors demonstrated the generation of chemical images consisting of up to 153,600 measurement spots within an area of 20.8 x 13.9 mm^2 [4]. These chemical imaging systems can be used e.g., for the study of biological systems like cultured neurons or brain slices on microscale level.

However, for many physiological applications, manipulator elements are required to control the environmental conditions and/or to stimulate biological systems (e.g., by modifying the local pH value). The light-addressable electrode (LAE) consists of a thin semiconductor layer on a conductive transparent substrate, covered by a protective layer (see Figure 1b) [5]. The electrode is embedded in a measurement cell and the conductive layer as well as an electrode in the analyte solution are used to create electrical contacts for a dc voltage across the LAE structure. A light beam is used to create a region of high conductance within the semiconductor layer in a spatially resolved manner. Applying a voltage between the LAE and the counter electrode will result in a proportional current flow, whereas the illuminated region defines the preferred current path. Hence, by repositioning the light-beam, different regions on the electrode surface can be addressed without any additional wiring.

More information about the light-addressable principle can be found elsewhere [6, 7].

2. Set-up & Methodology

Since both systems, LAE and LAPS utilize the same addressing principle; it is feasible to combine them into a single microsystem set-up. This will allow stimulation by means of LAE and recording of resulting changes by LAPS simultaneously. Both systems share a flat and homogeneous surface, which supports the design of fluidic channels.

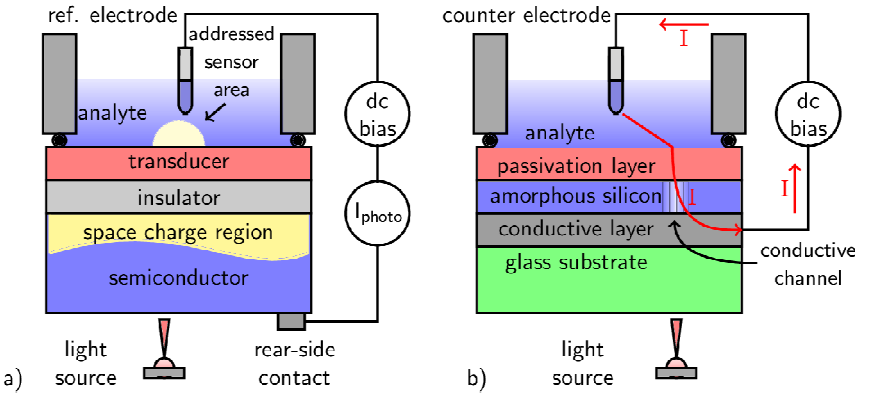

Fig. 1. Schematic representation and working principle of a) a light-addressable potentiometric sensor (LAPS) and b) a light-addressable electrode (LAE).

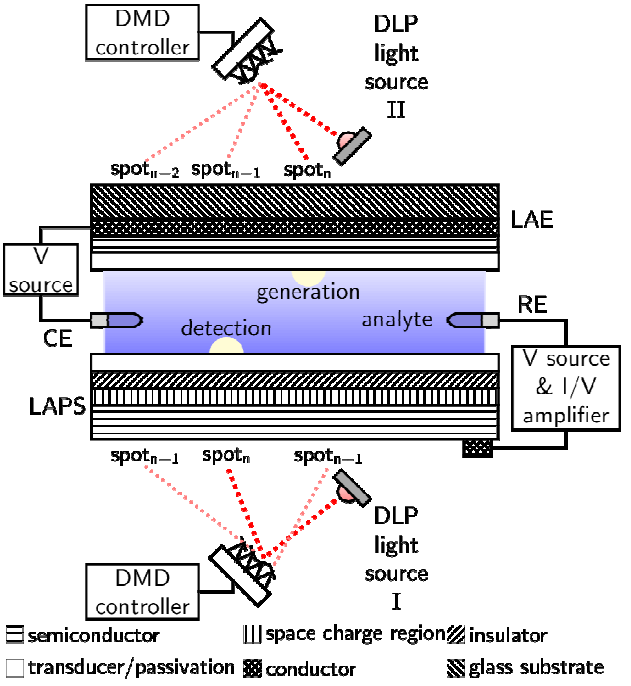

Fig. 2. Schematic representation of a combined LAE and LAPS microsystem. Both systems can be individually addressed by DLP-based light sources to generate different generation and detection spots.

Figure 2 depicts a possible arrangement of both LAE and LAPS forming a fluidic channel in between. Both systems can utilize a DLP (digital-light processing) a light source to define different shapes and sizes of generation- respectively detection spots at different locations on the structure. More information about the utilization of DLP-based light-sources for spatial addressing can be found elsewhere [4].

3. Results & Discussion

Figure 3 depicts chemical images recorded with the LAPS system. The LAPS structure consists of a n-type silicon material with a SiO_2 layer as insulator and a pH sensitive layer of Si_3N_4. The LAE structure consists of a glass substrate, a ZnO layer as conductive layer and amorphous silicon as semiconductor. Each image consists of 24 x 16 pixels with a spot size of 860 x 860 μm^2. Prior to each image the LAE structure was addressed by a light spot consisting of 500 light pulses of 2 ms each. During this time a dc voltage of 3 V was applied across the LAE structure. After that, the LAPS structure was used to record the spatial pH distribution above the sensor surface of an area of about 20.8 x 13.9 mm^2.

As shown in Figure 3, starting from the illuminated region of the LAE structure, a local change of the pH value is observable by the LAPS set-up, after applying series of stimulus pulse via the LAE and each successive series of pulses increases the local pH change. These measurements demonstrate the benefits of the combination of a LAE and a LAPS system in a single set-up. Local changes in the analyte solution or local triggering of biological species by the LAE system can be directly observed and controlled the LAPS-based chemical imaging technique. Furthermore, the new system can be used for many different purposes by utilizing individually designed light patterns. These light patterns can be programmatically generated and displayed e.g., by OLED panels [8] or DLP projectors [4]. This enables a quick and wide

adaption to measurement needs by simple reprogramming. Furthermore, the set-up is flexible enough to allow e.g., localization of biological cells and hence adapt light patterns to enable an optimized addressing during the experiment. Hence, the new set-up can serve as a cost-effective and highly flexible sensor-and-manipulator platform for miniaturized analytical systems.

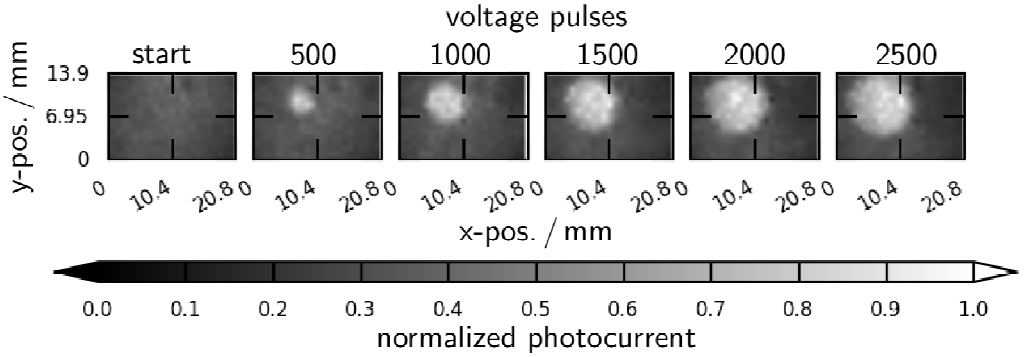

Fig. 3. Successive chemical images recorded by the light-addressable sensor, consisting of 24 x 16 measurement spots. Starting with an initial image, prior to each successive LAPS scan, 500 times 2 ms light pulses with an applied bias voltage of 3 V were applied to the LAE structure.

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