



Miniaturized amorphous-silicon based chemical imaging sensor system using a mini-projector as a simplified light-addressable scanning source



Anirban Das^{a,1}, Yen-Heng Lin^{a,b,c,*}, Chao-Sung Lai^{a,b,**}

^a Department of Electronic Engineering, Chang Gung University, Taoyuan 333, Taiwan

^b Healthy Aging Research Center, Chang Gung University, Taoyuan 333, Taiwan

^c Graduate Institute of Medical Mechatronics, Chang Gung University, Taoyuan 333, Taiwan

ARTICLE INFO

Article history:

Received 19 June 2013

Received in revised form 29 August 2013

Accepted 13 September 2013

Available online 23 September 2013

Keywords:

Chemical image sensor

Light addressable potentiometric sensor

Projector

Amorphous silicon

ABSTRACT

This paper reports the development of a chemical imaging sensor configuration addressing two important issues of imaging systems: the flexibility of the scanning technique and the resolution of the image. In this set-up, a commercial pico-projector in combination with an objective lens is placed directly below the sensor plate and is utilized as a light-addressing source to scan the sensor surface. The pico-projector provides the computer software interface that enables the user to generate a programmable light beam with control over its size, shape, color, movement, and even modulation frequency. This approach eliminates the requirement of complicated mechanics and optics in conventional scanning techniques based on linear X–Y stages or multiple light sources and effectively miniaturizes the set-up. Furthermore, no additional control unit is required to access the internal control of digital micro-mirror, thus simplifying the scanning set-up. An amorphous-silicon-based thin-film light-addressable potentiometric sensor (LAPS) structure is used as a sensor chip. At the present stage, pH sensitivity close to the ideal Nernstian value and a visibility of patterns of 25 μm chemical image were exhibited. Finally, the chemical imaging of a complex pattern was successfully demonstrated using this simple low-cost, miniaturized system.

© 2013 Elsevier B.V. All rights reserved.

1. Introduction

Chemical image sensors are important sensing systems used to analyze and interpret the complex interface reaction by producing an image for visualizing the two-dimensional (2-D) distribution of chemical species in electrochemical and biological systems. This image provides quantitative information of the relevant chemical species in a time- and spatially resolved manner. The use of fluorescent dyes is one of several well-established techniques in analytical chemistry to visualize chemical species [1–3]. Unfortunately, the toxicity of such dyes is a major problem for certain application in the biological and medical fields. In addition, a fluorescent dye may undergo photo-bleaching. To avoid such issues, a chemical imaging technique based on solid-state semiconductor devices can be used due to the advantages of being label free (i.e., no dyes are required)

and the possibility of miniaturization and integration with peripheral circuitry [4,5]. A well-known semiconductor-based chemical sensor is the ion-sensitive field effect transistor (ISFET), which already has several practical applications, such as a portable pH meter [6–9]. Another well-known example is electrolyte-insulator-semiconductor (EIS) structures as an individual capacitive sensor platform, which is relatively simple in manufacturing process and easy encapsulation [10,11]. In addition to the traditional ISFET and EIS, in 1988, Hafeman et al. developed the light-addressable potentiometric sensor (LAPS) by combining the scanned light pulse technique (SLPT) with EIS structures [12–16]. These sensors consist of a basic transducer-insulator-semiconductor structure that is in contact with electrolyte solution. The direct current (DC) bias voltage through the reference electrode is applied across the sensor structure between the rear side contact and analyte solution, which causes a field to appear in the semiconductor at the insulator-semiconductor interface, thus inducing a space-charge region. The local width of the space-charge region also depends on the surface potential at the analyte-transducer interface. However, this surface potential is influenced by the local concentration of the analyte on a pH-sensitive transducer surface according to the site-binding model [17]. As a result, monitoring the width of the space-charge region will indicate the local concentration of the analyte. In the

* Corresponding author at: Department of Electronic Engineering, Chang Gung University, Taoyuan 333, Taiwan. Tel.: +886 3 2118800x3789; fax: +886 3 2118507.

** Corresponding author at: Department of Electronic Engineering, Chang Gung University, Taoyuan 333, Taiwan. Tel.: +886 3 2118800x5786; fax: +886 3 2118507.

E-mail addresses: yenheng@mail.cgu.edu.tw (Y.-H. Lin), cslai@mail.cgu.edu.tw (C.-S. Lai).

¹ These authors contributed equally to this work.

case of the LAPS, the width of the space charge region is detected by measuring an alternative current (AC) photocurrent [13–16]. Illuminating the semiconductor surface with a focused and modulated light source generates electron–hole pairs in the bulk semiconductor. If these electron–hole pairs reach the space-charge region, then they will be separated by the electric field of the depletion layer. As a consequence, a measurable AC photocurrent will appear at the point of illumination. Thus, the read out mechanism of a LAPS enables a unique scanning technique of the sensor surface whereby the individual sensing site is addressed by utilizing a pointed and modulated light beam. This concept of addressing each measurement site can be implemented using a relatively simple structure to sense the bio-chemical processes on a chip surface spatially without any complex bonding, wiring, or encapsulation and can generate electrochemical image by converting the photosignal into a 2-D color map. For example, LAPSs have been employed successfully to biological applications, such as immunoassays [18,19], drug analysis [20], cell metabolism [21,22], and chemical imaging [23–26].

The implementation of LAPSs has two major issues: the spatial resolution of the image and the light-addressing scanning procedure. The spatial resolution may be defined as the smallest size of the potential distribution that can be resolved by mapping the sensor surface, and this resolution limits the pixel density of the chemical image. The spatial resolution has been demonstrated both experimentally and theoretically to rely on two key factors: the spot size of the light beam and the diffusion of photocarriers in the bulk semiconductor [27–29]. Two basic approaches have been adopted to improve the spatial resolution: thinning and increasing the doping concentration of bulk silicon [27,28] or using a semiconductor with a short minority carrier diffusion length [30,31]. A lateral resolution of approximately 10 μm was reported by thinning the bulk Si substrate down to 20 μm [32]. However, an infrared laser was used as a scanning source, which cannot be observed by the naked eye during the scanning process. Alternatively, a resolution of 5 μm was achieved with a 0.5- μm -thick Si layer [33]. However, in that work, the resolution was defined by the size of differently doped islands in the Si rather than a homogeneous LAPS surface. Furthermore, the fabrication process of 0.5- μm -thick single crystal Si is relatively complex. In addition to approaches involving the thinning of Si, promising resolution has been obtained by using semiconductors with shorter diffusion lengths. For example, GaAs (diffusion length of 3 μm) [30] and amorphous Si (a-Si, diffusion length = 120 nm) [34] substrates provide resolutions down to 3 μm and 1 μm , respectively. However, for the GaAs substrate, growing a high-quality insulator is a major problem. The best resolution of 0.8 μm was reported using an as-grown anodic oxide of thickness 6.7 nm on Si on sapphire (SOS) wafer [35]. However, this approach used a two-photon technique that is quite sophisticated and does not offer flexibility in the scanning method. Considering its utility in the form of large-area thin films and the available mature technology, a-Si is a potential candidate to offer both higher resolution and flexibility to the scanning technique. Moreover, the band gap of a-Si is appropriate to stimulate by visible light so that a commercial projector can be used as a light source.

The light-addressing scanning procedure for chemical imaging is also an important issue in terms of the flexibility, miniaturization, and measurement speed. Two different basic concepts of addressing locally different measurement sites on the sensor surface are utilized in a conventional LAPS set-up. One concept utilizes a focused laser beam in combination with a linear positioning mechanical X–Y stage to address the laser beam at different points of interest [32,36]. Although this technique offers higher resolution by using a sophisticated optical set-up to focus the laser beam, it is bulky, has speed limitations, and is expensive. In other approach, different measurement sites are simultaneously addressed with an

array of light sources modulated at different frequencies [37,38]. The recorded signal is the sum of the signals at each frequency component. The photosignal at each measurement site predefined with a different frequency can then be extracted by using the fast Fourier transformation (FFT) algorithm. This concept significantly improves the measurement speed because it uses a simultaneous addressing method rather than sequential point-to-point scans. However, this technique is limited in the fixed number of individually addressable light sources. Moreover, the size, shape, and position of the light spots are predefined for both techniques and cannot be modified in a user-defined manner during the scanning time. Recently, digital light processing (DLP) technology and an organic light-emitting diode (OLED) panel were used as a scanning light source to overcome these limitations [39,40]. Both techniques generate chemical images with no limitations regarding the size and shape of the light beam. However, both techniques utilize an additional processor board to access the internal control of the digital micro-mirror device (DMD) and OLED display panel, which require extensive development time and ability. Furthermore, both of these chemical image sensors use single crystalline Si as a basic semiconductor material to fabricate the LAPS chip; the resolution of this material is diffusion limited and thus limits the achievement of a higher-resolution chemical image. In addition, the use of a computer screen as a programmable light source was also demonstrated for chemical imaging by scanning light pulse technique (SLPT) [41] and surface plasmon resonance imaging [42]. However, the use of both cathode-rays tube screen and liquid crystal display screen are relatively bulky in size.

This work aims to develop a new chemical image sensor system that will deliver both a simple, miniaturized, inexpensive, flexible scanning set-up and higher resolution. We have used a commercially available DLP-based pico-projector in combination with a projection lens as a programmable scanning light source to fulfill the first requirement. The light spot was generated by simply drawing a white spot on the black background of a computer screen with commercially available software and then focusing the light onto the sensor surface by using a video projector in combination with a microscope objective. The size, shape, modulation, and movement of the spot can be easily controlled in a user-defined manner, thus promoting enormous flexibility in our proposed scanning set-up. In addition, a-Si on an indium tin oxide (ITO)/glass substrate was used as the semiconducting layer of the LAPS chip to accomplish the second requirement of higher resolution. The smaller diffusion length of a-Si confirmed that the resolution of the proposed chemical image sensor was only limited by optics. At the present state of development, the proposed chemical image sensor system has reached a visibility of patterns of 25 μm and has been successfully employed to generate a high-pixel-density chemical image of an artificially created potential distribution on the sensing surface in a very simple and straightforward manner.

2. Materials and methods

2.1. Set-up of the mini-projector-based LAPS

Fig. 1 illustrates the design details of the proposed electrochemical image sensor system. The light-addressing scanning component of the system was provided by a commercially available DLP-based pico-projector (PK301, Optoma, Taiwan). The projector is portable in size (120 mm \times 70 mm \times 30 mm) with contrast ratio of 2000:1, a brightness of 50 lumens, and a refresh rate of 60 Hz. The projector was placed underneath the LAPS chip, and the light beam diverging from the video projector was then focused onto the sensor surface by placing a 4 \times objective lens (UPFLN 4X, Olympus, Japan) between the projector and chip. Using a video projector allows

Download English Version:

<https://daneshyari.com/en/article/7148452>

Download Persian Version:

<https://daneshyari.com/article/7148452>

[Daneshyari.com](https://daneshyari.com)