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Planar electrochemical sensors for biomedical applications

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Abstract

Electrochemistry has superior properties respect to the other measurement systems because of the rapid, simple and sensitive characteristics. For all these reasons, electrochemical sensors are playing a key role in many scientific sectors.

Planar electrochemical sensors present many advantages respect to the three-dimensional devices, but this technology requires the use of specialty chemicals to meet the new functional requirements of planarization and miniaturization. In this paper, some production techniques and procedures to obtain planar electrochemical sensors are reported, together with their applications.

Keywords: Planar electrochemical sensors; Thick film technology; Thin film technology; Screen printed electrodes; Field effect transistor; Electrochemical biosensors

1. Introduction

Electrochemical sensors represent the most rapidly growing class of chemical sensors. An useful definition for a chemical sensor is "a small device that as the result of a chemical interaction or process between the analyte and the sensor device, transforms chemical or biochemical information of a quantitative or qualitative type into an analytically useful signal" [1]. While chemical sensors contain a physical transducer and a chemically sensitive layer, the instrument sends out an energy signal, be it thermal, electrical, or optical, and reads the change in this same property, caused by the intervening chemical.

Compared to the other sensors, electrochemical sensors are especially attractive because of their remarkable detection capability, experimental simplicity and low cost. They have a leading position among the presently available sensors that have reached the commercial stage and which have found a vast range of important applications in the fields of clinical, industrial and biomedical analyses [2]. Recent developments in chemically modified electrode sensors, microelectrodes, and some electrochemical methods (such as adsorptive stripping voltammetry and potentiometric stripping analysis) has opened the door for the application of electrochemical sensors to the analysis of many more chemical species.

Between electrochemical sensors, planar devices have a large development in latest years and they have been brought into use for measuring in different applications [1,3,4]. Production techniques used for the development of planar electrochemical sensors can be classified in different ways; as other 'Solid-state sensors', they have been made from classical semiconductor materials (such as Si or Ge), solid electrolytes, insulators, metals and catalytic materials; thick film and thin film technologies, photolithography and silicon technology are the most used techniques to produce planar electrochemical sensors.

Electrochemical sensors respond also to the most important trend in the research of latest years, which is to go smaller in device dimensions [5]; micro- and nanoelectrodes and microtechnological approaches to manufacturing sensors demonstrate the strong link between chemistry, physics, and engineering in this field. Finally, the integration into microfluidic platforms is just the latest, logical step in the miniaturization direction, especially for clinical applications [5].

Current paper will focus the attention on the recent developments in planar electrochemical sensors, showing also some of their clinical and biomedical applications.

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2. Thick-film sensors

2.1. Thick film technology

Thick-film technology was introduced about thirty years ago as a means of producing hybrid circuits. Such circuits comprise semiconductor devices, monolithic ICs and other discrete devices, in addition to the thick-films themselves [6,7].

A key factor distinguishing a thick-film circuit is the method of film deposition, namely screen printing, which is one of the oldest forms of graphic art reproduction. The use of thick-film techniques shows several significant advantages respect to other techniques, such as flexibility of design and choice of materials, low cost in infrastructure, possibility of automation of the fabrication process and low barrier for technological transfer capability [8,9].

A thick-film sensor is generally formed by layers (or films) of special inks or pastes deposited sequentially onto an insulating support or substrate [10,11]. The film is applied through a mask contacting the substrate, and deposited films are obtained by pattern transfer from the mask (Fig. 1). After the printing step, the next stage is to dry the printed film. All pastes contain various organic solvents which are needed in order to produce the correct viscosity for screen printing; these can be removed by drying the film in a conventional box oven. Conventionally, thick-film sensors were baked at temperatures ranging from 300 and 1200 °C; alternatives include cold-cured ink formulations and a photocured process using ultraviolet light. After drying, the films retain a rigid pattern on the substrate and are relatively immune to smudging.

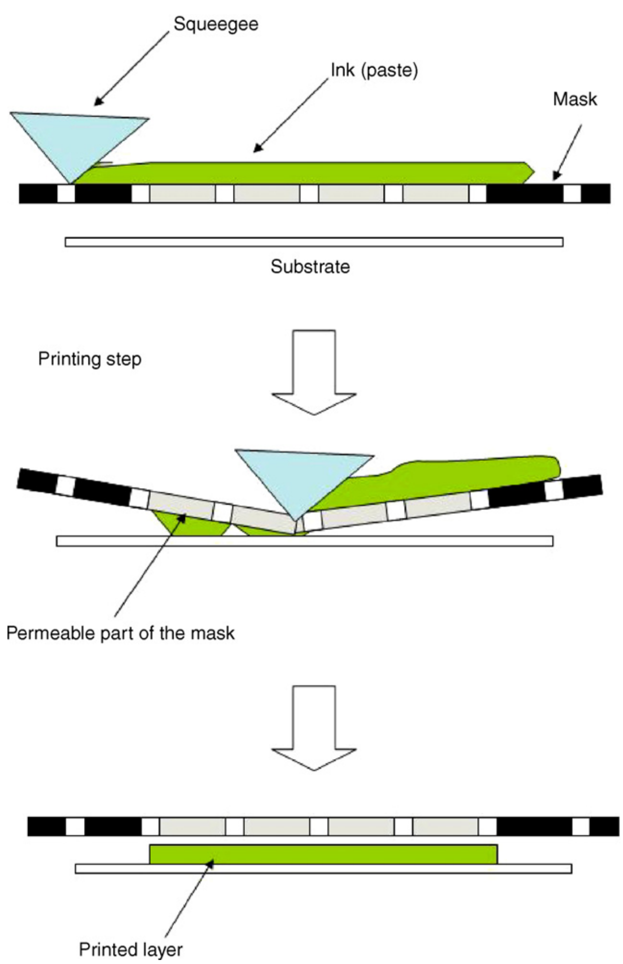

Fig. 1. A draw representing the different phases of the screen printing process.

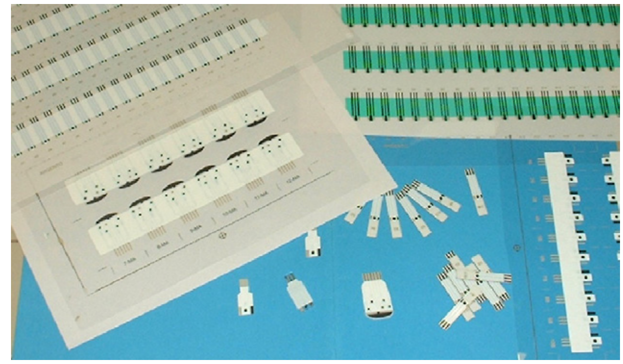

Fig. 2. A picture showing various screen-printed electrodes.

Complex structures can be built up by repeating the print process using the materials appropriate to the specific design and a range of mask designs. In this way, a variety of screen-printed thick-film devices can thus be fabricated (Fig. 2). One of major advantages of this technology is the ability to produce hybrid integrated circuits in a robust and miniaturized package. These planar devices present in fact many advantages including disposability and small dimensions, which facilitates the design of portable measuring systems.

2.2. Thick-film sensors applications

Thick-film sensors have been used for a number of chemical sensing applications, including the measurement of humidity, gas, liquid composition and acidity (pH). It is difficult to define a comprehensive scheme for the classification of thick-film chemical sensors, since so many variants appear in the literature [11]. A broad classification based on two categories seems to cover most devices: impedance-based sensors, in which the analyte is measured by variation of resistance and capacitance, and electrochemical systems in which potential or current variations are evaluated.

Screen printing technique is also one of the most promising technologies to produce planar electrochemical biosensors [12–14] to be placed large-scale on the market in the near future, because of advantages such as miniaturization, versatility and low cost and particularly for the possibility of mass production [15].

The most well-known application of screen-printing technology in biomedical application has been in the clinical analysis of blood glucose levels in people with diabetes [16]. The deceptively simple combination of a fungal enzyme (glucose