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Porous silicon biosensor: Current status

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A B S T R A C T

Biosensing technologies cater to modern day diagnostics and point of care multi-specialty clinics, hospitals and laboratories. Biosensors aggregate the sensitivity of detection methodologies and constitutional selectivity of biomolecules. Endeavors to develop highly sensitive, fast, stable and low cost biosensors have been made possible by extensive and arduous research. Immense research work is going on for detection of molecules using various materials as immobilization substrate and sensing elements. Amongst materials being used as bio-sensing substrates, nano-porous silicon (PS) has amassed attention and gained popularity in recent years. It has captivating and tunable features like ease of fabrication, special optico-physico properties, tailored morphological structure and versatile surface chemistry enhancing its prospects as transducer for fabricating biosensors. The present review describes the fabrication of PS and its biosensing capabilities for detection of various analytes including, but not limited to, glucose, DNA, antibodies, bacteria and viruses. Attention has been consecrated on the various methodologies such as electrical, electrochemical, optical and label free techniques along with the performances of these biosensors. It concludes with some future prospects and challenges of PS based biosensors.

Contents

Abbreviations: PS, Porous silicon; ss, Single strand; ds, Double strand; c-DNA, Complimentary DNA; Ab, Antibody; PL, Photoluminescence

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1. Introduction

Nanotechnology is the science of materials which ranges in nano dimensions. The properties of a bulk material are quite dissimilar from a nanostructured material. Shrinking the size of any material causes tremendous (sometimes entire) change in its properties making it suitable for various applications. Nanostructured materials have not only paved the way for upcoming technologies but also invited numerous challenges for the research community. Porous silicon (PS) is a nanostructured material, which provides plentiful advantages to ace the present nano sized material community. As the name suggests PS is like a quantum sponge, containing a web like structure consisting of nanocrystallites and pores (Bisi et al., 2000). Not only PS but silicon itself is an attractive and a useful material. Any device application using silicon is bound to be a successful device as silicon is readily available, low cost and easily compatible with the modern IC industry. There are some unique properties of silicon which are noticeable when its structure reduces to nano-dimension. These changes in properties are the outcomes of Quantum Confinement Effect. Thus PS exhibits properties like, enhanced surface to volume ratio ($\sim$500 $m^2\,cm^{-3}$), high surface reactivity and luminescent properties at room temperature. Because of its versatile nature, PS has a large number of applications in sensing, optoelectronics, micromachining, biotechnology, wafer technology etc. (Lehmann and Gösele, 1991; Föll et al., 2002). PS has been extensively exploited as sensor because of its fascinating aforementioned features.

Sensor is a device that as a 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 (Stetter et al., 2003). Detection of an analyte or molecule is confirmed by a sensing material when any of the material properties show a considerable change, upon exposure to analyte or molecule. Biosensing is a small section of the wide term sensing, which is the recognition of a bioelement (enzyme, antibody, tissue, dead or live cell etc.) upon its exposure to a sensitive material. The change in material properties is fluxed with a transducer from where the actual output is obtained. This change in material properties can be detected by various scientific techniques thus forming a biosensing device (Mohanty and Kougianos, 2006).

PS demonstrating both optoelectronic properties and biocompatibility has attracted the attention of researchers in biosensing field. Many applications of PS being used as biosensor have been discussed in the recent past (Singh et al., 2009; Tembe et al., 2008; Stefano et al., 2007). PS is being used for detection of glucose, DNA, bacteria, viruses, proteins and many more biomedical treatments and diagnostics. The present comprehensive study reviews current status on the biosensors developed utilizing PS as a sensing matrix for the detection of various analytes. It also focuses on fabrication of PS, protocols followed for surface modification for biomedical applications on the PS surface and its eventual application in fabricating biosensors for the qualitative and quantitative estimation of relevant biomolecules.

2. Porous silicon (PS)

The captivating features of silicon like ease of availability, low cost and compatibility with advanced electronic industry make it an attractive, utile and suitable material for commercial industry. Its key parameters can further be enhanced by reducing bulk silicon to nano structured material. For example, silicon can be transformed from a poor emitter to an efficient emitter of light by making it porous using a simple electrochemical technique.

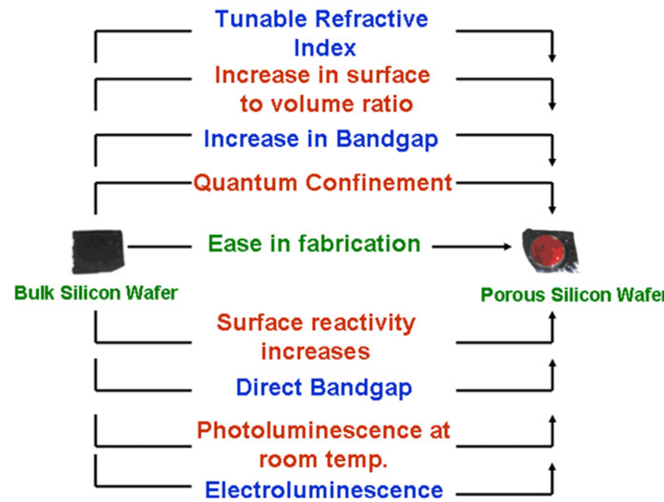

Fig. 1. Change of properties from bulk to PS.

Creation of porous layer where Quantum Confinement plays a dynamic role causes wide change in the material properties, such as optical and electrical, of silicon enhancing its capability of being used in industry of sensors, light emitting devices, transistors, solar cells, integrated circuits and many high end applications (Fig. 1). The pores on the surface of porous silicon (PS) act as binding sites attracting foreign species which get adsorbed on the spongy structure of PS. This forms the basis of sensing mechanism. PS surface can be easily subjected to modifications and chemical reactions to tailor their interface chemistry in view of realization of biosensors. The fascinating properties of PS have captured the industry's eye and proven not only its usefulness as optical devices but also as an expeditious sensor.

2.1. Fabrication of PS

One of the common, simple and efficient methods for fabrication of PS involves employment of electrochemical etching technique. The etching process requires a thorough pre-cleaning of silicon wafer by a chemical procedure for removal of any unwanted deposition on the silicon wafer. This cleaned wafer undergoes a galvanostatic electrochemical etching process which comprises of an etching cell, silicon wafer (anode), a constant current source, platinum wire (cathode) and an electrolyte (Sailor, 2012). The electrolyte consists of hydrofluoric acid (HF, 49%) and ethanol. The current is allowed to flow for a fixed duration called as etching time. The most accepted model for describing etching mechanism has been proposed by Lehmann and Gösele (1991) which is illustrated as Fig. 2 and the net reaction for silicon etching is given in Eq. (1): (Rauscher and Spohn, 2001), where h^+ and e^- represent hole and electron respectively

$$Si+6HF+h^+ \rightarrow SiF_6{}^{2-}+H_2+4H^+ +e^- \quad (1)$$

Hydrogen gas evolution resulting from this reaction can be observed from the silicon surface during the etching process. It is evident from the reaction that silicon atoms are knocked out from the surface generating porous structure containing nanocrystallites of silicon.

2.2. Porosity

PS fabrication forms pores ranging from macro, micro to nano sizes. Porosity is the fraction of total pore volume to the apparent