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A highly sensitive and distinctly selective D-sorbitol biosensor using SDH enzyme entrapped Ta_2O_5 nanoflowers assembly coupled with fiber optic SPR

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ABSTRACT

The current work introduces a novel platform for detection of D-sorbitol in aqueous samples employing surface plasmon resonance (SPR) as the cardinal sensing principle. The sensing probe encompasses an assembly of sorbitol dehydrogenase enzyme entrapped tantalum pentaoxide nanoflowers decorated onto the plasmonic metal silver coated unclad core of an optical fiber. When the sensing probe is brought in vicinity of D-sorbitol solutions of varying concentration, the formation and subsequently decomposition of enzyme-analyte complex is entailed, which, in turn, alters the dielectric function of the sensing layer. This tailoring of dielectric function within the premises of sensing probe is manifested in terms of the shift in resonance wavelength. The concentration range 0.1–1.1 μg/ml of D-sorbitol defines the limit of operation of the sensor, for which a blue shift of 55 nm in resonance wavelength has been observed. The sensitivity and the limit of detection are obtained as, 92.16 nm/μg/ml and 3.6 ng/ml, respectively, which excel the previously reported results. Influence of pH over the performance and selectivity/specificity of the sensor are also investigated. The sensor showcases immense scope of usage in medical, pharmaceutical and food industry on grounds of myriad advantages provided by combination of SPR and fiber optics.

1. Introduction

The avenue of sensor technology has witnessed a substantial development since the report of the first sensing application making use of surface plasmon resonance (SPR) phenomenon [1]. The same has also been influenced to a great extent due to the advances made in the field of fiber optics over the past three decades. The SPR technique coupled with fiber optics provides a precise, specific, fast and reliable sensing mechanism, and therefore, this combination turns out to be immensely advantageous and successful for sensing applications [2,3]. Basically, a surface plasmon (SP) wave represents a transverse magnetic (TM) polarized wave, that propagates along the interface of a metal and a dielectric when a particular resonance condition is satisfied [4,5]. The commonly employed fiber optic SPR sensor configuration involves first the removal of cladding from a small middle portion of an optical fiber followed by the deposition of a definite thickness of a plasmonic metal over unclad portion. The metal coated region of the optical fiber forms the sensing region which is placed in the vicinity of the dielectric medium (analyte) to be sensed. Light launched through one end of the fiber generates an evanescent wave at the fiber core-metal interface, which, in turn, excites SPs at metal-dielectric interface. The matching of the wave vector of the evanescent wave with that of the SP wave causes the evanescent wave to transfer maximum of its energy to the SP wave. This is reflected in terms of a dip in the spectrum of the transmitted light obtained at the other end of the fiber optic probe at a particular wavelength termed as resonance wavelength, which happens to be a function of the refractive index of the sensing dielectric medium. Thus, by measuring the shift in the resonance wavelengths occurred because of the change in the dielectric sensing medium, the change in the refractive index of the dielectric medium can be determined. Based on this principle, tremendous amount of work has been reported in the literature on SPR based fiber optic chemical and biochemical sensors [6–12].

D-sorbitol, a type of sugar alcohol, is a biologically important saccharide. Referred to as a nutritive sweetener, it finds applications in fields as diverse as medicine, food, pharmaceutics and cosmetics. The clinical importance of D-sorbitol arrives from the fact that it is an intermediate compound in the polyol pathway, which is a

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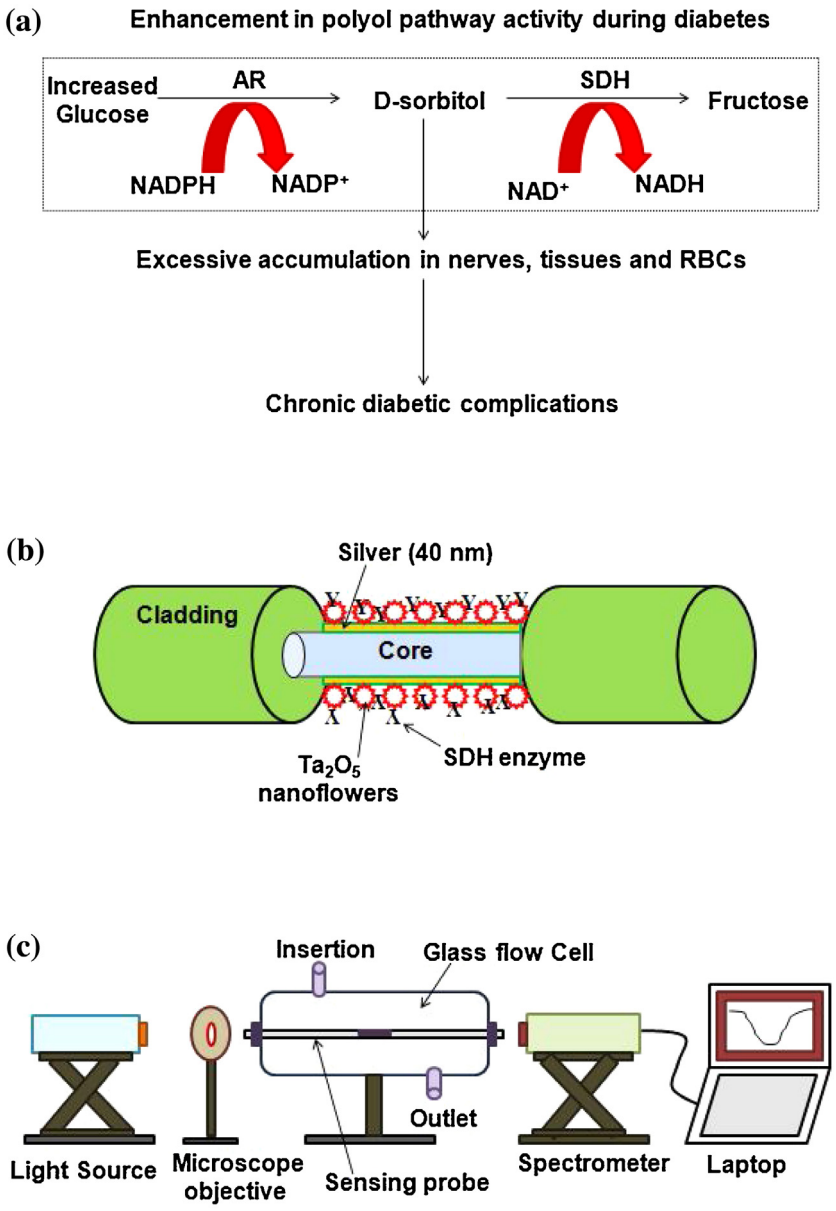

Fig. 1. (a) Schematic of polyol pathway emphasizing the importance for D-sorbitol detection, (b) schematic of the fabricated fiber optic sensing probe, and (c) schematic of the experimental setup for the characterization of D-sorbitol sensor.

two-step enzyme mediated metabolic pathway that involves the conversion of glucose into D-sorbitol, which is subsequently converted into fructose through the consecutive action of enzymes aldose reductase (AR) and sorbitol dehydrogenase (SDH). During diabetes, a boost in the activity of polyol pathway is noted, which leads to an elevated conversion of glucose into D-sorbitol, the load of which starts getting accumulated in several body tissues including nerves and erythrocytes due to its poor cellular permeability. This is considered to be the onset of diabetes associated complications such as retinopathy, nephropathy, peripheral neuropathy and microvascular damage [13–15]. The D-sorbitol level within erythrocytes or other tissues is thus established as an indicator for the diagnosis and monitoring of diabetes. In addition to its role as a biomarker for diabetes and the concomitant diabetic complications [16], D-sorbitol is commercially used as an important food additive, primarily as an agent for preserving moisture as it has ability to strongly bind with water, and therefore, usually added in food and other materials to prevent dehydration on exposure to air [17]. It has also been observed that an excessive intake of D-sorbitol may give rise to a laxative effect which could produce abdominal pain [18]. The above mentioned factors underline the importance of sensing of D-sorbitol and the same has been illustrated in Fig. 1(a).

The biological and industrial importance of D-sorbitol has motivated the scientific community to design numerous sensors utilizing various physical and chemical techniques for the reliable and rapid detection and quantification of D-sorbitol. Several of these methods include chromatography [19–22], fluorescence [17,23,24], amperometry [18], colorimetry [25] and electrochemical [26]. Some amperometric methods involving the immobilization of dehydrogenase enzymes utilizing certain chemical entities and the subsequent modification of the electrode have also been reported [27–29]. However, these methods require considerable financial investment, use of expensive instrumentation, longer duration of pretreatment time for samples and advanced analytical techniques in addition to involving complex fabrication strategies. Gel entrapment is also one of the techniques used for

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