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Label-free glucose sensing with temperature modulation

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ABSTRACT

Label-free detection of glucose molar concentration was carefully studied with a device which was designed to modulate temperature in a local area by Joule heating from room temperature to human body temperature. Very small amount of glucose concentration up to sub-millimolar range was detected based on the glucose concentration dependent electrical resistance change with the temperature modulation since it allowed more electrical conductivity enhancement for lower glucose concentration.

1. Introduction

Diabetes mellitus, or briefly diabetes is a family of a metabolic disease that people shows when they have a high blood sugar level in their body. The blood sugar level is generally regulated by the insulin, a peptide hormone that transfers monosaccharides from the blood to the cell. However, when our body stops producing the insulin it can induce the metabolic disorder because of the excess monosaccharides, especially glucose which exists in the blood.

To control this metabolic disease, the blood sugar level should be controlled in a certain range. In order to keep that level, it is necessary to use blood glucose monitoring system. Several types of measurements of glucose concentration, such as the electrochemistry [1–3], Raman spectroscopy [4], and optical measurement [5] have been investigated over the last couple of years. Especially the electrochemistry based on enzyme–substrate complex reaction in electrolysis is the only commercialized measurement.

In glucose sensing mechanism, glucose oxidase, a macromolecule-sized protein, is a catalytic enzyme that converts glucose molecule to another product by binding process. On this sensing mechanism, a crucial problem is the bulky size of glucose enzyme [6]. When chemical reaction is driven and integral binding is formed, electrons involved in antigen–antibody complex reaction cannot move easily to the working electrode because of the bulky-sized enzyme. This is a key factor to reduce the charge carrier transferring and electrical sensing performance.

The current–voltage characteristic is a technique that usually plots the electrical resistance of a material or device. This measurement has been considered as the most simple and effective way to evaluate the electrical property change and used widely in various bio-sensing studies such as biotin-streptavidin [7], DNA [8], and chemical vapor atoms [9] as well as blood glucose measurement. In this paper, we measured the electrical resistance change of a drop of glucose solution on a silicon chip which was fabricated to modulate the local temperature and milli-molar concentration change of glucose in a solution was detected.

The device which was designed to induce local Joule heating was also regarded as an efficient heat convertor based on the low power operation [10]. The device modulating the local temperature generally has advantages compared to previous studies such as electro-osmotic flow [11], thermo-migration [12] and light emitting diode [13] since it can provide in-vivo testing conditions and activate the target molecules.

To draw the biocompatible response of sensing environment, the temperature modulation was limited within the voltage range from 0.5 V to 2 V. This results in the positive contribution to several, electrical performances, such as the accuracy, linearity, and sensitivity [14,15].

2. Device preparing

Fig. 1(a) shows schematic image of the device. The device is consists of two different functional layers one for Joule heating and

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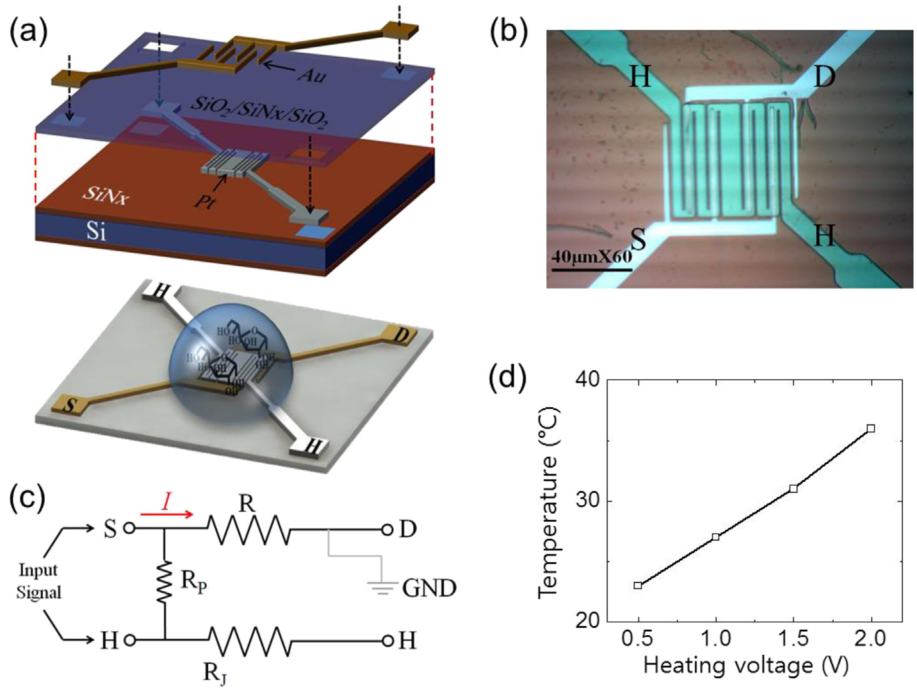

Fig. 1. (a) schematic image of device structure, (b) optical image of the device, (c) circuit model for glucose measurement and (d) temperature modulation result.

the other for glucose sensing which were separated by oxide layer. As shown in an optical image of the device (Fig. 1(b)), the heating electrodes were designed to induce the high electrical resistance and source-drain electrodes for the glucose sensing were placed on an overlapped position to the heating electrodes. Fig. 1(c) is an equivalent circuit model of the device. R is the electrical resistance that occurs in the I–V measurement, R_J is the resistance from Joule heating passage, and R_P represents the resistance of the passivation layer to separate each current path. The sensor device was prepared by depositing 2 μm thick SiN_x on silicon (Si) substrate through the low pressure chemical vapor deposition (LPCVD). Platinum (Pt) was deposited, which acts as the heating electrodes for the temperature

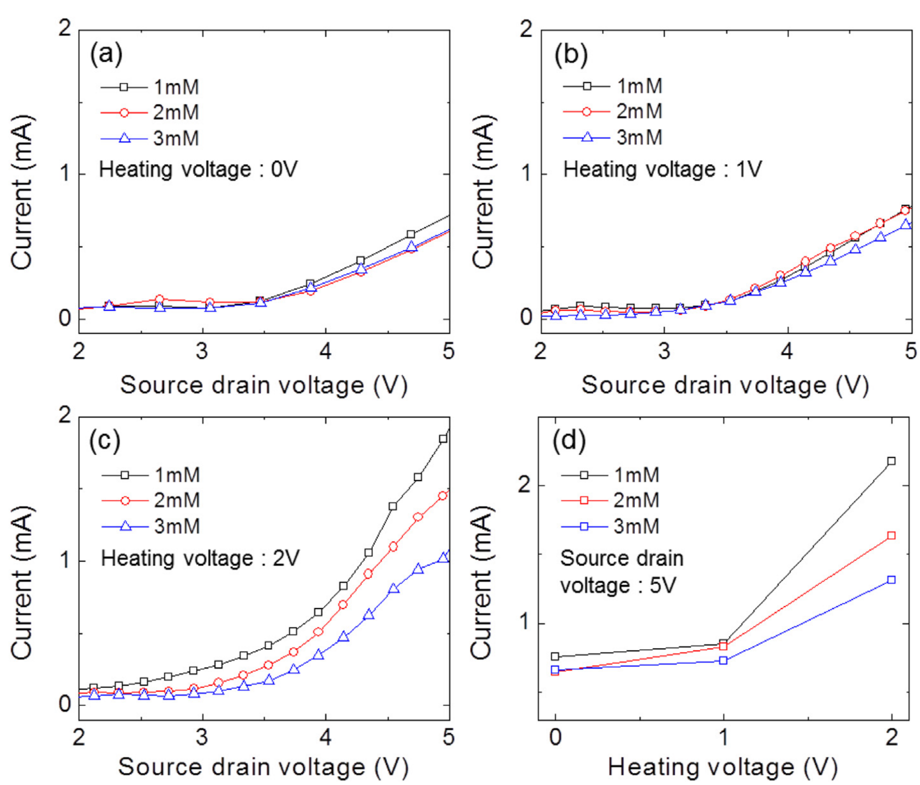

Fig. 2. (a)–(c) I–V characteristics of the device with various heating voltage from 0 V to 2 V. (d) Source drain current variation with the heating voltage. The current signals for various glucose concentration start to be distinguishable at the higher heating voltage.