

In vitro monitoring of goat-blood glycemia with a microwave biosensor



Seungwan Kim^a, Jongchel Kim^a, Kyoungchul Kim^a, Jung-Ha Lee^b, Arsen Babajanyan^c, Barry Friedman^d, Kiejn Lee^{a,*}

^a Department of Physics and Basic Science Institute for Cell Damage Control, Sogang University, Seoul 121-742, Republic of Korea

^b Department of Life Science and Basic Science Institute for Cell Damage Control, Sogang University, Seoul 121-742, Republic of Korea

^c Department of Radiophysics, Yerevan State University, Manoogian 1, Yerevan 0025, Armenia

^d Department of Physics, Sam Houston State University, Huntsville, TX 77341, United States

ARTICLE INFO

Article history:

Received 13 June 2013

Received in revised form

7 January 2014

Accepted 20 January 2014

Available online 31 January 2014

Keywords:

In vitro

Goat-blood

D-Glucose

Microwave cavity sensor

ABSTRACT

We used an electromagnetic microwave cavity sensor for real time measurement of the glycemia in goat-blood for three animals. We could determine the concentration of D-glucose in blood in the range of 90–550 mg/dl at the resonance frequency near 4.76 GHz with a bandwidth of 300 MHz. The change in microwave reflection coefficient S_{11} (due to the variation of D-glucose concentration in blood) was about 16.33 dB, 23.92 dB, 7.66 dB and resonance frequency shift was about 21.78 MHz, 36.29 MHz, 20.77 MHz, respectively, for the three different samples. The in vitro results show the measured signal-to-noise ratio of about 32 dB, and the minimum detectable signal level of about 0.025 dB/(mg/dl). The results clearly show the sensitivity and usefulness of this microwave sensor for these types of biological investigations. This proposed system provides a unique approach for real contactless glucose monitoring and, it may serve as a bloodless glucometer for the calibration of different glucose levels.

© 2014 Elsevier B.V. All rights reserved.

1. Introduction

Noninvasive diagnosis and monitoring of diabetes has attracted tremendous attention in the past two decades because of the emergence of diabetes as a major epidemic, especially when associated with the increased overall obesity of the population [1]. The noninvasive measurement of blood glucose in particular is of great individual and economic importance because of the large population of diabetics who require regular and accurate information regarding their blood glucose concentrations. Noninvasive determination of glucose will promote more frequent testing, allows tighter control of diabetes, and delays the onset of diabetes complications and their associated health care costs. Recently new glucose measurement methods have been developed, exploiting the effect of glucose on erythrocyte scattering, new photoacoustic phenomenon, optical coherence tomography, thermo-optical studies on human skin, Raman spectroscopy studies, fluorescence measurements, and use of photonic crystals [2–13]. In addition to optical methods, *in vivo* electrical impedance results have been reported [14].

Some of these methods measure intrinsic properties of glucose; others deal with its effect on tissue or blood properties. An interesting approach for the analysis of the glucose-induced dielectric property variations is the use of electromagnetic sensors thus avoiding any direct contact with the medium to be investigated [3,15,16]. The electromagnetic coupling technique based on the impedance measurement stresses the importance of dielectric parameters of blood. The relation between dielectric parameters and the glucose concentration in blood has been developed.

Microwave instruments have been used to analyze the dielectric property variations and have the ability to make nondestructive measurement of parameters inside a volume where direct contact with the sample cannot be achieved [17–19]. This property of microwave sensors provides the prospect for suitable noninvasive measurements of biological tissues. An important issue in noninvasive glucose measurement is calibration. One calibration approach is to study glucose concentration ranges in vitro measured signals over the *in vivo* range to be monitored. Analytical studies for in vitro measurement sensors include study of determination of factors affecting accuracy, precision and interference studies in different blood samples. Analytical calibration of a noninvasive glucose sensor implies determination of glucose concentration from a standard curve generated by using a theoretical model. The aim of this study is to outline the design of a microwave

* Corresponding author. Tel.: +82 27058425.

E-mail address: klee@sogang.ac.kr (K. Lee).

sensor that could be applied for noninvasive detection and monitoring of glycemia.

Using microwave signal analysis, it is possible to detect the glucose concentrations and levels due to indirect measuring of the dielectric permittivity or direct measuring of the microwave reflection coefficient S_{11} . The estimated parameter is the complex dielectric permittivity ϵ , which is one of the main material characteristics of the medium. The basic principle for measurement of glucose concentration at microwave frequencies is described in our recent works [20,21].

In this paper, we monitor the glycemia in three different goat-bloods by measuring the microwave reflection coefficient S_{11} using a microwave cavity sensor. Along with the measurements, simulations were done for the three different D-glucose concentrations in glucose aqueous solution. The change of the D-glucose concentration is directly related to the change in the reflection coefficient due to an electromagnetic interaction between the resonator and blood sample.

We modeled the microwave cavity sensor for glucose concentration measurements by using HFSS 5.4 simulation software which accurately predicts response of the microwave signal from the resonator with samples.

2. Experimental

2.1. Structure and model of sensor

The fabricated glucose sensor based on the design of a waveguide cavity resonator is shown in Fig. 1(a) and a detailed description is given in Ref. [21]. To increase the sensitivity and selectivity of the sensor we modified the microwave source size and position in the resonator according to the computer analysis of the Q -factor of the resonant cavity. The outer sizes of the cavity stayed the same; just the size and position of the microwave source and the diameter of the tube for the sample was changed. First, we increased the tube diameter from 6.8 mm to 14.4 mm and the source diameter decreased from 5.3 mm to 4 mm. Secondly, the source position changed from the front side (same side as the sample entrance) to the back side of the cavity. At same time the source position in the xy plane shifted with respect to the cavity wall with the $l/3$ and $2l/3$ proportions ($l/2$ and $l/2$ proportions for the sensor in Ref. [21]). As a result, the resonator Q -factor increased from 110 to 648 for new the configuration. This growth of Q -factor of about 6 times increased the sensitivity and selectivity of the measurement. Now the sensor is able to determine smaller changes in the electromagnetic characteristics of the sample. Note to

improve the sensor Q -factor we used computer simulation due to the complexity of an analytical analysis of the sensor structure. To determine the glucose concentration changes, we measured the microwave reflection coefficient S_{11} and the resonant frequency shift of the microwave resonator using a network analyzer (Agilent 8753ES). Subsequent changes in electromagnetic coupling between the cavity and the sample cause changes in the magnitude of S_{11} and shift the resonant frequency. This allows characterization of the electromagnetic properties (dielectric, conducting, volumetric etc.) of the sample. At resonance, the mode we used was TE_{011} , which is the dominant mode, and the sensitivity of the device is highest for this operating mode. The resonant frequency and microwave reflection coefficient minima for DI water were $f = 4.76$ GHz and $S_{11} = -12.17$ dB, respectively. Fig. 1(b) shows the sensor model as it appears in the HP HFSS interface. Note that the microwaves used in the model have a frequency of order 4.76 GHz and a wavelength of order 6.7 cm; hence a boundary sphere of 13 cm was used in the model. The parameters of the coax, not identical to the experimental values, were selected to give the transmission line an impedance of 50 Ω . All metallic surfaces in the model were chosen to be perfect conductors (Al); it is possible to treat the metallic boundaries more realistically, a wave impedance boundary condition with the relevant conductivity. However, a limited amount of numerical “experimentation” indicated for the cavity the perfect conducting boundary condition is adequate.

2.2. Preparation and biological analysis of samples

The initial test samples based on goat's blood have the glycemia of 140 mg/dl, 92 mg/dl, and 110 mg/dl in the blood for the three different animals. These samples will be defined as sample A, sample B, and sample C, respectively. By adding D-glucose to the initial samples, 5 samples were prepared with 100 mg/dl glycemia difference for each case. The goat-blood was mixed with sodium citrate ($C_6H_5Na_3O_7$) to avoid fast coagulation and then stored in a refrigerator with storage limitation of about 3 days. All samples were analyzed by the veterinary services. Table 1 shows the results of biological tests for the three blood samples.

3. Theory

3.1. Microwave reflection coefficient

The microwave reflection principle can be explained by the plane-wave solution model. An interpretation of the reflection

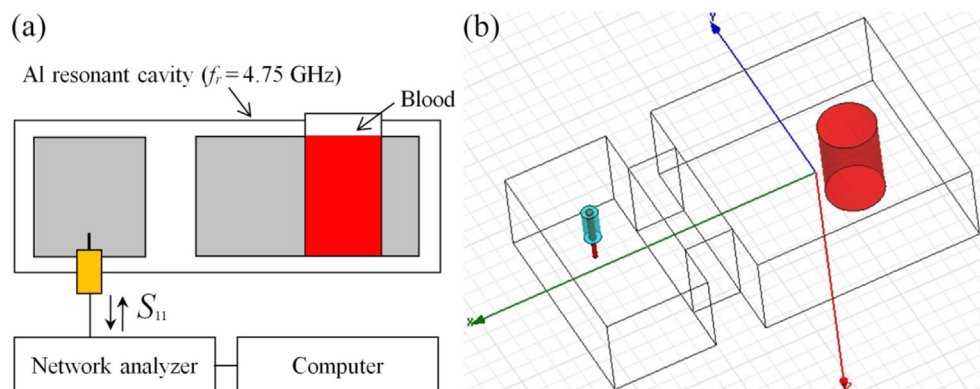


Fig. 1. (a) The schematic view of experimental system for the microwave cavity sensor with sample. (b) Model as it appears in the HP HFSS interface. The surrounding sphere is not shown.

Download English Version:

<https://daneshyari.com/en/article/1786097>

Download Persian Version:

<https://daneshyari.com/article/1786097>

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