Radio Frequency Based Analysis for the Detection of Level of Glucose

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Abstract

This paper presents the design and implementation of a microwave based cavity based structure to determine the real-time glucose level based on the frequency shift. The glucose meter, which has an attenuation level greater than -30 dB using a single transmission pole, resulted in better selectivity and can be implemented for the measurement glucose concentration in an aqueous glucose solution. The noticeable variation in the resonance frequency as well as complex permittivity was achieved using the various glucose that validates the possibility of the devices as a glucose meter. The obtained parameters supports the development of resonance-based dielectric sensors using permittivity characterization with a resolution of 3.11 pF/mgdl⁻¹ and a minimum detectable glucose level of 8.60 mgdl⁻¹. This unique approach, which has long-term reliability for mediator-free glucose sensing, is the incremental step in the filed non-invasive glucose monitoring.

Keywords: Radio Frequency; Biosensing; Glucose; Permittivity

1. Introduction

Recently, a number of methods have been introduced by different groups with different techniques and possibilities. We consider radio frequency (RF) technique as an interesting candidate for the application in the field of glucose detection with the future possibility towards the non-invasive biosensing [1-2]. The design of the sensor was validated by different operating parameters like sensitivity, good linearity, low limit of detection, and mediator free. The attraction in the field of RF biosensor sensor is supported by its possibility for the non-invasive, mediator free and label free detection with minimum operating power. This procedure works with the lab-on-chip methodology, which enables a miniaturized size through microfabrication. Moreover, this method provides the ease in the trend of glucose detection with the possibility of the point of care testing (POCT).

Figure 1. Demonstrating the concept and operating phenomenon of the proposed biosensor.
The present work emphasizes developing a glucose meter on a GaAs substrate using an integrated passive device (IPD) technology. The variation of the resonance frequency for the different volume of blood sample has been simulated and the result is validated by the measurement analysis of the D-glucose solution as represented in Figure 1. The variation of the complex permittivity and, ultimately, the air-bridge capacitance of the reservoir for different concentrations in the range of 25 to 225 mgdl\(^{-1}\) of an aqueous solution is efficiently characterized for the detection of the glucose level. The parameters, such as reflection coefficient (\(S_{21}\)), the absolute and relative variation of the resonance frequency, characterization of the permittivity [\(\varepsilon_r(\omega, \kappa)\)] were accurately and efficiently modelled for different glucose concentration levels to reflect the actual and real behavior of diabetic patients. The present methodology will be helpful for the diabetes patients from the point of POCT and real time detection [3-4].

### 2. Design Consideration and Approach

The design of the sensor was implemented using the basic concept of the resonator with high out-band and in-band attenuation level, resulted in excellent selectivity. The new concept of the container like structure is created on the surface of the resonator by the meandered-line to facilitate the sample to be confined in the sensitive part of the resonator. The top sensing surface was gold electroplated to remove unnecessary oxidation. The IPD is used as a basic principle for the fabrication with the glucose sample from Sigma-Aldrich. A different sample of the solution was prepared in the concentration range of 25 to 225 mgdl\(^{-1}\) using a standard additive technique.

To monitor the response of the propose sensor in an artificial environment, a simulation model was created, where the different volume of the sample solution was modeled by the layer above the resonator as shown in Figure 2. Different width of the simulation model was created depending upon the value of the sample solution starting from 1 to 12 µm. For the real-time testing of the device for the D-glucose solution, a sample model with 1 µl of D-glucose was poured on the air-bridge structure of the sensor and caused a change in the electrical behavior due to a variation in the permittivity. The permittivity characterization was implemented for optimizing the degree of sensing. The Debye relaxation process was implemented for the aqueous solution to find the permittivity of the particular glucose concentration [5].

![Graphical representation of the simulated blood sample on the surface of the sensor.](image)
3. Results and Discussion

This developed biosensor resulted in a good dynamic performance for the deionized water glucose concentration from 25 mg dl\(^{-1}\) to 225 mg dl\(^{-1}\). The shift in the resonance frequency caused by different concentration of the glucose level present in the blood for five different samples was demonstrated as shown in Figure 3. The featured characteristics based on the resonance concept of detection are critically analyzed by capacitor, inductor and resistor. The finding support the development of resonance-based sensing with an excellent sensitivity of resolution of 3.11 pF/mgd\(^{-1}\) change in glucose level, a detection limit of 8.60 mg dl\(^{-1}\). The studied biosensor provided a rapid response for each of the glucose concentration within the linear calibration ranges of 25 to 225 mg dl\(^{-1}\), with the correlation coefficient of 0.9983. The noticeable variation in the resonance frequency was observed for the different volume of the sample solution. The resonance frequency varied from 7.1 to 6.3 GHz for different glucose volume in the cavity as represented in the Figure 4. The reusability of the glucose meter can be obtained simply by flushing the sample solution with deionized water along with phosphate buffer solution.

![Figure 3. Performance of the sensor for the different volume of the blood sample.](image)

![Figure 4. Performance of the sensor for the different volume of the blood sample.](image)
3. Conclusion

We have successfully demonstrated the concept of RF glucose meter for the effective detection of the glucose concentration in an aqueous solution. The variation sample solution with different volumes and concentration were tested and simulated to validate the findings. Capacitive sensing has been demonstrated with a best resolution of 3.11 pF/mgdl. The tolerable change in the response of the sensor was observed in which resonance frequency and glucose concentration are negatively correlated possessing excellent correlation coefficient. The proposed concept is helpful for the implementation of the RF concept for the non-invasive glucose detection.

References


