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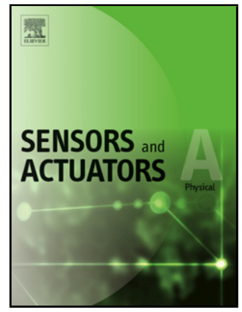

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Microwave Reflective Biosensor for Glucose Level Detection in Aqueous Solutions

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ABSTRACT

This article presents the design and analysis of a real-time non-invasive microwave microfluidic sensor for measuring glucose concentration in aqueous solutions. The sensor is made of an open-ended microstrip transmission line loaded with a complementary split-ring resonator (CSRR). The CSRR shows a very intense electric field concentration at resonance, which is highly sensitive to the dielectric sample loading. A microfluidic channel is designed to deliver the glucose solutions to the sensitive area of the device. By applying liquid samples to the channel, a resonance frequency shift is detectable in the reflection coefficient (S_{11}) of the device. This in turn leads to a change in the $|S_{11}|$. Both of the frequency shift and $\Delta|S_{11}|$ can be used to measure the glucose level in the solution. Mathematical models are developed based on the measurement results of the glucose-water solutions using the resonance frequency shift and $\Delta|S_{11}|$. The developed sensing models are then used for detecting the glucose levels down to physiological values using the designed biosensor. The results prove the potential compatibility of the proposed biosensor for human glycaemia monitoring.

1. Introduction

Biosensors are fundamental components in nowadays medical and biological experiments and diagnostics. A majority of this type sensors measure the dose of various biochemicals species in aqueous solutions [1, 2, 3]. Example are bacteria growth monitoring sensors [4], biosensors for blood cholesterol monitoring [5], uric acid detection in urine [6], etc. These examples show a vast requirement in designing biosensors for medical and biological aqueous samples dosing.

The blood glucose level is one of the most critical health factors. In normal health, the blood glucose level is automatically controlled through the insulin hormone. If insulin production is low, blood glucose can reach to dangerous levels causing hyperglycaemia. This condition greatly increases the risk of a range of diseases, including heart disease, blindness, gangrene and kidney disease. Glucose sensors are important devices helping in monitoring and controlling the blood glucose levels. A majority of commercial glucose monitoring sensors are based on electrochemical methods [7, 8, 9, 10], which offer selective glucose detection by using a chemical mediator. In spite of their high accuracy, this type of sensors are invasive to the sample under test. This limits their application since only a single measurement can be performed on each sample under test. More importantly, the commercial glucose test strips are not reusable resulting in high expense in strips investment [1].

Dielectric spectroscopy at RF and microwave frequencies has shown a great potential in non-invasive characterization of aqueous solutions [11, 12, 13, 14, 15, 16, 17, 18]. The operation principle in most of these devices is based on the resonators. Applying dielectric liquid samples to the sensitive areas of the resonators modifies the electric and magnetic fields distributions around them [19, 20, 21, 22]. This causes a shift in the resonance frequency of the device from which the dielectric properties of the materials under test are determined. The introduction of metamaterials in recent years paved the way for designing more compact resonance-based microwave sensors with high sensitivity [23, 24, 25, 26, 27, 28]. At resonance, the metamaterial-based particles such as split-ring resonators (SRRs) and their complementary counterparts produce highly dense electromagnetic fields concentrations, which are very sensitive to the materials loading or geometry alterations [29, 30, 31, 32]. The efforts on the design of microwave biosensors for glucose detection show a promising potential of this approach in label-free and non-invasive detection [33, 34, 35, 36, 37, 38, 39]. The devices in [33, 34] are based on three-dimensional resonators, which renders their application in the integrated lab-on-a-chip platform. There is no channel in [35, 36, 39] sensors for controlling the amount of the liquid sample applied to the sensing area. This might cause added measurement error due to cross-sensitivity to the amount of the liquid sample under test. The sensitivity of the devices in [37, 38] is limited for low concentration measurements. In addition, all of these sensors are two port devices relying on transmission coefficient measurement requiring a two port measurement system.

Here, we propose a single port microwave-based microfluidic biosensor using a complementary split-ring resonator (CSRR) loaded on an open-ended microstrip transmission line. A notch appears in the reflection coefficient (S_{11}) of the sensor at the resonance frequency of the CSRR. A microfluidic channel is attached to the sensor for delivering the

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