Cancerous or not? Microwave Judges! Microwave systems for dielectric characterization and actuation at the single-cell level in life sciences

Maede Chavoshi, *Graduate Student Member, IEEE,* Dominique Schreurs, *Fellow, IEEE*

***Abstract*—This report explores the development of an integrated sensing and actuation platform utilizing resonance-based microwave structures. The research focuses on leveraging microwave dielectric spectroscopy and heating for biological cell characterization and manipulation. By integrating these technologies, the platform aims to enhance real-time monitoring and actuation in biomedical applications, including cancer cell differentiation and separation.**

***Index Terms*—Dielectric Spectroscopy, microfluidics, microwave heating, multiphysics simulation, permittivity.**

I. Introduction

MICROWAVE heating and sensing have become influential in the biomedical field, offering advanced methods for dielectric characterization and actuation in various applications. Water, which constitutes a major component of biological tissues and fluids, exhibits unique dielectric properties with large energy dissipation at microwave frequencies.

In biomedical research, microwave dielectric spectroscopy is utilized to analyze the composition and condition of biological samples. For instance, it can differentiate between cancerous and non-cancerous cells based on their dielectric properties, enabling early diagnosis and targeted treatments. Additionally, microwave sensors can detect changes in the dielectric properties of biological samples, such as glucose [1] or salt, which can be indicative of various physiological and pathological conditions in biological fluids.

Microwave heating benefits from the high dielectric loss of water at specific frequencies to generate localized heating. This contactless and efficient heating mechanism is ideal for various biomedical applications, such as hyperthermia treatment [2], polymerase chain reaction (PCR) [3], and applications involved with thermo-responsive smart materials such as enhancement of drug delivery through targeted thermal effects [4].

The integration of microwave sensing and heating technologies into biomedical devices has great potential for revolutionized microfluidics and cell cytometry [5]. Developing such systems allows for high-throughput, real-time monitoring of cellular responses to various stimuli, facilitating advanced research in cell biology and personalized medicine. As a perspective, artificial intelligence can further empower this goal [6]. In this report, we study the development of microwave sensing and characterization using the sensor structure described in [7].

The authors are with the WaveCoRE Division, Department of Electrical Engineering (ESAT), KU Leuven, 3001 Leuven, Belgium (e-mail: maede.chavoshi@kuleuven.be; dominique.schreurs@kuleuven.be).

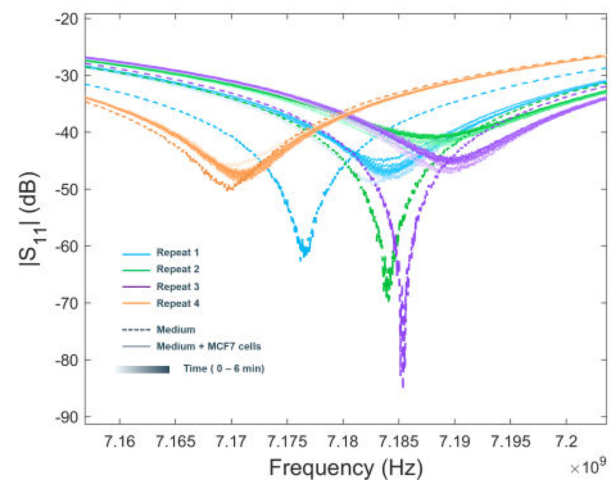

Fig. 1. Measurement results for different repeats of cell medium without and with MCF-7 cells in 30-second time interval measurements

II. Microwave Dielectric Sensing

In order to make the sensor described in [7] compatible with cell measurement, some adaptations were applied. The dimensions were adjusted for a higher sensitivity and the sensor was made biocompatible by using gold electrodes. Fabrication of microwave sensor includes deposition of a thin layer of TiW for adhesion promotion of Au layer on fused silica substrate. The layer is covered by positive photoresist S1818 patterned using photolithography. For the backside of the wafer, we used Cu adhesive layer cut for chip size precision and defected ground. The measurement setup includes an impedance tuner connected to the input port of the one-port sensor for higher sensitivity. Cancerous breast cell MCF-7 and their growth medium were measured using the sensor tuned for the medium. As a microwell was used on the sensing area, one should account for sedimentation during the measurements; thus, the measurements were done in 30-second intervals for 6 minutes. The results show the distinction between samples with and without cells. Nevertheless, a comprehensive study on uncertainties is required.

III. Microwave Dielectric Heating

Microwave power provides fast, selective, and contactless heating that can be widely used in biomedical applications. For some applications, scalability is an important factor so that multiple samples can be simultaneously heated up. The heater pair that is developed in this work benefits from this independent performance through separated resonance frequency dips. Microwave heating is made possible through amplified continuous waves (CW) at the corresponding frequencies. Microfluidics channels are placed over each sensor with the thermocouples embedded inside them. The Frequency and power at the signal generator are controlled to achieve the desired temperature inside each channel. With this setup, we have been able to achieve independent and simultaneous regioselective heating.

IV. Conclusion

In this report, we demonstrated the possibility of a scalable platform for simultaneous sensing and heating of samples using resonant microwave structures. The dual-purpose system shows potential for significant advancements in biomedical applications, particularly in cell studies and biosciences. The ability to differentiate cells, along with the capability for localized and efficient heating, highlights the platform's utility in early diagnosis and targeted treatment. Future work will focus on further refining and scaling the system, reducing uncertainties, and exploring additional biomedical applications to fully realize its potential in advancing cell biology research.

V. Impact Statement and Career Plan

Receiving the IEEE MTT-S Graduate Fellowship for Biomedical Applications has been a great honor and has significantly advanced my research. This fellowship provided me the opportunity to attend IMS2023, where I interacted with pioneering researchers, discovered cutting-edge technologies, and met peer graduate students. These experiences have broadened my professional network and inspired new directions in my work, highlighting the critical role of interdisciplinary collaboration in the advancement of biomedical technologies using RF and microwaves.

I aim to pursue a career at the intersection of microwave technology and biomedicine, leveraging my PhD research to develop innovative healthcare solutions. Open to both academic and industry pathways, I am committed to contributing impactful advancements in biomedical applications of microwaves.

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