COST-EFFECTIVE INTERDIGITATED CAPACITIVE SENSORS FOR EFFICIENT BACTERIA DETECTION

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Abstract— **This paper represents design, fabrication and characterization of non-invasive capacitive sensor for oral bacteria detection. The sensor was fabricated in Printed Circuit Board (PCB) technology and it consists of a pair of interdigitated electrodes. Measurement setup for testing and characterization has been developed in laboratory conditions. The characteristics of sensor - the capacitance as a function of frequency for a different bacteria solution and different sensor sizes are presented. The obtained results demonstrate different resonant frequencies for each bacteria which can be used for its detection.**

Key words- capacitive sensor, bacteria detection, oral health, PCB technology

I. INTRODUCTION

Microorganisms, even though 3.5 billion years old, are still under-researched, primarily because of its large possibility of changing. They change their properties, increase the virulence and pathogenic potential. Because of all this, their recognition and identification is still a big challenge.

Bacteria have great potential for division and 24-hour changes 100 generations, and thus gain some new features which are primarily related to their resistance [1].

The most common causes of diseases and infections such as bacteremia, meningitis, serious infections in neonates, hospital infections, endocarditis, nosocomial infections, formation of dental caries, urinary infections, infections of wounds and burns to septicemia, etc. are *Streptococcus pneumonia*, *Streptococcus agalactae, Streptococcus viridans, Enterococcus, Staphylococcus aureus, Pseudomonas aeruginosa* and *Klebisella pneumoniae* [2]-[11]. All these species belong to the realm of Bacteria. *Candida* belongs to the kingdom Fungi, the most common type of *Candida albicans* as part of the normal flora of the skin, mouth, throat, digestive and urogenital tract. However, it can be an important cause of nosocomial infections in patients at risk, such as immunocompromised patients or patients on immunosuppressive therapy and neutropenia, as well as stay in the intensive care units and the presence of central venous catheter. But surely the most common infection with *Candida albicans* is due to prolonged use of broad spectrum of antibiotics [12].

The rapid identification of bacteria from biological samples is a major goal in the human health care, food safety and environmental monitoring. Two main identification methods are actually used: 1. the traditional culture associated with biochemical identification and 2. the polymerase chain reaction. The former is time consuming, whereas the latter requires expensive equipment and specialized personnel training [13].

In previous works sensors for detection same or similar microorganisms were developed.

M. S. Mannoor et. al. developed passive, wireless graphene nanosensors capable of extremely sensitive chemical and biological sensing, with detection limits down to a single bacterium, while also wirelessly achieving remote powering and readout [13].

Tang et. al. introduced a new interdigitated array microelectrode-oxide-silicon (IDAMOS) sensor with label-free high sensitivity and specificity for fast detection of *Staphylococcus aureus* [14].

Ong, Bitler, Grimes, Puckett and Bachas demonstrated remote query printed thin/thick-film LC sensor for detection of *Bacillus subtilis, Escherichia coli JM109*, and *Pseudomonas putida* growth in milk, meat, and beer [15].

Liu, Marrakchi, Xu, Dong and Andreescu reported the use of modularly designed and site-specifically oriented synthetic antimicrobial peptides as novel recognition agents enabling detection and quantification of *Escherichia coli, Pseudomonas* aeruginosa, *Staphylococcus aureus* and *Staphylococcus epidermidis* [16].

The aim of this paper is to present interdigitated capacitive sensors, fabricated in cost-effective and easily accessible PCB technology, with a very high sensitivity for detection of various bacteria and fungi obtained from human isolates. For the testing purpose in house measurement setup tool was developed. The results show that sensor is able to rapidly

detect bacteria and *Candida* as well as to differentiate them one from each other.

II. DESIGN AND FABRICATION

The sensors were fabricated in PCB technology as an interdigitated capacitor with different number of electrode pairs. Three different sizes of the same design were fabricated as it is shown in Fig. 1a, 1b and 1c respectively to its sizes.

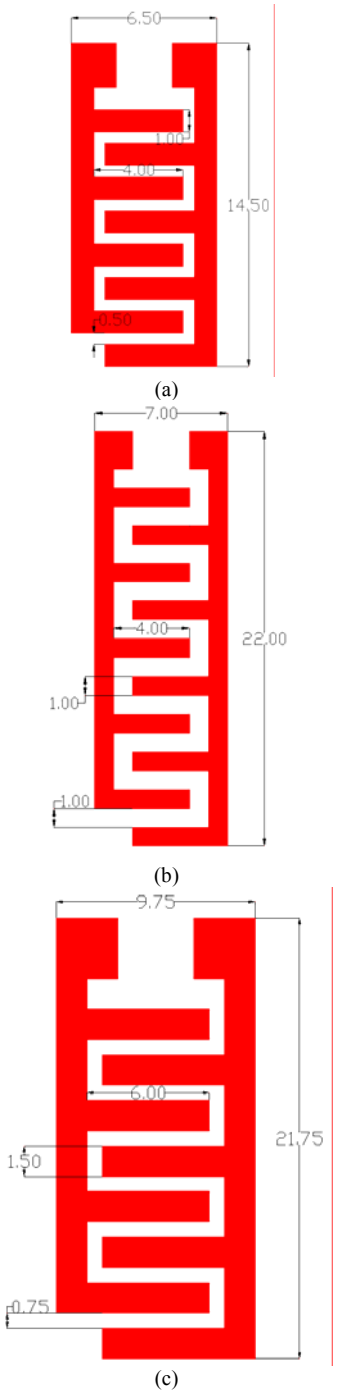


Figure 1. Design of Sensor 1, Sensor 2 and Sensor 3, respectively (all dimensions are in mm)

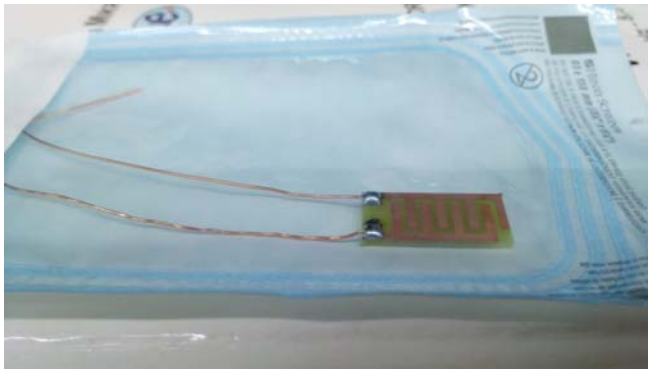
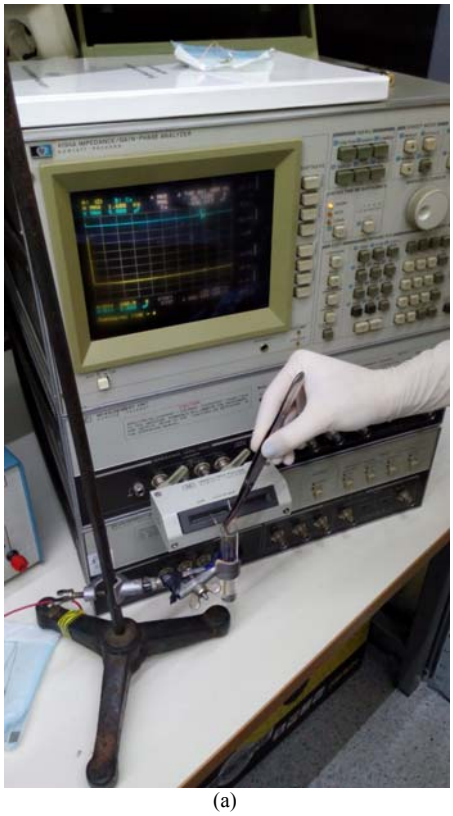


Figure 2. Sensor after making contacts and after sterilizing

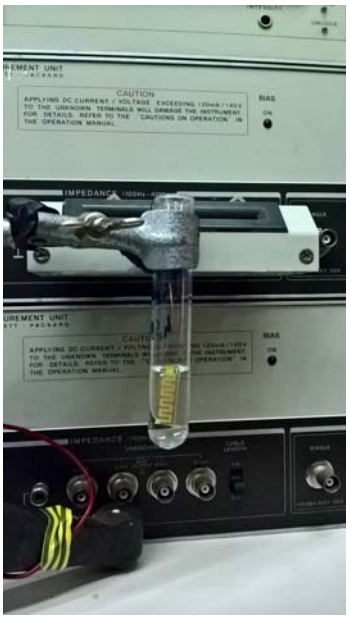
After the fabrication, contacts on each sensor were made and all sensors were medically sterilized to avoid any possibility of impurities which could disturb measurements. One sensor after making contact and sterilizing, covered in sterile bag is shown in Fig. 2.

III. RESULTS AND DISCUSION

Measurements were performed using in house measurement setup, shown if Fig. 3a it consists of a sterile test tube filled with testing material, test tube holder and Hewlett and Packard 4194A Impedance/gain-phase analyzer connected to PC. As can be seen from Fig. 3b sensor is placed inside of solution in test tube and connected to Impedance analyzer.



(a)



(b)

Figure 3. Measurement setup

As testing material human isolates of *Enterococcus, Streptococcus agalactiae, Streptococcus viridans, Streptococcus pneumoniae, Staphylococcus aureus, Pseudomonas aeruginosa, Klebisella pneumoniae* and *Candida albicans* from materials that are routinely arrived for treatment in the Centre for Microbiology, Institute of Public Health of Vojvodina are used. From colonies of 24-hour cultures on blood agar (HiMedia, India) for all mentioned bacteria as well as of the colonies on Sabouraud dextrose agar (HiMedia, India) for *Candida*, in sterile tubes, suspensions with density 0.5 MCF were made in 4.5 ml of physiological saline using EUCAST standard [17].

Measurements were performed for all 7 bacteria, for *Candida* and for a clean physiological saline as a referent solution, and capacitance as a function of frequency is measured. For *Enterococcus, Pseudomonas aeruginosa and Klebisella pneumonia* the Sensor 1 was used. For *Candida* and *Streptococcus pneumonia* the Sensor 2 was used and for *Streptococcus agalactiae, Staphylococcus aureus* and *Streptococcus viridans* the Sensor 3 was used.

Fig. 4. displays the test results of the capacitance versus the frequency for the Sensor 1. It can be seen that each bacteria as well as physiological saline have their own resonant frequency which makes them easily recognizable one from each other.

Fig. 5. shows the test results of the capacitance versus the frequency for the Sensor 2, while Fig. 6. presents the test results of the capacitance versus the frequency for the Sensor 3. The Sensor 2 and the Sensor 3 are also showing a great possibility of differentiating bacteria one from each other and in that way easily recognize which bacteria is present according only to its resonant frequency.

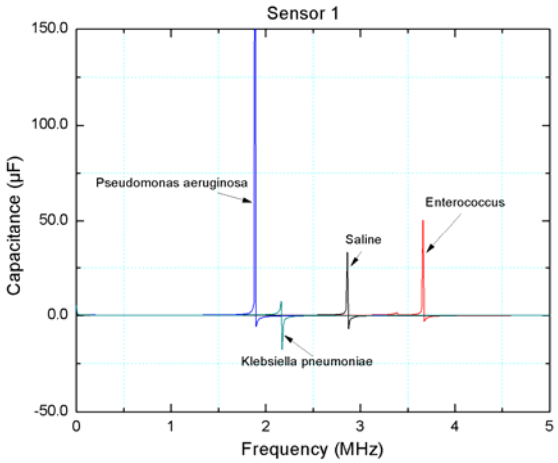


Figure 4. Capacitance change of Sensor 1

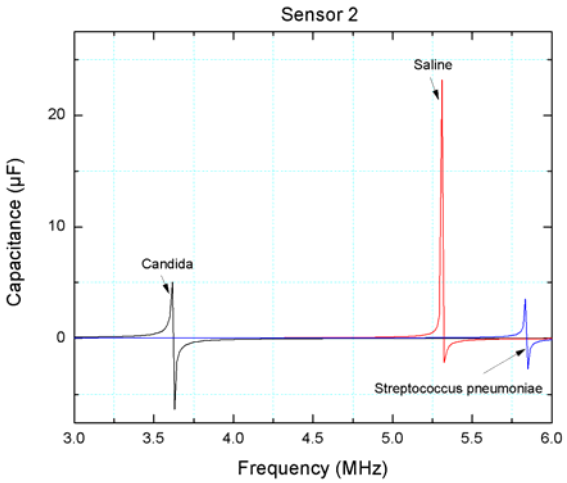


Figure 5. Capacitance change of Sensor 2

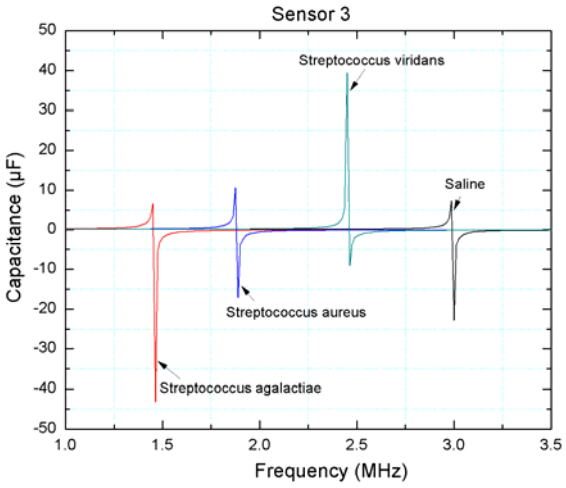


Figure 6. Capacitance change of Sensor 3

TABLE I. RESONANT FREQUENCIES FOR DIFFERENT BACTERIA AND SENSOR SIZES

Dispersion	Resonant frequency (MHz)		
	Sensor 1	***Sensor 2***	***Sensor 3***
Saline	2.86	5.31	2.99
Enterococcus	3.67	-	-
Pseudomonas aeruginosa	1.88	-	-
Klebisella pneumoniae	2.16	-	-
Candida	-	3.62	-
Streptococcus pneumoniae	-	5.84	-
Streptococcus agalactiae	-	-	1.45
Streptococcus aureus	-	-	1.88
Streptococcus viridans	-	-	2.45

As it can be seen from the Table I. each bacteria as well as *Candida* have their own resonant frequency value which makes them easily recognizable. In a case of the Sensor 1 and the Sensor 3 these values are closer than for the Sensor 2, which can be a result of the design of those two sensors which is more similar than in the case of the Sensor 2 where the gap between sensor's fingers is bigger.

In this way, as resonant frequencies of these bacteria and *Candida* are known values, after placing the sensor in unknown environment, for example in the mouth of the patient, it can be easily recognized which bacteria or pathogen organism is mostly present there. Thanks to this long and sometimes expensive analyses of biological material could be avoided and the treatment of the patient can be improved.

IV. CONCLUSION

In this paper three different sizes of capacitive sensor have been fabricated. The sensors consisted of an interdigitated electrodes structure made in PCB technology. The capacitance changes as a function of a frequency were investigated by exposing sensors to different solutions of human isolates of *Enterococcus, Streptococcus agalactiae, Streptococcus viridans, Streptococcus pneumoniae, Staphylococcus aureus, Pseudomonas aeruginosa, Klebisella pneumoniae* and *Candida albicans*. The resultant sensors are showing excellent selectivity of tested microorganisms catching their resonant frequencies. The sensor can be used for fast, accurate and low-cost detection of bacteria presence in mouth of patients helping in that way the improvement of the oral health of whole human population.

ACKNOWLEDGEMENT

This work was supported by the Project no. 114-451-833/2015-01 founded by the Provincial Secretariat for Science and Technological Development of The Province of Vojvodina and partially supported by Ministry of Education, Science and Technological Development within the Project no. TR32016.

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