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Lab on Chip for Detection of E.coli. Bacteria in Water using Capacitance modulation.

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Abstract: In this paper**,** lab on chip (LoC) is made to detect E.coli bacteria in water. LoC is a chip of size ranges from millimeter to few centimeter in which we can combine laboratory functions. LoC allows us automation and miniaturization of some applications like bio-sensing, bio-medical etc [2]. The main components in lab on chip are micro fluidic structure, functionalized sensing block, measurements system. The sensing part is the Capacitance modulation in the presence and absence of E.coli bacteria in the fluid. The capacitive sensor is designed in Comsol multiphysics version 3.5.Results shows the capacitance differences with and without bacteria in water.

Keywords: Biosensors, Micro fluidics, E.Coli, Capacitance modulation.

1. Introduction: There is an increasing need to perform biological testing such as E.coli detection for biohazards, on site environmental and medical studies. Micro-organism in water and food product like Coli form bacteria causes various diseases in human being and has resulted into hospitalization of people each year. In today's world Clinical platforms for performing such testing are bulky, high-power, and require large amounts of reagents, making them suited for such applications. Moreover, the complexity of biological systems makes testing expensive, labor intensive, and time consuming, often experiments are need to be repeated several times to achieve the better level of reliability. Consequently, there is a necessity to develop hand-held, miniaturized, and highly automated testing platforms to save time and low-cost analysis. To address this need, there have been recent efforts to develop lab-on-chip solutions in which sampling, preparation, analysis and reporting of a wide range of chemical compounds are integrated and automated [2].In addition to reducing system size, cost, and power consumption, such lab-on-chips can increase system throughput, thus reducing testing time and labor. Symptoms of disease include abdominal cramps and diarrhea. Fever and vomiting may also occur. The incubation period can range from three to eight days, with a median of three to four days. Most patients recover within 10 days, but in a small proportion of patients (particularly young children and the elderly), the infection may lead to a life-threatening disease, such as hemolytic uremic syndrome (HUS). HUS is characterized by acute renal failure, hemolytic anemia and thrombocytopenia. It is estimated that up to 10% of patients with EHEC infection may develop HUS, with a case-fatality rate ranging from 3% to 5%. It can cause neurological complications (such as seizure, stroke and coma) in 25% of HUS patients and chronic renal sequelae, usually mild, in around 50% of survivors, although in a few cases the disease may become life-threatening.

2. Principle: We can know the presence of bacteria with the help of capacitance measurement difference. In water without bacteria we will have one value of capacitance C1.The bacteria has been modeled as an ellipsoid with some dielectric constant of 40. Now as Capacitance is directly proportional to the dielectric constant and water has higher dielectric, so with bacteria the capacitance will decrease. Hence we will get lower value of capacitance C2.As the number of bacteria increases the capacitance value decreases. Now the difference C1-C2 will tell us the presence of bacteria in water. Figure 2 shows the ellipse like structure of bacteria. So nature of Bacteria will support our analysis.

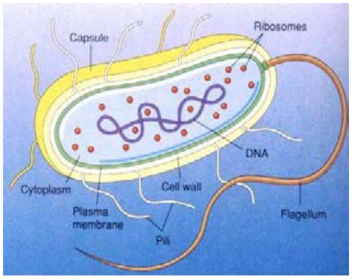

Figure 1：Bacterial Cell[4]

The capacitance of a parallel plate capacitor is given by,

$$C = \frac{K\varepsilon_0 A}{d} \qquad (1)$$

Where K is the dielectric constant, A is the cross sectional area of the plate and d is the distance between two plates. ε_0 is the absolute permittivity having value $8.85*10^{-12}$ F/m.

The capacitance of a ellipsoid is given by equation 2. [3]

$$C = 4\pi\varepsilon_0 R_{eq} \qquad (2)$$

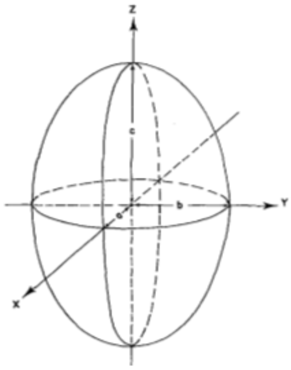

Figure 2: Ellipsoid $(\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2})=1$, [1]

Here Req is the equivalent radius of the ellipsoid. It is calculated from

$$R_{eq} = \frac{2\lambda}{F(\varphi/m)} \qquad (3)$$

$$F(\varphi/m) = \int_0^{\varphi}(1 - m\sin^2\theta)^{(-1/2)}d\theta \qquad (4)$$

Where λ is given by equation (5)

$$\lambda = \frac{c}{2}\sqrt{1-(\frac{a}{c})^2} \qquad (5)$$

These formulae are valid only when c>b>=a; and Φ is given by

$$\varphi = \arccos(\frac{a}{c}) \qquad (6)\ O$$

One more parameter needed for calculation of equivalent Radius is

$$m = \frac{1-(\frac{b}{c})^2}{1-(\frac{a}{c})^2} \quad \text{for } m<1 \qquad (7)$$

The capacitance of capacitor changes if the dielectric constant of the material inside the capacitor also changes or it's having combination of dielectric materials.

3. Model Definition in MultiphysicsTM:

The Model is designed in comsol multiphysics with application modes of electrostatic and Incompressible Navier Strokes.
The electrostatics model uses the equation

$$Q=C*V \qquad (8)$$

Where C is the equivalent capacitance, V is the voltage applied and Q is the charge developed.
Figure 3 shows the rectangular shape model simulated in comsol. Figure 4 shows the model with a single bacterium in between plates.

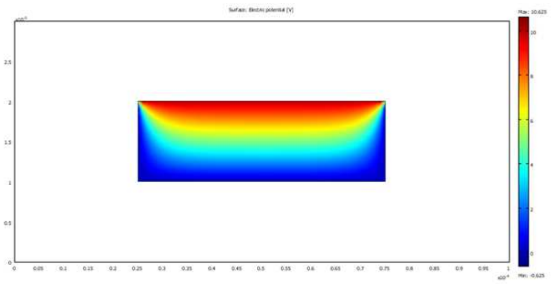

Figure 3: Rectangular model without bacteria

The model is a rectangular in shape with dimensions of 50um X 10um, where 50 um is the width and 10 um is the channel size through which fluid is flowing. The sensor is being filled with a material of dielectric constant of 80, since 80 is the dielectric constant of water. The two sides of rectangle will act like a capacitor plates, on one of the plate the voltage applied is 10 V while other plate is treated as a ground.

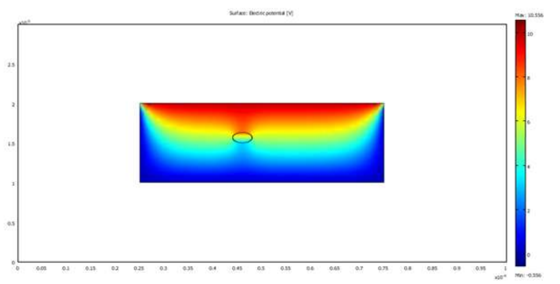

Figure 4: Rectangular model with bacteria

The E.coli bacteria are treated as an ellipsoid with dimensions of 2um X .65 um.[5]
The dielectric constant of an ellipsoid is taken as 40.

4. Analysis of Model:

To improve the sensitivity we have increase the area of sensor so that capacitance value is increased and it is measureable and also the accuracy will increase. With the increased area of sensor the measured capacitance value is shown in table 1. Also the comparison is done with the sensor designed in [1] we found that we have better results in terms of capacitance resolution.
The sensitivity of the model is given by,
S = (C – C')/C.
Where C is the capacitance without bacteria and C' is the capacitance with bacteria.

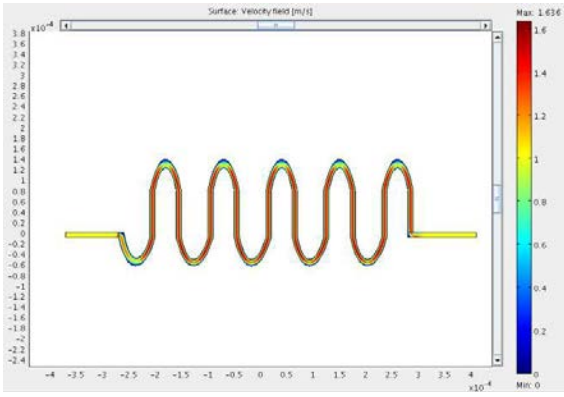

Figure 5: Sensor with increased overlap area without bacteria

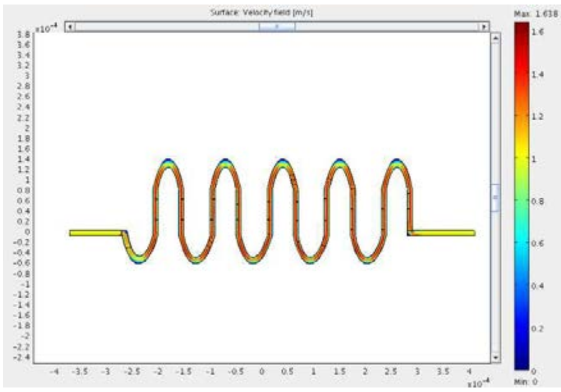

Figure 6: Sensor with increased overlap area with 20 bacteria

Sr. No	Model	Value of capacitance in model [1] in Farad	Value of capacitance in figure 5 and 6 in Farad
1	Equivalent Capacitance of electrode array without any cell	$1.33*10^{-13}$	$2.87*10^{-12}$
2	Equivalent capacitance with 20 bacterial cell over electrode array	$1.02*10^{-13}$	$1.46*10^{-12}$
3	Resolution in the capacitance measurement required	$31*10^{-15}$	$1.41*10^{-12}$

Table1: Comparison of models.

The capacitance value measured is now given to a chip. The chip consists of capacitor to voltage converter, signal conditioning unit. The output of chip is given to the display unit.

5. Conclusion: - In conclusion, we have proposed detection of bacteria based on capacitance modulation for Lab on Chip applications. A novel microfluidic flow sensor based on capacitance measurement is designed. The proposed capacitive measurement technique is good alternative for bio-sensing applications. The simulation results show that we are able to detect small variations.

6. Reference:-

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