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Development of Impedance Base Microfluidic Flow Sensor

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Abstract - ***This study presented an impedance base microfluidic flow and speed sensor devices which can detect a microfluidic droplet or wetting, study were carried out with available commercial material such as acrylic, copper board, double sided tape and glue.***

However, the aim of the project is to develop electronic device that can detect very small volume of fluid, therefore, device development consists of channel and geometry parameters that model and analyze while further development incorporate microcontroller that allow device to read and display result on LCD and excel datasheet. The model become more easy and in-expensive as less circuit is required for simple electronics model, also device can easily be implemented because device fabrication do not really require lab-on-chip process.

Key Words: *Microfluidic, Impedance, Speed Channel, Geometry, Copper Etching, Modeling*

1. Introduction

Several works had carried out for micro fluidic modeling, more than a decades, microelectronic industry has been moving towards the maximum compactness possible. Drastic increase in the number of electronic components per unit volume has led to ever-increasing amounts of heat fluxes, other focus base on the use of capacitive mechanism for fluid sensing, ultrasonic transducer, electromagnetic sensor, breeze sensor, coriolis mass flow sensor, thermal transport sensor [1] Another typical example is droplet detection changes in micro-fludic channel using coplanar electrodes [2].

In this paper, analysis emphasis on gap and channel diameter model and analysis of capacitive base sensor for microfluidic channel, study focus on channel geometry, and velocity profile. Therefore, two conducting plate were use and design of microfluidic device hardware was implemented and tested.

2. Materials and Methodology

The current market of microfluidic diagnostic devices is relatively low cost while there are several groups of devices leading the market, therefore, there are much rooms for growth and improvement, the goal of the project plan is to provide an insight toward the project implementation, the objective of the project is to create a low cost microfluidic device that can serve as fluid speed measurement for medical diagnostic and other related field.

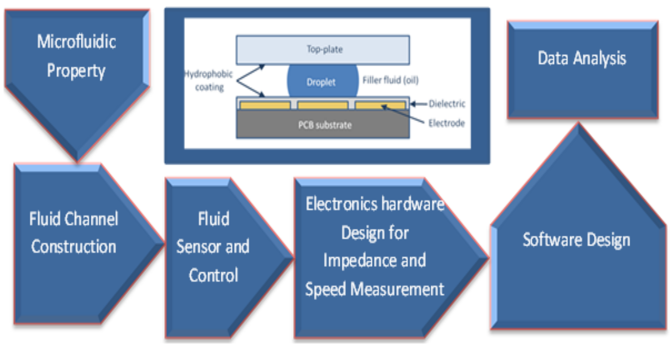

Fig -1: Design proposed for fluid impedance collection and speed measurement

2.1 Channel Design

Field of microfluidics for channel construction mostly originated in hard material such as silicon and glass, that makes them to be relatively expensive, required special fabrication techniques yet; they have many drawbacks such as temperature instability, gas permeability and optical visualization especially when working with biological molecule or materials like cells. Specifically, polymer material such as PDMS as greater advantage as they provide high permeable to gases and transparent though availability is the main concern for this material.

Create an acrylic or paper based device will dramatically reduce cost, competitive and benefit resource-poor research facilities area where lower cost fluid handling systems would improve the speed, accuracy, and throughput of diagnostic tests.

Project intended to design a device which can collect and test the concentration fluid impedance. Project will consider water collection device for design purpose, fluid impedance collection devices includes will include acrylic sheet or paper, copper board, adhesive material and hand hold plastic.

2.1.1 Fluid Sensor and Control

Sensing and controlling of fluid particles is critical in many lab-on-chip applications, most fluids are controlled by external forces, lots of applications control fluid by utilizing mechanical, electrical and optical, thermal force. The project focus on electrical and mechanical methods for fluid sensor and control, this method required integration of electrodes and application of pressure to the microfluidic channel.

When electric field applied between two electrodes on the same plane, a non-uniform electric field distribution will form within the channel and the directionality and adaptability of the field is limited thus, the generated electric field is directly proportional to applied voltage across this electrode. This principle will allow the sensing of fluid to take place, though, control of the fluid in channel can be tedious and produce un-accurate analysis if electrical control by aligning electrodes on all walls of microfluidic channels integrates with the channel.

Therefore, pressure control can be beneficial to generate external force in order to move fluid through a desire direction within the channel.

2.1.2 Proposed Channel Design

Sketch of design of impedance base microfluidic flow sensor channel construction

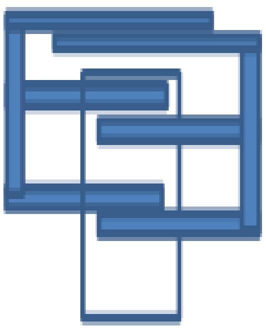

Fig -2: Channel and electrode arrangement

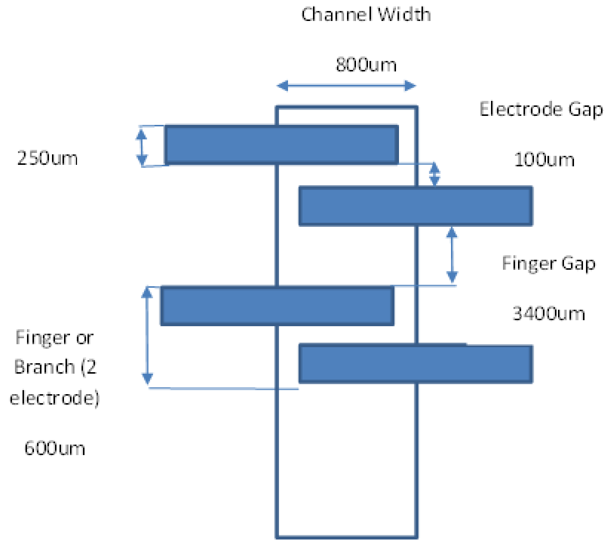

Fig -3: Channel and geometry of electrode

2.2 Overview of Channel

Two main type of configuration can be implemented for droplet or digital microfluidics, these are known as open and closed format configuration type, closed format is performed whereby, fluid is sandwiched between two substrates and open format only involve a fluid to stay on top of a single substrate. For two substrate pattern known as closed format, the bottom of the substrate usually consists of driving electrode while top are always denote as ground though this can be vice versa and it all depends on application requirement.

A situation where fluid is placed on the top of a single substrate housing of both actuation and electrode ground (typically, anode and cathode section) regarded as open format. Both format required insulated layer of dielectric material to be deposited at actuation and ground electrode, these layer are to coat with hydrophobic coating material, these will allow ease fluid flow, reduce fluid friction or droplet sticking to the surface.

Closed and open configuration have their own advantages toward fluidic devices, closed are more suitable for droplet operation for microfluidic devices, moving and merging seems to be more visible than open configuration while slitting are more difficult for droplet in open configuration however, Open configuration have greater advantage to move large droplet of fluid, it facilitate fast and also enhance regent mixing.

Open configuration have ease of fabrication and also give higher access for external detector, in addition to open configuration, evaporation rate are higher, this may be inconvenient, cause flow instability and can also be advantageous while it all depends on application.

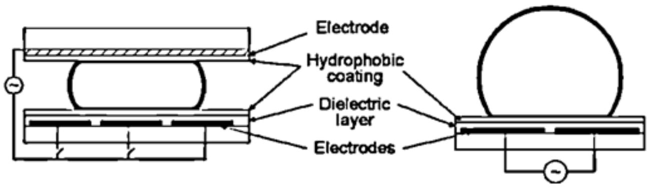

Fig -4: Schematics of closed and open Configuration of droplet microfluidic devices. In the open format, actuation and ground electrodes are housed in the bottom substrate

2.2 .1 Prototyping in copper Substrates

This phase present the prototyping techniques of an inexpensive impedance base microfluidic flow and speed sensor, using a commercial available printed circuit board for copper substrate, this techniques pattern and implement an actuated electrode by wet etching process and homemade photolithography process. Process involves an electrode to be printed directly on a circuit printed circuit board (PCB).

Electrode print on a copper using laser printer method allow high throughput approximately 70 device per every 10 minute but consider more expensive than the approach method, approach method required a method of printing the circuit on a photo-resist paper and complete the method using an homemade photolithography which only require light source such as 12 Watt bulb, the circuit on photo resist paper, a photo frame or any transparent glass, etching chemical such as Ferro-chloride solution and cleaning solution known as PCB developer while it is considered cheap and inexpensive though rate is slow.

Major difference between this work and other works is the time consuming for material and project implementation, this system produce fast implementation method as it only required approximately 45 minute to 1 hour for process time because other systems using required chip to be designed and this consider time consuming process and require limited lab.

2.2.1.1 Copper Substrate Prototyping Material

Printed circuit board was evaluated, thin and flexible double side paper used along with positive acting presensitized photo resist PCB used as prototyping board and dicing taping used for etching protection. Transparent paper used rather than photo resist paper.

Chemicals include ferro-chlorize solution, caustic soda serve as PCB developers, other material include, superglue, solvent cleaner such as methylated spirit, plain paper while channel materials is transparent acrylic sheet rather than PDMS glass, hydrophobic coatings, 1cc/mL and 3cc/mL syringe made by terumo syringe and HP-P1120 laser printer.

2.2.1.2 Laser Printing Fabrication

Electrode Fabrication is done by Photolithography and result to Channel Fabrication. Pattern is designed with ultiboard software for laser printing fabrication, this pattern subsequently serves as a mask for copper etching, this method, it was possible to create around eighty 2 × 2 cm chips in less than 10 minutes. The limitation on this method is resolution; i.e., for the 1200 × 1200 dot per inch (dpi) printer that was used, the minimum inter-electrode gap that could be resolved after etching was ~100 μm.

Cleaning of the PCB using developer chemicals, this is to allow clean trace of printed electrode as space of each electrode is small and required precision. Electrode pattern printed out onto a photo resist paper for pcb development.

In a dark room, kinsten PCB board package covered with blue sticker, the main aim is to protect or prevent it from expose to external light source while this also allow trace line to be drawn as guide during cutting. All required dimension are cut and edge are smooth using 80 grit sand paper and the blue sticker serve as protective layer peel off and note that room are to remain dark or can be equipped with low lumens light source or colored light source such as red bulb.

Electrode circuit design with ultiboard printed with HP-P1120 laser printer on a transparency film, devices were exposed to UV radiation through a photomask, formed by high-resolution printing on transparency film using 35 watts phillip yellow bulb, this process continue for about 30 minute, when perfect trances observed, substrates were supported with electric iron(100°C,1 min), removed and develop using caustic soda solution to strip out the remaining photo resist on boar then, board place for about 10 to 15 minute of etchant solution, this remove unwanted copper and leave copper trace. Therefore, copper trace observe same dimension as design during modeling phase using comsol multiphysics and Patern electrode were coated by Parylene-C.

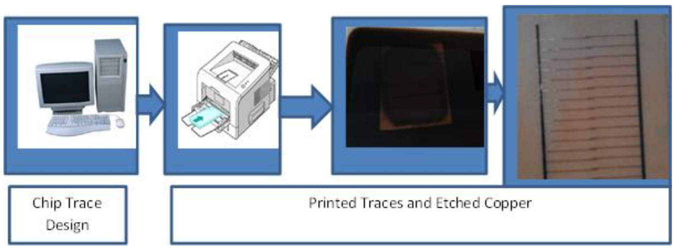

Fig -5: Rapid prototyping by laser printing; electrode array is first designed using ulti-board

2.3 Channel Fabrication

Channel is fabricate with cheap and cost effective material known as acrylic sheet, typical channel size maintain similar width analyze using Comsol Multiphysics, that is, 800 micro meter width but 80000 though micrometer long, the main idea is to analyze the speed of the fluid in the channel with more electrode since the design is an open format electrode construction.

It is observe that rather than worry about how long the fluid will take to flow from inlet to outlet of the channel, the project focus on understand the capacitance that occur at each electrode and also the conductivity in order to determine the speed of a moving fluid in a channel.
The first channel fabrication is the substrate, that is cleaning both location from inlet to outlet that is creating a path way for fluid to be insert from inlet to outlet of the channel.

Preparation of channel template typically required a transfer of backing tape of adhesive firm which can also called double sided tape. Double sided tape stick firmly at the back of the prototyping electrode and top of the acrylic sheet substrate cut with knife, then trace of unwanted tape are remove.

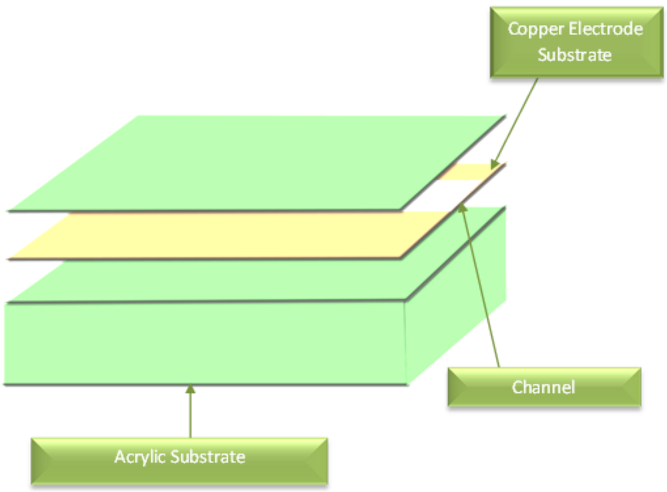

Fig -6: Illustrate the idea used for channel construction

2.3 Electronics hardware Design for Impedance and Speed Measurement

Expected signals regarding for this project are analogue in nature, therefore circuit design consist of impedance measurement circuit, this circuit is to convert signal into voltage reference for display and further analysis purpose, circuit is incorporated with LCD, amplification circuit, and microcontroller integrated with serial communication module and other support electronics such as personal computer for graphical purpose. Below is the block diagram of circuit design.

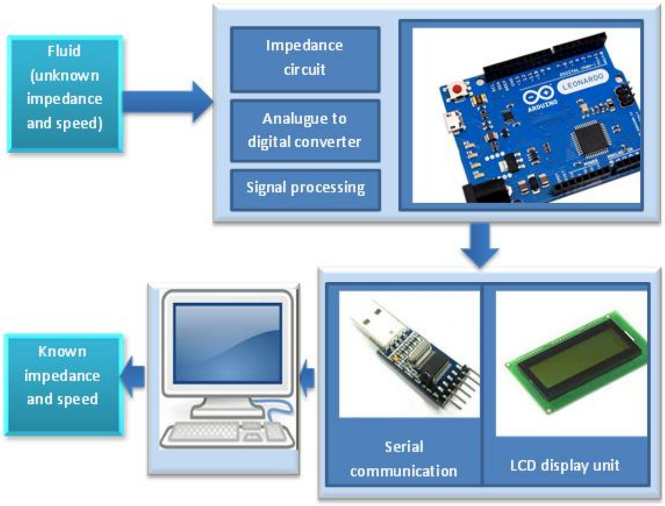

Fig -7: Complete system development.

3. Result and Discussion

The critical features of design and fabrication of impedance base microfluidic flow and speed sensor is the design of the dimension and gap between actuation electrodes as shown in Fig-2. This dimension is also well suited for microfluidic sensing device, though it was observe that, sensitivity and response to fluid are slow for very small amount of fluid and also obstruct small volume of droplet movement even if dielectric coating apply.

3.1 Open Format Actuation

Open format copper substrate used as a single plate actuation, this actuate by low cost 12VAC transformer with 0.5A current rating at 60Hz and ground potential (0V) to a single rail that attached a pair actuator or finger. Water droplet were manipulated in channel with size range between 0.01mL to 0.5mL, another droplet manipulation is by suspending droplet in an immiscible oil to provide smooth fluid flow towards fluid speed measurement.

Final coating are made with home cooking oil which are easily remove and replaced, that is can be clean with soft cloth or tissue paper and spray, this is valuable as most microfluidic channel device as coated permanently, device at constructed in such a way that, channel can easily adjusted incase if wider allow device fluid measurement is need.

Device complement with a single lead to each finger known as rail for any point measurement and circuited with microcontroller unit which provide the capability to read device function, such as it impedance, speed, voltage analysis, current flow through each fingers, also to understand the behavior of electric field and charge built up with channel and behavior of dielectric material and it capacitance, note that electronics such as microcontroller was circuited on breadboard for experimental purpose.

To demonstrate the capacity and perform reaction of devices, the project analyze and provided result for droplet sizes, electrode capacitance, fluid volume, rate of movement knows as speed, voltage and current parameters.

3.1.1 Capacitance Impedance Measurement Due to Size of Droplet

Droplet of water (di-electric material was scale with syringe and drop on substrate electrode, scale vary between 0.01mL to 0.5 mL and result was computed for fluid size, voltage across electrode and capacitance of the electrode. Mathematically, electric field is directly proportional to its current density and inversely proportional to the material dielectric constant while increment or changes in electric field result to change in voltage across electrode configuration, though voltage across electrode is relatively proportional to electric field before breakdown will occur at junction electrode.

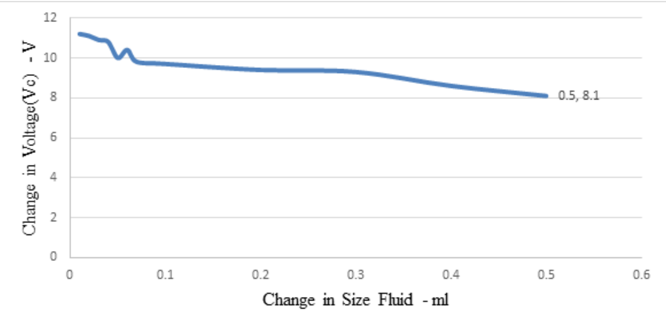

Fig -8: Result demonstrate the change in potential difference across electrodes of the channel due to change in sizes of fluid and dielectric (water) effect of fluid on electrode

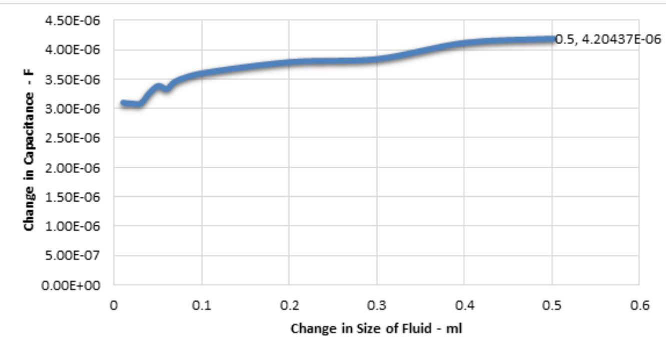

Fig -9: Change in impedance (capacitance) which result from change in sizes of fluid and dielectric

3.2 Speed Measurement and Effect on Electrode inside the Channel

Speed detection achieved via rising and falling edge signal, for this implementation phase, rising and falling is receiving analogue signal, all peak voltages are measured with voltage peak detected circuit and result are for every milli-seconds time with Arduino Leonardo microcontroller unit.

Two Open format electrode construction was made which consist of 14 fingers and 18 fingers type and they both have similar measuring characteristics, for every speed measurement, the average time for every finger is taken, the system have the capability to measure up to approximately 3980µm due to maximum gap of 4000µm between fingers.

0.1ml liquid examine and pump was used to move liquid from inlet to outlet at a low pressure, as the liquid reaches each finger, conduction take place, conductive signal was measure using microcontroller, therefore, electric field increase while increase in electric field tend to cause increase in current density, conductive electrode causes changes in current and voltage of electronics circuit and changes are observed though resistor, signal are measured and converted to high and low signal which refer to rising and falling edge in this project . That is, at every time that each fingers are conductive, the average time of conductive fingers are recorded and speeds are calculated in real time.

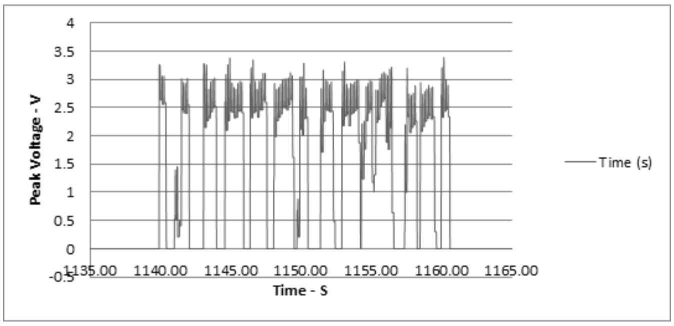

Fig -10: 0.1 mL fluid measurement tested to flow through microfluidic channel for about 21.37 sec at average speed of 0.000019m/s.

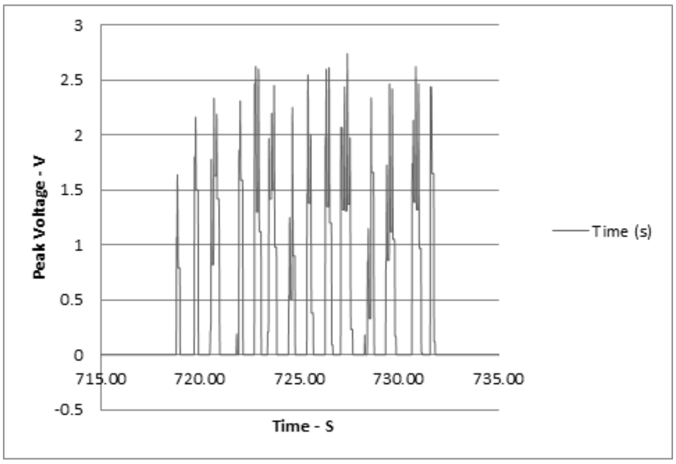

Fig -11: 0.3mL fluid measurement tested to flow through microfluidic channel for about 12.37 sec at average speed of 0.000021m/s

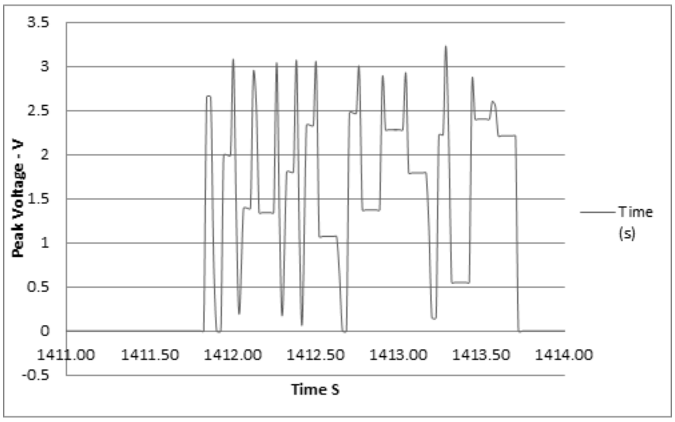

Fig -12: 0.1 mL fluid measurement tested to flow through microfluidic channel for about 1.83sec At average speed of 0.000018m/s

Fig -13: Result indicates the rising edge at conductive electrode with capacitance C value in farad

4. CONCLUSIONS

Project research carried out by investing time to investigate various works done by other researchers, research found out that, microfluidic sensor design is useful for various applications such as biodefense, genetic, electronics and lots more. Variety of microfluidic sensor have been fabricated, these are, transduction schemes used capacitive sensing rather than resistive type or other, project implement capacitive type as to determine the impedance and the rate of fluid flow in a micro channel.

Common method of fabricating an microfluidic flow sensor can be regarded as lab on chip process, while common insulating channel material is PDMS material. Project reduces cost performing an homemade microfluidic flow sensor, using etching techniques and transparent acrylic sheet for channel design.

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