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Testing: Novel Schemes Guiding towards a Fault Free Microfluidic System

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Abstract: Reliability is an important property for microfluidics based biochips which are anticipated to revolutionize several life critical applications and costly lab experiments such as point of care medical diagnostics, DNA analysis, air quality supervising, finding toxicity in water sample etc. Manufacturing defects are inevitable on these bio-MEMS (microelectromechanical system) as well as malfunctioning modules may have serious impact on the robust execution of the target bioassays. Therefore, these devices must be tested enough after fabrication of the biochip as well as during the time of bioassay operations. In this paper, different testing procedures have been introduced**.**

Keywords: biochip; bio-MEMS; lab-on-a-chip; digital microfluidics; catastrophic faults;

I. INTRODUCTION

The basic thought behind the microfluidics based biochips lie on the principal of integrating all indispensable functionalities of a biochemical process onto a chip by using microfluidic technology. Conventional microfluidic technologies are based on the continuous liquid flow through fabricated micro-channels. This technique is adequate for simple, well defined biochemical applications but not desirable for complicated bioassays that requires a prominent flexible atmosphere. An alternative to the continuous flow closed channel system is droplet based digital microfluidic technology. Digital Microfluidics based biochips apply the principle of electrowetting on dielectric(EWOD) to move biological samples such as blood, serum etc. in the form of a micro or nano litre volumes of droplet on a two-dimensional electrode array [1] [2] [3] [4] [5] [6] [7] [8] [9]. These bio-MEMS are expected to play an important role as a substitute of a laboratory containing cumbersome instruments. Figure 1. depicts a unit cell of this lab-on-a-chip having two parallel glass plates.

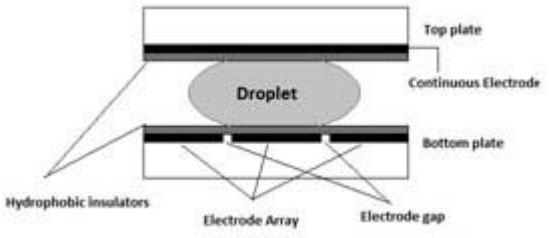
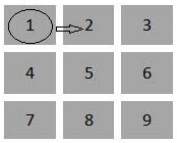


Figure. 1: Basic cell of a biochip.

The bottom plate carries an array of electrodes and the top plate is continuous which is grounded. Dielectric insulator e.g. parylene C is used for coating of the bottom plate. A hydrophobic thin flim is also added on the both plates to reduce the chance of unwanted residue. Any biochemical sample along with filler fluid such as silicone oil is placed on the bottom plate. Now the droplet can be moved to a desired nearby location by activating the target electrode and at the same time deactivating the electrode under the droplet [1] [2][6][8][9][10][11][12][13][14]. Suppose the droplet is placed on electrode 1 as shown in figure2. It is to be moved to electrode 2. In order to move the droplet, electrode mentioned as number 2 is activated and the electrodes numbered as 1, 3, 4 and 5 should remain deactivated.



. Figure. 2: A 3x3 microfluidic array

Several fluid handling operations such as mixing, splitting, dispensing can be performed by altering electrode activation sequence pattern.

II. FAULT MODELLING, TESTING AND DIAGNOSIS

Faults in Digital microfluidic biochips can be either catastrophic or parametric. Catastrophic faults (Table 1) happens mainly due to physical defects as stated in [2] [10][11][12][13][14][15].

Table 1

Cause of Defects	Results
Overweening activation voltage applied	Droplet electrode short. Droplet gets electrolyzed.
Electrode activated for long duration	Unwanted droplet movement or the droplet gets stuck on electrode surface.
Excessive mechanical force applied	Misalignment of glass plates
Coating failure	Fragmentation of droplet
Abnormal metal layer deposition or particle contamination	Electrode short. Droplet movement impeded.

Structural testing technique mainly targets physical defects. According to this method, a test droplet is dispensed from the droplet source, suppose A as mentioned in figure 3. The droplet is guided to traverse the unit cells of the microfluidic array following the test plan towards the droplet sink B.

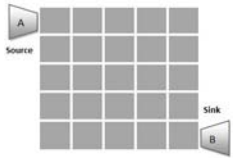


Figure 3: A 5x5 microfluidic array

As proposed in [16][18] a Capacitive Sensing Circuit (figure 4) can be used for test read out. As on chip detectors may not reside at droplet sink or using alternative one is not feasible due to high cost, Capacitive Sensing Circuit is viable enough due to low cost and its advantage of integrating facility to any location of the microfluidic array.

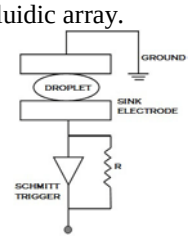


Figure 4: Capacitive Sensing Circuit

The specified microfluidic array can be supposed a defect free if a droplet can be transported through all the cells of the array. That means, starting from the dispensing port, the droplet should visit each cell at least once before reaching the droplet sink. As the same cell is visited more than once, this process increases the testing time and causes electrode degradation. To overcome this problem, the microfluidic array can be modeled as an undirected graph. The testing route is determined following the Hamiltonian path [2] [17] or Hamiltonian Cycle (if source and sink represent the same cell) of a graph. Despite the fact that most of the physical defects causes total malfunctioning of the microfluidic module, in some faulty cases such as electrode-short fault, Hamiltonian path based testing methodology is not sufficient to detect the faulty cell [18]. Suppose, figure 5 represents one of the test based possible routing path and the droplet is supposed to be residing at electrode (1, 1).

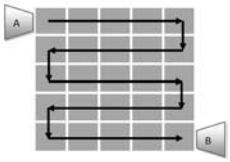


Figure 5: Test based Possible routing path.

Electrode (1, 2) is supposed to be shorted with electrode (1, 3). Now, the droplet is moved following the routing path .It is found that (figure 6), the droplet gets stuck in between electrode (1, 2) and (1, 3). In this scenario, Hamiltonian path based testing procedure is sufficient to detect the faulty cell. But, if the cell (2, 2), which is aligned vertically with the routing path, is shorted with (1,2) as depicted in figure 7.Then, even though the droplet trends to move in between electrode (1, 2) and (2, 2), it finally moves to electrode (1,3).Here, Hamiltonian path based approach fails to identify the defective cell. Therefore, the test droplet has to traverse not only all the cells but also the cell boundaries as well. In this regard, an Euler Path and Euler Circuit based test planning method have been proposed where the test droplet has to visit every edge exactly once[18][19][20].

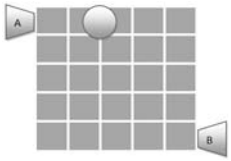


Figure 6:Electrode-short fault along the test based routing path.

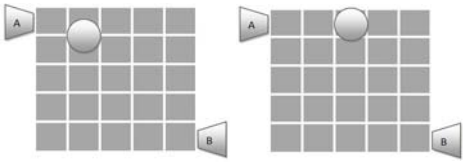
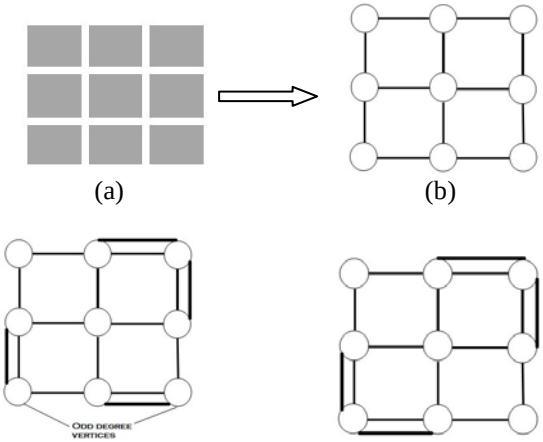


Figure 7: Shorted electrode aligned vertically with the test based routing path.

The microfluidic module is modeled as an undirected graph. The graph is 'eulerized' and the test droplet is routed along the Euler path, obtained from the graph on the basis of Euler Theorem [18] [19] [20]. This path is adequate to identify any directly adjacent faulty neighborhood cell. Figure 8(a) and figure 8(b) shows a 3x3 microfluidic array and its corresponding undirected graph.



8.(a) 3x3 microfludic array; (b)Corresponding undirected graph; (c) Euler Path; (d) Euler Circuit.

The above structural test based methodology for detecting faulty cell focuses only on physical flaws. Apart from physical flaws, there may be problem in respect of module functionality. For example, a fault free microfluidic reservoir may dispense droplet of undesired volumes or a splitter consisting of defect free cells may split droplet of unbalanced volumes. These types of malfunctions have serious impact on the robust execution of the bioassay operation. Therefore, more elaborate testing procedure needs to be complied with to detect malfunctioning units. Dispensing test, Mixing test, Splitting test, Capacitive sensing test are some of the comprehensive testing procedures [14].

Dispensing test targets the malfunctioning scenario when the dispensed droplet may not be detached from the reservoir. An unwanted droplet may be extracted along with the desired one. Capacitive Sensing Circuit based testing methodology is carried out to point out such problem.

Mixing and Splitting test aims at checking correctness of the mixing and splitting modules. Four steps should be guaranteed to accomplish this task i.e. Horizontal

Splitting, Horizontal Mixing, Vertical Splitting, Vertical Mixing.

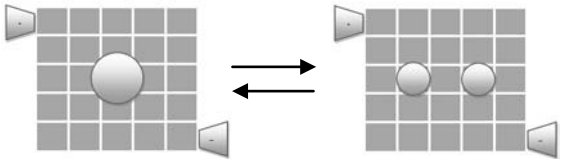


Figure 9. Horizontal Splitting and Horizontal Mixing.

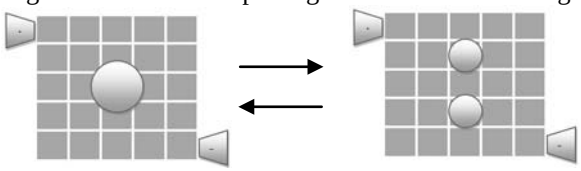


Figure 10. Vertical Splitting and Vertical Mixing.

III. CONCLUSIONS

I have presented a survey of research on different test techniques for digital microfluidic biochips. Common faults have been distinguished. Based on these faults, several testing techniques have been discussed. These testing techniques will guide microfluidic biochips to become a more convenient means for deployment in the emerging healthcare market.

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