On-Line Testing of Lab-on-Chip Using Digital Microfluidic Compactors

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List of topics

- Digital microfluidics
- Lab-on a chip
- Problems in LOCs
- Online testing
- Microfluidics gates
- Applications of DMF

What is Digital Microfluidics

•Discrete droplets of nanoliter volumes can be manipulated in a “digital” manner under clock control on a two-dimensional array of electrodes.

•An especially promising technology platform is based on the principle of electrowetting-on-dielectric.

Lab-on-a-chip (LOC)

•It is a device that integrates one or more laboratory functions into a single chip.

•The size of the chip can be from few millimeters to few centimeters.

•LOCs can handle extremely small fluids of volume down to Picoliters

Need for Testing a Microfluidic LOC

- Microfluidic based lab-on-chips are used in processes like immunoassays, clinical diagnosis and DNA sequencing.
- Hence these devices are expected to be deployed for safety critical biomedical applications such as health assessment and screening for infectious diseases.

Problems Faced in LOCs

•An increase in the density and area of microfluidic based lab-on-chip will lead to high defect densities.

•These systems need to be tested adequately not only after fabrication, but also continuously during its operation.

On-Line Testing

•This testing allows normal biochemical assays to run simultaneously on a microfluidic system.

•It facilitates built-in self test (BIST) of microfluidics based lab-on-chip systems and makes them more cost effective.

•Capacitive sensing is other general technique used for testing LOC.

Digital Microfluidic Platform

•Microfluidic droplets of nanoliter volumes (typically 300nL) are manipulated on a two-dimensional electrode array and size of the electrode is 1.5 mm× 1.5 mm.

•A unit cell has a pair of electrodes as two parallel plates.

•The bottom plate contains a patterned array of individually controlled electrodes, and the top plate is coated with a continuous ground electrode.

Digital Microfluidic Platform

•A droplets generally move on a hydrophobic surface over an electrode.

•Droplets are moved by applying a voltage to a unit cell by creating a potential difference between two adjacent cells along the desired path of the droplet.

•Droplet routes and operation schedules are programmed into a microcontroller that drives the electrodes.

Microfluidic AND Gate

Principle:

•In the digital microfluidic platform, droplets of unit volume (1x) or larger can be easily moved .

•A droplet of 0.5x volume is not large enough to have sufficient overlap with an adjacent electrode and hence it cannot be moved with a nominal actuation voltage.

Microfluidic AND Gate

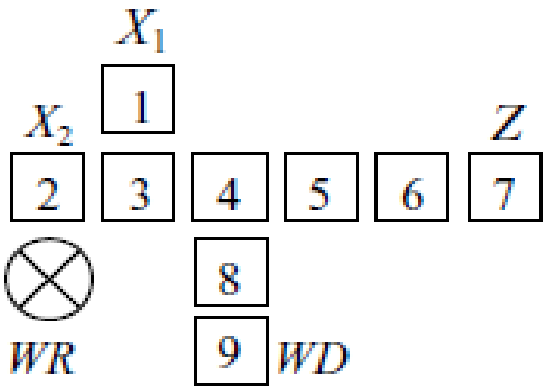
- The time required for dispensing one droplet, splitting a droplet into two, merging two droplets into one and transporting a droplet to an adjacent electrode are nearly identical and it is one clock cycle.

- The inputs of the Logic AND gate is interpreted as :
  - The presence of a droplet of 1x volume at an input or output port indicates a logic value of ‘1’.
  - The absence of a droplet at an input or output port indicates the logic value ‘0’.

Microfluidic AND Gate

- The AND gate incorporates a waste reservoir (WR) and nine indexed electrodes.
- Electrode 1 and Electrode 2 are the two input ports X1 and X2.
- Electrode 7 is the output port (Z) and Electrode 9 is the washing port (WD).

Microfluidic AND Gate



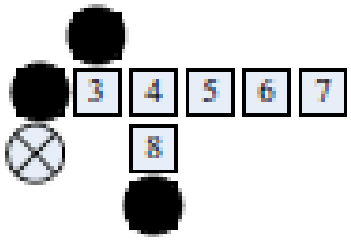
AND gate: $Z = X_1 \cdot X_2$

Schematic Diagram of Microfluidic AND gate

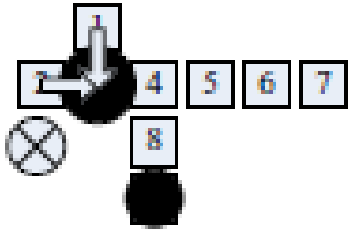
Actual Voltage Sequence for AND gate

Clock cycle	Electrode No.								
	1	2	3	4	5	6	7	8	9
0	1	1	0	F	F	F	F	0	1
1	0	0	1	0	F	F	F	0	1
2	0	1	0	1	0	F	F	0	1
3	F	0	0	0	1	0	F	0	1
4	F	F	F	0	0	1	0	0	1
5	F	F	F	F	0	0	1	0	1

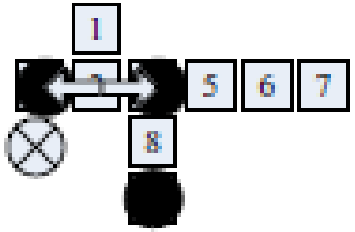
Microfluidic AND Gate



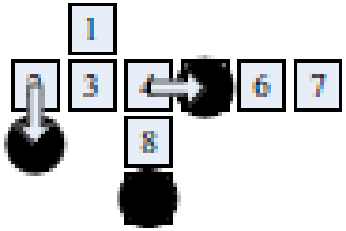
(a) $t = 0$, two 1x droplets stay at the input ports.



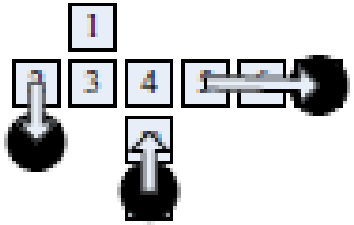
(b) $t = 1$, two 1x droplets are merged into a 2x droplet.



(c) $t = 2$, a 2x droplet is split into two 1x droplets.

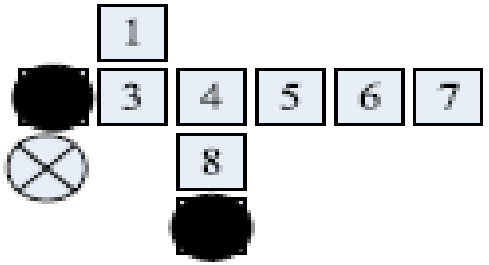


(d) $t = 3$, a 1x droplet moves right from electrode 4 to 5.

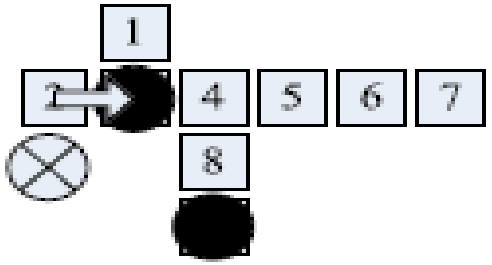


(e) $t = 4$ to 5, a 1x droplet moves right from electrode 5 to 7. While the washing droplet moves upwards.

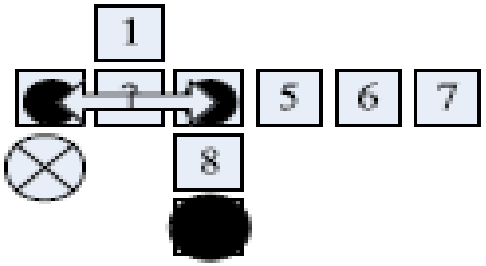
Microfluidic AND Gate



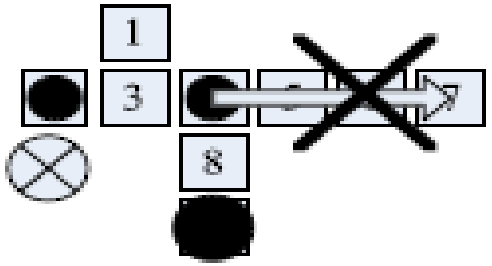
(a) $t = 0$, one 1x droplet stays at the input port 1.



(b) $t = 1$, one 1x droplet moves right from electrode 2 to 3.



(c) $t = 2$, a 1x droplet is split into two 0.5x droplets.



(d) $t = 3$ to 5, 0.5x droplet on electrode 4 cannot be moved to electrode 7.

Application of Online Testing

A concurrent testing technique has been proposed for detecting catastrophic faults in digital microfluidic lab on chips.

This method offers an opportunity to implement BIST for microfluidic systems, and therefore eliminates the need for external test equipment.

Advantages of Online testing and drawbacks of Capacitive Sensing

- Online Testing doesn't need any additional steps like pulse-sequence detection seen in the Capacitive sensing circuit.
- The other procedure is especially prone to errors arising from inaccuracies in sensor calibration.
- The complexity of the capacitive-sensing circuit and the need for pulse-sequence analysis make previously proposed testing methods less practical, especially for field operation.

Conclusion

- Microfluidics and its applications
- Online testing
- Advantages of online testing
- Applications