Logic Gate Simulation for Fluidic Computers

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Abstract: Micro computation provides a special-purpose computing paradigm and is integrated on small-scale microfluidic platforms. Because of their very small size, fluidic computers have a number of advantages and potential. Fluidic computers works on fluids such as air, water etc. and does not depend on electrical power traditional semiconductor electronics based computers. The major aim of fluidic computing is to enhance the functionality of different applications, by integrating a computing capability with the inherent advantages of microfluidics. Here, simulations on the operation of basic fluidic logic gates are performed in COMSOL Multiphysics platform and all the possible combinations for the logic operations are tested and are compared with the corresponding truth table. A fluid is pressurized from the inlet of a microfluidic channel and the valves perpendicular to the channel are pressurized to control the flow operations as per the required logic operations. The inlet pressure of the fluid is taken as 1 Pa and the valve pressure to create deflection of its diaphragm is considered as 1.2 Pa. The deflection of the diaphragm of the valve closes the pathway of the fluid flowing and thus provides 'logic 0' where as the flow of fluid is considered as 'logic 1'. These independent logic gates can be assembled for large fluidic computations in a proposed fluidic computer.

Keywords: Fluidic computer, Microfluidic, logic gates, digital, computations.

1. Introduction

Microfluidic devices is used to investigate a variety of different problems in every field of interest, ranging from basic research in physical, biological and chemical aspects [7]. A number of these applications require an additive involvement of valves, mixers, and other components into the devices in order to faithfully carry out various steps. The involvement of actively controlled functionalities, either directly in the device or via a fixed interface with external components, often leads to more complex fabrication and the need for auxiliary equipment. The use of active and independent microfluidic components, while sometimes requires more complex fabrication, and can help to reduce or eliminate the need for additional equipment. Thus by diminishing the role of external components makes point-of care devices handy and facilitates operation of many devices in parallel, which is of particular interest for large parametric screening applications. A wide range of fabrication techniques used to create microfluidic devices were first emerged for microelectronics, so it is fitting that a number of parallels can be drawn between the two fields. The components which are basically used to compare the electronic network with the fluidic networks are resistance, driving forces (pressure/voltage), and current (fluid/electrons). This idea has been further extended in microfluidics to include diodes, rectifiers, memory elements, and capacitors. Two-phase flow has currently been used to encode and decode data sets using droplets. As with electronics, microfluidic components can be integrated to form more complex devices, and a microfluidic breadboard can also be utilized to address problems which are not easily solved using standard computational methods [7]. Though fluid-based computing does not aim to replace traditional silicon-based technology, computing elements, but will serve to the communities in the remote areas proving them the digitized computation capability and thus leading to technological advancement. To date, most of these have been fabricated at the micro scale, but as applications develop, many of these could be further shrunk to significantly smaller, nano-fluidics sizes for more precise and rapid computations. In this paper, basic fluidic logic gates i.e. NOT and AND along with universal logic gates NOR and NAND are simulated in COMSOL Multiphuysics software platform. The fluid flow along with the valve operations provides the basic logic of the different gates. The obtained results are compared and analyzed.

2. Simulation in COMSOL Multiphysics

A rectangular tube in two dimensional (2D) platform is considered with length 100 um and height of 50 um. The tube geometry is changed according to nature of the logic gates considered. The fluid flow inside the micro channel is controlled by a pressure driven valve, which operates according to the function of the gate. The physics involved in this simulation is from single phase fluid with laminar flow, the study involved is stationary and the model is solved with free triangular meshing elements in COMSOL Multiphysics platform. Figure 1 shows the schematic of the microfluidic flow for logic operations. When the valve is closed, there is no fluid flow from the inlet to the output of the channel. When the valve is open the output is obtained. Thus here the valve acts as a logic level i.e. 'logic 1' when closed and 'logic 0' when open.

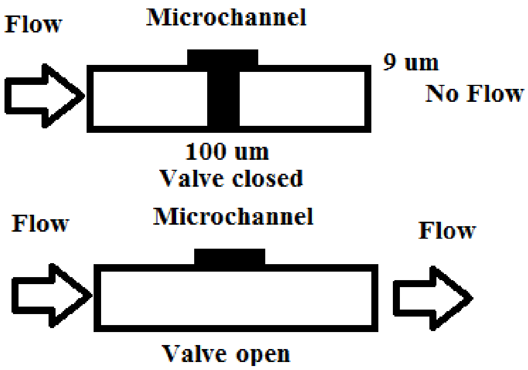

Figure 1. Schematic explaining the concept of operation of the gates in a microfluidic channel.

3. Results and discussions

Figure 2(a) shows that when the valve is not closed there is no obstruction between the input and the output. So the liquid flows continuously from the input to the output in the channel. If the opening of the valve is considered as 'logic 0' state then 'logic 1' in form of the flow is obtained and the vice versa is possible as shown in the simulation. For the AND gate operation shown in figure 2(b), NAND and NOT gates are combined to obtain logic operations of an AND gate. The NOR gate in figure 2(c) is implemented using successive operation of the two valves for controlling the fluid flow in a single channel with opening and closing state of the valve. NAND gate presented in figure 2(d), the two valves are placed in the pathway of two channels which are parallel to each other.

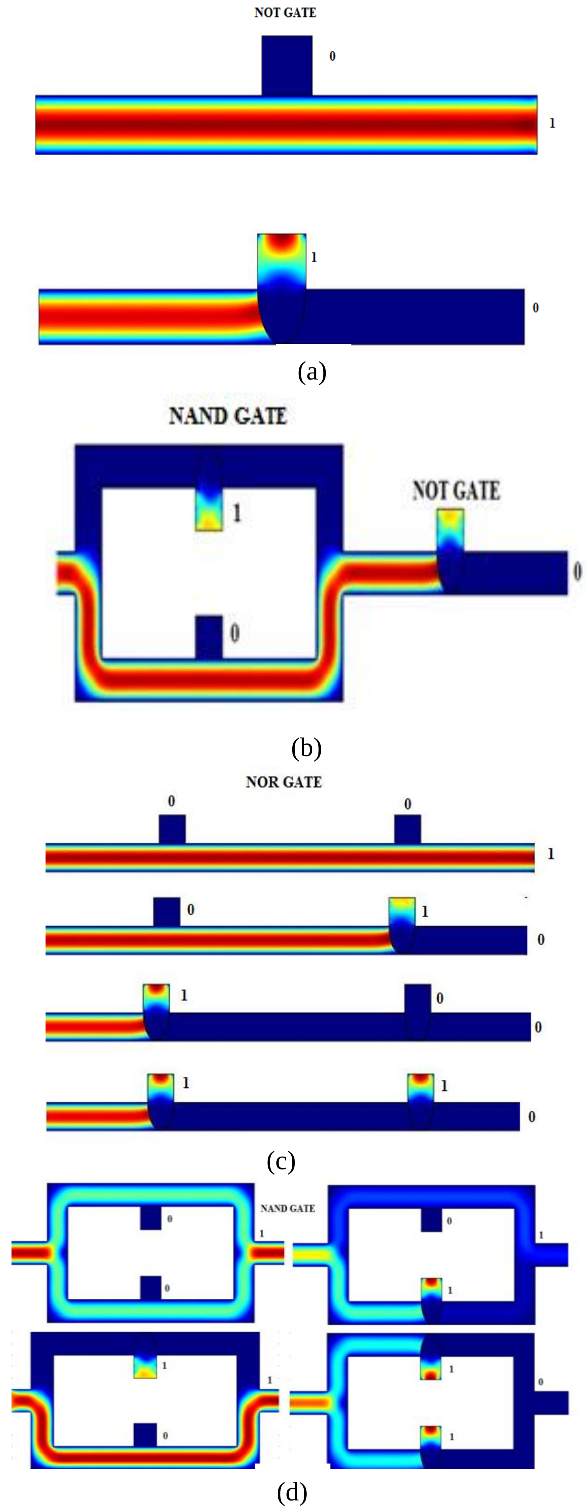

Figure 2. Simulations on the logic gates in a microfluidic channel using pressure controlled flow.in a (a) NOT gate, (b) AND gate,(c) NOR gate and (d) NAND gate

The pressure for closing the valve was applied in the order of 1.2 Pa whereas the fluid was forced to flow with a pressure of 1 Pa through the inlet. The results obtained during the simulation validates with the result from the truth tables of the respective gates [5].

4. Conclusions

In this paper we have presented the operation of some of the basic and universal digital logic gates in microfluidic platform by controlling the switching mechanism of the valves which lies along the path of the fluid flow. In this way different complex digital circuits can be implemented using different geometries of the microfluidic channel along with controlling the operation of the valves. This will be a great challenge to develop a microfluidic computer which computes different operation based on the dynamics of the fluid flow inside the channel in the near future.

5. References

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6. Acknowledgements

Authors would like to thank Dr. Madhura Mehendale, Jagruti Bhalke, Oshin Sharma, Snehal Shah and Dr. D. Paul for the guidance and support. Also facilities provided by Ninad`s Research Lab for fabrication and testing of the devices.