Digital Microfluidic Droplet Adapter for Interconnection of Biochips

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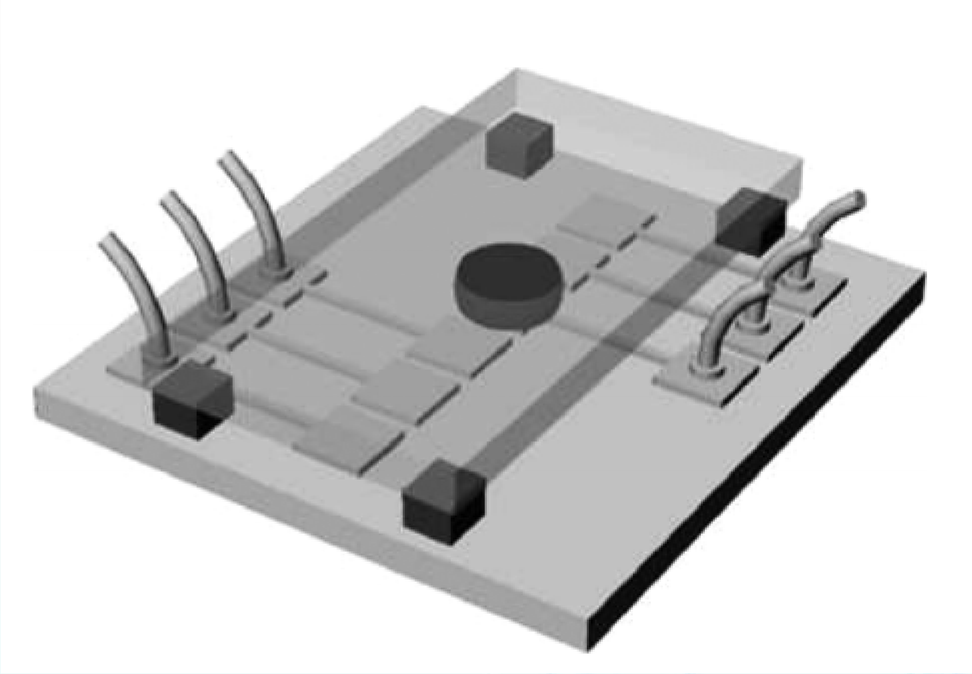
Outline

- ✓ Introduction and Backgroud
- ✓ Plan of adapter
- ✓ COMSOL Simulation
- ✓ Discussion
- ✓ Conclusion and future work

What is Digital Microfluidics?

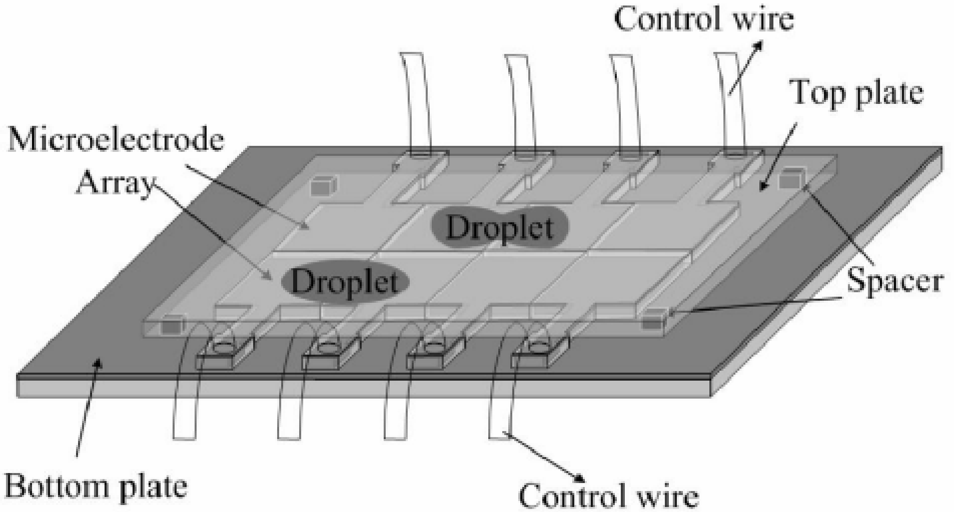
Digital Microfluidic Biochips (DMFBs) handling discrete microfluidic droplets have been used in DNA analysis, micro drug delivery, biomolecular recognition and other applications.

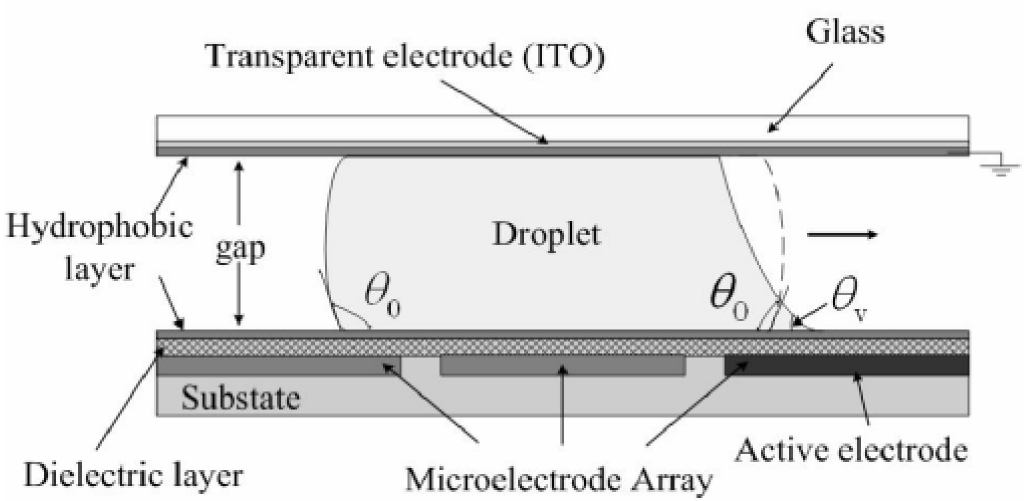
DMFBs have the advantages of significantly reduced sample size, low energy consumption, high throughput, as well as being reconfigurable and scalable in its architecture.



(Shawn W. Walker 2006)

Structure of DMFB





(Jiangang Wu 2006)

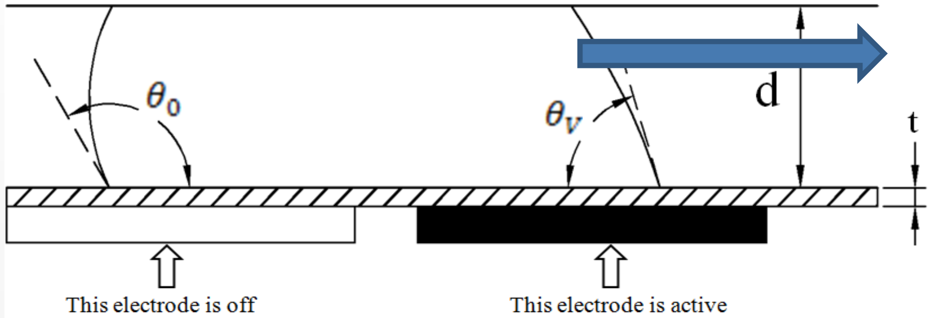
Microelectrode is the most important part in the DMFB.

Control wire can change the voltage of microelectrode, which will decide the electrode is active or not.

The surface tension of droplet will be changed, if the electrode under it become active, then the droplet can move on the hydrophobic layer.

Between the two hydrophobic layers, there is oil that fills all the rest space.

Principle of droplet motion on DMFB



fm

$$\cos\theta(V) = \cos\theta(0) + \frac{\varepsilon_r \varepsilon_o V^2}{2t\gamma_{lg}}$$ Lippmann-Young equation

Where εo (8.85 E-12 F/m) is the permittivity of vacuum, εr is the dielectric constant of the insulator layer, V is the applied voltage, θ(0) is the non-actuated contact angle, and θ(V) is the droplet contact angle when voltage V is applied, γlg is the liquid-gas interfacial tension.

The equation of droplet's driving force f_m can be calculated as

$$f_m = \gamma_{lg}\left(\cos\theta_V - \cos\theta_0\right)$$

When the electrode is active, the contact angle will decrease according to the Lippmann-Young equation. That is, θ(v) < θ(0), so the fm>0, the droplet will be driven to move forward.

Electrowetting-on-dielectric (EWOD) actuation can manipulate microfluidic droplets to move, split, merge and perform other movements.

The basic motion of droplet is moving, merging, splitting.

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Parameter of comsol simulation

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Design Parameters	Values
Size of large electrode	2mm×2mm
Size of small electrode	1mm×1mm
Droplet height D	0.15mm
Actuation voltage V	85V
Initial contact angle	125°
Contact angle θ_V with voltage applied	45°
Insulation layer thickness t	1μm
Liquid-gas interfacial tension γ_{lg}	50×10^{-3}N/m

Material Property	Microfluid (CP)	Silicone Oil (DP)
Density (kg/m^3)	1000	1000
Dynamic viscosity (mPa)	1.5	8

The design parameters of the size adapter and the material properties used in COMSOL simulation are listed in Table.

During COMSOL simulation, we used the Multiphase Flow model, Laminar Two-Phase Flow (tpf) model, as well as Level Set method.

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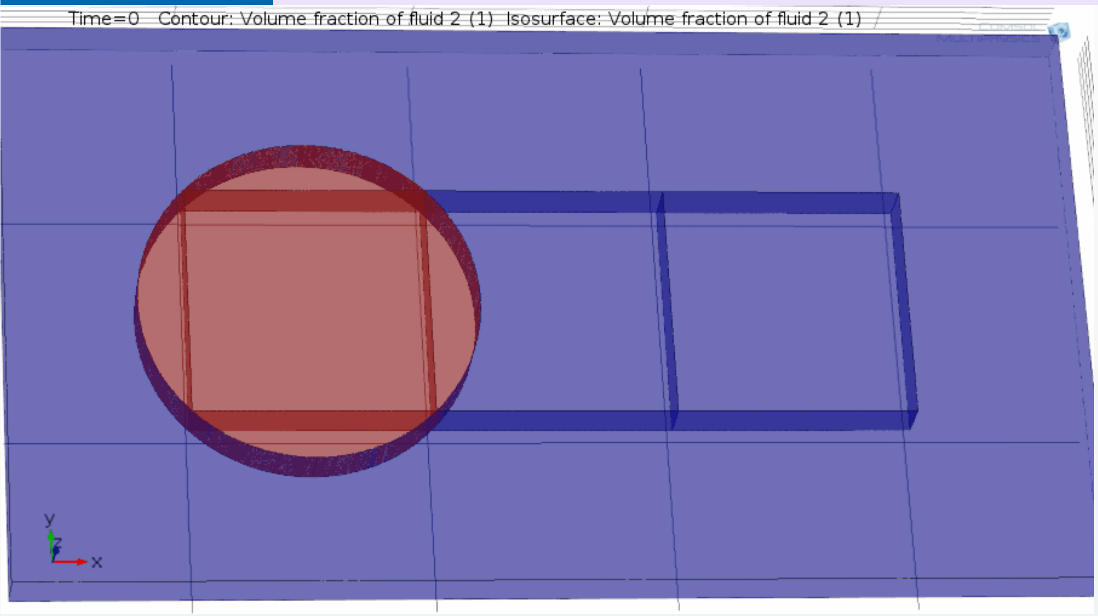
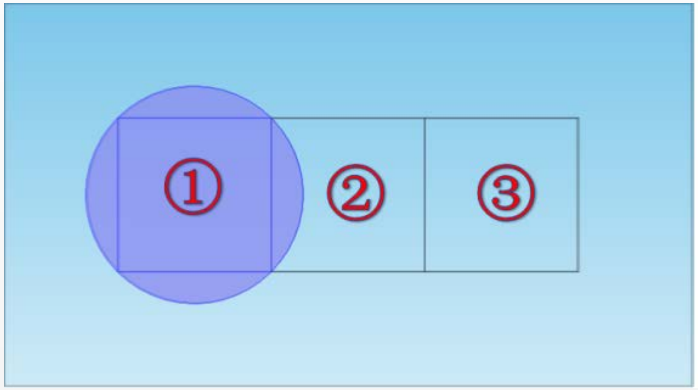
COMSOL Simulation – Droplet Moving





To achieve the movement of droplet on DMFB, at least need three independent control wire to control the condition of electrode.

The mesh size is normal. Electrode size is 1mm.
The number of freedom need be solved is 229770.
Simulation time is 32ms.
The time used to compute is about 5 hours.

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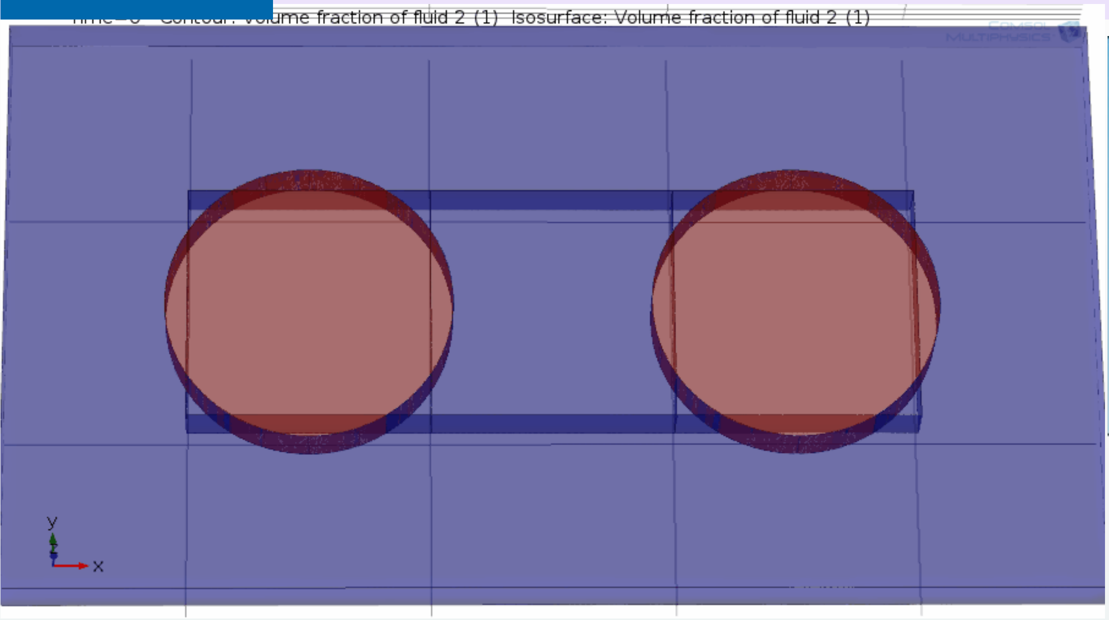
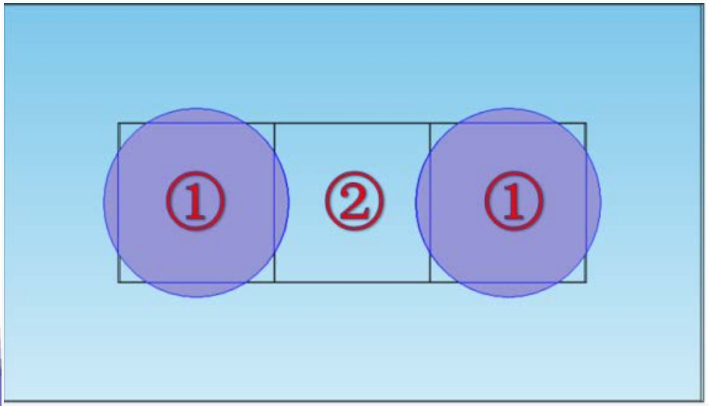
COMSOL Simulation – Droplet Merging

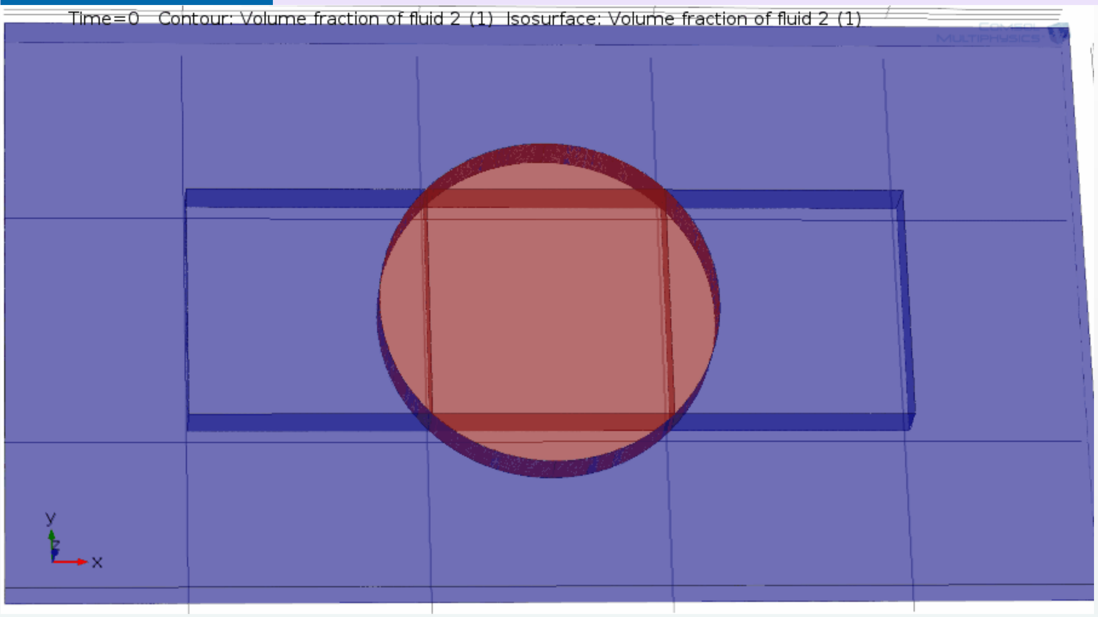


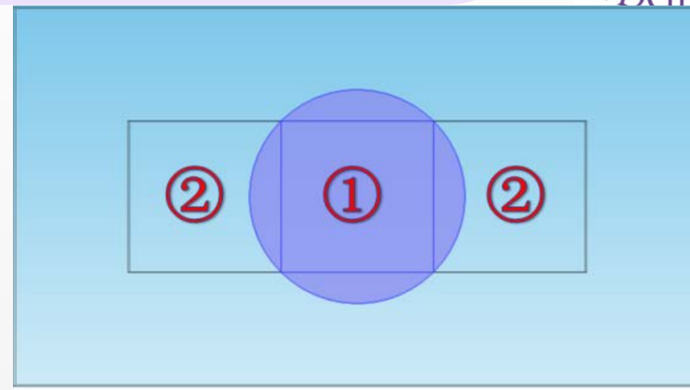


Droplet mixing can be achieved by moving two droplets toward each other. The COMSOL simulation results of droplet mixing is shown in Figure.

The mesh size is normal. Electrode size is 1mm.
The number of freedom need be solved is 251220.
Simulation time is 22ms
The time used to compute is about 4 hours.

COMSOL Simulation - Droplet Splitting





To split a microfluidic droplet, the droplet is first located in the middle of three neighboring electrodes (marked as #1). After that, the central electrode is deactivated, and both side electrodes are activated at the same time (marked as #2).

The mesh size is normal. Electrode size is 1mm.
The number of freedom need be solved is 242478.
Simulation time is 22ms.
The time used to compute is about 4 hours.

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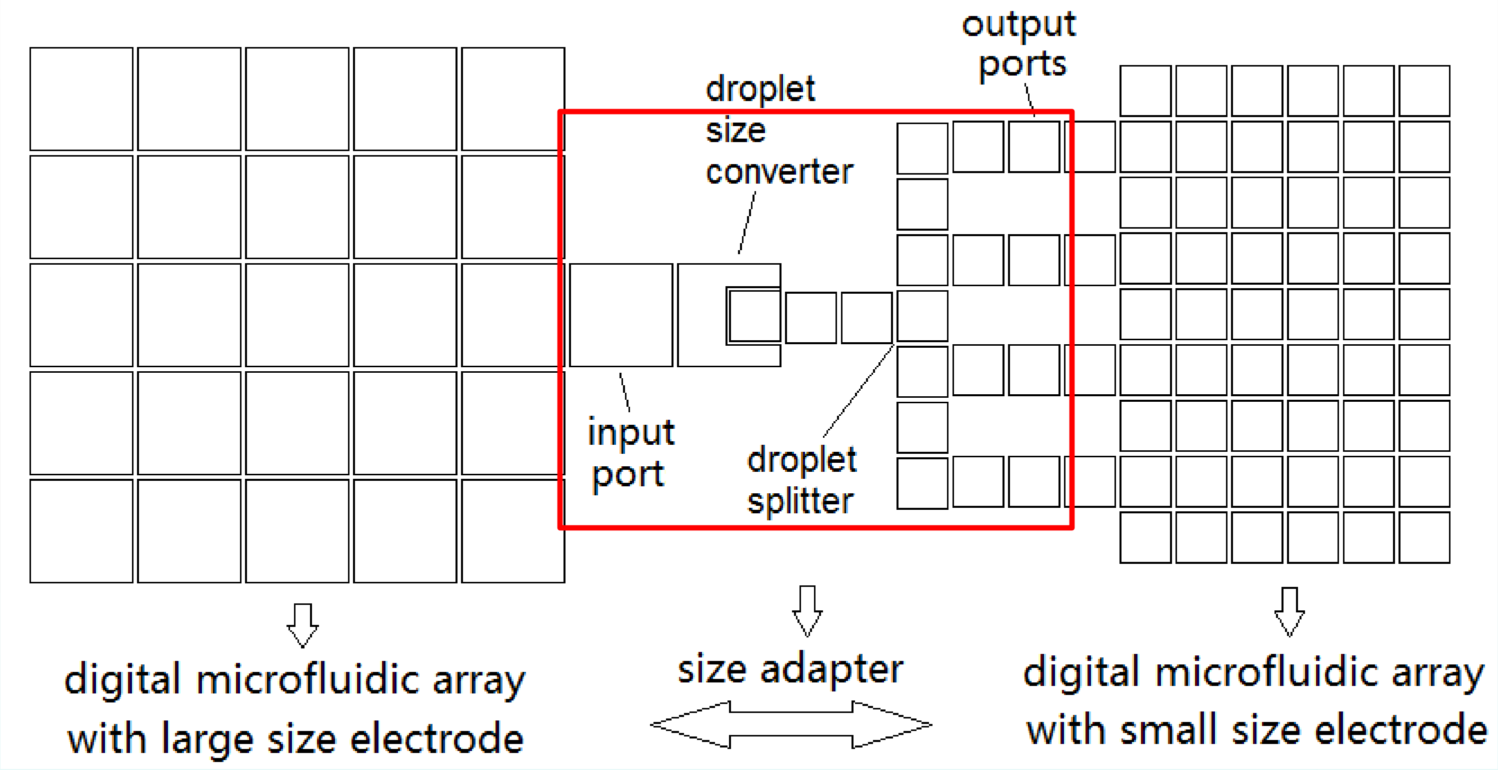
Design of microfluid droplet size adapter for interconnect of biochips



The proposed digital microfluidic droplet size adapter for interconnecting DMFB chips is shown in Figure. It includes input port, droplet size converter, T-shape droplet splitter, and several output ports. The droplet size converter consists of a large electrode with a small electrode embedded inside of it.

The purpose of the adapter is to exchange the droplet from different DMFB and

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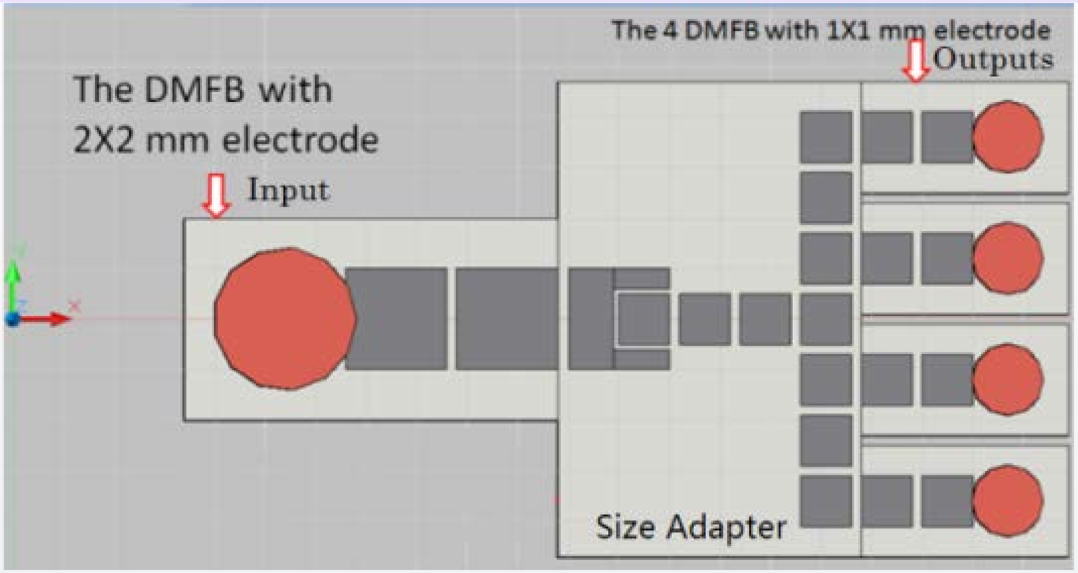
Adapter for DMFB



Based on the understanding in COMSOL simulation of droplet moving/merging/splitting, we designed and simulated the microfluidic droplet size adapter, as shown in Figure.

The proposed design is actually a 4:1 size adapter. However, such design can be adjusted to any other size ratio as well. This microfluidic size adapter can change the size of droplet pass through it, so that the droplet coming from one DMFB can continue to be processed in another DMFB with different electrode size.

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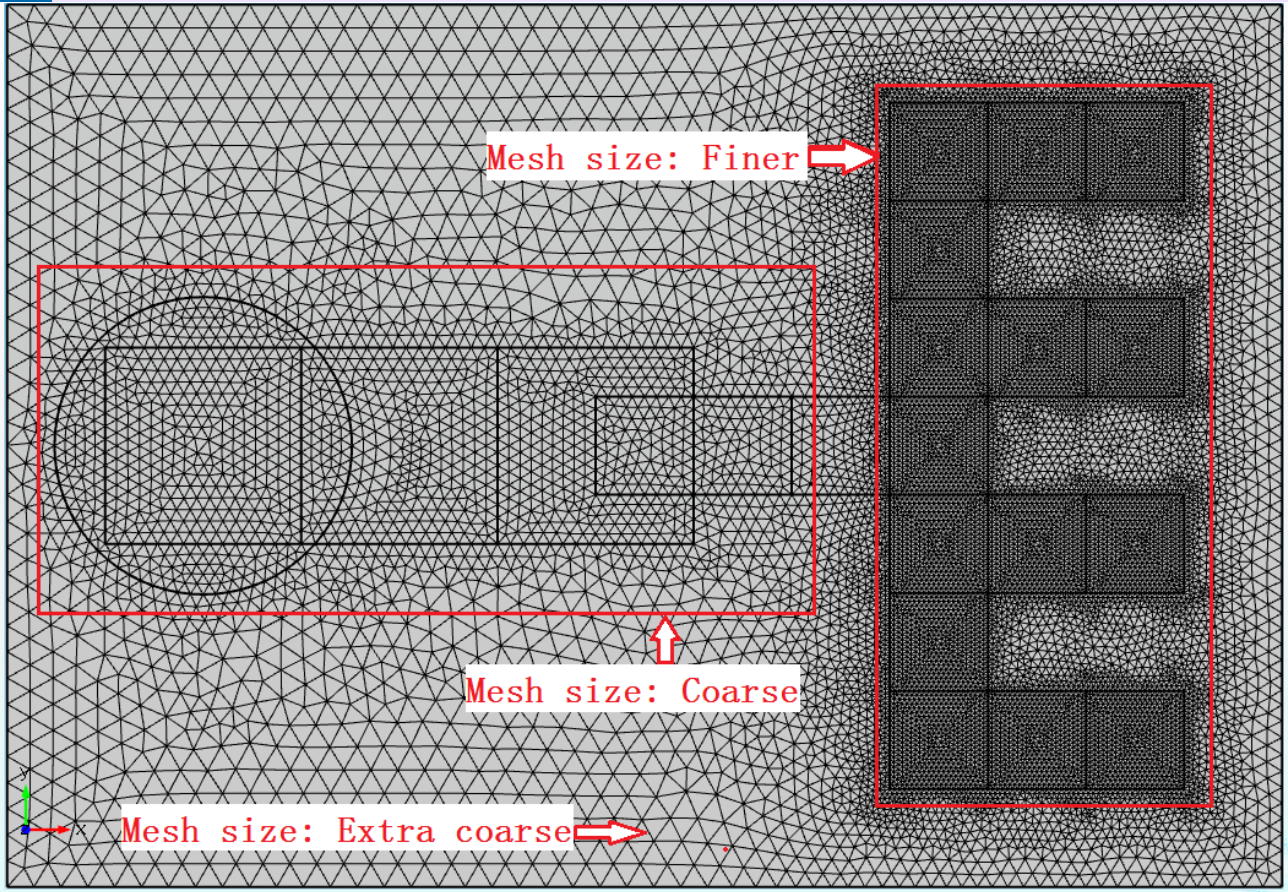
Comsol mesh of Adapter



To study this adapter and retain the result more accurate. The mesh model of adapter is shown in the figure.

The number of freedom is about 670,000. The time used to compute is about 100 hours.

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Use Functions to control the active of electrode

Variables

Geometric Entity Selection

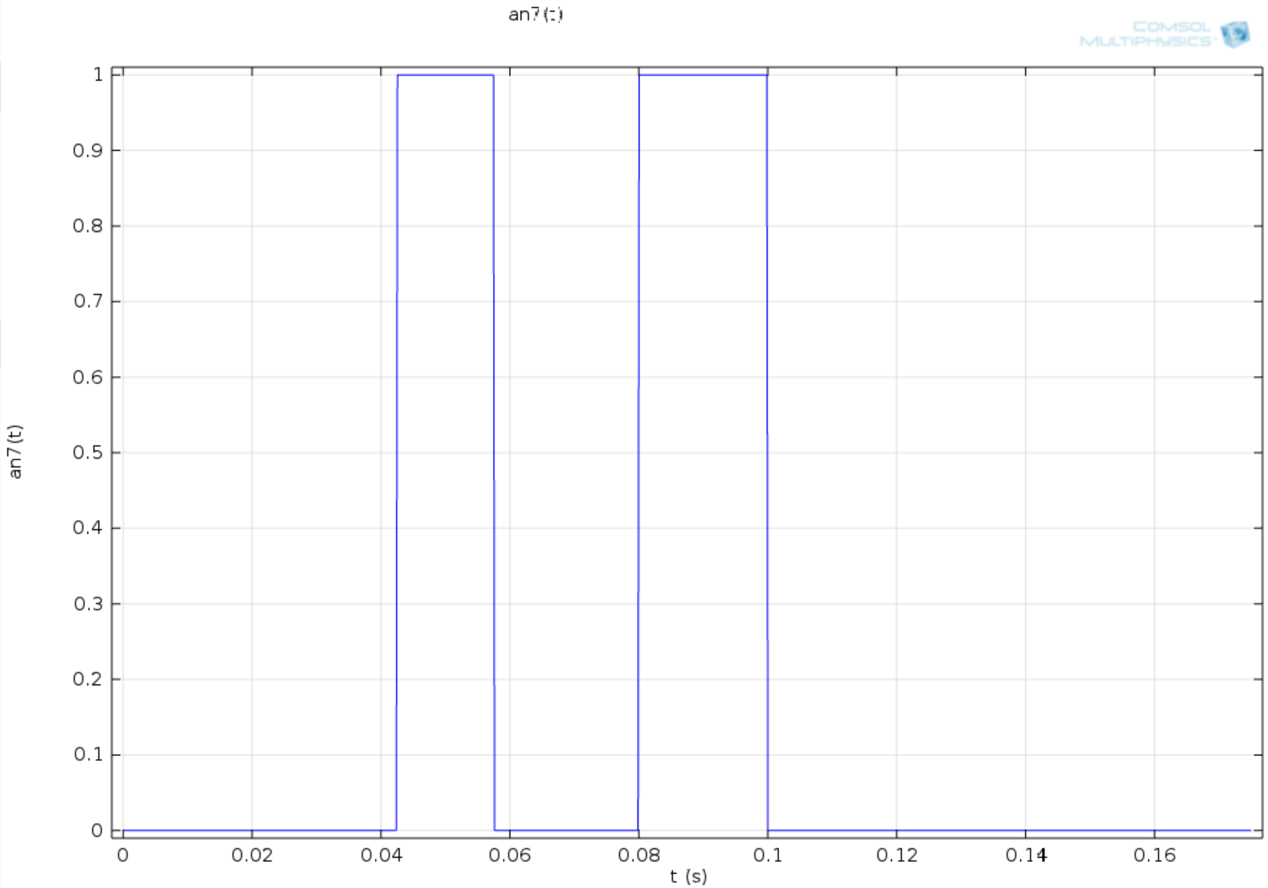
Geometric entity level: Entire model

ON

Active

Variables

Name	Expression	Unit	Descripti
theta1	theta0-an1(t)*d	rad	
theta2	theta0-an2(t)*d	rad	
theta3	theta0-an3(t)*d	rad	
theta4	theta0-an4(t)*d	rad	
theta5	theta0-an5(t)*d	rad	
theta6	theta0-an6(t)*d	rad	
theta7	theta0-an7(t)*d	rad	
theta8	theta0-an8(t)*d	rad	
theta9	theta0-an9(t)*d	rad	
theta10	theta0-an10(t)*d	rad	
theta11	theta0-an11(t)*d	rad	
theta	theta00	rad	



We can set up some independent functions to control the different electrodes which like the control wire in the actual DMFB.

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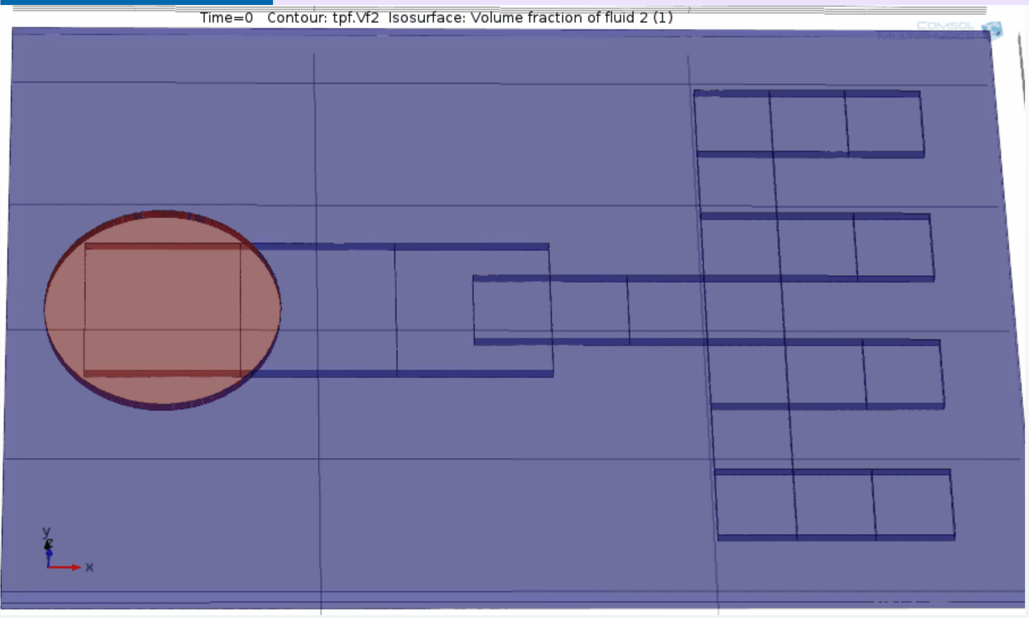
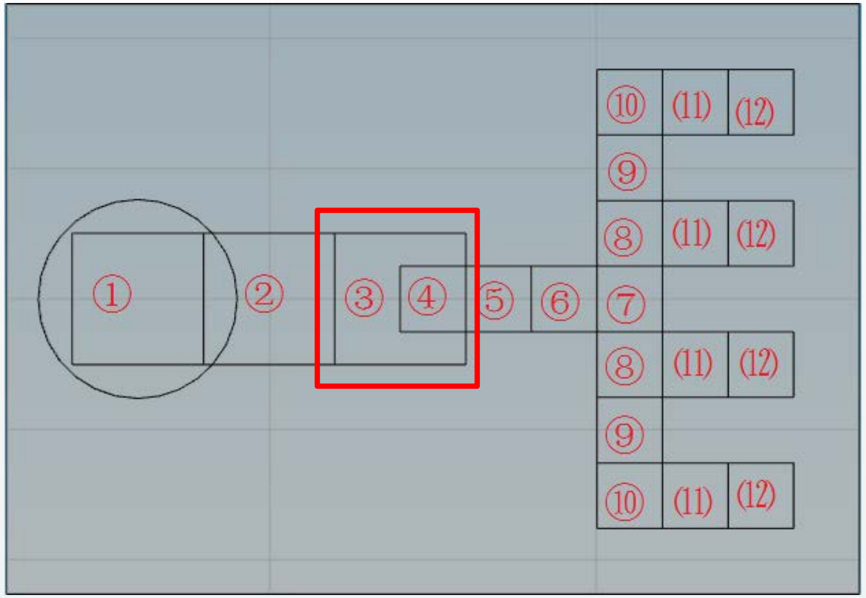
Forward size conversion of the 1:4 size adapter





The order of the applied voltage pulses are clearly listed in each electrodes as circled numbers. It requires totally 12 consecutive stages of voltage pulses to complete the size conversion process.

As a result, a large droplet coming from left size electrode will be split into four small droplets coming out from four parallel output ports.

The key to control the splitting droplet size is the time of electrode active. From the number ‘3’ to number ‘6’ electrode, the distance is 4mm, and the time is 50ms.

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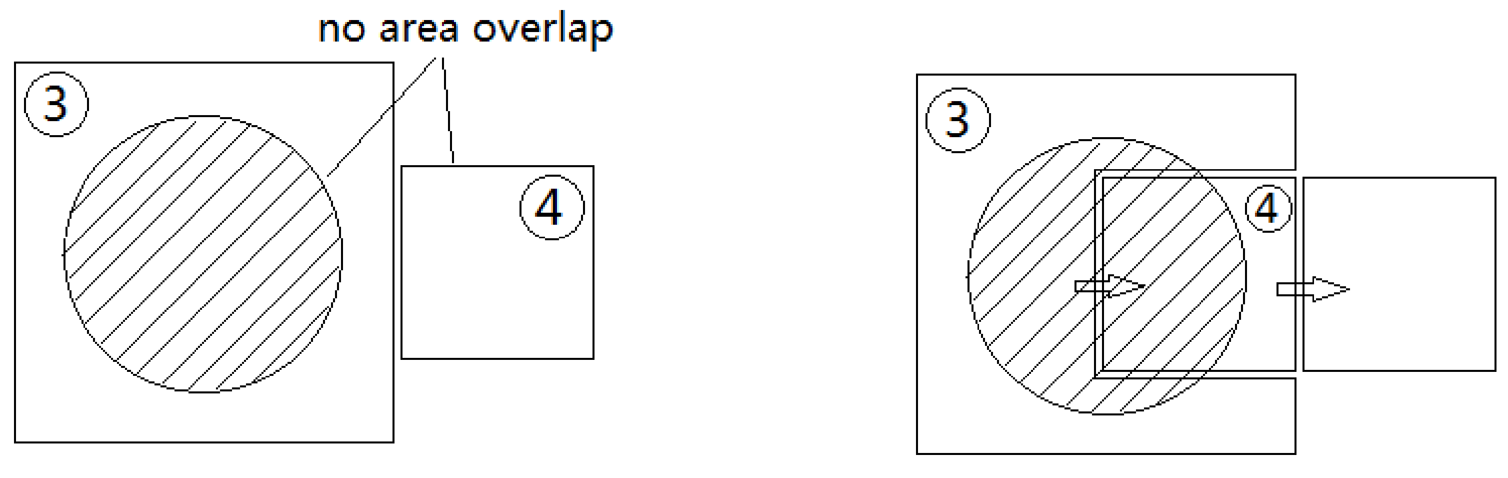
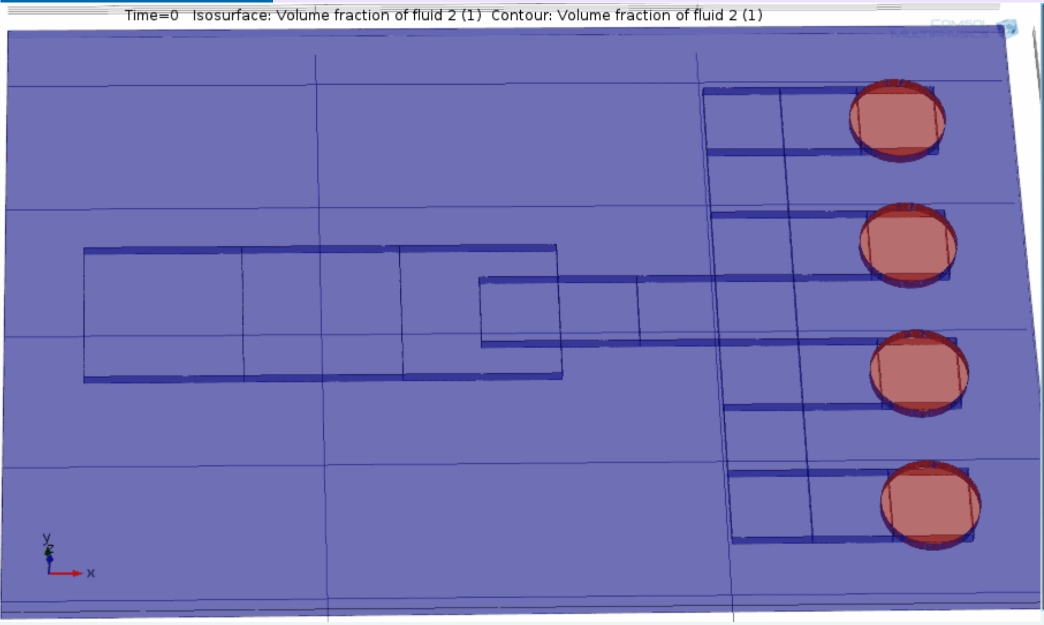
Size converter electrode

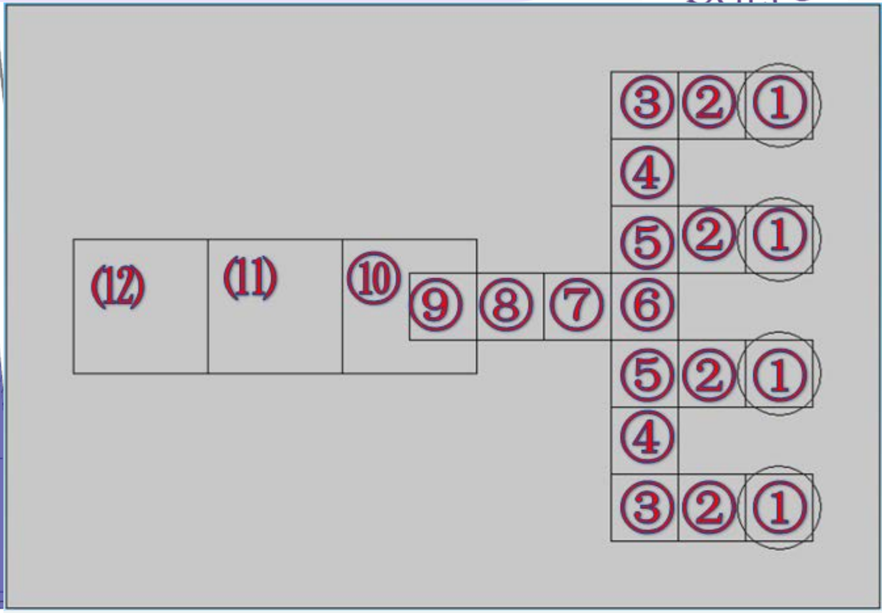


The key part of this size adapter is the size converter electrode: a large size electrode (marked with number "3" in Figure 8) with embedded small size electrode (marked with number "4") along its right side.

If the size converter does not have enclosed smaller electrode, after the first small droplet is separated out, the volume of the remaining droplet shrinks and it recesses back to the center of the electrode. As a result, it loses area overlap with its neighboring electrode, and the next electrode would not be able to drag it out. Thus the remained droplet will be trapped in the big electrode and the size conversion process cannot continue.

Reverse size conversion of the 4:1 size adapter





The proposed microfluidic size adapter is bi-directional. When the voltage pulses are applied in the reverse sequence, it can also convert the droplet size in the opposite direction.

Applying the voltage sequence in the reverse order, four small size droplets can be merged back into a larger size droplet, and output to the DMFB with larger size electrodes for further processing.

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Conclusion

COMSOL simulation is very useful and helpful to design the new DMFB. The result has verifed the correct function of the adapter and guide the design optimization.

The design and simulation of a microfluidic droplet size adapter used to connect multiple DMFB boards with different electrode sizes is reported.

The proposed droplet adapter can convert droplet into different sizes, so that the digital droplets can be passed between multiple DMFB boards with different electrode size.

This facilitates the system integration of multiple DMFBs with different electrode sizes.

That is, large droplet can be converted into small droplets, and small droplets can also be merged back into large droplet by reversing the voltage sequence.

Future work

In the future, we will use comsol to design and simulate microfluidic size adapter with other arbitrary size conversion ratio (i.e. any m:n ratio).

We plan to design a "smart" size adapter which can automatically identify the size of input/output electrodes, and convert the size of input droplet to fit that of the output droplet.

Such "universal" size adapter offers more flexibility in interconnecting DMFBs with different electrode sizes, and promote the DMFB system integration.

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Thank You!

Q&A?