The introduction and comparison of two techniques of fluid transport at the microscale

Kaiyue Jiang
Yantai development zone senior high school
jwwthu@163.com, 1901110384@pku.edu.cn

Abstract. With the development of human society, people's level of science and technology is also improving. In the process of continuous exploration, people often find some new unknown areas. Although we are very unfamiliar with these uncharted areas, they can have a significant impact on our lives, such as the field of microfluidics. It can perform small tasks at the micro and nano level, reducing our resource consumption, reducing some of our risks, but increasing our safety and new application tools. The exploration and development of the field of microscopic fluids can bring great help to our lives, especially in medicine, and significantly increase our surgical success rate. This article is summarized by analyzing and comparing the academic research of many experts. In this era, the role of the microfluid field is still significant.

1. Introduction
What is microscopic fluid? In nature, you can find a lot of microscopic fluid phenomena. For example, the tubes in a plant stem are very thin capillaries in the body. The force against gravity makes the water up through the tiny tube that people call capillary action [1]. Another example, the self-cleaeness of lotus leaf, feathers of some birds and some insects wings (for instance, dragonfly wings, butterfly wings) is caused by the formation of the gas film which exists at the solid-liquid interface of the particular microstructure on the surface of lotus leaf, feathers, and wings. The particular microstructure is at the micro and nanometer scale. Even dirt water is sprinkled to the surface; the lotus leaf, feathers, and some wings would keep clean and dry, not get wetting. The gas film shows the super-hydrophobicity with the inability of water droplets to infiltrate [2]. One example more, human tears on the surface of the cornea formed a six micron-7 micron thick smooth liquid film, it can not only keep the surface of eye wet, smooth eyelid contact with the eye, so that the eye is flexible but also can make the corneal surface more smooth and delicate, thereby reduce astigmatism, improve its optical properties. The unique micron and nanostructure of natural organisms endow them with surface permeability characteristics. Wettability is the crucial characteristic of the material surface [3]. It is much helpful for both industrial applications and basic science research to study the controllable surface wettability.

And micro-scale transport adopted by a human in the world has a history of many years. Biologists have found the reasons why the shark swims faster than most of the other fishes in the sea. One of the reasons is that the shark-skin has lots of V-shaped folds on the surface [4]. The V-shaped folds of shark skin with particular microstructure can significantly make the friction of water flow lower, make the water around the body flow more efficiently and make the shark swim faster. After such research of shark skin and a large number of experiments, shark-skin swimsuits were created for professional athletes, designed to imitate shark skin microstructure, to guide the surrounding water, decrease fluid resistance and increase people swimming speed. In the mechanical field, in the factory, the maintenance people lubricate the machine by using of some lubricating oil lube. Two metal surfaces in relative motion
are entirely separated by a lubricating film to reduce friction to get less wear and longer lifetime of the moving parts [5]. Microfluidics means the technology of operating, measuring, managing, and controlling complex fluids at a micro-scale. It is a new subject that is tightly linked connection to nanotechnology, microelectronics, micromechanics, and bioengineering. This technology is closely related to our life and is especially crucial in the medical field. Many other technologies have been developed for this purpose. Because of its tiny size, it can do things that conventional machines cannot. Nowadays, how to control the fluid composition of arbitrary shape has become a big focus of the field.

In view of the characteristics of this field, we have found many methods to control the microscopic fluid transport so far, such as surface patterning liquid flow and lithographically induced self-construction of polymer microstructures for resistless patterning [6]. Through the application and analysis of these techniques, we have a deeper understanding of the micro-hydrodynamics. I am very interested in these two approaches in microscale fluid mechanics and would like to analyze them, that is, to understand surface patterning liquid flow and LISC (Lithographically induced self-construction), and then to compare them. Look at the help and experience that previous generations have given us to better understanding the field of micro-hydrodynamics.

In this paper, we study how to control the flow of liquid at the microscale in the field of microfluid and how to control the speed and the shape of the liquid flow. The research method of this paper is to understand the technology and method principle that the predecessors have mastered in the field of microcosmic fluid by consulting the paper materials. I will summarize and compare the technology of the predecessors and make arrangements. To understand the unremitting efforts of our forefathers in the field of microcosmic fluid, and to inherit their spirit and experience. The principle of this micro-scale device is that the uneven local temperature of the fluid leads to the imbalance of intermolecular forces on the surface of the fluid, resulting in the surface tension gradient, and the resultant surface tension drives the flow of the liquid [7]. This method has been around the world for more than one hundred years.

Patterning liquid film through surface tension gradient due to temperature gradient:

The first control method of liquid flow is based on the surface tension gradient [8]. With the significant improvement and development of microfluidic devices, to solve the problems and challenges of fluid transport, people began to use mechanical pumps to generate the gradient pressure needed to drive fluid transport [9]. Surface tension gradients can be produced in a variety of ways, through electrical, chemical, or light, thermal, and other energies. For example, we can change the surface tension of a liquid-solid interface by using the applied potential energy of the conductive fluid. But this method can only be applied to a conductive fluid, which is the limitation of this method. Recent research has suggested utilizing temperature gradients to control microscopic flow on a defined surface, which is patterned in advance. Experts demonstrated a simple. A thin and wetting film is placed on a solid base plate. Apply a temperature gradient to the solid base plate. It will happen that the thin and wetting film will flow from the high-temperature zone to the low-temperature zone. This phenomenon is caused by the development of thermo-capillary shear stress at the air-liquid interface [10]. If the wetting film is thin enough, the convective resistance would be far higher than the thermal conductive resistance. So the thermal gradient at the solid surface is directly delivered to the air-liquid interface. Thermal stress provides flux upward. Gravitation drainage provides downward flux. The film grows up since the flux upward is more significant than downward flux. Thermo-capillary shear stress can drive the film to climb a vertical substrate [11]. As long as the ratio of surface-to-volume at the microscale is large, the liquid can get a big movement even by slight thermal gradients. Microfluid can be led to flow along the defined channels by the combination of the stress at the air-liquid surface and the force at the liquid-solid interface.

The leading cause of microscopic liquid flow is the changing of liquid surface tension. Explain the surface tension, which is the force exerted by a liquid such as water to make the surface as small as possible [12]. The water droplets condensed on the leaves in the morning, the water droplets slowly hanging from the faucet, are all formed under the action of surface tension. Besides, the water strider stands on the surface because of surface tension. The surface tension is due to the change in temperature
[10]. As a general rule, the control method of liquid flow based on surface tension gradient is to vary the surface tension by changing the temperature and then control the liquid flow because of the surface tension. The temperature gradient created by the thermal imbalance causes the surface tension gradient to be uneven, which is ultimately what causes the fluid to flow. In addition, the surface tension determines the flow direction and speed of the liquid.

But this method still has some flaws. For example, the fluid flow is not stable, not controllable; the path and shape of the liquid are not controllable. Unable to control liquid completion of the specified pattern, unable to pass through the specified path. Of course, where there is a problem, there is a solution. That's surface patterning, making bumps on the material that controls the flow of the liquid, making the pattern that you want to make where you want to make the pattern, and the liquid will naturally make the pattern that you want to make. Or by using microchannels to restrict the flow direction of the liquid and form a specified path.

The applications of this method are still extensive. Microfluidic transport control devices can operate small volumes of liquid at the nanometer and micron scales for basic research on individual cells and molecules, as well as clinical trials [13]. For example, it can enter a person's blood to check whether all the functions of the human body are reasonable and whether there is a disease. Because of its small size, it will save a lot of resources and be more convenient. Besides, it can be powered by solar energy instead of electricity. So it will be available for various situations, such as the wild area without electric power.

2. Patterning polymer by LISC

The second method is through the melting and condensation of the polymer, the attraction of the polymer, to form a pattern [14]. Because the current technology cannot freely control the path of liquid flow and the pattern formed, people can process and treat the material attached to the liquid first, so that it can control the flow of micro liquid more quickly, so people think of this method. In terms of controlling liquids, this method dramatically reduces the control difficulties. One of the features of this method, called lithographically induced self-construction (LISC), can produce thermoplastic polymers faster, reducing the flow of operations.

Because most of the materials of the experimental devices will be severely damaged by some commonly used anti-solvent, direct ultraviolet radiation or chemical developer and etching, people must carry out some processing to protect these devices. These materials are protected by the use of processes such as photoresist, etching, development, and exposure. However, the LISC method can directly form thermoplastic polymers without using these methods, which significantly reduces the fabrication steps and costs, but increases the yield.

Let's introduce one of the devices involved in this approach. First, we need to apply a liquid film to the solid surface on which the liquid flows. In LISC, to cast a flat polymer on a substrate, put a mask with the protruded pattern above the flat polymer, make sure to keep a specific clearance between the mask and the polymer. Through a stage to elevate the polymer temperature above the glass transition temperature from room temperature, then let the temperature drop back to ambient temperature, the polymer is drawn to the mask protrusions, build the polymer mesas by itself. The mesas have the same lateral dimension as the protruded pattern on the mask, a vertical dimension equal to the clearance between the base plate and the mask, and a sidewall with a quite steep slope. Although LISC is a perfect method for resistless patterning, its working mechanism is not precise yet. It is not found that which kind of force makes the polymer up resist the gravity and surface tension. The temperature gradient could play a vital role in driving the polymer up. And the electrostatic force also could play a crucial part in the polymer growing up [10]. Maybe both of them work for this phenomenon happening. The principle that is not fixed. The research will continue to look for the truth. In this way, the microstructure of the polymer can be formed without the use of an inhibitor, an etching agent, a developer, or an exposure agent. The practical application also shows that this method can be used in the fabrication of polymer electronic devices and optical instruments. It is easier to prepare and less resource lost.
3. Comparison
In contrast, the two approaches are different. First, the two methods have different forms of motion. The liquid in one method flows primarily from the top down like a river, and the second method is used to flow from the bottom up when gravity is needed to be overcome. Secondly, the pattern complexity of the two methods is different. The patterns of the first method are formed mainly by temperature gradients. It isn't easy to form relatively intricate patterns, and the surfaces they form are connected. But the second way is you can make the pattern more complex, and you can make the pattern independent, which means you can make a pattern disconnected. The reason for this pattern is that it is made by means of a template, and the texture of the template determines what the pattern looks like [14]. But the purpose of both methods is to form patterns. Finally, the first method is arguably safer, and the energy used to drive the liquid flow is solar, not electrical, which makes it easier and safer to use [8]. Even the practice of clinical trials would be safe and not life-threatening. The second method is processed in the manufacturing process, streamlining the production process, reducing the consumption of resources, increasing the okay direct rate of finished products. One is safer to use, and the other is easier and cheaper to make. One is special for microscale fluid transport; the other is special for the manufacturing of the polymer electronic devices. What these two methods have in common is that they both rely on temperature gradients, and the goal is to achieve patterning, printing, micro-fluidization, and biochemical analysis.

4. Conclusion
In general, both methods give us a deeper understanding of the field of microscopic fluids. If we can combine the advantages of the two methods with each other, integrate the two methods, and use them rationally, we may have unexpected results. It may give us a special significance in the field of microfluids.

Today, the speed of technological development and iteration is faster and faster. And the research and application of microfluidics are also increasing. The deep integration of microfluidics technology with intelligence, digitization, and electronic control technology is bound to change our life and our future. Some specialists are already working on a material whose texture forces cooling water to flow upward to cool computer hardware instead of fans, which tend to collect dust and clog vents that can disable cooling. Super-capillary could provide a better way to cool computer hardware and completely clear the big hurdle for a new generation of high-energy microprocessors [15].

In the automotive industry, electric vehicles have become the new mainstream of development. The battery is one of the core components of an electric vehicle. The cooling performance of the power battery directly affects not only the efficiency of the battery but also affects the life and safety of the battery. Better cooling performance to a battery, more efficiency, and longer life and more safety the battery will get. Liquid cooling is one of several application methods of battery thermal management system. If we apply microfluidics technology to the battery cooling system, I believe that we will get unexpectedly good results. Microfluidics technology will promote the development of the electric vehicle, thus contributing to the promotion of energy-saving and emission reduction to improve the atmosphere quality.

At present, there are still many unknown microcosmic worlds that we need to explore and study. Microfluidics technology is such an excellent tool to know the micro-world and solve the related problems. Although microfluidic has significant advantages, it has not been widely used all over the world. More scholars and scientists are needed to continuously discover new technologies in the field of microfluidics through more scientific experiments, to introduce the laboratory technologies into industry and solve practical problems in human life.

It is ardently hoped that more microfluidics technology will be applied to the development and production of electronic chips in electronic technologies, such as mobile phone and internet connection devices integrated circuit boards, to realize smaller size, higher calculation capability, higher speed and better performance. In this way, the 5G network application will significantly help and lead humankind to a new era [16]. I am more inclined to combine the microfluidic technology to carry out combinatorial innovation, such as the development and application of medical chips, related diagnostic instruments,
micro-robot, and other microdevices, which may be implanted into the human body for biomedical analysis, to explore the mystery of life and solve human health problems. At the same time, microfluidic technology may realize single-molecule analysis, which is beneficial to the basic research of cell and molecular biology. The development of new microfluidic tools will provide a revolutionary advance in areas such as in-vitro diagnostics in the future. It is believed that microfluidics technology has played an important role in vaccine development to prevent and control the new coronavirus that broke out in 2020.

References

[1] Hocking lm, & rivers ad. (2006). The spreading of a drop by capillary action. Journal of fluid mechanics, 121(1), 425-442.
[2] Latthe, S., Terashima, C., Nakata, K., & Fujishima, A. (2014). Superhydrophobic surfaces developed by mimicking hierarchical surface morphology of lotus leaf. Molecules, 19(4), 4256-4283.
[3] Li, X. B., & Liu, Y. (2008). Control and preparation to wettability of material surfaces. Journal of Materials Engineering (4), 74-80.
[4] Oeffner, J., & Lauder, G. V. (2012). The hydrodynamic function of shark skin and two biomimetic applications. Journal of Experimental Biology, 215(5), 785-95.
[5] Hidenobu Mikami, Koya Ohira, Yoshinobu Akamatsu, Masaki Egami, & Takashi Yasunishi. (2002). Lubricating oil film on bearings for friction resistance. US.
[6] Giacomello, A., Chinappi, M., Meloni, S., & Casciola, C. M. (2013). Surface patterning for wetting and liquid flow control. European Cells and Materials.
[7] Prokudina, & L., A. (2014). Influence of surface tension inhomogeneity on the wave flow of a liquid film. Journal of Engineering Physics & Thermophysics, 87(1), 165-173.
[8] Kataoka, Dawn E, & Troian, Sandra M. (1999). Patterning liquid flow on the microscopic scale. Nature, 402(6763), págs. 794-797.
[9] Zeng, S., Chen, C. H., Jr, J. C. M., & Santiago, J. G. (2000). Fabrication and characterization of electrokinetic micro pumps. Conference on Thermal & Thermomechanical Phenomena in Electronic Systems. IEEE.
[10] Amador, G. J., Ren, Z., Tabak, A. F., Alapan, Y., Yasa, O., & Sitti, M. (2019). Temperature gradients drive bulk flow within microchannel lined by fluid – fluid interfaces. Small
[11] Dietzel, M., & Troian, S. M. (2009). Formation of nanopillar arrays in ultrathin viscous films: the critical role of thermocapillary stresses. Physical Review Letters, 103(7), 074501.
[12] T. Arbatan, W. Shen, Tina Arbatan, & Wei Shen. (2011). Surface tension of liquid marbles, an experimental approach.
[13] P. Marmottant, & S. Hilgenfeldt. (2004). A bubble-driven microfluidic transport element for bioengineering. Proceedings of the National Academy of Sciences.
[14] Chou, S. Y., Zhuang, L., & Guo, L. (1999). Lithographically induced self-construction of polymer microstructures for resistless patterning. Applied Physics Letters, 75(7), 1004-1006.
[15] Sultan, H., Chauhan, A., & Sarangi, S. R. (2019). A survey of chip-level thermal simulators. ACM Computing Surveys, 52(2), 1-35
[16] CHRIS, & DeMARTINO. (2016). News: makers of chips, cars, and radio equipment - join forces to connect cars with 5g. Microwaves & RF.