INTRODUCTION

Surface tension, a line force, is a unique type of force, which scales directly to length. When the dimension of interest shrinks down to sub-millimeter range, the size range typical for MEMS devices, surface-tension force becomes dominant over most other forces, such as those based on pressure (surface force) or mass (body force), e.g., see [1,2]. This dominance of surface tension has most typically been the source for a serious hindrance against successful fabrication and operation of micro devices, calling for elaborate analyses and fabrication techniques in MEMS [3-6]. A completely different approach would be to design micro devices, which use surface tension. Indeed there have been a few attempts in MEMS to utilize surface tension, some passively using surface tension to block unwanted movements and some actively controlling it to induce movements.

Many examples can be found that use surface tension to stabilize small objects. A few examples of utilization of surface tension are the bubble check valve that increases ejection frequency of a droplet from the inkjet head by several folds and the passive valve to stop liquid flow using an abrupt geometry change in the channel.

ACTIVE USE OF SURFACE TENSION

More ambitious goal is the active usage of surface tension, such as driving liquids directly by surface tension. Surface tension induced motion is possible by creating surface tension difference in fluid-fluid or fluid-solid interface. Unfortunately, however, there has been little knowledge on how to make a machine run by this unfamiliar force. There are several ways to control the surface tension, such as chemical (i.e., the use of surfactant), thermal (e.g., Marangoni force), and electrical methods (i.e., electocapillary, [10,11]).

CURRENT METHODS

Out of the listed methods for controlling surface tension use of electocapillary has been investigated the most, as it is believed to offer following advantages above other methods:
1) Energy efficient (vs thermal).
2) Potentially simple and long lasting operation (vs chemical).

We state the principle involved in these devices in brief and state some of serious disadvantages that they have.

PRINCIPLE OF MOTION BY ELECTRICALLY VARYING SURFACE TENSION

Electrical potential across the interface between two immiscible media can change the surface tension at the interface. If the amount of variation is not uniform in space, a flow can be induced by the surface-tension difference.

Continuous Electro wetting:

A flow motion of liquid metal can be induced by a gradient along the surface of the liquid metal as a result of the electocapillary effect. This particular phenomenon, called CEW, is an electrical
analog of the flow motion driven by a thermally induced surface tension gradient, i.e., the well-known Marangoni effect. Figure 1 contains schematics that illustrate this concept.

The surface tension on the right hand side is, therefore, less than that on the left hand side. The gradient in surface tension induces motion of the liquid metal to the right hand side of the figure. This motion can be interpreted as a tendency to minimize surface energy by wetting more to the area where surface tension is lower, i.e., the right hand side of the figure.

The main disadvantage for such type of an actuation mechanism is that electric actuation affects the charged molecules in the solution making them not suitable for applications in on-chip biological analysis system.

This calls for designing a new actuation mechanism that would diminish all these disadvantages while keeping all the advantages. In this project we have investigated such a mechanism that is being explored for possible practical usage in near future.

**SCOPE OF THIS PROJECT**

In this project, we attempt to design a micro-device to manipulate the position a liquid drop in a microchannel. This control is achieved by an activation mechanism that can very accurately move the drop by specific distances if required together with a mechanism to locate the drop dynamically. A feedback loop can be setup to then couple the actuations and the location measurement to precisely position the drop. Drops of diameters of a fraction of millimeters are considered.

The movement of the drop is carried out by changing the surface roughness properties and thus changing the surface energy equations. It is observed that certain values of roughness lead to an increase in the apparent hydrophobicity and thus a change in the apparent contact angle. This property is used to bring about locomotion.
of the drop in a microchannel by controlling the surface roughness features at various points. The feedback control to bring about an accurate manipulation of the drop position requires the knowledge of the position of the drop. A simple, capacitance based, mechanism is suggested for this purpose.

This project will consider some of the design and manufacturing issues of this approach. A tentative design of this micro mechanism and one possible way to fabricate it will be presented.

**DESIGN CONCEPTS**

As noted earlier, the actuation mechanism will consist of a technique to selectively change the surface roughness at various points on the interface. The surface wettability can be dynamically switched between medium and super-hydrophobic by a membrane pull-in actuation.

![Figure 2. Photograph of water droplets (a) super hydrophobic (b) medium hydrophobic.](image)

The mechanism consists of a membrane resting over a set of pillars, with aluminum deposition on the bottom of it and a Teflon coating on top. The membrane is made up of a polydimethylsiloxane(PDMS), owing to good elastic properties of the material and our ability to fabricate thin membranes (~2micrometer) of the material. Below the pillars is a set of aluminum deposition that act as a set of parallel plates to form a capacitor with the membrane. Applying a potential difference between the bottom plates and the membrane results in an electrostatic force on the membrane and causes it to deflect, revealing the pillars underneath and thus changing the roughness. The dimensions used for the design are shown in figure******. This technique is borrowed from the research conducted by Bo He under Dr. Lee and experimental research on it is still under progress. The computational work is being carried out by Yong Chen under Prof. Patankar’s direction.

The motion of the droplet can be brought about by changing the roughness on one end of the droplet and keeping the surface at the other end flat. (figure 3).

![Figure 3. Transport Mechanism by dynamic surface roughness control.](image)

One explanation for the cause of motion can be given as follows: Altering the roughness at one end of the drop would cause a change in the contact angle there and hence the radius of curvature of that surface. Hence the pressure jump across the drop will change and cause a pressure gradient inside the drop that will cause the flow. Another way to see that the drop will indeed move is to notice that the total surface energy can be reduced by reducing the area of the liquid interface with the rough surface.

The location of the drop for feedback purposes can be found by introducing an array of capacitance plates on the wall. The capacitance plates are arranged staggered with respect to the variable roughness cells so as to maximize the effectiveness of the mechanism. The capacitance plates are coated with an insulator so as to allow the
use of an electrolyte solution in the droplet. The mechanism works on the principle that the dielectric constant of the liquid differs considerably from the dielectric constant for air. Thus the capacitance between any of the pairs will depend on the amount of area overlapped by the liquid drop as:

\[ C = \frac{(C_1A_1 + C_aA_a)}{(A_1 + A_a)} \]  

(2)

where \( C_1 \) = capacitance with liquid,
\( C_a \) = capacitance with air,
\( A_1 \) = Area overlapped by liquid,
\( A_a \) = Area overlapped by air.

There is a very large difference in the permittivity of air and liquids. Dielectric constant for water is about 80 and very close to 1 for air. Polar liquid have very large dielectric constant and this technique will be very sensitive for polar liquids. Thus from the knowledge of the capacitance between the two plates, we can very accurately pinpoint the position of the liquid-air interface. The relation between the position of the interface and the capacitance is linear, as can be seen from equation (2). This technique cannot be used when the composition of the drop is to be kept uniform, as then, the electrolytic separation of ions cannot be prevented.

The thickness of the teflon coating is calculated considering the fact that dielectric failure voltage for teflon is about 20 V/um. The capacitance between the inclined plates with air inside is about 10 pF, significant enough to be measured by MEMS devices. The capacitance would increase 80 times if a water drop is inserted in the plates.

FABRICATION PROCESSES

1. Fabrication of bottom wafer. (Wafer 1)

Figure 4 shows the fabrication process of the membrane pull in mechanism. Due to the different functions of wafer, the top wafer and bottom wafer have different fabrication process.

Substrate for the bottom wafer is glass. First, the substrate is photo resist patterned using Mask 1. Then, the grooves are etched out using Reactive Ion Etching (RIE). (See the section view Figure 4-2.) It will produce many small pillars and some blocking area to separate two adjacent areas of aluminum.

Aluminum is used as electrode material and deposited at the bottom of the grooves by Electron Beam Evaporation (E-BEAM). (See Figure 4-3) Next, photoresist is deposited into the grooves; it will serve as a substrate when we deposit the membrane on top of it in future.(See Figure 4-4) Then the substrate is polished down to remove the aluminum on top of the pillar.(See Figure 4-5) Now, by E-BEAM we can deposit a thin sandwich membrane which has aluminum on the bottom, followed by PDMS, and another thin film of Teflon is coated on the top. To make the residual stress small in the membrane, we can deposit aluminum at a low temperature, while the PDMS and Teflon are spin coated. (See Figure 4-6) Finally the side of the wafer is scratched (See Figure 4-8) and the photoresist is etched away by acetone to release the membrane. (See Figure 4-8)
2. Fabrication of top wafer. (Wafer 2)

Figure 5 shows the fabrication process of the wafer 2. Wafer 2 will be bonded to bottom wafer, and serve as a feedback system. It can accurately locate the position of drop dynamically.

Substrate for the bottom wafer is silicon. First the substrate is photoresist patterned and then etched by KOH. (See Figure 5-1) Then we deposit a layer of photoresist on top of the wafer (See Figure 5-2) and pattern it using Mask 2. (See Figure 5-3) Now we have open several windows to deposit aluminum, which will form a series
of capacitance to detect the position of drop. (See Figure 5-4)

Deposit aluminum on the window to form capacitance and electrode by E-Beam, (See Figure 5-5) and then remove the residue photoresist in the channel. (See Figure 5-6, 5-7)

Again, photoresist is deposited in the channel (See Figure 5-8) and patterned using Mask 3. (See Figure 5-9) It will open 2 long windows. (See Figure 5-10) Then a thin film of Teflon can be deposited to the two windows and it can function as a film of insulator between aluminum and drop. (See Figure 5-11)

Use acid mixture to remove the residue photoresist (See Figure 5-12) and use KOH solution to etch the bottom part of wafer 2. (See Figure 5-13)
Figure 5-6. Photoresist removal.

Figure 5-7. Top view after aluminum deposition.

Figure 5-8. Photoresist deposition.

Figure 5-9. Mask 3.

Figure 5-10. Photoresist patterning.

Figure 5-11. Teflon deposition.

Figure 5-12. Photoresist removal.

Figure 5-13. Substrate removal.
3. Wafer 1 and 2 are then bonded together to get the final system as can be seen in Figure 6.

CONCLUSION

In this project, we present a surface roughness driven flow mechanism to drive droplets of millimeter size. A mechanism is also proposed to incorporate a feedback by locating the drop. If this actuation mechanism is fully developed, we can achieve precise micro fluidic motion control and can also be used on the on-chip micro fluid operations.

Figure 6. The final cross section of microchannel.
REFERENCES


