INTRA-DROPLET MAGNETIC BEAD MANIPULATION INTEGRATED ON A DIGITAL MICROFLUIDIC CHIP

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ABSTRACT

This paper demonstrates a device which is capable of performing both magnetic molecular segregation within a droplet as well as droplet actuation. Segregation of magnetic beads is performed within a droplet while the droplet is dispensed and transported using electrowetting on dielectric (EWD). The reason it is important to investigate such devices is that the capability could be used in current applications, including immunoassays, cell labeling and DNA isolation.

KEYWORDS: EWD, Magnetic bead, Segregation

INTRODUCTION

The device introduced in this paper is an integrated design, which allows both magnetic bead manipulation and droplet actuation. Previous work in separating particles within a droplet in a EWD system demonstrated binary separation using charged latex particles and weak-field electrophoresis. [1, 2] The previous use of magnetic separation in microfluidic devices was directed towards continuous flow systems.[3] The magnetic bead capability integrated with an EWD device provides highly efficient in-droplet molecular separation, which has heretofore not been available. In addition, previous demonstrations of magnetic-bead segregation have relied on relatively cumbersome off-chip supporting systems, which are required to generate the magnetic field, manage heat dissipation and supply high current.[4] The presence of off-chip systems precludes device integration. We demonstrate that current-controlled magnetic bead manipulation is suitable for integration with EWD devices due to its minimal heat generation, single-level metal structure, and easy actuation of beaded droplets on and off electrodes with integrated current-carrying wires.

THEORY

The basic design is based on the Biot-Savart law[4]. The design uses a magnetic field gradient to apply a magnetic force on the beads contained in a droplet localized over the wires, hence moving the magnetic beads to certain locations within the droplet by changing the location of the peak of magnetic field. As an illustration, a total of four wires and magnetic beads are shown in Figure 1, each having a width of 10µm. A liquid covers the area. In the simulation, 100mA of current is passed through each wire in sequence, illustrated by the red color in the figures. The magnetic beads are the brown dots in the first row of the figure. The second row of the figure represents the magnetic field, and the peak of the magnetic field is aligned closely with the current carrying wires. The magnetic beads are initially uniformly distributed throughout the liquid region. By applying current in a wire, the beads in close vicinity are attracted to the activated wire. When current is sequentially switched through the wires from left to right, the magnetic beads are collected to the location of the right-most wire as illustrated in the figure.

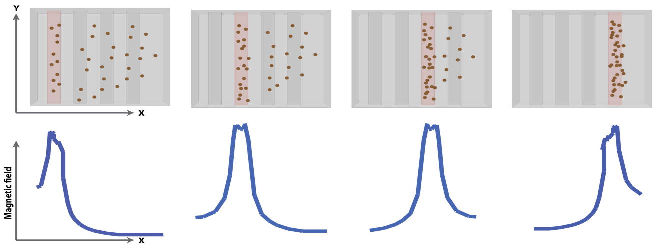

Figure 1. Magnetic field vs. current structure

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EXPERIMENTAL

The EWD magnetic separation device is designed to use only one conductive layer to accommodate both the EWD function and the magnetic-bead manipulation function. The layer structure of the device is shown in Figure 2. The device starts with a layer of thermally grown silicon dioxide on a silicon wafer, then the Cr/Cu/Cr stack is formed on the oxide. The dielectric layer needed for EWD is applied over the metal. The dielectric layer is 1.5µm thick Parylene C. A film of CYTOP is applied as the hydrophobic layer. The top plate consists of an acrylic layer, ITO layer and CYTOP layer. The ITO provides the conductive layer and CYTOP is the hydrophobic layer. The top and bottom plate is separated by a gasket layer 120µm thick.

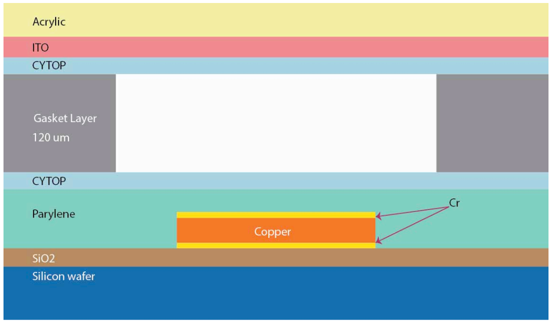

Figure 2: Layer structure of device

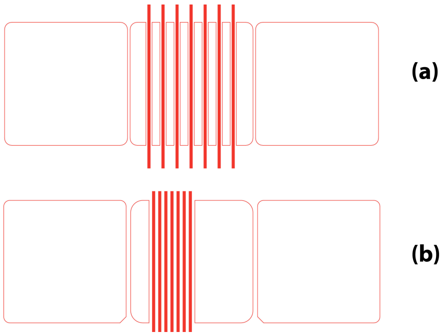

Figure 3: Chip layout

The magnetic separation EWD device is designed as shown in Figure 3. The device consists of two parts: the current-bearing wires responsible for the magnetic bead manipulation function and the electrode responsible for droplet actuation. The wire in the design has a width of 15µm and the wire has length sufficient to cover the entire electrode region. Two types of chip layouts are designed: the first type shown in figure 3 (a) has wires spaced across the electrode region such that isolated electrode metal exists between pairs of wires. In this layout, two kinds of chip are fabricated. The first kind has wires spaced 35µm apart and the second one has wires spaced 65µm apart. The second type shown in figure 3 (b) has closely-spaced wires over a portion of the electrode region. The wires in this design are spaced 10 µm apart, and since there is only a small space in between wires, there is no exposed electrode metal for EWD in the wire region. When performing electrowetting, voltage is applied onto the wires so that electrowetting function will not be interrupted.

The experiment starts with dispensing 0.6 nano littler droplets with magnetic beads out of a reservoir, and the droplet is then moved onto the EWD device by applying 50 volts at 1 kHz to the electrodes. The droplet is pinned on the magnetic separation region with the actuation electrode turned on at 30 volt 1 kHz. Then 200 mA of current is passed through the wires in sequence to manipulate the magnetic beads. In such an experiment, Dynabeads M-270 are used, since they can provide sufficient magnetic force in a relative small size. The current is passed through each wire from right to left for a period time ranging from 1 second to 20 seconds. The magnetic beads move following the magnetic field peak and will be collected at the left-most wire. Hence, the segregation of magnetic beads in the droplet is achieved.

RESULTS AND DISCUSSION

It can be seen in Figure 4 that the current sweeps from the right-most wire to the left. The magnetic beads in Figure 4a are dispersed, but as the field sweeps right to left, the beads are collected and moved to the right most wire. In this device, the wires are in between two electrodes for electrowetting. The wires are 10µm apart, and 200 mA is applied to each wire for 2 seconds.

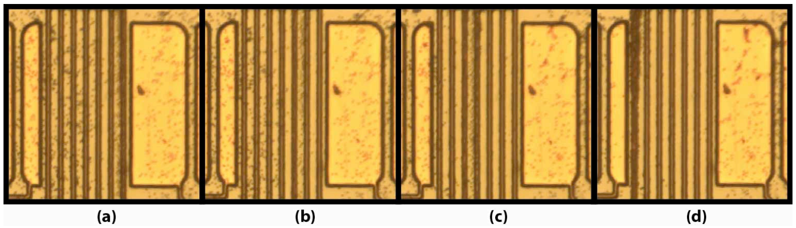

Figure 4. Magnetic beads segregation

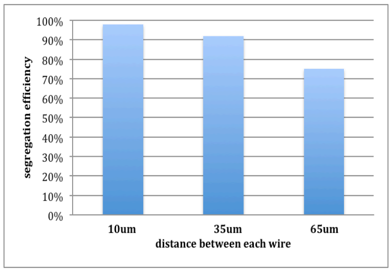

Figure 5. Segregation efficiency

Several factors contribute to the efficiency of magnetic bead segregation: the distance between each wire, the current density in the wires, switching frequency for the current passing through each wire, and the type of magnetic beads used. As shown in the experiment, the decrease in distance between each wire has a positive effect on segregation efficiency, while the current density and the switching frequency are kept the same. It is also observed that an increase in current density and a decrease in switching frequency also has a positive effect on the segregation efficiency. The efficiency of magnetic segregation is calculated by counting the beads before and after magnetic separation in the area between the right-most and left-most wire.

The experimental result shows that the distance between each wire has significant impact on the segregation effect. Figure 5 shows the final result of segregation with respect to different chip layouts and distances between wires. From this result, we can observe that the reduction of distance between wires increases the segregation efficiency. To achieve the result in the 10µm distance case, the layout in figure 3(b) is used, and 200 mA of current is applied for 2 seconds, and bead segregation is achieved by switching the current through the array of wires once. The layout in figure 3(a) is used in the 40µm case and 200 mA of current with time interval of 4 second is applied. In the case of an 80µm wire separation, the layout in figure 3(a) is used and the time interval is 16 seconds while requires the current to be switched through the array for 4 times. It is shown that by decreasing the distance between the wires, increasing the current density and increasing the duration of current flow in each wire, the segregation efficiency can be improved. Comparing with previous work[2], our work shows higher segregation efficiency of 98% and the capability of moving beads to specific locations on the device by using magnetic manipulation instead of electrophoresis.

CONCLUSION

In this paper, we demonstrated the segregation of magnetic beads on an EWD device. The influence of distance between each wire, current density and switching frequency on the efficiency of segregation were investigated. The device integrating both magnetic and electrowetting function can provide many possibilities for varieties of applications.

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