MODE TRANSITION & ITS MECHANISM OF RNA/DNA TRAP BY ELECTRIC AND HYDRAULIC FORCE FIELD IN MICROFLUIDIC TAPER SHAPE CHANNEL

Yuzuru Takamura[1], Wako Nagasaka[1], Kunimitsu Ueno[1], Yuichi Tomizawa[1], and Eiichi Tamiya[1,2]

[1]Japan Advanced Institute of Science and Technology (JAIST), JAPAN

[2]Osaka University, JAPAN

ABSTRACT

The accumulation of flowing DNA is observed near the narrowest part of taper shape microfluidic channel when both hydro pressure and electric field are applied in the opposite direction. The position and the shape of the accumulated DNA are changed with increasing the electric force and decreasing the hydro pressure, showing mode transition. To discuss the mechanism, three forces act on DNA, i.e. dc dielectric force, hydro drag force, Lorentz force, are estimated in the channel, and numerical simulation is also performed. It is revealed that the dielectric force is 10^{-4} times smaller than the other forces and the mode transition is described by the change of the balancing position of Lorentz force and hydraulic force.

Keywords: Biomolecule manipulation, DNA/RNA extraction, purification.

1. INTRODUCTION

Extraction and purification of DNA/RNA from cells on chip is an important issue for practical DNA-based micro total analysis systems. We have reported that the DNA is selectively trapped and accumulated at the narrowest position of taper shape channel when electric force and hydro drag force are applied simultaneously in opposite direction[1]. Using this technique, DNA, RNA, Protein, organelles can be trapped, concentrated, and extracted in mixed solution[2]. However, the trap mechanism, is still not clear.

In this paper, we investigated trapping feature of DNA at various conditions, especially from the view point of the mode transition of the accumulating shape and its position of trapped DNA. Then to describe the mechanism, the three forces act on a trapping DNA such as; dc dielectrophoretic (DEP) force, hydro drag force, and Lorentz force, were directly measured in the channel. Based on these values, we discuss about the mode transition and the trap mechanism with numerical simulation method .

2. EXPERIMENTAL

The micro channel was made of polydimethylsiloxane (PDMS) using a conventional photolithograph technique with SU-8 thick resist. The channel was totally 30 mm long, 100 μm wide, 10 μm deep, and at the center of the channel, a narrow part of 10 μm wide was designed as shown in figure 1. A solution of T4 DNA stained by YOYO1 in 0.5 Tris borate EDTA buffer was introduced into the channel. The hydro drag force and the electric force were applied to the solution at the same time in mutually reverse directions by a syringe and dc power supply, respectively. By these force fields, DNA was to be trapped near the narrow position. The motion of each DNA molecule was observed by a fluorescence

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microscope with high sensitive CCD camera, and was stored in PC as digital data. The electric field, and the flow velocity of the solution were numerically calculated using COMSOL Multiphysics software. The Lorentz force for DNA was calculated from the electric field and charge density of DNA molecule. Hydro drag force was calculated from the solution velocity and experimental value of Lorentz force at a condition when DNA was stopped by balancing the hydro drag force and Lorentz force. DEP force for DNA strongly depends on the solution concentration. We estimated DC DEP force at typical trap condition (DC 20 V, 5 hPa) from frequency dependence of AC DEP force at 2 kVpp, 0.1-100 kHz by extending the value to frequency = 0. The AC DEP force is experimentally measured in our channel by counter hydro drag force to push away DNA against given AC DEP force.

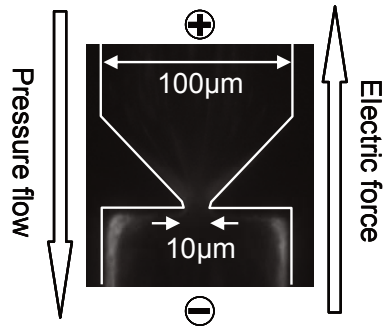

Figure 1. Shape and size of narrowest part of taper shape channel for DNA/RNA trap.

3. RESULTS AND DISCUSSION

Typical photograph of trapped DNA were shown in figures 2. At applied voltage =20V, the DNA molecules are trapped near the side wall. With increase voltage up to 35V, it makes a mode transition of changing its shape and position from side to center. Increasing voltage more to 40V, the shape was elongated along with flow. The condition for the mode transition was investigated at various pressure and voltage. Figure 3 shows the condition map of each trap pattern. From these results, the trap pattern is approximately depend on the ratio of pressure and voltage, i.e. the same ratio shows the same pattern. To discuss the mechanisms of the trap and the mode transition, we estimated three forces act on DNA, i.e. dc dielectric force, hydro drag force, Lorentz force. As result, the DEP force is 10^{-4} times smaller than the other Lorentz force and hydro drag force, and negligible in our trap. By actual motion of the trapped DNA, our trap seems to be caused by the dynamic motion of trap molecule around the balanced position of the two forces, dc electric force and hydro drag force. If this hypothesis is true, the trap position should be located near the area where the two forces are balanced, and the balanced position should move as changing the ratio of

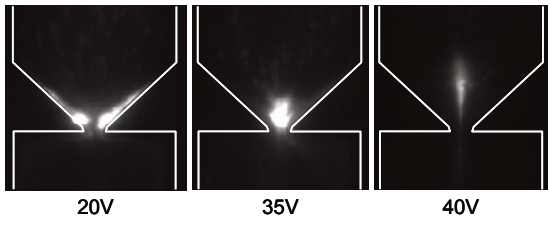

Figure 2. Typical photograph of trap DNA. It shows mode transition with increasing applied voltage.

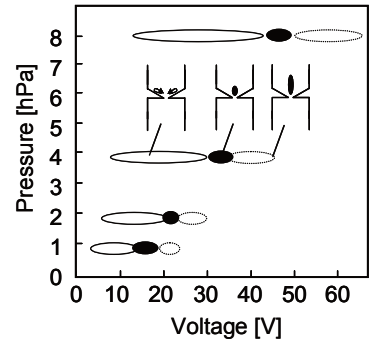

Figure 3. Condition map for each trap pattern.

the two forces. Figures 4 show the typical results of numerical simulation for the total force act on each DNA molecule; left, center, and right figures represent at high pressure / low voltage, middle pressure / middle voltage, and low pressure / high voltage conditions, respectively. The gray area shows the position where the hydro drag force and electric force is nearly balanced. These areas are well correspond with the trap positions in figures 2. The mode transition is clearly described by the change of the balanced position. Chou et al. [3] reported DNA trap by insulated DEP (iDEP) with taper shape channel. In our case, DEP is negligibly small and hydro drag force and Lorentz force seems to play main role for trap mechanism.

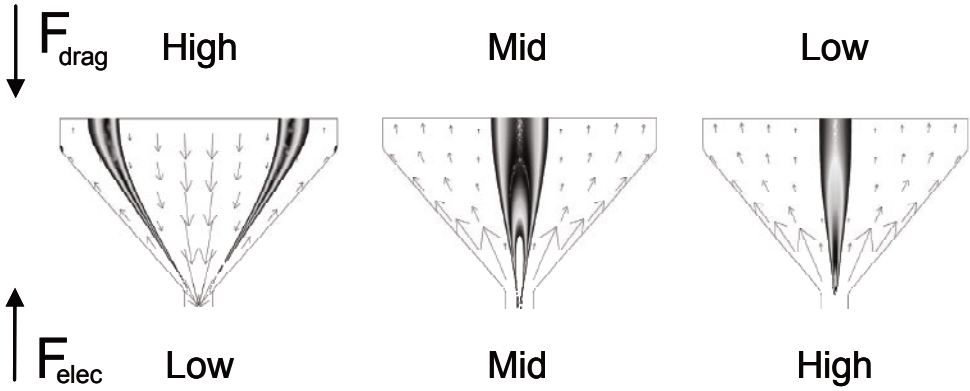

Figure 4. Numerical simulation of the total force act on each DNA molecule. Gray area shows the position where the hydro drag force and electric force is nearly balanced.

4. CONCLUSIONS

The position and shape of trapped DNA by hydro drag force and electric force in taper shape channel was investigated at various condition. The position and the shape changed as a function of the ratio of the electric force and the hydro drag force, and also those were well correspond with the balancing position and the shape of the electric force and the hydro drag force calculated by numerical simulation. On the other hand, three forces act on DNA, i.e. dc dielectric force, hydro drag force, Lorentz force, were estimated in the channel with typical trap condition. It is revealed that the dielectric force is 10^{-4} times smaller than the other forces, and hydro drag force and Lorentz force were major forces in this trap.

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