Stretching of DNA in Sealed Microchannels Using Electrokinetic Forces

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DNA stretching is important for many applications including single-molecule DNA-protein interactions, base mutation detection, DNA sequencing, and DNA-templated active devices such as transistors and nanowires. In this paper, we demonstrate an electrokinetic-based DNA immobilization and stretching technique in a microfluidic system using Au electrodes integrated with Si microchannels.

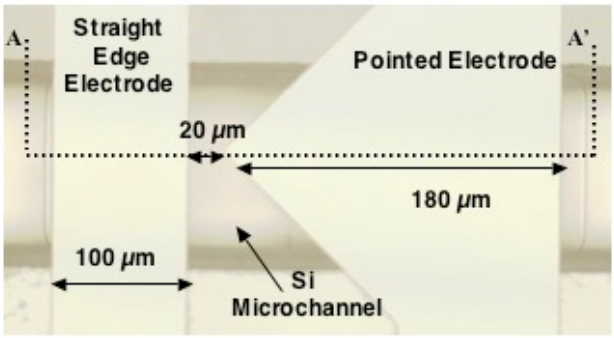
A number of electric field based DNA stretching techniques have been demonstrated. In all the existing techniques, DNA immobilization to electrodes is dependent on chemical modification to either the DNA or the electrode surface or both. These techniques result in very few DNA molecules getting immobilized to electrode. In our technique, pH of the buffer is adjusted to 5.8 to enhance DNA immobilization to Au electrodes integrated with Si microchannel. Due to the fluid flow generated by the electric field, DNA molecules are in continuous circulatory motion near the edges of the electrode, leading to a large number of DNA being immobilized to the electrode. With increase in electric field, the immobilized DNA molecules are stretched out due to the electric field induced torque and the direction of the field induced fluid flow.

Si microchannels are sealed with Au electrodes on a 100 μm thick glass using PMMA bonding. Figure 1(a) shows a micrograph of a pair of electrodes integrated with 100 μm wide and 75 μm deep Si microchannel. Schematic of the channel cross-section is shown in Fig. 1(b). Figure 2(a) shows λ-DNA molecules in electrode gaps when a 6 V, 100 KHz voltage is applied. At this voltage, the DNA molecules move towards the electrode edges from the gap. Figures 2(b)-(d) show stretching of DNA molecules as the voltage is increased from 8 to 16 V. At higher electric fields, the direction of the induced flow reverses to move from the electrode edges towards the gap. The flow reversal first occurs near the sharp electrode tip and with increase in field, the flow is also reversed along the straight edge electrode. Hence DNA stretching is observed initially form the sharp tip at 8 V followed by stretching from both the sharp and straight edge electrodes. The DNA stretch length increases with applied voltage and the molecules are longer at 100 KHz as shown in Fig. 3.

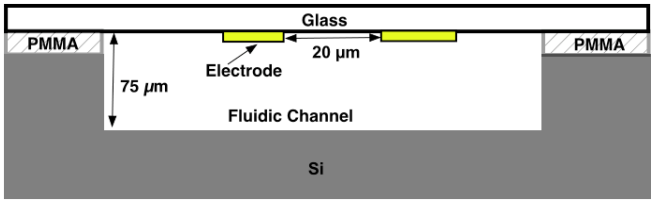
To achieve DNA immobilization at 2 ends across the electrode gaps, a floating electrode is added. Figure 4(a) shows T2 DNA molecules stretched in the presence of hydrodynamic and electrokinetic forces. The DNA are initially attached to the sharp tip with 13 V bias at 100 KHz. In order to ensure immobilization at the other end of DNA to the floating electrode, hydrodynamic flow is initiated. Figure 4(b) shows stretched DNA molecules across electrode gaps when the applied voltage is removed and the flow is stopped. A number of DNA molecules remain attached to the electrodes at both ends.

The applied electric field also causes stretching of DNA that are located outside the electrode gap. Figure 5 shows the velocity of DNA molecules increases with voltage applied across the electrode gap for λ-DNA in a 100 μm wide, 16 μm deep channel at a location that is 1100 μm away from the gap. Figure 6 shows stretching of DNA molecules at the same location at 14 V that are attached to the PMMA surface inside the microchannel. The DNA are stretched by the same electrokinetic force due to the applied electric field across the electrodes.

In summary, we have shown the stretching of DNA molecules across electrode gaps and at a distance of 1100 μm away from the gap using 100 KHz ac fields in an integrated microchannel-system. This precise placement of stretched DNA in a microfluidic system is used for many biomedical studies.



(a)



(b)

Fig. 1. (a) Micrograph of Au electrodes integrated with Si microchannel. (b) Cross-section of sealed microchannel across the electrode gap.

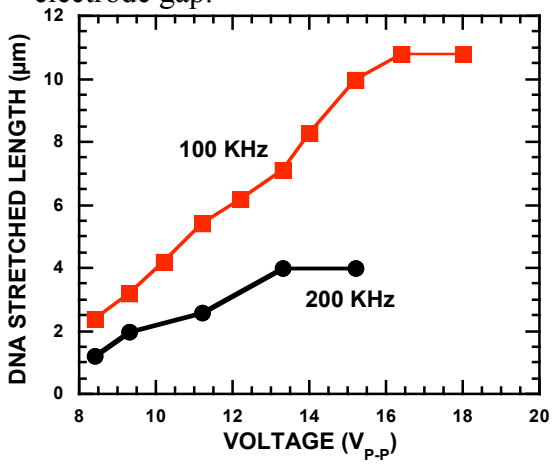


Fig. 3. λ-DNA stretched length variation with voltage at 100 and 200 Khz.

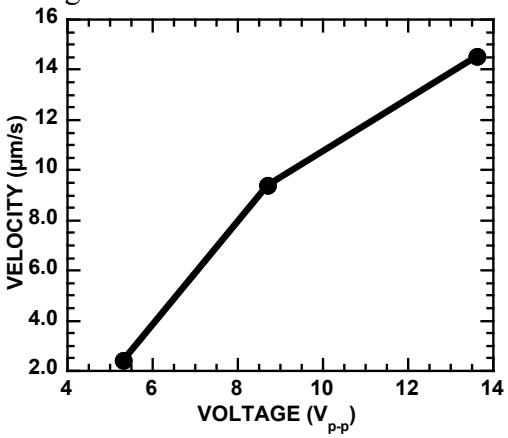


Fig. 5. Electric field induced λ-DNA velocity as a function of applied voltage at a distance of 1100 μm away from the center of electrode gap.

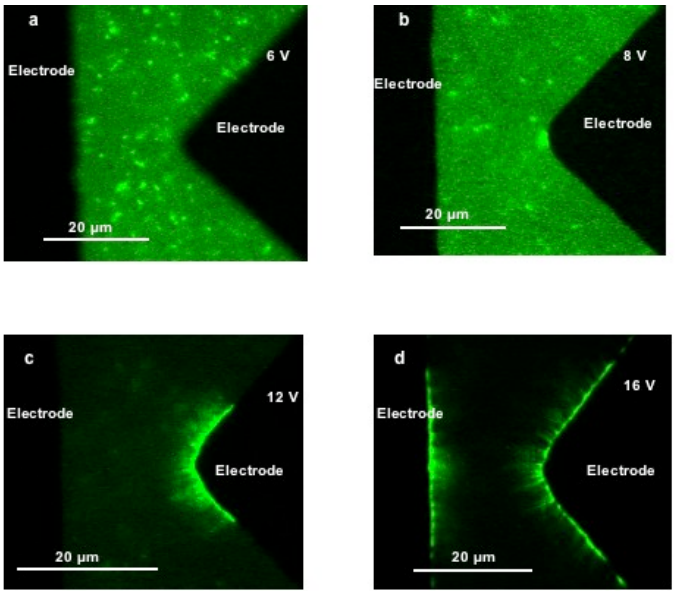


Fig. 2. (a)-(d) λ-DNA molecules stretched and immobilized at different voltages using 100 KHz ac fields in integrated microchannel.

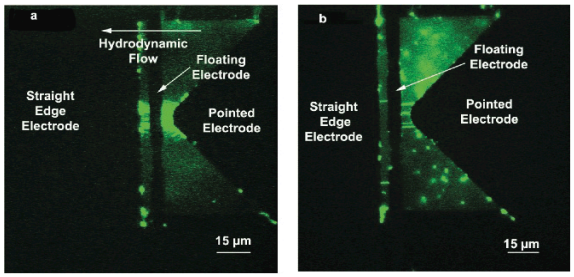


Fig. 4. (a) T2 DNA stretched across a floating electrode at 13 V in the presence of fluid flow. (b) Stretched T2 DNA remain attached at both ends across electrode gaps in absence of electric field and flow.

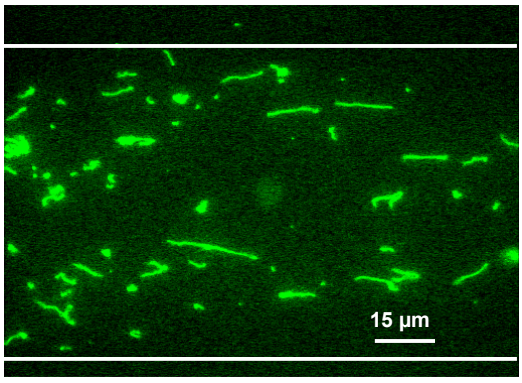


Fig. 6. Stretching of λ-DNA attached to PMMA in a microchannel at a location of 1100 μm away from electrode gap.