Integration of Nanochannels with Electrodes to Control Single Molecule DNA Movement

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Nanochannels are used to perform studies on fluidic behavior at nanoscale and DNA analysis at single molecule level. In many applications such as single molecule DNA sequencing, DNA-templated electronics devices, and DNA-protein interactions, DNA immobilization and stretching are critical. We have developed an integrated nanofluidic system to immobilize, stretch, and control the motion of DNA molecules in nanochannels using high frequency ac fields. Due to the confined volume in nanochannels, the system is more suitable for single-molecule DNA analysis compared to microchannels.

The integrated nanofluidic system consists of nanochannels etched in Si and sealed with 100 μm thick glass using PMMA as an adhesive layer. The Si channels are cleaned in 1:1 H_2SO_4:H_2O_2 to provide hydrophilic surface before being sealed. PMMA does not clog the nanochannels during bonding since the PMMA viscosity is high at the bonding temperature of 110 °C and 0.4 MPa pressure. The hydrophilic Si surface helps to drive the DNA molecules into the nanochannels by capillary action. Au electrodes are integrated with the sealed Si nanochannels to immobilize, stretch, and control the motion of DNA molecules using high frequency ac fields.

Figures 1(a)-(c) show the time sequence of a DNA molecule entering into a 350 nm wide nanochannel driven by the capillary force of the fluid. The nanochannels have a fluidic input and output openings at two ends. T2 DNA molecules in tris ethylene diamine tetraacetic acid (EDTA) buffer (pH=8.0) are introduced at the input opening and the nanochannels are immediately filled with the buffer. Since the output opening is open to atmosphere, there is a continuous pumping of fluid due to evaporation, resulting in DNA molecules being driven into the nanochannels.

Electrodes are integrated with nanochannels to control the placement and stretch DNA molecules inside the nanochannels by applying high frequency ac fields. Figure 2 shows 20/50 nm thick Cr/Au electrodes integrated with 500 nm wide and 100 nm deep nanochannels using PMMA bonding. Electrodes are successfully integrated with nanochannels without any leakage, which is a critical requirement for control of DNA molecules by electric fields. Figure 3 shows λ-DNA molecules, in 350 nm wide and 100 nm deep channels integrated with Cr/Au electrodes. When there is no fluid flow the λ–DNA molecules are ~1 μm long in the nanochannels. Figure 4 shows T2 DNA molecules immobilized and stretched in 500 nm wide and 100 nm deep nanochannels using 100 KHz, 18 V_{p-p} ac voltage. The buffer used for the electrokinetic stretching is TRIS-EDTA (pH=8.0).

Motion is induced in DNA molecules in nanochannels through high frequency ac fields applied across the integrated electrodes. When the field is applied, the position of DNA molecules in nanochannels can be controlled precisely. Figure 5 shows the velocity of T2 DNA molecules induced by applying voltage at 100 KHz. These DNA are 600 μm away from the electrode gap in 500 nm wide and 100 nm deep nanochannels. DNA molecules away from the electrode gap start to move with various velocity when the voltage is 12 V or above, and they move at higher velocity when higher voltage is applied.

In summary we have demonstrated the fabrication of a nanofluidic system using low temperature PMMA bonding for single-molecule DNA analysis. The DNA molecules are driven into the nanochannels by the capillary action. Electrodes integrated with nanochannels are used to immobilize and stretch DNA molecules at precise locations using ac fields. In addition ac fields are used to control the motion of DNA molecules. This system enables the control of the position of DNA molecules in nanochannels for single molecule DNA assays.

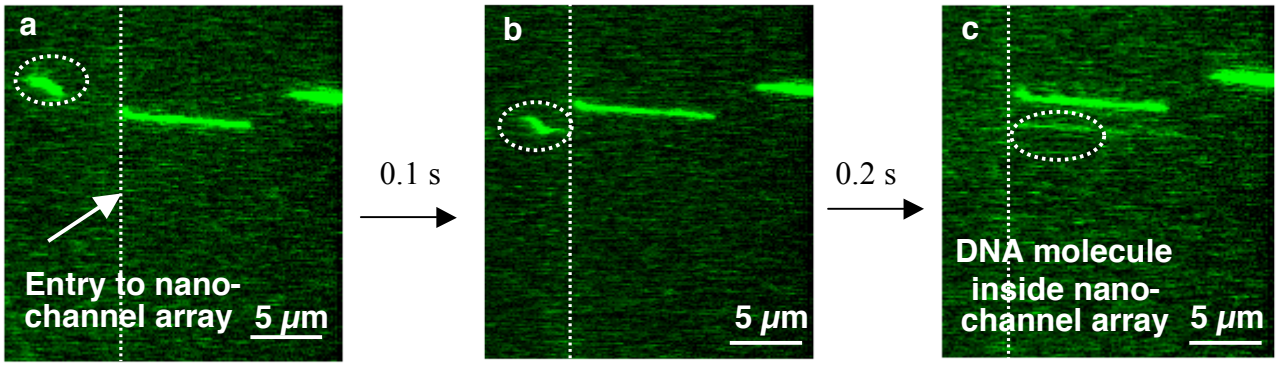

Fig. 1. T2 DNA molecules introduced into 350 nm wide and 100 nm deep nanochannels by capillary action.

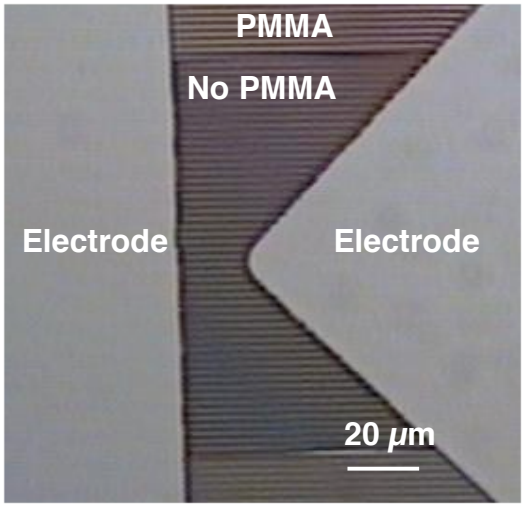

Fig. 2. Micrograph of electrodes integrated in 500 nm wide and 100 nm deep nanochannels.

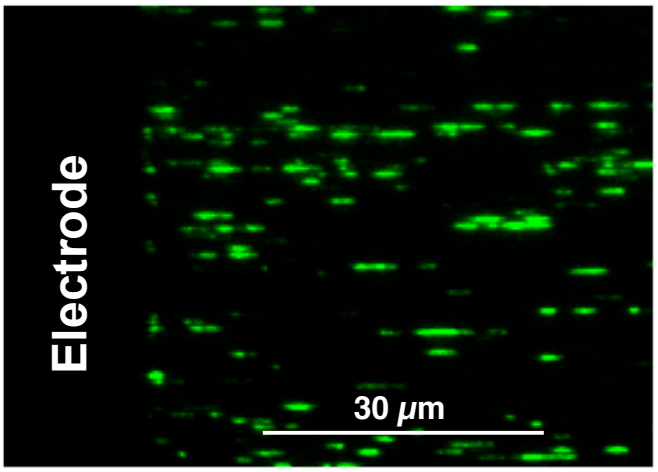

Fig. 3. λ-DNA molecules in 350 nm wide and 100 nm deep nanochannels with integrated electrodes on the left.

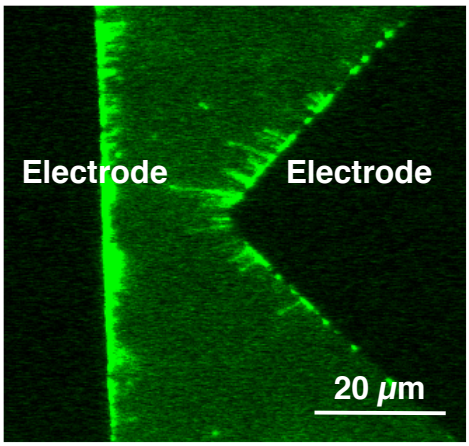

Fig. 4. T2 DNA molecules stretched and immobilized with100 KHz, 18 V_{p-p} ac signal applied across electrodes.

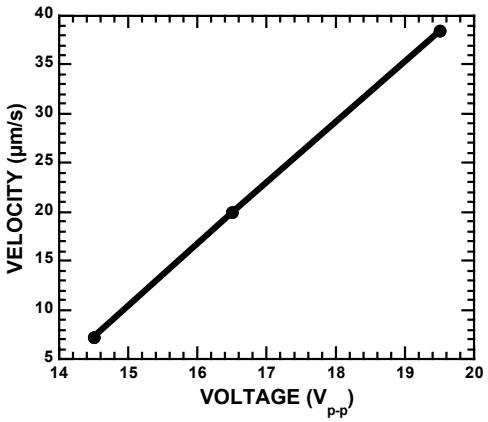

Fig. 5. Velocity of T2 DNA molecules in 500 nm wide, 100 nm deep nanochannels at 100 KHz.