DNA MOVEMENT IN SUB-20 NM NANOSLITS

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ABSTRACT

The movement of XbaI digested λ-DNA in 20 nanometer and λ-DNA in 12 nanometer high slits was investigated. We found that DNA moved intermittently and following preferential pathways, indicating an important influence of surface roughness. From these intermittent movements two different mobilities were calculated, the total averaged mobilities and averaged mobilities between the intermittent sticking events. The friction coefficient per unit length was calculated from the latter mobilities. A three order of magnitude increase was found for the 12 nm slits compared to the theoretical value. The mobility furthermore differs less than one order of magnitude between 20 nm and 12 nm slits, and the influence of varying the ionic strength of the buffer was not significant. This work is the first time DNA movement in such shallow constrictions is investigated.

Keywords: DNA, intermittent movement, nanoslits

1. INTRODUCTION AND THEORY

This work describes the investigation of the mobility of extremely confined DNA as a function of confinement and ionic strength. To roughly estimate the friction experienced by the DNA, the measured mobilities were used to calculate the friction coefficient per unit length according to [1].

$$\xi = \lambda E / v \qquad (\lambda = \text{charge per unit length} = 1.1\ e_0 / \text{nm}) \qquad (1)$$

The theoretical value for the friction coefficient per unit length was derived from a model of a moving cylinder of width w in a slit of height h [2].

$$\xi = 2\pi\eta / \ln(4h/\pi w) \qquad (h = \text{height nanoslit}, w = \text{width DNA}) \qquad (2)$$

With increasing ionic strength, the screening (Debye) length decreases. This will result in a decrease of the effective width of DNA and an increase of the effective slit height and thus a decrease of the friction coefficient ξ. The dynamics of DNA has been studied before but in a different way and in channels or slits of other dimensions [3, 4].

2. EXPERIMENTAL

Figure 1 schematically presents the Fused Silica chip used. Between two microchannels an array of 100 nanoslits is situated (width 3 μm, length 500 μm) with 12 nm or 20 nm height depending on the etching time with diluted HF. Devices were fusion bonded at 1100°C. Surface roughness was 1 nm rms as measured with AFM. Buffer was introduced through the microchannels and voltage applied over the nanoslits array. An optical setup

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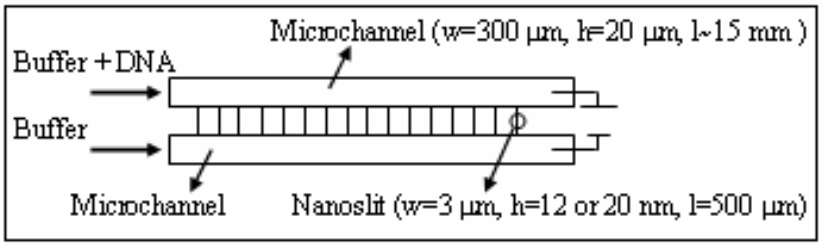

Figure 1. Schematic presentation of the device.

for fluorescence was used with a CCD camera to detect the emitted light. XbaI digested λ-DNA of length 9 μm and λ-DNA of length 18 μm was labeled with YOYO-1 (ratio one dye per 10 basepairs), β-Mercaptoethanol was used against bleaching and polyvinylpyrrolidone (PVP) to prevent surface adsorption and electro-osmotic flow. In 20 nm high slits an electrical field of 4.10^5 V/m was applied and in the 12 nm high slits 2.10^5 V/m.

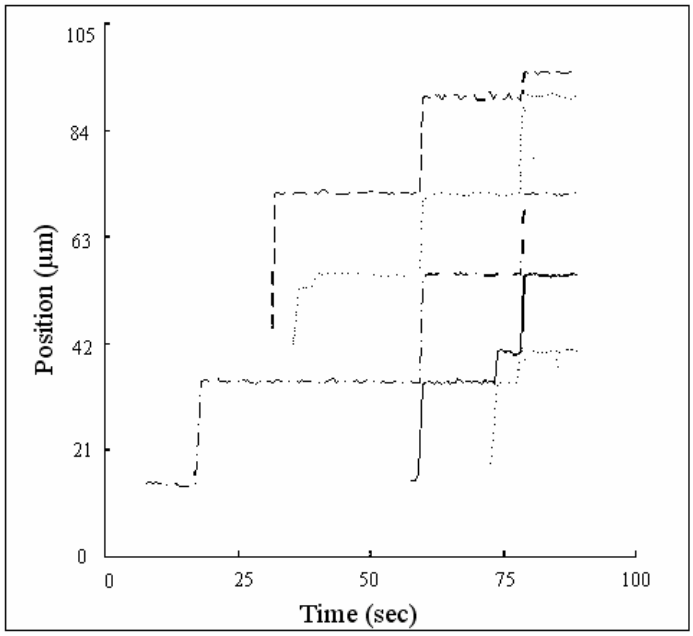

Figure 2. Stop and go movements of undigested λ-DNA (18 μm) in a 12 nm high nanoslit. (1xTBE, 2.5%PVP and 3% β-mercaptoethanol, 2.10^5 V/m). Each DNA molecule is represented as a line. Note that the DNA molecules stop (stick) at the same positions on the channel length axis, followed by movements with comparable slope.

3. RESULTS AND DISCUSSION

Single DNA molecules were traced in time inside the slits. The DNA was seen to move following preferential pathways, suggesting a possible influence of surface roughness. The movements of DNA through the nanoslits furthermore were intermittent as presented in figure 2. The time-averaged total mobilities for both 12 nm and 20 nm high slits are presented in figure 3A and 3B. In fig. 3A XbaI–digested λ-DNA and in 3B whole λ-DNA is used. Clearly no significant influence of the ionic strength on the mobility could be found due to the large standard deviation of the data which we attribute to the influence of local surface roughness introducing a large difference between data measured in different slits. The averaged mobilities in both 12 nm and 20 nm differ less than one order of magnitude.

For the the 12 nm slits, the theoretical friction coefficient is 2.0 mPa·s. If the mobility was determined only from the moving phases in the 12 nm high slits, a friction coefficient of 2.2 Pa·s was calculated with the DNA sticking for 90% of the time. Possible explanations for the large discrepancy of three orders of magnitude are direct surface / DNA friction, an increased water viscosity close to the wall due to molecular ordering, an increased viscosity of the solution adjacent to the wall due to the presence of wall-adsorbed PVP and an influence of electrical double layer repulsion.

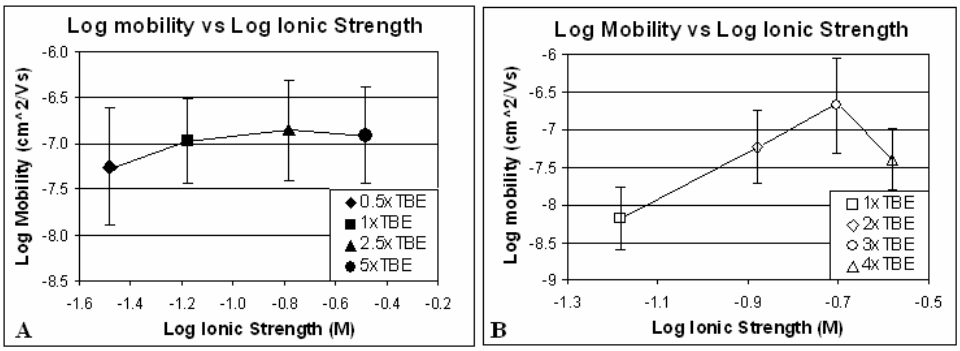

Figure 3. The averaged mobility of λ-DNA. (A) Mobility of XbaI digested λ-DNA in 20 nm high slits (2.5%PVP and 0.2% β-mercaptoethanol and 0.4 MV/m). (B) Mobility of λ-DNA in 12 nm high slits (2.5%PVP and 3% β-mercaptoethanol and 2.10^5 V/m).

4. CONCLUSIONS

This study shows that DNA proceeds through 12 nm and 20 nm slits much slower than predicted from simple theory. Intermittent movements of the DNA and the occurrence of preferential pathways through the slits indicate an influence of surface roughness. No significant influence of the ionic strength on the mobility could be found within our measurement error. The average mobility without intermittence of movement was used to calculate the experimental friction coefficient per unit length of DNA inside a 12 nm slit. The experimental value showed a dramatic increase when compared to the theoretical value. Presently, work is going on to extending the dataset and to decrease the experimental error.

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