Nano-2 Course - F1
Home Assignment on DNA nanofluidics - Nanopit paper

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Introduction

This exercise is part of the lecture on 'DNA nanofluidics'. You should start reading the paper 'Directed Self-organization of single DNA Molecules in a nanoslit via embedded nanopit arrays' by Walter Reisner et al., PNAS 106(1) pp. 79-84 (2009).
In this paper, DNA molecules are confined in a device with nanopits. The contour length of a DNA molecule is noted L, the persistence length P, the DNA width is w. Note that lower case l is denoting the spacing between pits and that the parameters L_s and L_p denote the length of DNA (in terms of contour length) that is found in the slit and a pit respectively when a molecule extends partially between the confinement of the slit and one or more pits.
To save time in solving part 3, it is recommended to already implement the equations in part 1 and 2 in a code.

Part 1

The chip layout is shown in Fig. 1. Microchannels, 1μm high and 50μm wide connect the reservoirs (fluidic inlets) to the central region, which consists of a shallow channel, called the nanoslit, h=100 nm high and 50μm wide. The floor of the nanoslit is fitted with d=100 nm deep, a=300 nm wide square holes, called nanopits. In the problems below, we consider either λ-DNA with a contour length $L = 21\mu$m, or T4-DNA with L=71.8μm.
In Questions 1-3, we only consider the microchannels and the nanoslit, while we disregard the nanopits.
In the paper, the persistence length used is $P \approx 64$ nm and the effective width is w_{eff} =9 nm. The contour length of a whole λ-DNA molecule is $L = 21\,\mu$m after correcting for the staining by the dye YOYO-1.

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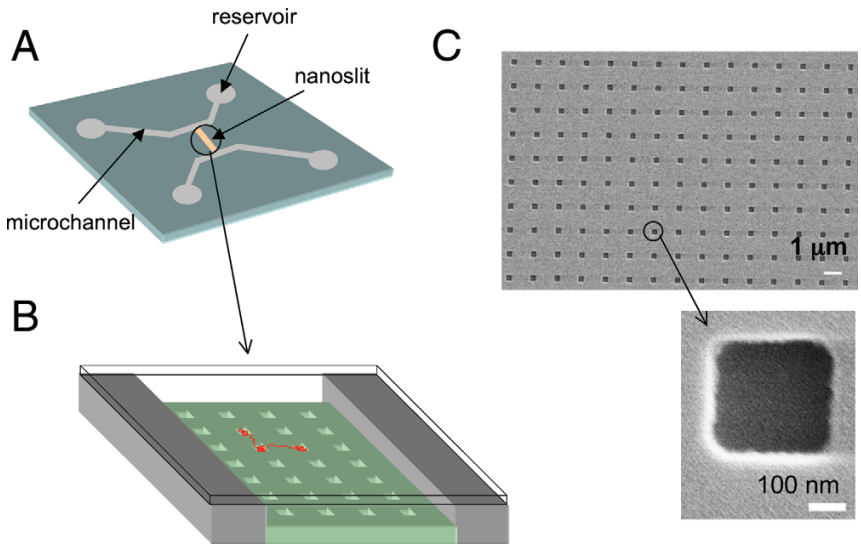

Figure 1: Chip design. (A) Schematic of chip design showing microchannel arms connecting the circular reservoir pads to the nanoslit (yellow). (B) An enlarged 3D view of the nanopit lattice in the nanoslit with a cartoon DNA molecule (red) spanning 3 pits. (C) SEM images of 300 x 300 nm nanopits at high and low magnification.

Question 1: Calculate the Flory Radius for T4-DNA in the experiments and then the radius of gyration R_g.

Question 2: Calculate the free energy of a whole T4-DNA molecule in the microchannel in terms of thermal energy k_BT using Equation 2 in the paper and Equation 3.3 in the lecture note. Would the DNA molecules spontaneously enter the microchannels? Why?

Question 3: Calculate the free-energy change associated with the T4-DNA moving from the microchannel to the nanoslit using Equation 2.

Question 4: Conclude if in the experiment a DNA molecule left in the slit would spontaneously migrate to the microchannel.

Part 2

In the following we consider the DNA is in the region of the chip where the nanopits are.

Question 5: Calculate the free-energy of a whole T4-DNA molecule in a single nanopit. Consider both situations where self exclusion is neglected or not.

Part 3

We now have all the elements to use Equation 1 and we consider to design a new device where N=2 and N=3 are stable conformations of T4-DNA simultaneously.

Question 6: Write a code to compute $\Delta F_{tot}/k_BT$ as function of Lp/L as in Figure 6E for λ-DNA and the parameters of the figure then compute the case N=1 and N=2 and make a plot. OBS! Adjust the effective width w to 6 nm in order to get the minimum of the N=1 curve at approximately Lp/L=0.25.

Question 7: Now add a plot at higher N and compute for T4-DNA instead. Find design parameters (ie. changing h, d, a or l) so that N=2 and N=3 are both the most stable configurations. You could provide a plot to show this is the case and explain your optimization procedure.

Question 8: What is the Lp/L at the stable configuration?