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DNA DIFFUSION CONTROL

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ABSTRACT

Here, we demonstrate the specific diffusion control of DNA in a microfluidic obstacle array. We show, that the diffusion was enhanced up to a factor of 700 compared to the free diffusion. This finding might allow new approaches to purification as well as mixing at low Reynolds numbers.

KEYWORDS: Diffusion, DNA, microfluidics

INTRODUCTION

The typical dimensions and flow velocities in microfluidics systems usually imply laminar flow conditions characterized by a low Reynolds number. This has important significance for dispersion in microfluidic systems. As a consequence, mixing is often limited by diffusion in Lab-on-a-Chip devices. Here, we address this problem and demonstrate how the diffusion of DNA can be enhanced and specifically controlled for future mixing and purification applications.

THEORY

It was predicted theoretically that the diffusion of particles can be enhanced by orders of magnitude when the particle moves in a tilted periodic potential *W* and conditions far from thermal equilibrium are established by an external (tilting) force [1,2]. In case of a deterministic and overdamped dynamics, the mechanism can be understood as follows. A particle in an untilted periodic potential landscape is confined to a potential minimum. Tilting of this potential leads to a decreasing potential barrier.

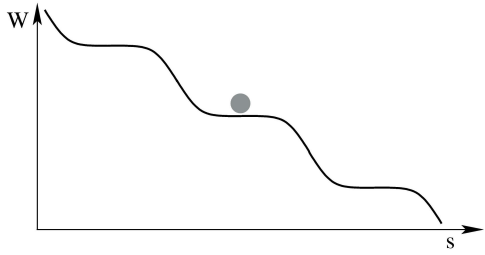

Figure 1: A spherical Brownian particle in a critically tilted periodic potential (W potential energy, s position).

Hence, at some point the so called *critical tilt* with just vanishing potential barrier is reached (see Fig. 1), where any (arbitrarily small) thermal force is sufficient to 'kick' the object from the plateau, which – as a consequence – leads to a huge dispersion. Recently, this effect was demonstrated experimentally for a single colloidal particle species in corrugated optical vortices [3].

EXPERIMENTAL

A tilted periodic potential landscape is realized in a poly(dimethylsiloxane) (PDMS) microfluidic device (Fig. 2), according to [4]. The central part is an array of non-conducting posts. Upon application of an AC-voltage with amplitude U_{ac} and frequency *w*, an inhomogeneous electric field is created in the microstructured channel. The electric field induces a dipole in the DNA coils. This dipole interacts with the electric field gradients leading to potential minima in the constrictions between two neighboring posts in a row (positive dielectrophoresis). Additional application of a static voltage U_{dc} leads to a total time dependent voltage of $U(t) = U_{ac} \sin w t + U_{dc}$ and a tilting of the experimental quasi 2D potential landscape. The motion of fluorescently labelled DNA molecules in this potential landscape was recorded compared to the free diffusion (D_0), as previously described [4].

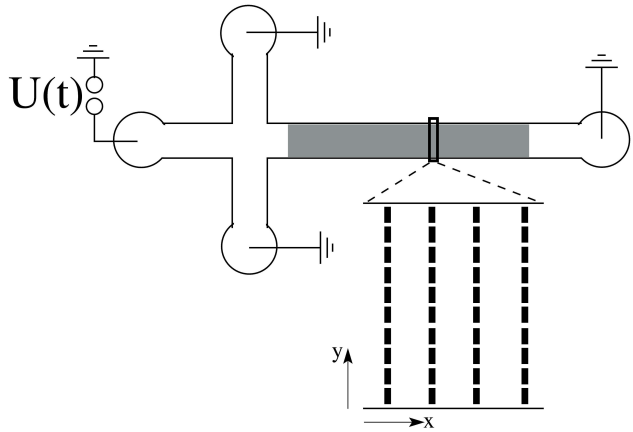

Figure 2. Schematic setup. A cross injector layout with buffer reservoirs at the ends is used. The channels are about 100 micron wide and 6 micron high. The three short channels have a length of 2 mm. The gray shaded area symbolizes the microstructured section and has a length of 3.8 mm, with a total channel length of 5 mm. Ten posts (area 7 x 2 µm^2) make up one row with a distance of 2 µm, and 180 rows are periodically arranged with a period of 21 µm.

RESULTS AND DISCUSSION

First, a detailed analysis of trajectories of the DNA molecules in this quasi 2D potential was performed, with the result that the migration can be approximated by the motion in a tilted periodic 1D potential where the tilt is controlled by the static voltage U_{dc} and the depth of the potential minima by U_{ac}. Furthermore, as every escape from such a potential minimum can be considered as being independent of the

previous ones, the effective diffusion could be obtained from the distribution of the first passage times [1,2].

Further, the effective diffusion coefficient D_{max}/D_0 was determined for two different DNA species (λ(48.5kbp)- and T2(164 kbp)-DNA) at different values of U_{dc}. Table 1 shows, that the diffusion could be enhanced up to a factor of 700.

Table 1. Diffusion coefficients of l- and T2-DNA. D_0 is the diffusion coefficient in an unstructured region without electric potentials applied. D_{max} denotes the maximum diffusion enhancement achieved at the critical tilt of the potential.

# [kbp]	Diffusion		
	D_0 [μm²/s]	D_{max} [μm²/s]	D_{max}/D_0
48.5 (λ)	0.68±0.09	130±33	191
164 (T2)	0.39±0.05	270±68	692

For the two studied DNA species, the diffusion is enhanced at different values of U_{dc} resulting in distinct maxima when sweeping U_{dc}. Thus, the diffusion can be specifically accelerated for one species, while the other species undergoes the usual dispersion in an array of posts. For comparison, numerical simulations were performed based on a Langevin dynamics in a 2D potential landscape reflecting the experimentally used geometry. They qualitatively reproduced the experimental results with respect to the existence and the position of the peak maxima. Further studies are necessary in order to reproduce the experimental results quantitatively.

CONCLUSIONS

The occurrence of diffusion enhancement at different static voltages was experimentally demonstrated for two DNA species. This phenomenon will allow to specifically control the diffusion of the different species and could thus be exploited for purification as well as enhanced diffusion based mixing for DNA and other biomolecules in microfluidic applications.

ACKNOWLEDGEMENTS

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