Surface Charge Density Dependent DNA Capture through Polymer Planar Nanopores Fabricated by NIL

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Nanopore-based fluidic devices are considered as a promising tool for DNA sensing due to their label-free, high-throughput, and low-cost features [1]. The sensing mechanism is simple: when a negatively charged DNA molecule passes a nanopore filled with electrolyte, ion transport through the nanopore is temporarily blocked, resulting in a transient current signal as a molecular signature. The nanopore-based DNA sensing platforms can be classified into two categories: biological nanopores and solid-state nanopores which have their own advantages and disadvantages [2]. However, regardless of the kinds of nanopore sensing platforms used, efficient capture of DNA molecules into nanopores is the basic but challenging operational requirement [3]. Among several factors for improving DNA capture in nanopore-based sensing platforms, controlling surface charge density of nanopore walls is the most effective approach for polymer-based solid-state nanopores because of the availability of different polymers.

In this work, we will study the effect of surface charge density on the capture of double-stranded (ds) DNA molecules into a polymer planar nanopore numerically and experimentally. First, we simulated the effective driving force (F_{eff}) for the translocation of a dsDNA through a planar nanopore with different sizes and surface charge densities (Figure 1). The simulation results were then verified by performing dsDNA translocation experiments using a planar nanopore with 10 nm equivalent diameter imprinted on three polymer substrates having different surface charge densities, e.g. poly(ethylene glycol) diacrylate (PEGDA), poly(methyl methacrylate) (PMMA), and cyclic olefin copolymer (COC) by using nanoimprint lithography (NIL) and thermal bonding (Figure 2). A Si master mold was prepared via a combination of photolithography and focused ion beam milling, which was replicated into two different UV resins (e.g. hydrophobic PFPE (Fluorolink MD 700) for imprinting PEGDA and tri(propylene glycol) diacrylate (TPGDA) for imprinting PMMA and COC) on a PET backbone substrate by using UV-NIL. Using the resin molds, PEGDA was UV-imprinted by exposing to flash-type UV light (250−400 nm) for 1 min at an intensity of ~1.8 W/cm^2. PMMA and COC were thermally imprinted at 135 °C, 3.5 MPa and 160 °C, 5 MPa for 15 min, respectively. For bonding at 70 °C, 1 MPa for 15 min, a thin COC sheet with low T_g (T_g = 78°C) was used as a cover plate for all three planar nanopore substrates. Then, lambda-DNA was electrically driven through the bonded substrates in order to study lambda-DNA capture through the planar nanopores.

Reference:

[1] Haque, F.; Li, J.; Wu, H.-C.; Liang, X.-J.; Guo, P.; "Solid-State and Biological Nanopore for Real-Time Sensing of Single Chemical and Sequencing of DNA" Nano Today 2013, 8, 56-74.
[2] Dekker, C.; "Solid-State Nanopores" Nat. Nanotechnol. 2007, 2, 209-215.
[3] He, Y.; Tsutsui, M.; Fan, C.; Taniguchi, M.; Kawai, T.; "Gate Manipulation of DNA Capture into Nanopores" ACS Nano 2011, 5, 8391-8397.

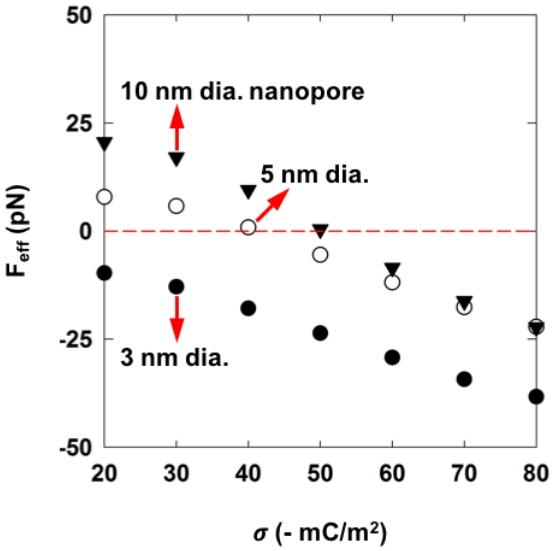

Figure 1. Simulated effective driving force (F_{eff}) for a rod-shaped DNA located at the mouth of nanopores with different pore sizes and various surface charge densities.

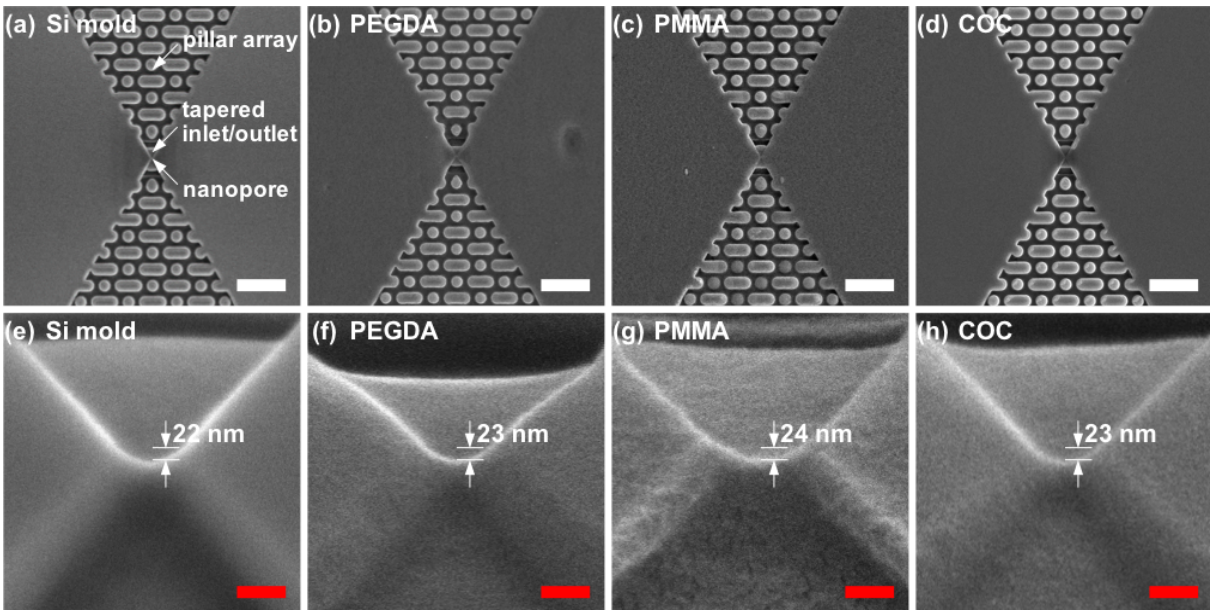

Figure 2. SEM images of Si master mold (a, e) and imprinted planar nanopore on PEGDA (b, f), PMMA (c, g), and COC (d, h) substrates. The scale bars are 3 μm in white and 100 nm in red.