Mechanical Unzipping of DNA Molecules in Parallel Using Nanophotonic Tweezers

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Primary CNF Tools Used: ASML deep ultraviolet stepper, Oxford 100 plasma etcher, Unaxis 770 deep Si etcher, Heidelberg mask writer DWL2000, SÜSS MA6-BA6 contact aligner, Gamma automatic coat-develop tool, LPCVD nitride - B4 furnace, wet/dry oxide - B2 furnace, N2 annealing - B1 furnace, AJA sputter deposition, CVC sputter deposition, GSI PECVD, Oxford PECVD, SC4500 odd-hour evaporator, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

Optical trapping has become a major technique widely used in biological and materials sciences, on size scales ranging from the single molecule to the cellular level, and force scales ranging from sub piconewton (pN) to tens of pN [1]. The rapid development of nanofabrication techniques in the past few decades has bolstered the emergence of nanophotonic evanescent-field traps. The ability of nanostructures to direct and confine light beyond the diffraction limit enables miniaturized, on-chip devices with abilities beyond traditional microscope-based optical tweezers [2,3]. The Wang lab has developed and implemented such an on-chip device based on Si or Si_3N_4 waveguides, coined a nanophotonic standing-wave array trap (nSWAT), that allows for controlled and precise manipulation of trapped single biomolecule (such as DNA) arrays via microparticle handles [4-7]. We present here the latest development of the nSWAT platform based on a resonator design that achieves large enough manipulation forces for mechanical unzipping an array of DNA molecules. This benchmark achievement is one step closer to the full realization of nanophotonic tweezers' capabilities, promising increased accessibility and expansion of these platforms to a wide range of biological and biomedical research topics.

Summary of Research:

Over the past decade, the Wang lab has demonstrated a high-throughput, near-field nanophotonic trapping platform that achieves stable trapping and precision manipulation of microparticles [4-7]. The kernel of this platform is the formation of standing waves along a nanophotonic waveguide: by counter propagating two coherent laser beams along a single mode nanophotonic waveguide. The antinodes of the standing wave form an array of stable optical traps. We call this type of trap a nanophotonic standing-wave array trap (nSWAT). By tuning the phase difference between the two counter-propagating laser beams via thermo-optic effect, the antinode locations can be precisely repositioned, and consequently, the optical trap positions can be precisely manipulated. The nSWAT platform holds the capability for high throughput precision measurements for single biomolecules.

Since 2018, we have implemented major upgrades of the nSWAT platform, including the following three aspects.

(1) We have implemented a resonator-based design for ultimate local intensity enhancement into the nSWAT devices. Compared to previous designs, this resonator design gives the highest force enhancement factor, limited only by the total scattering loss of the trapped beads onto the waveguide. We have measured around four times force enhancement, reaching > 30 pN, significantly larger than our previous force-double design [6].

(2) We have implemented a balanced layout and differential operation mode for the micro heaters. This greatly reduced the response time of the micro heaters (from ~ 30 μs to ~ 1 μs). This is shown to be crucial

for maintaining high trapping forces for a trapped bead under strong biased forces under single molecule manipulations.

(3) We have also designed a special sample holder for the nSWAT chip that can greatly reduce (by two orders of magnitude) the thermal drift of the sample caused by the micro heaters. This greatly enhanced the thermal stability of the nSWAT devices. Thanks to the above described improvements, we have achieved mechanical DNA unzipping on the nSWAT devices for the first time.

In the past year, we have continued optimizing the nSWAT platform to achieve our final goal of unzipping an array of DNA molecules. We have further optimized the flow chamber design of the nSWAT devices to achieve better DNA molecule trapping efficiency. We have also implemented SU-8 layer as the anti-corrosion protection layer for the nSWAT device which works significantly better than the Si_3N_4 protection layer we used before [5]. With all these improvements, we are looking forward to the achievement of trapping and unzipping an array of DNA molecules in the near future. Our development and improvement of the nSWAT platform has led to seven publications in the past few years [2-7], and more to come later this year.

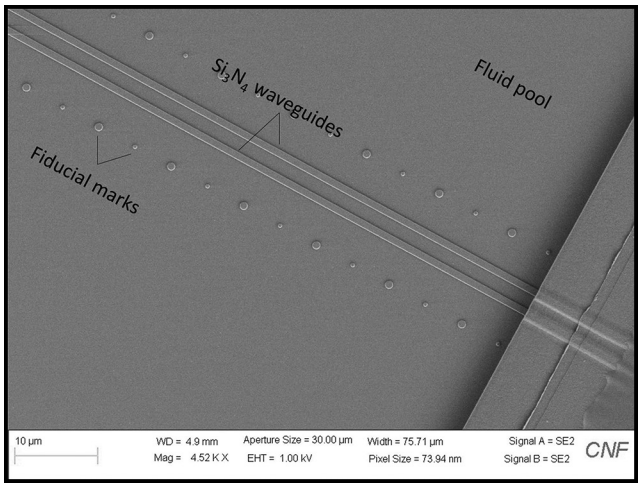

Figure 1: An SEM image of the step boundary of the fluid pool region. Inside the fluid pool region, the two parallel Si_3N_4 waveguides trap two arrays of polystyrene microbeads (380 nm diameter) with DNA molecules tethered in between. The dot arrays near the parallel waveguides are fiducial marks for local position tracking.

References:

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