Resonator Nanophotonic Standing-Wave Array Trap for Single-Molecule Measurements

CNF Project Number: 1738-08

Principal Investigator(s): Michelle D. Wang

User(s): Yifeng Hong

Affiliation(s): a) Department of Electrical and Computer Engineering, Cornell University; b) Department of Physics, Cornell University; c) Howard Hughes Medical Institute

Primary Source(s) of Research Funding: Howard Hughes Medical Institute

Contact: mdw17@cornell.edu, yh874@cornell.edu

Website: http://wanglab.lassp.cornell.edu/

Primary CNF Tools Used: ASML Deep Ultraviolet Stepper, Oxford 100 Plasma Etcher, Oxford 81 Etcher, Oxford 82 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, AJA Sputter Deposition, Oxford PECVD, SC4500 Odd-Hour Evaporator, SC4500 Even-Hour Evaporator, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

Optical trapping force has been the greatest limitation of the nanophototic tweezer platform. To overcome this obstacle, we designed and fabricated a resonator nanophotonic standing-wave trap (RnSWAT) device that supports significant force enhancement. As a result, the maximum force is no longer a limiting factor for standard single-molecule experiments, such as DNA stretching and unzipping. We experimentally demonstrated bound protein localization through unzipping a DNA molecule on the RnSWAT and achieved a maximum trapping force of 20 pN with sub-pN and sub-nm resolution. The RnSWAT is the first reported nanophotonic platform realizing standard table top single-molecule measurements.

Summary of Research:

Our lab developed the nanophotonic standing-wave array trap (nSWAT) device. The nSWAT makes use of two counter-propagating modes to form multiple trapping spots along waveguides [1-7]. The first demonstration of the nSWAT device used a silicon (Si) waveguide (Figure 1) [1]. However, due to the strong non-linear absorption, the laser power cannot be efficiently delivered to the Si waveguide at the trapping region.

To resolve this problem, we developed an Si_3N_4 device coupled with 1064 nm laser for the second generation of the nSWAT (Figure 1) [2]. To generate more force, we designed the waveguide path so that the force would be doubled at the trapping region, which we termed as the double-force nSWAT (Figure 1) [3]. However, these nSWAT devices still could not achieve sufficient force for high-force single-molecule experiments, which typically require at least 15 pN.

Last year, our lab finalized the latest generation of nSWAT. We can now generate ~ 20 pN force using a resonator waveguide loop (Figure 1) [7]. The resonator nSWAT wavegudies were patterned with deep ultraviolet

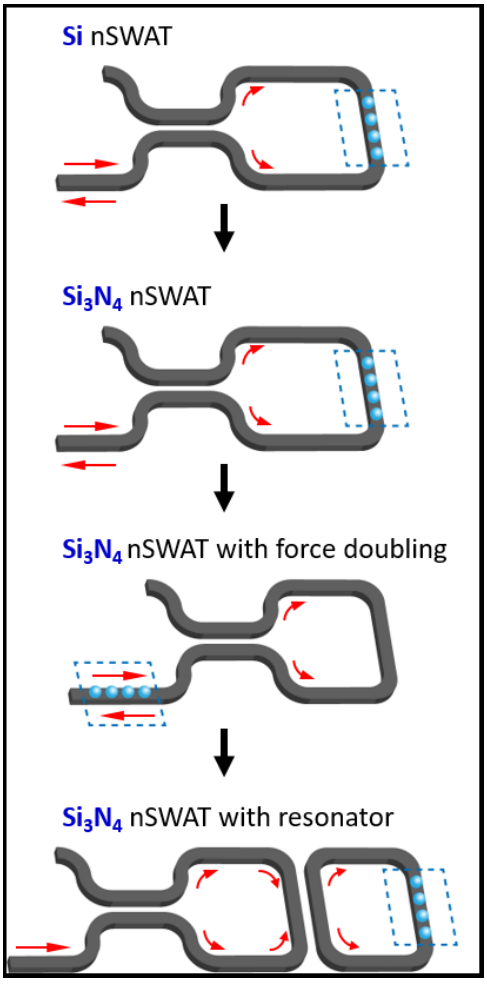

Figure 1: Development progression of the nSWAT platform. Gray structures denote waveguides, and red arrows indicate light propagation [7].

(DUV) lithography. Multiple heaters were deposited on the waveguides (isolated with SiO_2 protection layers) to realize the control of the standing-wave position as well as the resonance condition.

A 15-μm tall and 100-μm wide SU-8 flow channel was patterned to allow the biological sample injection to the waveguides at the trapping region (Figure 2). The resonator nSWAT was then used for single-molecule measurements.

We demonstrated simultaneous unzipping of five DNA molecules [7]. The capability of unzipping through DNA molecules opened up the opportunity of more advanced single-molecule measurements, such as protein localization. We also demonstrated high-throughput ZraI/dCAS9 localization at base-pair resolution with the DNA unzipping mapper technique on the resonator nSWAT [7]. We believe the resonator nSWAT can be a fundamental platform for a broader range of single-molecule applications.

Figure 2: SEM of the fluid pool containing waveguides of the trapping region. The scattering gratings of the four light intensity samplers from the two resonators are clearly visible. Scale bar is 20 μm [7].

References:

[1] M. Soltani, J. Lin, R. A. Forties, J. T. Inman, S. N. Saraf, R. M. Fulbright, M. Lipson, and M. D. Wang, "Nanophotonic trapping for precise manipulation of biomolecular arrays" Nature Nanotechnology 9(6), 448-452 (2014).

[2] F. Ye, R. P. Badman, J. T. Inman, M. Soltani, J. L. Killian, and M. D. Wang, "Biocompatible and high stiffness nanophotonic trap array for precise and versatile manipulation" Nano Letters 16(10), 6661-6667 (2016).

[3] F. Ye, M. Soltani, J. T. Inman, and M. D. Wang, "Tunable nanophotonic array traps with enhanced force and stability" Optics Express 25 (7) 7907-7918 (2017).

[4] J. E. Baker, R. P. Badman, and M. D. Wang, "Nanophotonic trapping: precise manipulation and measurement of biomolecular arrays" WIREs Nanomed Nanobiotechnol. e1477 (2017).

[5] R. Badman, F. Ye, W. Caravan, and M. D. Wang, "High Trap Stiffness Microcylinders for Nanophotonic Trapping" ACS Appl. Mater. Interfaces 11(28), 25074-25080 (2019).

[6] R. Badman, F. Ye, and M. D. Wang, "Towards biological applications of nanophotonic tweezers", Current Opinion in Chemical Biology, 53, 158-166 (2019).

[7] F. Ye, J. T. Inman, Y. Hong, P. M. Hall, M. D. Wang, Resonator nanophotonic standing-wave array trap for single-molecule manipulation and measurement. Nat. Commun. 13, 77 (2022).