Nanophotonic Standing-Wave Array Trap for Single-Molecule Applications

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, Chevy Chase, Maryland

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

Contact(s): mdw17@cornell.edu, yh874@cornell.edu

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

Primary CNF Tools Used: ASML DUV 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, CVC SC4500 odd--even hour evaporator, Zeiss Supra SEM, Zeiss Ultra SEM

Abstract:

As a fundamental tool in single-molecule science, optical tweezers have been used broadly for decades. The Wang Lab has developed a nanophotonic standing-wave array trap (nSWAT) device, which integrates the functions of a conventional microscope-based optical tweezer into a centimeter-scaled chip. Here, we present our latest progress on nSWAT applications, focusing on high enough force generation. This increased force enables us to unzip an array of DNA molecules along the waveguide, thus providing a platform for parallel single-molecule measurements.

Summary of Research:

In the past few years, the Wang Lab has been working on developing the nanophotonic standing-wave array trap (nSWAT) device, aiming for high-throughput single-molecule manipulations and measurements [1-6]. In principle, the nSWAT is generated by the interference of two counter-propagating waves along a single-mode waveguide. Polystyrene beads attached to biomolecules like DNA can be trapped within the antinodes of the near-field evanescent waves at the waveguide surface (Figure 1). As a result, those biomolecules can be manipulated in parallel by modulation of the trapping array. For instance, a simple application of parallel DNA molecule sorting has been demonstrated [2].

To further make use of the nSWAT platform for fundamental single-molecule studies, such as an unzipping assay for protein-DNA interaction, we have to overcome the force limitation of the existing nSWAT. Recently, a more advanced version of the Si_3N_4 nSWAT (operated at 1064 nm laser) [3] has been developed to enhance the maximum trapping force applied to the biomolecules, and includes features such as minimized absorption and bending loss as well as a fastest heater reset time. Increased trapping force enables us to unzip DNA molecules, and expands opportunities to study protein-DNA interaction in a high-throughput manner.

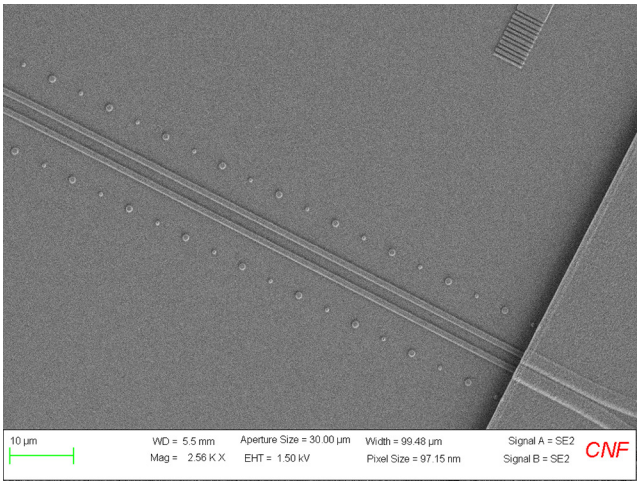

Figure 1: An SEM image of the waveguides at the trapping region (fluid pool). A standing wave is generated along each waveguide, forming a trapping array for 380 nm polystyrene beads. The dot arrays near the waveguides are fiducial marks for monitoring the global drifting during operation. (See cover for more detail.)

So far, this technique has been applied to locate a bound protein with nearly nm spatial resolution, which serves as a benchmark of on-chip optical trapping techniques. We hope this high-throughput technique can become a fundamental tool in other aspects of biological studies.

The achievements based on the nSWAT have led to six publications [1-6]. The latest demonstration of unzipping DNA to map a bound protein has been submitted for publication this year.

References:

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

[2] 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).

[3] 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).

[4] 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).

[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).