Creating an On-Chip and High Throughput Alternative to Optical Tweezers

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Abstract:

Optical trapping is one of the most common and useful measurement techniques in single molecule biological research. Current optical trapping devices typically use free space optical tweezer laser traps, which only provide low throughput, single measurements that can often take hours or days. An alternative to free space lasers is trapping in the evanescent field sharply decaying away from nanophotonic waveguide surfaces. The Nanophotonic Standing Wave Array Trap (nSWAT) created by the Wang lab is one such on-chip evanescent trap device that can provide much higher throughput measurements than free space traps, with potentially comparable trapping force. In order for the trapping force per trap in the nSWAT to match the specifications of traditional optical tweezers, higher index of refraction materials with negligible non-linear absorption effects are needed for the waveguide and the nanoparticles. Previous work utilized silicon waveguides and polystyrene beads for the nSWAT [1], but silicon had problematic non-linear absorption that limited trapping force, and polystyrene has a low refractive index. In this report we have explored both the fabrication and measurements of high refractive index waveguides and nanoparticles for higher force nSWAT trapping.

Summary of Research:

Optical tweezers are a tool commonly used to obtain "force spectroscopy" measurements through DNA stretching. Measuring DNA lengths at different forces can reveal the identities and dynamics of DNA binding proteins. The Nanophotonic Standing Wave Array Trap (nSWAT) created by the Wang lab [1], is a high throughput device that holds hundreds of optical trap centers allowing hundreds of DNA force measurements to be performed simultaneously, see Figure 1. The nSWAT can potentially provide DNA stretching with the full force range of traditional optical tweezers. To achieve higher trapping forces, a number of parameters must be optimized, such as an increase in laser power (requiring higher power tolerance waveguide materials), an increase in the refractive index of the waveguide, and an increase in the refractive index of the trapped nanoparticle.

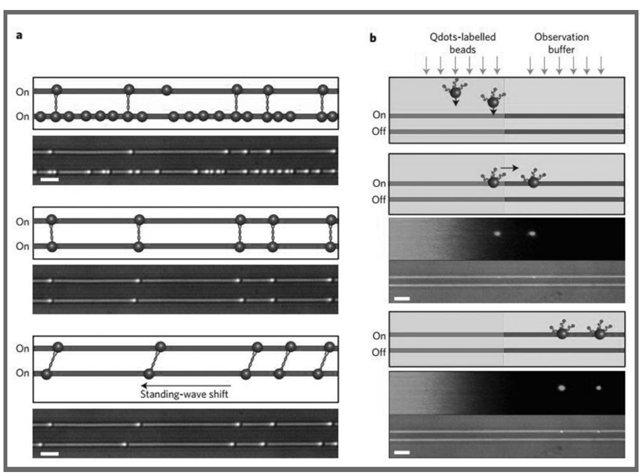

Figure 1: DNA dumbbells, formed with deoxyribonucleic acid (DNA) tethered between two polystyrene (PS) beads, being trapping and manipulated along two parallel waveguides in a nSWAT device. See Ref. [1] for more information. Reproduced with permission from Ref. [1].

Waveguides. To increase the trapping force of the nSWAT, one goal was to create low loss high index of refraction waveguides. Previously, silicon waveguides were used in the nSWAT [1], however to further increase the trapping force, tantalum pentoxide (Ta_2O_5) waveguides were fabricated this summer due to its high index of refraction (2.15 at 1064 nm), and its ability to couple 3 W or higher of 1064 nm laser power [2], relative to silicon which can only tolerate a few hundred mW of power [1].

The tantalum pentoxide films were optimized by radio frequency (RF) sputtering an oxide target in the AJA sputter deposition tool. To determine the loss of the Ta_2O_5 thin film, the Metricon prism coupler was employed. The waveguides were then etched with the Oxford 100 plasma etcher (see Figure 2) and the loss after fabrication was measured using infrared measurements.

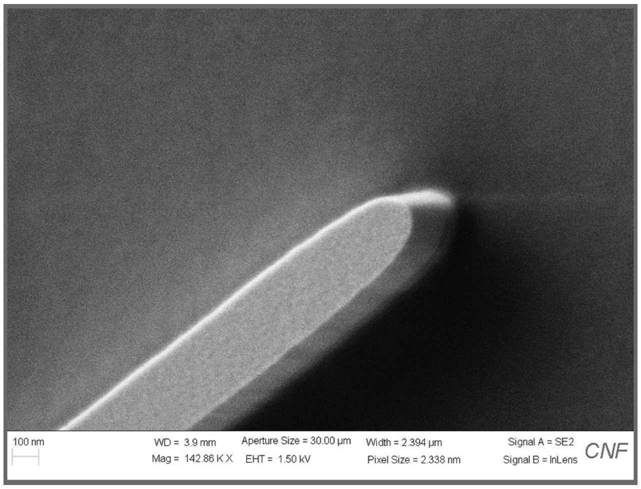

Figure 2: Scanning electron microscope (SEM) image of the tapered ends of an ultra low loss tantalum pentoxide waveguide.

The Metricon prism coupler measured an ultra-low film loss of << 1 dB/cm. Through infrared measurements the final waveguide propagation loss was found to be 0.46 ± 0.19 dB/cm, with the added loss contributions coming from the presence of bends in the waveguide pattern (higher loss than straight waveguides) and the small roughness induced from waveguide etching. We thus achieved our goal of creating a waveguide below 1 dB/cm loss at 1064 nm.

Nanoparticles. The nanoparticles tethered to DNA also need high index of refraction for an increase in trapping force. Traditionally, polystyrene beads (n=1.55-1.59 at 1064 nm) [1] are used for optical trapping, however the trapping force can be approximately three times higher with silicon nitride nanoparticles (n=2.0) or five times higher with titania nanoparticles (approximately n=2.3). Four types of shapes for the nanoparticles can be used on the nSWAT: spheres, disks, and long and short cylinders. All four shapes were made and tested this summer to determine which will provide the highest force, see Figures 3 and 4 for examples of the novel non-spherical shapes.

Titania nanospheres were created through the reproduction of a previous 2004 paper [3]. The beads were then placed in phospate buffered saline (PBS) to increase the size and stability of the nanospheres. The titania nanospheres were tethered to DNA for stretching which demonstrated that titania, although photocatalytic, does not damage DNA during typical experimental time periods. The stability and size of the beads were determined using the Zetasizer in the Nanotechnology Center (NBTC). The titania nanodisks and silicon nitride nanocylinders were fabricated through a new method and will be tested on waveguides, details will be disclosed in a future publication.

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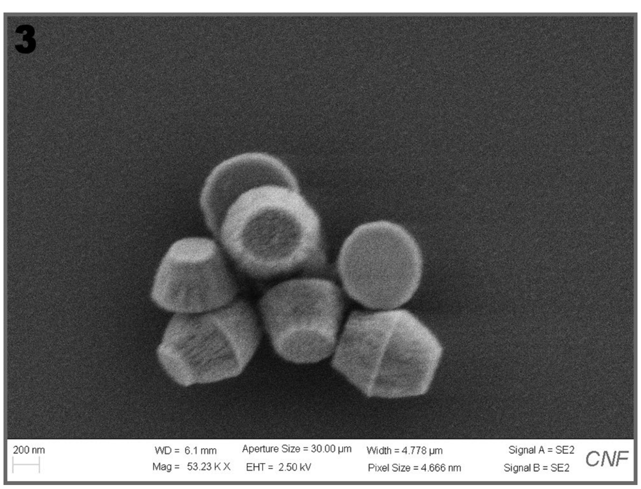
References:

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

[2] B. S. Ahluwalia, O. G. Helleso, A. Z. Subramanian, N. M. B. Perney, N. P. Sessions, J. S. Wilkinson "Fabrication and optimization of Tantalum pentoxide waveguides for optical micro-propulsion," Proc. SPIE 7604, Integrated Optics: Devices, Materials, and Tech. XIV, 76040W (2010).

[3] Eiden-Assmann, S., J. Widoniak, and G. Maret. "Synthesis and characterization of porous and nonporous monodisperse colloidal TiO_2 particles." Chemistry of Materials 16.1 (2004): 6-11.



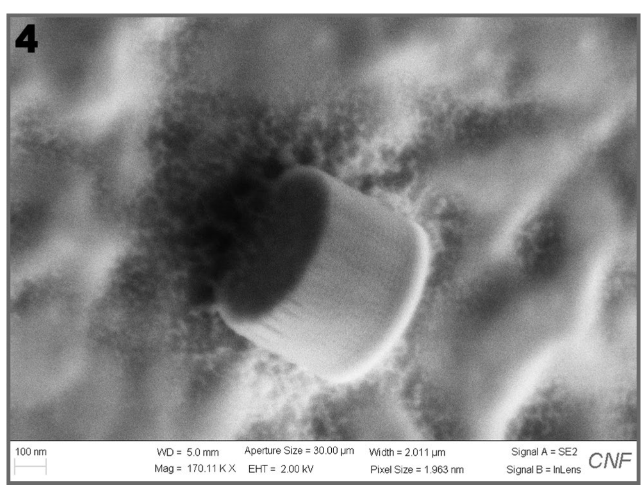


Figure 3, left: *SEM of highly uniform TiO_2 trapezoidal disk nanoparticles fabricated for high force trapping on a waveguide.*
Figure 4, right: *SEM example of straight-side-wall cylinder Si_3N_4 nanoparticle fabricated for high force trapping.*