# Optical Tweezing of Microspheres and Cells Using Integrated Optical Phased Arrays

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***Abstract*—We demonstrate optical trapping and tweezing of microspheres and cancer cells using an integrated optical phased array for the first time, representing a two-orders-of-magnitude increase in the standoff distance of integrated optical tweezers and the first cell experiments using a single-beam integrated optical tweezer.**

***Keywords—integrated optical phased arrays, optical tweezers, silicon photonics***

## I. Introduction and Motivation

Optical trapping and tweezing has garnered significant interest as a preferred technology for the non-contact manipulation of cells and microscale particles, producing impactful research for applications including cell classification, force sensing, and characterization [1-2]. However, the cost, size, and complexity of these tools when using standard bulk-optical components has limited their utility. As an alternative, the development of on-chip optical traps has been pursued, using evanescent fields from waveguides, resonators, and plasmonic devices [3-4]. While these systems have offered significant advantages in cost, form factor, and complexity, they have been restricted to trapping within microns of the chip surface, which limits their widespread adoption in practical biophysics experiments and for in-vivo applications that require mm-scale standoffs. Moreover, many of these systems have been fundamentally limited to passive demos that lack active spatial tuning, necessary for object tweezing and manipulation.

In contrast, integrated optical phased arrays (OPAs), which enable emission and non-mechanical control of arbitrary free-space radiation patterns from compact photonic chips, have the potential to resolve these limitations. Specifically, they provide a promising approach to extending the standoff operating distance, enabling spatial tuning for tweezing, and expanding to multi-beam capability for sorting. However, motivated by applications such as LiDAR sensing, the majority of integrated OPA demonstrations to date have been limited to generating and steering beams in the far field [5], which do not generate the tightly-focused beam profiles required for optical trapping. Recently, our group demonstrated the first integrated OPAs that enable these focusing beam profiles [6].

In this work, we demonstrate integrated OPA-based optical trapping and tweezing for the first time. The OPA system focuses the emitted light and provides a steerable potential-energy well that can be used to trap and tweeze microscale particles (Fig. 1a-b). Using this approach, we increase the standoff distance of integrated optical tweezers by over two orders of magnitude compared to prior demonstrations and show trapping and non-mechanical tweezing of polystyrene microspheres 5 mm above the surface of a silicon-photonic chip. We then use the tweezer to stretch mouse lymphoblast cells, showing, to the best of our knowledge, the first cell experiments using a single-beam integrated optical tweezer.

## II. Focusing Integrated OPA Architecture

The near-field-focusing integrated OPA [6] was fabricated in a CMOS-compatible foundry process at the SUNY Polytechnic Institute. At the input, an inverse-taper edge coupler couples light from a 1550-nm-wavelength off-chip tunable laser source into an on-chip silicon waveguide. A 9-stage splitter tree network then distributes the input power to 512 waveguide arms with a final pitch of 2 μm. Each arm is terminated with a 0.9-mm-long grating-based antenna that radiates the light upwards out of the chip. Before each antenna, a phase bump structure is placed to encode a static hyperbolic phase distribution (Fig. 1d) that enables focusing of the off-chip emission in the array dimension. Additionally, the antenna period is adiabatically chirped to enable focusing in the antenna dimension. The OPA architecture is shown in Fig. 1c. Additional details on the focusing integrated OPA are provided in [6].

## III. Optical Trapping and Tweezing Results

To characterize our integrated OPA-based optical trap, the trap chip is mounted beneath a sample stage, and light is coupled onto the chip from a tunable benchtop laser.

To demonstrate optical trapping, we use samples consisting of two coverslips separated by a thickness of 375 μm, into which a 5.5% v/v solution of 10-μm-diameter polystyrene microspheres suspended in deionized water is pipetted. The sample is clamped into the stage, and a target sphere is moved into the focal spot of the trap, where its motion is recorded for 75 sec. To verify that the motion of the sphere is reduced specifically due to the trap, the laser is turned off, and the sphere's motion is recorded for an additional 75 sec. Using the TrackMate plugin for ImageJ [7], we track the motion of a group of microspheres, of which the middle sphere is trapped, as shown in Fig. 1e.

To quantify the trap's stiffness, we use the equipartition theorem and the mean squared displacement of spheres in the trap, measured using TrackMate [7-8]. We perform four repeated measurements over a range of input powers. As shown in Fig. 1f, the results follow the expected linear trend, with error bars calculated as the standard error of the measurements.

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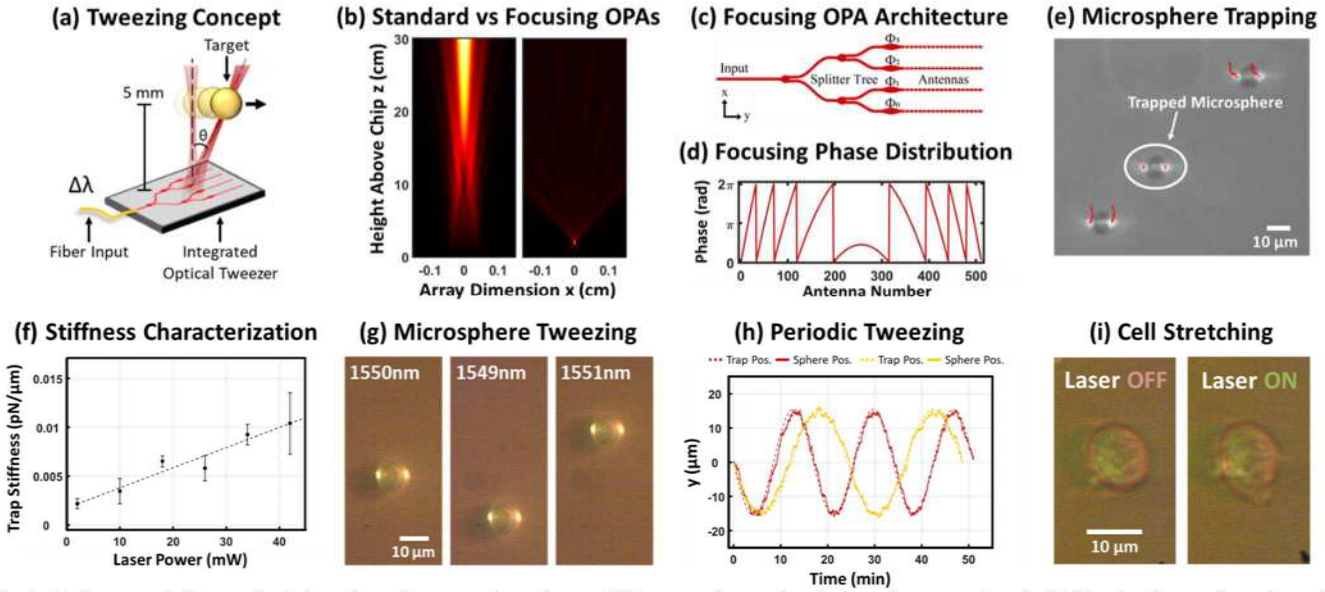


Fig. 1. (a) Conceptual diagram depicting microsphere tweezing using an OPA tweezer by varying the input laser wavelength. (b) Simulated array-factor intensity above the chip for a standard non-focusing OPA (left) and near-field-focusing OPA with a 20-mm focal height (right). (c) Schematic of a passive splitter-tree-based focusing OPA architecture with 4 antennas. (d) Element phase distribution for a focusing OPA with a 20-mm focal height, 512 antennas, 2-μm antenna pitch, and 1550-nm wavelength. (e) Microscope image of microspheres in a sample well with superimposed tracks showing their motion over time (red lines); the motion of the microsphere located at the focal spot of the OPA (circled in white) is significantly reduced compared to its neighbors, indicating successful trapping. (f) Measured trap stiffness versus optical power for polystyrene microsphere trapping; error bars are found by calculating the standard error of the dataset. (g) Microscope image showing the position of a microsphere for input wavelengths of 1550nm (left), 1549nm (center), and 1551nm (right); the position varies with input wavelength, confirming successful tweezing. (h) Position of the spot formed by the optical trap (dashed line) and position of the optically tweezed microsphere (solid line) versus time for two different sinusoidal wavelength control signals, demonstrating consistent tweezing over arbitrary 1D patterns. (i) Microscope image showing a TIB-49 mouse lymphoblast cell trapped in the focus of the optical trap (left); the wavelength of the input laser is reduced by 0.6nm, steering the trap focus in the y direction below the cell, resulting in the cell being stretched downward by the movement of the trap (right).

To transform the system from a static trap to a dynamic tweezer, we leverage the non-mechanical spot steering capability of our OPA system. Specifically, we vary the wavelength of the laser input into the OPA system to steer the location of the spot emitted by the OPA, resulting in the microsphere successfully following its motion. To demonstrate that the microsphere can be steered in arbitrary patterns in one dimension, we show repeated tweezing of the microsphere in a sine-wave pattern with two different frequencies (Fig. 1g-h).

Finally, we use the OPA system to perform, for the first time, cell experiments with a single-beam integrated optical tweezer, showing controlled deformation of cells. We culture TIB-49 mouse lymphoblast cells in RPMI-1640 media with 10% Fetal Bovine Serum and 1% 10,000 U/mL Penicillin-Streptomycin. We incubate the cells at 37°C in a humidified 5% CO2 incubator and pipette them into a sample well. We position a cell in the optical trap and steer the trap in the y direction in the focal plane. We record the cell and observe that its bottom edge is attracted to the new trap position (Fig. 1i), leading to an increase in the cell aspect ratio of over 25% along its long axis. Upon turning off the laser, the cell relaxes to its prior unstretched state.

## IV. Conclusions and Acknowledgements

This work introduces a new paradigm for integrated optical tweezers, presenting a fundamentally different approach based on integrated OPAs that enables significantly larger standoff distances and arbitrary active tweezing functionality. This OPA-based approach combines the advantages in cost, footprint, complexity, and throughput of integrated tweezers with the functionality of state-of-the-art bulk-optical systems. It thus represents a significant improvement in the utility and compatibility of integrated optical tweezers for biological research and opens the door to a variety of experiments that have not been previously possible with prior implementations of integrated tweezers, spanning biophysics research with microsphere-conjugated molecules, cell experimentation, high-throughput cell sorting, and emerging in-vivo trapping research.

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