Optoelectronic Tweezers for Nanomanipulation

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Abstract Optoelectronic tweezers is a new optical manipulation technique to trap particles with sizes of tens from nanometers to hundreds of micrometers. This paper will review the principle and highlight recent advances in manipulating semiconductor nanowires.

Introduction *Optoelectronic* tweezers (OET) is a new optical manipulation technique to trap, transport, and assemble micro- and nanoscopic particles [1]. Using optically-controlled dielectrophoretic force, OET enables complex, dynamic manipulation functions using light intensities that are 100,000 times lower than that of conventional laser tweezers [2]. Large-area parallel manipulation is achieved by projecting the control pattern with a spatial light modulator. We have successfully generated 30,000 individually addressable optoelectronic traps using a digital-micromirror-device (DMD) projector [1]. This paper will review the principle and device design of the OET, and highlight recent advances in manipulating semiconductor nanowires [3].

Optical Tweezers, Dielectrophoresis, and Optoelectronic Tweezers

Optical tweezers and dielectrophoresis (DEP) are two commonly used manipulation techniques for micro and nanoscopic particles. The optical tweezers, invented by Arthur Ashkin in 1986 [2], uses optical gradient forces to confine particles, as illustrated in Fig. 1 [4]. It is effective in trapping particles as small as tens of nanometers, and is widely used in research laboratories. However, the high laser intensity (10^5 to 10^7 W/cm^2) limits the number of parallel traps and its use in trapping organic particles (e.g., cells). The tight focusing requirement also restricts its working area (~ 100x100 μm^2). The electrical analog of optical tweezers is DEP [5], which relies on the gradient of an electric field, rather than an optical field (Fig. 2). Dielectrophoretic force results when the interaction of the electric field gradient with the induced dipole of particles within the field produces a net force on the particles. However, the fixed electrode patterns in conventional DEP devices limit their flexibility.

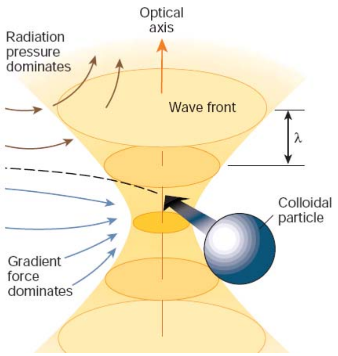

Fig. 1 Schematic of single-beam optical tweezers. Particle is trapped by optical gradient force.

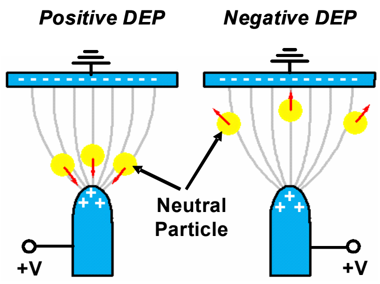

Fig. 2. Schematic illustrating dielectrophoresis (DEP) resulted from electric gradient force.

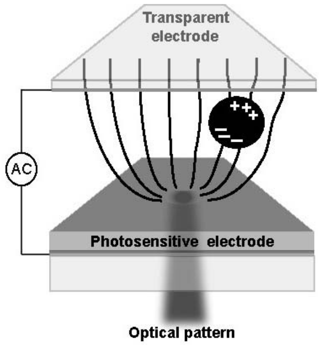

Fig. 3. Schematic of optoelectronic tweezers (OET), or optically-induced DEP.

Recently, we have demonstrated a new optical manipulation technique that combines the advantages of both optical tweezers and DEP, resulting in optically-induced dielectrophoresis [1]. This technology, which we call optoelectronic tweezers (OET), uses a photoconductive surface to control the electric field landscape optically. The resulting non-uniform electric field then generates a DEP force on particles in the OET device (Fig. 3). As optical energy is not directly used for trapping, much lower optical intensities can be used as compared to optical tweezers, in the range of 0.1 to 100 W/cm^2. These optical intensities can be achieved by a computer projector or an LED, allowing the creation of complex optical manipulation patterns. In addition, the optical gradient force is no longer required, relaxing the focusing requirements and allowing the use of low numerical aperture lenses. As a result, in our current configuration, the effective manipulation of OET is 500 times larger than that of a typical optical tweezers setup. Furthermore, since the manipulation patterns are controlled optically, OET retains the flexibility and dynamic control enjoyed by optical tweezers. Unlike electrode-based DEP, OET is capable of trapping a *specific* single particle from a larger population.

The OET device consists of a bottom photosensitive electrode and a top transparent indium-tin-oxide (ITO) electrode. The liquid containing the particles of interest is sandwiched between these two electrodes. Our initial experiments

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used a 1-μm-thick amorphous Si as the photosensitive electrode. An AC voltage bias is applied across the electrodes. Depending on the compositions of the particles and the media, and the bias frequency, the OET force can be either attractive (positive) or repulsive (negative).

Trapping of Single Semiconductor Nanowires:

Recently, we have successfully trapped individual semiconductor as well as metallic nanowires with diameters of 100 nm and length of several microns. Nanowires have high aspect ratio, and their polarizability along the length direction is about three orders of magnitude larger than the spherical nanoparticles with the same diameter, resulting in large OET force. The nanowires experience positive OET force. We have successfully trapped and transported single nanowires using a 100-μW HeNe laser source. It is interesting to note that even with an optical beam size of 10 μm, we are able to separate nanowires spaced by less than 1 μm by moving the light spot. A maximum speed of 135μm/sec is obtained at 20 Vpp.

Conclusions

We have described a new optical manipulation technique called optoelectronic tweezers (OET). It combines the advantages of optical tweezers and dielectrophoresis, and is capable of trapping and transporting colloidal particles with diameters of tens of nanometers to hundreds of micrometers by light. Trapping of individual semiconductor nanowires with 100-nm diameter has been achieved.

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