Trapping and Transport of Silicon Nanowires Using Lateral-Field Optoelectronic Tweezers

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Abstract: We present a new optoelectronic tweezers device that produces electric fields parallel to the plane of the device. This device is capable of trapping and transporting p-type silicon nanowires at velocities of 20 μm/s.

OCIS codes: (170.4520) Optical confinement and manipulation; (230.3990) Microstructure devices

1. Introduction

Optically-induced dielectrophoresis, or optoelectronic tweezers (OET), provides a powerful, flexible method of manipulating microparticles and cells [1]. The OET device uses optical images to pattern an electric field landscape, resulting in a tool that is more flexible than microelectrode-induced dielectrophoresis [2], yet has a larger effective manipulation area than optical tweezers [3], while using 100,000 times less optical power density. In the current OET device, rod-shaped particles, such as silicon nanowires, align with the electric field, which is perpendicular to the photosensitive electrode surface [4]. Thus, in order to observe the long axis of rod-shaped particles, it is necessary to create an electric field in the lateral direction, parallel to the plane of the device surface.

In this paper, we demonstrate a new OET device that creates lateral electric fields on a single-sided device (Fig. 1a). While this lateral-field OET device (LOET) uses the same mechanism as conventional OET, optically-induced dielectrophoresis, the capabilities of LOET are substantially different, offering new functionality. The LOET device retains the flexibility and capabilities of a standard OET device (Fig. 1b), while enabling the manipulation of rod-shaped particles with the long axis parallel to the plane of the device. This ability means that LOET can be used in applications such as the assembly of nanowires in nanoelectronic circuits. Furthermore, the LOET device is implemented on a single photosensitive electrode surface, allowing greater flexibility for integrating LOET with other microelectronic or microfluidic devices. The electrode dimensions can be optimized for the manipulation of a particular particle type, such as nanowires.

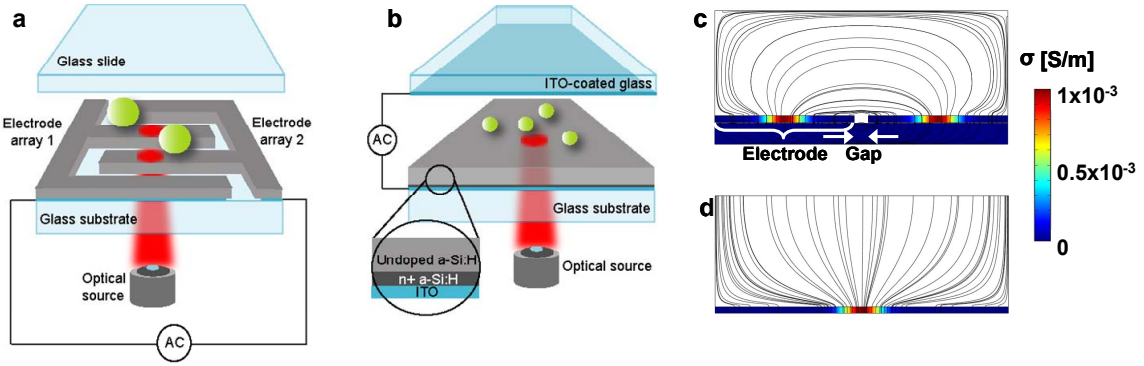

Fig. 1. (a) Lateral-field optoelectronic tweezers device (LOET), which consists of a photosensitive interdigitated electrode array on a glass substrate. (b) Standard optoelectronic tweezers (OET) device, which produces an electric field perpendicular to the plane of the device. Simulated electric field profile (streamlines) in the (c) LOET device and (d) OET device. The high-conductivity areas represent the illuminated portions of the device. The electric field lines are primarily in the lateral direction in the LOET device, and primarily in the vertical direction in the OET device.

2. Lateral-field optoelectronic tweezers design

The LOET device consists of interdigitated photosensitive electrodes on a glass substrate (Fig. 1a). The photosensitive electrodes consist of 100-nm-thick layer of indium-tin-oxide (ITO), a 50-nm-thick layer of heavily doped hydrogenated amorphous silicon (a-Si:H), and a 1-μm-thick layer of undoped a-Si:H. When not illuminated, the a-Si:H has a conductivity of 0.3 μS/m. However, under an illumination of 2 W/cm^2, the a-Si:H experiences a

large increase in conductivity, to 1 mS/m. Thus, the a-Si:H layer functions as a light-controlled virtual electrode; the illuminated area switches from a high-impedance state to a low-impedance state. An ac voltage is applied across the electrodes, creating a potential difference. A negligible electric field exists in the liquid solution if no optical pattern is projected onto the LOET device, as the electrodes are in a high-impedance state. However, if optical patterns are projected onto the electrodes, the electrodes are switched to a low-impedance state, switching the electric field to the liquid solution. The position of the electric field across the electrodes is controlled via the optical patterns. The electric field is non-uniform, as it is strongest only in the illuminated areas of the electrodes. This field gradient generates a dielectrophoretic (DEP) force, via optically-induced dielectrophoresis [1].

Although the force produced is similar to that of conventional OET, the directions of the electric field lines in the LOET device are predominantly parallel to the plane of the electrodes (Fig. 1c). In contrast, the electric field lines in a conventional OET device are normal to the photoconductive surface (Fig. 1d). Oblong particles that have a major axis significantly longer than the minor axis will line up with the electric field lines as a result of torque on the dipole of the particle.

3. Experimental

Silicon nanowires of varying diameters (50 to 200 nm) and lengths (5 to 50 μm) were fabricated by etching a silicon wafer [5]. The nanowires are suspended in deionized water by sonification. Potassium chloride is added to the nanowire suspension to adjust the conductivity to 1.5 mS/m. A 20-μL aliquot of the nanowire solution is introduced into the LOET device. The LOET devices used for nanowire manipulation had electrodes that were 20 μm in width, separated by 2 μm gaps. The electrodes were biased at 5Vpp at 50kHz. The optical source was a 650-nm diode laser, at an intensity of 10 W/cm^2.

Initially, no ac bias was applied to the LOET device. Using dark-field microscopy, randomly oriented nanowires were observed near the surface of the LOET device (Fig. 2a). Individual nanowires were identified, and the optical pattern was positioned near a specific nanowire (Fig. 2b). The ac bias was then applied, activating the LOET device and creating DEP force. The nanowire experiences an attractive force, and becomes trapped in the illuminated area. After the nanowire has been trapped, it can be transported across the LOET surface at a velocity of 20 μm/s (Fig. 2c). The initial position of the nanowire trapping and the final position of the nanowire after transport are shown in Fig. 2d.

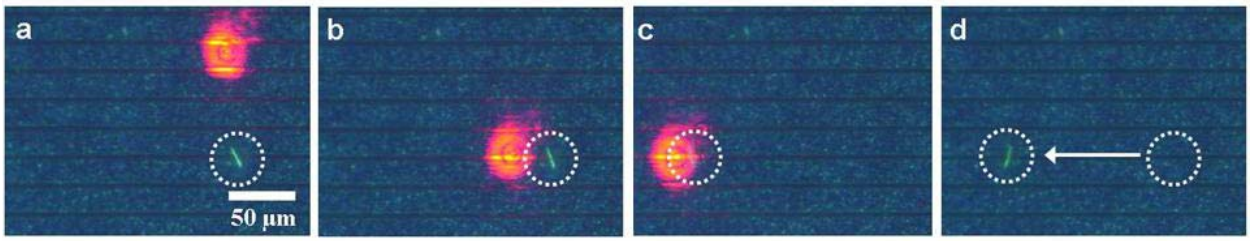

Fig. 2. Trapping and transport of Si nanowires in the LOET device. (a) The initial position of a Si NW, with the electric field turned off. The laser spot is visible in the upper right. (b) The laser is moved closer to the nanowire. This frame is immediately before the electric field is switched on; after the electric field is applied, the nanowire is attracted towards the laser. (c) The trapped nanowire is transported by scanning the laser spot at up to 20 μm/s. (d) The laser is switched off to show the final position of the nanowire in greater clarity. The initial position is also indicated; the direction of the transport is shown by the arrow.

4. References

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