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PARALLEL ASSEMBLY OF NANOWIRES USING LATERAL-FIELD OPTOELECTRONIC TWEEZERS

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ABSTRACT

We report on the parallel manipulation and assembly of nanowires using paired virtual optical tips projected on lateral-field optoelectronic tweezers. Precise position and angular control has been demonstrated on four 80-nm-diameter silver nanowires.

INTRODUCTION

An ongoing challenge for the mass production of nanowire-based electronics is the controlled assembly of single nanowires. Nanowire fabrication using "bottom-up" approaches presents difficulties to integration with heterogeneous material systems. Post-synthesis integration circumvents these issues, but has its own limitations. Post-synthesis assembly of individual nanowires and carbon nanotubes has been demonstrated using mechanical manipulators [1, 2] and optical tweezers [3, 4]; however, the parallel processing capabilities of these tools are limited. Single nanowires have also been assembled using the dielectrophoretic forces produced by microfabricated metal electrodes, but the trap locations and trapping patterns are static [5]. Optoelectronic tweezers uses optically-induced dielectrophoretic forces to assemble single nanowires in parallel, but is limited to aligning nanowires in a direction normal to the photoconductive surface of the device [6]. Using a lateral-field optoelectronic tweezers device (LOET), we demonstrate the parallel assembly of single nanowires, with control over the nanowire position and rotational orientation. This technology has the potential to fabricate nanowire electronics in a parallel assembly process.

LATERAL-FIELD OPTOELECTRONIC TWEEZERS (LOET)

Nanowires in an electric field experience a torque on their induced dipole, aligning them in parallel to the electric field lines. Thus, in order to use optoelectronic tweezers to assemble nanowires parallel to the plane of a substrate, electric fields must be generated laterally across the device surface. This is achieved using a lateral-field optoelectronic tweezers device. We have previously demonstrated nanowire trapping using an LOET device [7, 8]; however, this device did not provide control over the rotational orientation of the nanowires.

A new version of the LOET device has been fabricated that provides control of the in-plane orientation of nanowires. This device consists of an interdigitated array of 100-nm-thick aluminum electrodes on an oxidized silicon wafer (Fig. 1a). A 0.75-µm-thick amorphous silicon (a-Si) layer is blanket deposited over the aluminum electrodes using plasma-enhanced chemical vapor deposition. The electrode fingers are separated by gaps of 10 or 25 µm. The gap between the electrodes forms the active area for nanowire assembly.

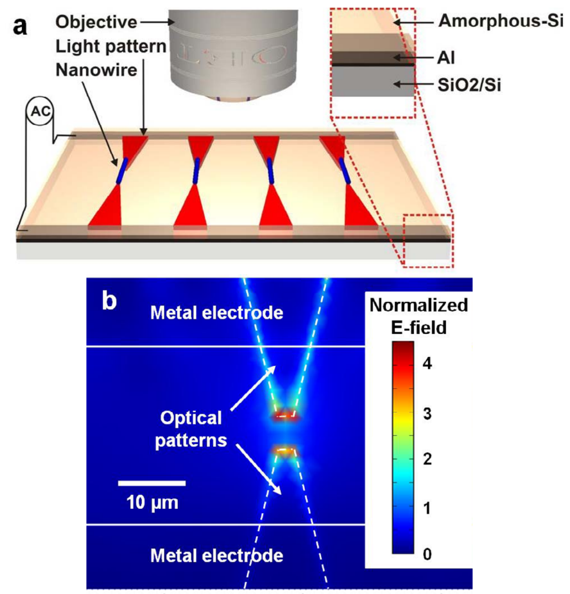

Fig. 1. (a) Schematic of lateral-field optoelectronic tweezers (LOET) for nanowire assembly. The device consists of an unpatterned amorphous silicon layer over an aluminum electrode array, fabricated on an oxidized silicon wafer. Paired triangular optical patterns create nanowire traps in between the metal electrodes. (b) Finite-element simulation of the electric field profile across the LOET electrodes.

The principle of operation for this version of the LOET is different from previous devices. An AC bias is placed across the electrode arrays, resulting in a uniform electric field between electrode fingers. To create a nanowire trap, optical patterns created by a digital micromirror device (DMD) are projected onto the LOET device. The optical patterns act as virtual electrodes by lowering the impedance of the a-Si in the illuminated areas. Thus, the optical patterns function as extensions of the metal electrodes. Paired triangular patterns are used to create a strong electric field gradient at the tips of the illuminated areas (Fig. 1b). The nanowires are attracted to these areas of strong electric field, and align between the triangular patterns. A typical triangular optical pattern has a tip diameter of 2 µm and a taper angle of 14 degrees. The gap between

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paired triangular patterns is adjusted to approximate the length of the trapped nanowire, which is typically 5 µm.

NANOWIRE ASSEMBLY

Silver nanowires with diameters of 80 to 100 nm and lengths of 1 to 10 µm were suspended in ethanol, and introduced into the LOET device. The optical patterns can be used to transport nanowires parallel to the plane of the LOET device, and can control the nanowire orientation in both the *x*- and *y*-directions (Fig. 2). Rotational control is achieved by adjusting the relative alignment of the triangular trapping patterns. Continuous rotation control has been performed over a range of ±28 degrees. Further optimization should result in a larger range of orientation control.

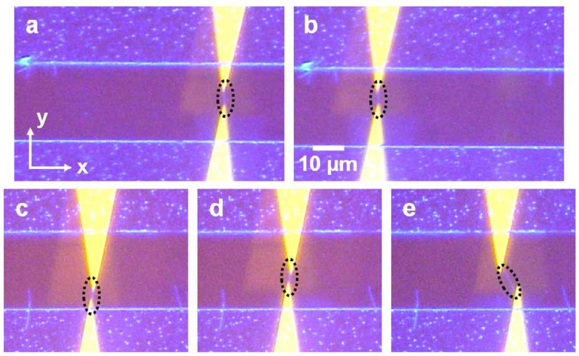

Fig. 2. Trapping of silver nanowires using lateral-field optoelectronic tweezers. Aluminum electrodes are visible underneath the amorphous silicon layer, at the top and bottom of each image. Optical patterns, visible as the bright areas, are used to create nanowire traps. The nanowire positions are indicated by dashed circles. (a, b) Transport of a nanowire in the negative x-direction at a rate of approximately 3 µm/s. (c, d) Transport of a nanowire in the positive y-direction. Other nanowires are weakly trapped at the edges of the electrodes, but can be moved by the LOET trap patterns. (e) Rotational control of a nanowire is achieved by moving the tips of the optical patterns relative to each other.

One of the advantages of LOET is its parallel manipulation capabilities. The proof-of-concept is demonstrated here with the assembly of four individual silver nanowires into a regularly-spaced array (Fig. 3). Each nanowire is trapped in parallel by a pair of optical patterns. The nanowires are positioned at with a 200-kHz AC signal at a voltage of 300 mVpp. Once the nanowires are trapped in the desired locations, the voltage is increased to 2.8 Vpp to anchor the nanowires to the surface.

CONCLUSION

We have demonstrated the parallel assembly of individual silver nanowires on a lateral-field optoelectronic tweezers device. Nanowires can be positioned with control over their *x*- and *y*-positions and rotational orientations. This technique enables parallel nanowire assembly for nanowire electronics.

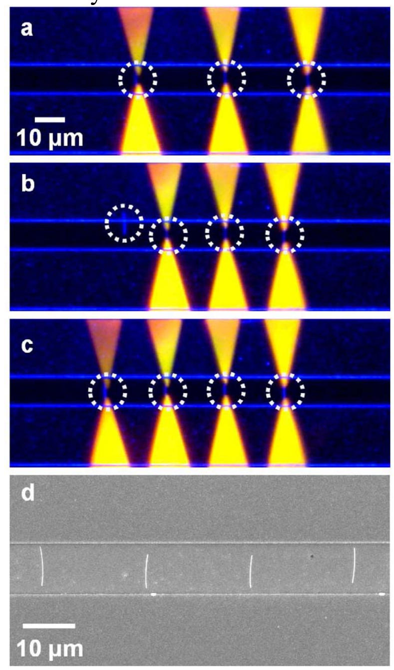

Fig. 3. Fabrication of a silver nanowire array. (a) Three nanowires have been trapped in parallel. (b) The nanowires are arranged in a closer, more regular spacing. Another nanowire can be seen to the left of the array. (c) The fourth nanowire is trapped by another set of optical patterns. The applied voltage is increased to assemble the nanowires on the surface of the device. (d) An SEM image of the nanowire array.

ACKNOWLEDGMENT

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