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SEMICONDUCTOR NANOWIRE MANIPULATION USING OPTOELECTRONIC TWEEZERS

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We demonstrate, for the first time, the trapping and manipulation of individual silicon nanowires by light-induced dielectrophoresis, or Optoelectronic Tweezers (OET). Optical manipulation provides a powerful means to bridge the micro and nano worlds. Optical tweezers have been used to trap single silicon and CdS nanowires [1,2], However, their ability to perform parallel assembly is hampered by the high optical power density (10^7 W/cm^2) and small working area (~1μmx1μm). Dielectrophoresis can trap nanowires between two fixed microelectrodes [3], however, it lacks the resolution to manipulate single nanowires and the trapping sites are fixed by the electrode pattern. In contrast, OET is capable of manipulating a large number of microparticles or cells over a large area [4,5]. Previously, the smallest particles that OET could trap individually were limited to 2 μm. In this paper, we report on the **trapping of single Si nanowires with diameters of 100 nm using OET** with an **optical power density of 100 W/cm^2. We show that OET can separate two nanowires that are 4μm apart, and transport a single nanowire at a speed of 68 μm/sec**. **Array patterns of silicon nanowires** have also been demonstrated.

Figure 1 shows the experimental setup. The OET device consists of 1-μm-thick amorphous silicon photoconductive bottom electrode and an ITO top electrode. Silicon nanowires of 100 nm diameter, ~ 5 μm length, and ~ 10^{16} cm^{-3} boron doping were diluted in a 1.6 mS/m conductivity solution of DI water and KCl. 3 μL of the sample was introduced into the OET device. A portion of the silicon nanowires showed Brownian motion in the solution while others adhered to the surface of the OET chip. A HeNe laser with a power of 100 μW at the OET surface was used to trap silicon nanowires. To increase the trapping force, we reduced the OET gap spacing to 75 μm, and employed a 40x objective lens to focus the optical beam. The resulting optical spot size is 10 μm (FWHM). AC Voltages of 12, 15, and 20V peak-to-peak at a frequency of 100 kHz were applied to the OET device.

Upon application of the voltage across the OET device, the long-axis of the nanowires aligned with the electric field in the liquid layer. After turning on the laser, silicon nanowires experienced an attractive force towards the illuminated area. Figure 2 shows measured maximum velocity of the nanowires versus the AC voltages. Velocities of 68 μm/s were observed with an applied voltage of 20 Vpp. Figure 3 shows measured trapping radius of OET for silicon nanowires, defined as the maximum distance that the laser spot can be from the nanowire, yet still be able to overcome the Brownian motion, as a function of AC voltage. Trapping radius of ~ 34 μm was achieved at 20Vpp. As expected, both the maximum velocity and the trapping radius increase as a function of voltage due to the increase in the dielectrophoretic force. Nanowires within a trapping radius can still be trapped individually by controlling the scanning speed of the laser spot. Figure 4 shows separation of two nanowires that are 4μm apart.

Figure 5(a) and (b) show the arrangement of silicon nanowires into a triangular and a diamond shape, respectively. The nanowires appear as circular dots since they were aligned to the vertical electric field. The white dots in the background are the nanowires that have adhered to the surface of the OET chip (the current OET surface has not been passivated). Potentially, a spatial light modulator can be used to create more sophisticated dynamic trapping patterns, or to sort nanowires of different material, conductivity, or size.

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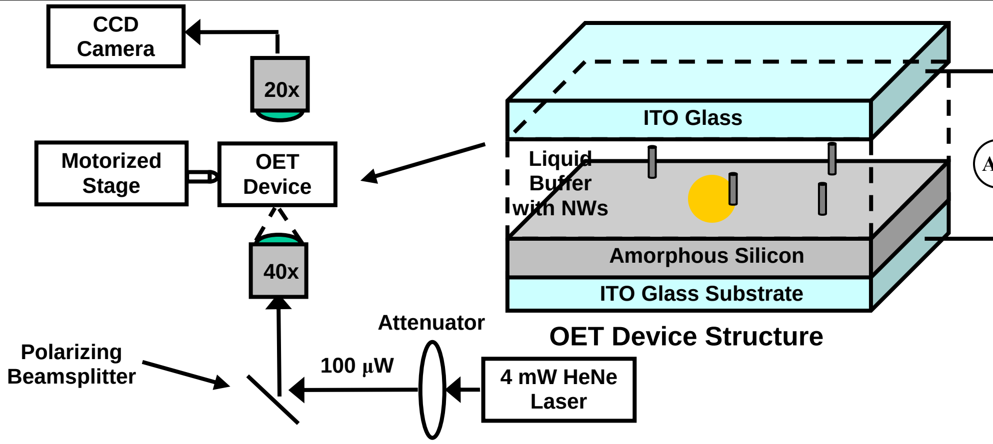

Figure 1: Experimental setup for manipulation of silicon nanowires. The inset shows the Optoelectronic Tweezers device structure. A 4 mW HeNe laser was attenuated to 100 µW and focused onto the OET chip using a 40X objective lens for manipulation of silicon nanowires in the field of view. Observations were made using the dark field mode of Olympus BX51M microscope and images were captured using a CCD camera.

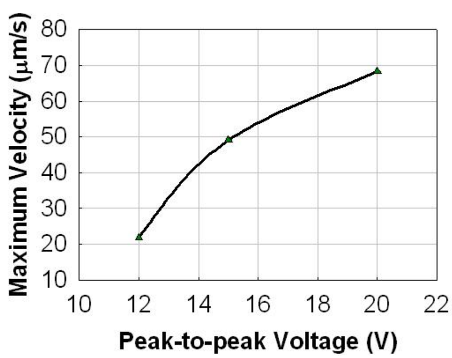

Figure 2: Maximum velocity measurements of silicon nanowires for three different voltages (12, 15, and 20 Vpp). Maximum velocity is defined as the maximum speed of the laser movement without losing the trapped nanowire. The velocity increase is due to increase in dielectrophoretic force created by the laser spot.

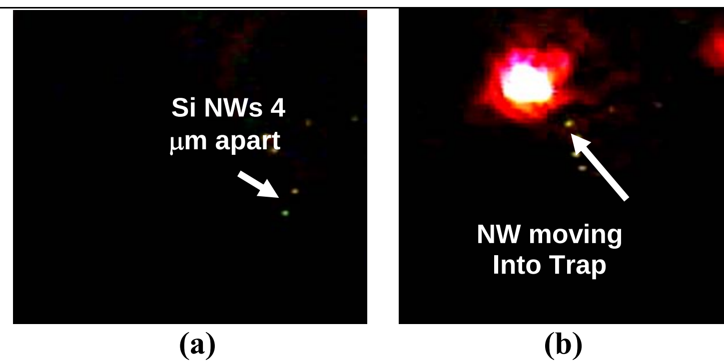

Figure 4: Separation of two Si nanowires, 4 µm apart from each other. An AC voltage of 15 Vpp, 100 KHz is applied to the OET device

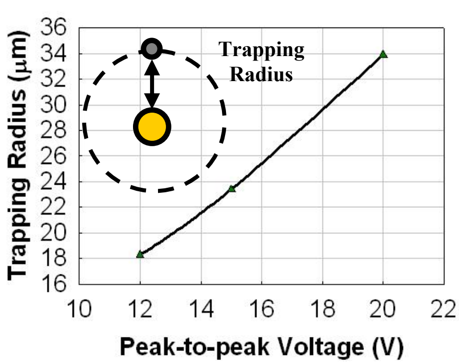

Figure 3: Maximum trapping radius of silicon nanowires versus AC voltage. Maximum radius is defined as the distance that the laser spot can be from the nanowire, yet still be able to overcome the Brownian motion, trapping the nanowire. The trapping radius increase is due to increase in dielectrophoretic force created by the laser spot.

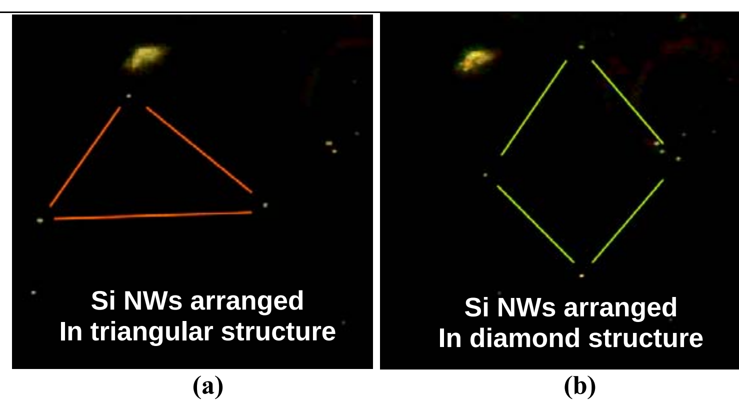

Figure 5: Arrangement of silicon nanowires into (a) a triangular structure (b) a diamond structure. Silicon nanowires were aligned vertically with the electric field. The white dots in the background are the wires that have adhered to the surface of the OET chip.