Supplementary Information

Dynamic manipulation and separation of individual semiconducting and metallic nanowires

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Raman analysis of NW positioned with OET

The ability to perform in-situ Raman spectroscopy of individual nanowires is essential for the detection and identification of nanowires of different types. Raman spectroscopy, combined with the arrangement of single nanowire arrays, can, for example, be used to create single nanowire arrays of alternating materials. **Fig. S1a** shows the detection of an individual silicon nanowire by adding the Raman detection ability to the OET setup. Initially, no voltage is applied to the OET device and nanowires are undergoing Brownian motion (**Fig. S1b**), therefore no Raman signal is detected. Once the voltage is applied to the device (**Fig. S1c**), the single silicon nanowire gets trapped in the laser trap (830 nm, 10 mW) which is also used for Raman excitation, and the silicon Raman peak (at approximately 520 cm^{-1}) appears in the spectra.

Real-time, dynamic formation of a 2×3 single silicon nanowire array

As mentioned before, one powerful aspect of OET is the ability to manipulate objects in parallel. Multiple independent trapping potentials may be projected and controlled electronically in real time with a digital micromirror device (DMD). As an example, **Figs. S2a-f** show the process of creating a 2×3 array of single silicon nanowires using real-time dynamic trapping. There are 6 single silicon nanowires present in the area of manipulation. Dynamic, computer-mouse-controlled traps are added in real-time to trap individual nanowires. Certain traps attracted multiple wires during the process of creating the array (**Fig. S2c**). In order to create an array of single nanowires, two additional traps were added. The two nanowires trapped together in the top traps were separated, as demonstrated in **Fig. S2d** and added to the array to create a single 2×3 array of vertical silicon nanowires (**Fig. S2e,f**). The positioning accuracy of the wire can be analyzed using particle tracking image analysis software. Once trapped, the wire in the

row 2, column 2 was measured to be localized in an area less than 0.22 μm^2 (Supplementary Information, Fig. S3, Video 5).

Nanowire trajectory analysis

To estimate the effect of the Brownian motion on the trapped nanowires, it is possible to use particle tracking software to extract the trajectory of trapped nanowires from captured videos. **Fig. S3a** shows the trajectory of a nanowire before it is trapped, as it is being trapped and transported, and while in the trap; **Fig. S3d** shows the nanowire while it is undergoing Brownian motion; **Fig. S3c** shows the nanowire while trapped and being transported by the laser spot; **Fig. S3b** shows the nanowire is in the trap. The nanowire spans an area of 28.9 $(\mu m)^2$ before, and an area of 0.22 $(\mu m)^2$ after it is trapped by the laser spot.

Simultaneous OET trapping of large nanowire array

Figs. S4a-c show a large OET trapping spot, containing several hundred individual nanowires that may be translated in unison. (Supplementary Information, Video 2)

Concentric Ring Collection of nanowires

Figs. S5a-d show the collection of a large number of silicon nanowires using shrinking concentric ring patterns, which trap the nanowires across the stage and concentrate them in the center. (Supplementary Information, Video 7)

Optoelectronic tweezers trap stiffness measurement for silicon nanowires

Fig. S6 shows the experimental measurement results for OET trap stiffness of silicon nanowires. The

stiffness (k) is measured by measuring the displacement of the nanowire from the center of the laser (Δx) for different translation speeds. The translation speed of the nanowires is used to calculate the DEP force (F_{DEP}), according to formula $F_{DEP} = 8\pi\eta l v_{drag} / (2\ln(l/r) - 1)^{1}$, where r is the radius of the wire, l is the length of the wire, v_{drag} is the velocity of the wire, and η is dynamic viscosity of water. The trap stiffness is calculated, by dividing the DEP force by the displacement from center of laser spot, to be 0.16 pN/μm for a silicon nanowire with 100 nm diameter and 5 μm length with a maximum speed of 50 μm/s at 15 V peak-to-peak voltage. A 100 μW trapping source was used for measuring the trap stiffness which gives an OET trap stiffness figure-of-merit of 1.6×10^{-6} N/(m×mW) which is approximately 2 orders of magnitude larger than trap stiffness figure-of-merit of optical tweezers for a nanowire.

Trapping and immobilization of a single silver nanowire in a photocurable polymer

Poly(ethylene glycol) diacrylate (PEGDA) is a UV-curable polymer that forms a three-dimensional polymer matrix in the presence of a UV source and a photoinitiator material. The transport and mechanical properties of PEGDA are customizable through adjusting the molecular weight and polymer percentage of the solution. In addition, high water content and tissue-like mechanical properties of PEGDA makes it a highly biocompatible material. **Fig. S7** shows trapping and immobilization of a single silver nanowire in a PEGDA solution. The silver nanowires are dispersed in a solution containing 20% w/v PEGDA and 0.2% w/v photoinitiator (Irgacure 2959). After the solution is introduced into the OET chamber, the silver nanowires can be trapped and transported in the PEGDA solution. Once desired positioning is achieved, it is possible to freeze the nanowires in place in 3-4 seconds, by introducing a UV source (325 nm, 8 mW HeCd laser) from top transparent ITO electrode and starting the polymerization process. Since PEGDA forms a three-dimensional matrix in the area that UV is present in such short time span, the orientation of the trapped wires is preserved in the immobilization

process. The presence of PEGDA increases the conductivity of the liquid approximately 6× optimal liquid conductivity for nanowire manipulation which screens the polarizability of the nanowires, decreasing the DEP force that nanowires experience. In addition, PEGDA increase the viscosity of the solution, decreasing the translation speed of the nanowires further. (Supplementary Information, Video 3)

Supplementary Information References

1. Morgan, H. & Green, N. *AC Electrokinetics: colloids and nanoparticles* (Research Studies Press Ltd., 2003).

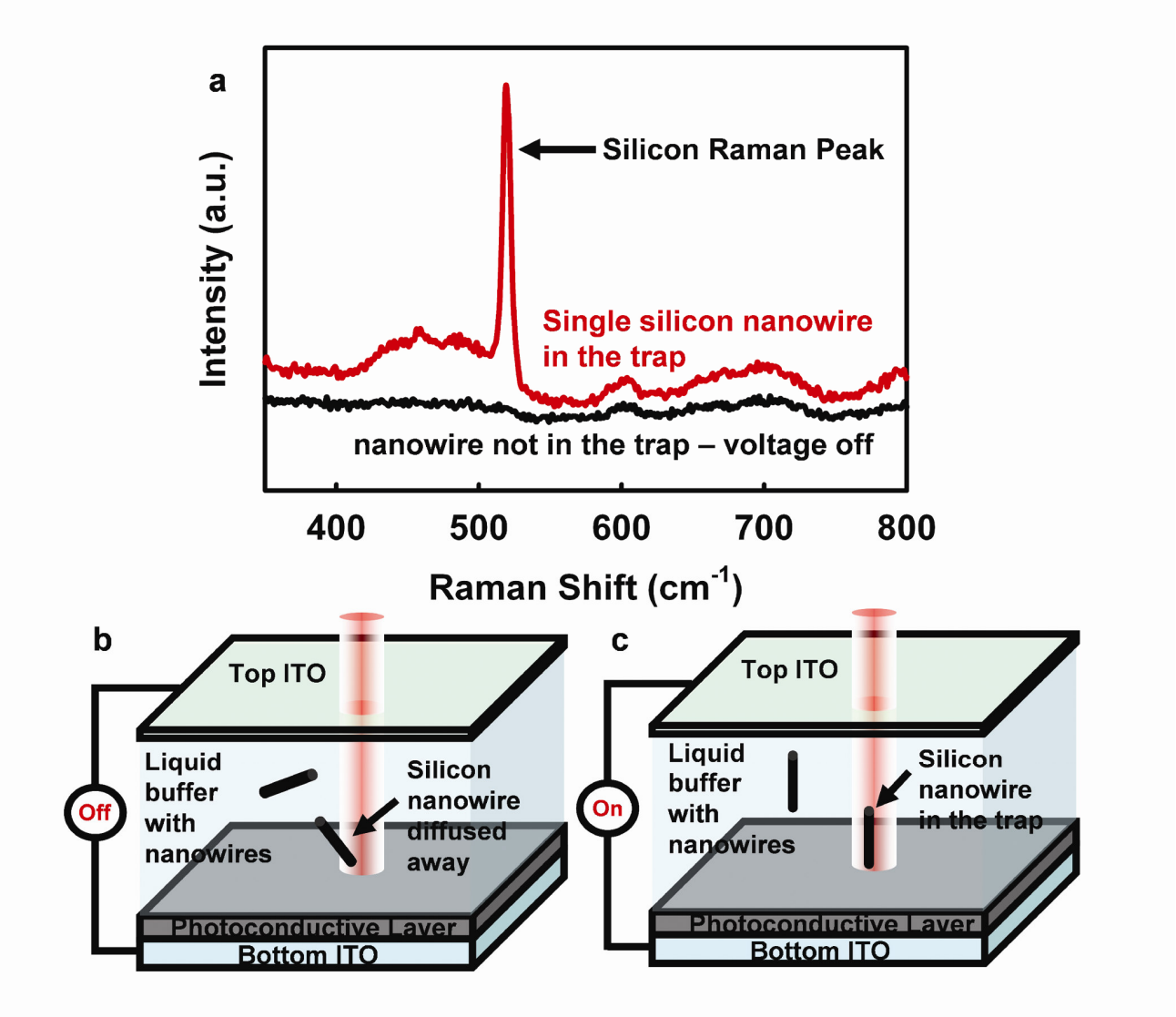

Figure S1 In-situ Raman detection of individual silicon nanowires. **a**, A silicon Raman peak is detected when the silicon nanowire is in the trap (red line) while in the absence of an AC bias, there is no nanowire trapped and no Raman peak is observed. **b**, No voltage is applied to the device, therefore the nanowire is not in the trap. **c**, Once the voltage is applied to the device the nanowire aligns with the electric field and gets trapped into the laser spot.

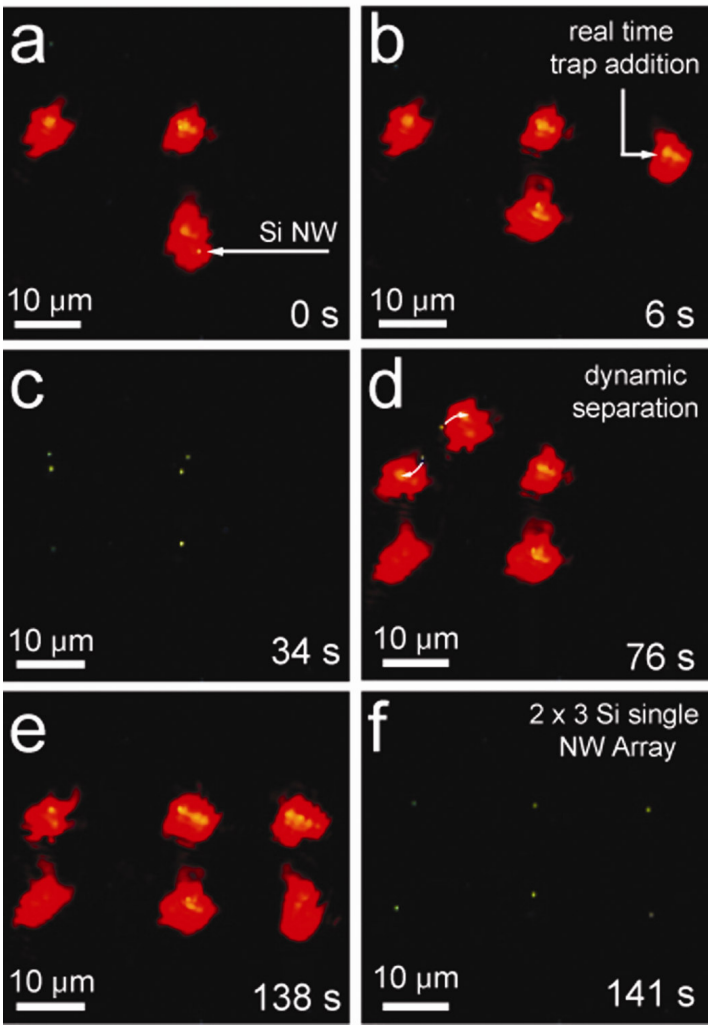

Figure S2 Real-time dynamic formation of 2×3 single nanowire array. Arrangement of six individual silicon nanowires into a 2×3 array using traps created with a digital micromirror spatial light modulator and positioned with a computer-mouse-controlled GUI. **a**, Individual silicon nanowire migrating into lower trap potential. **b**, Real-time addition of a new trap. **c**, The trapping laser is briefly filtered to show that the top traps each contain two silicon nanowires. **d**, A new trap is added to allow the separation of the nanowires in top left corner. **e**, The 2×3 single silicon nanowire array, **f**, with laser pattern filtered.

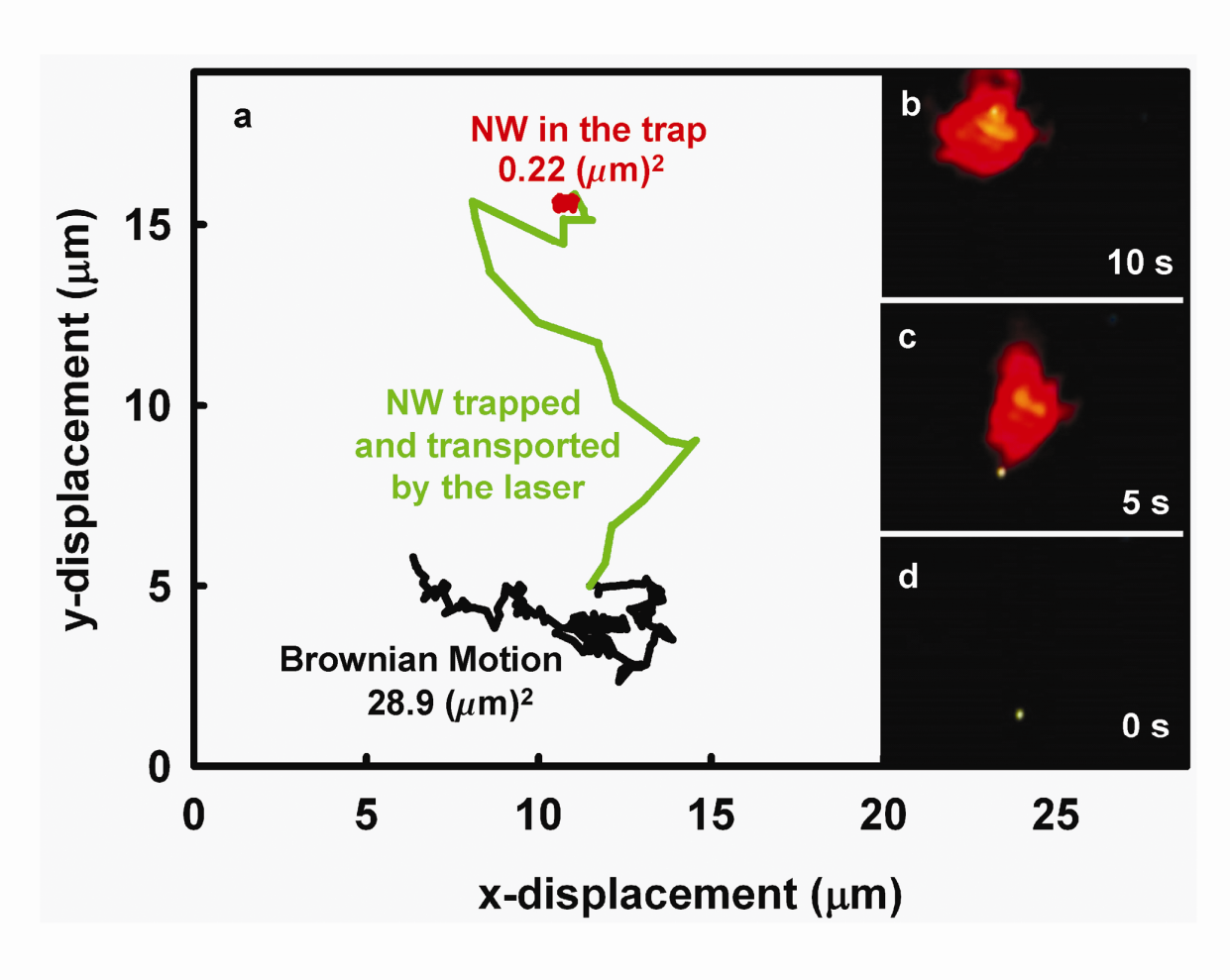

Figure S3 Manipulation trajectory of an individual silicon nanowire. **a**, Measured trajectory of a single silicon nanowire, **b**, while the nanowire is in the trap (spans an area of 0.22 $(\mu m)^2$), **c**, as the nanowire is trapped by the laser trap and transported to a new location, and **d**, as the nanowire undergoes Brownian motion (spans an area of 28.9 $(\mu m)^2$).

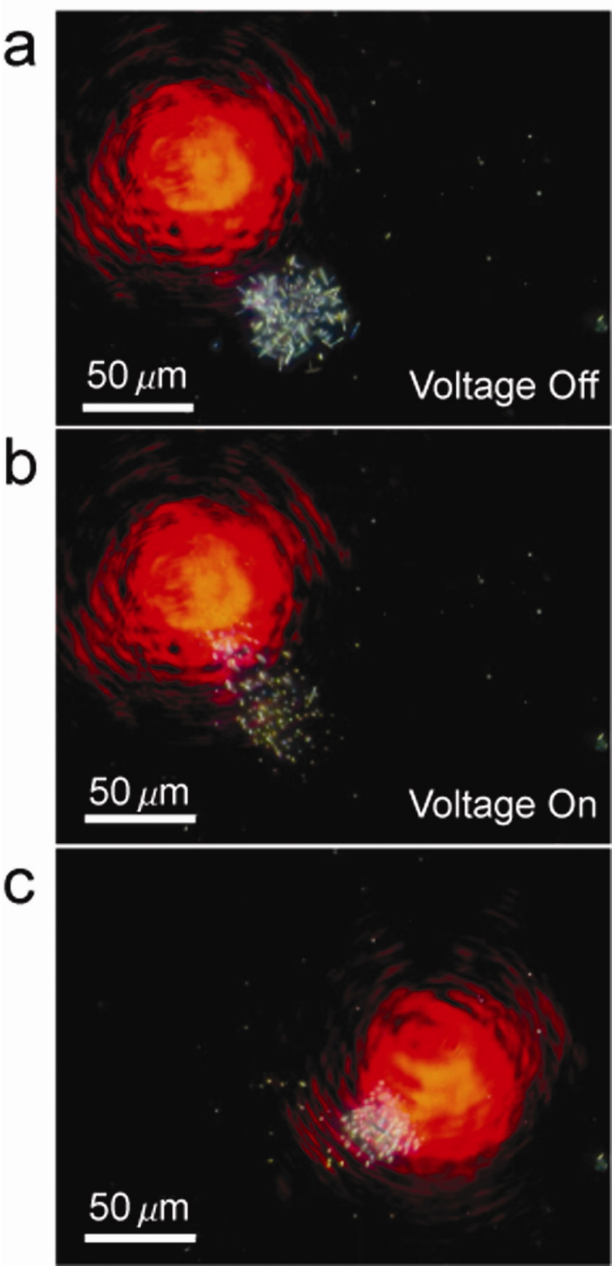

Figure S4 Collection of a large number of silicon nanowires. **a**, There is no voltage applied to the OET device and nanowires undergo Brownian motion. **b**, Once the voltage is applied the nanowires' long-axis aligns with the electric field simultaneously. **c**, Nanowires follow the laser trap as it is scanned across the stage.

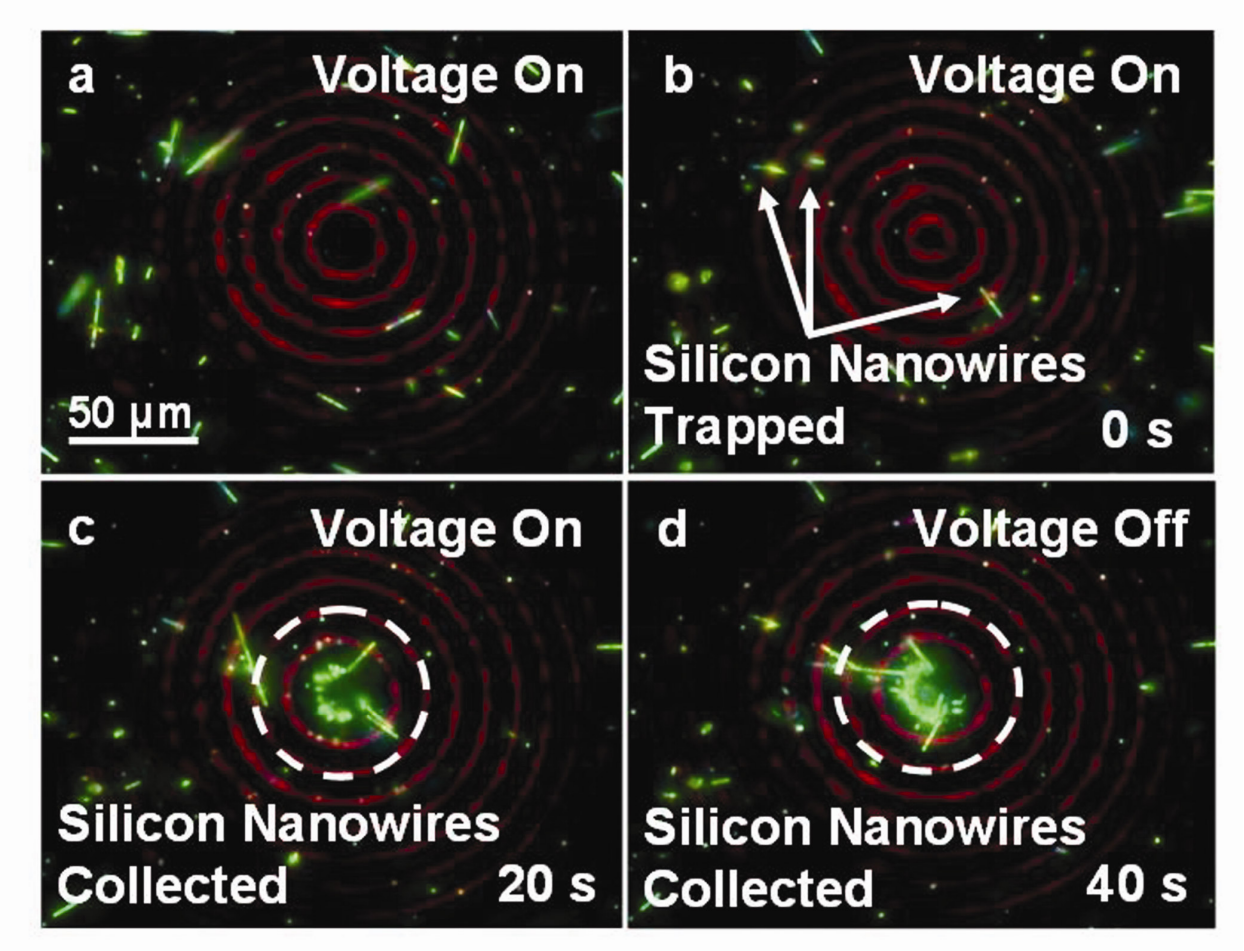

Figure S5 Collection of a large number of silicon nanowires using shrinking concentric ring patterns. **a**, No voltage is applied to the OET device and nanowires are undergoing Brownian motion. **b**, Once the voltage is applied, the long-axis of nanowires aligns with the electric field simultaneously. **c**, Nanowires are trapped by the concentric rings and moved to the center. **d**, The voltage is switched off, and the collected nanowires undergo Brownian motion.

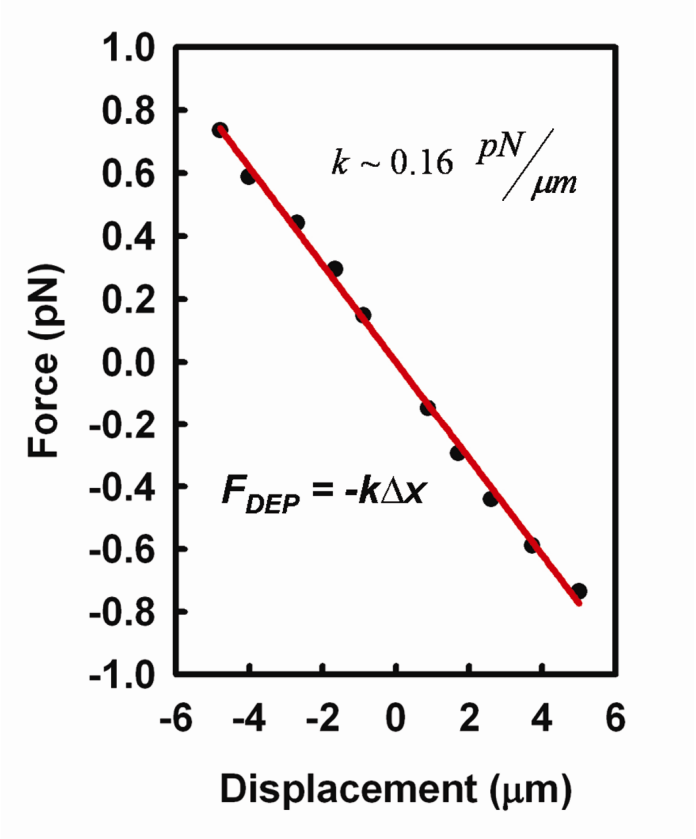

Figure S6 Measurement of trap stiffness of a silicon nanowire. The trap stiffness for a silicon nanowire with 100 nm diameter and 5 μm length is measured to be 0.16 pN/μm for an applied voltage of 15 V peak-to-peak voltage and a maximum translation speed of 50 μm/s. For 100 μW trapping source, the OET trap stiffness figure-of-merit translates to 1.6 N/(m×mW).

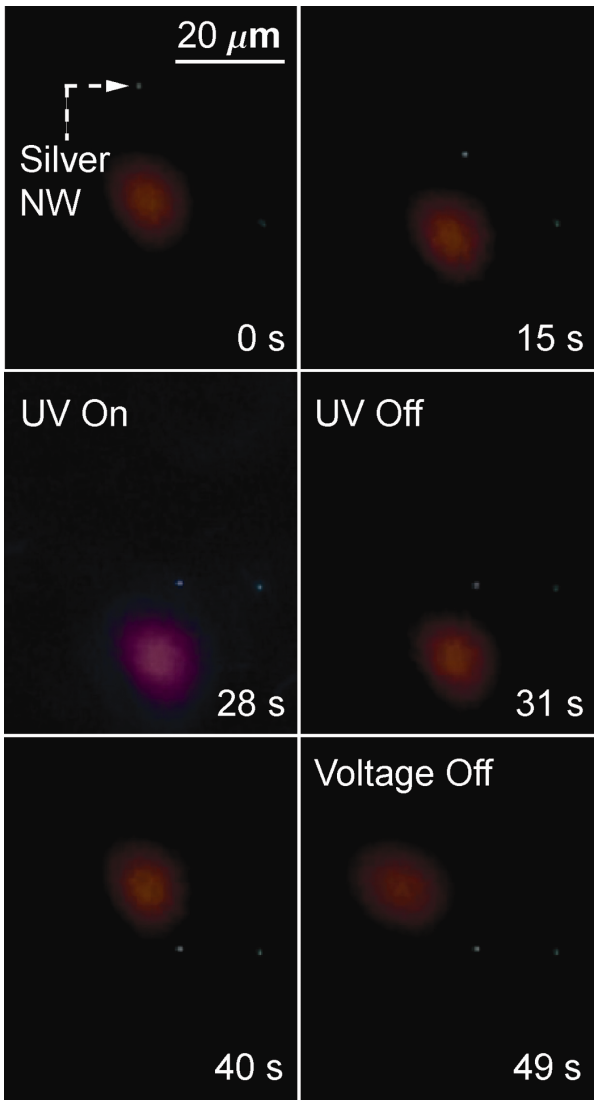

Figure S7 In-situ trapping and immobilization of an individual silver nanowire in a photocurable polymer matrix. A single silver nanowire is transported using OET in a poly(ethylene glycol) diacrylate (PEGDA) photocurable polymer solution. Once the nanowire is positioned at the desired location, the manipulation area is exposed to a UV source (325 nm, 8mW HeCd laser) polymerizing the hydrogel solution and fixing the wire in place. After the polymerization, the nanowire does not undergo Brownian motion and the laser trapping source is unable to move the nanowire. In addition, after turning off the AC potential, the nanowire's position and orientation are unaffected.