Virus-PEDOT Nanowires for Biosensing

Jessica A. Arter[†], *David K. Taggart*[†], *Theresa M. McIntire,*
Reginald M. Penner, and Gregory A. Weiss**
Department of Chemistry, University of California, Irvine, CA 92697-2025
[†]Joint first authors.
* Correspondence should be addressed to gweiss@uci.edu, rmpenner@uci.edu

Supporting Information

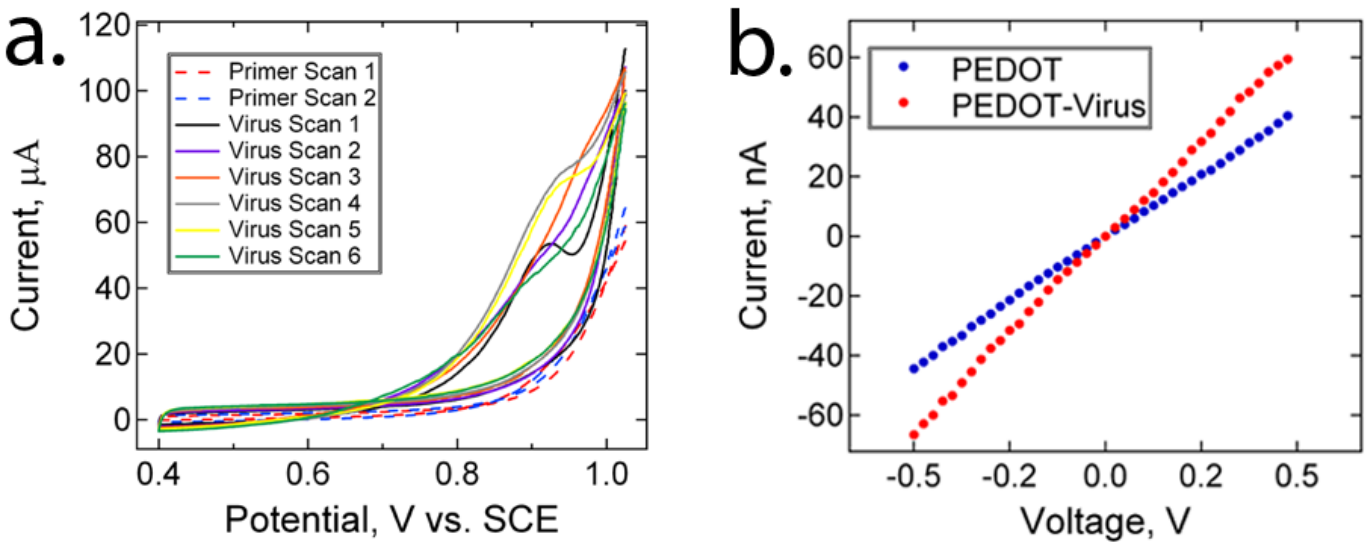
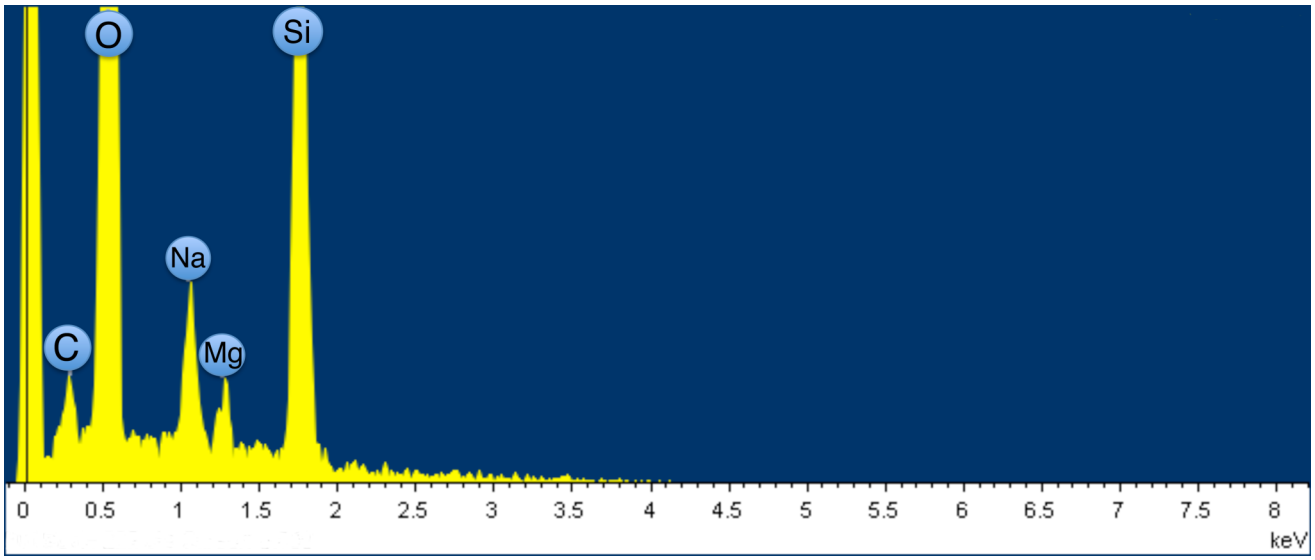


Figure S1. (a) A typical cyclic voltammogram for virus-PEDOT nanowire synthesis. (b) Current-voltage curves for PEDOT and virus-PEDOT single nanowires.

a.



b.

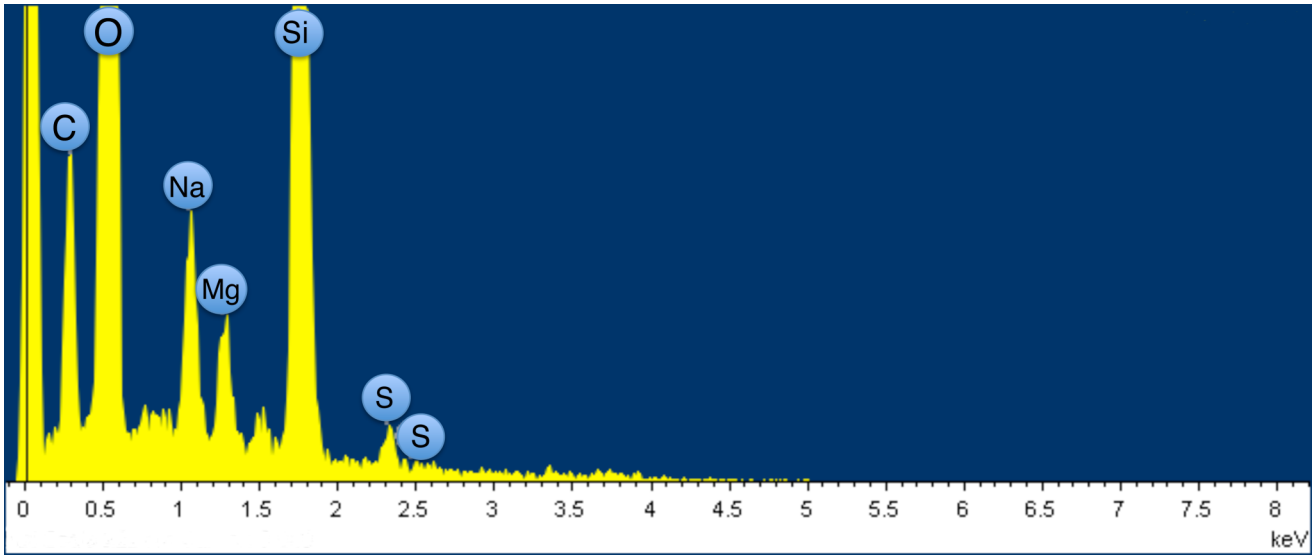


Figure S2. EDX analysis of (a) a glass slide, which highlight the strong emissions associated with both silicon and oxygen, or (b) a PEDOT nanowire, which includes contributions to the spectrum from carbon and sulfur.

Table S1. Band Assignments for the Transmission FTIR Spectrum of PEDOT Nanowires.*

Peak, cm^{-1}	Assignment	Reference
2950	asymmetric ν (C-H)	1
2860	symmetric ν (C-H)	1
1515	ν (C=C)	2–4
1334	C-C or C=C	4,5
1202	ν (C-O-C)	1
1141	ν (C-O-C)	2–5
1090	ν (C-O-C)	2–5
1050	ν (C-O-C)	2–4
979	ν (C-S)	4,5
945	ν (C-S)	2,3
844	ν (C-S)	2–5
807	Si	6
790	γ (C-S)	2,3
728	δ (C-S)	2,3
677	δ (C-S)	2,3,5
618	Si	5
610	Si	5

*Measured for the PEDOT nanowires shown in Figures 2a-b. [1-6]

Table S2. Electrical Conductivity of Single Nanowires.

Nanowire	Height, nm	Width, nm	Length, μm	Electrical Conductivity, $S \cdot m^{-1}$
Virus-PEDOT	70	591	248	774
PEDOT	70	205	88.5	527

Additional Experimental Methods

Lithographically patterned nanowire electrodeposition (LPNE). To pattern the PEDOT and virus-PEDOT nanowire arrays, the previously reported LPNE technique was adapted.[7,8] In brief, soda-lime glass microscope slides were cut into 1" x 1" squares, and cleaned in aqueous Nochromix solution before rinsing with millipore water and air drying. Onto each square, a 60 nm nickel film (ESPI, 5N purity) was deposited by hot filament evaporation at a rate of 0.5–1.0 $Ås^{-1}$. The film thickness and evaporation rate were monitored by a quartz crystal microbalance (Sigma Instruments).

The nickel-coated glass slides were then spin-coated with a positive photoresist layer (Shipley 1808). During this step, a 1 ml aliquot of photoresist solution was deposited onto each square, followed by rotation at 2,500 rpm for 80 s. Freshly coated slides were then baked for 30 min at 90 °C. After cooling to room temperature, a quartz mask was placed directly atop the slide, followed by 2.5 s exposure to an ultraviolet lamp with an output power of 500 W. The slide was then soaked in MF-319 developer solution for 14 s, rinsed with water, and dried thoroughly by compressed air.

To form a nickel contact, the edge of the slide was exposed to acetone to remove the photoresist. Half of the slide, which was entirely covered with patterned photoresist, was next dipped into a solution of HNO_3 (0.8 M) for 6 min. After removal from the acid, the slide was rinsed thoroughly with distilled water.

Electrodeposition of PEDOT was carried out in a 100 ml, one-compartment, three-electrode cell from an aqueous solution containing $LiClO_4$ (12 mM) and EDOT (2.5 mM). Cyclic voltammetry scans (Figure S1a) applying a potential of 400 mV to 1.025 V at 20 mVs^{-1} were run for two consecutive scans before five sequential scans were run in the same solution with the addition of M13 KO7 bacteriophage (10 nM). The slide was then removed from the solution, rinsed with acetone to remove any excess photoresist, and placed in HNO_3 (0.8 M) until all nickel was fully removed by etching.

Current-voltage curves. Single nanowires were fabricated using the same method reported

above with a mask directing the synthesis of a single wire by the photolithography. Once the single nanowires were freestanding on a glass slide, two silver contacts were pasted onto the nanowires (Table S2 provides wire dimensions). The electrical resistivity was measured using a source meter (Keithley Instruments, model 2400) in conjunction with a digital multimeter (Keithley Instruments, model 2000). The resulting I-V curves show ohmic behavior for both the PEDOT and virus-PEDOT nanowires (Figure S1).

M13 bacteriophage propagation. XL-1 Blue *E. coli* cells were used to inoculate a culture of LB buffer and tetracycline (5 μg/mL). The cells were grown for 4-6 h at 37 °C with shaking at 250 rpm. After the cells reached log-phase growth, the culture was infected with a 1:1000 dilution of M13 KO7 (10^{10} phage/mL) helper phage, and shaken at 250 rpm for 1 h at 37 °C. The starter culture was next transferred to 1 L of 2YT media and kanamycin (50 μg/mL). The culture was shaken at 250 rpm for 16-18 h at 37 °C. To isolate the phage from the cells, the culture was then transferred to centrifuge tubes, and centrifuged for 25 min at 10 krpm and 4 °C. The supernatant was decanted into separate centrifuge tubes, and 1/5 volume of PEG-NaCl (2.5 M NaCl, 20% PEG-8000) was added before the tubes were placed on ice for 1 h. Next, the phage solution was centrifuged for 25 min at 10 krpm and 4 °C. The supernatant was discarded, and the virus pellet was resuspended in a $LiClO_4$ (12 mM) and Tween (0.1%) solution. After centrifugation for 5 min at 15 krpm and 4 °C, the supernatant was transferred to a new centrifuge tube, and the phage were precipitated on ice for the second time with PEG-NaCl. After a final centrifugation step for 25 min at 10 krpm and 4 °C, the virus pellet was resuspended in a $LiClO_4$ (12 mM) solution. The concentration of the virus solution was obtained by a measurement of UV absorbance at 268 nm.

Fluorescence analysis. Nanowire arrays of PEDOT and virus-PEDOT with 10 μm gaps were made by photolithography and LPNE. Prior to antibody incubation, the nanowire arrays were imaged

by optical fluorescence microscopy with a 480 nm filter and a shutter open for ten seconds with gain set to one. The nanowire arrays were then incubated for one h with a 1:5000 solution of anti-M13-fluorescein antibody in PBF with 0.1% Tween. After one hour, the slides were rinsed thoroughly with PBF-Tween, followed by H_2O to remove any excess salts and detergent. The nanowire arrays were again imaged by optical fluorescence microscopy with a 480 nm filter and a shutter open for ten seconds with gain set to one.

Supplementary References

(1) Pavia, D. L. L., G.M.; Kriz, G.S. *Introduction to spectroscopy: a guide for students of organic chemistry*; 3rd ed.; Harcourt College Publishers: Fort Worth, 2001.

(2) Kvarnstrom, C.; Neugebauer, H.; Blomquist, S.; Ahonen, H. J.; Kankare, J.; Ivaska, A. *Electrochim. Acta* **1999**, *44*, 2739-2750.

(3) Kvarnstrom, C.; Neugebauer, H.; Blomquist, S.; Ahonen, H. J.; Kankare, J.; Ivaska, A.; Sariciftci, N. S. *Synthetic Met.* **1999**, *101*, 66-66.

(4) Seo, K. I.; Chung, I. J. *Polymer* **2000**, *41*, 4491-4499.

(5) Choi, J. W.; Han, M. G.; Kim, S. Y.; Oh, S. G.; Im, S. S. *Synthetic Met.* **2004**, *141*, 293-299.

(6) Choi, W. C.; Lee, M. S.; Kim, E. K.; Kim, C. K.; Min, S. K.; Park, C. Y.; Lee, J. Y. *Appl. Phys. Lett.* **1996**, *69*, 3402-3404.

(7) Xiang, C.; Kung, S. C.; Taggart, D. K.; Yang, F.; Thompson, M. A.; Guell, A. G.; Yang, Y.; Penner, R. M. *ACS Nano* **2008**, *2*, 1939-1949.

(8) Menke, E. J.; Thompson, M. A.; Xiang, C.; Yang, L. C.; Penner, R. M. *Nat. Mater.* **2006**, *5*, 914-919.