

# Electronic Supporting Information

## “Propulsion of Nanowire Diodes”

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**SI Video 1.** Motion of PPy/Cd, PPy/Au and monocomponent nanowires in uniform electric field.

**SI Video 2.** Motion of PPy/Cd, CdSe-Au-CdSe diode nanowires and polystyrene particles in uniform electric field.

**SI Video 3.** PPy/Cd nanowire and polystyrene particle motion in uniform vs. non-uniform electric field.

**SI Video 4.** Effect of solution ionic strength on the nanowire diode propulsion.

**SI Scheme 1.** Experimental cell design for (A) uniform electric field consisting of two parallel gold wires and a for (B) for non-uniform electric field using perpendicular gold wires.

### Experimental Section

The polypyrrole/cadmium (PPy-Cd) nanodiodes were prepared following the procedure of Park *et al.* with some modifications.<sup>1</sup> A porous alumina membrane template containing 200-nm diameter cylindrical pores and thickness of 60  $\mu\text{m}$  were purchased from Whatman (Catalog No. 6809-6022; Maidstone, UK). The branched surface of the membrane was initially sputtered with gold using a desktop sputtering machine (Denton Vacuum, Desk IV, Moorestown, NJ) to serve as a working electrode. A sacrificial gold layer was electrodeposited using a commercial gold plating solution (Orotemp 24 RTU RACK; Technic Inc., Anaheim, CA), a total charge of 1.5 C and a potential of -0.9 V [*vs.* Ag/AgCl (3 M NaCl)], in connection with a Pt wire counter electrode. The polypyrrole and cadmium segments were then subsequently electrodeposited into a porous alumina membrane to prepare PPy-Cd nanodiodes. Polypyrrole was deposited from a 0.5 M pyrrole (Sigma-Aldrich, St Louis, MO) solution containing 0.2 M tetraethylammonium tetrafluoroborate (Alfa Aesar, Ward Hill, MA) in acetonitrile (Fisher Scientific, Fair

Lawn, NJ). The polypyrrole deposition involved a total charge of 0.5 C and a potential of +0.8 V (*vs.* a Ag/Ag<sup>+</sup>/ACN non-aqueous reference electrode). The latter consisted of a silver wire immersed in a solution containing 0.01M silver nitrate in acetonitrile (ACN) (Bioanalytical systems, W. Lafayette, IN). The cadmium segment was deposited from an aqueous solution containing 0.3 M cadmium sulfate (Sigma-Aldrich) and 0.25 M sulfuric acid, using a potential of -0.8 V [*vs.* Ag/AgCl (3 M NaCl)] and a total charge of 3.5 C. Monocomponents polypyrrole, cadmium, gold and bicomponent PPy-Au nanowires (used as controls) were prepared under conditions similar to the individual segments of the diode nanowires.

CdSe-Au-CdSe nanowires were prepared by modifying the previously described method.<sup>2</sup> Briefly, an Au sputtered film was used along with a Ag sacrificial Ag layer (3 C) electrodeposited into the branched area. The CdSe plating solution was prepared from 0.3 M CdSO<sub>4</sub>, 0.25 M H<sub>2</sub>SO<sub>4</sub>, and 0.7 mM SeO<sub>2</sub>. Plating proceeded using cyclic voltammetry by scanning the voltage 12000 times between -357 mV to -757 mV at a scan rate 750 mV/s (*vs.* Ag/AgCl reference electrode). A gold segment was deposited on top of CdSe (at -0.9V and a charge of 1.5 C) followed by another CdSe segment. In order to obtain free standing nanowires, the sputtered gold film and the sacrificial silver layer were simultaneously removed by mechanical polishing using a cotton tip soaked with 35% HNO<sub>3</sub>. The membrane was then dissolved in a 3 M NaOH solution for 30 min to completely release the nanowires. The nanowires were collected by centrifugation at 6000 rpm for 10 min and were washed repeatedly with nanopure water (18.2 MΩ·cm) until a neutral pH was achieved. All nanowire solutions were stored in nanopure water at room temperature and their speed was evaluated on the same day of synthesis.

Polystyrene particles (2.0 μm), used for the control experiments, were purchased from Polysciences (Warrington, PA) and were washed by centrifugation at 10,000 rpm for 10 min with water to remove the excess of surfactant.

Scanning electron microscopy (SEM) images were obtained with Phillips XL30 ESEM instrument using an acceleration potential of 10 kV. The metal composition was also studied by energy dispersive X-ray analysis (EDAX) coupled with the Phillips XL30 ESEM instrument.

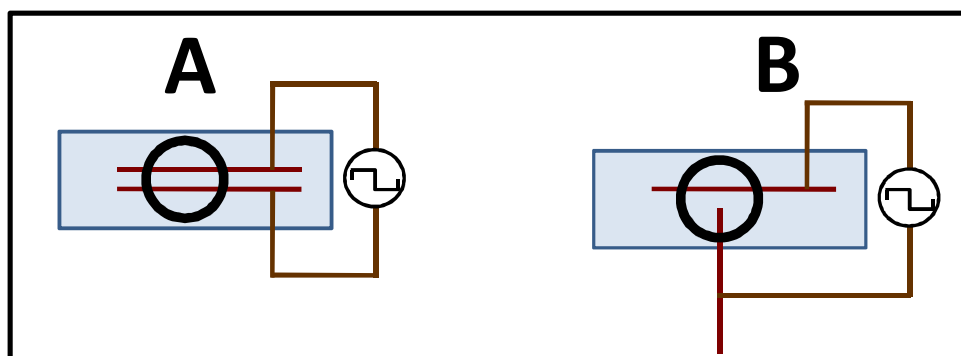
The motion of the synthesized nanowire diodes was examined by applying an external alternating electric field at varying frequencies and potentials. Cells consisted of two parallel or two perpendicular gold wires (of 200  $\mu\text{m}$  diameter and separated from each other by 2 mm), and were employed for both the uniform and non-uniform electric fields, respectively. An epoxy well embedded with a Viton<sup>®</sup> O-ring was prepared on a microscope cover slide (SI Scheme 1). An Agilent 33120A Function/Arbitrary Waveform Generator was used as the excitation source and generated a square wave encompassing a 50% duty cycle. All experiments were carried out at an external voltage of 50 V  $\text{cm}^{-1}$ , square-wave frequency of 18 Hz. The motion was examined using both spatially uniform and non-uniform electric fields (depending on the configuration of the gold electrodes, see Scheme 1).

Tracking of diode nanomotors was performed following the protocol reported earlier.<sup>3</sup> Briefly, an inverted optical microscope (Nikon Instrument Inc. Ti-S/L100) equipped with a 40x objective, a Photometrics QuantEM 512/SC camera (Roper Scientific, Duluth, GA) and a MetaMorph 7.6 software (Molecular Devices, Sunnyvale, CA, USA) were used for capturing video clips at a rate of 30 frames per second. The depth of the field was very small ( $\sim 2 \mu\text{m}$ ), and only the nanodiodes closer to the solution/air interface were brought into the focal plane. The nanomotor movement was tracked using a Metamorph tracking module and the results were analyzed using OriginLab software.

## References

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SI Scheme 1



Experimental cell design consisting of (A) two parallel gold wires for uniform electric field and (B) perpendicular gold wires for non-uniform electric field.