Electronic Supplementary Information (ESI) for Journal of Materials Chemistry

A Facile, One-Pot Synthesis of Ultra-long Nanoparticle-chained Polyaniline Wires

Supplementary Information

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Raman spectroscopy for a nanoparticle-chained polyaniline wire (NPW)

Raman spectra were recorded using an AFM-correlated micro-Raman microscope equipped with an inverted optical microscope (Axiovert 200, Zeiss) and a piezoelectric x, y sample scanner (Physik Instrumente) manipulated by an independent homemade scanning controller. The 633 nm line of a He-Ne laser (JDSU, USA) was used as the excitation source coupled with a single-mode optical fiber. A dichroic mirror (Chroma Technology Corp.) directs the excitation laser beam from 50 nW to 1mW into the oil-immersion microscope objective (x100, 1.3 numerical aperture, Zeiss), which focuses the beam to a diffraction-limited spot (<300 nm) on the upper surface of the cover glass slip. The AFM (Bioscope, Digital Instruments, Veeco Metrology Group) with a Nanoscope IV controller was mounted on a micro-mechanical stage. The background Raman signals were collected on a liquid-nitrogen-cooled (-125˚C) CCD (charge-coupled device). The tapping-mode closed-loop AFM scanner on top of the closed-loop piezoelectric flexure sample stage was used to correlate the Raman or Rayleigh scattering signal with the AFM topographical image and sample image with an overlap precision of <50 nm. The laser focal spot was matched with the center of the AFM tip so that it scattered symmetrically against the AFM tip end. The scattering spectra were recorded in the range of 500 ~ 2,000 cm^{-1}, in one acquisition, 10 s accumulations, and designated laser power at the sample. A Gran-Thompson prism polarizer was used for control of polarization. All of the data was baseline-corrected by subtracting the background signals from Si. Ploy-L-lysine coated cover glass (piranha-etched) was used for AFM-correlated micro-Raman analysis.

Finite-difference time-domain simulation (FDTD) Simulation

We employed a software package, FDTD Solutions, developed by Lumerical Solutions Inc., to perform FDTD calculations on a Au NP chain and a Au NW. We used Johnson and Christy data which match well with the dielectric behavior of our Au NP and Au NW. The polarization-dependent field enhancement of the Au NP chain and the Au NW was calculated by setting the electric field of the plane wave parallel/perpendicular to the length direction of the Au NP chain and the Au NW. In case of the Au NP chain, the simulation was performed over the region including a number of the Au NP chains along the long axis to minimize the boundary effect.

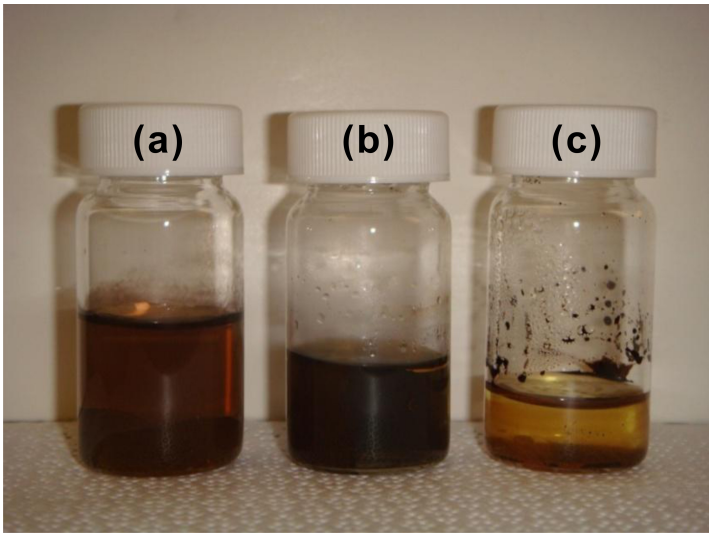

Fig. S1 Continuing development of the PANI and Au composite nanostructures. (a) PANI and Au NP solution without light curing. Reddish color in water phase indicates the formation of Au NP chains. (b) PANI and Au NP solution after a process of polymer curing (5 min, tungsten halogen lamp). The purple greenish color indicates the oxidized states of PANI. (c) PANI and Au NP aqueous solution of (b) after 1 week. Greenish water phase was still visible after precipitation of heavy aggregates.

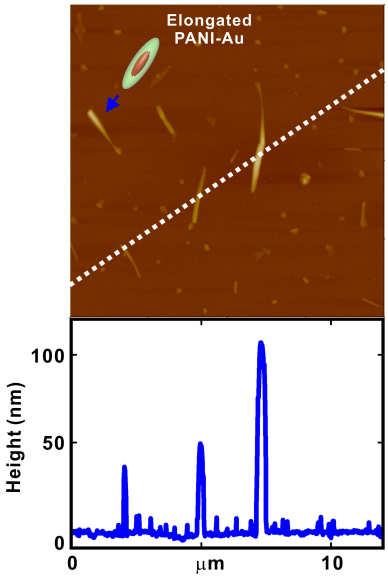

Fig. S2 Tapping-mode AFM topography image (top) and the height profile (bottom) of the elongated PANI-Au nanoseeds. The heights of the elongated PANI-Au nanoseeds varied in the range from a few nm to 100 nm.

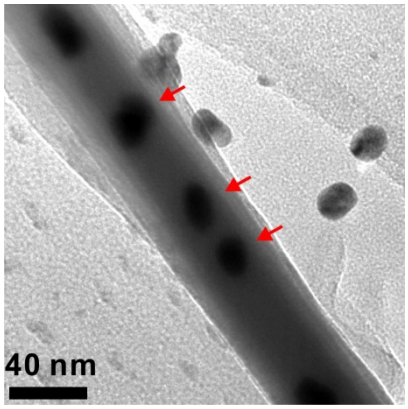

Fig. S3 High resolution transmission electron microscopy (TEM) images for the Au NPs embedded in the NPW. A 200kV field emission TEM (Tecnai F-20) was used for the TEM imaging. The dark spots (red arrows) represent the embedded Au NPs in the NPW.

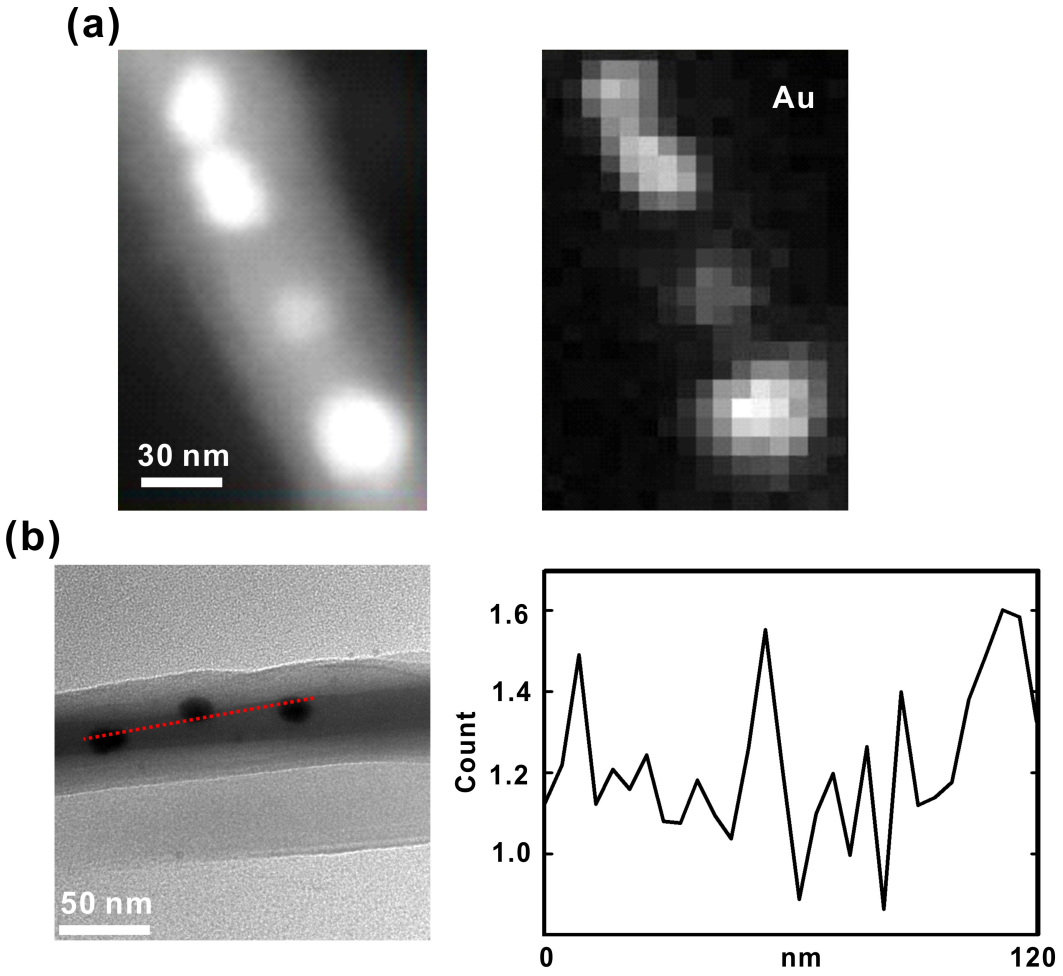

Fig. S4 (a) Scanning transmission electron microscopy (STEM) image (left) and energy-dispersive X-ray spectroscopy (EDS) mapping image (right) showing the Au NPs embedded in the NPW. A 200kV field emission TEM (Tecnai F-20) was used for the STEM imaging and the EDS mapping of the NPW. The Au element (heavy atom) appears bright due to the scattering between the Au and the beam in the STEM. We chose the energy window around 11.5eV for Au signals in the EDS mapping. (b) TEM image (left) and EDS line scan profile (right) of Au along the red dotted line. It confirms that the Au NPs were embedded in the NPW.

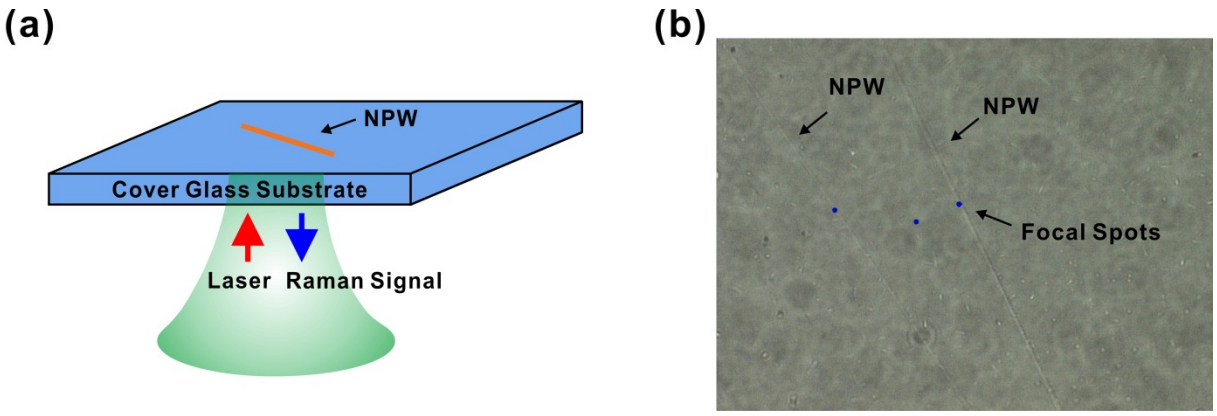

Fig. S5 Raman spectroscopy for NPWs. (a) Schematic diagram showing a micro-Raman microscope equipped with an inverted optical microscope (Axiovert 200, Zeiss). A 300 W He-Ne laser (Melles Griot) with the excitation wavelength of 632.8 nm was used as the excitation source. The laser was focused on a NPW on a cover glass slip. The Raman spectra of the sample were recorded in the range of 500 ~ 2,000 cm^{-1}. (b) Optical microscopy image of NPWs and the focal spots.