Electronic Supplementary Material (ESI) for Nanoscale.

Supporting Information

Long conducting polymer nanonecklaces with a 'beads-on-a-string' morphology: DNA nanotubes-template synthesis and their electrical property

Guofang Chen,[*a] and Chengde Mao[*b]

[a] *Department of Chemistry, St John's University, Queens, New York, 11439, USA.*

[b] *Department of Chemistry, Purdue University, West Lafayette, Indiana 47907, USA.*

* *Corresponding Authors*

* *E-mail: gfchen08@yahoo.com; mao@purdue.edu*

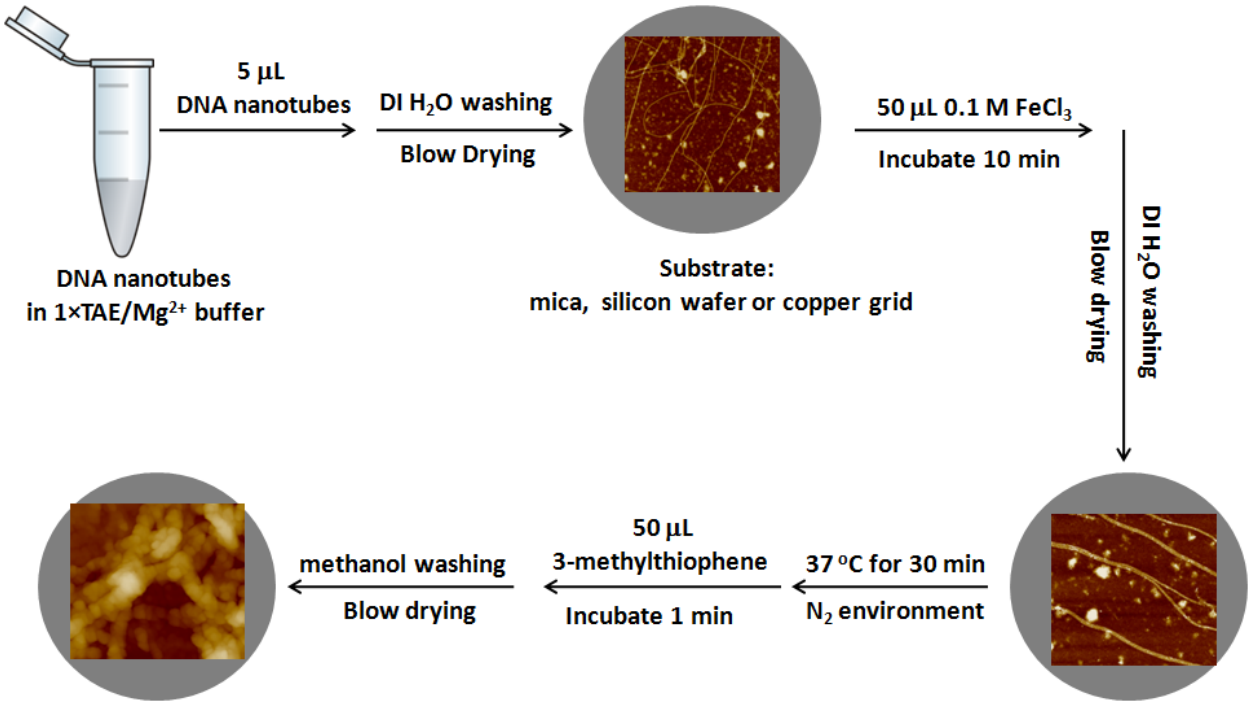

Fig. S1 Schematic of the synthesis of long conducting PMTP nanonecklaces based on self-assembled DNA nanotubes

Experimental Section

Formation of self-assembled DNA nanotubes by 2-day slow annealing

The sequence of 52-nucleotide ssDNA with 4 palindromic segments of 10, 16, 16 and 10 bases long (*5*'- CCA AGC TTG GAC TTC AGG CCT GAA GTG GTC ATT CGA ATG ACC TGA GCG CTC A -*3*') were designed by a computer program "SEQUIN".[1] All oligonucleotides were purchased from IDT, Inc. and purified by 20% denaturing polyacrylamide gel electrophoresis (PAGE); bands were cut out of gels and eluted in a solution containing ammonium acetate (500 mM), magnesium acetate (10 mM), and ethylenediamine tetraacetic acid (EDTA; 1 mM). The

self-assembled DNA nanotubes were formed following the modified procedure published in previous paper.[17] Briefly, 20 μL ssDNA of 5 μM was prepared by dissolving the purified oligonucleotides (52 nt) in 1×TAE/Mg^{2+} buffer (40 mM Tris base, 20 mM acetic acid, 2 mM EDTA and 12.5 mM magnesium acetate). Then slowly cool down solution from 95 to 4 ^{o}C for 48 h.

Template-synthesis of PMTP/DNA nanonecklaces at surface-immobilized DNA nanotubes

1. On mica by blow drying

5 μL of self-assembled DNA nanotubes in 1×TAE/Mg^{2+} buffer was deposited onto the freshly cleaved mica and blown dry with compressed air. The surface was rinsed with DI water and blown dry. Then 50 μL of 0.1 M $FeCl_3$ aqueous solution was added onto the mica and left to incubate for 10 min within closed petri dish, followed by 4 cycles of DI water washing and compressed air blow drying. To initiate efficient polymerization reaction, the residual water should be removed thoroughly and oxygen-free reaction environment need to be kept. Therefore, the mica with $FeCl_3$-impregnated DNA nanotubes was heated at 37 ^{o}C for 30 min to remove the residual water, followed by blow dry with the compressed nitrogen. Subsequently, 50 μL of *3*-methylthiophene monomer was added and allowed to incubate with $FeCl_3$-impregnated DNA for 1 min. After removing the *3*-methylthiophene monomer by compressed air blowing, the surface was rinsed thoroughly with methanol to further clean un-reacted monomer, dried with compressed air and characterized with AFM.

2. On UV ozone-modified silicon wafer with the gold source-drain electrodes by natural drying

For the electrical measurement, PMTP/DNA nanonecklaced structures were also prepared on silicon wafer with the gold source-drain electrodes. The embedded gold electrodes were formed by photolithography on a Si wafer with 300-nm SiO_2 surface layer. The silicon wafer was first cleaned with hot piranha solution (H_2SO_4 (98%)/H_2O_2 (30%) = 7/3 (v/v)), followed by sonication in DI water and acetone for 6 min respectively. Then the silicon wafer was modified to be hydrophilic by the exposure to UV-ozone for 1 h. To form PMTP/DNA nanonecklaces on the silicon wafer, 20 μL of self-assembled DNA nanotubes in 1×TAE/Mg^{2+} buffer was deposited and left to evaporate till complete drying. Then 100 μL of 0.1 M $FeCl_3$ aqueous solution was added onto the silicon wafer and allowed to incubate for 10 min within closed petri dish, followed by 4 cycles of DI water washing and compressed air blow drying. Moreover, the silicon wafer with $FeCl_3$-impregnated DNA nanotubes was heated at 37 ^oC for 30 min to remove the residual water, followed by blow dry with the compressed nitrogen. Subsequently, 100 μL of *3*-methylthiophene monomer was added and allowed to incubate with $FeCl_3$-impregnated DNA for 1 min. After removing the *3*-methylthiophene monomer by compressed air blowing, the surface was rinsed thoroughly with methanol to further clean un-reacted monomer, dried with compressed air and characterized with AFM and Keithley 4200 Semiconductor Characterization System.

3. On carbon-coated copper TEM grids

The carbon-coated copper TEM grid was modified to be hydrophilic by the exposure to UV-ozone for 30 min. To form PMTP/DNA nanonecklaces on the TEM grid, 10 μL of self-assembled DNA nanotubes in 1×TAE/Mg^{2+} buffer was deposited on the grid held by self close clamping tweezer and left to evaporate till complete drying. Then 10 μL of 0.1 M $FeCl_3$ aqueous

solution was added onto the copper TEM grid and allowed to incubate for 10 min within closed petri dish, followed by 4 cycles of DI water washing and compressed air blow drying. Moreover, the TEM grid with $FeCl_3$-impregnated DNA nanotubes was heated at 37 ^oC for 30 min to remove the residual water, followed by blow dry with the compressed nitrogen. Subsequently, 10 μL of *3*-methylthiophene monomer was added and allowed to incubate with $FeCl_3$-impregnated DNA for 1 min. After removing the *3*-methylthiophene monomer by compressed air blowing, the surface was rinsed thoroughly with methanol to further clean un-reacted monomer, dried with compressed air, and characterized by TEM/EDX.

AFM imaging

A MultiMode 8 AFM (Bruker) was used to image the samples under ScanAsyst-Air mode, using a ScanAsyst-air nanoprobe (Bruker).

TEM/EDX characterization

Dark-field TEM imaging and EDX element analysis were conducted on a Tecnai T20 field emission transmission electron microscope with accelerating voltage of 200 kV.

Two terminal current-voltage characterization

Two-terminal current-voltage measurements were performed using Signatone Triaxial Probe Station and Keithley 4200 Semiconductor Characterization System. The current was measured for applied voltages from -10 to 10 V in steps of 0.05 V. All of the electrical measurements were carried out in air at room temperature.

Reference

1. N. C. Seeman, *J. Biomol. Struct. Dyn.* 1990, **8**, 573.