

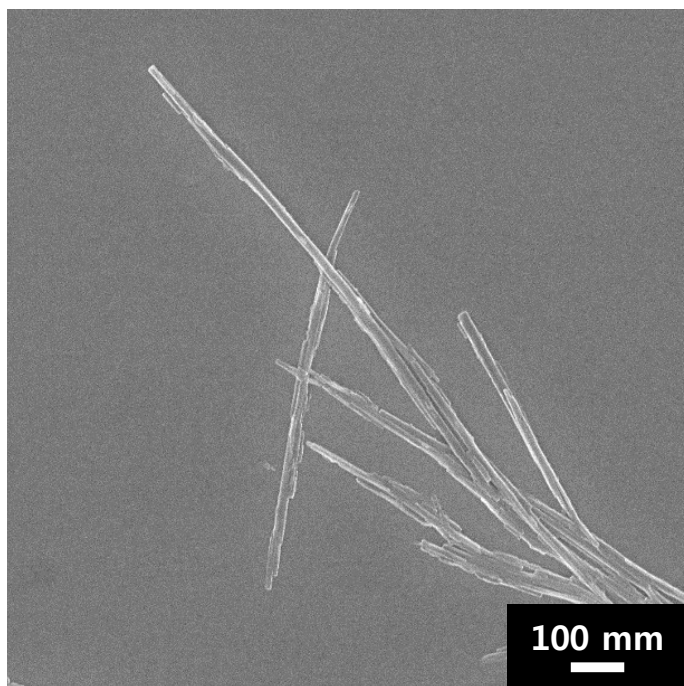
Supporting information for

Size-controllable Ultrathin Carboxylated  
Polypyrrole Nanotube Transducer for  
Extremely Sensitive  $17\beta$ -estradiol FET-type  
Biosensor

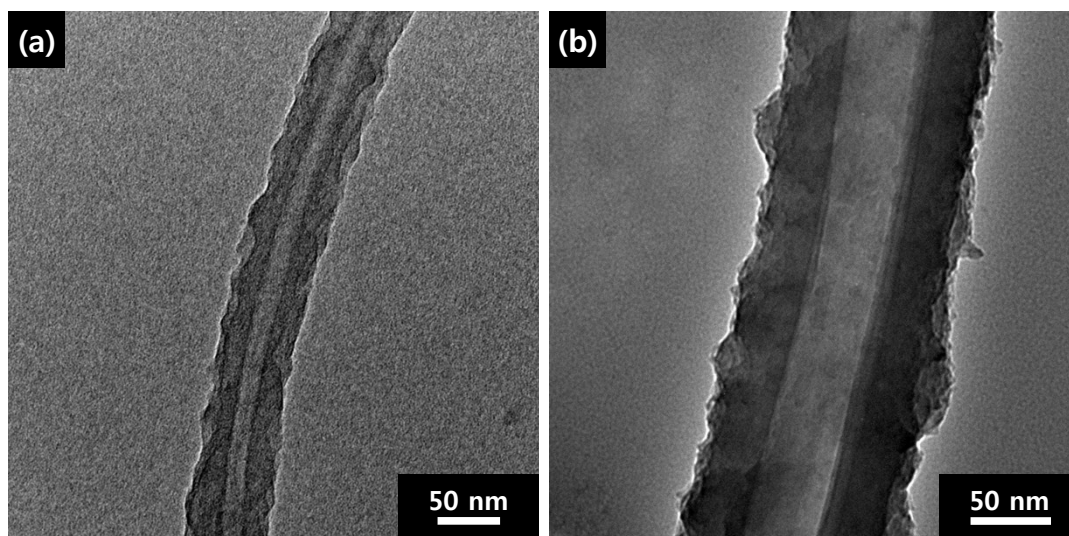
*Wonjoo Na, Jin Wook Park, Ji Hyun An and Jyongsik Jang\**

School of Chemical and Biological Engineering, Seoul National University, 1 Gwanak-ro,  
Gwanak-gu, Seoul 151-742, Korea

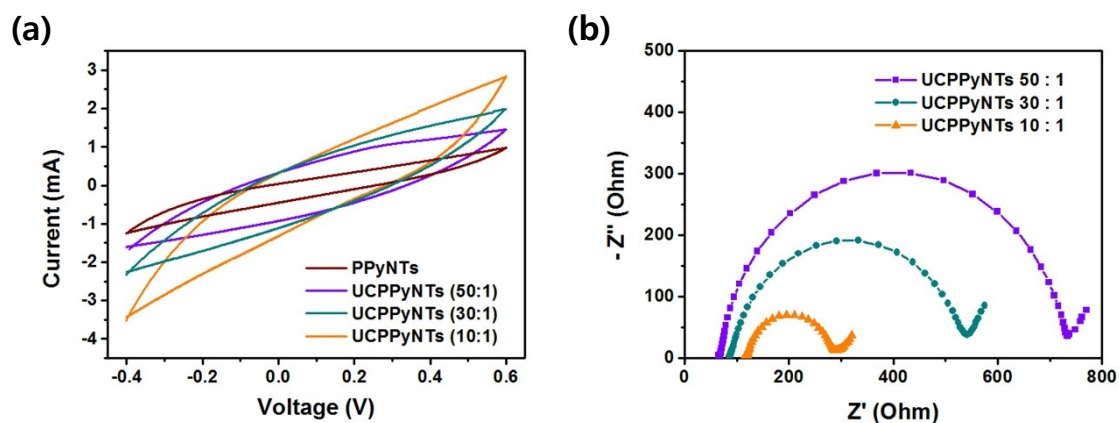
[\*] Tel.: 82-2-880-7069; Fax: 82-2-888-7295; E-mail: [jsjang@plaza.snu.ac.kr](mailto:jsjang@plaza.snu.ac.kr)



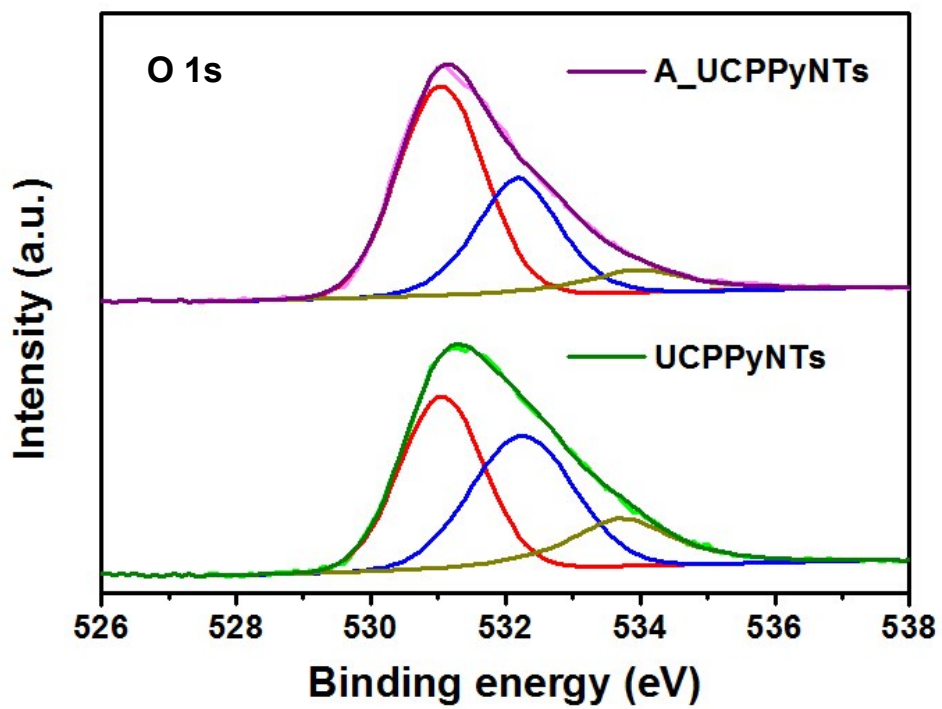
**Fig. S1.** SEM image of MO-FeCl<sub>3</sub> template fabricated at 10 °C



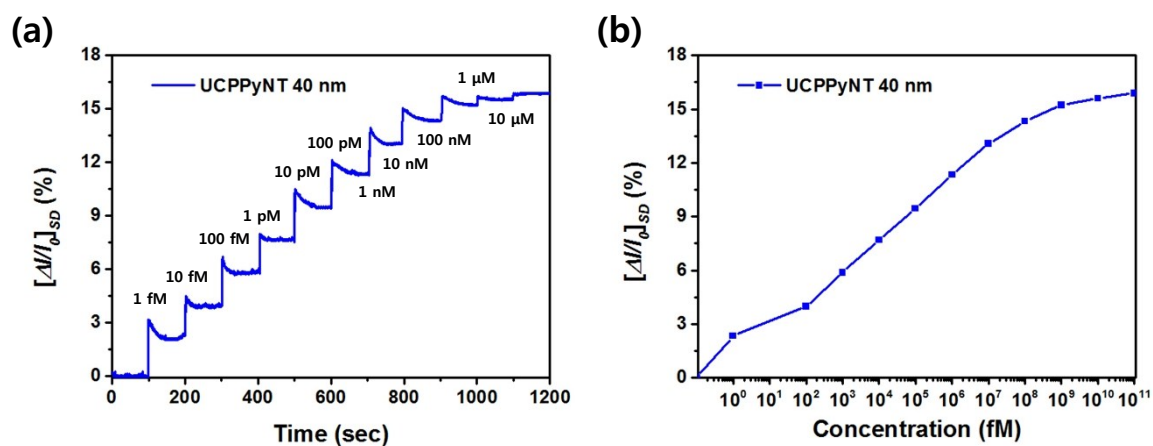
**Fig. S2.** TEM images of UCPPyNTs at room temperature (20°C) with different molar ratio of monomer/MO/FeCl<sub>3</sub> (a) 5:1:10, (b) 20:1:10.



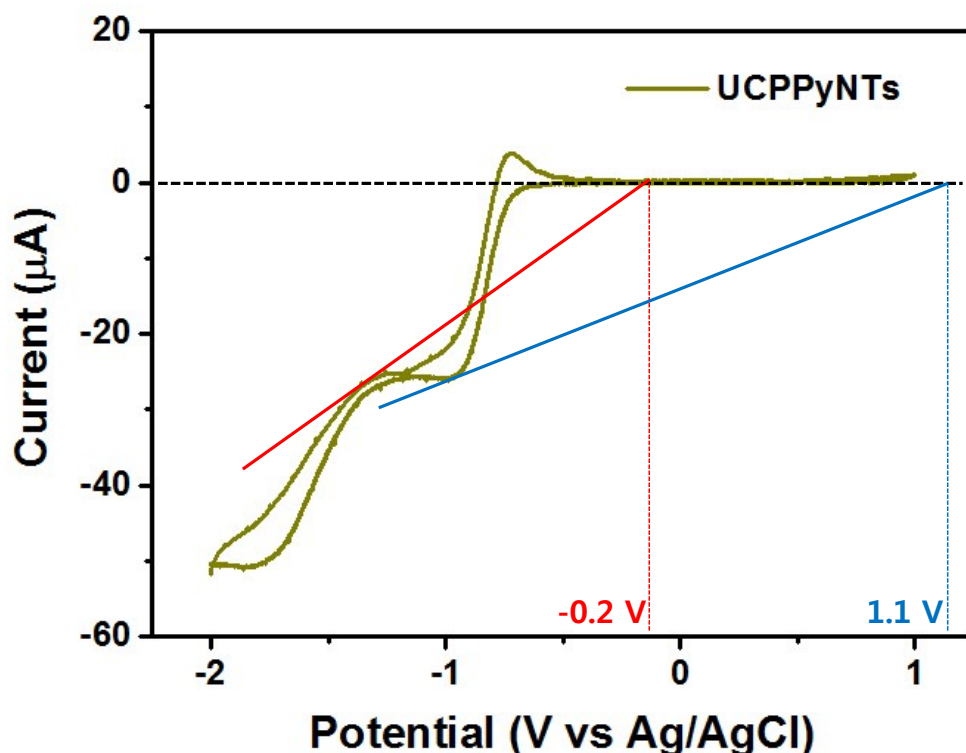
**Fig. S3.** (a) Cyclic voltammetry (CV) curves of PPyNTs and UCPPyNTs with different ratio of Py and P3CA in a 0.1 M PBS electrolyte at  $5 \text{ mV s}^{-1}$ . (b) Electrochemical impedance spectra (EIS) of UCPPyNTs with different ratio of Py and P3CA in the frequency range from 1 Hz to 1 mHz.



**Fig. S4.** X-ray photoelectron spectroscopy (XPS) O 1s peak deconvolution spectra of the UCPPyNTs and A-UCPPyNTs that before and after the attachment of the aptamer.



**Fig. S5.** (a) Real-time responses for the FET-type biosensors of 40-nm A-UCPPyNT with normalized current changes measured until saturated signal had appeared. b) Calibration curves of real-time response for the FET-type biosensors as a function of 17β-estradiol concentration. The normalized current changes used after 30 sec of 17β-estradiol exposure. ( $V_G$ : -0.7 V,  $V_{SD}$ : 0.01 V)



**Fig. S6.** Cyclic voltammetry (CV) curves of UCPPyNTs on glassy carbon electrode in a 0.1 M tetrabutylammonium hexafluorophosphate (TBAPF6) in acetonitrile electrolyte. (voltage window from  $-2$  V to  $1$  V at scan rate  $5$   $\text{mV s}^{-1}$ )

We carried out cyclic voltammetry (CV) measurement of UCPPyNT for determining HOMO and LUMO of carboxylated polypyrrole (**Fig. S6**). The HOMO and LUMO can be calculated where the onset of oxidation and reduction peak as follows:

$$E_{\text{HOMO}} = - (E_{\text{onset, ox vs. Ag/AgCl}} + 4.4) \text{ (eV)} \quad (1)$$

$$E_{\text{LUMO}} = - (E_{\text{onset, red vs. Ag/AgCl}} + 4.4) \text{ (eV)} \quad (2)$$

The onset oxidation peak occurred at  $1.1$  V and the onset reduction peak occurred at  $-0.2$  V. Therefore The HOMO and LUMO of carboxylated polypyrrole was  $-5.5$  V and  $-4.2$  V, respectively. The Fermi level of gold is known as  $-5.1$  eV and UCPPyNTs have a bandgap between that value.<sup>S1-S7</sup> Therefore, UCPPyNTs and gold electrode were contacted well and performing Ohmic behavior.

## REFERENCE AND NOTES

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