Electronic Supplementary Material (ESI) for Materials Horizons.

Supporting Information

Stable Water-Floating Transistor with Recyclability

Ilhwan Yu,[1] Quyen Vu Thi,[1] Jaehyoung Ko,[1, 2] Dong Su Lee,[1] Dae-Young Jeon,[1] and Yongho Joo[1*]

[1]Institute of Advanced Composite Materials, Korea Institute of Science and Technology (KIST), 92 Chudong-ro, Bongdong-eup, Wanju-gun, Jeonbuk 55324, Republic of Korea

[2]Department of Chemical and Biomolecular Engineering and KAIST Institute for Nano Century, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Korea

[*]To whom correspondence should be addressed, yjoo0727@kist.re.kr

Experimental section

Materials

Semiconducting single-wall carbon nanotubes (s-SWCNTs) wrapped with conjugated polymers (IsoSol-S100) were purchased from Nanointergis (Canada). Chloroform (> 99.9%) was purchased from Sigma-Aldrich (USA). The deionized (DI) water was obtained from a Human Power 1+ purification system. All materials were used without further purification.

Floating System

To prepare dispersed s-SWCNTs, the mixture of s-SWCNTs (0.2 mg) and chloroform (10 mL) were sonicated for 1 min using a tip sonicator at a power of 150 W (VCX500, SONICS, U.S.). The well-dispersed s-SWCNT ink (600 μL) was sprayed over the Langmuir-Blodgett (LB) trough (KSV NIMA KN 2001) that filled with DI water at room temperature. After the evaporation of chloroform (30 minutes), s-SWCNT at the air-water interface was controlled through the barrier of LB trough, and the surface tension was monitored with Wilhelmy balance (platinum plate). For the characterization of the sensing system, barrier positioning was controlled with compressions in the barrier position range of 0 − 60 mm. At the same time, the copper foil was attached to the barrier to use as an electrode, and electrical sensing characteristics were measured at 1V voltage using a semiconductor parameter analyzer (Keithley 4200-SCS, Tektronics, U.S.).

Imaging

The morphology of the prepared s-SWCNT film was characterized by an optical microscope (AXIO Imager A2m, ZEISS, Germany) with a polarizing filter and a field emission scanning electron microscope (MERLIN, ZEISS, Germany). A transmission electron microscope (Titan G2, FEI) was utilized for the TEM images with an accelerating voltage of 200 kV. The s-SWCNT film for analysis was prepared by the Langmuir-Schaefer (LS) method at certain surface pressure. Silicon wafer was used as the substrate and washed with acetone to remove surface contamination. The thickness of the s-SWCNT thin film can be analyzed by transferring the s-SWCNT film from the water surface to the silicon wafer and the thickness of the s-SWCNT film was ~ 200 nm at a surface pressure of 60 mN m^{-1}.

Polarized Raman Spectroscopy Characterization

Raman characterization was performed using a confocal Raman spectrometer equipped with a charge-coupled device (CCD) detector and laser source of an excitation wavelength of 532 nm (XPERRAM200, Nanobase, South Korea). A microscope with 50 times objective lens was used for focusing the laser beam and collecting the scattered light. The polarization behavior of the s-SWCNT film was obtained by adjusting the rotation angle of the linear polarizing filter.

WFGT Fabrication and Measurements

The WFGT was characterized at the surface pressure of 60 mN m^{-1} (Thickness of thin-film: ~200 nm). Graphene ink (2 μL of 0.2 mg ml^{-1}) was coated on the tip-electrode for the formation of the electrode. The graphene tip was directly used as electrode between the s-SWCNT array on the water surface. (Channel length = ~ 2 cm and the channel width = ~3 cm). To minimize the leakage current of the transistor, PFO-BPy ink (2 μL of 0.2 mg ml^{-1} in chloroform) was dropped with a micropipette at the position of the source and drain. After the evaporation of organic solvent (30 minutes), the transfer and output characteristics were measured using a semiconductor parameter analyzer (Keithley 4200-SCS, Tektronics, U.S.).

Recycling of s-SWCNT

All s-SWCNTs floated at air-water interfaces were collected using pipet and tweezer on the vial and allowed to dry in a vacuum chamber overnight. The collected s-SWCNTs were used for the spectroscopy characterization and for the use to weigh. The total amount of s-SWCNT and the volume of ink recovered after recycling were determined based on the total volume of ink dropped in water. For the re-dispersion, the same amount of s-SWCNT (0.2 mg of s-SWCNTs and 10 mL of chloroform) was dissolved in chloroform using tip-sonication. The electronic absorption spectra were collected using a 2-mm-path quartz cell using a Varian 5000 spectrometer to evaluate the concentration.

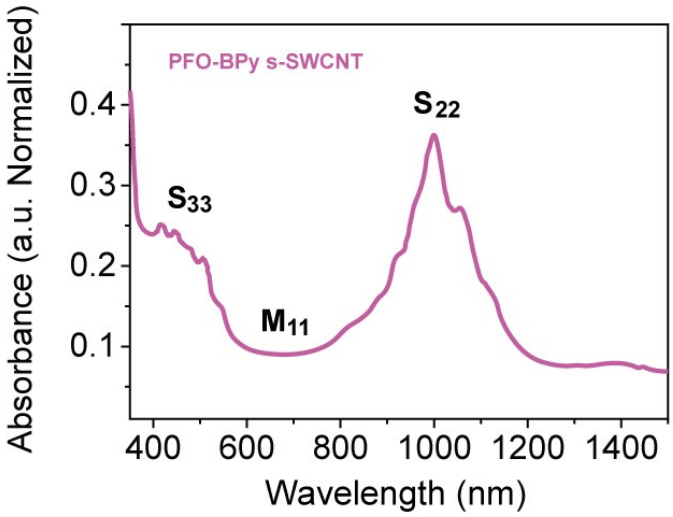

Figure S1. Absorption spectrum of sorted s-SWCNT wrapped by PFO-BPy, indicating the high purity of semiconducting electronic nature.

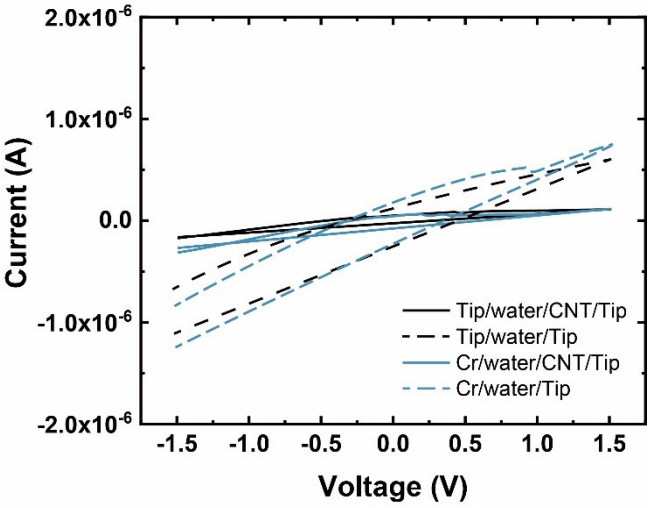

Figure S2. Current-voltage characteristics for the capacitors of tip-water-tip and the tip-water-s-SWCNT-tip structure.

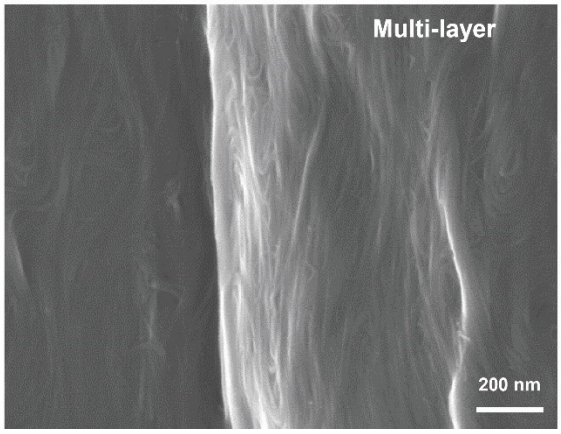

Figure S3. SEM characterization of s-SWCNT thin film showing the multi-layer at the surface pressure of 40 mN m^{-1}.

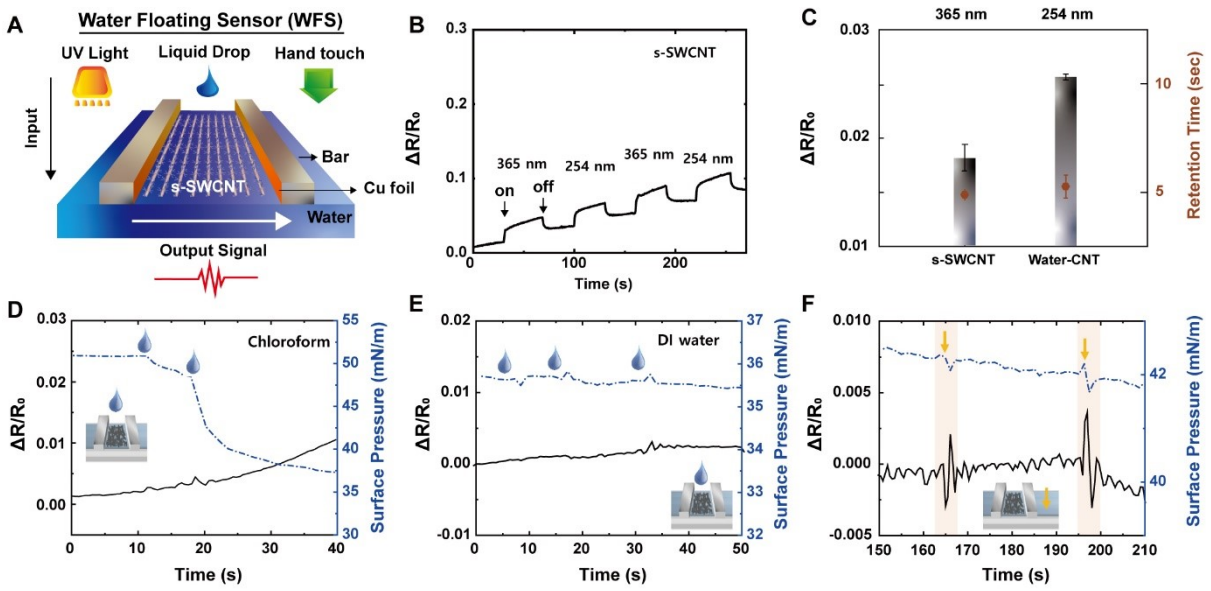

Figure S4. (**A**) Schematic diagram of the WFS working as multifunctional sensor against several stimuli such as UV light, liquid drops (water and organic solvent), and human touch. (**B**) Monitoring the resistance response of WFS by UV light irradiation (UV source: 254 nm, and 365 nm). (**C**) Sensitivity and retention time variation regarding the two different laser sources, indicating the higher sensitivity on the 254 nm laser source than 364 nm with the similar retention time (5 sec) for WFS. (**D, E**) The surface pressure and resistance response to solvent (water, and chloroform) drop were monitored in the floating system. (**F**) A sensing test of the human touch was performed to confirm the detection ability by the impact on WFS.

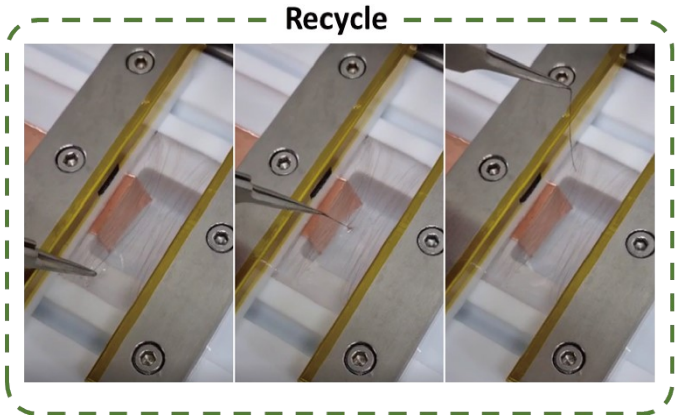

Figure S5. (B) Photograph of recycling of s-SWCNT from water.

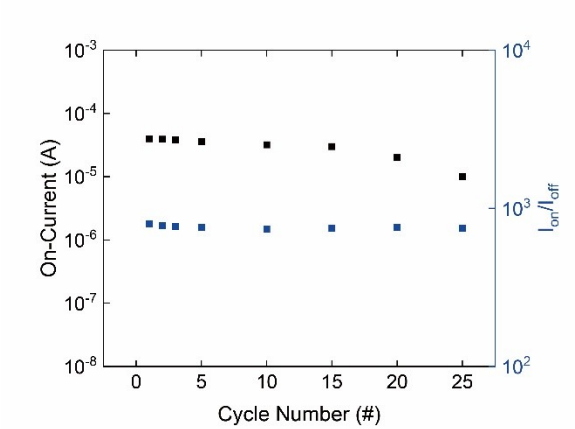

Figure S6. The change of the on-current and the I_{on}/I_{off} ratio as a function of the cycle number up to 25.