Experimental section

1.1 Materials

Materials: PM6, Y6, PDNIO were purchased from Solarmer Materials Inc., Beijing. 1-chloronaphthalene (CN) was purchased from TCI, Shanghai. Conductive PEDOT:PSS aqueous (named PH1000 and Clevios PVP Al 4083) were purchased from Heraeus corporation (PH1000 with a solid content of 1.0-1.3% and a specific conductivity of 850 S/cm , and PEDOT:PSS(4083) with a solid content of 1.5-1.7% and a specific conductivity of 3980 S/cm). GR&AgNWs flexible transparent conductive film purchased from Vigon technologies. Surfactant-polyethylene glycol 2,5,8,11-tetramethyl-6-dodecyne-5,8-diol ether (PEG-TmDD, Superwet-340, surfy- Chem T&D).

1.2 Fabrication of photovoltaic devices:

GR&AgNWs films on PET substrates were gently scrubbed with a cotton dipping ethanol. The ITO films based on glass and PET were ultrasonically cleaned with soapy water, deionized water, acetone, and isopropanol respectively for 20 min. Then, PH1000 aqueous with 5 wt% Dimethyl sulfoxide (DMSO) and 0.5 vol% PEG-TmDD was spin coated on top of GR&AgNWs film PET-based filtered with 0.45 μm syringe filter, and change the thickness by adjusting the spin coating speed. PH1000 aqueous with 0.45 μm syringe was also spin-coated with 1500 r/min for 60s on PET substrate as an electrode. And then thermal annealing was followed at 90 °C for 20 min.

Next, prior to the spin-coating of PEDOT:PSS aqueous (Clevios PVP Al 4083) , The ITO films were treated by UV-plasma for 20 minutes. Then, PEDOT:PSS aqueous (Clevios PVP Al 4083) were spin-coated onto the surface of PH1000, ITO, AgNWs, and graphene films by spin-coating at 3000 rpm for 60 s as an anode interface layer and annealed at 90 °C for 20 min as an interface layer. the PEDOT:PSS aqueous (Clevios PVP Al 4083) were conducted again mentioned above in the case of double buffer layer.

Subsequently, the active layer of PM6:Y6 (1:1.2, weight ratio) solution with the total concentration of 16 mg/ml dissolved in chloroform, 0.5 vol% 1-chloronaphthalene (CN) as solvent additive was spin-coated at 2500 rpm for 60 s onto the Clevios PVP Al 4083 layer in the N_2-filled glove box and annealed at 110 °C for 10 min. The thickness of the PM6:Y6 active layer is about 120 nm. Next, PDINO dissolved in methanol (1.5 mg/ml) was spin-coated on the active layer at 3000 rpm for 60 s as a cathode interface layer (thickness: 10 nm). Finally, the top electrodes Al (thickness: 100 nm) were thermally evaporated at a base pressure of about 10^{-5} mbar using Vacuum evaporation system under a shadow mask providing an effective area of 4.0 mm^2.

2.1 Characterization

Sheet resistance of films was measured by the Vander Pauw four-point probe method using Keithley 2400 source meter. Transmittance and reflectance spectra were performed on a spectrophotometer (Lambda950, Perkin-Elmer). Under illumination of AM 1.5 G, 100 mW/cm^2 and in the dark, the J-V characteristics were tested by the source meter (Keithley 2440) controlled by the program (Newport-Oriel Sol3A 450W) in the N_2-filled glove box. The EQE spectra were detected by a NewportOriel® IQE 200™ under monochromatic illumination. And a standard Si solar cell was performed as a calibration. Ultraviolet photoelectron spectroscopy (Kratos ULTRA DLD UPS/XPS system) was used to characterize of work function (WF). The experiments were performed at a base pressure of 10^{-10} mbar using monochromatic Al (Kα) X-rays (1486.6 eV) and He I (21.22 eV) source, respectively. The thickness of the active layer was obtained with computer-controlled Dektak 150 Veeco. The surface morphologies provided by atomic force microscope (Veeco Dimension 3100V).

Table S1 Key parameters of flexible OSCs on PET with the devices based on PH1000, AgNWs, and Graphene electrode.

Electrode	V_{oc} [V]	J_{sc}[mA/cm^2]	FF [%]	PCE$_{max}$[%]
PH1000/ PEDOT:PSS	0.827	16.68	52.84	7.29
AgNWs/PEDOT:PSS	0.794	6.46	24.83	1.27
Graphene/ PEDOT:PSS	0.824	15.30	42.89	5.40

Table S2 Key parameters of flexible OSCs based on ITO/PET devices without and with surfactant doped into interface layer.

Electrode	V_{oc} [V]	J_{sc}[mA/cm^2]	FF [%]	PCE$_{max}$ [%]
ITO/ PEDOT:PSS	0.832	20.31	66.77	11.28
ITO/PEDOT:PSS（PEG-TmDD）	0.828	17.06	43.18	6.10

Table S3 Key parameters of flexible OSCs with different PEDOT:PSS thickness based on GR&AgNWs/PH1000(160 nm) electrode.

Electrode	PEDOT:PSS Thickness(nm)	V_{oc} [V]	J_{sc} [mA/cm^2]	FF [%]	PCE$_{max}$ [%]
GR&AgNWs/PH1000 (160nm)/PEDOT:PSS 1	40	0.805	20.47	67.30	11.08
	70	0.815	22.05	64.28	11.55
	100	0.816	21.05	66.27	11.38

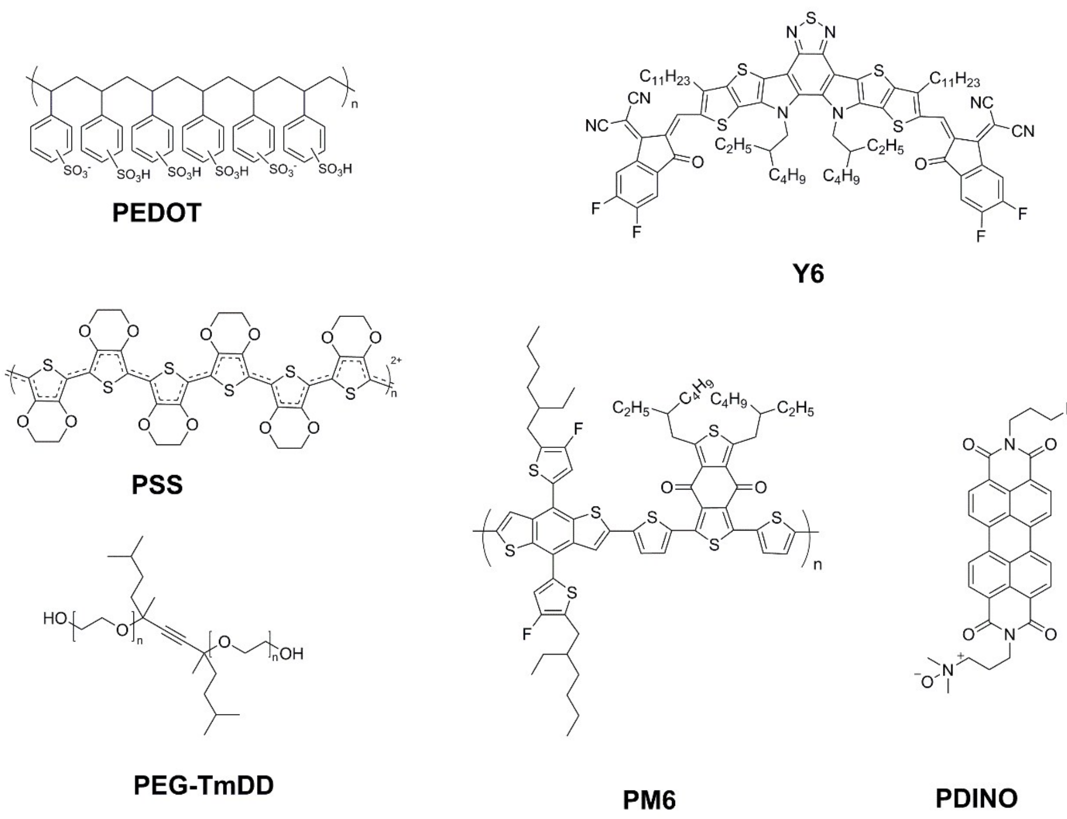

Figure S1. Molecular structures of PM6, Y6, PEG-TmDD, PEDOT:PSS and PDINO.

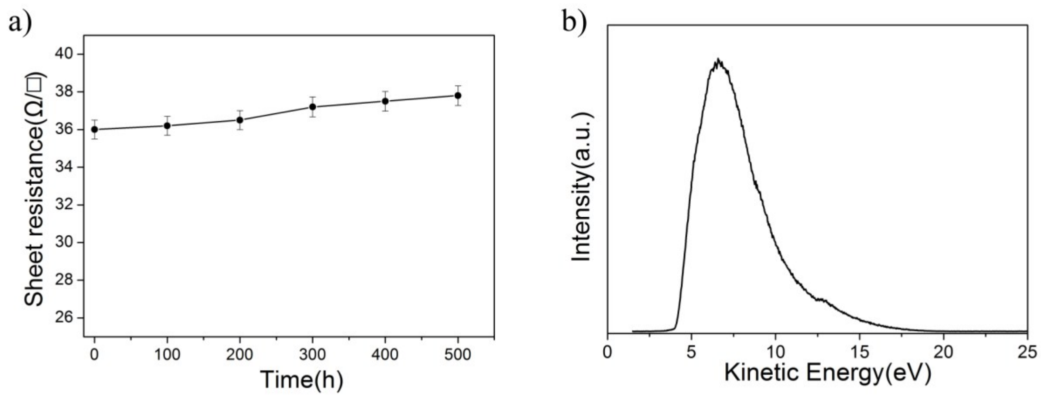

Figure S2. a) The stability of GR&AgNWs electrode's sheet resistance. b) The UPS spectra of GR&AgNWs film.

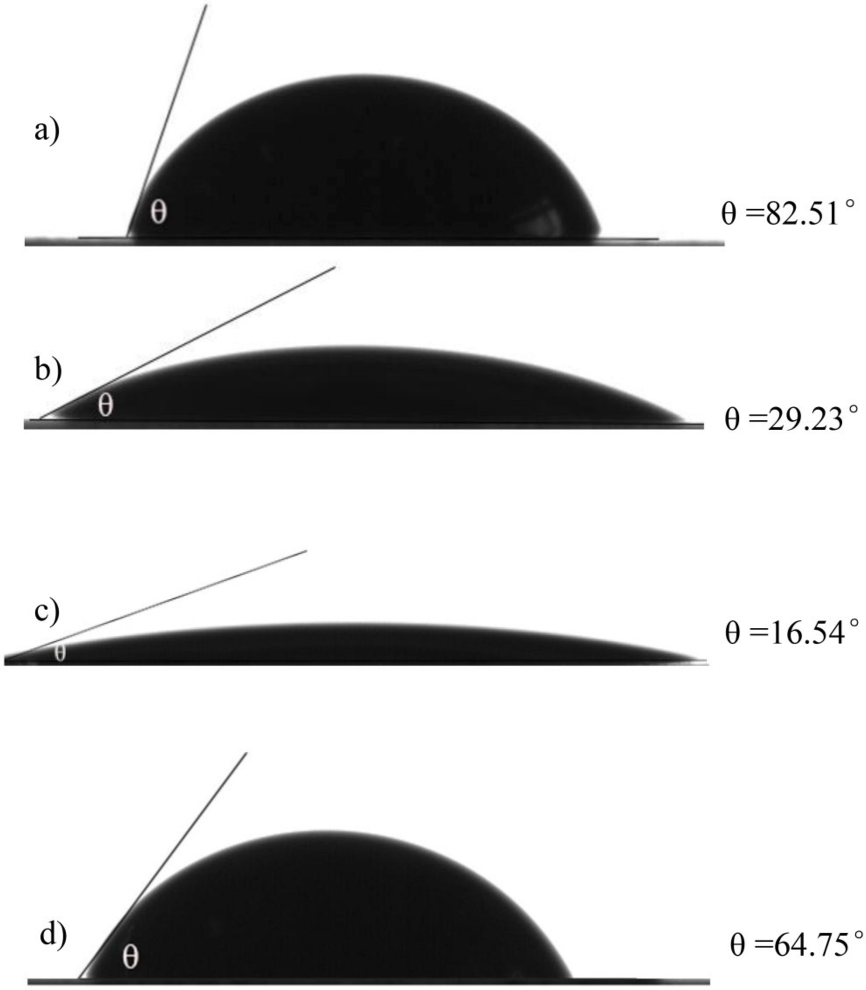

Figure S3. a,b) Water contact angle images of PH1000 and PEG-TmDD (surfactant) droplets on GR&AgNWs film respectively. c,d) Wettability characteristics of PEDOT:PSS droplets on PH1000 (doped with PEG-TmDD) and one-layer of PEDOT:PSS respectively. All substrates are PET.

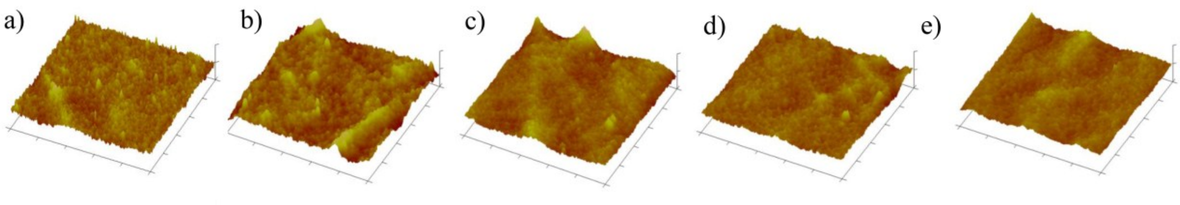

Figure S4. 5×5 μm^2 AFM 3D surface plot. a) PH1000 with 160nm thickness. b) one PEDOT:PSS and c) double PEDOT:PSS based on hybrid electrodes. and the active layer based on d) GR&AgNWs/PH1000/ PEDOT:PSS^1. e) GR&AgNWs/PH1000/ PEDOT:PSS^2.

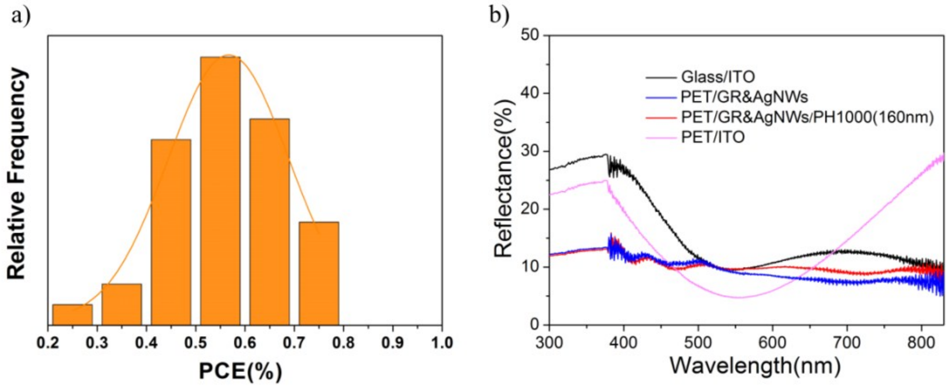

Figure S5. a) Histogram of the PCE measurements for 40 devices based on GR&AgNWs electrode. b) Reflectance spectra of GR&AgNWs, GR&AgNWs/PH1000 (160 nm), and ITO based on glass and PET. (excluding the substrate).

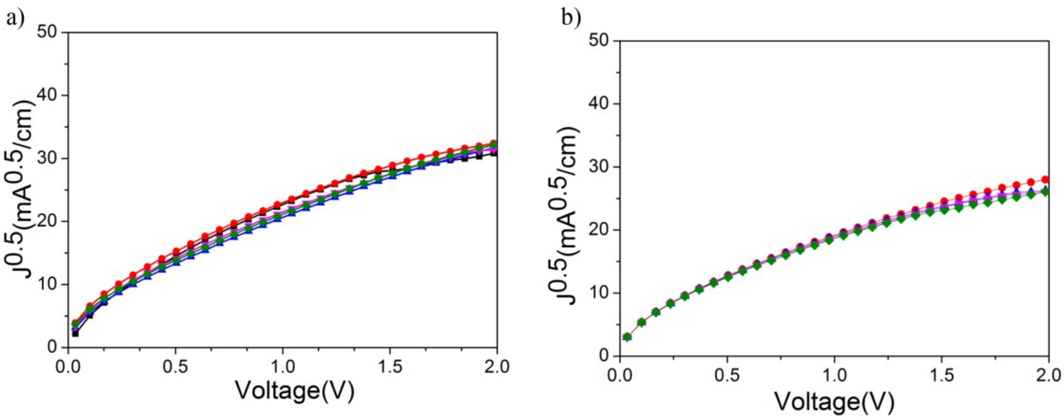

Figure S6. Electric filed dependence of the $J^{0.5}$ of the hole-only flexible devices: a) One buffer layer PEDOT:PSS[1], b) Double buffer layer PEDOT:PSS[2] (both are based on GR&AgNWs/PH1000 (160 nm) electrode). Measure five devices' average to verify the values of hole mobility.

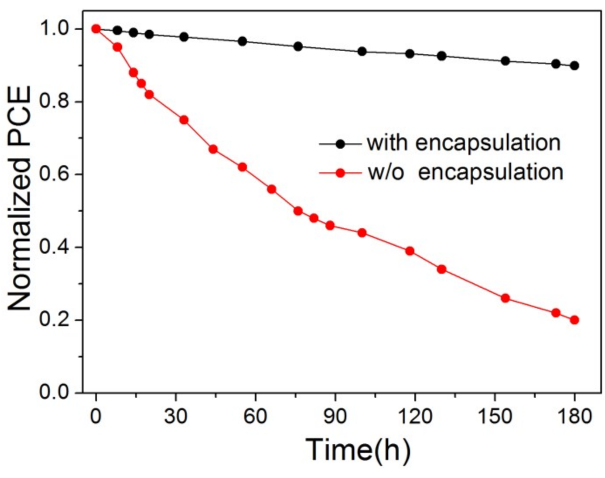

Figure S7. The stability of devices PM6:Y6 based with encapsulation and without encapsulation on GR&AgNWs/PH1000 electrode.

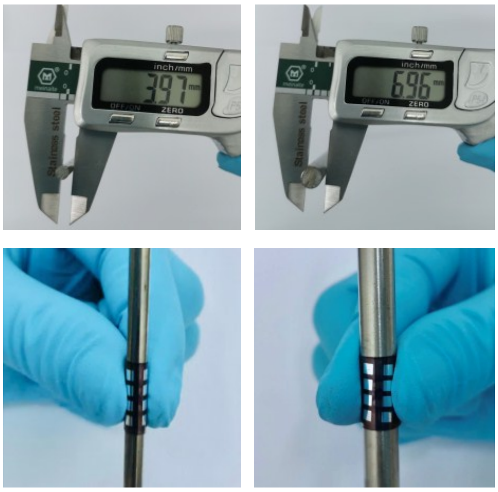

Figure S8. The partial image (r=2, 3.5 mm) of bending test and corresponding curved radius.

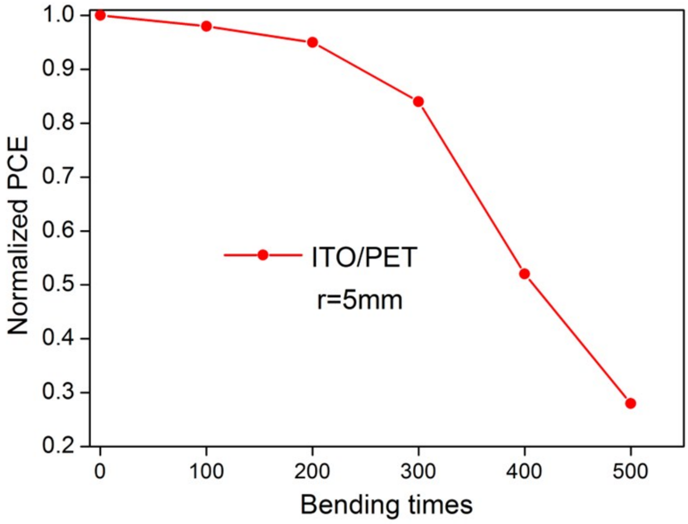

Figure S9. Normalized PCEs of flexible OSCs based on ITO electrode tested in bending radius of 5 mm.