Supporting information

High-Performance Flexible Fully-Printed All-Carbon Thin Film Transistors and Ultrasensitive NH_3 Sensors

Yunfei Ren[1,2], Min Li[1], Xiaoqian Li[1], Yue Geng[1], Xin Wang[1], Jianwen Zhao[*1,2]

[1]Printable Electronics Research Centre, Suzhou Institute of Nano-Tech and Nano-Bionics, Chinese Academy of Sciences, 398 Ruoshui Road, SEID SIP, Suzhou, 215123, PR China

[2]Institute of Nano Science and Technology, University of Science and Technology of China, 166 Ren Ai Road, SEID SIP, Suzhou, Jiangsu, 215123, PR China

E-mail: jwzhao2011@sinano.ac.cn.

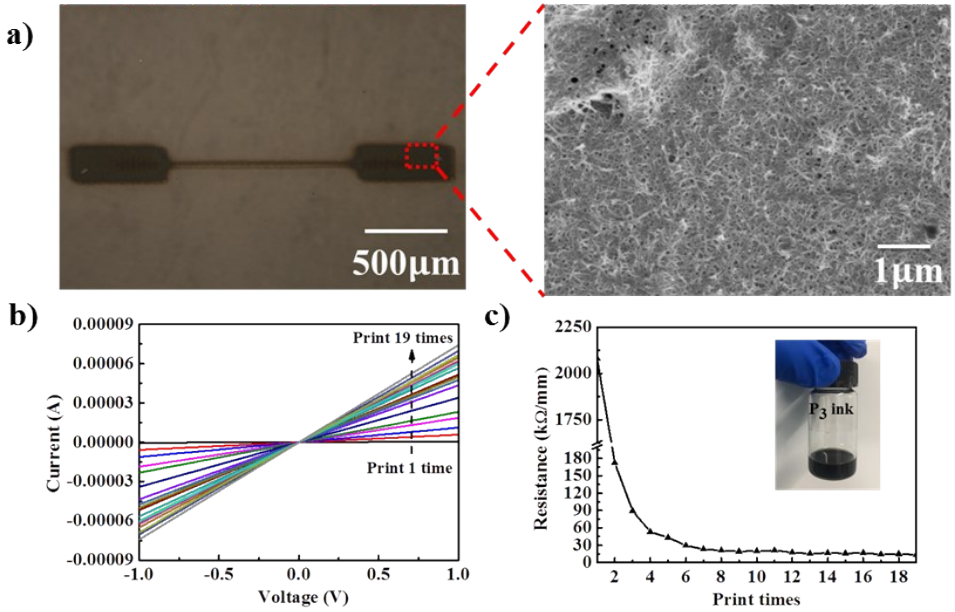
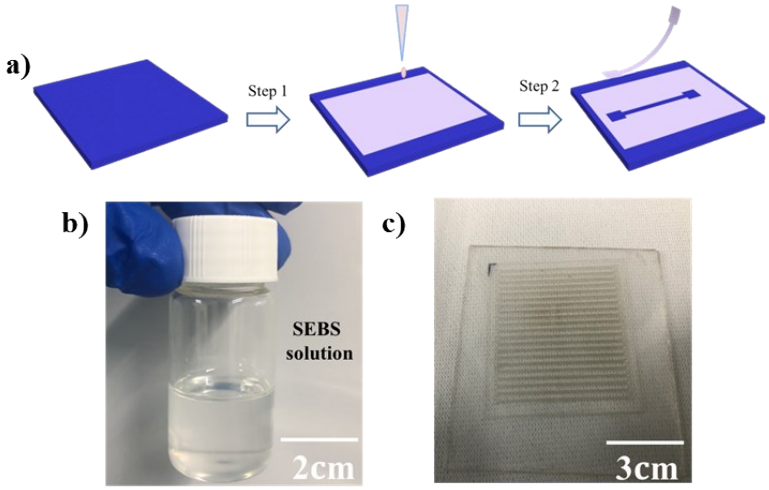


Figure S1 a) Optical image and SEM of P_3 SWCNT thin films with a printed length of 1 mm. Sheath flow rate, carrier flow rate and speed are 90 sccm, 15 sccm, and 1.5 mm/s, respectively. b), c) Characterizations of the P_3 SWCNT thin film resistances with different printing times. The inset in **Figure S1c** is the optical image of the printable P_3 ink.



Step 1: Drip-coating and curing SEBS solution on a clean glass at room temperature.

Step 2: Using laser to etch SEBS film and peeling off SEBS lines.

Figure S2 a) Schematic illustration of the fabrication steps of the patterned SEBS films, b) optical images of SEBS solution and c) the patterned SEBS film, respectively.

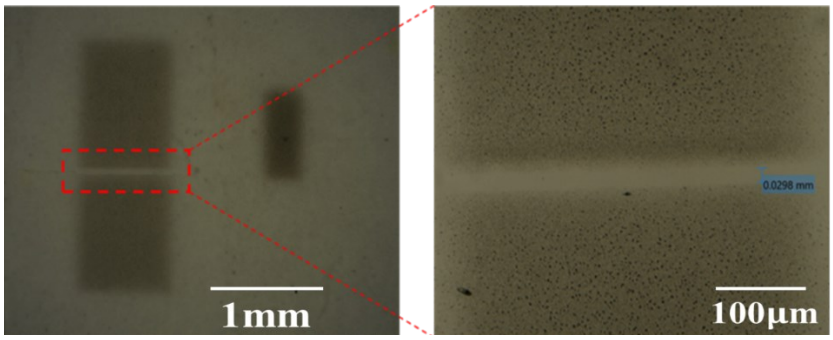


Figure S3 Optical images of the printed P_3 electrodes with the channel length of 29.8 μm with aid of the stretchable SEBS protected layer.

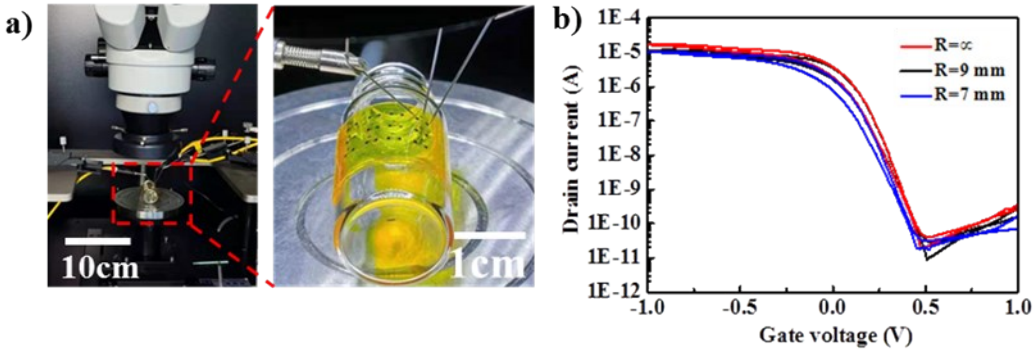


Figure S4 Measurement setup (a) and transfer curves for TFTs (b) under various bending radii (V_{DS}= -0.25 V).

Table S1 Summary of TFT performance under various bending radii.

Bending Radius (mm)	**μ ($cm^2V^{-1}s^{-1}$)**	**Vth (V)**	**Log (I_{on}/I_{off})**
∞	12.4	0.41V	~6
5	9.8	0.32V	~6
8	8.0	0.26V	~6

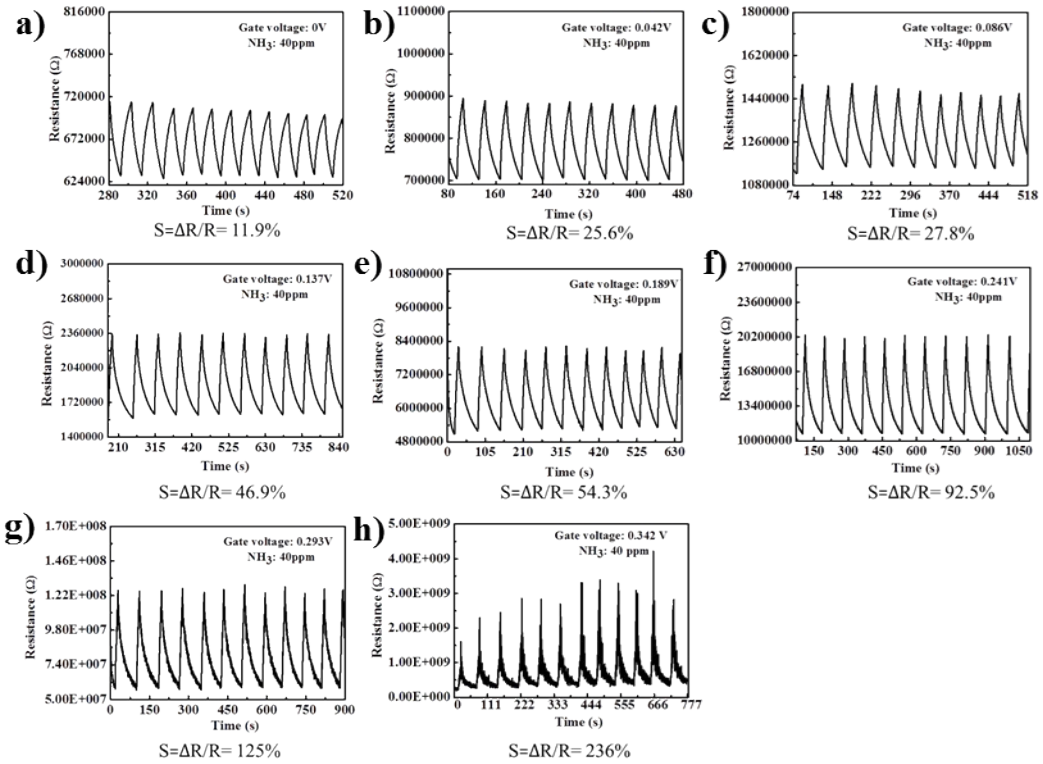


Figure S5 Response curves of transistor-type NH_3 sensor at different gate voltages (ion gels no contact with P_3 SWCNT source/drain electrodes, and the voltage between the source and drain electrodes of 0.25 V).

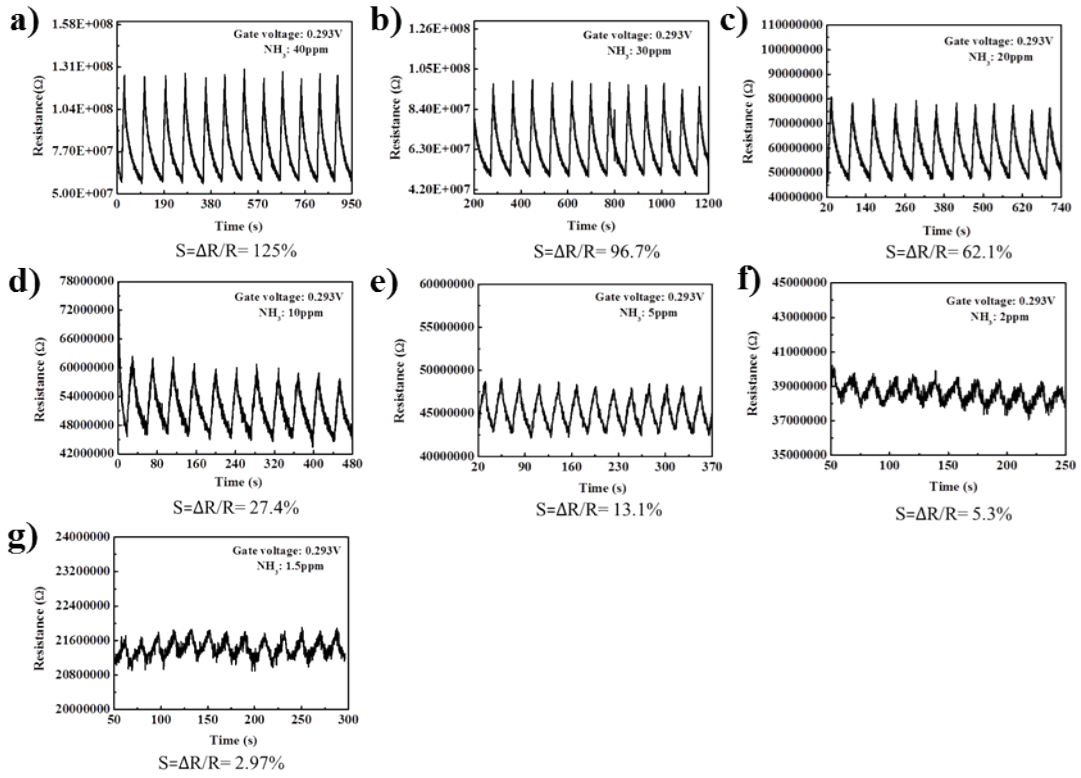


Figure S6 Response curves of the transistor-type gas sensor under different NH_3 concentrations at the gate voltage of 0.293 V (ion gels no contact with P_3 SWCNT source/drain electrodes, and the voltage between the source and drain electrodes of 0.25 V).

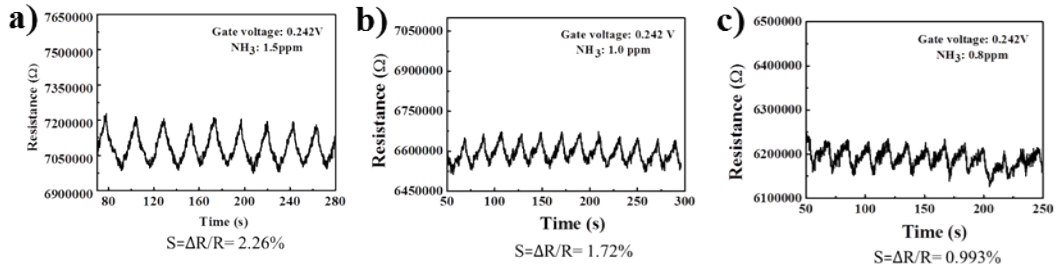


Figure S7 Response curves of the transistor-type gas sensor under different NH_3 concentrations at gate voltage of 0.242 V (ion gels no contact with P_3 SWCNT source/drain electrodes, and the voltage between the source and drain electrodes of 0.25 V).

Table S2 The lowest power consumption and the highest power consumption via SEBS film to protect electrode channel under different NH_3 concentrations are obtained by the formula: $P=U \times I=U^2/R$, where U and R are the sensor voltage and resistance between the source and drain electrodes, respectively.

NH_3 concentration/ppm	1.5	2.0	5.0	10.0	20.0	30.0	40.0
Lowest power consumption/nW	2.845	1.580	1.292	1.025	0.797	0.630	0.497
Maximum power consumption/nW	2.960	1.672	1.481	1.393	1.325	1.284	1.075

Note: All resistance data are from **Figure S6**.

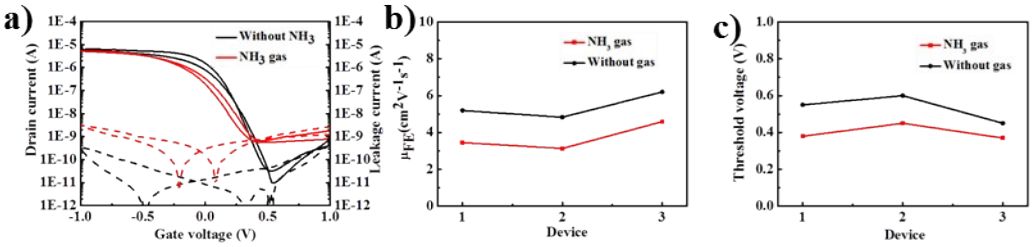


Figure S8 Electrical changes of TFT device parameters in NH_3 environment. a) The transfer curves of a fully-printed all-carbon TFT before and after exposure to NH_3 at V_{DS}= -0.25 V, b) mobility, and c) the threshold voltage (Ion gels no contact with P_3 SWCNT source/drain electrodes, L and W are 150 and 800 μm).

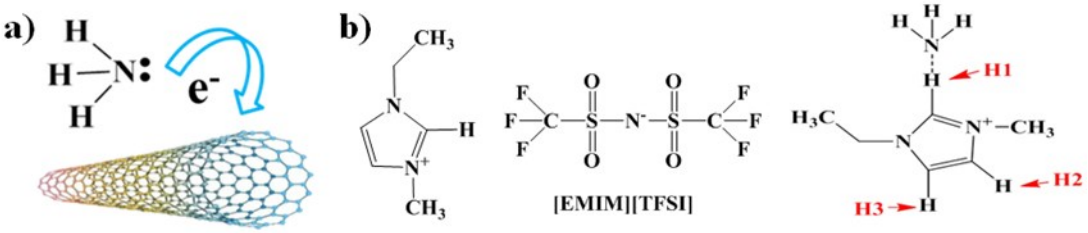


Figure S9 a) The scheme of charge transfer between NH_3 molecules and sc-SWCNTs, b) the chemical structures of ILs, and the hydrogen bonding between an NH_3 molecule and an [EMIM] cation at the H1 position.

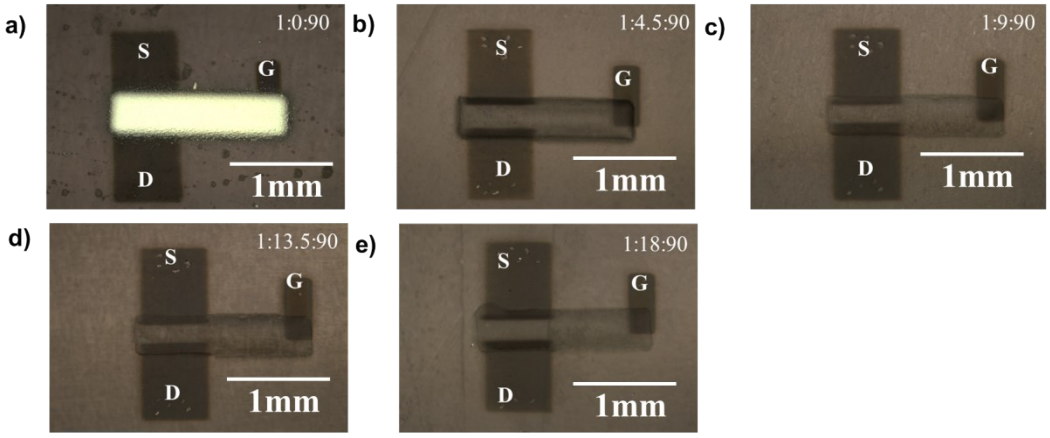


Figure S10 Optical images of fully-printed all-carbon TFTs with ion gels fully covered in the device channel at different weight ratios of ILs.

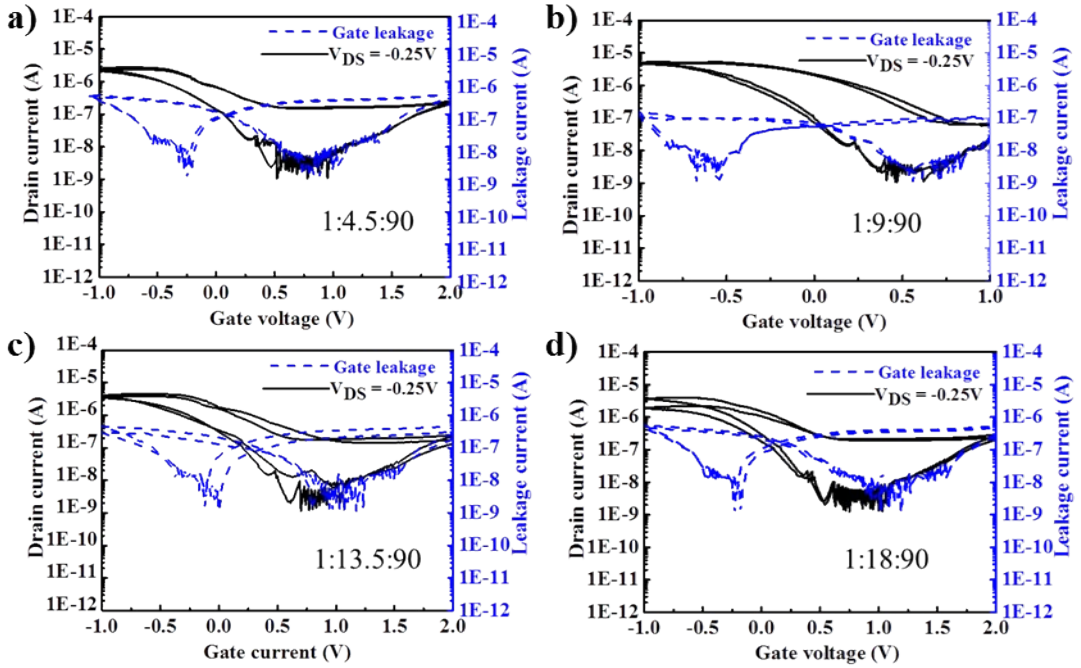


Figure S11 Transfer curves of fully-printed all-carbon TFTs with ion gels fully covered in the device channels at different weight ratios of ILs.

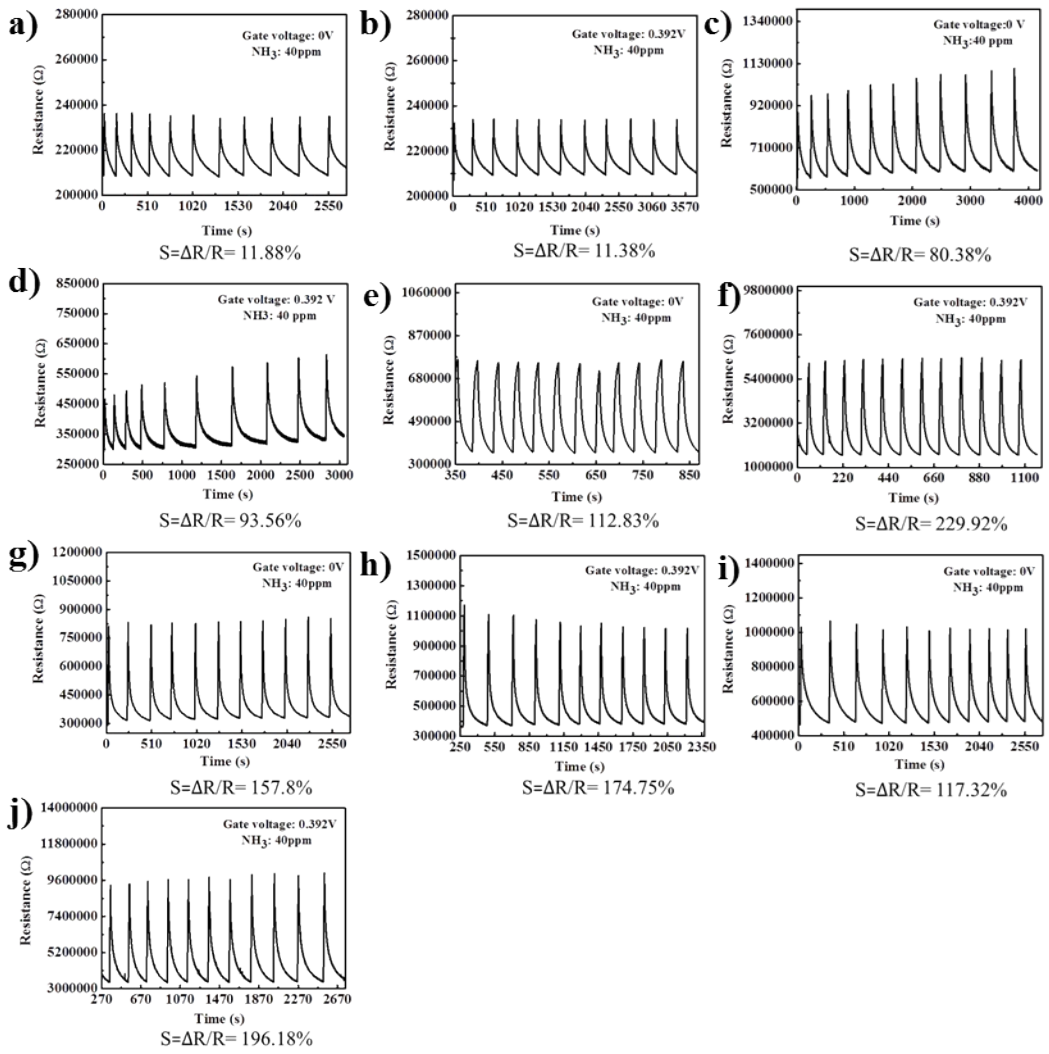


Figure S12 a), c), e), g), i) were the response curves when the weight concentrations of the ILs were 0%, 4.71%, 9%, 12.92%, and 16.51% without the gate voltage, respectively, while b), d), f), h), j) at gate voltage of 0.392 V (Ion gels fully covered in the device channels, and the voltage between the source and drain electrodes of 0.25 V).

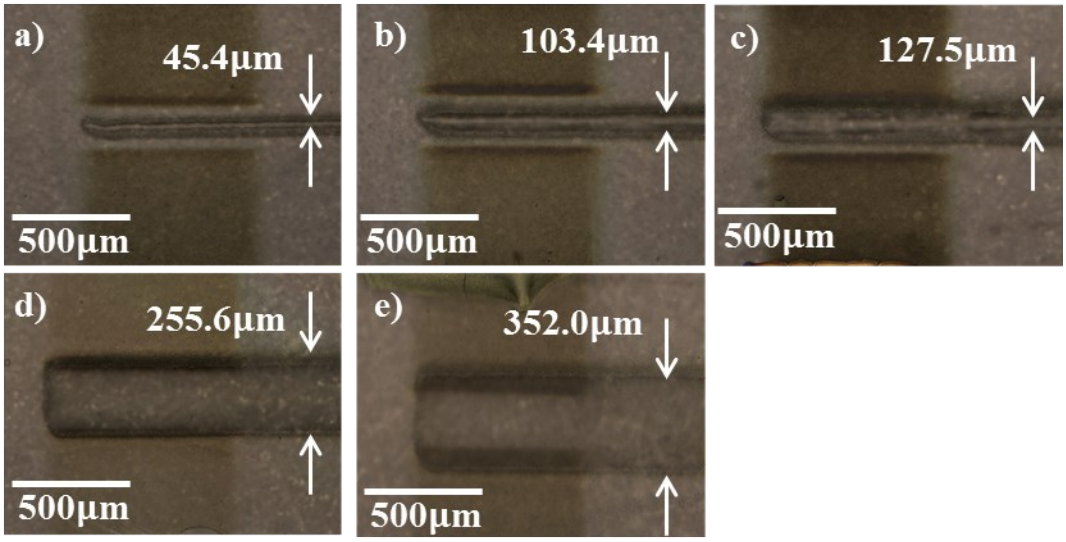


Figure S13 Optical images of the transistor-type sensors with different channel coverage area of ion gels

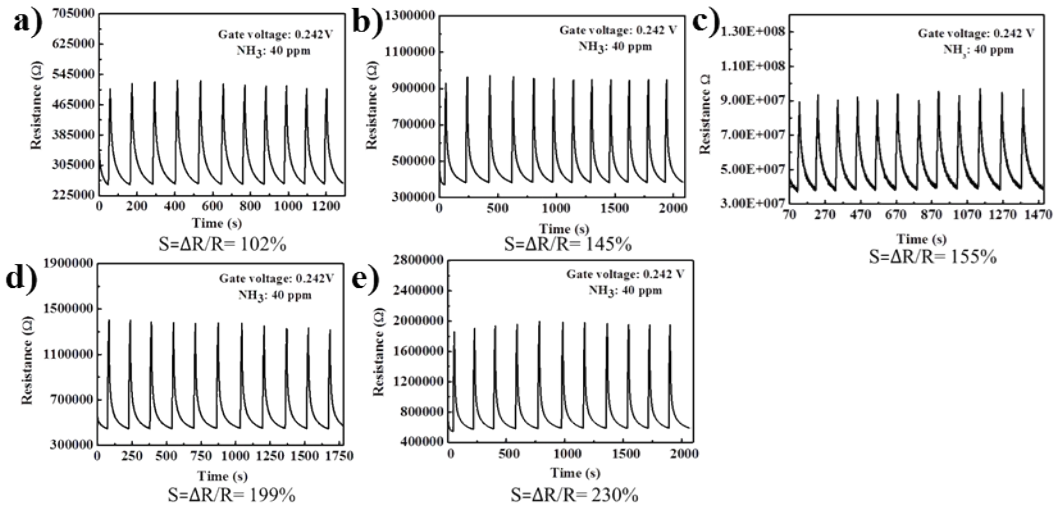


Figure S14 a), b), c), d), e) were the response curves when the channel coverage area of ion gels were 45.4 μm, 103.4 μm, 127.5 μm, 255.6 μm, and 352.0 μm at gate voltage of 0.242 V, respectively (The voltage between the source and drain electrodes of 0.25 V).

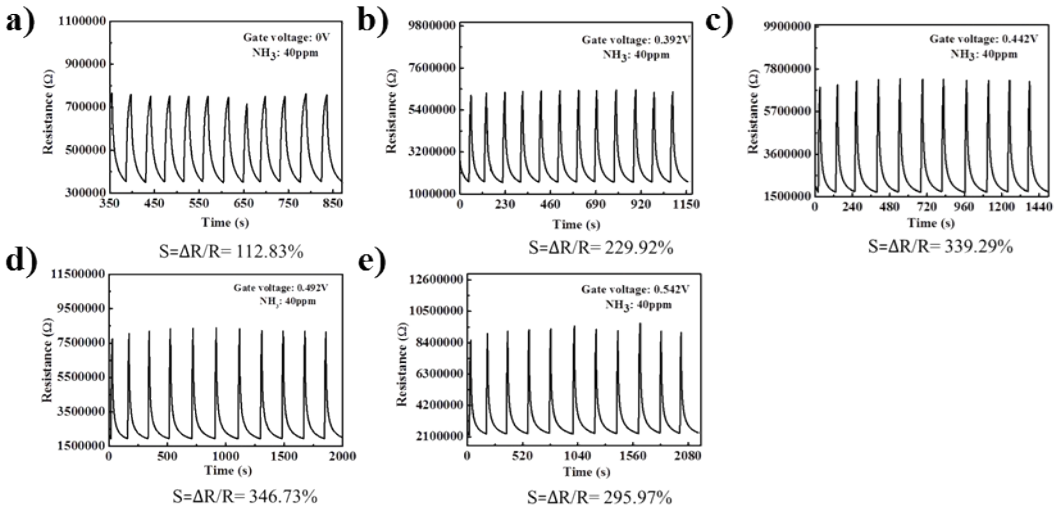


Figure S15 Response curves of the NH_3 sensor with ion gels fully covered in the device channels at different gate voltages (The voltage between the source and drain electrodes of 0.25 V).

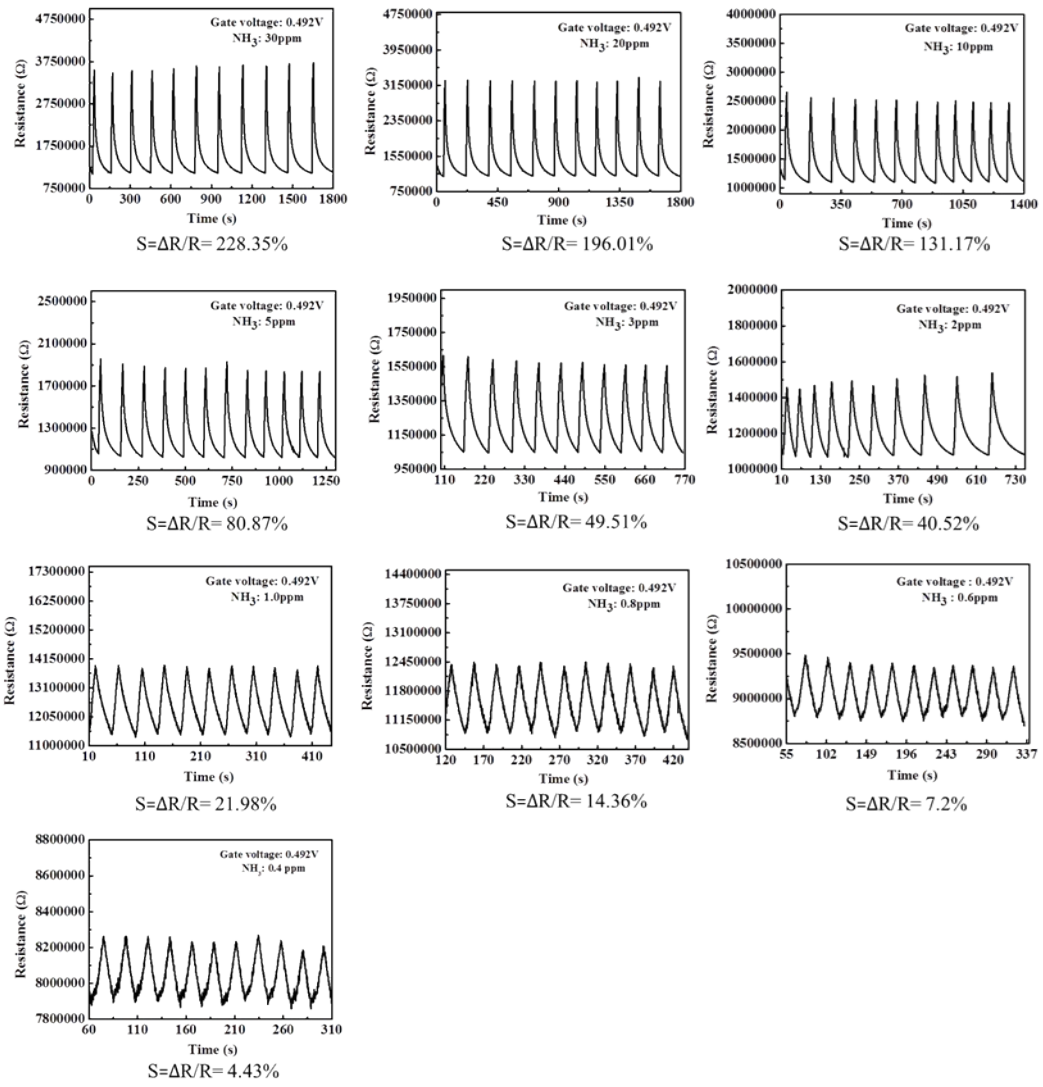


Figure S16 Response curves of the gas sensor with ion gels fully covered in the device channels under different NH_3 concentrations at the gate voltage of 0.492 V (the voltage between the source and drain electrodes of 0.25 V).

Calculate statistical parameters and regular residual (Yi-y) of 5th order polynomial fit and the root-mean squared deviation (RMS_{noise}) and LOD using Equations (1) and (2). The results are shown in **Table S2** and **S3**.

$$RMS_{noise}(ppm\text{-}1)=(V_x^2/(N))^{1/2} \quad (1)$$

where $V_x^2 = \sum (Yi - y)^2$

$$LOD(ppm)=3 \times RMS_{noise}/Slope \quad (2)$$

Table S3 Polynomial fitting data

Time(s)	Yi-y	$(Yi-y)^2$
0.752	-0.00094	8.91145E-07
1.7949	0.002225	4.95196E-06
2.9775	0.001229	1.50961E-06
4.0205	-0.00036	1.31854E-07
5.0605	-0.00135	1.82264E-06
6.1064	-0.00204	4.17224E-06
7.2998	-0.00129	1.6724E-06
8.4902	-1.8E-05	3.24809E-10
9.5303	0.000761	5.78367E-07
10.7187	-0.00022	4.71081E-08
11.9062	0.000187	3.5092E-08
12.9512	-0.00014	2.00878E-08
13.8437	7.41E-05	5.49019E-09
14.8877	-7.1E-05	5.0841E-09
15.9268	-0.0006	3.63585E-07
17.1191	-0.00165	2.73581E-06
18.3066	-0.00103	1.05371E-06
19.5049	-0.00086	7.37762E-07
20.6963	-0.00093	8.63868E-07
21.291	-0.00077	5.96433E-07
22.3252	-0.00019	3.74834E-08
23.5195	-0.00051	2.63318E-07
24.415	-0.00234	5.46415E-06
25.0059	-0.00209	4.38391E-06

Table S4 Calculation of RMS noise and LOD

Sensing gas	**Slope(%) (Sensitivity)(ppm^{-1})**	**Standard error (ppb^{-1})**	**V_X^2**	**RMS noise**	**LOD (ppm)**
NH3	0.1631	0.14401	3.23×10^{-5}	1.161×10^{-3}	0.021353

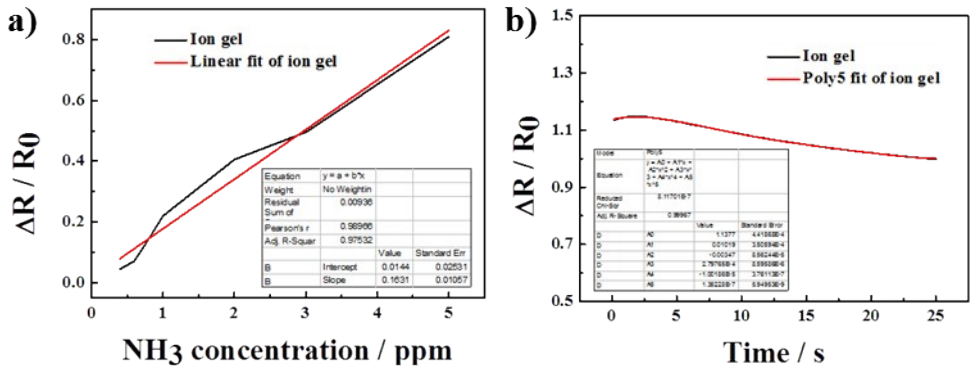


Figure S17 Calculation of the limit of detection (LOD) for NH_3 gas sensing. a) Plots of response as a function of NH_3 concentration. b) Plots of 5th order polynomial fitted normalized resistance at the baseline before NH_3 exposure as a function of time

Table S5 The lowest power consumption and the highest power consumption with ion gels fully covered in the channels under different NH_3 concentrations are obtained by the formula: $P=U \times I=U^2/R$, where U and R are the sensor voltage and resistance between the source and drain electrodes, respectively.

NH_3 concentration/ppm	0.4	0.6	0.8	1.0	2.0	3.0	5.0	10.0	20.0	30.0	40.0
Lowest power consumption/nW	7.561	6.657	5.056	4.52	4.141	39.62	33.09	25.19	19.01	16.79	7.369
Maximum power consumption/nW	7.922	7.1439	5.759	5.488	58.2	59.88	61.08	57.51	56.51	56.35	32.53

Note: All resistance data are from **Figure S15, S16**.

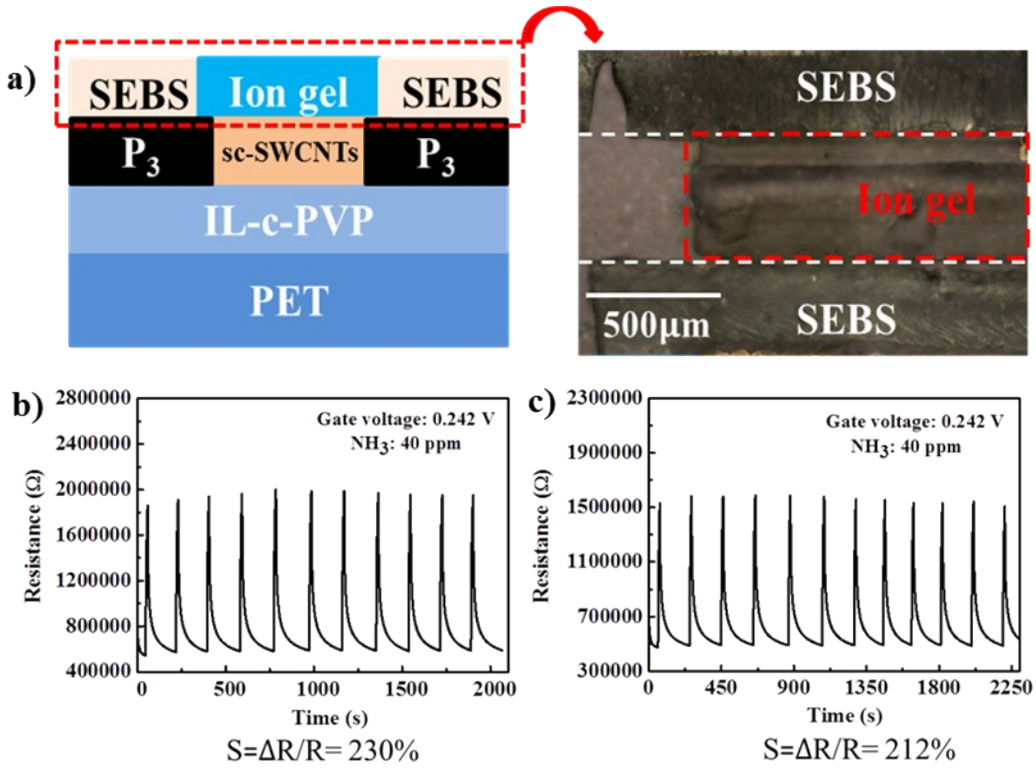


Figure S18 a) Optical images of the transistor-type sensors with all the P_3 SWCNTs electrodes covered by SEBS, b), c) the response curves of the transistor-type sensors before and after all the P_3 SWCNTs electrodes covered by SEBS at gate voltage of 0.242 V, respectively. (The voltage between the source and drain electrodes of 0.25 V).

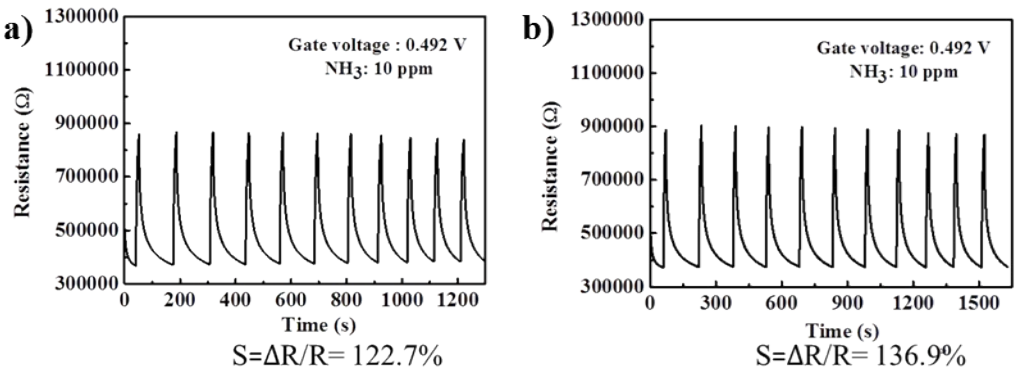


Figure S19 a) the response curves of the transistor-type sensors in the humidity of 30% and b) in a humidity of 70% at gate voltage of 0.492 V. (The voltage between the source and drain electrodes of 0.25 V).