Supporting Information

Ultrafast Response Polyelectrolyte Humidity Sensor for Respiration Monitoring

Jianxun Dai[†], Hongran Zhao[†], Xiuzhu Lin[†], Sen Liu[†], Yunshi Liu[†], Xiupeng Liu[†], Teng Fei[,†,‡] and Tong Zhang*[,†]*

Jianxun Dai[†], Hongran Zhao[†], Xiuzhu Lin[†], Sen Liu[†], Yunshi Liu[†], Xiupeng Liu[†], Teng Fei*[,†,‡] and Tong Zhang*[,†]

[†]State Key Laboratory on Integrated Optoelectronics, College of Electronic Science and Engineering, Jilin University, Changchun 130012, P.R. China

[‡]State Key Laboratory of Transducer Technology, Shanghai 200050, P.R. China

E-mail address: feiteng@jlu.edu.cn (T. Fei); zhangtong@jlu.edu.cn (T. Zhang).

KBr Pellet

KBr pellet was used to prepare the samples for FTIR measurement. Firstly, 200 mg dry KBr and 2 mg polymer (PMDS or PPDS) were put into a mortar, the mixture was then grinded for 2 minutes and the white powder was obtained. The powder was pressed into a slice at 20 MPa for 2 min.

Depth of Respiration Calculation Method

Initially, the respiration signals should be turned into logarithmic coordinates. Then the baseline can be obtained, which is the average of the impedance values in the air. The difference values between the baseline and every trough is the one DR of the single breath process. Finally, the average of these depth values is the final DR in this state.

Table S1. Elemental analysis data of PPDS and PMDS.

	C content		H content		S content	
	theoretical	practical	theoretical	practical	theoretical	practical
PPDS	55.67%	58.28%	5.61%	6.22%	18.71%	16.66%
PMDS	48.89%	50.22%	6.08%	6.39%	16.94%	15.87%

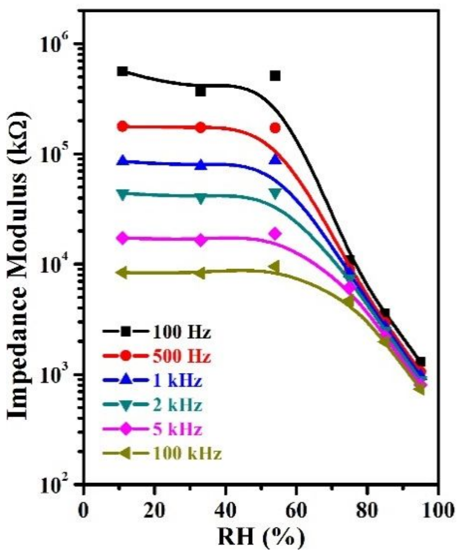

Figure S1. The dependence of impedance on RH for PMDS sensor at various frequencies. At 54% - 95% RH, the linearities (Adj. R-Square) are 0.9674, 0.9909, 0.9994, 0.9948, 0.9553 and 0.8941 at 100 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz and 100 kHz, respectively.

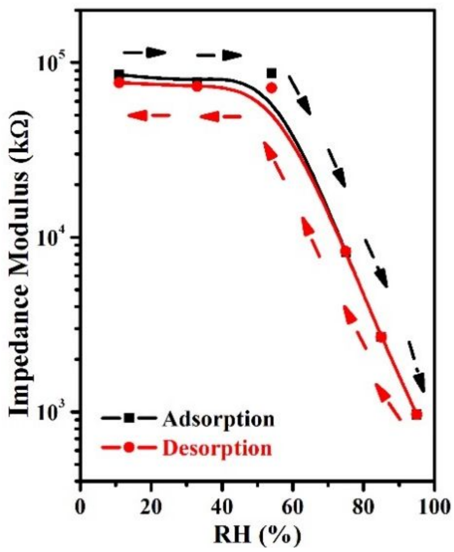

Figure S2. The humidity hysteresis curve of PMDS sensor (1 V AC, 1 kHz).

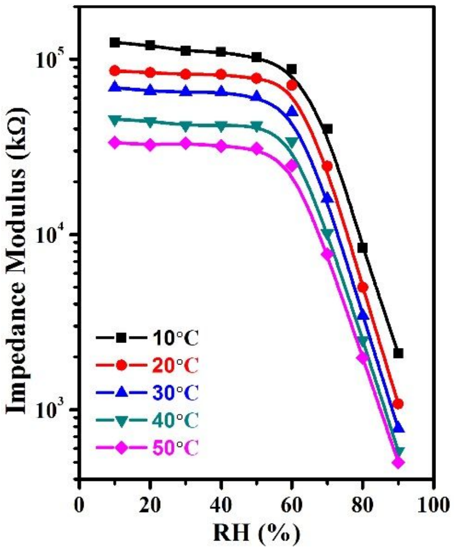

Figure S3. The impedance modulus of PMDS sensor under different temperatures (1 V AC, 1 kHz). The temperature compensation coefficient was calculated by the following Equation: Temperature compensation coefficient $= \frac{\Delta|Z|/\Delta T}{\Delta|Z|/\Delta RH} = 0.29 \pm 0.05(\%RH/°C)$. ΔT and Δ|Z| stand for PMDS sensor's temperature change and impedance modulus change at corresponding ΔRH.

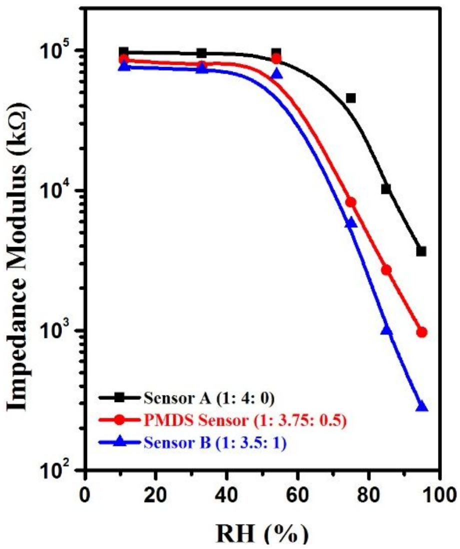

Figure S4. The dependence of impedance on RH for three sensors based on polyelectrolytes with different comonomer molar ratios.

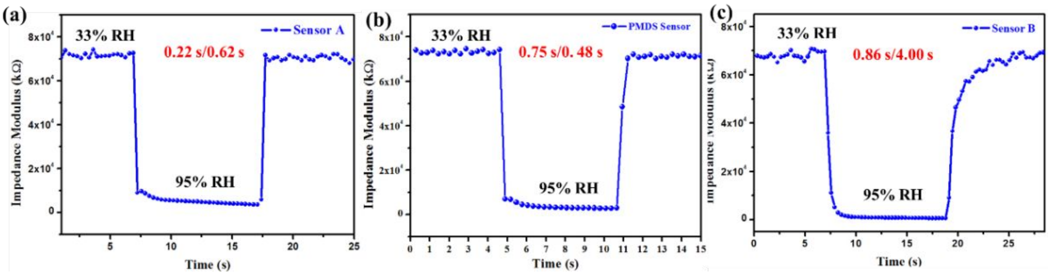

Figure S5. Response of three sensors to humidity change between 33% RH and 95% RH. (a) MPOSS: DVB: SSS=1: 4: 0, (b) MPOSS: DVB: SSS=1: 3.75: 0.5, (c) MPOSS: DVB: SSS=1: 3.5: 1) Without SSS, the sensitivity and linearity of Sensor A are not very good, although the response/recovery time is very short. On the basis of fast response/recovery, subtle increase of SSS improves the sensitivity. Continuous growth of SSS ratio will lead to longer recovery time (recovery time of Sensor B is 4.00 s).

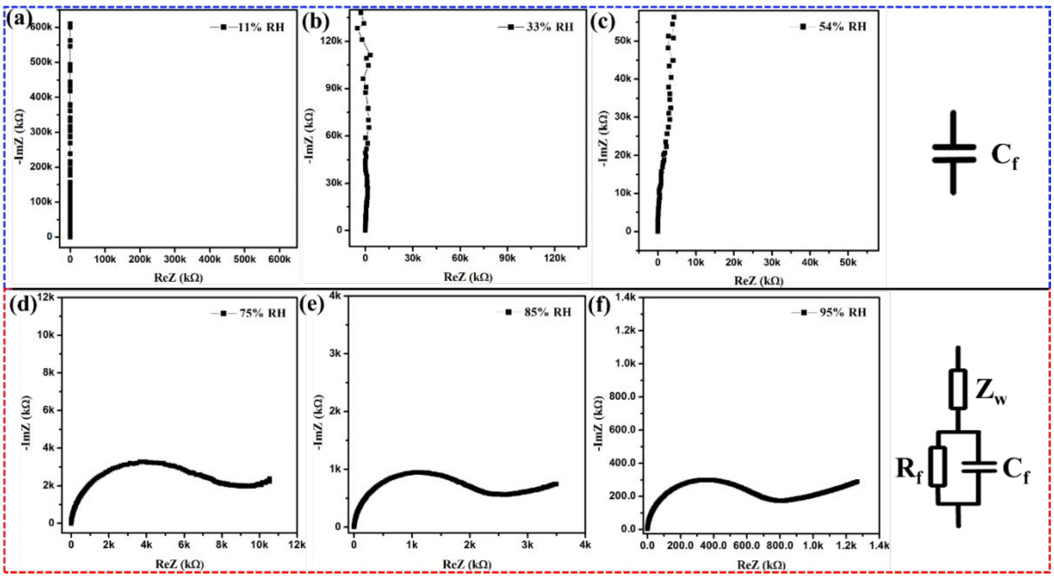

Figure S6. The complex impedance spectroscopy plots of PMDS sensor at different RHs (corresponding equivalent circuits on the right side, film resistance (R_f), film capacitance (C_f), Warburg impedance (Z_w)).

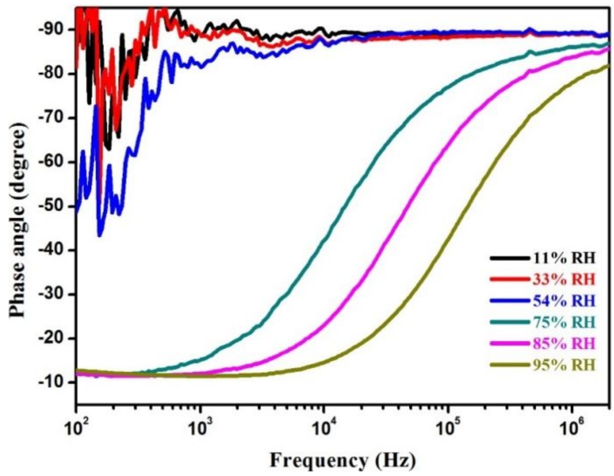

Figure S7. The phase angles of PMDS sensor under different frequencies (1 V AC).

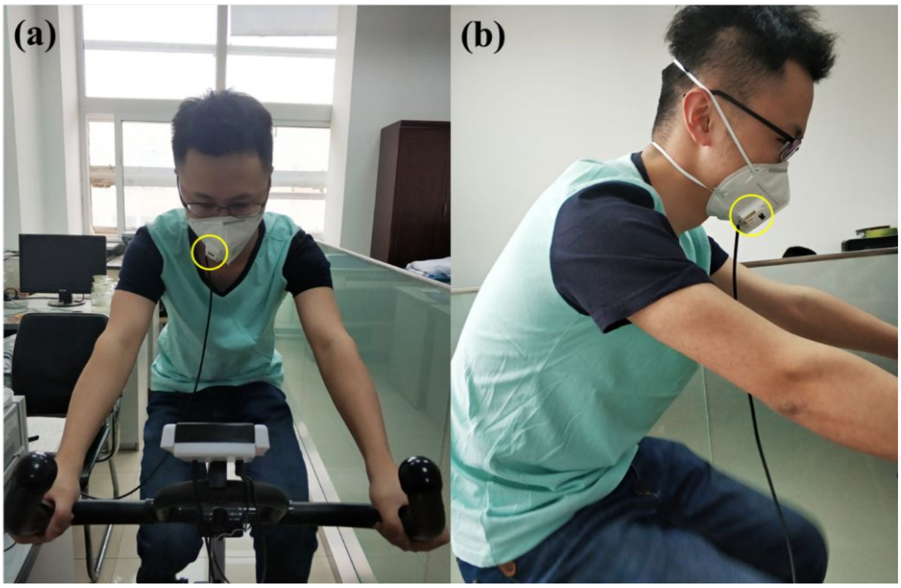

Figure S8. The (a) front view and (b) side view of the breath measurement.

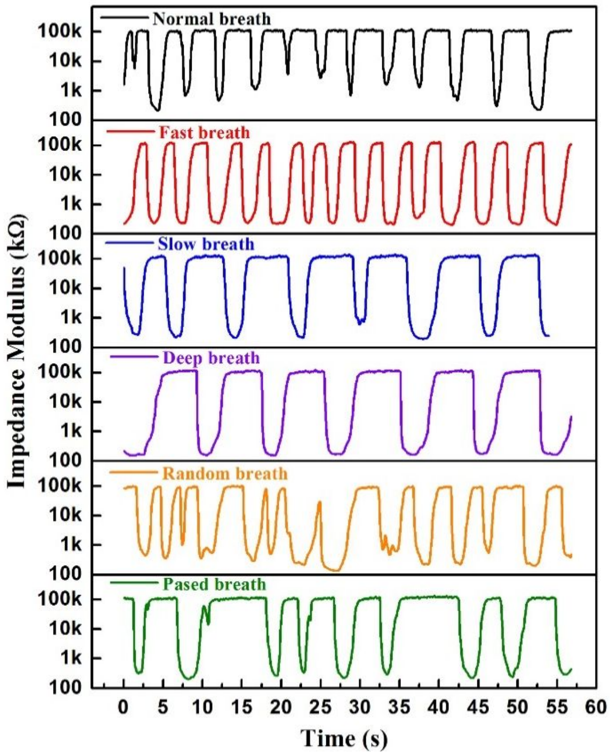

Figure S9. The 6 respiration patterns (normal breath, fast breath, slow breath, deep breath, random breath and paused breath) recorded by PMDS sensor in semi-log coordinates.

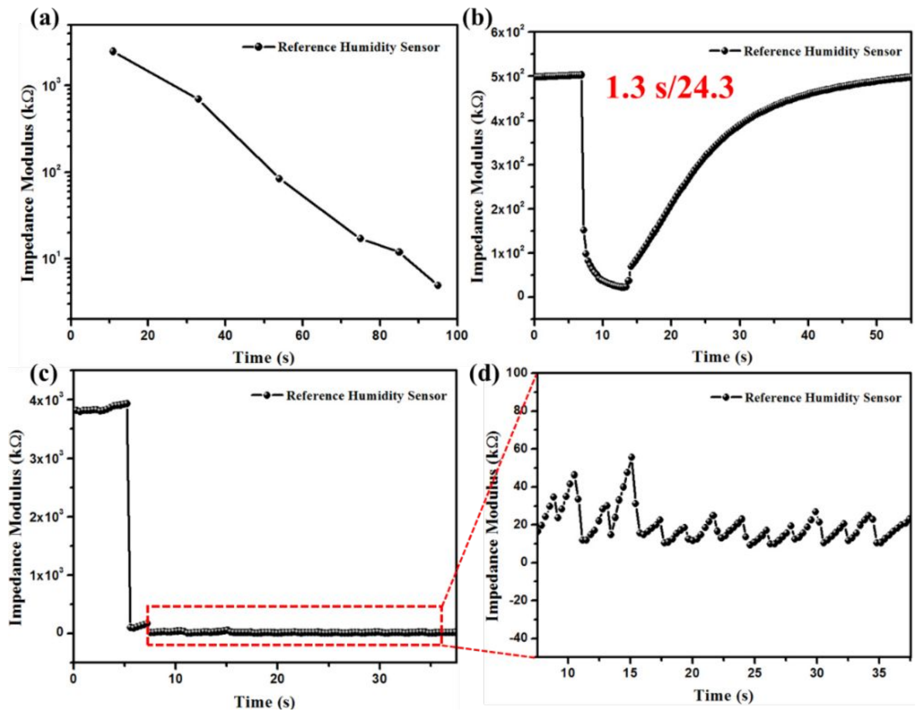

Figure S10. (a) The dependence of impedance on RH for reference humidity sensor. (b) The response and recovery properties of reference humidity sensor. (c) The impedance response of reference humidity sensor to continuous normal breath, and the inset (d) is the partial enlargement. A polymer humidity sensor produced by Guangzhou Cybersen Technology Co., Ltd was utilized as the reference. The recovery time of the reference sensor is about 24.3 s (Figure S8b), which is much longer than human expiration time. Therefore, there's not enough time for the reference sensor to recover to the balance level (high impedance) (Figure S8c). The sensor cannot monitor and evaluate human breath well.

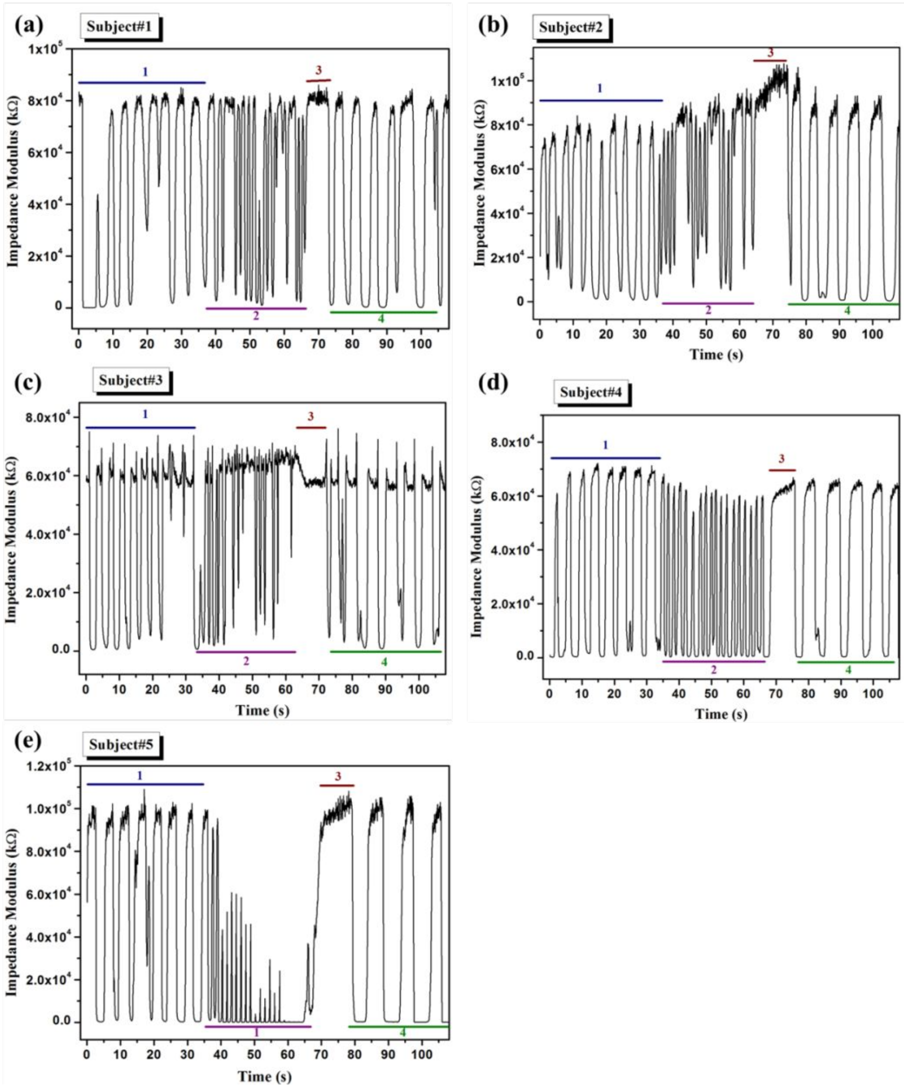

Figure S11. Recorded respiration signal (impedance modulus) of (a) Subject #1, (b) Subject #2, (c) Subject #3, (d) Subject #4 and (e) Subject #5. (1) Normal breath, (2) shallow and fast breath, (3) a pause in continuous breath, (4) deep and slow breath.

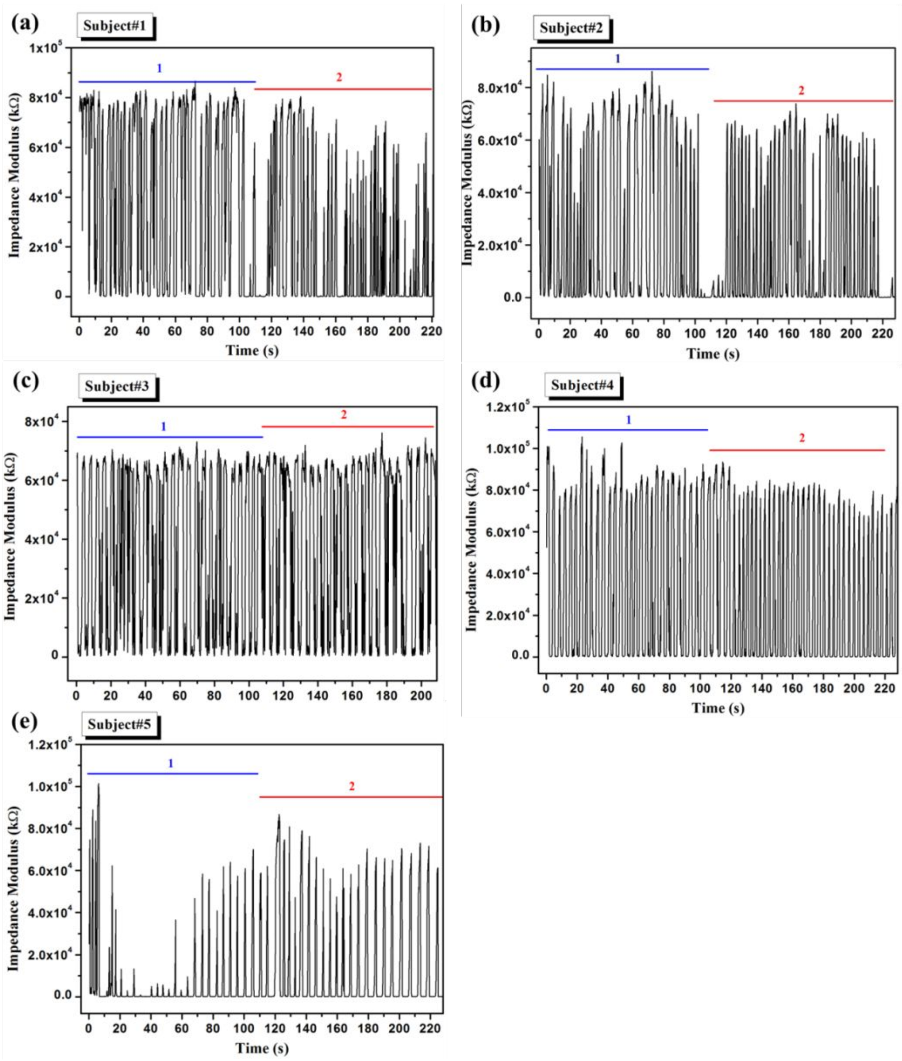

Figure S12. Recorded respiration signal (impedance modulus) of (a) Subject #1, (a Subject #2, (c) Subject #3, (d) Subject #4 and (e) Subject #5. Motion state 1: light exercise, Motion state 2: vigorous exercise.

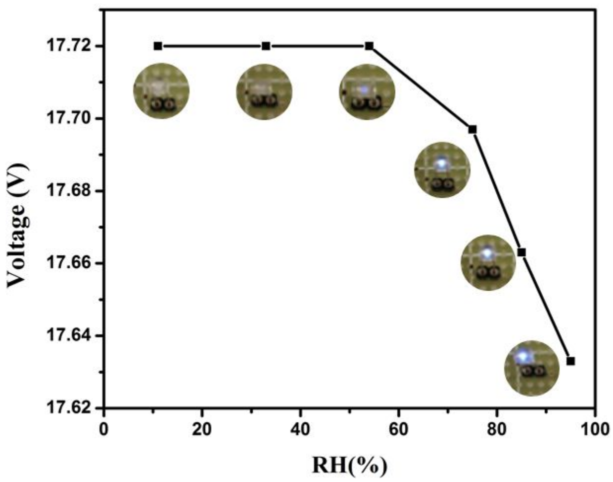

Figure S13. The change of the PMDS sensor's voltage under different RHs in the integrated circuit (The insets below every point shows LED's different degrees of brightness under different RHs) .