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Supporting Information for

Force and Humidity Dual Sensors Fabricated by Laser Writing on Polyimide/Paper Bilayer Structure for Pulse and Respiration Monitoring

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S1. Recovery, reusability, and stability test of the PI/paper bilayer film humidity sensor

With the sample prepared by imidization at 150 °C and stored in a dry condition for ~6 months as an example, we examined the recovery and the reusability of the PI/paper bilayer film based humidity sensor by applying a multiple cyclic humidity test. The test protocol for each cycle is the same as shown in **Figure S1**a: the RH was ramped first from 0% to 80% at a rate of 2%/min; when the RH reached 80%, the water vapour supply was switched off and the system returned back to 0% RH state. Three repeating tests were performed with the same protocol. For each test, the sensor resistance change was recorded and the results are shown in Figure S1b. Upon 6 months storage, the overall behaviour of the sensor in response to humidity variation has not changed much when compared with Figure 4b. This shows the reasonably good recovery and reusability of the PI/paper bilayer humid sensor. However, as summarized in **Table S1**, we do notice a resistance increase of the sensor at RH = 0% by ~10% and at RH = 80% by ~33%. We suspected that the resistance increase was mainly related to the electrical contact preparation, which was done by manually adhering thin copper wires to the carbon patterns by using silver paste, and the process quality is difficult to control. This issue can be mitigated with further optimization of the sensor fabrication process.

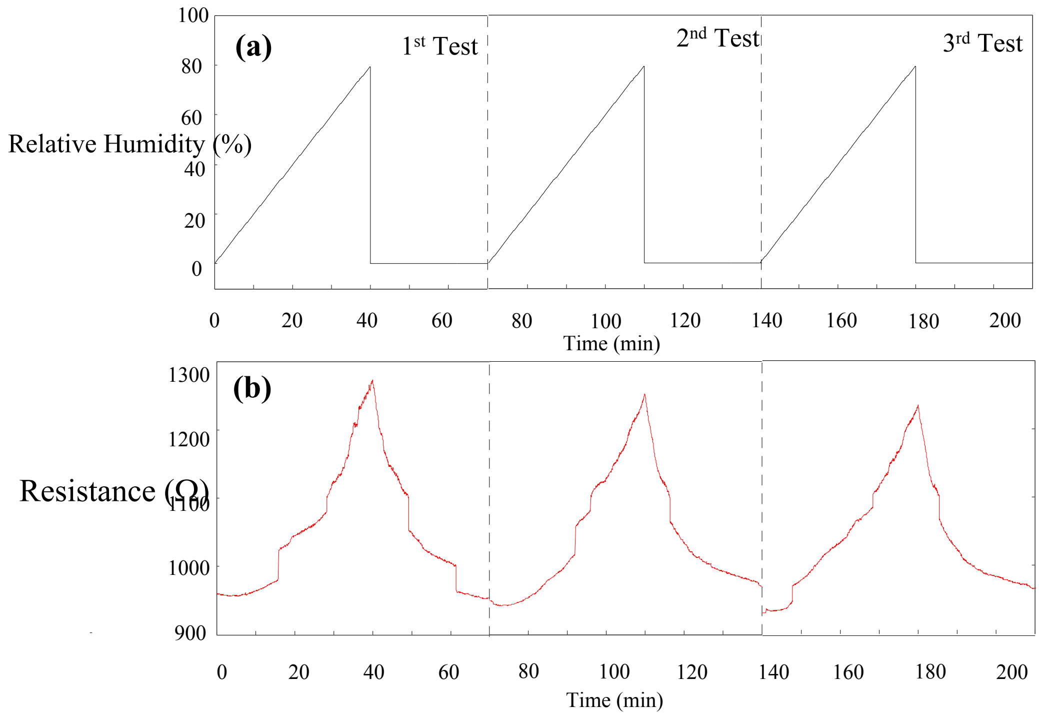

Figure S1. Recovery, reusability and stability test of the PI/paper bilayer humidity sensor (imidization temperature = 150 ^{o}C) after ~6 months storage in a dry environment (a) Humidity control protocol; (b) Sensor resistance response.

Table S1. Recovery, reusability and stability test of the PI/paper bilayer humidity sensor – Results Summary

Humidity sensor (imidized at 150 ^{o}C)	Resistance (Ω)	6 months ago	6 months later		
			1st test	2nd test	3rd test
RH_0 =0% (beginning of the test)	R_0	864	961	950	951
RH_{max}= 80%	R_{max}	941	1274	1252	1235
RH_{end} = 0% (end of the test)	R_{end}	857	954	961	921

Table S2. Sensing characteristics comparison between the PI based capacitive humidity sensors and the PI/paper hybrid film based humidity sensors

Sensing Characteristics	**PI based capacitive humidity sensors (Ref. 39)**	**PI/paper hybrid film based humidity sensors (this work)**
Transduction method	Capacitive	Resistive
Mechanism	Moisture-induced change in the dielectric constant of PI film	Hygroscopicity difference between PI and paper induced bending and thus caused resistance change
Role of PI	Active sensing elements	Passive sensing elements + Carbon generating precursor
Sensitivity	$\frac{\Delta C}{C_0} / RH = 0.298$	$\frac{\Delta R}{R_0} / RH = 0.138$
Response time	Short	Short
Capacitance/resistance drift with time	0.34% in 52 days	0.11% in 180 days
Processing steps	Spin coating followed by immidization	Spin coating followed by immidization and direct laser writing

S1. Durability test of the PI/paper bilayer film force sensor

The durability test was done for a PI/paper bilayer force sensor prepared with imidization temperature of 200 °C. The sensor was subjected to multiple cycles of loading – unloading conditions. Each cycle includes first ramping the force from 0.001N to 0.5N at a rate of 2N/min and then unloading the force to 0.001N and holding for 0.25 min. A total of 1500 cycles was applied. The loading conditions as well as the test results over entire 1500 cycles are shown in **Figure S2**b. For clarify, the first 50 cycles and the last 50 cycles testing results and the corresponding loading conditions are shown in Figure S2a and S2c. After 1500 cycles of loading-unloading test, the sample resistance changed from 728.8 Ω to 787.2 Ω, increased by ~ 0.56 %, which manifested good durability for the sensor being tested.

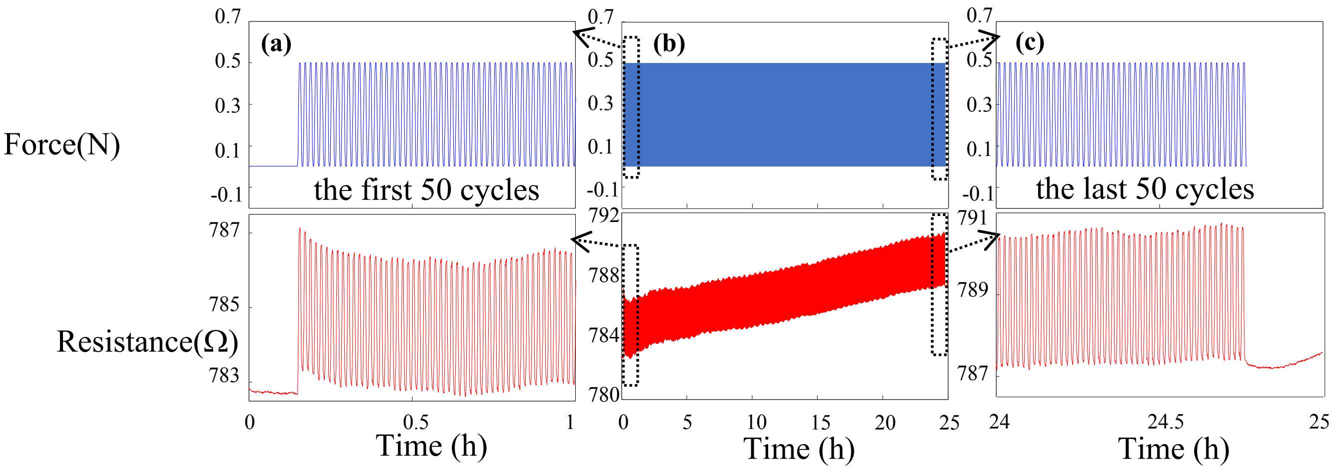

Figure S2. Durability test of the PI/paper bilayer force sensor prepared with imidization temperature of 200 °C. The loading conditions and sensor resistance response for (a) the first 50 cycles; (b) the entire 1500 cycles; (c) the last 50 cycles.