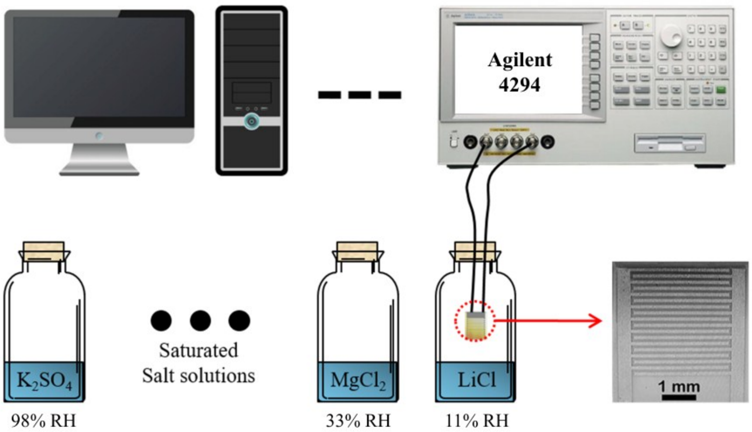
Electronic Supplementary Material (ESI) for Materials Chemistry Frontiers.

Supporting Information

High-performance ionogel-based humidity sensor for real-time monitoring of breath

Songhua Xiao, Jianxia Nie, Rou Tan, Xiaochuan Duan,* Jianmin Ma, Qiuhong Li and Taihong Wang*

S1. Results and Discussion



Scheme S1. Schematic diagram of humidity sensing experimental setup.

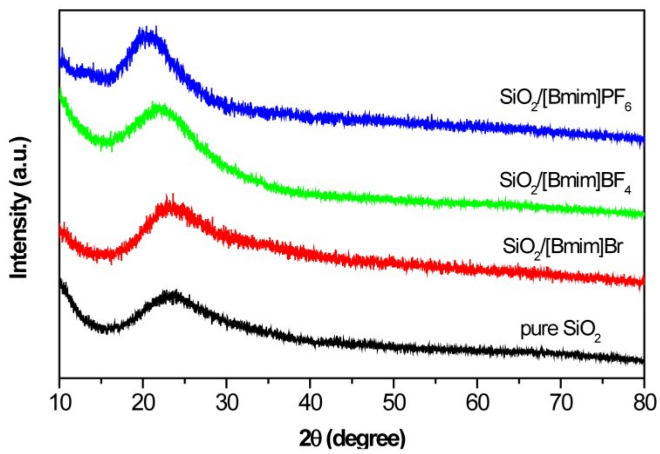


Figure S1. XRD patterns of pure SiO_2, SiO_2/[Bmim]Br, SiO_2/[Bmim]BF_4, SiO_2/[Bmim]PF_6.

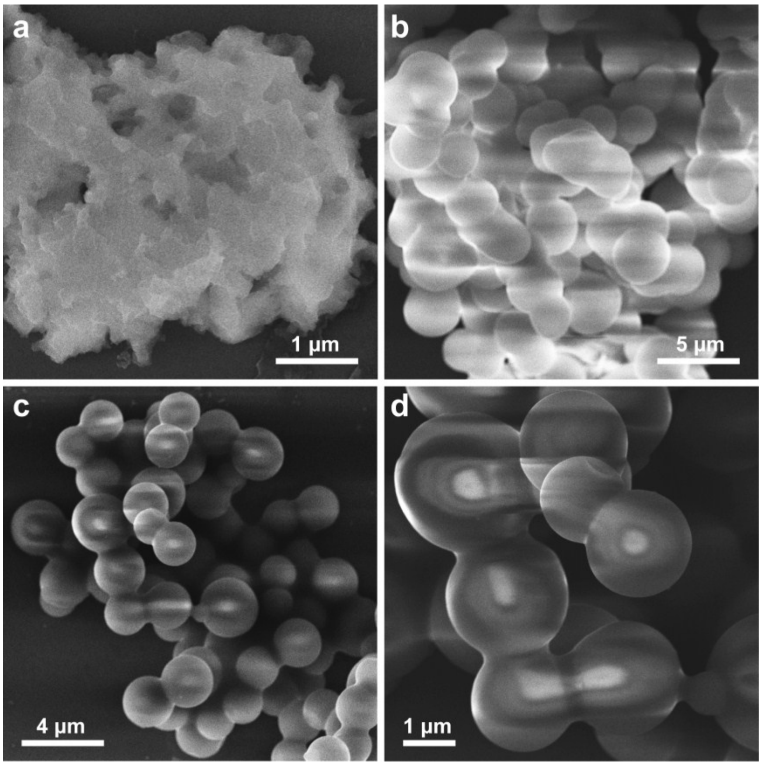


Figure S2. SEM images of ionogels: (a) SiO_2, (b) SiO_2/[Bmim]BF_4, (c and d) SiO_2/[Bmim]PF_6.

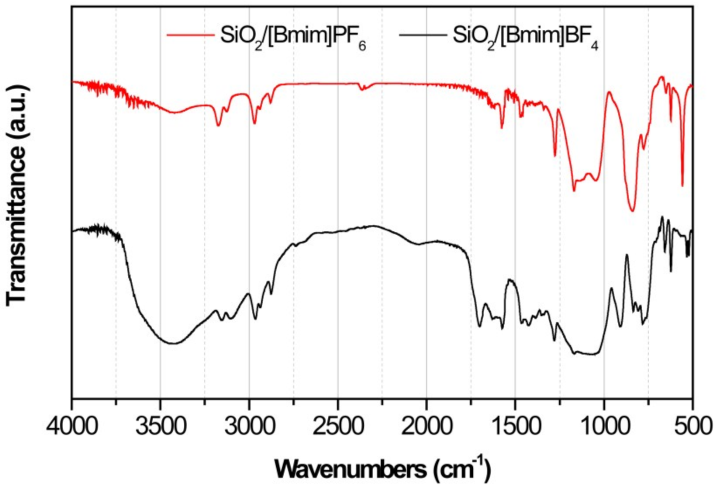


Figure S3. FT-IR spectra of SiO_2/[Bmim]BF_4 and SiO_2/[Bmim]PF_6.

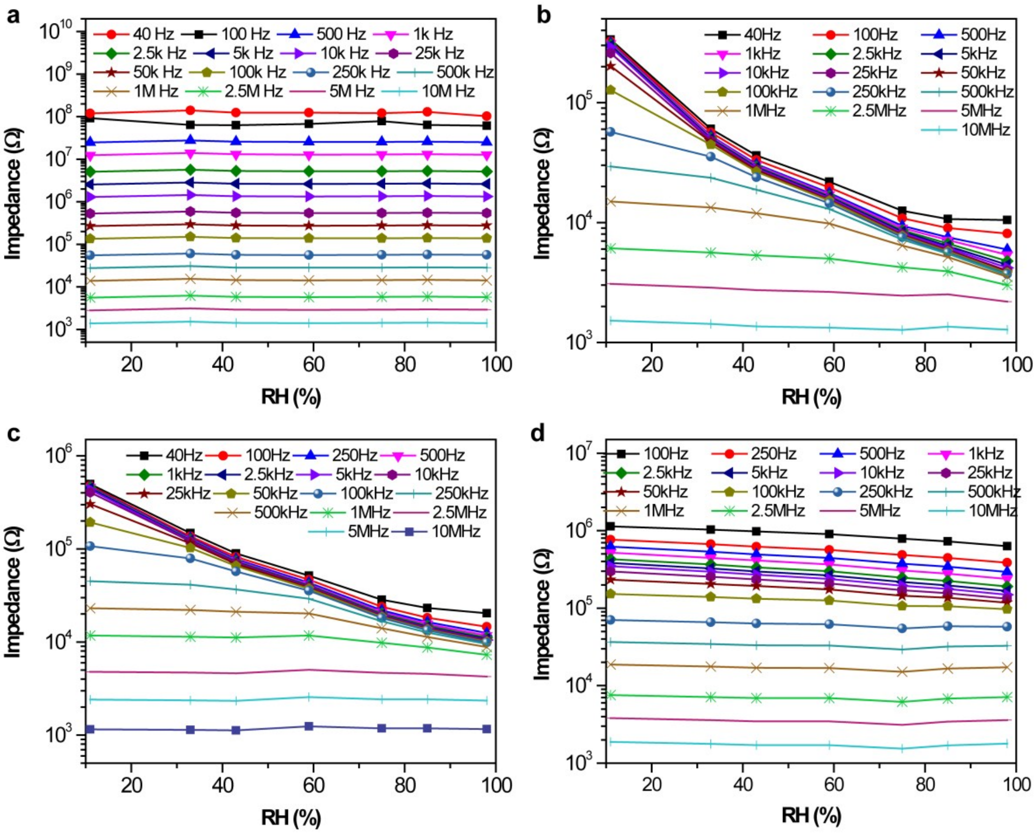


Figure S4. The dependence of impedance on RH for ionogel humidity sensors measured at various frequencies: (a) pure SiO_2; (b) SiO_2/[Bmim]Br; (c) SiO_2/[Bmim]BF_4; (d) SiO_2/[Bmim]PF_6.

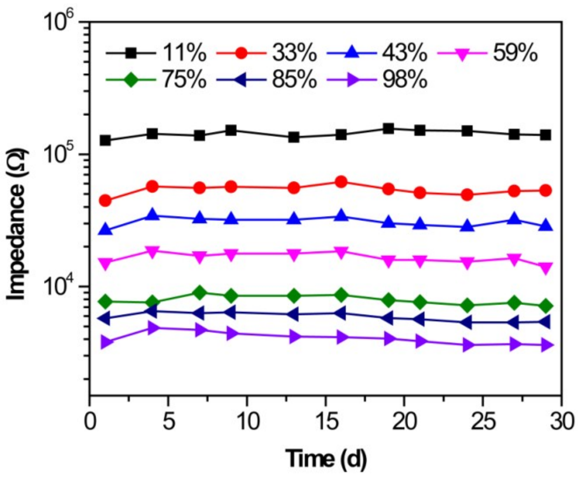


Figure S5. Long-term stability of SiO_2/[Bmim]Br humidity sensor.

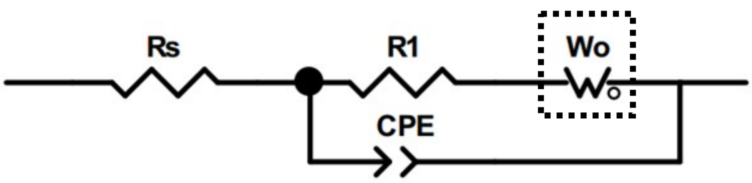


Figure S6. Equivalent electrical circuit of the ionogel-based humidity sensor.

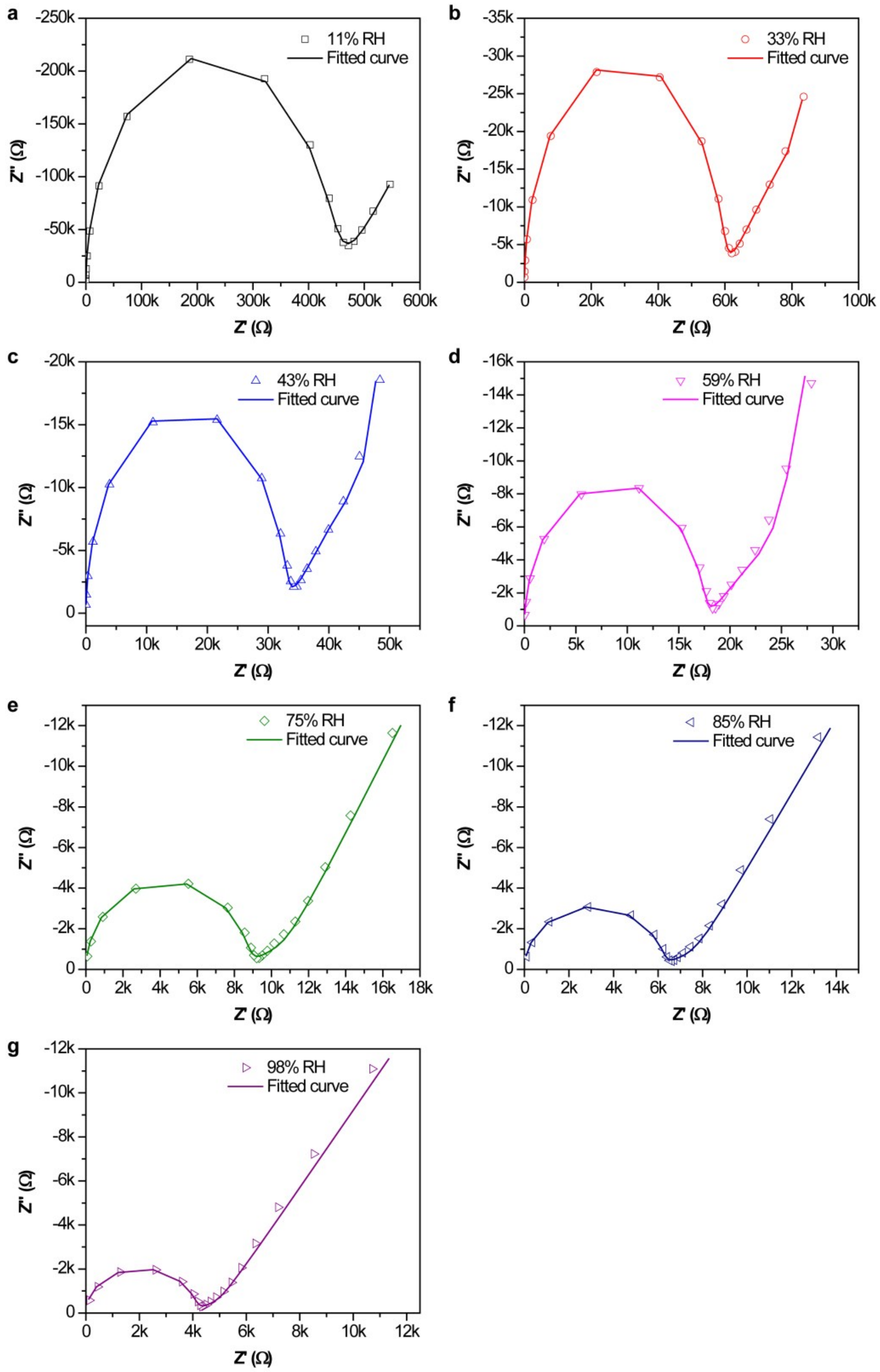


Figure S7. Nyquist plots of SiO_2/[Bmim]Br humidity sensor at different RH. The points represent measured data, and the solid lines represent simulated value using the equivalent circuit.

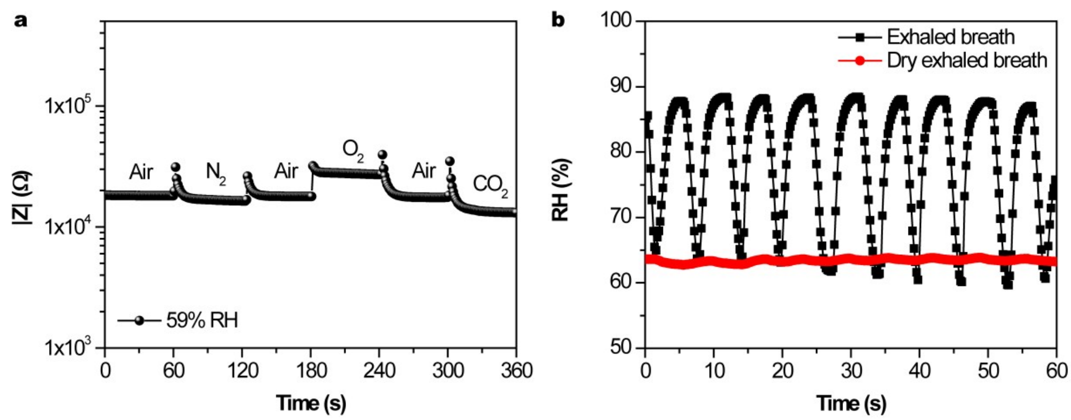


Figure S8. (a) The effect of interfering gases on the humidity performance of the SiO_2/[Bmim]Br ionogel sensor. (b) Response of the ionogel humidity sensor under exhaled breath and dry exhaled breath at 10 breaths/min.

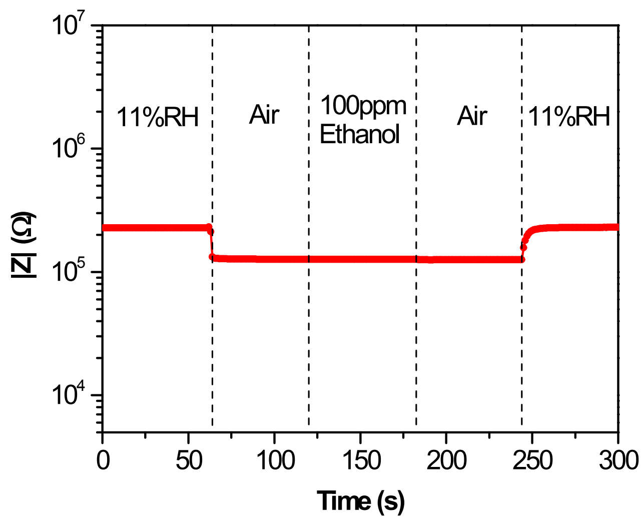


Figure S9. The effect of ethanol on the humidity performance of the SiO_2/[Bmim]Br ionogel sensor.

Table S1. Performance of the presented ionogel humidity sensor in this work compared with previous work.

Type	Sensing material	Fabrication method	Range (%RH)	$^{a}R_s/R_c$ (s)	Reference
Impedance	Poly-AMPS/SiO_2	Co-polymerization 100 °C, 1 h	30 ~ 90	60/120	1
Impedance	Poly-MAPTAC/SiO_2	Co-polymerization 100 °C, 1 h	7 ~ 86	60/120	2
Impedance	mesoporous SiO_2	MWD 150 °C 1.3MPa, 5 min	11 ~ 95	40/100	3

Optical	Fe_3O_4@SiO_2/PEGDA	High-temperature hydrolysis 120 °C, 1 h	22 ~ 100	540/180	4
QCM	SnO_2/SiO_2	sol-gel 40 °C, 24 h	11.3 ~ 96.1	14/16	5
Impedance	Fe_2O_3/SiO_2	synchronous assembly strategy	11 ~ 95	20/40	6
Impedance	ZnO/SiO_2	situ method	11 ~ 98	15/16	7
Resistance	Mn/SBA-15	situ method	11 ~ 92	110/170	8
Conductance	ZnO2@SiO2 QDs	situ method	5 ~ 98	10/15	9
Impedance	SBA-15-PSS	situ method	11 ~ 95	5/106	10
Impedance	Li/SBA-15	sol-gel/heat treated	11 ~ 95	21/51	11
Impedance	$Fe(NO_3)_3$/MCM-41	sol-gel/heat treated	11 ~ 95	10/180	12
Impedance	LiCl/PETMP-DVB	situ loading	11 ~ 95	3.5/63	13
Impedance	AuNPs/GO/MPTMOS	sol-gel	15 ~ 90	119/125	14
Impedance	[Bmim]Br/SiO_2	sol-gel 25°C, 24 h	11 ~ 98	3/10	this work

a. R_s represents the response time, and R_c represents the recovery time.

Table S2. Parameters of the equivalent circuit components.

RH (%)	Component Parameter Rs(Ω)			R_1(Ω)			Z_{CPE}(Ω)			Z_W(Ω)		
	Br	BF_4	PF_6	Br	BF_4	PF_6	Br	BF_4	PF_6	Br	BF_4	PF_6
11	6.75	6.8	6.85	4.15E+05	4.31E+05	2.59E+05	1.63E+05	4.54E+06	1.88E+08	1.79E+04	2.20E+04	1.05E+06
33	6.8	6.85	6.9	5.90E+04	1.20E+05	2.16E+05	1.48E+05	4.41E+06	1.77E+08	9.65E+02	5.04E+03	9.68E+05
43	6.85	6.9	6.95	3.26E+04	6.95E+04	1.96E+05	1.53E+05	4.36E+06	1.75E+08	6.76E+02	3.68E+03	9.21E+05
59	6.8	6.85	6.9	1.72E+04	3.71E+04	1.69E+05	1.56E+05	4.83E+06	1.72E+08	6.19E+02	3.59E+03	8.60E+05
75	6.85	6.9	6.95	8.44E+03	1.80E+04	1.35E+05	1.55E+05	4.57E+06	1.52E+08	6.24E+02	2.13E+03	7.57E+05
85	6.85	6.9	6.95	6.02E+03	1.31E+04	1.19E+05	1.51E+05	4.53E+06	1.69E+08	5.05E+02	1.74E+03	6.99E+05
98	6.75	6.8	6.85	3.95E+03	9.63E+03	9.69E+04	1.41E+05	4.34E+06	1.75E+08	4.17E+02	1.45E+03	6.05E+05

Table S3. The performance parameters of the as-prepared PIL-based humidity sensors.

IL used	Working range (%RH)	R2 of linear fit	Sensitivity	Maximum hysteresis (%)	Response time (s)	Recovery time (s)
[Bmim]Br	11-98	0.99847	37.98	1.83	3	10
[Bmim]BF_4	11-98	0.99429	29.06	2.01	2	20
[Bmim]PF_6	11-98	0.99081	1.81	3.66	16	18

Reference

[1] Su P G, Tsai W Y. Humidity sensing and electrical properties of a composite material of nano-sized SiO_2 and poly (2-acrylamido-2-methylpropane sulfonate)[J]. *Sensors and Actuators B: Chemical,* 2004, 100(3): 417-422.

[2] Su P G, Huang S C. Humidity sensing and electrical properties of a composite material of SiO_2 and poly-[3-(methacrylamino) propyl] trimethyl ammonium chloride[J]. *Sensors and Actuators B: Chemical,* 2005, 105(2): 170-175.

[3] Tu J, Li N, Geng W, et al. Study on a type of mesoporous silica humidity sensing material[J]. *Sensors and Actuators B: Chemical,* 2012, 166: 658-664.

[4] Xuan R, Wu Q, Yin Y, et al. Magnetically assembled photonic crystal film for humidity sensing[J]. *Journal of Materials Chemistry,* 2011, 21(11): 3672-3676.

[5] Zhu Y, Chen J, Li H, et al. Synthesis of mesoporous SnO_2–SiO_2 composites and their application as quartz crystal microbalance humidity sensor[J]. *Sensors and Actuators B: Chemical,* 2014, 193: 320-325.

[6] Yuan Q, Li N, Geng W, et al. Humidity sensing properties of mesoporous iron oxide/silica composite prepared via hydrothermal process[J]. Sensors and Actuators B: Chemical, 2011, 160(1): 334-340.

[7] Tomer V K, Duhan S, Sharma A K, et al. One pot synthesis of mesoporous ZnO–SiO_2 nanocomposite as high performance humidity sensor[J]. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 2015, 483: 121-128.

[8] Tomer V K, Duhan S, Adhyapak P V, et al. Mn‐Loaded Mesoporous Silica Nanocomposite: A Highly Efficient Humidity Sensor[J]. Journal of the American Ceramic Society, 2015, 98(3): 741-747.

[9] Mahjoub M A, Monier G, Robert-Goumet C, et al. Synthesis and study of stable and size-controlled ZnO–SiO2 quantum dots: application as a humidity sensor[J]. The Journal of Physical Chemistry C, 2016, 120(21): 11652-11662.

[10] Zhao H, Zhang T, Qi R, et al. Organic-inorganic hybrid materials based on mesoporous silica derivatives for humidity sensing[J]. Sensors and Actuators B: Chemical, 2017, 248: 803-811.

[11] Geng W, Wang R, Li X, et al. Humidity sensitive property of Li-doped mesoporous silica SBA-15[J]. Sensors and Actuators B: Chemical, 2007, 127(2): 323-329.

[12] Anbia M, Neyzehdar M, Ghaffarinejad A. Humidity sensitive behavior of Fe (NO 3) 3-loaded mesoporous silica MCM-41[J]. Sensors and Actuators B: Chemical, 2014, 193: 225-229.

[13] Dai J, Zhang T, Qi R, et al. LiCl loaded cross-linked polymer composites by click reaction for humidity sensing[J]. Sensors and Actuators B: Chemical, 2017, 253: 361-367.

[14] Su P G, Shiu W L, Tsai M S. Flexible humidity sensor based on Au nanoparticles/graphene oxide/thiolated silica sol–gel film[J]. Sensors and Actuators B: Chemical, 20