Electronic Supplementary Material (ESI) for Journal of Materials Chemistry C.

Supporting Information

A high-performance humidity sensor based on alkalized MXenes and poly(dopamine) for touchless sensing and respiration monitoring

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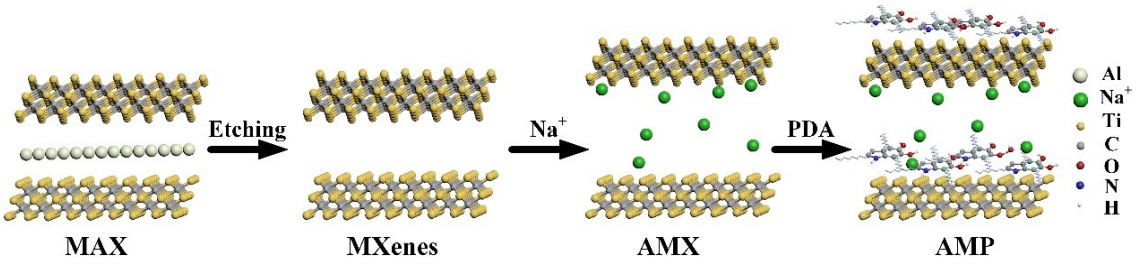

Figure S1. Fabrication process of AMP composite. (a) MAX

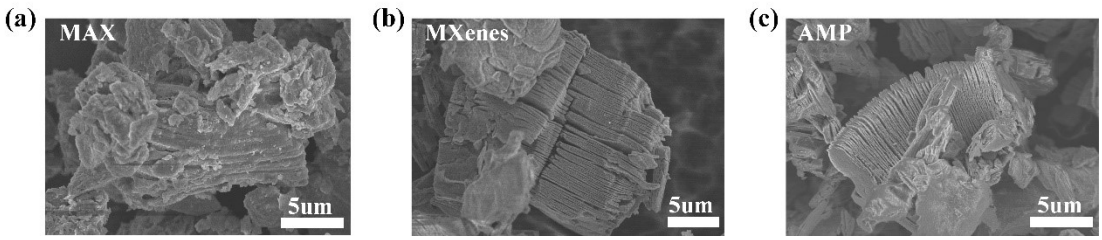

Figure S2. SEM images of (a) MAX($Ti_3AlC_2T_x$), (b) MXenes($Ti_3C_2T_x$) and (c) AMP

Table S1 Value of *d* derived from XRD results.

Materials	2θ (°)	sinθ	*d* (nm)	Δ*d* (nm)	Increase percentage
MXenes	9.00	0.0784	0.98	-	–
AMX	7.12	0.0621	1.24	0.26	26.5%

*Na^+, radius: 0.097 nm λ=0.15406 nm

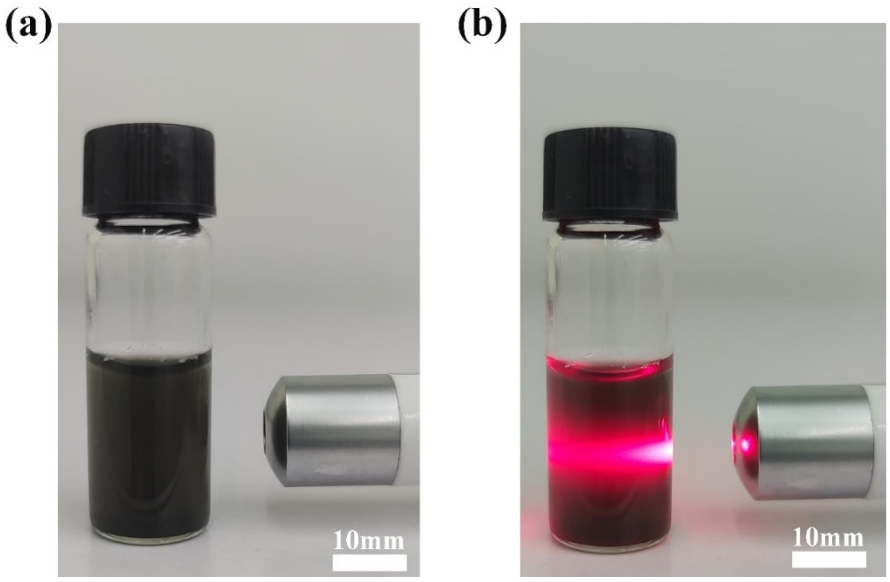

Figure S3. The synthesized AMP3 dispersion (a) and Tyndall effect of it (b).

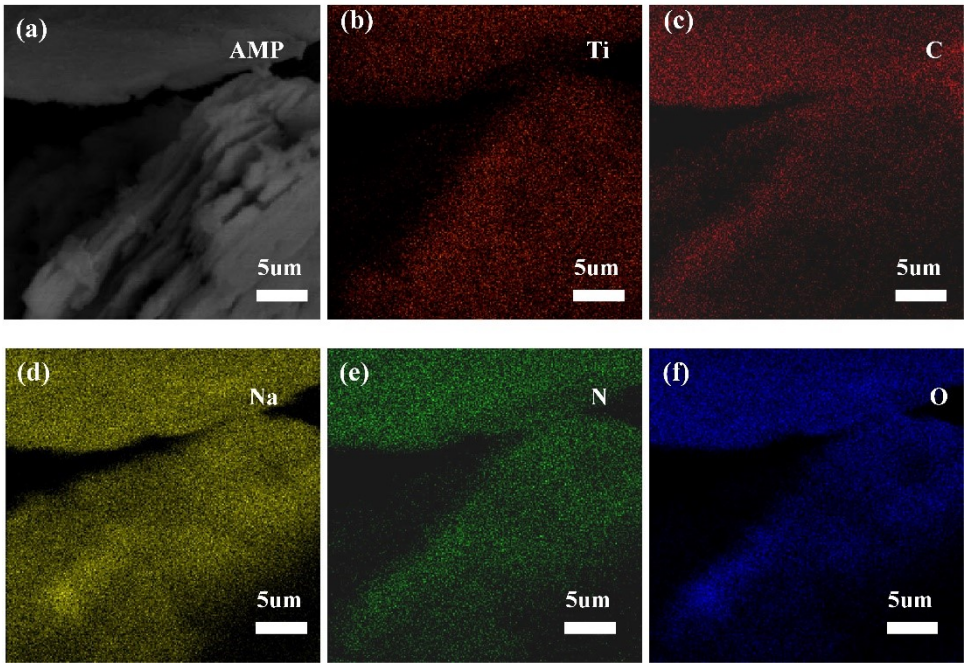

Figure S4. SEM elemental mapping of Ti, C, Na, N, O.

To investigate whether PDA is actually inserted between the MXenes layers, the SEM image and corresponding mapping images of Ti, C, Na, N and O elements of the AMP3 composite material was taken, as shown in Fig. S4. It can be seen the distribution of N element, which mainly comes from the -NH_2 functional group in PDA wrapped on AMX surface, was highly homogeneous and didn't exhibits bright and dark stripes with the presence of multilayer MXenes gap, which can confirm that PDA is actually inserted between the MXenes layers.

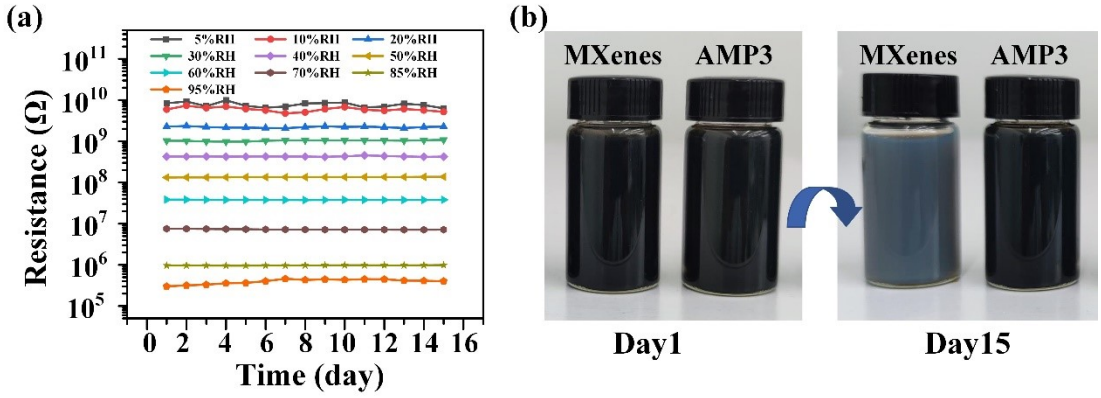

Figure S5. (a) The long-term stability of the AMP3 humidity sensor. (b) Optical images of MXenes and AMP3 aqueous dispersions stored indoors for 15 days.

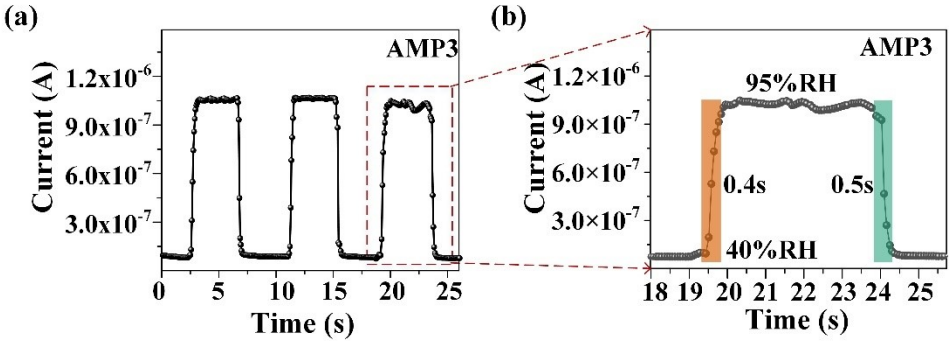

Figure S6. The three response times of AMP3 sensor.

The rise times was tested by a rapid humidity change from the environment humidity (~40 RH%) to that inside a high humidity chamber(~95 RH%). As shown in Fig. S6, we repeatedly tested three response times of a sample, which were 0.41 s, 0.38 s and 0.40 s respectively. Therefore, we calculated the rise time was 0.4 s. Indeed, as reviewer point out, 0.4 s of rise time is very slow, we have tried to shorten the humidity change time to reduce the rise time, but it didn't work. Generally, the humidity sensor needs to recover to their initial states within 3 – 5 s to accurately monitor breath pattern [1], has the response plus very time of our AMP3 sensor is only 0.9s, which can meet the operating requirement.

Table S2. Comparison of the sensing performance of some previously reported ones with that of our AMP sensor.

Sensor type	Sensing material	Measurement range	Sensitivity	Time(s)		Reference
				R_s	R_r	
Resistive	alkalized Ti_3C_2/PDA	5-95%RH	~17875	0.4	0.5	This work
Resistive	PVA/graphene nanofiber	11-98%RH	38.2%	22	50	[5]
Resistive	alkalized $Ti_3C_2T_x$	11-98%RH	300	1	201	[6]
Resistive	$Ti_3C_2T_x$/ chitosan-quercetin	1-90%RH	317%	0.75	1.6	[7]
Resistive	$Ti_3C_2T_x$/ PDAC	10-70%RH	46%	0.11	0.22	[8]
Resistive	MoO_3 nanosheets	0-100%RH	100000	0.3	0.5	[9]
Resistive	G/PEDT:PSS	12-97%RH	0.0321	31	72	[10]
Resistive	PMDS	33-95%RH	100	0.29	0.47	[11]
Resistive	silicon-nanocrystal film	20-95%RH	100000	12	2	[12]
Resistive	SnS flakes	3-99%RH	24910	6	4	[13]

Table S3 Materials bill of the humidity noncontact multistage switch

Comment	Designator	Footprint	LibRef	Quantity
4.7kΩ	R1, R2	AXIAL-0.3/ Resistor	4.7kΩ /AXIAL-0.3	2
1kΩ	R4, R5	AXIAL-0.3/ Resistor	1kΩ /AXIAL-0.3	2
10MΩ	R6, R7	AXIAL-0.3/ Resistor	10MΩ /AXIAL-0.3	2
1Ω	R8	AXIAL-0.3/ Resistor	1Ω /AXIAL-0.3	1
AD8605	/	WLCSP-5	AD8605	1
LED	Red, Green	/	Red LED Green LED	2

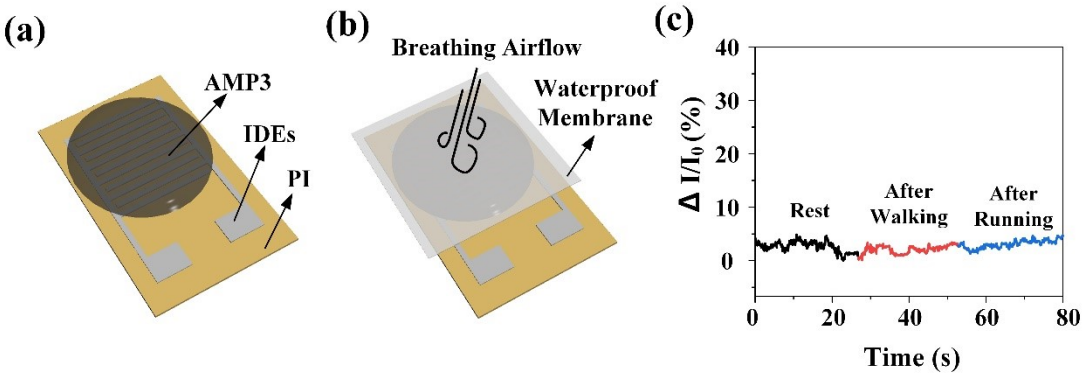

Figure S7. Schematic illustration of (a) AMP3 sensor and (b) AMP3 sensor added with waterproof membrane. (c) Current response of AMP3-based sensor with waterproof membrane under rest, after walking, after running conditions.

To study the effect of pressure caused by different breathing airflow, the AMP3 sensor was covered with a layer of waterproof membrane (PI), which insulated moisture from the device.[2] Fig. S7 (a) and (b) showed the schematic illustration of AMP3 sensor and AMP3 sensor added with waterproof membrane, respectively. And the output current of the latter was measured under three breath conditions, including rest, after walking, after running. It can be seen from Fig. S7 (c) that under the pressure of three breath conditions, the current change ratio

($\Delta I/I_0$) of AMP3 sensor added with waterproof membrane was less than 5% and had no obvious regularity. However, the current change ratio ($\Delta I/I_0$) of AMP3 sensor leaded by the humidity of three breath conditions was more than 1000. Hence, this phenomenon indicated that the effect of pressure caused by different breathing airflow was negligible compared with that of humidity. As the reviewer points out, MXenes material is sensitive to pressure, but in this manuscript, the pressure caused by breathing airflow is only a few tens of pascals[3], which is smaller than the detection lower limit of MXenes material sensor[4], so the pressure caused by different breathing airflow barely leads a change in response resistance.

References

1 Y. Su, G. Chen, C. Chen, Q. Gong, G. Xie, M. Yao, H. Tai, Y. Jiang and J. Chen, *Adv. Mater.*, 2021, 2101262.

2 Q. Wang, S. Ling, X. Liang, H. Wang, H. Lu and Y. Zhang, *Adv. Funct. Mater.*, 2019, **29**, 1808695.

3 J. Zhong, Z. Li, M. Takakuwa, D. Inoue, D. Hashizume, Z. Jiang, Y. Shi, L. Ou, M. O. G. Nayeem, S. Umezu, K. Fukuda and T. Someya, *Adv. Mater.*, 2021, 2107758.

4 Y. Ma, N. Liu, L. Li, X. Hu, Z. Zou, J. Wang, S. Luo and Y. Gao, *Nat. Commun.*, 2017, **8**, 1207.

5 Z.-C. Chen, T.-L. Chang, K.-W. Su, H.-S. Lee and J.-C. Wang, *Sens. Actuators B Chem.*, 2021, **327**, 128934.

6 Z. Yang, A. Liu, C. Wang, F. Liu, J. He, S. Li, J. Wang, R. You, X. Yan, P. Sun, Y. Duan and G. Lu, *ACS Sens.*, 2019, **4**, 1261–1269.

7 X. Li, Y. Lu, Z. Shi, G. Liu, G. Xu, Z. An, H. Xing, Q. Chen, R. P. S. Han and Q. Liu, *Sens. Actuators B Chem.*, 2021, **329**, 129209.

8 H. An, T. Habib, S. Shah, H. Gao, A. Patel, I. Echols, X. Zhao, M. Radovic, M. J. Green and J. L. Lutkenhaus, *ACS Appl. Nano Mater.*, 2019, **2**, 948–955.

9 J. Yang, R. Shi, Z. Lou, R. Chai, K. Jiang and G. Shen, *Small*, 2019, **15**, 1902801.

10 Y. Pang, J. Jian, T. Tu, Z. Yang, J. Ling, Y. Li, X. Wang, Y. Qiao, H. Tian, Y. Yang and T.-L. Ren, *Biosens. Bioelectron.*, 2018, **116**, 123–129.

11 J. Dai, H. Zhao, X. Lin, S. Liu, Y. Liu, X. Liu, T. Fei and T. Zhang, *ACS Appl. Mater. Interfaces*, 2019, **11**, 6483–6490.

12 S. Kano, K. Kim and M. Fujii, *ACS Sens.*, 2017, **2**, 828–833.

13 H. Tang, Y. Li, H. Ye, F. Hu, C. Gao, L. Tao, T. Tu, G. Gou, X. Chen, X. Fan, T. Ren and G. Zhang, *Nanotechnology*, 2019, **31**, 055501.