Supporting Information for *Journal of Materials Chemistry A*

An Integrated Solar Evaporators with Multilevel Hierarchy and Multifunctional Properties for Efficient and Salt Fouling-Resistant Desalination

Zhi Yang,[a,b] Lei Chen,[a,b] Kaijie Yang,[c] Cheng Chen,[a,b] Yuyao Zhang,[a,b] Shan Li,[a,b] Chiheng Chu,[a,b] Xiaoying Zhu,[a,b] and Baoliang Chen*[a,b]

[a.] Department of Environmental Science, Zhejiang University, Hangzhou, Zhejiang 310058, China;

[b.] Zhejiang Provincial Key Laboratory of Organic Pollution Process and Control, Hangzhou 310058, China;

[c.] c. Advanced Membranes and Porous Materials(AMPM) Center, Physical Sciences and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia

* Corresponding author: phone & Fax: 0086-571-88982587

Email: blchen@zju.edu.cn

This file includes:

1. Supplementary Notes 1 (Devices for solar desalination and solar recovery tests)
2. Supplementary Notes 2 (Devices for recycling freshwater from real seawater and wastewater)
3. Supplementary Notes 3 (Cost analysis)
4. Supplementary Figures (Figure S1-S14.)
5. Supplementary Tables (Table S1-S7.)
6. References

1. Supplementary notes 1 (Devices for solar desalination and solar recovery tests)

Solar desalination performance can be deeply influenced by thermal management and water transport. Here, two devices were designed to figure out the importance of thermal management and water transport. The schematic of the two devices is shown in **Figure S3a-b**. Setup 1 is similar to most state-of-the-art solar evaporation devices, the solar absorber material directly floats on the bulk water. The second setup has a heat-insulating layer made up of polystyrene foam wrapped by a hydrophilic cellulose paper put under the solar absorber. A solar absorber of 10 mm in thickness and 40 mm inside length is used to evaluate the solar desalination performance of the above two devices.

The solar desalination performance of the solar absorber is represented by the mass change of water under 1 sun illumination over time. The typical results of time-dependent mass change under 1 sun (1 kW m^{-2}) are given in **Figure S3c**. As the graph shows, the intrinsic evaporation rate of pure water under 1 sun is 0.318 kg m^{-2} h^{-1}. Setup 1 directly putting a solar absorber on the bulk water (setup 1) has an enhanced solar evaporation rate to 0.638 kg m^{-2} h^{-1}. Further promotion is gained by equipping with a thermal insulating layer and a hydrophilic non-woven fiber (setup 2), of which the solar evaporation rate is 1.014 kg m^{-2} h^{-1}.

2. Supplementary notes 2 (Devices for recycling freshwater from real seawater and wastewater)

A device was designed with a quartz roof for collecting the desalinated or purified water as shown in **Figure S14**. The was illuminated by a solar simulator of which the solar flux was calibricated by an optical power meter (PL-MW 2000, Perfect Light, China). The mass change of bulk water was recorded real-time by a high-accuracy balance (ME204E, Mettler Toledo, Germany). As for the device, the roof was made of quartz ensuring most of the incident light penetrated to the evaporation system. In the evaporation process, the vapor continuously produced, upflowed, and then condensed by the relatively cold roof. The concentrations of metal ions and dyes in original liquid and condensed water were measured by an inductively coupled plasma optical emission spectrometer (ICP-OES 6300, Thermo Scientific, Germany) and an ultraviolet and visible spectrophotometer (UV-2550, Shimadzu, Japan).

3. Supplementary notes 3 (Cost analysis)

The cost for estabilishing a solar desalination system is analyzed. As for our design, on the one hand, constructing our system is low-cost. The total cost of our solar system is $0.349 including a melamine foam (4×4×1 cm^3), a polystyrene foam (4×4×0.5 cm^3), graphite oxide (60 mg), sodium hydroxide (1 M, 2 mL), and polyethyleneimine (180 mg). Moreover, establishing a solar evaporator of 1 m^2 costs $21.8.

Table. The cost analysis of the solar desalination system

Chemicals	Vendor	Weight or Size	Price	Materials or Device	Device cost
Melamine foam	Shanghai Xuxian Technology Co., Ltd.	50×50×1 cm^3	$4.879	4×4×1 cm^3	$0.031
Non-woven cloth	Shenzhen Purcotton Technology Co., Ltd.	600 pieces	$6.970	0.25 piece	$0.003
Polystyrene foam	Wuhan Mingyu Technology Co., Ltd.	60×60×3 cm^3	$1.059	4×4×0.5 cm^3	$0.001
Graphene oxide	Self-produced	30 g	$81.69	60 mg	$0.163
Sodium hydroxide	Sinopharm Chemical Reagent Co., Ltd.	1000 g	$4.043	0.08 g	$0.000
Polyethyleneimine	Shanghai Aladdin Bio-Chem Technology Co., Ltd.	5 g	$4.182	180 mg	$0.151
Total	$0.349 for a 16 cm^2 solar evaporator				

4. Supplementary Figures (Figure S1-S14.)

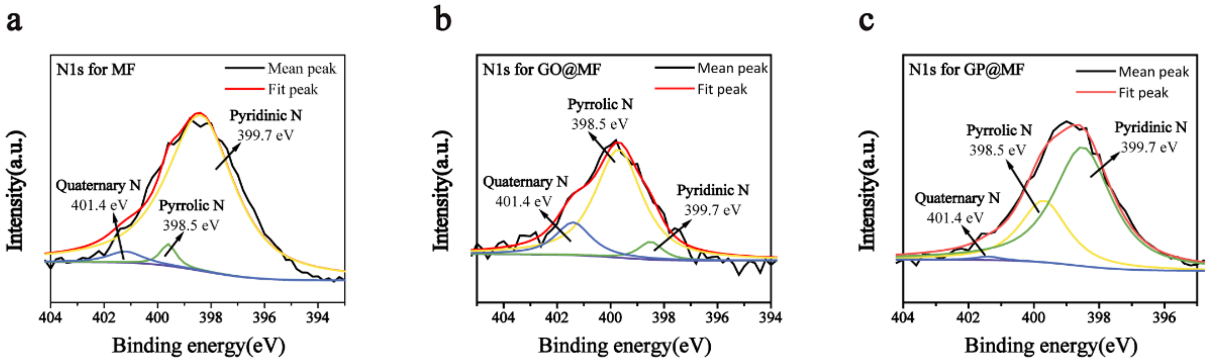

Figure S1. N 1s high-resolution XPS spectra:
(a) MF, **(b)** GO@MF and **(c)** GP@MF.

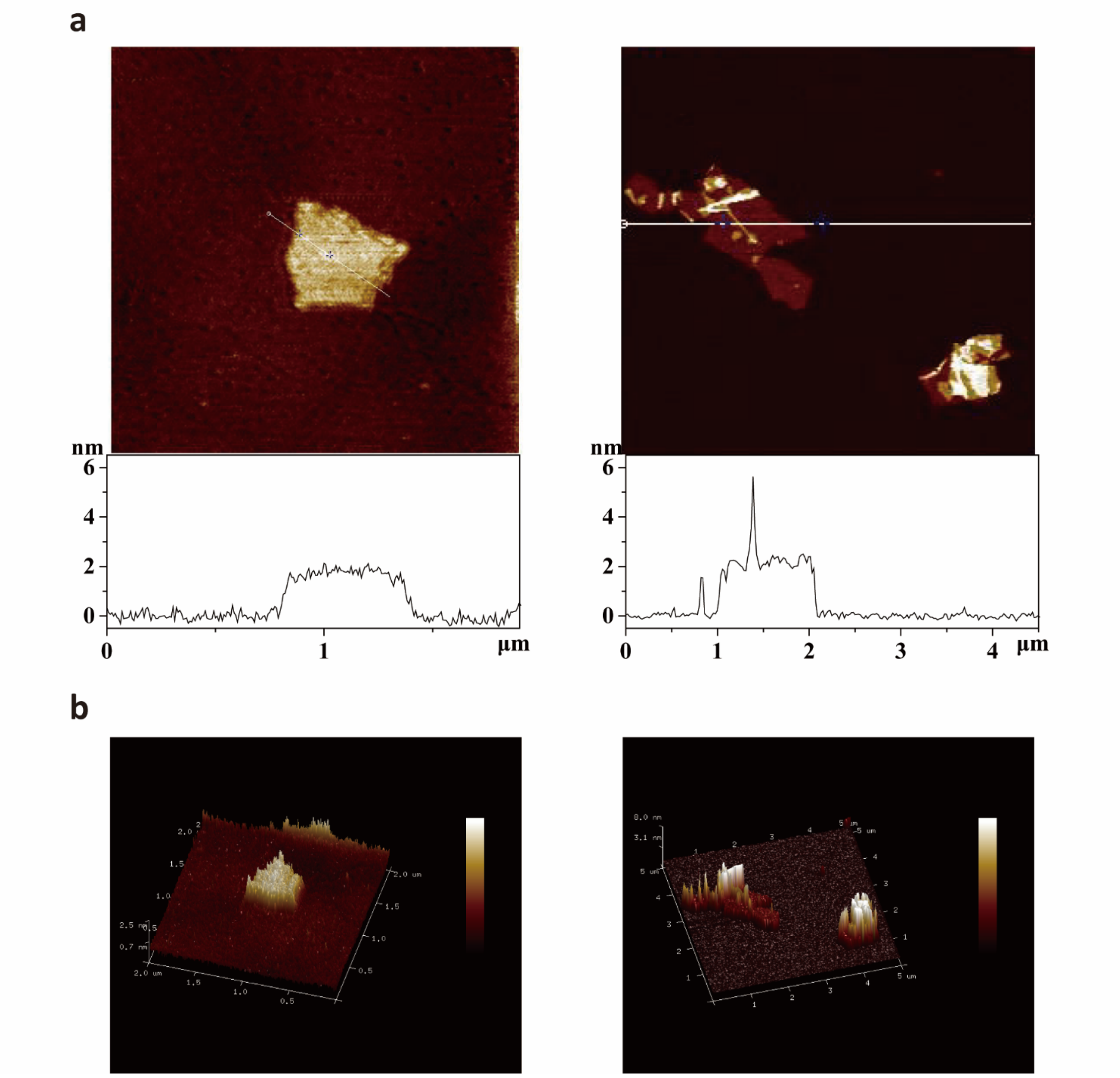

Figure S2. The height distribution of GO (left) and GP (right) nanosheets detected by AFM: **(a)** 2D images **(b)** 3D images.

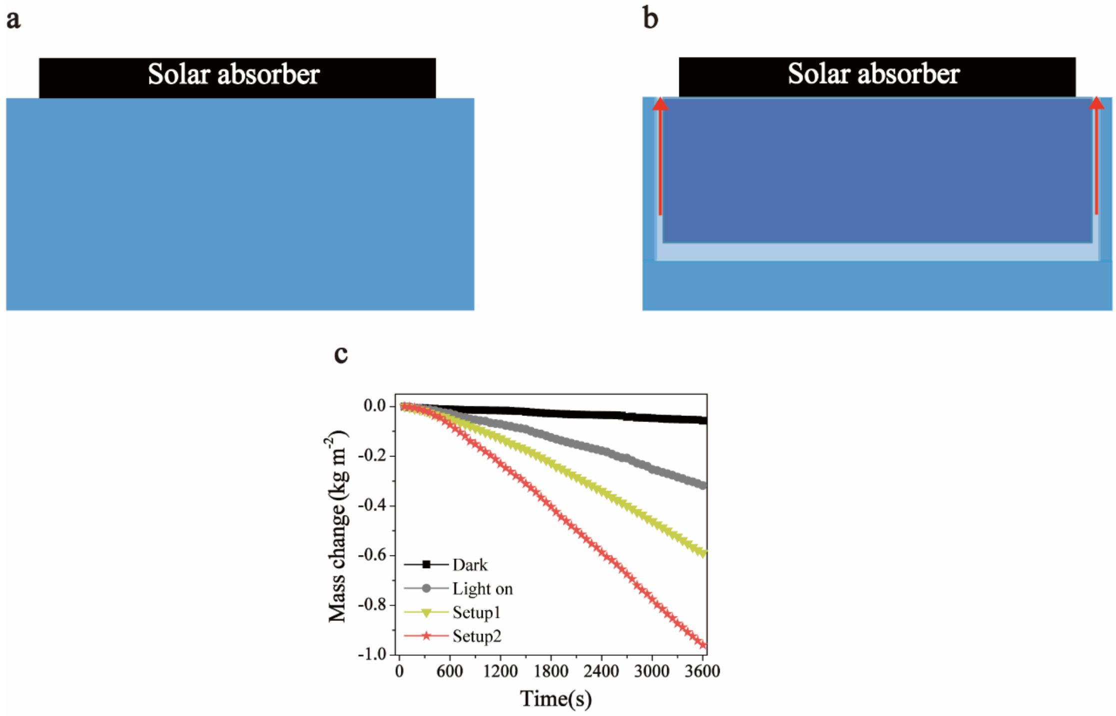

Figure S3. Schemes of two solar desalinatino setups: setup1 **(a)** and setup2 **(b)**; the time-dependent mass change of fabricated setups **(c)**.

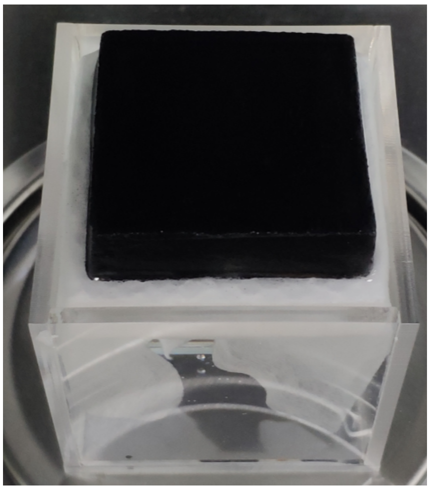

Figure S4. The real photo of solar desalination device (Setup2).

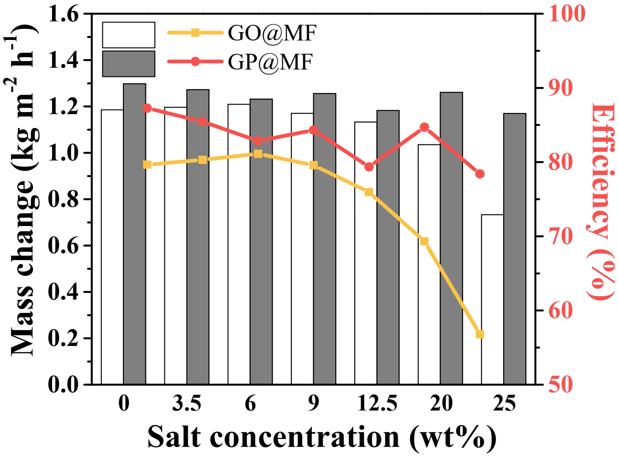

Figure S5. The contraction solar desalination tests of GO@MF and GP@MF in six different salinities.

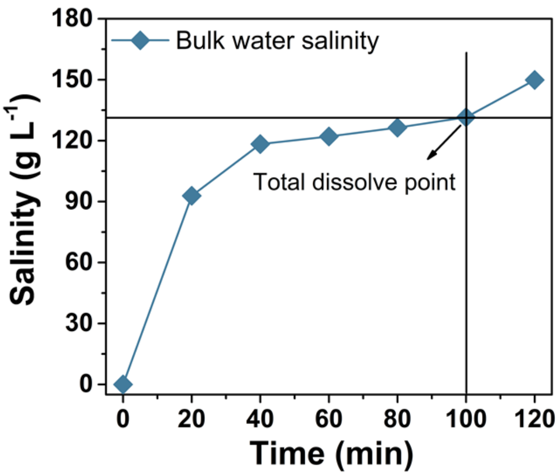

Figure S6. The time-dependent salinity change of the bulk water.

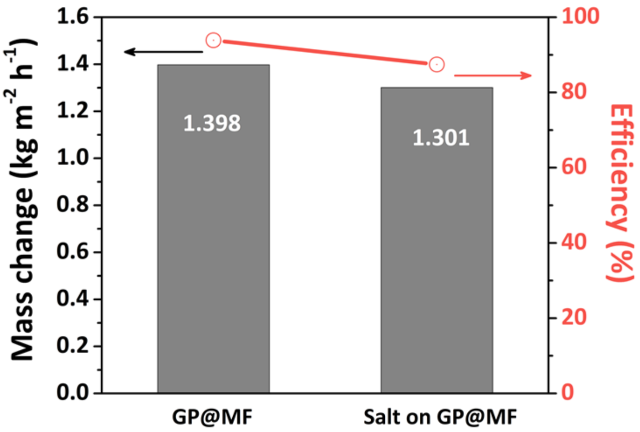

Figure S7. The time-dependent solar evaporation performance of GP@MF in two states: in pure water and with salt crystal on the evaporator.

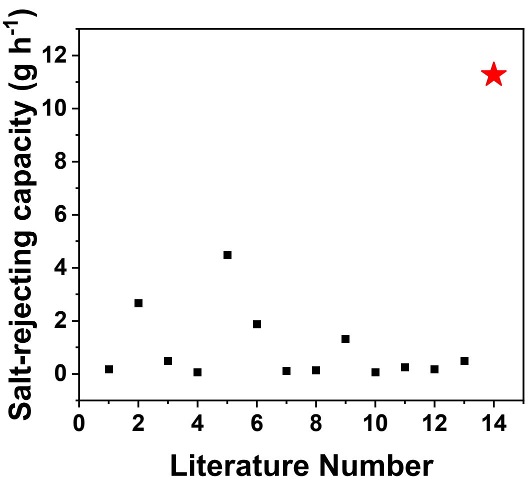

Figure S8. Comparison of the salt-rejecting ability between the state-of-the-art with GP@MF.

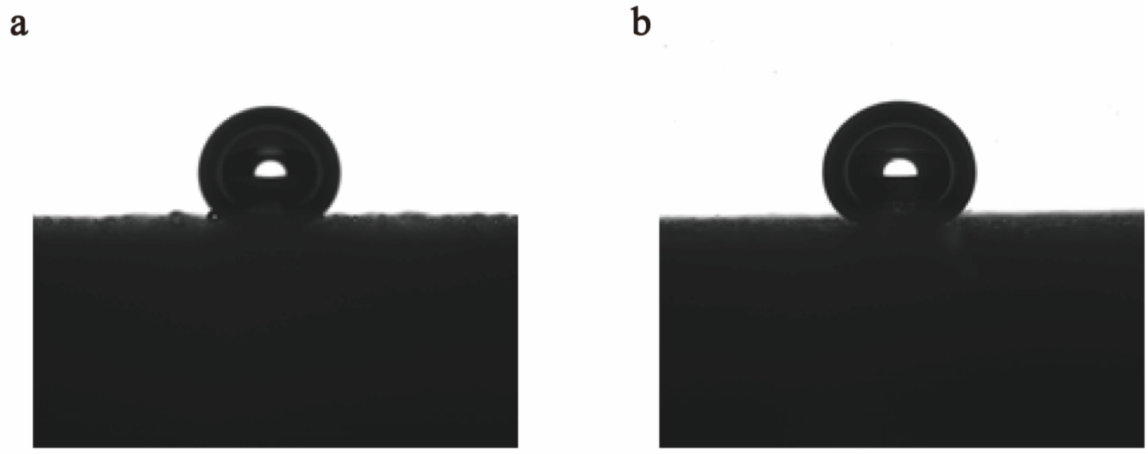

Figure S9. The air contact angles of GO@MF **(a)** and GP@MF **(b)**.

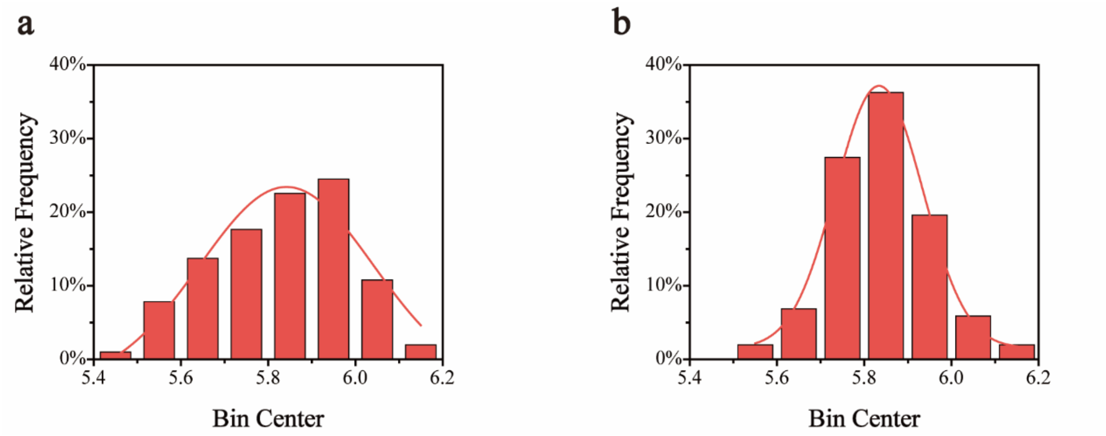

Figure S10. Distributions of adhesion forces measured in air by AFM on particle surfaces: **(a)** GO, **(b)** GP.

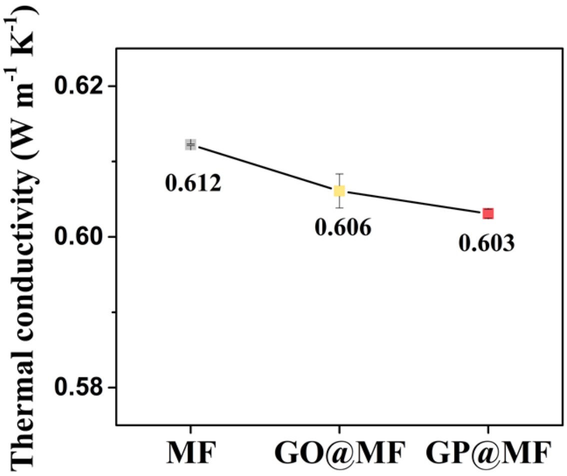

Figure S11. The thermal conductivity coefficient of the samples in wet states.

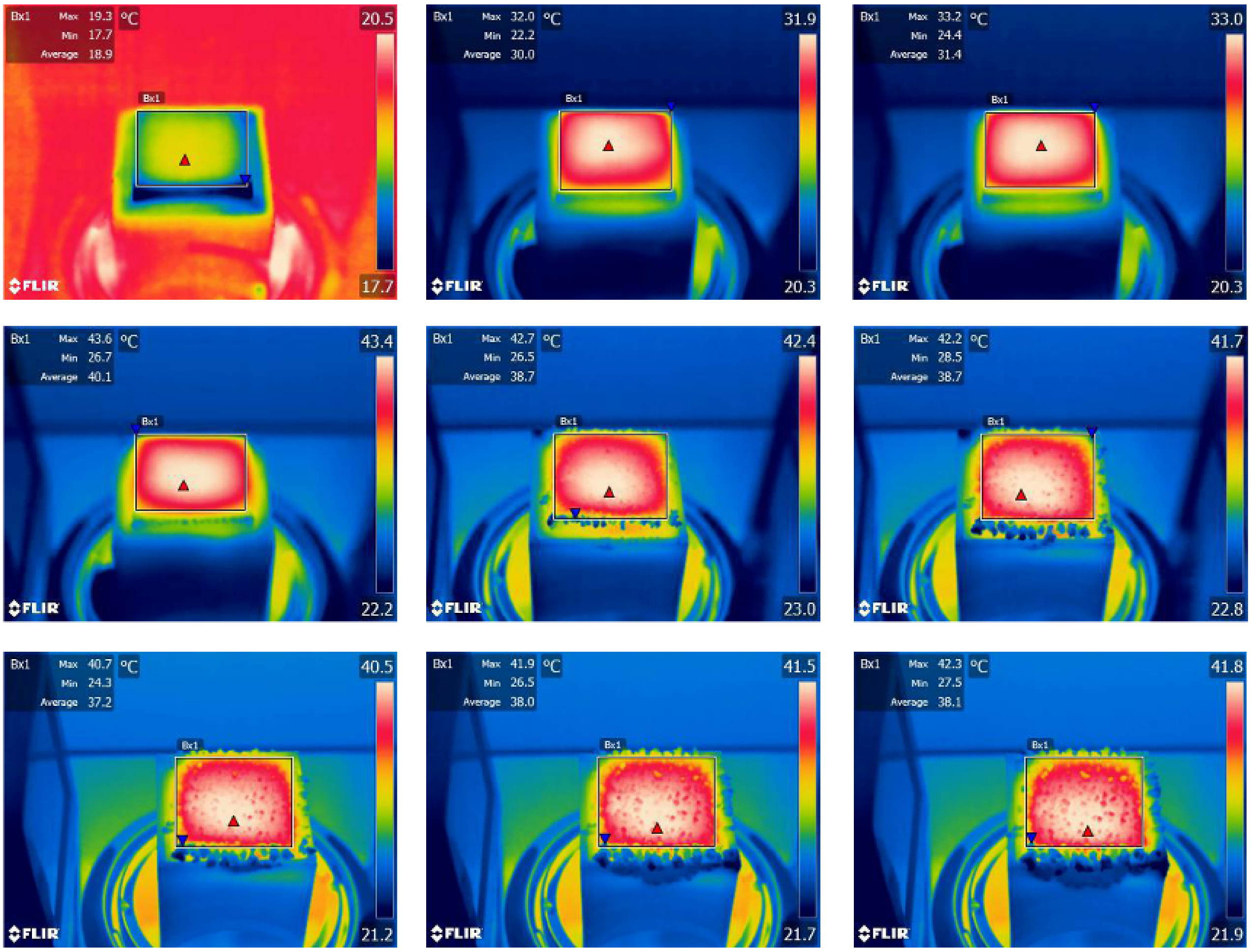

Figure S12. A record of infrared GP@MF under 1 sun illumination when treating the 25 wt.% NaCl solution.

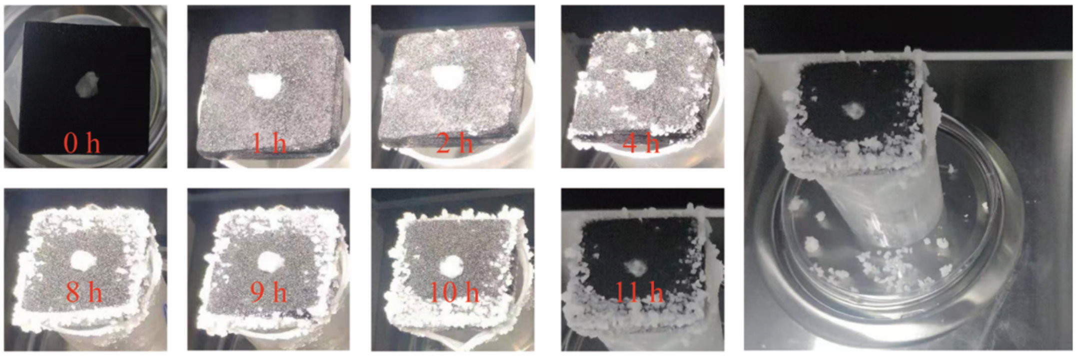

Figure S13. The record of the solar evaporator during the desalination process: a solar absorber GP@MF put on the simulated brine (20 wt.% NaCl) with a central hole for water supply.

Figure S14. The solar evaporation system for freshwater collection from seawater and wastewater.

5. Supplementary Tables (Table S1-S7.)

Table S1. The relative content of C, N and O species in MF, GO@MF and GP@MF.

Samples	C(%)	N(%)	O(%)
MF	39.28	29.26	31.46
GO@MF	68.00	6.83	25.16
GP@MF	66.91	16.16	16.94

The relative content of each species was calculated from the high-resolution XPS spectra. The equation (3) was employed to analyze the C, N and O XPS spectra, A is the peak area of the coresponding spectra, S_i is the sensitivity factor of different species.

$$C\% = \frac{A}{S_i} \quad (3)$$

Table S2. A comparison of energy efficiency between previous reports and GP@MF under 1 sun.

Ref.	Mass change (kg m^{-2} h^{-1})	Energy efficiency (%)
[1]	1.9	89.16
[2]	1.27	88
[3]	1.39	84.7
[4]	1.6	75
[5]	1.33	83.5
[6]	1.43	90
[7]	1.05	86.5
[8]	1.27	87.5
[9]	1.29	81.25
[10]	1	58
[11]	1.45*	80
[12]	1.3	87
[13]	1.17	86.5
[14]	1.38	86
[15]	1.358	86.7
[16]	0.96	71.4
[17]	1.42	89.9
[18]	0.967	83.6
[19]	1.17	80
[20]	1.492	90.8
[21]	1.28	93.63
[22]	1.227	78
[23]	1.26	88
[24]	1.95(-)	92.4
[25]	1.313	87.4
[26]	1.27	87.3
[27]	1.3	84
[28]	1.52	94.42
[29]	1.3	88.6

[30]	0.9	57.3
[31]	1.2	82
[32]	"hemisphere"2.81	94.7
[33]	2.17	85.49
[34]	2.43	83.6
[35]	1.21	82.2
[36]	1.21	53.6
[37]	1.22	81.4
[38]	1.18	72.4
[39]	1.08	74
[40]	1.43	89.7
[41]	1.2	75.8
[42]	1.15	80.4
[43]	-	-
[44]		75
[45]		57
[46]		<65
[47]	1.24	83
[48]	1.25	79
[49]	0.93	63
[50]	1.3	87.04
[51]	1.05	71.7
[52]	1.82	
[53]	1.5	
[54]		
[4]	1.65	75
[55]		16.1
[56]		73.39
[57]	1.01	62.7
[58]	1.13	70.9
[59]	2.49	90
[60]	1.12	80
[61]		79.3

[62]	1.41	84.8
[63]	1.45	94.84
[64]	1.45	87.58
[65]	1.38	83.1
[66]	1.013	61.4
[67]		
[68]	1.27	
[69]	1.18	74.3
[70]	1.25	71.9
[71]	2.07 kg day^{-1}	28.16
[72]	0.87	89.7
[73]		
[74]	0.95	68.9
[75]	1.492	90.8
[76]	1.26	81
[77]	1.44	83.1
[78]	1.014	72.5
[17]	1.48	102
[79]	1.52	92.42
[80]	1.56	93.8
[81]	2.08	93.6
[20]	1.262	86.6
[82]	1.314	85.81
[83]	1.48	89.2
[84]	1.41	86.4
[85]	1.394	90.1
[86]	1.38	86.9
[87]	1.41	88.6
[88]	1.27	88.6
[89]	1.3	72
[90]	1	78
[91]	1.62	85.7
[92]	1.24	83.3

[93]	1.37	83.5
[94]	1.38	86.5
[95]	1.191	76.5
[96]	1.375	82.11
[97]	1.282	89
[5]	1.33	83.5
[98]	1.25	78.5
[99]	1.34*	85.7
[100]	1.31	82
[101]	1.23	82
[102]	1.46	92.4
[103]	1.74	"W"89.9→82.4
[104]	1.38*	85.5
[105]	1.31	83
[106]	1.35	92.3
[107]	1.399	74.21
[108]	1.31	79.8
[109]	0.48	64
[110]	1.33	86
[111]	1.304	91.5
[112]	1.2	90.67
[113]	1.47	92.4
[114]	1.16	80
[115]	1.31	83
[116]		72
[117]	1.15	82
[118]	1.22	80.4
[119]	1.442	88.2
[120]	(r=4 cm) 1.05	57.9
Our work	1.392	93.4

134

Table S3. Comparison of the solar evaporation performance in various salinitiesty between the state-of-the-art and our design under 1 sun.

Ref.	Salt concentration (wt%)	Mass change (kg m^{-2} h^{-1})	Energy efficiency (%)
[1]	0	1.9	89.16
	3.5	1.7	
	17.5	1.6	
[4]	0	1.6	75
	3.6	1.3	52
[7]	0	1.05	86.5
	15		80
[10]	0	1	58
	2.75		57
[12]	0	1.62	87
	1.4	1.5	
	3	1.47	
	3.5	1.45	
	4	1.42	
[14]	0	1.62*(0.32)	86
	10	1.24	
[20]	0	1.492	90.8
	3.5		
[29]	0	1.3	88.6
	3.5	1.2	
[32]	0	"hemisphere"7→2.81	94.7
	3.5	"hemisphere"5.7→2.65	89
	15	2.25	
[34]	0	2.43	83.6
	3.5	1.93	
[35]	0	1.21	82.2
	1	1.11	75.7
	3.5	1.08	73.8

	4.1	1.09	73.9
	23	1.05	71.6
[37]	0	1.22（1.314）	81.4
	3.5	1.27	
	10	1.24	
	20	1.22	
[43]	0	-	-
	1.1		59.4
	15	0.8	57.2
[45]	0		57
	3.5		56
[48]	0	1.70→1.25	79
	3.5	1.2	
	15	1.12	55
	25	1.06	0.51
[50]	0	1.3	87.04
	0.9		*87*
	3.5	1.125	
[51]	0	1.05	71.7
	3.5	0.998	
[52]	0	1.82	
	3.5	1.69	
[121]	0(10 suns)	13.26	93.39
	3.5 Na	12.88	90.71
	3.5 Mg	12.75	89.82
[54]	0		
	3.5	4.1	
	15	3.4	
[4]	0	1.65	75
	3.6	1.24	
[55]	0		16.1
	20		11.1
[56]	0		73.39

	5		73.24
	8.26		73.4
	15.25		71.05
	26.47		55.08
[57]	0	1.01	62.7
	3.5		60.2
[63]	0	1.45	94.84
	3.5	1.42	92.55
	20	1.35	87.96
[72]	0	0.87	89.7
	3.5		76
[75]	0	1.46	
	3.5	1.41	
	lake water	1.35	
[17]	0	1.42	
	3.5	1.33	
	10	1.3	
	20	1.25	
[28]	0	1.52	92.42
	5	1.52	
	10	1.51	
	15	1.49	
[122]	0	1.56	93.8
	3.5	1.36	82
	Yellow sea	1.4	
[85]	0	1.394	90.1
	3.5	1.322	
	10	0.98	
[89]	0	1.3	72
	3.5	0.75 h	51
[90]	0	1	78
	2	0.75	
	3.6	0.7	

	5	0.5	
	7	0.36	
	15	0.25	
[93]	0	1.37	83.5
	3.5		<83.5
[100]	0	1.31	82
	3.5	1.15	72
[101]	0	6.7	94
	3.5	5.5	
[105]	0	1.31	83
	3.5	1.19	72
[106]	0	1.35	92.3
	5		87.6
	10		84.3
	20	1.2	82
[107]	0	1.399（1.620）	74.21
	seawater（East China Sea）	1.568	71.51
	15% KCl	1.356	60.66
[113]	0	1.47	92.4
	20	1.31	80.9
[116]	0		72
	3.5		63
[119]	0	1.442(2.287)	88.2
	7	2.03	
	10.5	1.8	
Our work	0	1.392	93.4
	3.5	1.391	93.2
	12.5	1.319	88.0
	25	1.236	82.8

Table S4. Comparison of the salt-rejecting capacity between the state-of-the-art and our work.

Literature number	**Salt mass (g)**	**Time for dissolve (h)**	**Dissolve speed (g h^{-1})**
[3]	0.500	3.000	0.167
[7]	4.000	1.500	2.667
[123]	0.500	1.000	0.500
[19]	0.260	4.000	0.065
[23]	4.500	1.000	4.500
[32]	7.000	3.750	1.867
[40]	0.250	2.000	0.125
[43]	1.000	7.000	0.143
[45]	1.524	1.150	1.325
[67]	0.500	8.000	0.063
[70]	0.500	2.000	0.250
[20]	1.000	6.000	0.167
[28]	1.000	2.000	0.500
Our work	16.00	1.420	11.268

Table S5 The temperature change of the solar absorber between the dry and wet state under 1 sun.

Samples	GP@MF	GO@MF	MF
Dry state	62.6 ^{o}C	59.6 ^{o}C	30.2 ^{o}C
Wet state	37.6 ^{o}C	36.8 ^{o}C	29.4 ^{o}C
Temperature rise	25.0 ^{o}C	22.8 ^{o}C	0.8 ^{o}C

Table S6. The thermal conductivity results of the additive in the same substrate.

Samples	**Thermal conductivity (W m^{-1} K^{-1})**			**Mean**	**Standard Deviation**
FP	1.558	1.559	1.561	1.560	0.00139
GO-FP	1.328	1.326	1.325	1.326	0.00156
GP-FP	1.159	1.158	1.160	1.159	0.00073

Table S7. The porosity calculation parameters of the three evaporators.

Samples	m_{Dry} (g)	m_{Wet} (g)	Density(g m^3)	Porosity(%)
GP@MF	0.0970	14.869	14.869	99.52
GO@MF	0.1500	12.913	12.913	97.11
MF	0.2580	13.129	13.129	98.60

6. Reference

[1] K. Liu, W. Zhang, H. Cheng, L. Luo, B. Wang, Z. Mao, X. Sui, X. Feng, *ACS Appl. Mater. Interfaces.* **2021**, 13, 10612.

[2] Q. Wang, Q. Guo, F. Jia, Y. Li, S. Song, *ACS Appl. Mater. Interfaces.* **2020**, 12, 32673.

[3] J. Deng, S. Xiao, B. Wang, Q. Li, G. Li, D. Zhang, H. Li, *ACS Appl. Mater. Interfaces.* **2020**, 12, 51537.

[4] J. Zeng, Q. Wang, Y. Shi, P. Liu, R. Chen, *Adv. Energy Mater.* **2019**, 9, 1900552.

[5] M. Kim, K. Yang, Y. S. Kim, J. C. Won, P. Kang, Y. H. Kim, B. G. Kim, *Carbon* **2020**, 164, 349.

[6] K. Yin, S. Yang, J. Wu, Y. Li, D. Chu, J. He, J.-A. Duan, *J. Mater. Chem. A* **2019**, 7, 8361.

[7] W. Zhang, X. Chen, G. Zhang, J. Li, Q. Ji, C. Hu, Z. J. Ren, H. Liu, J. Qu, *J. Mater. Chem. A* **2020**, 8, 12089.

[8] Y. J. Li, T. T. Gao, Z. Yang, C. J. Chen, Y. D. Kuang, J. W. Song, C. Jia, E. M. Hitz, B. Yang, L. B. Hu, *Nano Energy* **2017**, 41, 201.

[9] J. Xu, F. Xu, M. Qian, Z. Li, P. Sun, Z. Hong, F. Huang, *Nano Energy* **2018**, 53, 425.

[10] L. Zhou, Y. Tan, J. Wang, W. Xu, Y. Yuan, W. Cai, S. Zhu, J. Zhu, *Nat. Photonics* **2016**, 10, 393.

[11] X. Li, W. Xu, M. Tang, L. Zhou, B. Zhu, S. Zhu, J. Zhu, *Proc. Natl. Acad. Sci. U. S. A.* **2016**, 113, 13953.

[12] X. Han, L. Zang, S. Zhang, T. Dou, L. Li, J. Yang, L. Sun, Y. Zhang, C. Wang, *RSC Adv.* **2020**, 10, 2507.

[13] X. Lin, M. Yang, W. Hong, D. Yu, X. Chen, *Front. Mater.* **2018**, 5, 74.

[14] Y. Chen, C. Sha, Y. Yu, W. Wang, *Adv. Sustain. Syst.* **2022**, 6, 2100300.

[15] X. Chen, X. B. Zhu, S. M. He, L. B. Hu, Z. J. Ren, *Adv. Mater.* **2021**, 33, 2001240.

[16] Y. Zhang, S. K. Ravi, J. V. Vaghasiya, S. C. Tan, *Iscience* **2018**, 3, 31.

[17] C. Liu, K. Hong, X. Sun, A. Natan, P. Luan, Y. Yang, H. Zhu, *J. Mater. Chem. A* **2020**, 8, 12323.

[18] D. Wu, C. Du, C. Huang, *Appl. Therm. Eng.* **2021**, 195, 117238.

[19] M. S. Zafar, M. Zahid, A. Athanassiou, D. Fragouli, *Adv. Sustainable Syst.* **2021**, 5, 2100031.

[20] S. Cheng, Z. Sun, Y. Wu, P. Gao, J. He, Z. Yin, L. Liu, G. Li, *J. Mater. Chem. A* **2021**, 9, 22428.

[21] J. Liu, J. Yao, Y. Yuan, Q. Liu, W. Zhang, X. Zhang, J. Gu, *Adv. Sustainable Syst.* **2020**, 4, 21000126.

[22] N. Xu, X. Hu, W. Xu, X. Li, L. Zhou, S. Zhu, J. Zhu, *Adv. Mater.* **2017**, 29, 1606762.

[23] J. Li, X. Zhou, Y. Jing, H. Sun, Z. Zhu, W. Liang, A. Li, *ACS Appl. Mater. Interfaces* **2021**, 13, 12181.

[24] Y. Geng, W. Sun, P. Ying, Y. Zheng, J. Ding, K. Sun, L. Li, M. Li, *Adv. Funct. Mater.* **2021**, 31, 2007648.

[25] J. Liu, Q. Liu, D. Ma, Y. Yuan, J. Yao, W. Zhang, H. Su, Y. Su, J. Gu, D. Zhang, *J. Mater. Chem. A* **2019**, 7, 9034.

[26] X. Lin, J. Chen, Z. Yuan, M. Yang, G. Chen, D. Yu, M. Zhang, W. Hong, X. Chen, *J. Mater. Chem. A* **2018**, 6, 4642.

[27] L. Yang, G. Chen, N. Zhang, Y. Xu, X. Xu, *ACS Sustainable Chem. Eng.* **2019**, 7, 19311.

[28] Y. Zhao, D. You, W. Yang, H. Yu, Q. Pan, S. Song, *Environ. Sci. Water Res.* **2021**, 8, 151.

[29] Z. Liu, H. Song, D. Ji, C. Li, A. Cheney, Y. Liu, N. Zhang, X. Zeng, B. Chen, J. Gao, Y. Li, X. Liu, D. Aga, S. Jiang, Z. Yu, Q. Gan, *Glob. Chall.* **2017**, 1, 1600003.

[30] M. Zhu, Y. Li, G. Chen, F. Jiang, Z. Yang, X. Luo, Y. Wang, S. D. Lacey, J. Dai, C. Wang, C. Jia, J. Wan, Y. Yao, A. Gong, B. Yang, Z. Yu, S. Das, L. Hu, *Adv. Mater.* **2017**, 29, 1704107.

[31] J. Li, X. Zhou, J. Zhang, C. Liu, F. Wang, Y. Zhao, H. Sun, Z. Zhu, W. Liang, A. Li, *ACS Appl. Energy Mater.* **2020**, 3, 3024.

[32] Y. Tian, X. Liu, J. Li, Y. Deng, J. A. DeGiorgis, S. Zhou, A. Caratenuto, M. L. Minus, Y. Wan, G. Xiao, Y. Zheng, *Cell Rep. Phys. Sci.* **2021**, 2, 100547.

[33] X. Suo, J. Yang, Y. Zhang, Y. Hao, J. Yang, H. Qiao, *Adv. Sustain. Syst.* **2021**, 5, 2100031.

[34] H. Liu, R. Jin, S. Duan, Y. Ju, Z. Wang, K. Yang, B. Wang, B. Wang, Y. Yao, F. Chen, *Small* **2021**, 17, 2100969.

[35] Y. Lu, T. Dai, D. Fan, H. Min, S. Ding, X. Yang, *Energy Technol.* **2020**, 8, 2000567.

[36] C. Zhang, B. Yuan, Y. Liang, L. Yang, L. Bai, D. Wei, W. Wang, H. Chen, Sol. *Energy Mater. Sol. Cells* **2021**, 227, 111127.
[37] D. Li, D. Han, C. Guo, C. Huang, *ACS Appl. Energy Mater.* **2021**, 4, 1752.
[38] X. Gao, H. Lan, S. Li, X. Lu, M. Zeng, X. Gao, Q. Wang, G. Zhou, J. M. Liu, M. J. Naughton, K. Kempa, J. Gao, *Glob. Chall.* **2018**, 2, 1800035.
[39] H. Liu, C. Chen, G. Chen, Y. Kuang, X. Zhao, J. Song, C. Jia, X. Xu, E. Hitz, H. Xie, S. Wang, F. Jiang, T. Li, Y. Li, A. Gong, R. Yang, S. Das, L. Hu, *Adv. Energy Mater.* **2018**, 8, 1701616.
[40] P. Ye, K. Chen, Y. Yin, Y. Cheng, Y. Wu, M. Lin, K. Xiao, J. Environ. *Chem. Eng.* **2022**, 10, 106890.
[41] Q. Fang, T. Li, Z. Chen, H. Lin, P. Wang, F. Liu, *ACS Appl. Mater. Interfaces* **2019**, 11, 10672.
[42] X. Li, C. Guan, X. Gao, X. Zuo, W. Yang, H. Yan, M. Shi, H. Li, M. Sain, *ACS Appl. Mater. Interfaces* **2020**, 12, 35493.
[43] S. He, C. Chen, Y. Kuang, R. Mi, Y. Liu, Y. Pei, W. Kong, W. Gan, H. Xie, E. Hitz, C. Jia, X. Chen, A. Gong, J. Liao, J. Li, Z. J. Ren, B. Yang, S. Das, L. Hu, *Energy Environ. Sci.* **2019**, 12, 1558.
[44] P. Yang, K. Liu, Q. Chen, J. Li, J. Duan, G. Xue, Z. Xu, W. Xie, J. Zhou, *Energy Environ. Sci.* **2017**, 10, 1923.
[45] G. Ni, S. H. Zandavi, S. M. Javid, S. V. Boriskina, T. A. Cooper, G. Chen, *Energy Environ. Sci.* **2018**, 11, 1510.
[46] J. Wang, Y. Li, L. Deng, N. Wei, Y. Weng, S. Dong, D. Qi, J. Qiu, X. Chen, T. Wu, *Adv. Mater.* **2017**, 29, 1603730.
[47] Y. Jin, J. Chang, Y. Shi, L. Shi, S. Hong, P. Wang, *J. Mater. Chem. A* **2018**, 6, 7942.
[48] Y. Shi, C. L. Zhang, R. Y. Li, S. F. Zhuo, Y. Jin, L. Shi, S. Hong, J. Chang, C. S. Ong, P. Wang, *Environ. Sci. Tech.* **2018**, 52, 11822.
[49] Lin Zhou, Yingling Tan, Dengxin Ji, Bin Zhu, Pei Zhang, Jun Xu, Qiaoqiang Gan, Zongfu Yu, J. Zhu, *Sci. Adv.* **2016**, 2, 1501227.
[50] Y. Yang, R. Zhao, T. Zhang, K. Zhao, P. Xiao, Y. Ma, P. M. Ajayan, G. Shi, Y. Chen, *ACS Nano* **2018**, 12, 829.
[51] C. F. Wang, C. L. Wu, S. W. Kuo, W. S. Hung, K. J. Lee, H. C. Tsai, C. J. Chang, J. Y. Lai, *Sci. Rep.* **2020**, 10, 12769.
[52] W. Wang, Y. Shi, C. Zhang, S. Hong, L. Shi, J. Chang, R. Li, Y. Jin, C. Ong, S. Zhuo, P. Wang, *Nat. Commun.* **2019**, 10, 3012.
[53] X. Dong, L. Cao, Y. Si, B. Ding, H. Deng, *Adv. Mater.* **2020**, 32, 1908269.
[54] X. Liu, Y. Tian, F. Chen, A. Caratenuto, J. A. DeGiorgis, M. Elsonbaty, Y. Wan, R. Ahlgren, Y. Zheng, *Adv. Funct. Mater.* **2021**, 31, 2100911.
[55] M. Lyu, J. Lin, D. Shi, *Energy Technol.* **2021**, 9, 2100590.
[56] L. Yi, D. Qi, P. Shao, C. Lei, Y. Hou, P. Cai, G. Wang, X. Chen, Z. Wen, *Nanoscale* **2019**, 11, 9958.
[57] V. Kashyap, A. Al-Bayati, S. M. Sajadi, P. Irajizad, S. H. Wang, H. Ghasemi, *J. Mater. Chem. A* **2017**, 5, 15227.
[58] G. Zhu, J. Xu, W. Zhao, F. Huang, *ACS Appl. Mater. Interfaces* **2016**, 8, 31716.
[59] D. A. Kospa, A. I. Ahmed, S. E. Samra, A. A. Ibrahim, *RSC Adv.* **2021**, 11, 15184.
[60] T. Li, H. Liu, X. P. Zhao, G. Chen, J. Q. Dai, G. Pastel, C. Jia, C. J. Chen, E. Hitz, D. Siddhartha, R. G. Yang, L. B. Hu, *Adv. Funct. Mater.* **2018**, 28, 1707134.
[61] Y. Yuan, C. Dong, J. Gu, Q. Liu, J. Xu, C. Zhou, G. Song, W. Chen, L. Yao, D. Zhang, *Adv. Mater.* **2020**, 32, 1907975.
[62] Q. Zhang, Z. Fu, H. Yu, S. Chen, *J. Mater. Chem. A* **2020**, 8, 8065.
[63] Z. Chen, Q. Li, X. Chen, *ACS Sustainable Chem. Eng.* **2020**, 8, 13850.
[64] J. Liu, L. Xu, Y. Li, J. Zhao, X. Jia, J. Chao, B. Lv, Y. Zhao, *Adv. Sustainable Syst.* **2021**, 6, 2100274.
[65] H. Peng, D. Wang, S. Fu, *ACS Appl. Mater. Interfaces* **2021**, 13, 38405.
[66] C. Du, C. Huang, *Appl. Therm. Eng.* **2022**, 201, 117834.
[67] C. Gao, J. Zhu, Z. Bai, Z. Lin, J. Guo, *ACS Appl. Mater. Interfaces* **2021**, 13, 7200.

[68] A. Mnoyan, M. Choi, D. H. Kim, B.-J. Ku, H. Kim, K. J. Lee, A. S. Yasin, S. Nam, K. Lee, *RSC Adv.* **2020**, 10, 42432.
[69] Y. Zhang, X. Yin, B. Yu, X. Wang, Q. Guo, J. Yang, *ACS Appl. Mater. Interfaces* **2019**, 11, 32559.
[70] Q. Fang, T. Li, H. Lin, R. Jiang, F. Liu, *ACS Appl. Energy Mater.* **2019**, 2, 4354.
[71] A. K. Thakur, R. Sathyamurthy, R. Saidur, R. Velraj, I. Lynch, N. Aslfattahi, *Desalination* **2022**, 526, 115521.
[72] Z. Wang, Q. Ye, X. Liang, J. Xu, C. Chang, C. Song, W. Shang, J. Wu, P. Tao, T. Deng, *J. Mater. Chem. A* **2017**, 5, 16359.
[73] C. Tian, J. Liu, R. Ruan, X. Tian, X. Lai, L. Xing, Y. Su, W. Huang, Y. Cao, J. Tu, *Small* **2020**, 16, 2000573.
[74] Y. Xia, Y. Li, S. Yuan, Y. Kang, M. Jian, Q. Hou, L. Gao, H. Wang, X. Zhang, *J. Mater. Chem. A* **2020**, 8, 16212.
[75] X. Feng, J. Zhao, D. Sun, L. Shanmugam, J.-K. Kim, J. Yang, *J. Mater. Chem. A* **2019**, 7, 4400.
[76] H. Gao, M. Yang, B. Dang, X. Luo, S. Liu, S. Li, Z. Chen, J. Li, *RSC Adv.* **2020**, 10, 1152.
[77] W. Huang, G. Hu, C. Tian, X. Wang, J. Tu, Y. Cao, K. Zhang, *Sustainable Energy Fuels* **2019**, 3, 3000.
[78] W. Zhang, G. Zhang, Q. Ji, H. Liu, R. Liu, J. Qu, *ACS Appl. Mater. Interfaces* **2019**, 11, 9974.
[79] H. D. Kiriarachchi, A. A. Hassan, F. S. Awad, M. S. El-Shall, *RSC Adv.* **2021**, 12, 1043.
[80] J. Ma, Y. Han, Y. Xu, T. Zhang, J. Zhang, D. Qi, D. Liu, W. Wang, *J. Mater. Chem. A* **2020**, 8, 21771.
[81] Z. Wang, Y. Yan, X. Shen, Q. Sun, C. Jin, *Sustainable Energy Fuels* **2020**, 4, 354.
[82] S. Wu, B. Gong, H. Yang, Y. Tian, C. Xu, X. Guo, G. Xiong, T. Luo, J. Yan, K. Cen, Z. Bo, K. K. Ostrikov, T. S. Fisher, *ACS Appl. Mater. Interfaces* **2020**, 12, 38512.
[83] Z. C. Xiong, Y. J. Zhu, D. D. Qin, R. L. Yang, *ACS Appl. Mater. Interfaces* **2020**, 12, 32556.
[84] B. Zhang, Q. Gu, C. Wang, Q. Gao, J. Guo, P. W. Wong, C. T. Liu, A. K. An, *ACS Appl. Mater. Interfaces* **2021**, 13, 3762.
[85] Q. Zhang, L. Li, B. Jiang, H. Zhang, N. He, S. Yang, D. Tang, Y. Song, *ACS Appl. Mater. Interfaces* **2020**, 12, 28179.
[86] Q. Zhang, G. Yi, Z. Fu, H. Yu, S. Chen, X. Quan, *ACS Nano* **2019**, 13, 13196.
[87] C. Liu, C. Cai, X. Zhao, *ACS Sustainable Chem. Eng.* **2020**, 8, 1548.
[88] S. Wu, G. Xiong, H. Yang, B. Gong, Y. Tian, C. Xu, Y. Wang, T. Fisher, J. Yan, K. Cen, T. Luo, X. Tu, Z. Bo, K. Ostrikov, *Adv. Energy Mater.* **2019**, 9, 1901286.
[89] W. Xu, X. Hu, S. Zhuang, Y. Wang, X. Li, L. Zhou, S. Zhu, J. Zhu, *Adv. Energy Mater.* **2018**, 8, 1702884.
[90] C. Finnerty, L. Zhang, D. L. Sedlak, K. L. Nelson, B. Mi, *Environ. Sci. Tech.* **2017**, 51, 11701.
[91] R. Zhang, C. Liu, N. Li, L. Chen, T. Xu, Y. Qin, S. Zhang, Z. Wang, *Ind. Eng. Chem. Res.* **2020**, 59, 18520.
[92] R. Hu, J. Zhang, Y. Kuang, K. Wang, X. Cai, Z. Fang, W. Huang, G. Chen, Z. Wang, *J. Mater. Chem. A* **2019**, 7, 15333.
[93] D. D. Qin, Y. J. Zhu, R. L. Yang, Z. C. Xiong, *Nanoscale* **2020**, 12, 6717.
[94] K. Xu, C. Wang, Z. Li, X. Yan, X. Mu, M. Ma, P. Zhang, *Environ. Sci. Water Res.* **2021**, 7, 879.
[95] D. D. Han, Z. D. Chen, J. C. Li, J. W. Mao, Z. Z. Jiao, W. Wang, W. Zhang, Y. L. Zhang, H. B. Sun, *ACS Appl. Mater. Interfaces* **2020**, 12, 25435.
[96] S. Gao, X. Dong, J. Huang, J. Dong, F. D. Maggio, S. Wang, F. Guo, T. Zhu, Z. Chen, Y. Lai, *Glob. Chall.* **2019**, 3, 1800117.
[97] F. Peng, J. Xu, X. Bai, G. Feng, X. Zeng, M. R. Ibn Raihan, H. Bao, Sol. *Energy Mater. Sol.* **2021**, 221, 110910.
[98] X. Chen, C. Meng, Y. Wang, Q. Zhao, Y. Li, X.-M. Chen, D. Yang, Y. Li, Y. Zhou, *ACS Sustainable Chem. Eng.* **2020**, 8, 1095.
[99] D. D. Qin, Y. J. Zhu, F. F. Chen, R. L. Yang, Z. C. Xiong, *Carbon* **2019**, 150, 233.
[100] Y. C. Wang, L. B. Zhang, P. Wang, *ACS Sustainable Chem. Eng.* **2016**, 4, 1223.
[101] Y. Yang, X. Yang, L. Fu, M. Zou, A. Cao, Y. Du, Q. Yuan, C.-H. Yan, *ACS Energy Lett.* **2018**, 3, 1165.

[102] T. Hu, L. Li, Y. Yang, J. Zhang, *J. Mater. Chem. A* **2020**, 8, 14736.

[103] Z. Qin, H. Sun, Y. Tang, S. Yin, L. Yang, M. Xu, Z. Liu, *ACS Appl. Mater. Interfaces* **2021**, 13, 19467.

[104] Y. Lu, X. Wang, D. Fan, H. Yang, H. Xu, H. Min, X. Yang, *Sustainable Mater. Technol.* **2020**, 25, 00180.

[105] L. Shi, Y. C. Wang, L. B. Zhang, P. Wang, *J. Mater. Chem. A* **2017**, 5, 16212.

[106] X. Chen, S. He, M. M. Falinski, Y. Wang, T. Li, S. Zheng, D. Sun, J. Dai, Y. Bian, X. Zhu, J. Jiang, L. Hu, Z. J. Ren, *Energy Environ. Sci.* **2021**, 14, 5347.

[107] H. Y. Zhao, J. Zhou, Z. L. Yu, L. F. Chen, H. J. Zhan, H. W. Zhu, J. Huang, L. A. Shi, S. H. Yu, *Cell Rep. Phys. Sci.* **2020**, 1, 100074.

[108] J. L. Ning Xu, Yang Wang, Chang Fang, Xiuqiang Li, Yuxi Wang, Lin Zhou, Bin Zhu, Zhen Wu, Shining Zhu, Jia Zhu, *Sci. Adv.* **2019**, 5, 7013.

[109] G. Ni, G. Li, S. V. Boriskina, H. Li, W. Yang, T. Zhang, G. Chen, *Nat. Energy* **2016**, 1, 1501227.

[110] G. Chen, N. Zhang, N. Li, L. Yu, X. Xu, *Adv. Mater. Interfaces* **2019**, 7, 1901715.

[111] C. Shen, Y. Zhu, X. Xiao, X. Xu, X. Chen, G. Xu, *ACS Appl. Mater. Interfaces* **2020**, 12, 35142.

[112] Q. Wang, L. Wang, S. Song, Y. Li, F. Jia, T. Feng, N. Hu, *Desalination* **2022**, 525, 115483

[113] C. Xiao, W. Liang, L. Chen, J. He, F. Liu, H. Sun, Z. Zhu, A. Li, *ACS Appl. Energy Mater.* **2019**, 2, 8862.

[114] Q. Chen, Z. Pei, Y. Xu, Z. Li, Y. Yang, Y. Wei, Y. Ji, *Chem. Sci.* **2018**, 9, 623.

[115] G. Chen, N. Li, J. He, L. Qiao, F. Li, S. Wang, L. Yu, P. Murto, X. Li, X. Xu, *J. Mater. Chem. A* **2020**, 8, 24664.

[116] X. Huang, Y.-H. Yu, Oscar L. de Llergo, S. M. Marquez, Z. Cheng, *RSC Adv.* **2017**, 7, 9495.

[117] Y. Chang, Z. Wang, Y.-e. Shi, X. Ma, L. Ma, Y. Zhang, J. Zhan, *J. Mater. Chem. A* **2018**, 6, 10939.

[118] Y. Wang, C. Wang, X. Song, S. K. Megarajan, H. Jiang, *J. Mater. Chem. A* **2018**, 6, 963.

[119] X. Han, S. Ding, L. Fan, Y. Zhou, S. Wang, *J. Mater. Chem. A* **2021**, 9, 18614.

[120] Y. Xia, Q. Hou, H. Jubaer, Y. Li, Y. Kang, S. Yuan, H. Liu, M. W. Woo, L. Zhang, L. Gao, H. Wang, X. Zhang, *Energy Environ. Sci.* **2019**, 12, 1840.

[121] C. Xing, D. Huang, S. Chen, Q. Huang, C. Zhou, Z. Peng, J. Li, X. Zhu, Y. Liu, Z. Liu, H. Chen, J. Zhao, J. Li, L. Liu, F. Cheng, D. Fan, H. Zhang, *Adv. Sci.* **2019**, 6, 1900531.

[122] Y. Wang, C. Wang, X. Song, M. Huang, S. K. Megarajan, S. F. Shaukat, H. Jiang, *J. Mater. Chem. A* **2018**, 6, 9874.

[123] T. Chen, H. Xie, X. Qiao, S. Hao, Z. Wu, D. Sun, Z. Liu, F. Cao, B. Wu, X. Fang, *ACS Appl. Mater. Interfaces.* **2020**, 12, 50397.