Supporting Information

Broadband Aggregation-Independent Plasmonic Absorber for Highly Efficient Solar Steam Generation

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Section 1. Methods

Materials: L-cysteine (L-Cys) was obtained from Sigma Aldrich (USA), $HAuCl_4$ was purchased from J&K chemical (Beijing, China). Ascorbic acid, silver nitrate, sodium borohydride and sodium stearate were obtained from Sigma Aldrich (USA). Hexadecyl trimethyl ammonium bromide (CTAB) and sodium oleate (NaOL, >97.0%) were purchased from J&K chemical (Beijing, China). Hydrochloric acid (HCl, 37 wt%) was purchased from Sigma Aldrich (USA). PVA (Mw=13000-23000) were purchased from Sigma Aldrich (USA). Unless otherwise special declared, all chemicals were used without further purification

Preparation of nano-trepang:

1 Synthesis of AuNR0:

Gold nanorods were prepared by a standard seed mediated method.[1] Firstly, gold seed solution was prepared by adding 25 μL 10 mM $HAuCl_4$ into 1 mL 0.1 M CTAB solution, then 60 μL fresh prepared ice cold $NaBH_4$ solution (20 mM) was quickly injected into the above CTAB solution, the mixture was placed on magnetic stirring for 2 mins then the seed solution was aged at 37 ^oC for 2 hours. The certain aspect ratio gold nanorods were prepared as follow: 140 mg CTAB was dissolved into 5 mL deionized water, then the solution was placed at 60 ^oC after 24.6 mg NaOL was added into the solution. The solution was allowed to cool down to room temperature and keep undisturbed, then 5 mL $HAuCl_4$ (1 mM) solution and 192 μL $AgNO_3$ (10 mM) were mixed with the solution, after that, 72 μL hydrochloric acid (HCl, 37 wt. % in water)

was added in order to adjust the pH. After stirring at 1000 rpm for 10 mins, 25 μl (0.064 M) ascorbic acid was introduced into the mixture. Finally, 16 μL of as-prepared seed solution was added into the growth solution, then the growth solution was placed at 37 ^{o}C overnight. The resultant gold nanorods solution was purified by centrifugation at 8,000 rpm for 20 mins followed by removal of the supernatant. The gold nanorods absorption spectra was measured by ultraviolet spectrometry (Shimadu-1700, Japan).

2 Synthesis of nano-trepang:

Nano-trepang were synthesized as follow: 1.0 mL of 0.1 M CTAB solution was added into 3.8 mL deionized water. Then 0.2 mL of 10 mM $HAuCl_4$ was introduced into the mixture and the resultant mixture solution was stirred for 5 mins. 0.475 mL of ascorbic acid (0.1 M) was mixed into the solution to reduce Au^{3+}, then 0.5 mL of diluted AuNR0 was added into the solution and after stirred at 1000 rpm for 30 s, 10 μL of L-Cysteine (1 mM) was quickly injected into the mixture solution. After another 60 mins of stirring at 1000 rpm, the prepared gold nanoparticles were isolated by centrifugated at 5000 rpm for 5 mins and washed with DI water for three times.

Fabrication of plasmonic aerogel network (PAN): Hybrid hydrogel was prepared as following: 1 g PVA (Mw=13000-23000) was dissolved into DI water (10 mL), then the as prepared PVA solution was mixed with 0.125 mL glutaraldehyde (10 % in DI water) thoroughly by sonication for 30 mins. Then 7 mL prepared nano-trepang (350 μg/mL) and 2 mL HCl solution (1.2 M) were added into the mixed PVA solution, finally 1 mL water was added into the mixture solution. The gelation was carried out for 3 h at room temperature, and the obtained hybrid hydrogel was immersed into DI water at least 8 h

before obtaining pure hybrid hydrogel. -20 ^{o}C freezer was used to freeze the prepared hybrid hydrogel and then thawed in water bath at 37 ^{o}C. The freeze-thawed process was repeated at least 10 times. Then a lyophilization process was proceeded to obtain the PAN. The obtained PAN was reduced by hydrazine aqueous solution at 70 ^{o}C for 8 h. Finally, the PAN was washed with deionized water three times to remove extra hydrazine and followed by freeze-drying for the following experiments.

Experimental Setup for Steam Generation: To evaluate photothermal performance of the as prepared PAN, the water evaporation experiment was carried out at room temperature, the PAN (with a diameter of 28 mm and thickness of 9 mm) was allowed to float on the surface of bulk water in a 25 mL beaker under solar simulator with radiation intensity of 1 kW m^{-2} (1 sun). The solar simulator was configurated with an optical filter for the standard AM 1.5 G spectrum (Newport). Once the simulated sunlight was on, the water mass change was immediately monitored by a high-accuracy electrical balance every 5 min (Shimadzu, AUW22OD, 0.01 mg in accuracy). The real-time temperature change was recorded by a FLUKE Ti400 infrared camera. Temperature data and infrared images were exported by a software (SmartView 4.3) connected to a desktop computer for the calculating the steam generation rate and efficiency. The respective evaporation rates under varied simulated solar irradiation density were calculated to identify the effect of solar irradiation on evaporation rates.

Evaporation rate in the group set without simulated solar irradiation was treat as blank control, the evaporation rate in experimental group was revised by subtracted the blank control. The real sea water was obtained from Tsim Sha Tsui, Kowloon, Hong

Kong (10:00, August 10, 2019). All the sea water used in the following experiments were treated with 0.22 μm filter membrane to exclude potential bacterial and other solid impurities. All the experiments were typically carried out at an ambient temperature of ≈22 °C and a humidity of ≈55%.

Section 2. Characterizations

Dynamic light scattering (DLS) measurements and *Zeta* potentials were carried out with a Malvern Zeta-sizer instrument. Sizes and morphologies of AuNRs were investigated using scanning electron microscopy (SEM, Philips XL-30 FEG) and transmission electron microscope (TEM; Philips Technai 12). UV-Vis absorption was recorded with UV−vis spectrophotometer (Shimadzu 1700). Concentration of prepared nano-trepang was determinate by ICP-OES (Optima 8000, PerkinElmer, USA). Infrared images were captured by infrared camera (Fluke Ti400, USA). All the obtained data were processed by Origin 8.5.

Section 3. Calculate energy efficiency (η) for solar steam generation

The corresponding energy efficiency (η) for solar to steam generation can then be calculated using the following formula:

$$\eta = \frac{mh_v}{C_{opt}P_o} \quad (1)$$

where m is the calibrated mass change rate under solar illumination, h_v is the water vaporization enthalpy in PAN, P_0 is the solar irradiation density (1 kW m^{-2}), and C_{opt} is the optical concentration on the evaporator surface. According to the previous research, the vaporization enthalpy of water confined in the PAN molecular mesh is smaller than that of bulk water. [1,2] The solar to vapor energy efficiency (η) of the PAN was about 79.3 %.

Section 4. Additional table and figures

Table S1. Summary the dimension of AuNR at different growth stage

	Length (nm)	Width (nm)	Aspect ratio
AuNR0	72.2	18.2	4.0
AuNR1	125.1	61.3	2.0
AuNR2	192.3	104.0	1.9
Nano-trepang	272.3	165.5	1.7

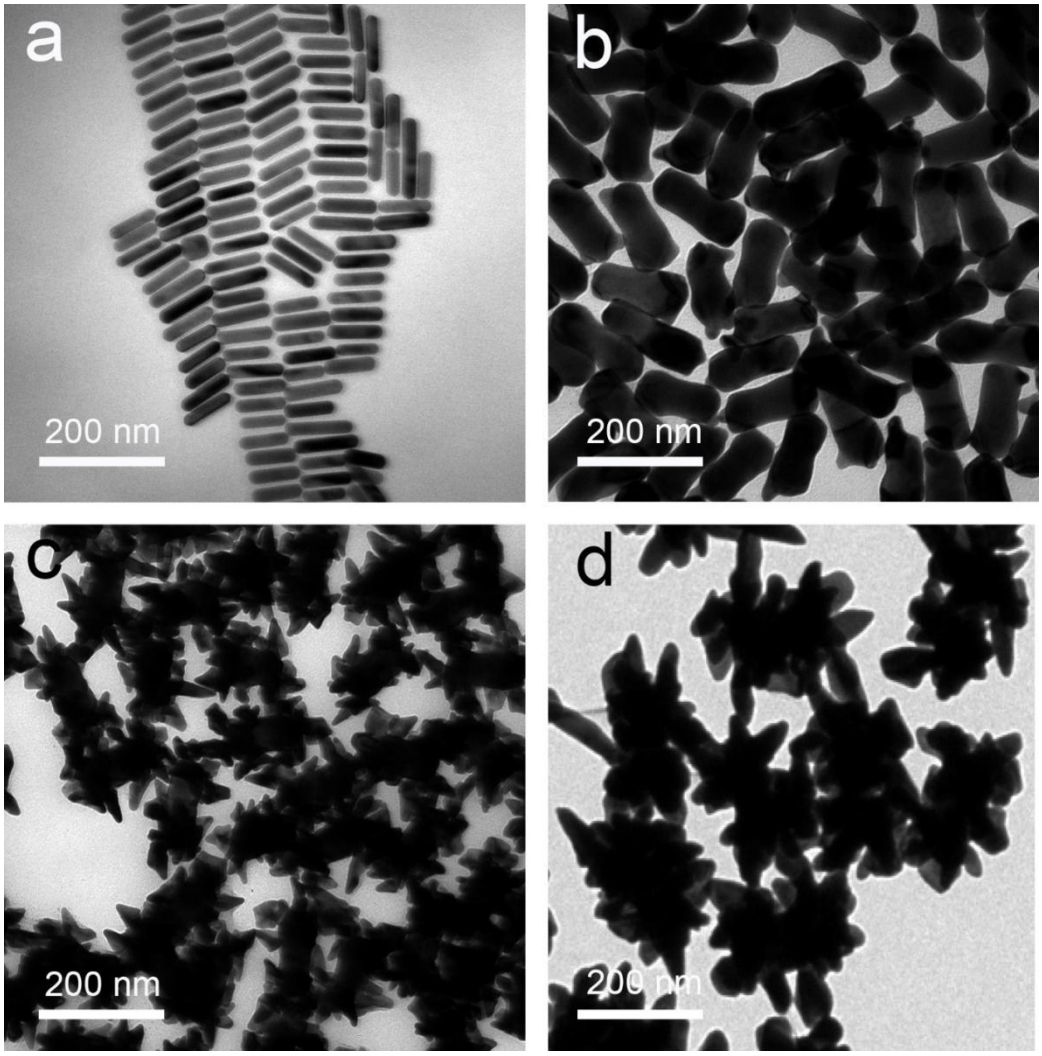

Fig. S1 (a) TEM image of AuNR0 (Initial gold nanorods). TEM images of (b) AuNR1, (c) AuNR2, (d) Nano-trepang.

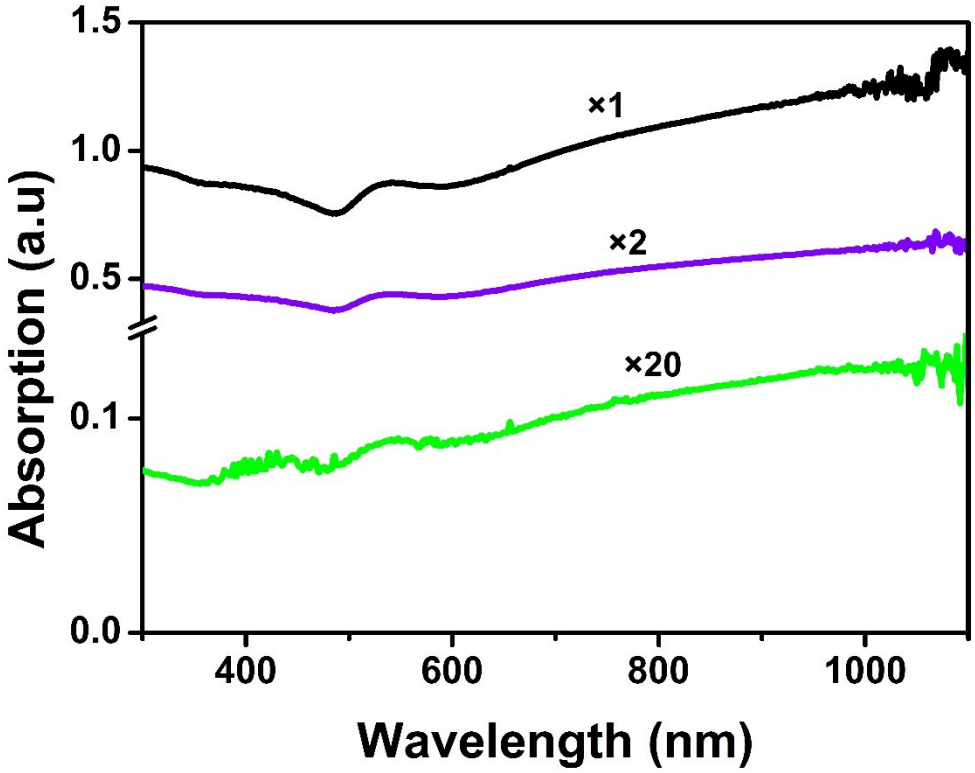

Fig. S2 The absorption spectrum changes of nano-trepang (200 μg/ml) after diluted 2 times, 20 times respectively.

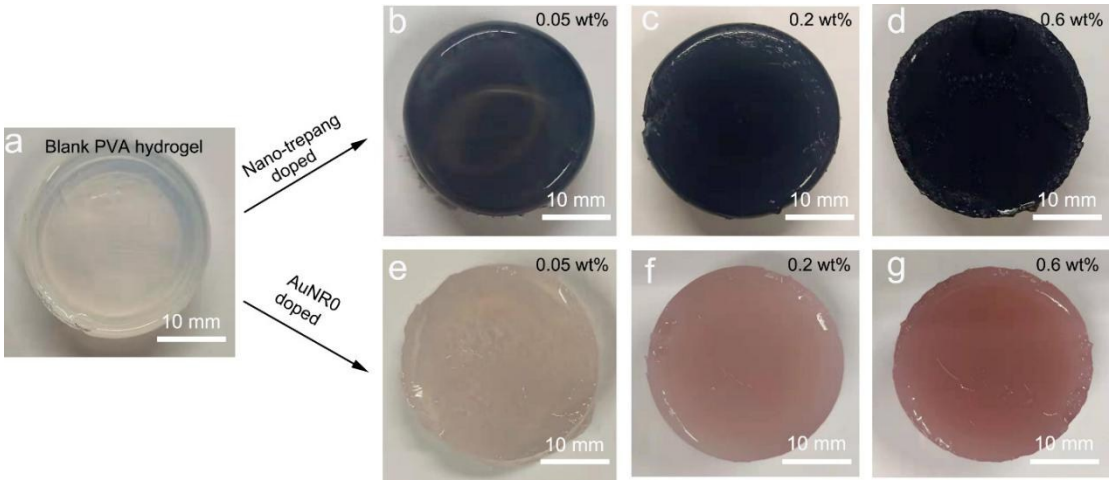

Fig.S3 (a) Blank PVA hydrogel. PVA hybrid hydrogels doped with (b) 0.05; c) 0.2; and (d) 0.6 wt% of nano-trepang. PVA hybrid hydrogels doped with (e) 0.05; (f) 0.2; and (g) 0.6 wt% of AuNR0.

Fig. S4 Bright field images and corresponding IR images under solar irradiation of real pattern of PVA hybrid hydrogel.

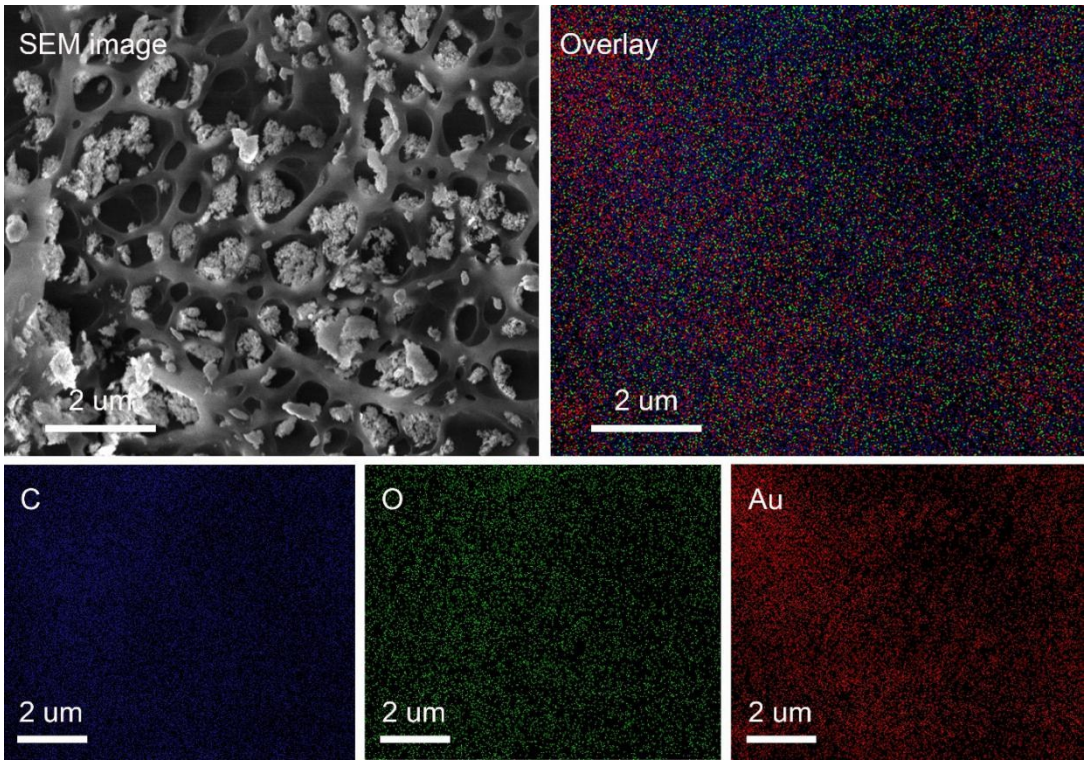

Fig. S5 Elemental mapping images of selected section of PAN-3.

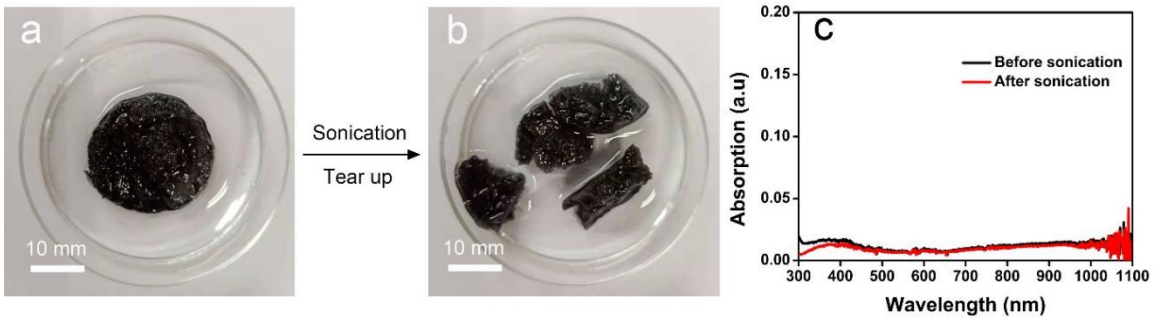

Fig. S6 (a) PAN was soaked in water. (b) PAN was torn into small pieces before undergoing an overnight sonication. (c) The absorption spectrum of soak solution before and after overnight sonication.

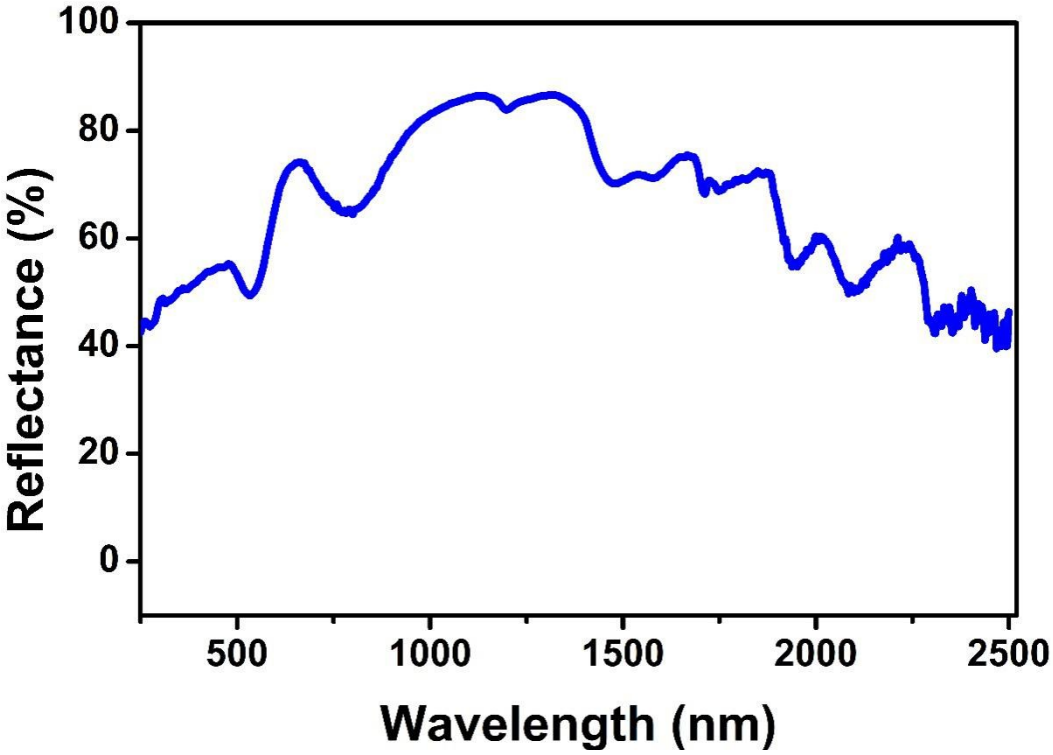

Fig. S7 Reflectance spectra of PVA hybrid hydrogel doped with 0.6 wt% AuNR0.

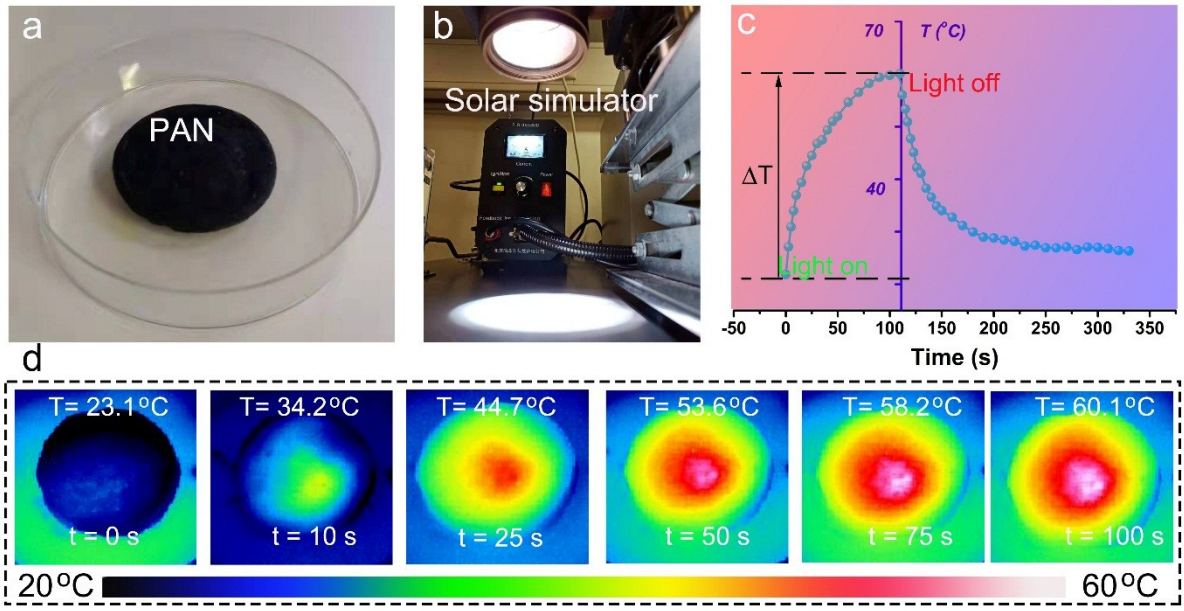

Fig. S8 (a) Image of the prepared PAN. (b) Simulated solar resource setup. (c) The temperature changes with light on and further temperature initialization after lighting off. (d) IR photographs of the PAN under solar irradiation (solar irradiation density: 3 kW m^{-2}, AM1.5 G, time: 110 s).

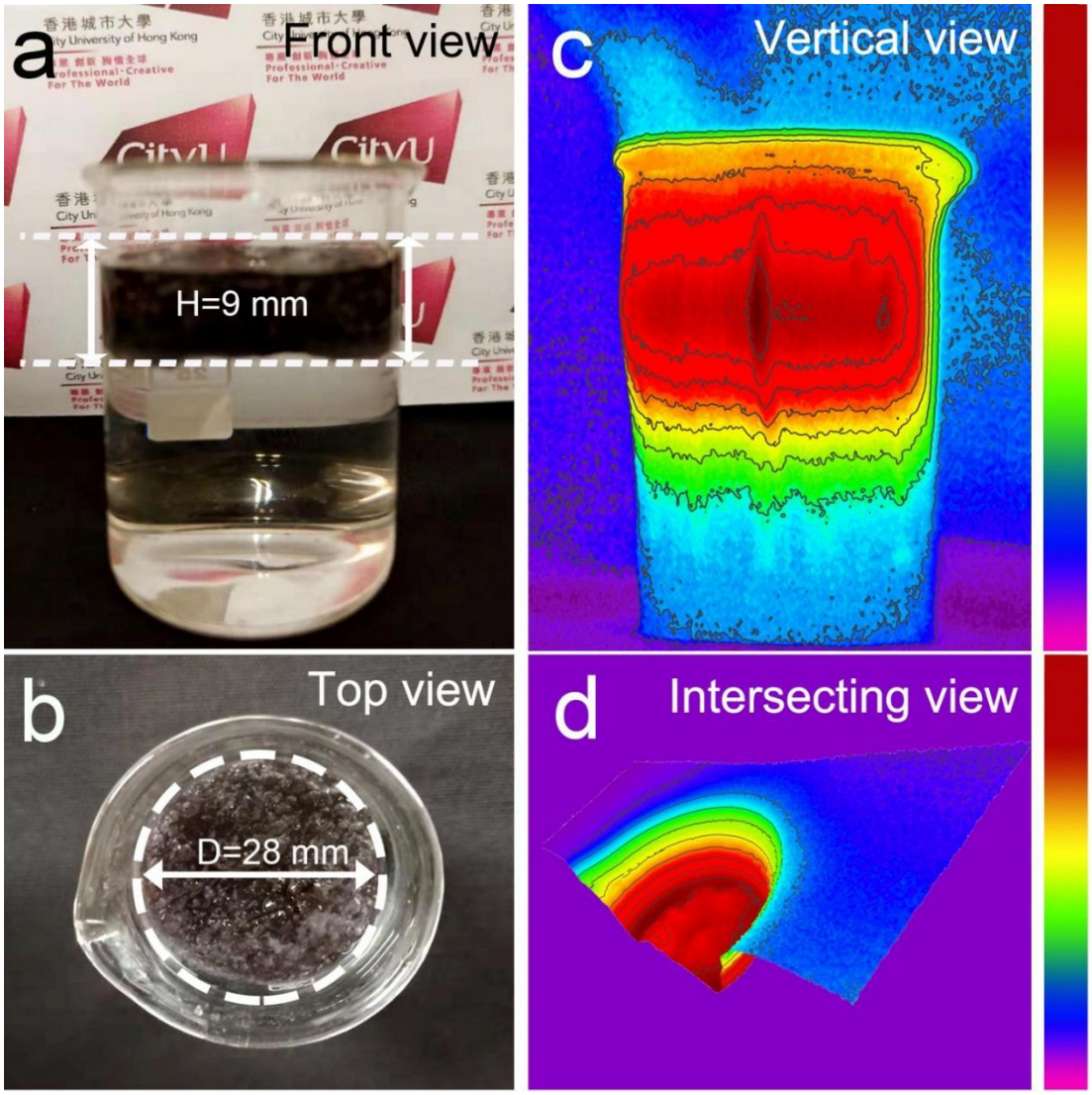

Fig. S9 (a, b) Front and top view images of the prepared PAN floating on bulk water in a beaker. (c, d) Vertical and intersecting view of 3D temperature profiles under solar irradiation (1 sun).

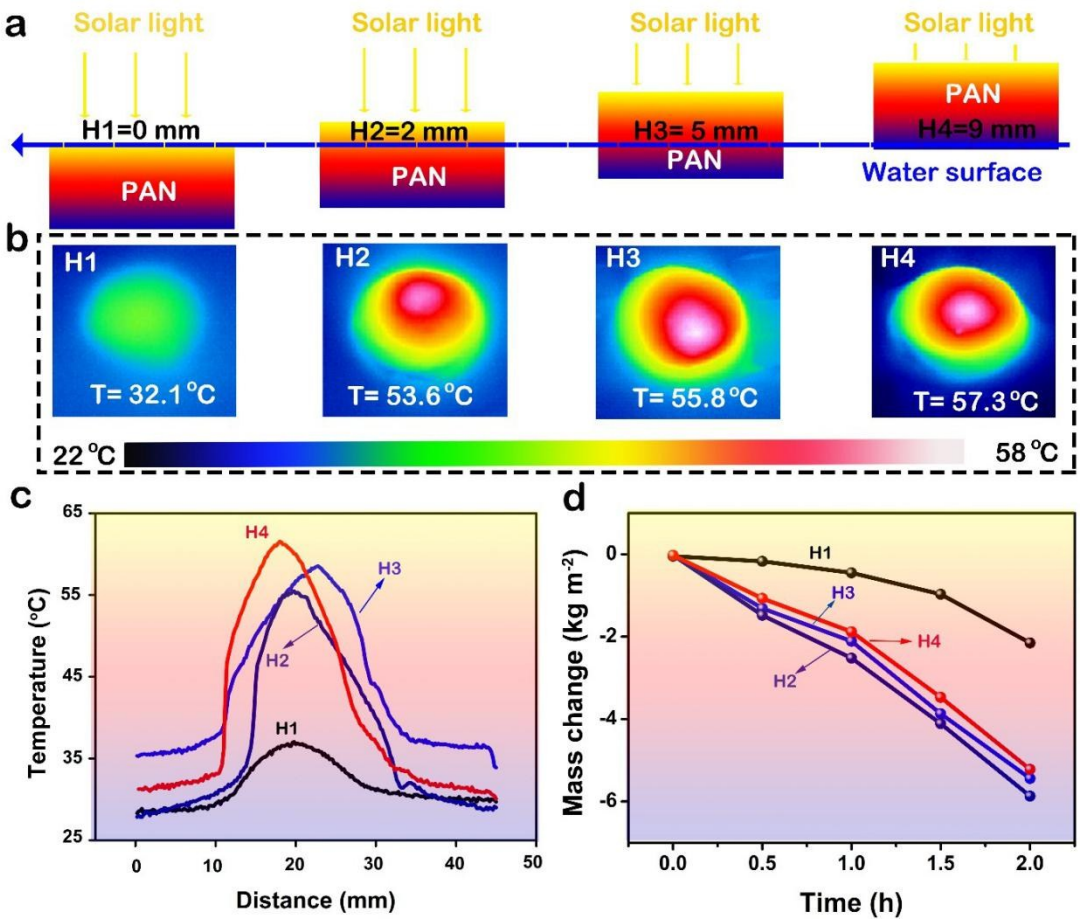

Fig. S10 (a) Schematic illustration of PAN-3 under different height configuration with solar light irradiation. (b) IR images of PAN-3 under solar light irradiation under various height configuration. (c) The surface temperature profiles of PAN-3 under different height configuration. (d) Mass change under different height configuration.

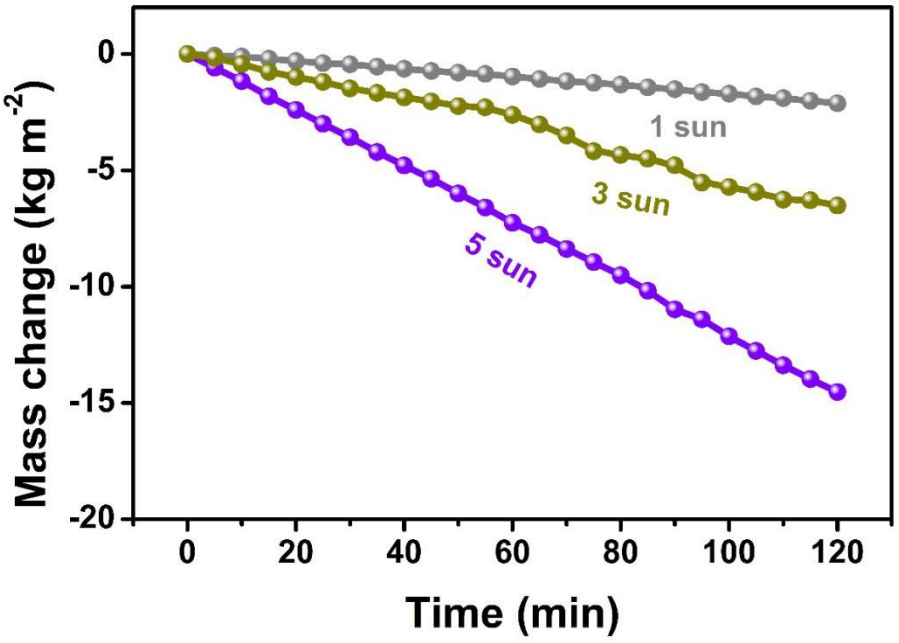

Fig. S11 The mass loss of water for PAN-1 over time at various solar irradiation density.

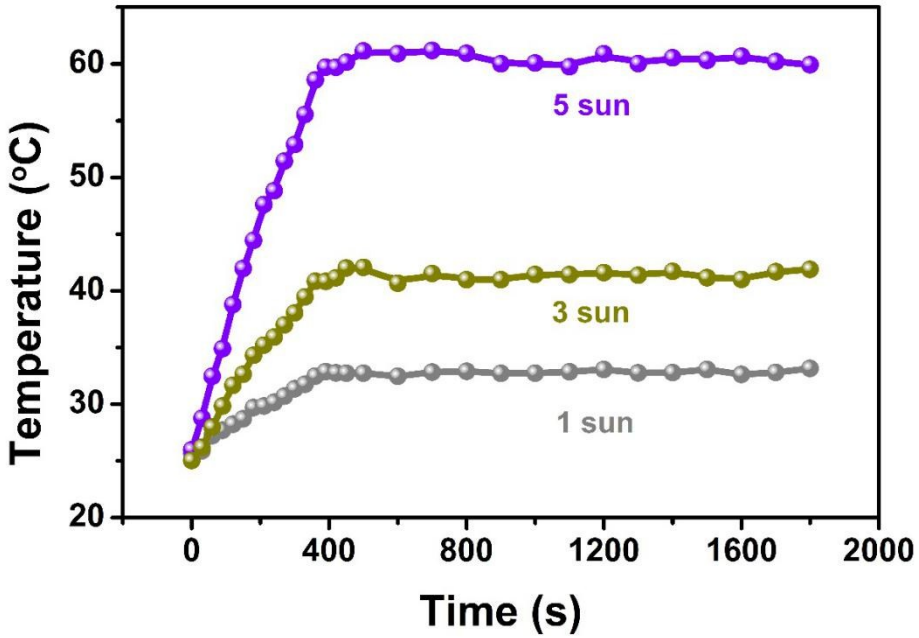

Fig. S12 The change of surface temperature of PAN-1 with time under different solar irradiation density.

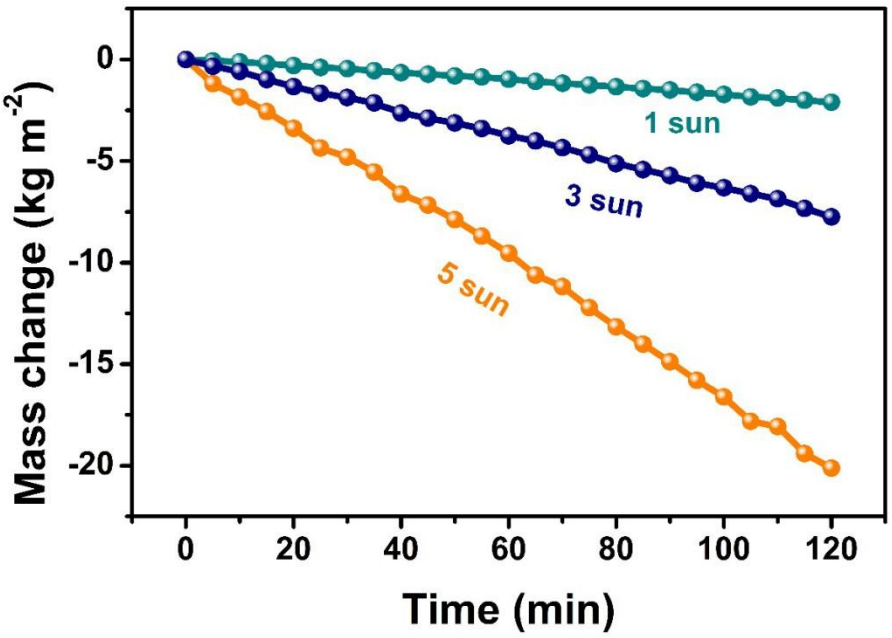

Fig. S13 The mass loss of water for PAN-2 over time at various solar irradiation density.

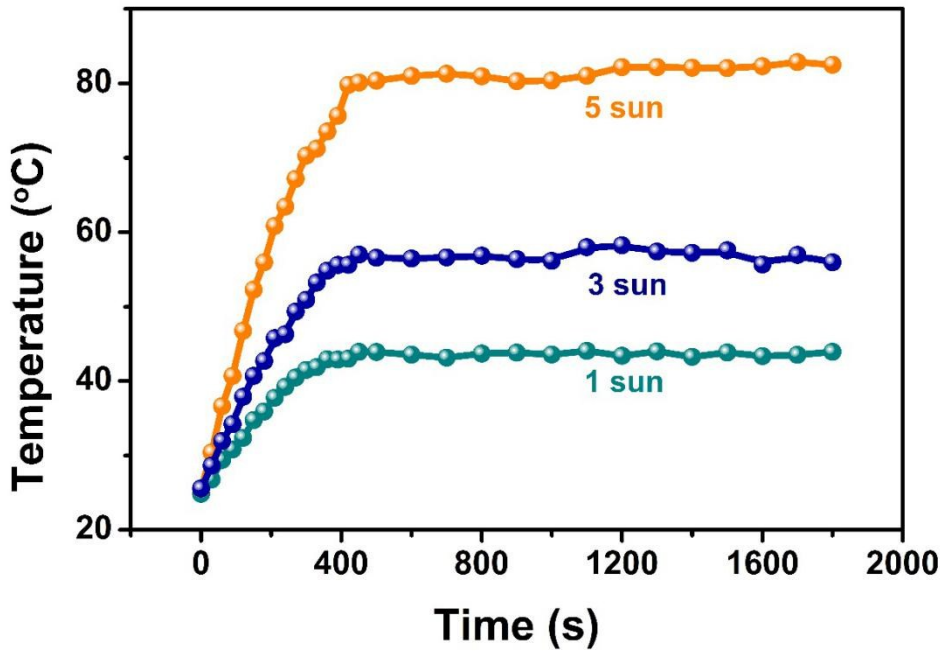

Fig. S14 The change of surface temperature of PAN-2 with time under different solar irradiation density.

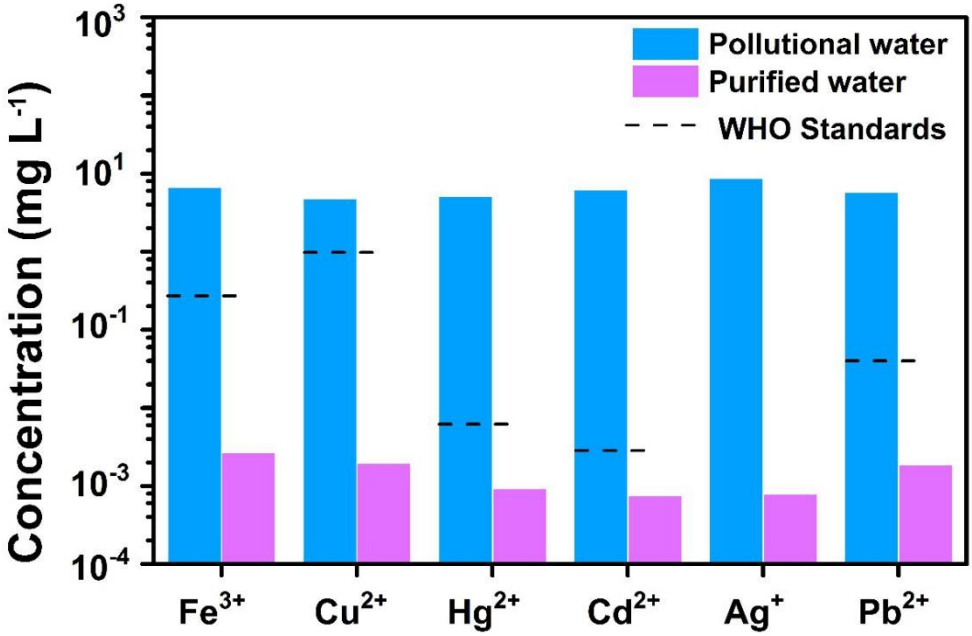

Fig. S15 Evaluated the performance pollution water purification by measuring the heavy ions before and after solar water purification.

Table S2. Evaporation rate of recently reported solar steam generation materials measured under 1 sun irradiation.

Materials	Evaporation rate ($kg\ m^{-2}\ h^{-1}$)	Efficiency (%)	Reference
PAN	**2.7**	**79.3**	**This work**
Ti_3C_2MXene membrane	1.31	*71*	*J. Mater. Chem. A,* **2018***,* 6, 16196–16204
Wood	0.8	75.1	*Energy Environ Sci.* **2019**, 12, 1558-1567
Three-dimensional MXene	1.41	88.7	*J. Mater. Chem. A,* **2019,** 7, 10446–10455
Mushroom	1.475	78	*Adv. Mater.* **2017**, 29, 1606762
PPy-coated SS mesh	0.92	58	*Adv. Mater.* **2015**, 27, 4889-4894
Carbon Sponges	1.39	90	*Adv. Energy Mater.* **2018**, 8, 1702149.
Ag/diatomite&filter paper	1.39	92.2	*J. Mater. Chem. A,* **2017**, 5, 17817-17821.
PVA–PPy-Chitosan	3.6	92	*Sci. Adv.* **2019**, 5, eaaw5484
CNT/CNC sponges	1.35	87.4	*Adv. Energy Mater.* **2019**, 9, 1900250
Graphene Oxide-Based Aerogels	1.395	83	*Adv. Mater.* **2017**, 29, 1604031
Ti_2O_3 nanoparticles	1.3	92	*Adv. Mater.* **2017**, 29, 1603730

MoS_2 hybrid film	1.1	91.5	*Adv. Funct. Mater.* **2018**, 28, 1704505
Graphene/CE membrane	1.62	86.5	*ACS Nano* **2017**,11, 5087-5093
Au&CNT integrated freestanding	1.233	82	*ACS Energy Lett.*,**2018**, 3, 1165-1171.
Au/silica aerogel	1.356	85	*Adv. Energy Mater.,* **2018,** 8, 1800711.

Section 5. References.

1 X. Ye, C. Zheng, J. Chen, Y. Gao, and C. B. Murray, *Nano Lett.*, 2013, **13,** 765.