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small methods

Supporting Information

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Architecting a Floatable, Durable, and Scalable Steam Generator: Hydrophobic/Hydrophilic Bifunctional Structure for Solar Evaporation Enhancement

*Tingting Gao, Yiju Li, Chaoji Chen, Zhi Yang, Yudi Kuang, Chao Jia, Jianwei Song, Emily M. Hitz, Boyang Liu, Hao Huang, Jianyong Yu, Bao Yang, and Liangbing Hu**

SUPPLEMENTARY INFORMATION

Architecting a Floatable, Durable and Scalable Steam Generator:

Hydrophobic/Hydrophilic Bifunctional Structure for Solar Evaporation Enhancement

Tingting Gao[1, 2a], Yiju Li[1a], Chaoji Chen[1], Zhi Yang[3], Yudi Kuang[1], Chao Jia[1], Jianwei Song[1], Emily M. Hitz[1], Boyang Liu[1], Hao Huang[3], Jianyong Yu[2], Bao Yang[3], Liangbing Hu[1]*

1 Department of Materials Science and Engineering, University of Maryland, College Park, Maryland, 20742, USA
2 Key Laboratory of Textile Science & Technology, Ministry of Education, College of Textiles, Donghua University, Shanghai 201620, P. R. China
3 Department of Mechanical Engineering, University of Maryland, College Park, Maryland, 20742, USA

* Email: binghu@umd.edu
a These authors contributed equally to this work.

Methods

Preparation of PVDF nanofiber layer

PVDF $(C_2H_2F_2)_n$, (average MW = 534,000 g mol^{-1}) was obtained from Sigma-Aldrich. Before use, the PVDF was first dried at 60°C for 24 h in a vacuum oven. Then the PVDF solution (15% w/v) was prepared by adding 3.2 g of dried PVDF powder to a 20 mL mixed solution of dimethylformamide and acetone (DMF:acetone = 2:3 by weight). The mixture was gently stirred at 40°C for about 6 hours until getting a transparent polymer solution. A plastic syringe with metal needle (20 gauge) was used as a reservoir. The PVDF solution was extruded at a flow rate of 0.8 mL h^{-1} controlled by a syringe pump, a high voltage of 15 kV applied by a high voltage power supply, and a distance of 15 cm between the needle tip and collector. The obtained PVDF nanofiber film was vacuum-dried overnight at 60°C. Afterward the dried PVDF nanofiber film was cured in a hot air oven at 105°C for about 6 hours.

Preparation of all-fiber structure evaporator

The all-fiber structure evaporator was obtained by electrospinning the CB/PAN nanofiber layer on a holey, thermal insulating PVDF substrate. A 20 mm diameter circular PVDF insulating layer was prepared by punching a PVDF nanofiber sheet using a round hollow punching tool. Seven water transport passages were obtained by perforating the PVDF nanofiber disc with a circular hollow punch having a diameter of 0.5 mm. The space between two water transport holes was about 5 mm. When completed, the holey PVDF thermal insulating substrate with water transport passages was affixed to aluminum foil. The CB/PAN layer was subsequently electrospun on a holey PVDF thermal insulating layer. Specifically, the PAN $(C_3H_3N)_X$, (average MW=15000 g mol^{-1}, Sigma-Aldrich) and CB powders were first dried at 60°C for 12 hours in a

vacuum oven. The dried CB powder was immersed in a 9.2 g mL^{-1} DMF solution and then sonicated for 10 hours in a bath-type sonicator. The CB/PAN dispersion with polymer 8wt.% was prepared by adding 0.8 g PAN powders in CB-dispersed DMF solution with a different specific amount of CB ranging from 0.09 to 0.55 g. This CB/PAN polymer solution was used for electrospinning. The CB/PAN nanofiber up-layer was successfully obtained by attaching it to the holey PVDF thermal insulating substrate covering on the aluminum foil, with a supplied high voltage of 15 kV, 15 cm tip to metal collector, and a flow rate of 1mL h^{-1}. All electrospinning process was operated at room temperature. The obtained bilayer film was vacuum-dried at 60°C for 12 hours. This fiber mat was then post-treated by hot-pressing at 105°C for 3 min on a hot plane. The round shape evaporator with the PVDF thermal insulating layer and CB/PAN black layer was finally obtained by pumping the post-treated bilayer film using the same round hollow punch.

Characterization methods

The morphologies of the all-fiber structure evaporator were characterized using a field-emission scanning electron microscope (Hitachi SU-70 FESEM) and a field-emission gun transmission electron microscope (JEM 2100 FEG TEM). The diameter distributions of fibers were investigated from SEM images via using Nano Measurer software. The Fourier-transform infrared (FTIR; Thermal Nicolet NEXUS 640) spectra were obtained from 4000 to 600 cm^{-1} at room temperature. The Raman spectra were recorded using a HORIBA Jobin Yvon Raman spectrometer with an excitation laser of 532 nm. The reflectance and transmittance spectra of the nanofiber mats were measured in the range of 250-2500 nm using a LAMBDA 35 UV/Vis spectrometer equipped with integrating sphere (PerkinElmer, USA). The wetting properties of

the CB/PAN nanofiber mats were examined using a smartphone and calculated by the CircuDyn contact angle measurement app. The thermal images and the surface temperature of the samples were captured by an IR thermal camera (FLIR Merlin MID-infrared Camera). The thermal conductivities of the samples were measured according to our previous works.[32, 40] The mechanical properties were characterized using a dynamic mechanical analyzer (DMA) under controlled conditions. Each measurement represents an average of at least three samples (20 mm length × 5 mm width × 0.125 mm thickness). The porosity of the hydrophilic CB/PAN nanofiber layer is calculated based on the increased weight (W_{H2O}) after full water adsorption (D_{H2O}: water density). The porosity of the CB/PAN nanofiber layer ($P_{CB/PAN}$) can be calculated based on the following equation (1):

$$P_{CB/PAN} = W_{H2O}/D_{H2O} \qquad (1)$$

For the porosity measurement of the hydrophobic PVDF nanofiber layer (V_{total}: total volume of PVDF nanofiber layer), we can first obtain the volume of PVDF nanofibers (V_{PVDF}) according to the weight (W_{PVDF}) and density (D_{PVDF}) of PVDF according to equation (2). Then, the porosity of the PVDF nanofiber layer (P_{PVDF}) can be calculated based on the following equation (3):

$$V_{PVDF} = W_{PVDF}/ D_{PVDF} \qquad (2)$$

$$P_{PVDF} = 100\% \times (V_{total} - V_{PVDF})/ V_{total} \qquad (3)$$

Solar steam generation experiment

The solar-steam-generation performance was measured using a custom optical measurement system comprising a solar simulator (Newport Oriel 69907) equipped with optical components (Newport Oriel 67005). The intensity of solar irradiation was adjusted using the Thorlabs PM100D power meter and controlled at 1 kW m^{-2}. The samples were placed on an electronic

calibrated electronic balance (Citizen CX301, accuracy: 0.1 mg) within a quartz container to real-time record the weight loss of water, which was used for calculating the steam generation rates. A thermocouple (Omega HH74K) was used to measure the surface temperatures of the samples under 1-sun illumination. The room temperature was ~20°C and the ambient relative humidity was ~30%. The surface temperature distribution of the samples was measured using an infrared thermal camera (FLIR Merlin MID Infrared Camera).

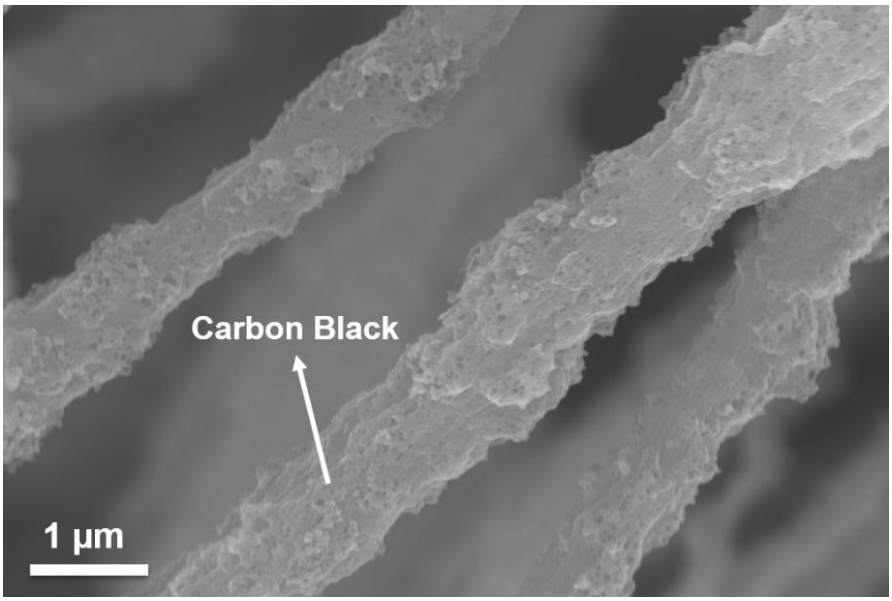

Figure S1. SEM image of the CB/PAN composite nanofibers. The CB nanoparticles are embedded in the PAN nanofibers.

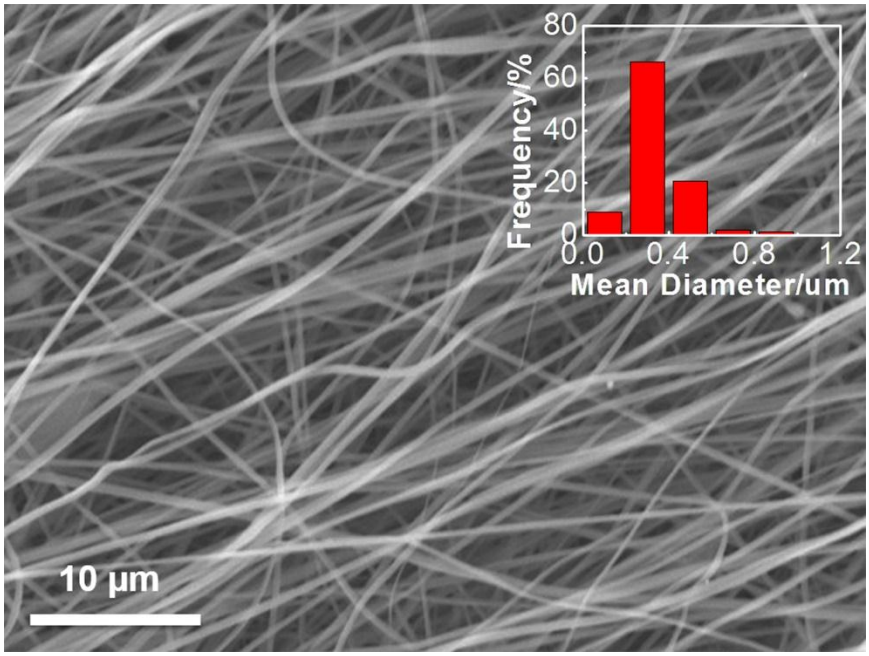

Figure S2. SEM image of the pure PAN nanofibers. The diameter size of the PAN nanofibers is mainly distributed at ~300 nm.

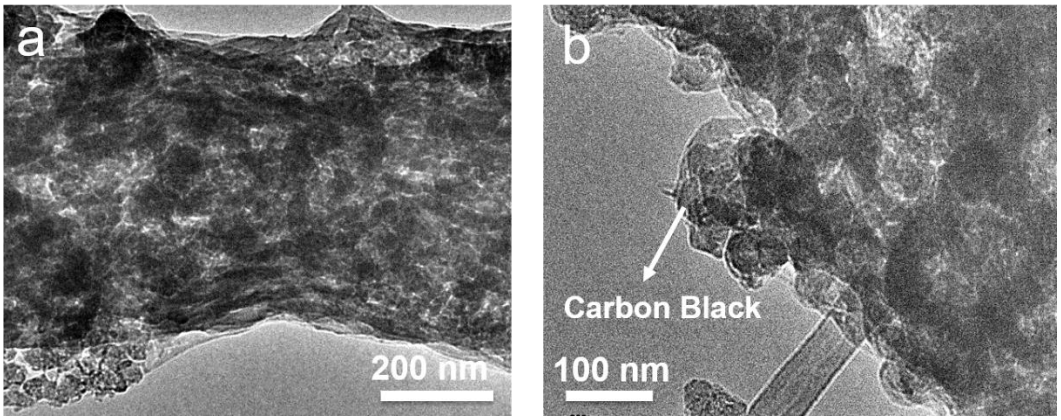

Figure S3. TEM images of the CB/PAN composite nanofibers. The CB nanoparticles are uniformly dispersed in the PAN nanofibers.

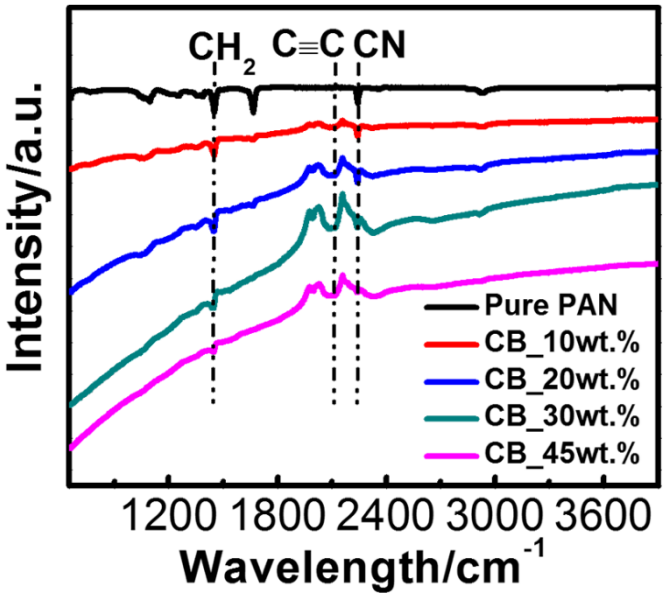

Figure S4. FTIR spectra of the CB/PAN composite nanofibers with various CB contents.

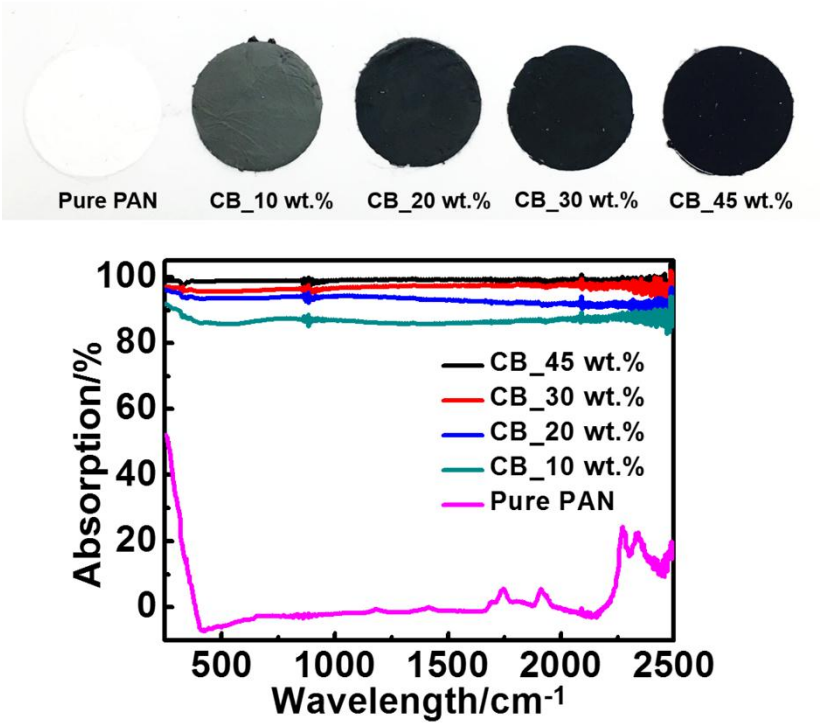

Figure S5. The absorption curves of the CB/PAN nanofiber layers with various CB contents.

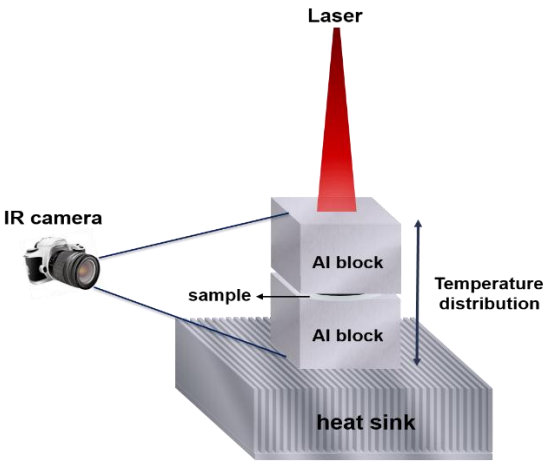

Figure S6. Schematic of the set-up of the thermal conductivity measurement.

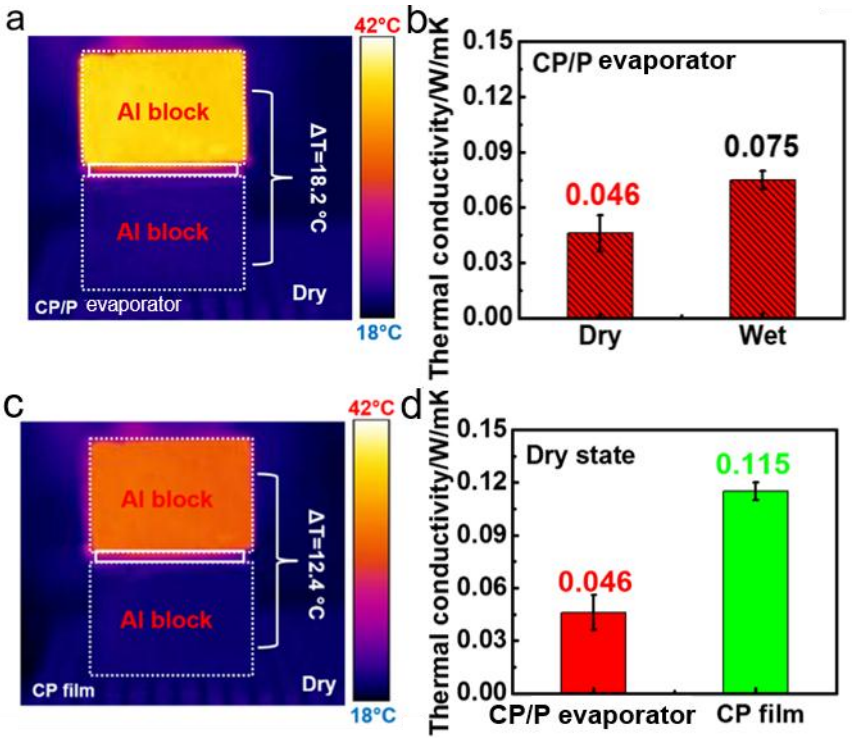

Figure S7. (a) Temperature measurement of the dry CP/P evaporator. (b) Thermal conductivity of the CP/P evaporator under dry and wet conditions. (c) Temperature measurement of the dry CP film. (d) Comparison of thermal conductivity of the pure CP and CP/P films in the dry state.

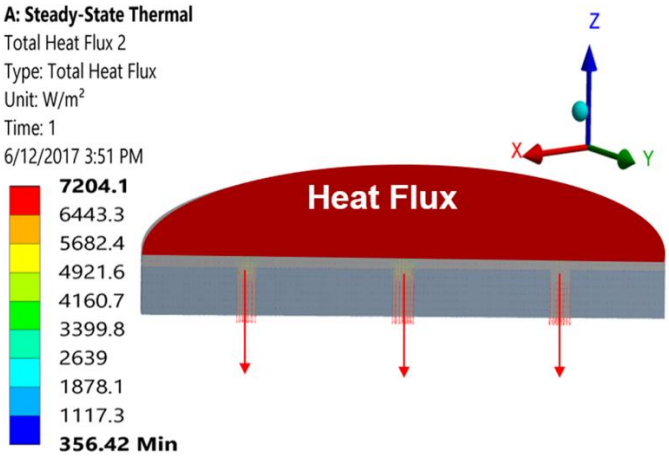

Figure S8. Heat flux distribution in the CP/P evaporator.

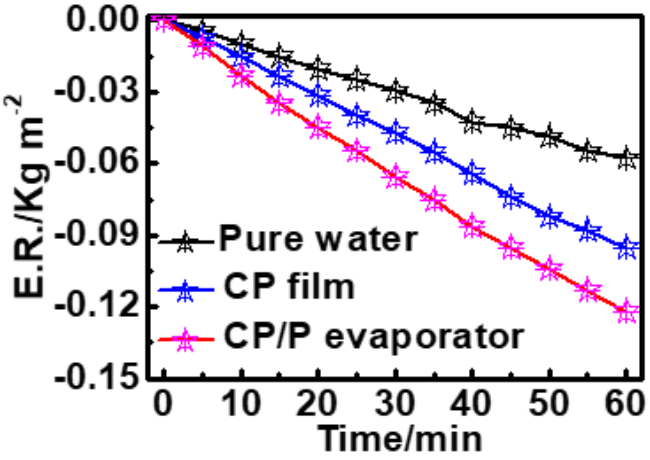

Figure S9. Cumulative weight change of the pure water, CP film and CP/P evaporator under dark field versus time.

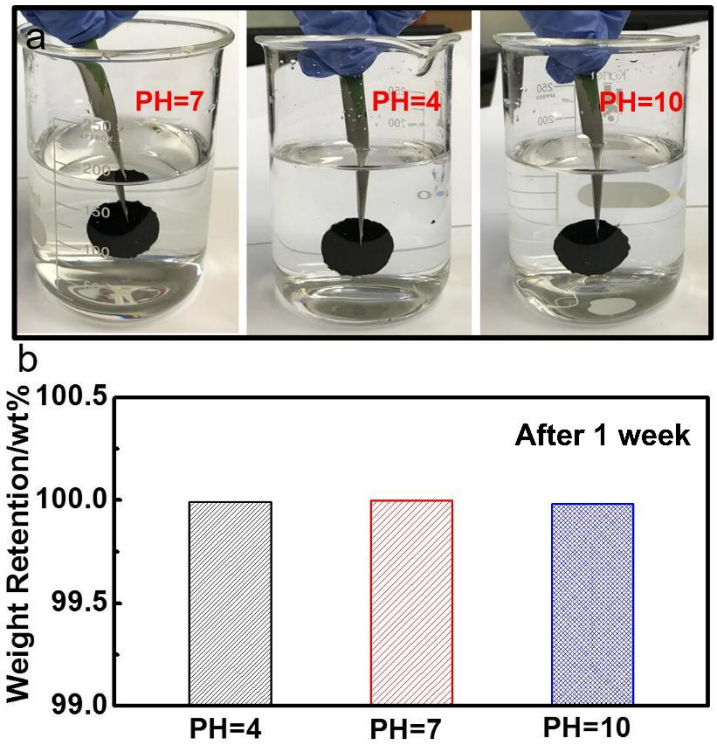

Figure S10. Acid and base durability measurement of the CP/P evaporator. (a) Photo images show the CP/P evaporator immersed in neutral, acid and alkaline solution for 1 week. (b) Weight retention of the CP/P evaporator after soaking in neutral, acid and alkaline solution for 1 week.