Three dimensional arched solar evaporator based on hydrophilic photothermal fibers inspired by hair for eliminating salt accumulation with desalination application

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Characterization

The UV-Vis-NIR absorption spectrum of hair and oxidized carbon fiber were recorded by HITACHI U-4100 ultraviolet/visible/near infrared spectrophotometer. The scanning electron microscope (SEM, EM-30 plus) was used to observe the morphology of materials. The contact angle of material was observed by a contact angle measuring instrument (DSA 100S). Functional groups and chemical bonds were determined by Fourier transform infrared (FTIR, Spectrum 400) analysis and X-ray photoelectron spectroscopy (XPS, Thermo Scientific). Infrared thermal imager (TESTO-869) was used to record the change of temperature.

Water evaporation performance test

The water evaporation experiments were conducted at a temperature of 25.0 °C and humidity of 29% to evaluate the solar evaporation rate and salt-rejection properties of the solar evaporator. The evaporator is put in a plastic box filled with water. The sunlight, generated by a solar simulator with an optical filter for the standard AM 1.5 G spectrum (CEL-S500), irradiated at the sample under specific optical concentrations. The weight loss of water was measurement by an electronic mass balance and the temperature over the process was recorded by an IR thermal camera. The energy conversion efficiency was determined according to previous methods.

Desalination of seawater

Collected real seawater samples from the Yellow Sea in China for desalination. Inductively coupled plasma spectrometer (ICP-OES, Avio™ 200) was used to determine the concentration of four main ions (Na^+, Mg^{2+}, Ca^{2+}, K^+) that originally existed in seawater before and after desalination.

Calculation of the efficiency for solar to vapor generation

The conversion efficiency η of solar energy in photothermal assisted water evaporation was calculated as the following formula. [S1]

$$\eta = \frac{\dot{m} h_{LV}}{C_{opt} P_0}$$

Where $\dot{m}$ refers to the mass flux (The shadow area of the arched evaporator was used for calculation evaporation rate) of water, h_{LV} refers to the total liquid vapor phase-change enthalpy (i.e., the sensible heat and the enthalpy of vaporization (i.e., $h_{LV} = Q + \Delta h_{vap}$)), Q is the energy provided to heat the system from the initial temperature to a final temperature, Δh_{vap} is the latent heat of vaporization of water P_0 is the nominal solar irradiation value of 1 kW m^{-2}, and C_{opt} represents the optical concentration. The schematic for the vaporization enthalpy of the vapor was as follows.

$$Q = C_{liquid} \times (T - T_0)$$

$$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2$$

$$Q_1 = C_{liquid} \times (100 - T)$$

$$Q_2 = C_{vapor} \times (T - 100)$$

In this paper, C_{liquid}, the specific heat capacity of liquid water is a constant of 4.18 (g °C)$^{-1}$. C_{vapor}, the specific heat capacity of water vaper is a constant of 1.865 J (g °C)$^{-1}$. Δh_{100} is the latent heat of vaporization of water at 100 °C, taken to be 2260 kJ kg^{-1}.

For example, the surface temperature of oxidized carbon fiber was 36 °C during the evaporation process, therefore T is 36 °C. As the above fomulas,

$$Q = C_{liquid} \times (T - T_0) = 4.18 \times (36 - 21.7) = 59.774\ kJ\ kg^{-1}$$

$$\Delta h_{vap} = Q_1 + \Delta h_{100} + Q_2 = 4.18 \times (100 - 36) + 2260 + 1.865 \times (36 - 100)$$
$$= 2408.16\ kJ\ kg^{-1}$$

$$h_{LV} = Q + \Delta h_{vap} = 59.774 + 2408.16 = 2467.934\ kJ\ kg^{-1}$$

$$\dot{m} = 1.38122\ kg\ m^{-2}\ h^{-1}$$

$$P_0 = 1\ kW\ m^{-2}$$

$$C_{opt} = 1$$

As a result, evaporation efficiency $\eta = \dot{m}h_{LV}/C_{opt}P_0 = 94.69\%$.

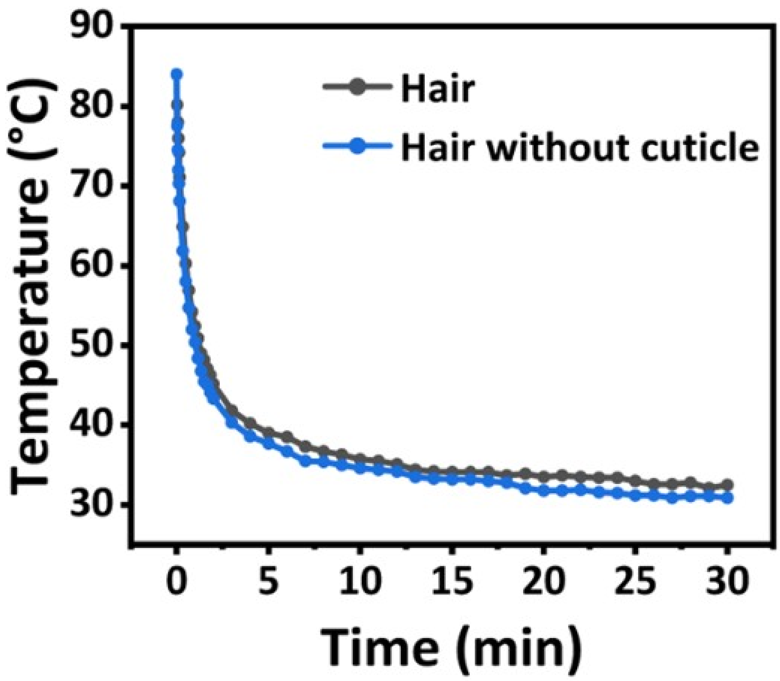

Figure S1. Photothermal behavior of black hair and black hair without cuticle.

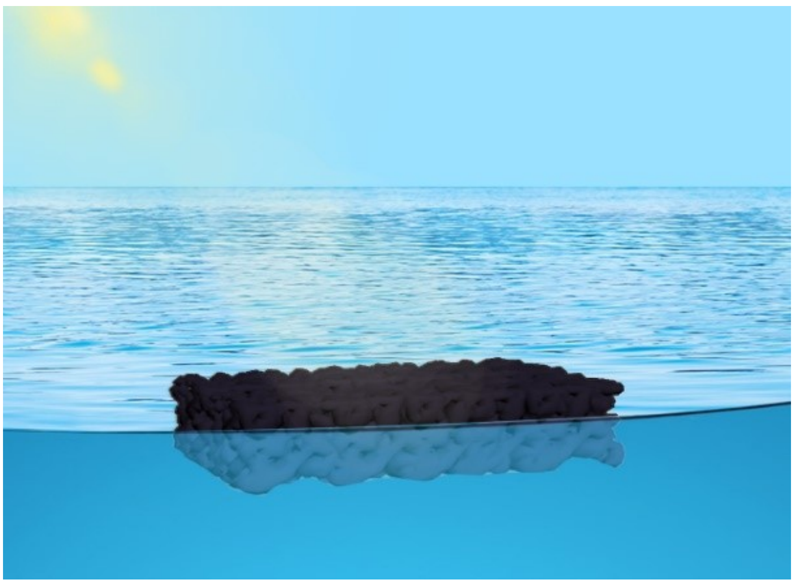

Figure S2. The diagram of the generic planar film exposed to water.

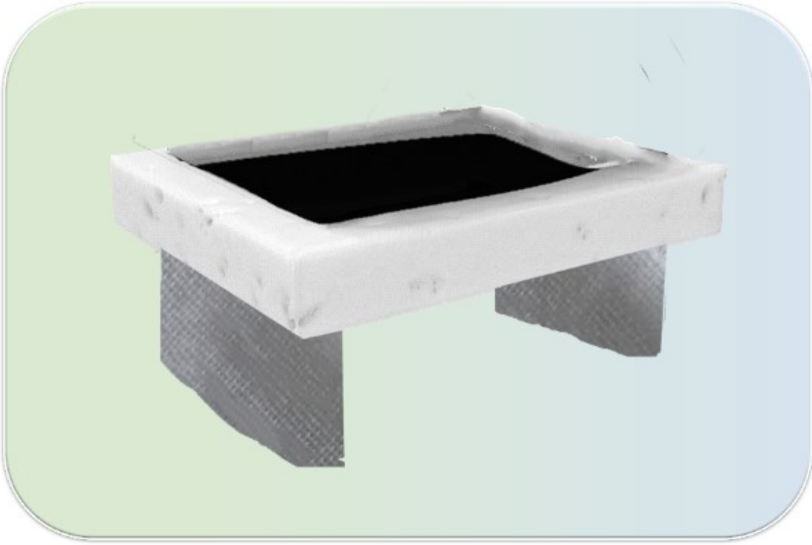

Figure S3. The diagram of black hair based planar evaporation device

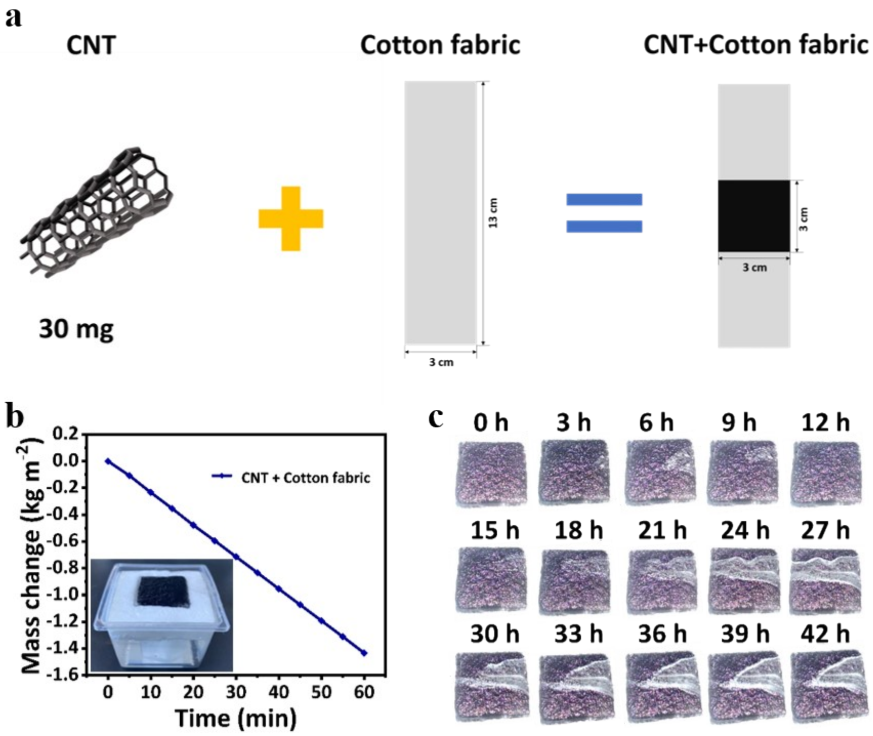

Figure S4. (a) Schematic illustration of the carbon nanotube (CNT) + Cotton fabric process. (b) Water evaporation curve of CNT + Cotton fabric under simulated sunlight with an intensity of 1 kW m^{-2}. Insets show digital photos of the CNT + Cotton fabric evaporator. The amount of CNT used in preparing CNT + Cotton fabric is 30 mg. (c) Optical picture time sequences describing the long-term desalination of CNT + Cotton fabric.

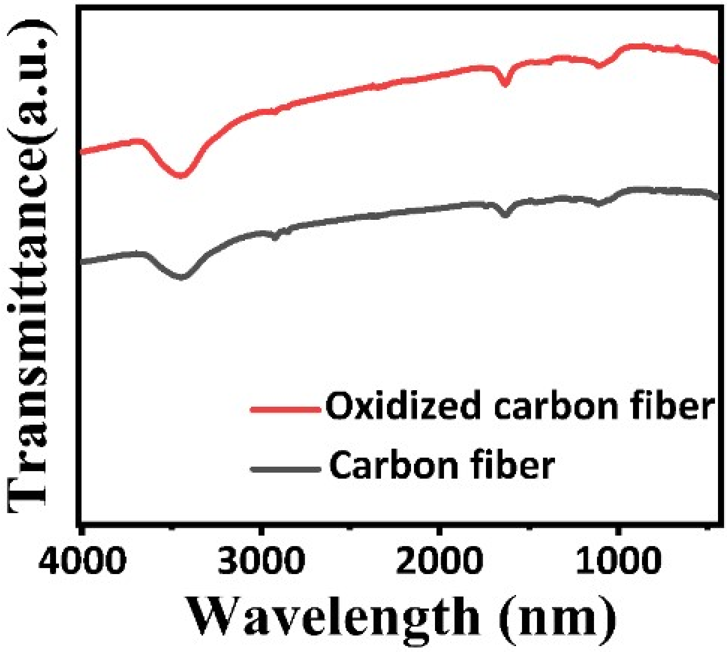

Figure S5. FT-IR spectra of carbon fiber and oxidized carbon fiber.

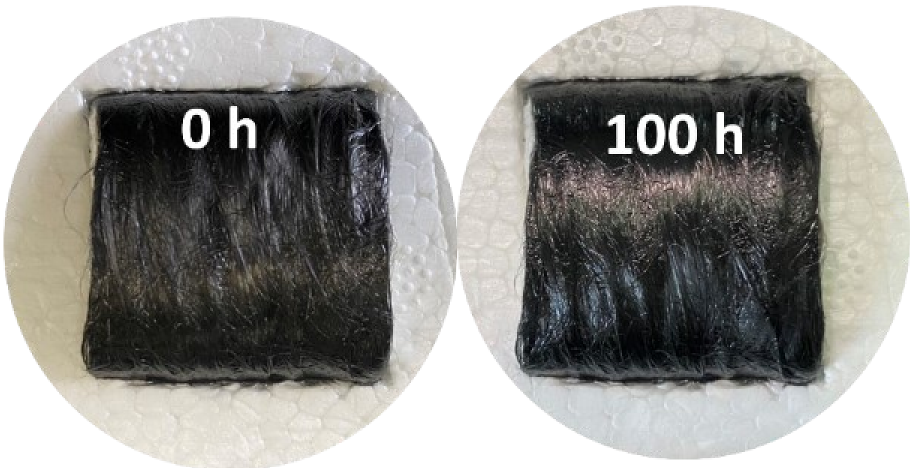

Figure S6. Digital photos of the device surface cleanliness before and after 100 h endurance measurement under 1.0 kW m^{-2} solar irradiation.

S1. G. Chen, J. Sun, Q. Peng, Q. Sun, G. Wang, Y. Cai, X. Gu, Z. Shuai and B. Z. Tang, *Adv Mater*, 2020, **32**, e1908537.