ISSN 2004-2965 Energy Proceedings, Vol. 23, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 0353

Efficient and anti-salt Cu plasmonic enhanced porous solar evaporator

Dan Xu[1,3], *Hong Zhong* [2], *Lin Lu* [1*]

1 Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong 999077, P. R. China

Email: vivien.lu@polyu.edu.hk

2 College of Electronic and Information Engineering, Shenzhen University, Shenzhen 518000, P. R. China.

3 Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, P. R. China

ABSTRACT

Recently, solar steam generation as an efficient way of solar harvesting shows great potential in solving the fresh-water shortage issue, due to it is zero carbon emission and high photothermal utilization. However, the drawbacks caused by salt accumulation on the evaporator surface would severely lower the efficiency and lifetime of the whole evaporation system. This research attempted to fabricate a facile and reliable evaporator by firstly introducing a plasmonic enhanced porous solar evaporator membrane via a one-step laser scribing method. The Cu nanoparticles scaled in multiple sizes would be cladded with the graphene and deposited onto the membrane surface. This novel evaporator obtains a high solar spectrum absorption of more than 98 %, which results in a high surface temperature of more than 80 ℃ under 1 sun irradiation. Meanwhile, the fabricated solar-driven membrane can achieve a high evaporation rate of 2.29 kg/m^2.h, besides it exhibits a high efficiency of 1.82 kg/m^2.h and long-term stability in a highly concentrated brine of 20 wt% NaCl.

Keywords: freshwater generation, anti-slat, solar driven, plasmonic enhanced

NONMENCLATURE

Abbreviations	
APEN	Applied Energy
Symbols	
n	Year

1. INTRODUCTION

Fresh water scarcity is a vital threat to sustainable development of the whole society, which is worsening along the environmental pollution and rapid global population growth. It is estimated that around three billion people would face the challenges of potable water shortage before 2025[1]. Note that, this planet is abundant in seawater. However, seawater cannot be directly used due to the concentrated salinity. Based on these concerns, technologies regarding seawater purification were developed rapidly in recent years. In some countries, the fresh water separated from the ocean is not only the supplement water resource[2] .For instance, both the domestic and industrial water are totally from the seawater desalination in Katar and Kuwait[3-5]. Moreover, the desalination technologies have been driven to be important pathways in more and more nearshore areas and coastal communities, due to the impacts from climatic variability and intensification of human activities[6, 7].

Traditional seawater desalination technologies, multi-effect distillation (MED) and multi-stage flash (MSF), have been phased out in recent years, due to the high energy consumption. With the rapid development of energy recovery equipment and membrane technologies, reverse osmosis device has been promoted and applied in the seawater desalination, and the energy consumption has been decreased by over 50%[8-10]. Nevertheless, the water desalination process still requires intensive energy. After estimation, producing 1000 m^3 per day of freshwater should expend 10000 tons of oil per year[11, 12]. Solar steam generation has been reported as a novel technology with great potential applied in seawater purification. It directly evaporates seawater to produce fresh water via sunlight based on highly efficient photothermal

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

materials. Recently, numerous investigations have focused on enhancing the photothermal conversion efficiency and evaporation rate. Chen et. al.[13] fabricated a interfacial solar driven steam generator using polypyrrole (PPy) and hydrophilic open-cell melamine foam (MF),with an evaporation rate of 2 kg/m^2 h. To enhance the light absorption and improve the efficiency of light-thermal conversion, other functional materials have been investigated. Graphene has touched many researchers' interest due to its special electronic and optical performance. Meng et. al.[14] developed a hollow melamine foam/reduced graphene oxide composite solar steam generator which exhibited a water evaporation of 1.476 kg/m^2 h under 1 solar irradiation. It is worth noticing the traditional methods to fabricate graphene are commonly complicated and expensive. Laser direct writing method from portable carbon precursors to fabricate graphene is a potential approach to promote and expand the graphene application in different fields, like super-capacity, electrocatalysts, photothermal sterilization and wearable devices[15-19].

Solar driven evaporation devices still suffer the issues of low salt resistance and poor stability. Pioneer work indicated that the porous surface and water pathway can efficiently decrease the salt aggregation during the evaporation process[20-22]. In this research, a highly efficient and anti-salt solar evaporator based on composites of laser induced graphene (LIG) and Cu plasmonic has been facilely developed. This portable device exhibits an excellent evaporation rate of 2.29 kg/m^2 h under 1 solar irradiation. And it also exhibits desirable stability in a concentrated slat solution (20 wt% NaCl), due to the micro-pathway inside the device.

2. MATERIAL AND METHODS

Polyimide (PI) films in 50 μm thickness were purchased from Suzhou Kunleng Film Industries Co. Ltd in Mainland of China. The non-woven fabrics as the substrate of the evaporation system is from San Heng Yi Shu Non-Woven Products Limited Company in China. The Cu layer was deposited on the PI surface through Denton Explorer 14 Sputtering System. And the PI/Cu film was scribed with DMG Lasertec40 in the CW mode. The energy of the laser in the pretreatment was 5.5w in a writing speed of 400mm/s, and the energy of the laser in the postprocessing was 0.3W at a scribing speed of 800mm/s. Finally, the graphene cladding with Cu nanoparticles would be transferred onto the surface of non-woven fabrics. The morphology of composited nanoparticles was observed by the field emission scanning electron microscope (FESEM, Tescan MAIA3). A scanning electron microscope (SEM) of Tscan VEGA3 was used to observe the structure of the novel plasmonic enhanced evaporator membrane. And the particle size distribution was analyzed through field emission electron microscope (STEM) of JEOL Model JEM-2100F. The crystal structure of the sample was recorded by X-ray diffraction (XRD) of Rigaku SmartLab. And the Raman Spectra of the sample was measured by the WITEC Confocal Raman System. The optical performance of the samples was measured with the UV-VIS-NIR spectrophotometer of Hitachi UH4150, and the surface temperature of the novel porous evaporator membrane was investigated by the infrared thermal imaging camera and solar radiation simulator which are purchased from Fluke and Honle, respectively. The water contact angle was observed and calculated through Sindatek 100SB optical contact angle meter by using a sessile drop method.

The evaporation efficiency was investigated in a homemade solar radiation system. Solar spectrum was simulated using a solar lamp (WXS-50S-1.5, AM1.5G), which is purchased from WACOM ELECTRIC Co., LTD. The porous evaporator membrane was suspended on the water surface in a beaker with an exposed area of 5 cm^2. And the beaker was placed on an electronic balance with data connection to computer. To calculate the evaporation efficiency of the novel porous evaporator membrane, the weight loss of water under dark field would be detracted which was measured in real-time.

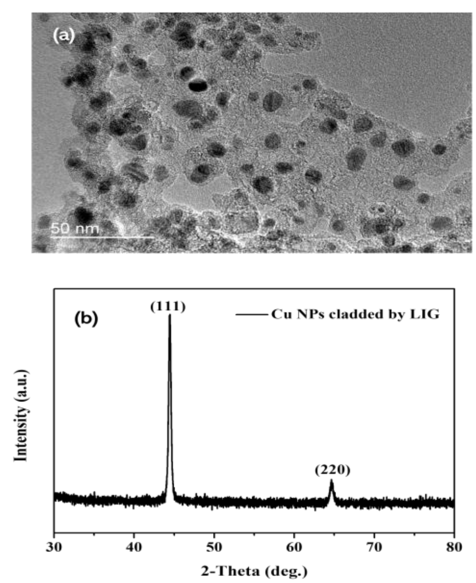

Fig. 1. TEM image of Cu nanoparticles cladded by laser indueced graphene (a); XRD pattern of the Cu nanoparticles cladded by laser induced graphene

3. RESULTS AND DISCUSSION

The Cu layer was deposited on the surface of PI film through a sputter system. After that, the Cu nanoparticles cladded by graphene was successfully transferred onto the surface of nano woven fabrics through a laser beam. To observe the particle size distribution, the Cu nanoparticle cladded by LIG was firstly transferred on the glass plane, and then the powder was collected and dispersed into ethanol for STEM test. Figure 1(a) shows the TEM image which revealed that the Cu nanoparticles was cladded by the graphene. The particle size is in the range of 3 nm-20 nm, and the average size is about 14 nm.

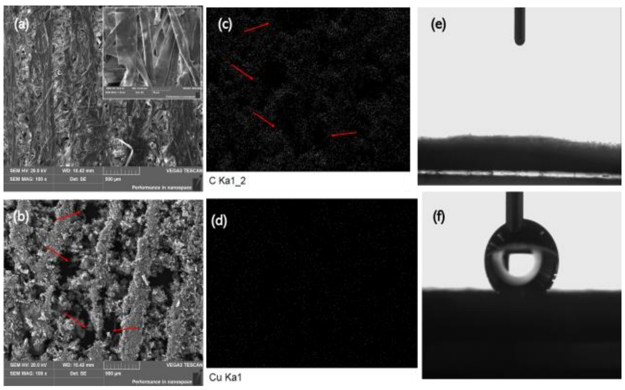

Fig. 2. SEM image of pristine non-wave fabric (a); SEM image of treated non-wave fabric (b); Mapping of treated non-wave fabric (c and d); WCA test of evaporation layer (e) and water absorption layer (f)

To ascertain the crystal structure of nanoparticles, the powder has been measured by XRD. The pattern is shown in Figure 1(b). It reveals that the degree of 43.3º and 74.2º are corresponded to the (111), and (220) planes of Cu (PDF#04-0836). Figure 2(a) shows the pristine non-wave fabric. Figure 2(b) shows the Cu nanoparticles/LIG deposit on the surface of non-wave fabric. There are a lot of micro-pores on the surface of fabric. And the size is almost 100 μm. Figure 2(c) and Figure 2(d) show the EDX mapping results of C element and Cu element. The Cu nanoparticles are uniformly distributed on the surface of non-wave fabric. Figure 2(e) and Figure 2(f) show the WCA test results of water absorption layer surface and evaporation layer surface, respectively. It also indicates the evaporation layer shows an excellent super-hydrophobic performance. While the absorption layer exhibits an outstanding super-hydrophilic performance. Figure 3(a) shows the light absorption of the treated fabric. To investigate the effect of the Cu nanoparticles on the light absorption, different thicknesses of Cu layers on the PI have been prepared for fabricating the generator. After calculation, the device exhibits a highly light absorption of more than 98% when the thickness is more than 50 nm. The light-thermal conversion test (Figure 3b and Figure 3c) shows the same result that the highest temperature of 87.83℃after 1min was obtained from Cu layer in 50 nm and 100 nm thickness. Figure 3(e) shows the water evaporation test. The generator prepared by 50 nm of Cu layer and 100 nm of Cu layer exhibit almost same evaporation rate of 2.29 kg/m^{2}h. Figure 3(f) shows the saltwater desalination result, the generator prepared by the Cu layer in thickness of 50 nm exhibits an excellent stability, and the evaporation rate on the salt water still reach to 1.82 kg/m^2 h.

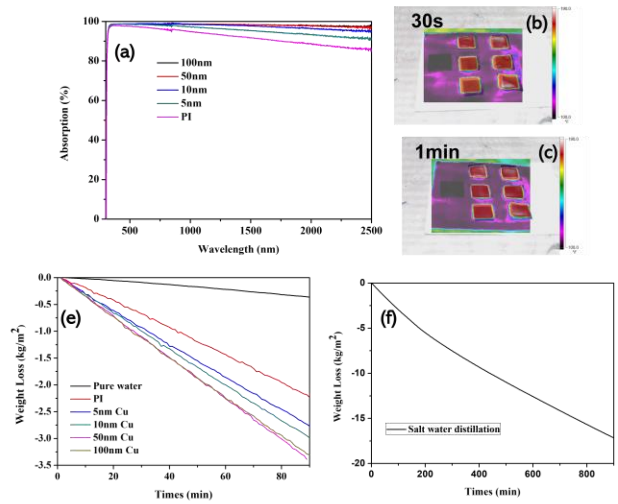

Fig. 3. Light absorption of generator (a); Light-thermal conversion test (b) (c); water evaporation test (e) and saltwater desalination (f)

4. CONCLUSIONS

This research successfully fabricated a Cu plasmonic enhanced solar steam generator through only one-step method. This device shows a high solar driven evaporation rate. And it also exhibits an outstanding performance in saltwater evaporation, which displays great potential to solve the freshwater issue in the future. The fabrication process is eco-friendly which can be for large-scale application.

ACKNOWLEDGEMENT

We acknowledge the support of the State Key Laboratory of Ultra-precision Machining Technology and Advanced Manufacturing Technology Research Centre (The Hong Kong Polytechnic University)

REFERENCE

[1] S.-L. Wu, H. Chen, H.-L. Wang, X. Chen, H.-C. Yang, and S. B. Darling, "Solar-driven evaporators for water treatment: challenges

and opportunities," *Environmental Science: Water Research & Technology,* vol. 7, no. 1, pp. 24-39, 2021.

[2] I. Ibrahim, V. Bhoopal, D. H. Seo, M. Afsari, H. K. Shon, and L. D. Tijing, "Biomass-based photothermal materials for interfacial solar steam generation: a review," *Materials Today Energy,* vol. 21, 2021.

[3] V.-D. Dao, N. H. Vu, and S. Yun, "Recent advances and challenges for solar-driven water evaporation system toward applications," *Nano Energy,* vol. 68, 2020.

[4] H. Li, H. Wen, J. Li, J. Huang, D. Wang, and B. Z. Tang, "Doping AIE Photothermal Molecule into All-Fiber Aerogel with Self-Pumping Water Function for Efficiency Solar Steam Generation," *ACS Appl Mater Interfaces,* vol. 12, no. 23, pp. 26033-26040, Jun 10 2020.

[5] X. Dong, Y. Si, C. Chen, B. Ding, and H. Deng, "Reed Leaves Inspired Silica Nanofibrous Aerogels with Parallel-Arranged Vessels for Salt-Resistant Solar Desalination," *ACS Nano,* Jun 21 2021.

[6] Y. Shi, O. Ilic, H. A. Atwater, and J. R. Greer, "All-day fresh water harvesting by microstructured hydrogel membranes," *Nat Commun,* vol. 12, no. 1, p. 2797, May 14 2021.

[7] Y. Lu, D. Fan, Y. Wang, H. Xu, C. Lu, and X. Yang, "Surface Patterning of Two-Dimensional Nanostructure-Embedded Photothermal Hydrogels for High-Yield Solar Steam Generation," *ACS Nano,* vol. 15, no. 6, pp. 10366-10376, Jun 22 2021.

[8] S. Zhao *et al.*, "Hydrophilicity gradient in covalent organic frameworks for membrane distillation," *Nat Mater,* Jul 22 2021.

[9] Y. Xu, J. Yin, J. Wang, and X. Wang, "Design and optimization of solar steam generation system for water purification and energy utilization: A review," *Reviews on Advanced Materials Science,* vol. 58, no. 1, pp. 226-247, 2019.

[10] Y. Wang *et al.*, "Adjustable photothermal device induced by magnetic field for efficient solar‐driven desalination," *EcoMat,* 2021.

[11] N. K. Khanzada, S. Rehman, S.-Y. Leu, and A. K. An, "Evaluation of anti-bacterial adhesion performance of polydopamine cross-linked graphene oxide RO membrane via in situ optical coherence tomography," *Desalination,* vol. 479, 2020.

[12] Y. H. Teow and A. W. Mohammad, "New generation nanomaterials for water desalination: A review," *Desalination,* vol. 451, pp. 2-17, 2019.

[13] J. Chen *et al.*, "Integrated Evaporator for Efficient Solar-Driven Interfacial Steam Generation," *Nano Lett,* vol. 20, no. 8, pp. 6051-6058, Aug 12 2020.

[14] S. Meng *et al.*, "A bridge-arched and layer-structured hollow melamine foam/reduced graphene oxide composite with an enlarged evaporation area and superior thermal insulation for high-performance solar steam generation," *Journal of Materials Chemistry A,* vol. 8, no. 5, pp. 2701-2711, 2020.

[15] H. Zhong *et al.*, "Reusable and Recyclable Graphene Masks with Outstanding Superhydrophobic and Photothermal Performances," *ACS Nano,* vol. 14, no. 5, pp. 6213-6221, May 26 2020.

[16] G. Li, "Direct laser writing of graphene electrodes," *Journal of Applied Physics,* vol. 127, no. 1, p. 010901, 2020.

[17] L. Huang, J. Su, Y. Song, and R. Ye, "Laser-Induced Graphene: En Route to Smart Sensing," *Nano-Micro Letters,* vol. 12, no. 1, 2020.

[18] H. Zhong *et al.*, "Plasmonic and Superhydrophobic Self-Decontaminating N95 Respirators," *ACS Nano,* vol. 14, no. 7, pp. 8846-8854, Jul 28 2020.

[19] D. Xu, K. C. Chan, H. Guo, H. Zhong, and L. Lu, "One-step fabrication of a laser-induced forward transfer graphene/CuxO nanocomposite-based electrocatalyst to promote hydrogen evolution reaction," *Journal of Materials Chemistry A,* vol. 9, no. 30, pp. 16470-16478, 2021.

[20] F. Nawaz, Y. Yang, S. Zhao, M. Sheng, C. Pan, and W. Que, "Innovative salt-blocking technologies of photothermal materials in solar-driven interfacial desalination," *Journal of Materials Chemistry A,* vol. 9, no. 30, pp. 16233-16254, 2021.

[21] M. Zhu *et al.*, "Plasmonic Wood for High-Efficiency Solar Steam Generation," *Advanced Energy Materials,* vol. 8, no. 4, 2018.

[22] Y. Kuang *et al.*, "A High-Performance Self-Regenerating Solar Evaporator for Continuous Water Desalination," *Adv Mater,* vol. 31, no. 23, p. e1900498, Jun 2019.