DESIGN OF BIO-INSPIRED MINIATURE BOAT AND ITS CONTROLLED MOVEMENT AT OIL/WATER INTERFACE

Ying Chu[1], and Qinmin Pan[2]

[1] School of Chemistry and Chemical Engineering, Harbin Institute of Technology, Harbin, P. R. China.
chuying@hit.edu.cn

[2] School of Chemistry and Chemical Engineering, Harbin Institute of Technology, Harbin, P. R. China.
panqm@hit.edu.cn

Keywords: Superhydrophobicity–superhydrophilicity transition, Miniature boat, Oil/water interface, Smart locomotion, Marangoni effect

ABSTRACT

Miniature aquatic device that work on water or oil surface will play a crucial role in the fields of military, environment, medicine, and so on. However, challenges remain in locomoting these devices at the interface of water and oil. In this article, we realized the movement of a "miniature boat" at variety of surfaces/interfaces (e.g., water surface, oil surface or oil/water interface) by Marangoni effect. The hull of miniature boat was fabricated by Cu mesh with superhydrophobic TiO_2 nanoparticles on its surface. The as-prepared miniature boat floated and remained motionless on the water surface. Then it was exposed to ultraviolet (UV) light, this boat dived in water and stood stably at the interface of water/$CHCl_3$. The actuator of this boat was a hollow microsphere containing ethonal. The shell of this microsphere was composed of a mixture of wax and Fe_3O_4@polydopamine nanoparticles. After the irradiation of near infrared (NIR) laser, the shell was pierced and ethonal released from this hollow microsphere. Then the miniature boat began to move due to the change of surface tension of water. Maximum speeds of the boat in forward motion at the water surface and oil/water interface were 1.0 and 0.5 cm s^{-1}, respectively. Owing to the small size, high flexibility and strong anti-interference ability of the as-prepared miniature boat, it could be widely used at small and narrow space, or even in the high temperature and pressure environment.

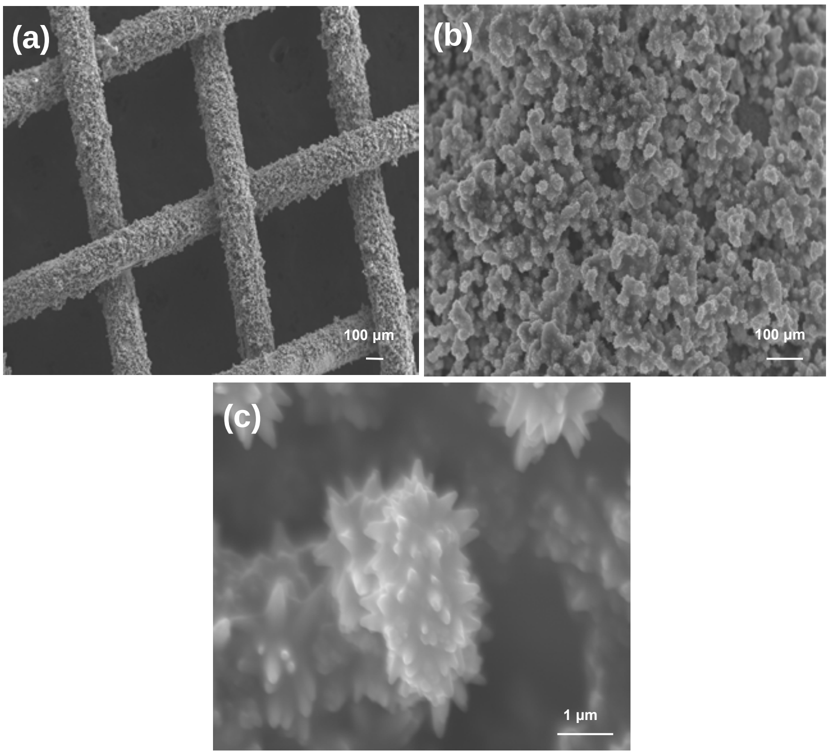

Figure 1 SEM images of the superhydrophobic copper mesh.

The morphology of superhydrophobic copper mesh was characterized by scanning electron microscope (SEM). Comparing with the original smooth copper mesh, microflowers was observed on the skeleton of superhydrophobic copper wire (Figure 1). The higher magnification of SEM image reveals that the diameter of microflower is 5-8 μm. Each microflower is built from needlelike nanorods, the diameter of the nanorod is 50 nm. These hierarchical microflowers efficiently increase the roughness of copper mesh. The energy dispersive X-ray spectroscopy (EDS) was used to analysize the composition of the as-prepared superhydrophobic copper mesh. It is shown from Figure 2 that the elements of C, O, F, Si, Ti, Cu and Zn are detected on the surface of the copper mesh. The mass fraction of each element was seen in Table 1. The presence of ZnO and TiO_2 not only play the role of a UV responsive material, but also provide the surface roughness by the aggregation of ZnO and TiO_2 nanoparticles.

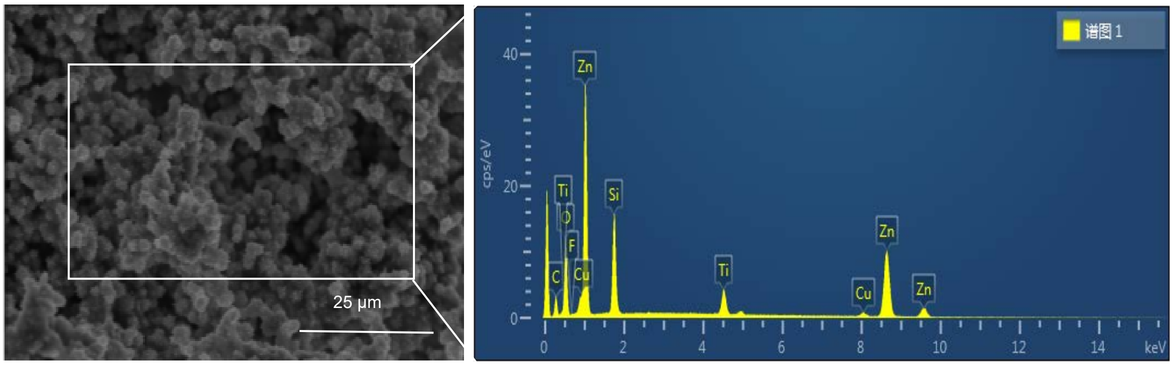

Figure 2 SEM and EDS images of the superhydrophobic copper mesh.

Surface wettability of the as-prepared copper mesh was characterized by contact angle measurement. The water contact angle (WCA) in air is 154.3 ± 1°, which demonstrating the superhydrophobicity of copper mesh (Figure 3a). After UV (254 nm, 3 W) illumination for 4 h, the WCA of this copper mesh decreased to 0 ° (Figure 3b). When this irradiated copper mesh was immersed into the water, the chloroform ($CHCl_3$) contact angle was 152.3 ± 1° (Figure 3c). The $CHCl_3$ droplet could easily roll off the surface of the irradiated copper mesh, which indicating the high oleophobicity underwater.

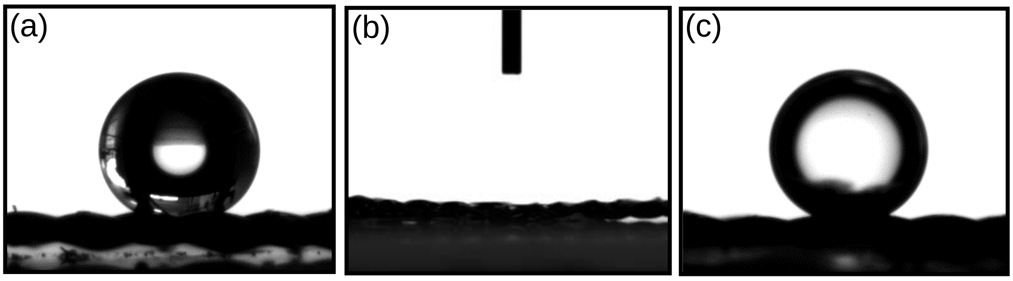

Figure 3 Water contact angle of superhydrophobic copper mesh (a) before and (b) after UV irradiation in air, (c) Contact angle of a $CHCl_3$ droplet on the copper mesh after UV irradiation for 2 h.

The microreservoir was made by using $CaCl_2$ particle as core and the mixture of Fe_3O_4@PDA nanoparticles and wax as shell. Then the $CaCl_2$ particle was dissolved to obtain a hollow spherical microreservoir with a diameter of ~0.5 cm (Figure 4a and 4b). The microscopic morphobology of the microreservoir shell was observed by SEM image. It is shown from Figure 4c that Fe_3O_4@PDA nanoparticles covered on the surface of solid wax uniformly. Owing to the photothermal property of Fe_3O_4@PDA nanoparticles[1-3], these nanoparticles, which were irradiated by NIR laser, could be considered as mini heater to heating the surrounding environment.

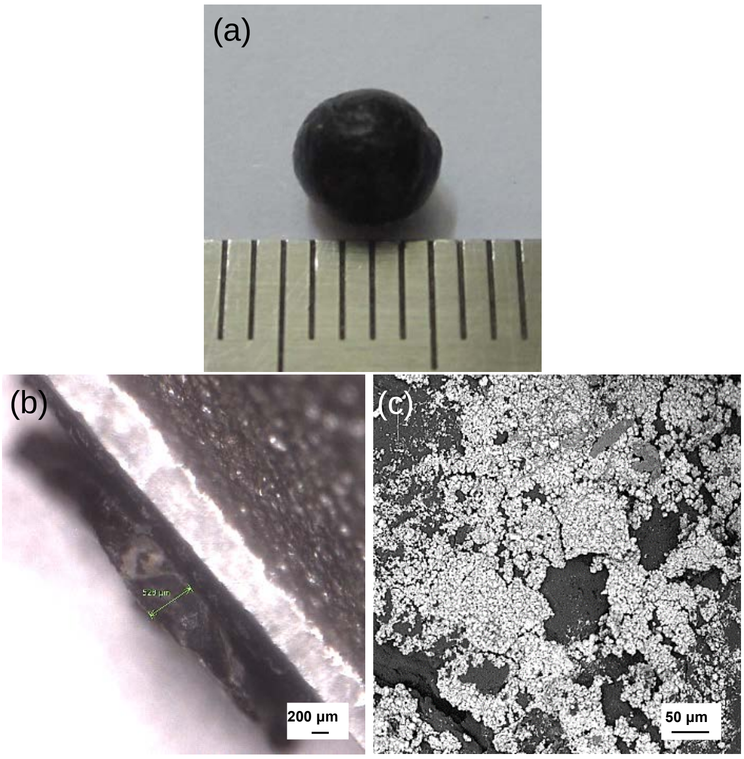

Figure 4 (a) Optical and (b-c) SEM images of microreservoir.

At last, the superhydrophobic copper mesh was folded to a rectangle boat and the microreservoir was assembled to this boat. As shown in Figure 5a, the boat first floated motionlessly on water surface. After the irradiating of microreservoir by NIR laser for 10 min, the shell of the microreservoir was punctured and ethanol released from this microreservoir immediately. Under the driving of interfacial tension gradient, the boat began to move at a speed of 1.0 cm s^{-1}. Interestingly, when the boat arrived at the border of beaker, it began to turn in another direction rather than pulling to the border. In addition, controllable movement of the as-prepared miniature boat at the water/$CHCl_3$ interface also investigated in this paper (Figure 6).

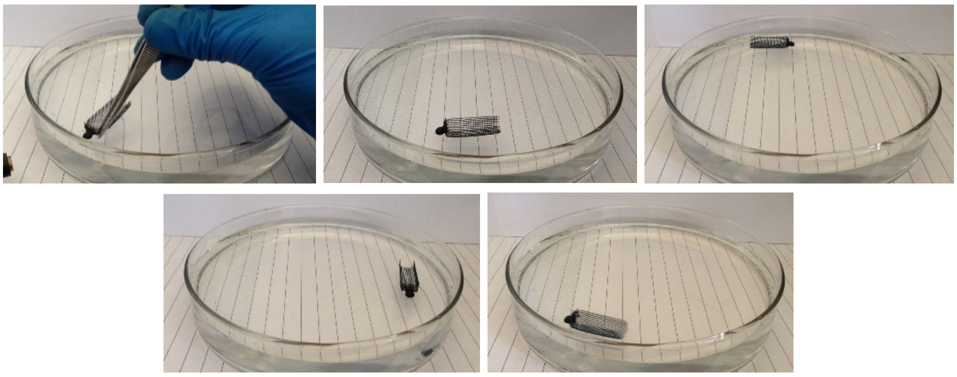

Figure 5 Optical images for the movement of superhydrophobic miniature boat on the water surface.

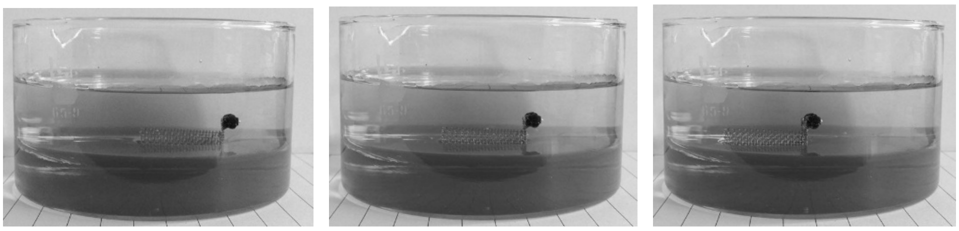

Figure 6 Optical images for the movement of miniature boat at the water/$CHCl_3$ interface.

ACKNOWLEDGEMENTS

The work was financially supported by a self-planned task of the State Key Laboratory of Robotics and Systems of the Harbin Institute of Technology (SKLRS201604C), National Natural Science Foundation of China (51473041), and the Foundation for Innovative Research Groups of the National Natural Science Foundation of China (51521003).

REFERENCES

[1] Y. Chu, F. Liu, L. Qin and Q. Pan, Remote Manipulation of a Microdroplet in Water by Near-Infrared Laser, *ACS Appl. Mater. Interfaces*, **8**, 2016, pp. 1273-1279.

[2] Y. Liu, K. Ai, J. Liu, M. Deng, Y. He and L. Lu, Dopamine-Melanin Colloidal Nanospheres: An Efficient Near-Infrared Photothermal Therapeutic Agent for in Vivo Cancer Therapy. *Adv. Mater*., **25**, 2013, pp. 1353-1359.

[3] L. Lin, Z. Cong, J. Cao, K. Ke, Q. Peng, J. Gao, H. Yang, G. Liu and X. Chen, Multifunctional Fe_3O_4@Polydopamine Core-Shell Nanocomposites for Intracellular mRNA Detection and Imaging-Guided Photothermal Therapy. *ACS Nano*, **8**, 2014, pp. 3876-3883.