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Regular Article

Stable Janus superhydrophilic/hydrophobic nickel foam for directional water transport

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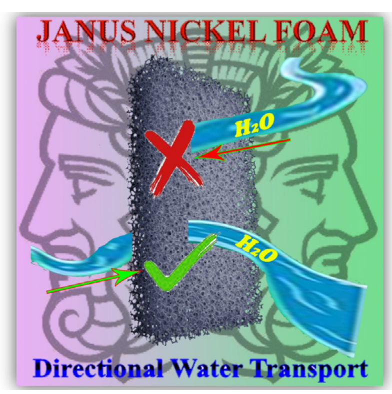
GRAPHICAL ABSTRACT

Janus superhydrophilic/hydrophobic macroporous nickel foam for directional water transport with extremely high transport rate and outstanding stability has been demonstrated via a simple floating strategy.



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ABSTRACT

Janus superhydrophilic/hydrophobic macroporous nickel foam for directional water transport has been demonstrated via a simple floating strategy. Water can transport from hydrophobic to superhydrophilic layer through Janus nickel foam, but cannot transfer from superhydrophilic to hydrophobic layer. This "3D water diode" Janus nickel foam shows extremely high transport rate and outstanding stability. After damaged by abrasion, its directional water transport property retains well.

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1. Introduction

Just as water flows down, fluid motion in vascular plant, water permeation across biological membranes and blood in veins, directional fluid transport in a single direction is widespread phenomenon no matter in nature or human body [1,2]. Gravity, mechanical pressure and chemical forces have been regarded as driving forces of directional fluid transport for a long time until Chaudhury and Whitesides proved that water drop could be driven by asymmetric surface tension in 1992 firstly [3]. Directional fluid transport driven by surface tension has deep study and application significances in many research fields, such as microfluidics manipulation, water collection, separation technology and fuel cells [4–6]. However, most of researches are still confined to 2D solid surface or 1D singer fiber [7–10]. In 2010, 3D directional fluid transport thin porous material was reported for the first time by Wang et al. [11] They demonstrated that the fabrics with gradient wettability have the ability to spontaneously transfer water unidirectionally through the fibrous architecture. This great work not only enriched research range but also opened a door to new applications.

According to different wetting properties, 3D directional fluid transport porous material can be divided into two categories: the first one is porous material with gradient wettability as mentioned before [11]. UV-irradiation is one of the main approaches to obtain gradient wettability porous material [12,13]. More recently, Janus wettability porous material with inner abrupt wettability change has been proved to directional fluid transport ability as well for the first time in 2012 [14]. Fibrous film consisted by hydrophobic polyurethane (PU) and hydrophilic crosslinked poly (vinyl alcohol) (c-PVA) fibrous layers has been reported by Wu and coworkers [14] By taking advantage of the hydrophobic-hydrophilic wettability difference, water can penetrate from the hydrophobic side, but be blocked on the hydrophilic side. Researchers vividly called this unique Janus porous material as “water diode” film. The preparation of Janus wettability porous material is more controllable than gradient wettability porous material, but the preparation method is usually limited to electrospinning technique. In fact, 3D directional fluid transport porous material has been reported in the literature rarely in recent years due to difficult fabrication. On the other hand, there are two major problems of 3D directional fluid transport porous material: short useful life caused by weak mechanical strength and low transport rate due to small pore size [15,16]. So far, 3D directional fluid transport porous materials only are achieved on woven/nonwoven fabrics, nanofiber membranes, metal meshes with 30–500 μm thickness successfully. How to structure extremely stable 3D directional fluid transport macroporous materials with high permeation rate? Can milli-scale thickness novel porous materials achieve directional fluid transport? These questions have been bothering researchers for quite long time.

To this end, Janus superhydrophilic/hydrophobic nickel foam for directional water transport has been demonstrated via a simple floating strategy. This macroporous Janus nickel foam with milli-scale thickness displays extremely high transport rate and outstanding stability. After damaged by abrasion, directional water transport property of Janus nickel foam can retain well, which can be described as “stable 3D water diode”.

2. Experimental

2.1. Materials

Potato starch was purchased from local market. Nickel foam was obtained from Liyuan New Materials Co. Ltd., Changsha, China. All other chemicals were analytical-grade reagents and used as received. Millipore water (resistivity~18 MΩ.cm) was used throughout this study.

2.2. Preparation of Janus nickel foam

At first, 4 g potato starch was dispersed in 20 mL water with stirring. After 12 min strong stirring at 80 °C, highly viscous white starch paste was obtained. Then, 10 ml ethanol was added into starch paste system with stirring and the fluidity was restored again. After ultrasonicated for 30 min at room temperature of starch paste ethanol dispersion, clear nickel foam (3 cm ∗ 3 cm) was placed on the surface of starch paste ethanol dispersion with slight stirring. Nickel foam can float on the surface and its bottom was wetted. After 30 s, the nickel foam was take out and was dried in 60 °C in air condition for 15 min. This float process needs to be repeated three times. Then, the Janus nickel foam was obtained.

2.3. Characterization

Field emission scanning electron microscope (FESEM) images were obtained on JSM-6701F, both with Au-sputtered specimens. TGA and DTA measurements were done with NETZSCH STA 449 C using a dynamic heating rate of 10 °C min^{-1}. Fourier transformer infrared spectra (FTIR) spectroscopy was recorded using Thermo Scientific Nicolet iS10. And an X-ray energy dispersive spectrometer (EDS) attached to the scanning electron microscopes (JEOL JSM-5600LV) was utilized to analyse the chemical composition of the as-prepared surfaces. The water contact angles (WCA) were measured with JC2000D with a 5 μL distilled water droplet at ambient temperature.

3. Results and discussion

Just like the two-faced Roman god Janus, Janus materials have two asymmetric faces with different or opposite property [17,18]. Janus particle was reported by Cho and Lee in 1985 for the first time [19]. Since then, Janus objects have been attracted a lot of attention of researchers for nearly thirty years. However, it is a big challenge to synthetic Janus interfacial porous materials duo to capillarity. There is no way to guarantee whether the asymmetric decoration only happens in one face. It will be much more difficult to create Janus interfacial porous materials with a certain thickness, because asymmetric decoration has to be controlled in a definite deep. Fortunately, taking the advantage of viscous starch paste dispersed in ethanol, nickel foam can float on the liquid surface when the gravity and buoyancy achieve a balance.. Most of nickel foam is dipped into liquid, which will be coated by starch paste forming superhydrophilic coating (the optical photograph is shown in Fig. S1, see Supporting Information). The rest of the nickel foam in air can keeps it original hydrophobicity (the synthesis process is illustrated in Fig. 1a and the preparation details are introduced in the Experimental section). The superhydrophilic nature due to abundant hydroxyl is the main reason why we chose starch paste to create superhydrophilic coating on nickel foam (the FTIR of starch is shown in Fig. S2, see Supporting Information). Second, as one kind of traditional adhesive [20], starch paste displays wonderful high adhesive force. So, starch paste superhydrophilic coating shows extremely high binding force with substrate. In addition, starch as an easily available nontoxic natural product has wide source including corn, potato, wheat and so on. Undoubtedly, starch is the optimal choice.

Cross-sectional image of Janus nickel foam is detected by optical microscope firstly (see Fig. 1b). The overall thickness of Janus nickel foam is about 1600 ± 10 μm. Thereinto, white superhydrophilic layer is about four-fifth of total thickness, namely, about