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Femtosecond laser fabrication of a gradient-wettability mesh for spilled oil crossflow collection

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ABSTRACT

Efficient continuous clean-up of large-scale oil spills is a global challenge. Herein, we present a simple method for fabrication of a gradient-wettability hydrophilic tilted mesh for fast spilled oil crossflow collection. After one-step femtosecond laser irradiation, the gradient-wettability mesh is tightly assembled and consists of four different pore size meshes, which possesses nanoripple structures. Meanwhile, the gradient-wettability mesh has a higher oil collection rate than single wettability meshes. This femtosecond-laser-induced gradient-wettability mesh design will have practical applications for efficient crossflow collection of large-area oil spills.

1. Introduction

Frequent oil-spill events not only serious damage marine ecosystems, but they also cause a large amount energy resource loss [1]. Traditional oil cleanup technologies [2], such as sorbents, skimmers, and chemical dispersion, have low efficiencies. Recently, superwetting meshes have become potential candidates for oil–water separation by the vertical gravity-driven method [3]. Guo's group proposed a facile method to prepare meshes by electroplating Cu nanoparticles on copper mesh, and the meshes exhibited the ability for oil/water separation [4]. However, single small-pore meshes are frequently blocked by oil and gravity-driven methods require an extra pump, which is inefficient for collecting large-area oil spills [5]. Thus, a feasible method for highly efficient collection of large-scale oil spills using superwetting meshes is still required.

In nature, crossflow filtration in fish gills can easily collect small food from parallel flow of the suspension liquid by efficiently draining away water [6]. Inspired by this process, Jiang's group proposed a ship-driven crossflow approach using a tilted hydrophilic gradient-wettability membrane for highly efficient spilled oil collection [7]. This method resolves the discontinuous and low efficiency problems of the gravity-driven method. However, hydrophilic gradient-wettability membrane preparation is complicated and time-consuming. The several steps of the preparation process require almost a day, which greatly restricts its practical applications. Femtosecond laser has the ability to fabricate functional surfaces [8–11], which provides a promising pathway for membrane preparation.

In this letter, a gradient-wettability mesh for efficient spilled oil crossflow collection was fabricated by femtosecond laser direct writing technology. The gradient-wettability mesh contains nanoripple structures and consists of four laser-treated meshes with different pore sizes.

2. Materials and methods

2.1. Materials

The four different pore size (~230, ~90, ~50, and ~10 μm) stainless steel (316L) meshes were used. The corresponding multiple pore size mesh (4.5 cm × 2 cm) is tightly assembled, as shown in Fig. 1(a).

2.2. Fabrication process

The assembled stainless steel mesh was fixed on a three-dimensional translation stage. A Gaussian laser pulse with a 250 fs pulse width, 75 kHz repetition rate, and 1030 nm central wavelength from a high-repetition femtosecond laser system (Pharos, Light Conversion, Lithuania) was used. The laser power was set to 6 W. The laser pulse entered a two mirror galvanometric scanner

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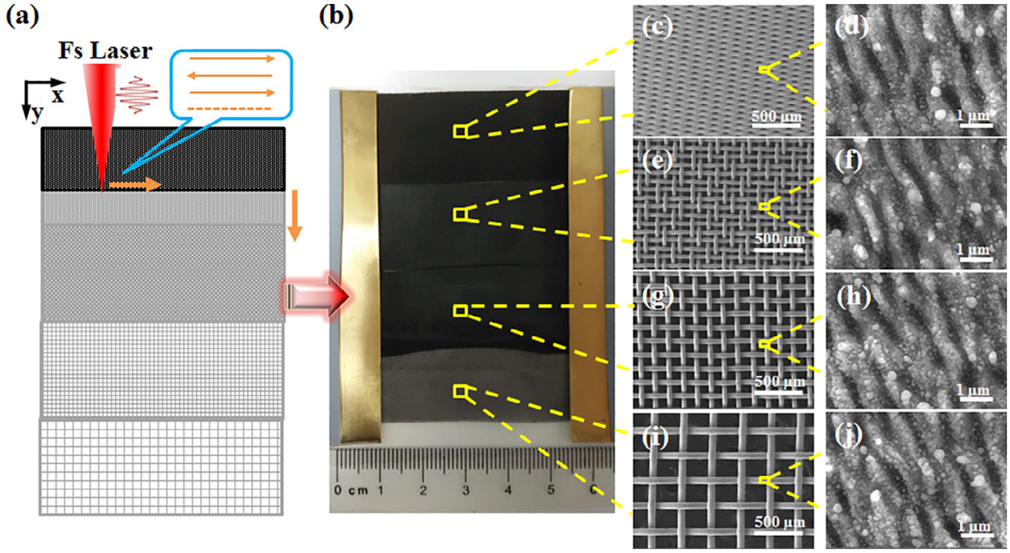

Fig. 1. (a) Schematic illustration of femtosecond laser processing to produce the gradient-wettability mesh. (b) Digital image of the gradient-wettability mesh (from top to bottom, pore size = ~10, ~50, ~90, and ~230 µm). (c)–(j) SEM images of the gradient-wettability meshes at different magnifications.

(intelliSCAN III 14, SCANLAB, Germany) and was finally focused on the surface of the assembled stainless steel mesh by an F-Theta lens (*f* = 100 mm). The laser direct writing procedure was described in our previous work [8]. The scanning speed and the gap of the scanning lines were fixed at 1.1 m/s and 10 µm, respectively.

2.3. Characterization

The morphologies of the samples were characterized by scanning electron microscopy (SEM, TESCAN, Czech Republic). The liquid contact angles were measured by a contact angle system (HARKE, China).

3. Results and discussion

Fig. 1(b) shows a digital image of the as-prepared mesh with dimensions of 4.5 cm × 8 cm. The large processing area only took several minutes at a high scanning speed of 1.1 m/s. In the corresponding SEM images of the gradient-wettability mesh, there are four different well-ordered pore size meshes. In the high-resolution SEM images (Fig. 1(d, f, h, j)), the mesh surface is composed of nanoripples with periods of 500–900 nm and lots of nanoparticles with sizes of tens to hundreds of nanometers randomly cover the periodic ripples.

The wetting behavior of water on the laser-treated mesh is shown in Fig. 2(a). A water droplet can easily move through the mesh in the large-pore region, and water rapidly spreads out in the small-pore region of the mesh. Both of these phenomena are attributed to the laser-fabricated nanostructures, which show hydrophilicity or superhydrophilicity. Moreover, the corresponding water contact angle (WCA) measurements show that the WCA decreases as the mesh pore size decreases. The oil behavior on the laser-treated mesh with different pore sizes is shown in Fig. 2(b). The mesh is pre-wetted by water and all of the mesh surfaces are rapidly sealed by water. The oil droplets cannot penetrate through the laser-treated meshes, and the oil contact angle increases as the mesh pore size decreases. The oil behavior indicates that the mesh possesses oil repellency.

Fig. 3(a) shows a schematic of the system designed to quantitatively characterize the oil collection efficiency, which includes two

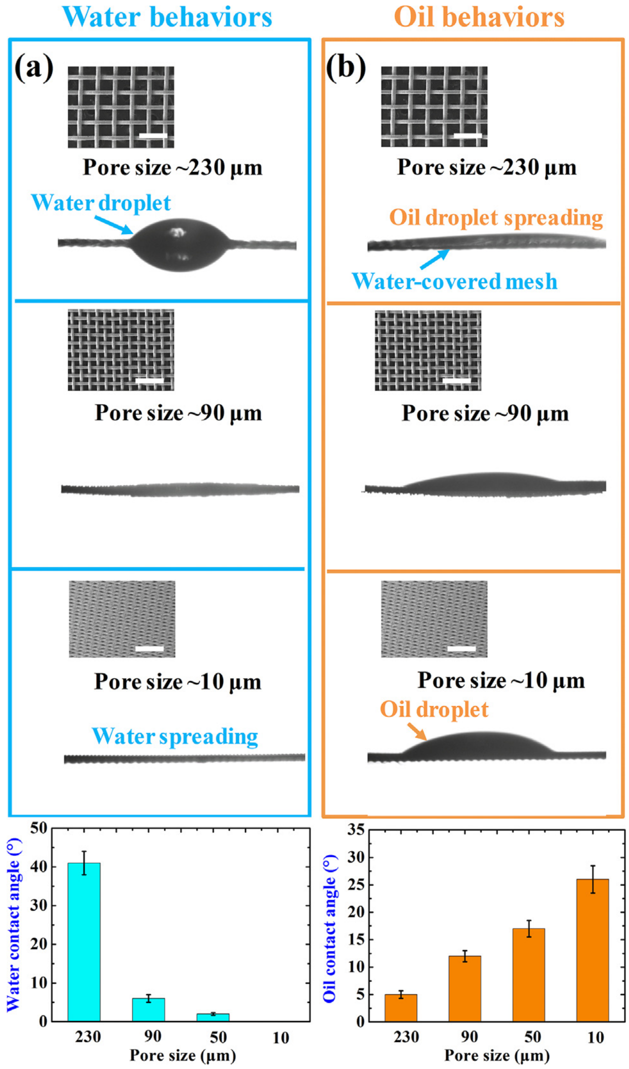

Fig. 2. Wetting behaviors of water and oil on the laser-treated mesh. (a) Water behavior on the laser-treated meshes with different pore sizes (the scale bars in the inserts are 500 µm). (b) Oil behavior on the laser-treated meshes with different pore sizes.