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Facile preparation of superhydrophobic surfaces based on metal oxide nanoparticles

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ABSTRACT

A novel method for fabrication of superhydrophobic surfaces was developed by facile coating various metal oxide nanoparticles, including ZnO, Al_2O_3 and Fe_3O_4, on various substrates followed by treatment with polydimethylsiloxane (PDMS) via chemical vapor deposition (CVD) method. Using ZnO nanoparticles as a model, the changes in the surface chemical composition and crystalline structures of the metal oxide nanoparticles by PDMS treatment were investigated by X-ray photoelectron spectroscopy (XPS), X-ray powder diffraction (XRD) and Fourier transform infrared (FTIR) analysis. The results show that the combination of the improved surface roughness generated from of the nanoparticles aggregation with the low surface-energy of silicon-coating originated from the thermal pyrolysis of PDMS would be responsible for the surface superhydrophobicity. By a simple dip-coating method, we show that the metal oxide nanoparticles can be easily coated onto the surfaces of various textural and dimensional substrates, including glass slide, paper, fabric or sponge, for preparation of superhydrophobic surfaces for different purpose. The present strategy may provide an inexpensive and new route to surperhydrophobic surfaces, which would be of technological significance for various practical applications especially for separation of oils or organic contaminates from water.

1. Introduction

The creation of superhydrophobic surfaces (water contact angle (CA) larger than 150°) has attracted considerable research interest both in academy and industry [1–6]. Extensive studies have revealed that the superhydrophobicity of a solid surface is governed by the surface free energy and roughness and it is usually enhanced by surface roughness [7–17]. Understanding the complementary roles of these two key parameters, so far a number of artificial superhydrophobic surfaces have been developed especially by controlling the geometrical structures of solid surfaces via various approaches such as lithographic methods [18–21], template-based extrusion methods [22–25], electrospinning [26–29], etc. However, these methods have limitations for practical applications caused by either the need of expensive or complicated fabrication techniques or limitations in substrates size [12]. From a practical point of view, the seeking of efficient approaches for the creation of superhydrophobic surfaces on the substrates with various manners by a facile process should be a priority and be of great importance especially for large-scale practical applications.

In recent years, the aggregation or assembly of various particles, including functionalized SiO_2 particles [30–34], polymer spheres [35–37], fluorosilane-treated TiO_2 particles [38], etc. by simple spin-coating or dip-coating on a substrate has been proven to be a feasible way to create superhydrophobic coatings over large-areas. By using particles aggregation or assembly followed by modification with low surface-energy substances, superhydrophobic surfaces can be formed with ordered or non-ordered roughness on scales from nanometers to micrometers [39]. In comparison with other methods, this method has advantages of low cost, without limitation in substrates size or shape, and does not need any expensive or complicated techniques. In the most cases, however, the drawback of this method lies in the need of multi-step process to create a microscopically rough surface of the particles layer. On the other hand, investigations on the construction of superhydrophobic surfaces by particles aggregation/assembly were mostly performed on those rigid and flat substrates (e.g. glass slide, silica wafer). Therefore, further exploiting simple and inexpensive methods for fabrication of superhydrophobic surfaces on various substrates based on particle aggregation or assembly is of special interest. More recently, the superwetting film has been prepared

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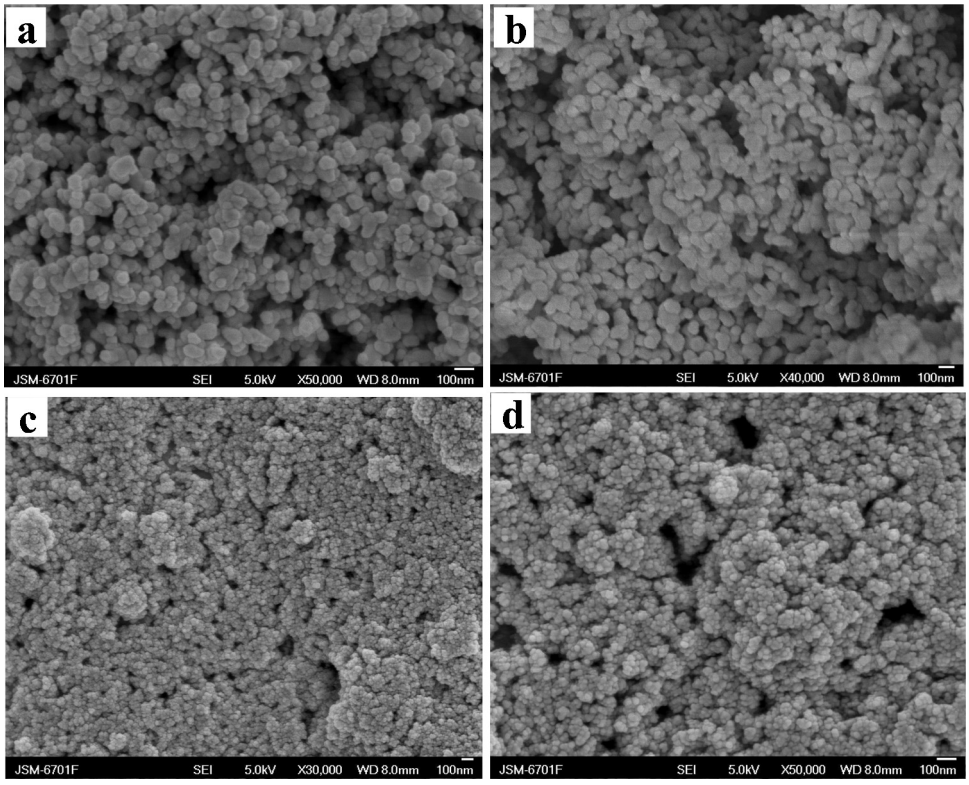

Fig. 1. The SEM images of (a) ZnO, (b) Al_2O_3 and (c) Fe_3O_4 nanoparticles. (d) The higher magnification of SEM image of Fe_3O_4 nanoparticles. Scale bar: (a–d) 100 nm.

by facile one-step treatment of MnO_2 nanowire with polydimethylsiloxane (PDMS) by chemical vapor deposition (CVD) method [11]. Motivated by this investigation, here we demonstrate a straightforward and versatile strategy for creation of superhydrophobic surface by directly treatment of various metal oxide nanoparticles aggregation with PDMS by CVD method. Also, deposition of metal oxide nanoparticles onto various substrates such as glass slide, paper, textile or sponge followed by treatment with PDMS by CVD method, the wettabilities of substrates can be changed from hydrophilic to superhydrophobic, which would be of technological significance for various practical applications especially for separation of oils or organic contaminates from water.

2. Experimental

2.1. Sample preparation

2.1.1. Preparation of ZnO nanoparticles [40]

In a typical procedure, $ZnSO_4$ solution (0.1 mol/L) was dropwise added into Na_2CO_3 solution (0.1 mol/L, volume ratio as 1:1) with stirring under ambient temperature. Then the resulting mixture was dried at 110 °C for 3 h and followed by washing with water and ethanol several times. Finally the white powder products were calcined at 700 °C for 1 h.

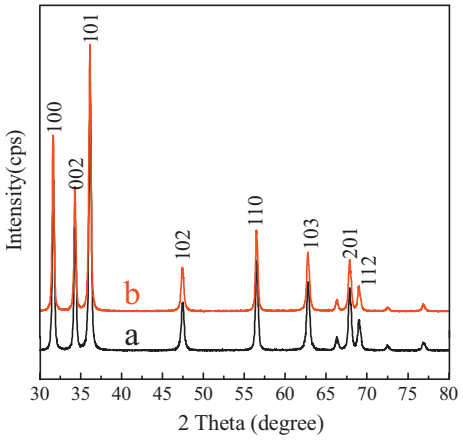

Fig. 2. XRD patterns of ZnO nanoparticles before (a) and after (b) PDMS treatment.

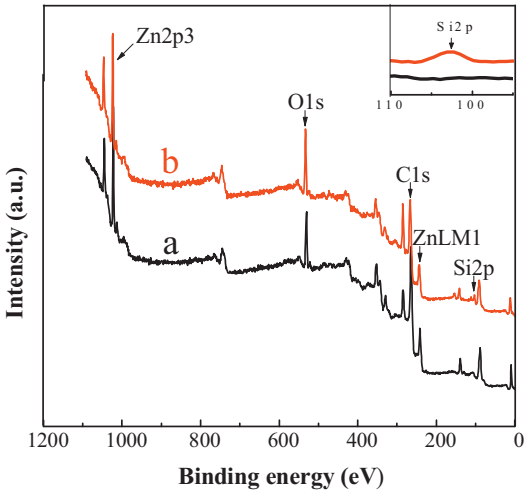

Fig. 3. XPS patterns of ZnO nanoparticles before (a) and after (b) PDMS treatment.