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Control over the wettability of amorphous carbon films in a large range from hydrophilicity to super-hydrophobicity

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Abstract

Control of wettability is of significance in industry as well as our daily live. Amorphous carbon (a-C) films with nanostructured surface were deposited on silicon and glass substrates at different substrate temperatures through a magnetron sputtering technique. The microstructures of the a-C films were studied by SEM and XPS, which indicate that the surface of the a-C films deposited at room temperature are smooth due to their much dense sp^3-bonded carbon, while they turn to be more porous graphite-like structure with elevated deposition temperature. The water contact angle (CA) measurements show that these pure carbon films exhibit different wettability, ranging from hydrophilicity with CA less than 40° to super-hydrophobicity with CA of 152°, which reveal that the surface wettability of a-C films can be controlled well by using nanostructures with various geometrical and carbon state features. The graphite-like carbon film deposited at 400 °C without any modification exhibits super-hydrophobic properties, due to the combining microstructures of spheres with nanostructures of protuberances and interstitials. It may have great significance on the study of wettability and relevant applications.

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Keywords: Wettability; Amorphous carbon films; Microstructure; Super-hydrophobic

1. Introduction

Wettability of solid surface, which is dependent on both the chemical composition and geometric microstructure, is a very important character in nature as well as in our daily life [1]. Control of wettability is of significance in many areas, for example, inspired by some interesting phenomenon of plants and insects [2,3], super-hydrophobic surfaces, whose contact angles (CA) with water are higher than 150°, attract much attention for their many practical applications because of their limited contact area.

Surface modification with low-surface-energy materials is a typical technique to control over the wettability of solid [4–6], and super-hydrophobic surfaces are fabricated successfully with micro- or nanostructured polymers surface [7–9]. As an environmentally benign and economically viable optoelectronic device material, amorphous carbon (a-C) films are of interests in various applications [10–12]. Combined with special wettability properties, a-C films may have greater potential applications [13]. Recently, super-hydrophobic behavior was found in nanostructured carbon materials [14–15], such as carbon nanotube and nanofiber and nanostructured carbon films also exhibited super-hydrophobicity in all pH environments, especially for corrosive liquid. However, these methods are ether expensive or substrate limited. For example, the high temperature (> 650°), high voltage or catalyst are needed for fabrication of super-hydrophobic carbon nanotube [14,15], thus such methods are not suitable for coating at the substrates of weak thermal stability, such as glass.

Sputtering is a simple and useful technique for preparing thin films with expected structure and properties, and recently, the growth of some interesting fractal aggregates on solid surface were also studied by this process [16,17]. In the present work, a-C films were prepared by magnetron sputtering on substrates as Si (1 0 0) and glass, without any special pretreatment. The wetting properties of these carbon layers with different structures were studied via contact angle measurement. The results indicate that these artificial surfaces exhibit different wettability, ranging from

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40° to 152°. Such changeable control between hydrophilicity and super-hydrophobicity of a-C films provide an opportunity to understand the further relationship between the surface wettability and morphology.

2. Experimental

Amorphous carbon films of different geometry microstructures were deposited on clean Si (1 0 0) and glass substrates by a radio frequency (RF) magnetron sputtering system. A graphite plate of 99.9% purity with the diameter of 100 mm was used as the sputtering target. After being evacuated to a base pressure of 3×10^{-3} Pa, the working chamber was filled with Ar (99.99% purity), the work pressure was held at about 0.5 Pa, and the RF power of 200 W was applied in the sputtering process with substrate temperature varying from room temperature to 400 °C.

The surface morphology of these films was studied by scanning electron microscopy (SEM JEOL JSM6500) at an accelerating voltage of 30 kV. The X-ray photoelectron spectrometer (XPS) analyses for the samples was performed on a PHI 5600 with a monochromatic Al Kα source at 14 kV and 350 W, and the photoelectron take off angle was 45°. The surface wettability of the a-C films were measured by a contact angle measurement system in air at ambient temperature, and distilled water droplets (about 5 μl) were carefully dropped onto these surfaces. The average CA value was acquired by measuring at three different positions of the same sample.

3. Result and discussion

Significant variations of morphology were observed in the films deposited at different temperatures. Fig. 1 shows the SEM images of the films prepared at different substrate temperatures. Obviously, the substrate temperature plays an important role in formation of different morphology of the surfaces, and such microstructure is independent of the Si and glass substrates. Fig. 1(a) shows a smooth and bare surface of the unheated

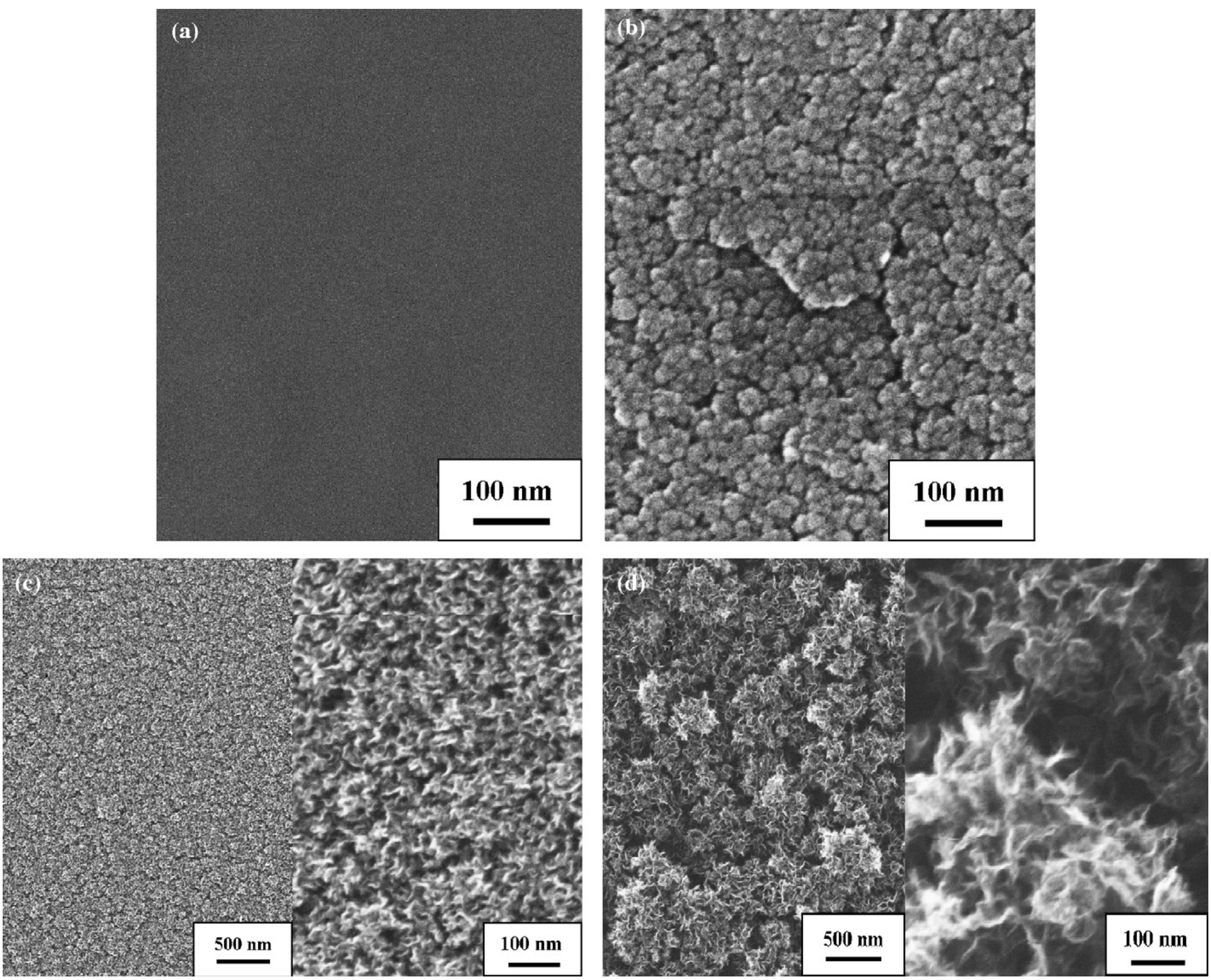

Fig. 1. SEM images of the surface of the a-C films prepared under substrate temperature at (a) room temperature; (b) 100 °C; (c) 200 °C; (d) 400 °C. The large-area image is show on the left of (c) and (d) images.