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Substrate material affects wettability of surfaces coated and sintered with silica nanoparticles

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ABSTRACT

Silica nanoparticles coating and sintering is a widely-used approach for creating hydrophobic and superhydrophobic surfaces. The role of substrate material in this process, however, has not been thoroughly investigated. In this work, the role of substrate material is examined by measuring surface wettability of three different substrate materials (glass, polyimide and copper) under systematically varied conditions. These surfaces are modulated from hydrophilic (water contact angle (WCA) < 90°) to superhydrophobic (WCA > 150°) by coating and sintering silica nanoparticles, followed by assembling a layer of fluorine compound. Static WCA characterization shows that surface wettability is not solely dependent on the concentration of the coating colloidal, but is also on the substrate material. In particular, copper substrate exhibits a larger WCA than glass and polyimide substrates. Scanning Electron Microscopy (SEM), Energy-Dispersive X-ray Spectroscopy (EDS) and Atomic Force Microscopy (AFM) characterizations show that the substrate material-dependent wettability is attributed to thermal-induced nanostructures on the copper surface, which contributes to the hierarchical micro-/nano- topography. This finding is important for designing hydrophobic/superhydrophobic surfaces comprised of different materials, especially those that would experience thermal cycles in surface functionalization and subsequent use.

1. Introduction

Surface wettability is one of the paramount properties of a solid surface and closely relates to fundamental science and practical applications. For example, hydrophobic surfaces with a static water contact angle (WCA) greater than 90° have been extensively used in a broader range of applications, including anticorrosion [1], fog condensation [2], and self-cleaning systems [3]. According to the scaling law, surface wettability becomes increasingly dominant when the characteristic dimensions of the subjects of interest reduce from conventional scale to micro/nanoscale. Studies show that surfaces with controlled wettability are able to regulate nanofluidic boiling [4], drive fluids in micro/nanochannels [5,6], and manipulate living cells at small scales [7].

In order to produce a surface with the desired wettability, simultaneous control of surface energy and roughness is required [8–11]. Surface energy is determined by the substrate material and can be modified by introduction of a surface coating. For example, -CF_3 groups engrafted and aligned on a planar hydrophilic surface can lead to a WCA of 120° [12]. Surface roughness further enhances surface hydrophobicity by creating micro/nanostructures. Common methods include nanoparticles deposition [13], nanowires growth [14], deep reactive ion etching [15], and X-ray lithography [16]. Of them surface coating with silica nanoparticles is a simple yet effective method that applies to various substrates [17–19]. Silica nanoparticles sized a few nm to tens of nm are dispersed and immobilized on a surface under an elevated temperature [20,21]. These nanoparticles of high surface-to-volume ratios are able to build up a hierarchical architecture and result in surface superhydrophibicity with WCA exceeding 150°. The method is compatible with a broad array of substrate materials [22], thus enables wettability modulation of a surface consisting of different materials.

In the method above the dependence of surface topography and wettability on the characteristics of silica nanoparticles, e.g., size and concentration, has been extensively studied [23–26]. But the role of substrate material receives little attention. As is known thermal sintering is an essential step to remove solvent and immobilize silica nanoparticles on the base substrate by thermally curing them at an elevated temperature [20,21]. In this process substrate materials are subject to properties change because of their distinct thermal characteristics. For example, glass largely retains its properties below 800 °C [27], while many metals change the hardness, surface morphology and crystalline structure, etc. below 300 °C [28]. Surface wettability may be altered accordingly. Moreover, a

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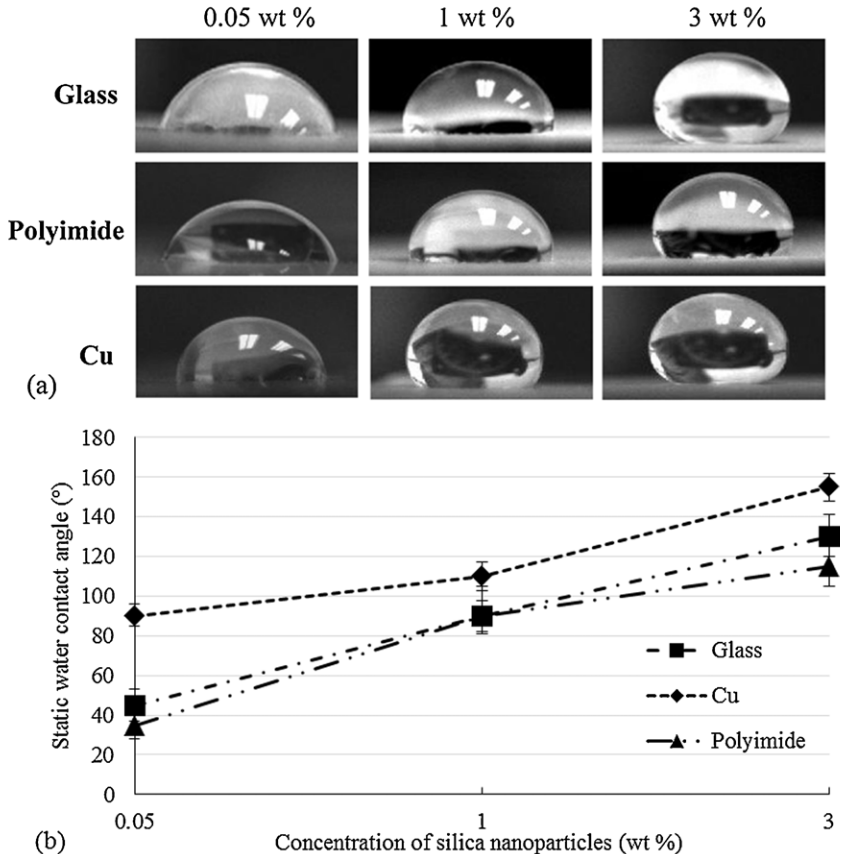

Fig. 1. Surface wettability of three substrates coated and sintered with silica nanoparticles under different suspension concentrations. (a) Droplet shapes in WCA measurements, and (b) WCA change with the substrate material and suspension concentration.

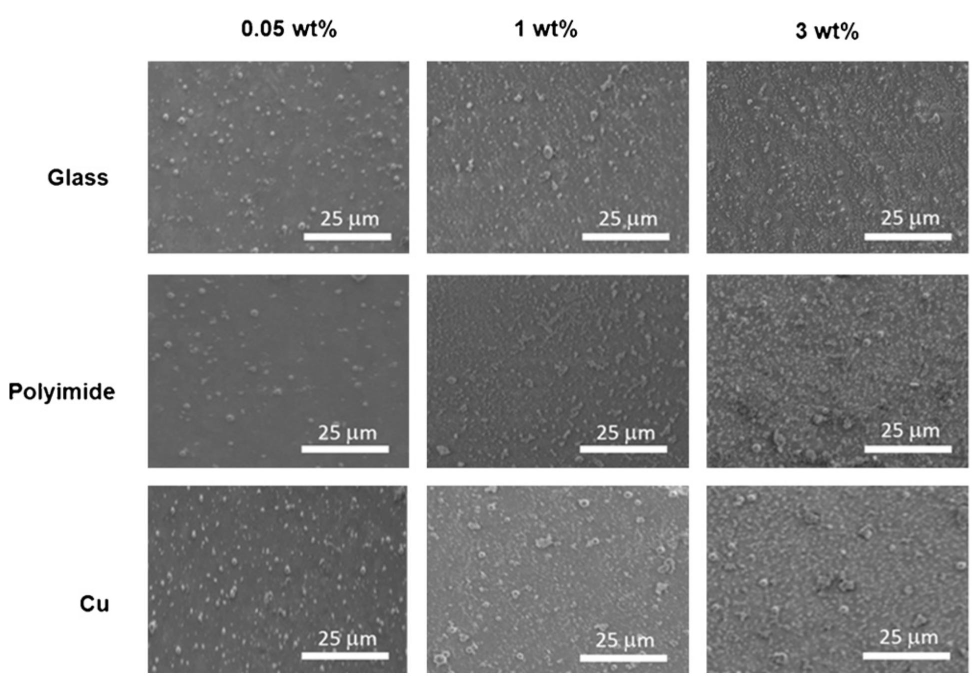

Fig. 2. SEM micrographs of the distribution of silica nanoparticles aggregations on glass, polyimide and glass substrates under 0.05%, 1% and 3% suspension concentration.