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Solution-Based One-Step Preparation of Three-Dimensional Self-Assembled Octadecyl Silica Nanosquare Plate and Microlamella Structures for Superhydrophobic and Icephobic Surfaces

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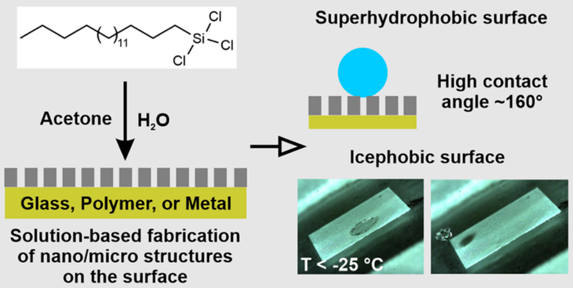
ABSTRACT: Icephobic surfaces have gained immense attention owing to their significant roles in decreasing the energy consumption of refrigerators and in improving safety issues by preventing the formation of ice on them. Superhydrophobic surfaces incorporating micro- or nanoscale roughness and hydrophobic functional groups have been shown to prevent ice accumulation. Herein, we report a simple, low-cost, and solution-based one-step process for the production of superhydrophobic surfaces with three-dimensional (3D) self-assembled structures. The controlled hydrolysis and polycondensation of *n*-octadecyltrichlorosilane (OTS-Cl) in an acetone solution produced a highly uniform superhydrophobic surface on various substrates such as glass, metals, and polymers without the limitation of the surface curvature structure. The as-prepared 3D self-assembled surface exhibited a very high contact angle of 161.7° and a low contact hysteresis of 1.47°. The solvent type, H_2O content in acetone, and carbon chain length of the silane compound were critical in the formation of self-assembled nanostructures. The thickness of the superhydrophobic 3D self-assembled structure could be varied by controlling the surface properties of the glass substrate. In addition, a novel octadecyl silica nanosquare plate structure was formed as an intermediate for the microlamella structure. The water drop impact experiments on the 3D self-assembled superhydrophobic glass substrates at low temperatures ($T < -25$ °C) showed that the as-prepared superhydrophobic glass possessed a high impalement threshold for water contact, resulting in excellent and stable icephobic properties. The preparation method proposed in this study is scalable and can be used on a flat glass surface or in a glass vial inside a glass tube. Moreover, it can be applied to various substrates such as metals and polyurethane surfaces with curvature. Therefore, the solution-based self-assembly method proposed in this study is a promising approach to produce superhydrophobic and icephobic surfaces on a wide range of substrates regardless of their structure and properties.



■ INTRODUCTION

The formation of icephobic surfaces is of great importance from the viewpoint of safety and economic aspects in various areas such as aircraft, power lines, wind turbines, as well as in many commercial and residential refrigerators and freezers.[1,2] Inspired by the superhydrophobic properties of the lotus-leaf surface, the formation of nano/microstructures with hydrophobic surface chemistry has been extensively investigated.[3] Theoretical studies have also indicated that a rough surface with a nano/microstructure is essential to produce superhydrophobic surfaces.[4] Wenzel and Cassie−Baxter theories have suggested that the two different wetting states of a surface with water droplets (fully wetted or composite states) can result in different superhydrophobicity performances.[1,5] Both the theories indicate that surface roughness and heterogeneity are essential for superhydrophobicity.

Various methods including lithographic patterning,[6] plasma etching, electrochemical deposition, chemical vapor deposition, sol−gel methods, layer-by-layer assembly,[7] etc. have been used to prepare superhydrophobic surfaces by mimicking the lotus-leaf surface structure.[8] Various materials such as silicon, silica,[9,10] polymers,[11] carbon nanotubes, and nano/microparticles have also been investigated for preparing superhydrophobic surfaces.[9] Compared to sophisticated lithographic methods, colloid-based methods are suitable for the large-scale fabrication of superhydrophobic surfaces. Lee et al. reported a layer-by-layer assembly method with two different silica nanoparticles (500 and <100 nm) to produce raspberry-like particulate films with superhydrophobic surfaces.[10] The films showed a high contact angle (θ = 169°).[10] Later, Yang et al. suggested the use of two different silica nanoparticles (100 and 20 nm) for preparing optically transparent superhydrophobic surfaces.[9] However, most of the methods reported previously

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