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Facile preparation of superhydrophobic nano-aluminum/copper(II) oxide composite films with their exposure and heat-release stability

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ABSTRACT

Practical application of nano/micro-composite is frequently hampered by the sophisticated fabrication process, expensive cost and easy loss of capacities due to hydrophilicity etc. This paper presents a facile method to fabricate a novel superhydrophobic nano-aluminum/copper (II) oxide composite via electrophoretic deposition (EPD) and followed by surface chemical modification using a low surface energy material-1H, 1H, 2H, 2H-perfluorodecyltriethoxysilane. The stable EPD suspension consists of ethanol and acetyl-acetone. Surface morphology, wettability, and chemical composition were characterized using SEM, EDS, XRD, water contact and sliding angle measurements. The resulting surface, with water contact angle of ~168°, is stable up to 12 months in ambient atmosphere and shows great exothermic performance. These results provide a new perspective for advancement of superhydrophobic surfaces in real industrial application.

1. Introduction

Nano-aluminum/copper (II) oxide (Al/CuO) composite with large densities and high impulses have received a growing interest because of a range of potential applications, especially in micro-triggers, pyrotechnics, microactuators, etc. [1,2]. Recent studies in Al/CuO composite mainly focus on three aspects of how to simplify the preparation methods, develop the morphology diversity, and improve energy output performance. However, Al/CuO composite easily suffer severe performance degradation exposed to the air due to the intrinsic hydrophilic or hygroscopic properties, which is fatal for the long-term stability for real industrial application [3]. However, there is little literature discussing how to improve their environmental resistance to keep performance stable in ambient conditions. So it is rather necessary to explore facile and convenient routes to develop the stability of Al/CuO composite.

The issue can be addressed by referring to the design concept of superhydrophobic materials that is constructing micro/nano-structure rough surface and decreasing surface energy [4–9]. The electrophoretic deposition (EPD) turns out to be a facile and high-efficiency technique to assemble charged particles, or various molecules to oppositely charged electron with the different deposition time under the controllable field strength, forming a promising micro/nano-structures, which is relatively rough but uniform on various target chips [10].

Herein, we firstly introduce the EPD and surface chemical modification to fabricate superhydrophobic nano-Al/CuO composite films with a relative high interface strength (Fig. S1 in Supporting Information). Except for the EPD-processed surface, selection of low surface energy materials is also crucial. 1H, 1H, 2H, 2H-perfluorodecyltriethoxysilane (PFTS) is regarded as a promising option to reduce the target coating surface energy because of the extremely low surface energy functional groups of $-CF_2-$ and the $-CF_3$ at 18 mJ m^{-2} and 6.7 mJ m^{-2} [11], respectively. In addition, the superhydrophobicity and heat-release stability of Al/CuO composite films were also studied in detail.

2. Experimental section

2.1. Materials and preparation

Nano-Al (50 nm, 99.9%), nano-CuO (100 nm, 99.9%) and PTFS were purchased from Aladdin Bio-Chem Technology (Shanghai, China), and stored in a vacuum drying oven. Acetylacetone and

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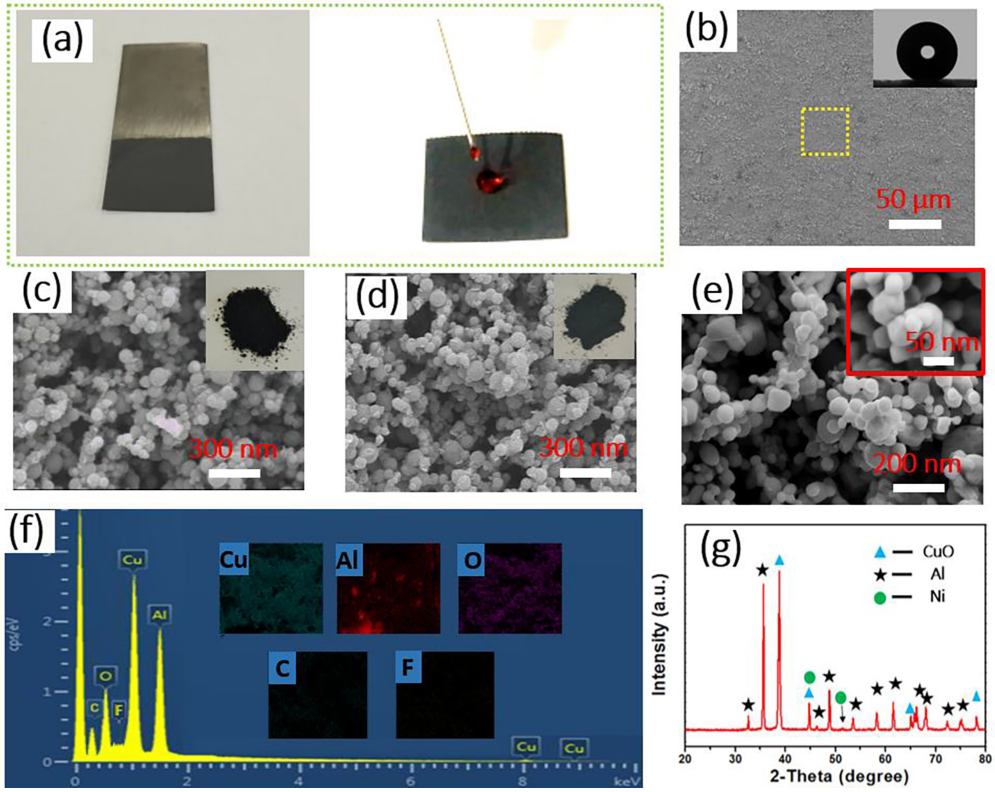

Fig. 1. (a) The optical photograph of superhydrophobic nano-Al/CuO coating on a nickel cathode, and a dyed water droplet on that surface. The typical SEM images of nano-CuO (c), Al (d) and Al/CuO composite (b: low resolution, and e: high resolution). Following are (f) the EDS spectrums and (g) XRD spectra of samples.

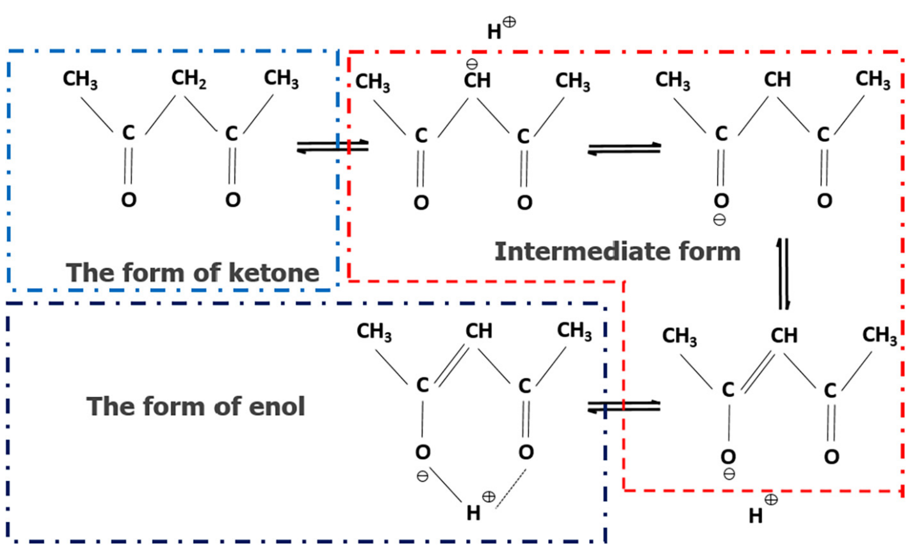

Fig. 2. The transformation process of the form from keto to enol in acetylacetone.

ethanol were used as received. All other reagents were of analytical grade without further purification.

Commercial nickel sheets (99.99%) with an effective area of 2 × 4 cm^2 were utilized as electrodes after polishing with 400–1000# grit sandpapers; and ultrasonic treatments with ethanol and deionized water. Cleaned and dried substrates were then used for EPD process. A stable dispersion for EPD was prepared by mixing a solid loading of 1 g/L in an acetylacetone–ethanol (1:1, v/v) solution, and sonicating for 25 min in an ultrasonic bath with 200 W to break up agglomeration of nanoparticles. The distance between the two electrodes was 1 cm, and EPD process was performed at 20 V mm^{-1}. Subsequently, deposited films were dried at 573 K in a vacuum oven for 30 min. Finally, the electrophoretic assembly nano-Al/CuO films were modified by immersing PFTS and ethanol mixture solution with the mass ratio of 1:99, for 1.5 h in a N_2 environment at 323 K. The films were then heat treated in a vacuum drying oven at 393 K for 15 min and cooled to ambient temperature.