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# Creation of a multifunctional superhydrophobic coating for composite insulators

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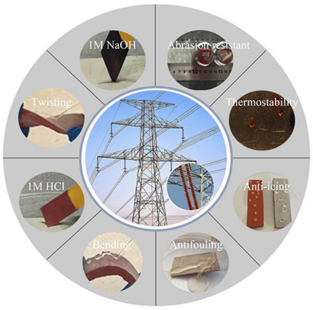
## HIGHLIGHTS

- The coating exhibits great mechanical durability, and excellent superhydrophobicity.
- The as-prepared coating still remains superhydrophobicity after 300 °C high temperature treatment.
- The coating of composite insulators for power system is extremely suitable.

## GRAPHICAL ABSTRACT

Multifunctional micro-nanoscale $SiO_2$/epoxy resin superhydrophobic coating created by a simple and low-cost method. Moreover, the coating exhibits great mechanical durability and excellent chemical stability and properties of anti-icing and self-cleaning, which makes the composite insulator run normally under extreme conditions and satisfies a completely need of power system.



## ARTICLE INFO

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## ABSTRACT

Composite insulators with a superhydrophobic coating can tremendously improve the reliability and stability of transmission line systems and railway systems; thus, they play a crucial role in global electricity issues and power systems. However, the majority of superhydrophobic coatings for composite insulators suffer from weaknesses, such as poor mechanical stability and complicated and toxic preparation processes. To improve these defects, a multifunctional, micro-nanoscale $SiO_2$/epoxy resin superhydrophobic coating for composite insulators was created. The coating maintained excellent superhydrophobicity through a bending experiment, a twisting test, a knife-scratch, a durability test, a pH test and UV light treatment. Moreover, it also performed well in the areas of anti-icing, high thermal stability (300 °C), self-cleaning and antifouling. In view of abovementioned advantages, composite insulators with the proposed superhydrophobic coating show great potential for the national economy and power industry.

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## 1. Introduction

Composite insulators, as an important component in transmission lines and railway systems, are usually used to support the conductor and prevent current return in global electricity issues [1]. However, it has been demonstrated that the power system suffers from various issues, including conductor shaking, environmental pollution and insulator icing, which could lead to insulator failures, insulation performance degradation and even tower collapse [2]. Therefore, it is necessary to endow composite insulators with desirable performance characteristics, from the point of view of safety and stability operation.

Inspired by natural superhydrophobic surfaces, such as lotus leaves [3], butterfly and dragonfly wings [4] and the water strider [5], a variety of superhydrophobic coatings were developed with a focus on the roughness and low surface energy of the material [6–8]. They were employed in many areas, including self-cleaning, anti-icing, antibacterial applications, oil-water separation and corrosion prevention [9–15]. In a word, a superhydrophobic coating is a suitable candidate for protecting the composite insulators from damages generated during practical applications [16–17]. Accordingly, Liao et al. reported a superhydrophobic coating for insulators [18]. The surface showed anti-icing and self-cleaning properties based on superhydrophobicity, contact angles (CAs) larger than 150° and sliding angles (SAs) less than 5°. Compared with room temperature vulcanized silicone rubber (RTV) coated glass slide, it could effectively reduce the freezing area. In addition, they [19] also fabricated a $ZnO/SiO_2$/PTFE (Polytetrafluoroethylene) sandwich-nanostructure superhydrophobic coating for composite insulators, which showed good corrosion resistance and insulating performance. Superhydrophobic coatings for insulators, however, are limited by poor mechanical stability, troublesome chemical processes and toxic substances. Taking practical applications and simple methods into account, global power systems urgently require a superhydrophobic coating with excellent anti-icing properties and mechanical durability. The coating is designed using a facile and environmentally friendly strategy, which continues to be a challenge for us.

The fabrication of a multifunctional, micro-nanoscale $SiO_2$/epoxy resin superhydrophobic coating for composite insulators in power systems is reported in this paper. The various substrates such as composite insulators, glass, wood and fabric were coated with micro-nanoscale $SiO_2$ particles using an epoxy resin, curing agent and PVDF. The results showed that the coatings possess superhydrophobicity, self-cleaning and anti-icing properties, high thermal stability and chemical durability. After a knife-scratch test, a UV light test, and even 500 abrasion cycles using sandpaper with a 400 g load, the coating maintained its superhydrophobicity on account of its low-energy stability and micro/nano structures. This method was proven to be more simple and efficient than other methods reported. Importantly, the $SiO_2$/epoxy coating can prevent liquid from contacting the surface of composite insulators, which indicates great potential for applications in the reduction of electricity loss, as well as safeguarding transmission line systems and railway systems.

## 2. Experimental section

### 2.1. Materials

Tetraethoxysilane (TEOS) (AR) was purchased from Shantou XILONG Chemical Reagent Co. Inc, China. Ammonium hydroxide ($NH_3{\cdot}H_2O$) (AR 97%) was obtained from Henan Xinxiang ZHONGYUAN organic chemical Co. Ltd., Chain. 3-hydroxytyramine hydrochloride (dopamine hydrochloride, 99.5%) was purchased from Sigma-Aldrich. 1,1,1,3,3,3-hexamethyl disilazane (HMDS, 98%) was obtained from Shanghai KEFENG Chemical Reagent Co. Lnc. Epoxy resin and curing agent were purchased from Beijing Yuhong Waterproof Technology Co. Ltd. Sudan red IV, orange II sodium salt and methylene blue were obtained from Aldrich. In addition, all other chemicals were analytical-grade reagents and were used as received.

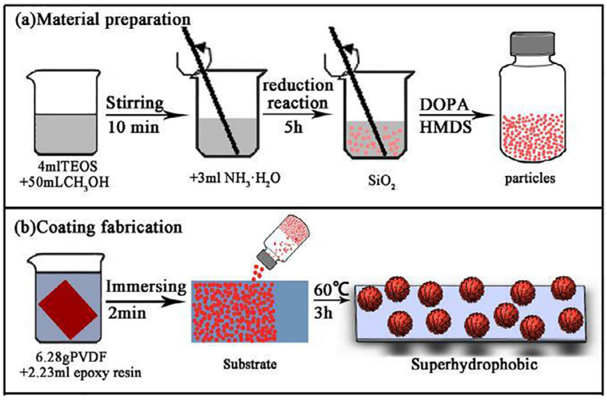

**Fig. 1.** (a) Preparation procedure of the superhydrophobic HMDS-DOPA $SiO_2$ powders and (b) coating fabrication.

### 2.2. Preparation of superhydrophobic powder

Schematic Fig. 1 shows the preparation procedure for the superhydrophobic coating. First, 4 mL of tetraethoxysilane (TEOS) was mixed with 50 mL of ethanol and stirred for 10 min. Next, 3 mL of $NH_3{\cdot}H_2O$ was added to the above mixture and stirred for 5 h at room temperature. Subsequently, 0.03 g of 3-hydroxytyramine hydrochloride (DOPA) and 8 mL of 1,1,1,3,3,3-hexamethyl disilazane (HMDS) were added into this solution while stirring. After the hydrolysis reaction (TEOS and HDMS) was down, the mixture was then dried in a vacuum oven at 100 °C for 3 h. The brown HMDS-DOPA particles were collected through filtration and washed with ethanol twice. Finally, the superhydrophobic powders were obtained and harvested for the subsequent experiment.

### 2.3. Characterization

To characterize the morphologies of the original $SiO_2$ powders and superhydrophobic HMDS-DOPA powders, field emission scanning electron microscopy (FESEM) images were obtained on JSM-6701F, using Au-sputtered specimens. Transmission electron microscopy (TEM) measurements were carried out with a TechnaiG20 (FEI) operating at 300 kV. X-ray photoelectron spectroscopy (XPS) (ESCALAB 250Xi, Thermo Scientific) measurements were performed using Al-Kα radiation and used to analyse elements and functional groups. Fourier transform infrared spectroscopy (FTIR), Nicolet iS10, and Thermo Scientific were used to record the spectra. Three-dimensional surface imaging was carried out using Surface Imaging System atomic force microscopy (AFM, CSPM 5500). The size distribution of particles was measured with Zetasizer Nano ZS ZEN 3600. The water CAs and SAs were measured (JC2000D) with a 5 μL distilled water droplet at ambient temperature. The average water contact angle and sliding angle values were obtained by measuring the same sample at five different positions. All photographs were obtained by a Sony camera (DSCHX200).

## 3. Results and discussion

### 3.1. Structure and characterization of superhydrophobic HMDS-DOPA $SiO_2$/epoxy powders

The micro/nano structure and morphologies of the original $SiO_2$ powders and superhydrophobic HMDS-DOPA $SiO_2$ powders were investigated by SEM and TEM, respectively, in Fig. 2. It is clearly shown that the radii of pristine $SiO_2$ particles were less than 100 nm, and the