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Synthesis, characterization and properties of ATO/potassium silicate film prepared by twice spray pyrolysis

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ABSTRACT

Hydrophilic coatings have received considerable attentions in recent years. This study investigates an ATO/potassium silicate hydrophilic film based on antimony doped tin oxide (ATO) and potassium silicate (PS) which deposited on aluminum sheets by twice spray pyrolysis. For comparison, four groups of samples including aluminum sheets (Al), aluminum sheets deposited with ATO film (Al/ATO), aluminum sheets deposited with potassium silicate film (Al/PS) and aluminum sheets deposited with both ATO and potassium silicate films (Al/ATO/PS) have been used for experiments. The morphologies, phase structures and chemical compositions of four samples have been characterized using FE-SEM, AFM, XRD and XPS. The hydrophilic, anticorrosive, thermal conductive and electrical resistive properties of the four samples have been studied in detail. The results show clearly that smooth PS film possesses good hydrophilicity and the water contact angle of ATO/PS film maintains below 17° after being exposed in air for 1 month. Moreover, the ATO/PS film shows lower corrosion current density comparing with other samples, revealing its excellent corrosion resistance property. The difference in the thermal conductivity values of the four samples is not significant. And the thermal conductivity is slightly increased by 4.0% for Al/ATO/PS, compared to Al/PS. These results indicate that ATO/PS film has superior hydrophilic performance, corrosion resistance and thermal conductivity than the individual potassium silicate film and ATO film.

1. Introduction

In recent years, the surfaces with excellent hydrophilicity or hydrophilic coatings have received considerable attention in many applications, such as anti-fogging, self-cleaning and heat dissipation [1–3]. In general, hydrophilic coatings include inorganic hydrophilic coatings, organic hydrophilic coatings and composite hydrophilic coatings [4–6]. Organic hydrophilic coatings are widely used due to its low cost and simple production process. Jankowski et al. [7] reported a stable hydrophilic film modification of polycarbonate via branched polyethyleneimine and poly (ethylene-*alt*-maleicanhydride) as the reagents, which exhibited excellent durability. Liu et al. [8] studied the modified hydrophilic PVDF membranes by adding trace amounts of tannin acid (TA) and polyethyleneimine (PEI), which showed remarkable hydrophilicity with water contact angle of 16°. However, the alkali resistance and environmental protection properties of organic hydrophilic coatings are poor. Inorganic coatings, like TiO_2 hydrophilic film, can achieve superior hydrophilicity and excellent mechanical properties compared with organic coatings [9]. However, UV radiation or photocatalytic treatment is usually needed to obtain high hydrophilicity for TiO_2 films [10]. Silicate is another raw material often used for inorganic hydrophilic coatings due to its low cost and abundant sources. Nielsen et al. [11] fabricated a highly performing large-area anti-reflective surface on glasses which rely on wet deposition of aqueous potassium silicate solutions and transformed into nanoporous silica layers then. Yang et al. [12] prepared a hydrophilic silicon dioxide film on the acrylate polyurethane coatings and the wetting angle was declined from 85° to 16°. It was found that the self-cleaning property of the SiO_2 film was superior after exposed to outdoor environment for 50 days. Silicate-contain hydrophilic films have shown up superior hydrophilicity. However, the thermal conductivity and anticorrosion properties of the

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present hydrophilic films are unsatisfied. It is needed to discover the new type of films with excellent thermal conductivity and anticorrosion properties to expand the applications of hydrophilic films.

On the other hand, Sb doped tin oxide (ATO) film has been widely studied because of its low electrical resistivity, preferable thermal conductivity and chemical stability. ATO film has been developed and used in variety of applications such as solar cells, sensors and electrode [13–15]. The preparation methods for ATO film mainly include magnetron sputtering [13], pulsed laser deposition [14], sol-gel dip coating [15], chemical vapor deposition [16], spray pyrolysis [17] and so on. The spray pyrolysis technology has been widely used in industrial production due to its low cost, better film uniformity and simplicity. Fauzia et al. [18] reported the fabrication of highly conductive transparent ATO thin films using a simple, low-cost ultrasonic spray pyrolysis method. Fadavieslam [17] deposited ATO film on glass substrates through spray pyrolysis, and found that the doping concentration of antimony had a huge influence on electrical and optical characteristics of ATO film. Jain [19] studied the influence of doping concentration of Sb ions on the properties of film, and found that carrier concentration was increased due to the substitution of Sb ions for Sn ions, and leading to the decrease of electrical resistivity. It was found recently ATO film can be used as the bottom layer of multilayer films to improve the thermal conductivity and electrical properties. Guillén et al. [20] prepared ATO/AZO bilayer films through DC magnetron sputtering on soda lime glass with stronger adhesion. The result showed that the electrical performance of electrodes was enhanced by using the ATO film as the bottom film. Yoo et al. [21] found that the deposition of ATO layer improved the thermal instability of triple-layered TCO substrate based on ITO/ATO/TiO_2 structure. Galaviz-Pérez et al. [22] prepared multilayered ATO/TiO_2 thin films by spin-coating method, and found that ATO film as the bottom film had a significant influence on its resistivity and showed a strong ability to absorb UV rays.

Considering that the silicate-based hydrophilic films prepared by common methods such as dip coating is normally thicker and with poor anticorrosion property, an ATO/potassium silicate film prepared by twice spray pyrolysis with high electrical and thermal properties for ATO and superior hydrophilicity for PS is designed in the present work. To the best of our knowledge, there are few reports on ATO/potassium silicate film. The structure, morphology, hydrophilic, anticorrosive, thermal conductive and electrical resistive properties have been analyzed for each individual layer and for the ATO/PS stack deposited on aluminum sheets, in order to develop a kind of new hydrophilic film with better properties.

2. Experimental

2.1. Materials

Antimony trichloride ($SbCl_3$, AR) was purchased from Aladdin Industrial Corporation. Tin chloride pentahydrate ($SnCl_4 \cdot 5H_2O$, AR) and Hydrochloric acid (HCl, 36-38 wt%) were obtained from Lingfeng Chemical Reagent Co. LTD (Shanghai, china). Potassium silicate solution (mole ratio of $SiO_2/K_2O = 2.5$ wt% in water, AR) was purchased from Huixin chemical Co. LTD (Guangzhou, china). Sodium hydroxide (NaOH, AR) was purchased from Sinopharm Chemical Reagent Co. LTD (Shanghai, china). Aluminum sheets with thickness of 1 mm were prepared from Hongwang Industrial Corporation (Shenzhen, China) and cut in with the dimension of 25 mm × 100 mm. All of the reagents were analytical grade and used without further purification.

2.2. Preparation of ATO/potassium silicate film

The schematic of the preparation of ATO/potassium silicate film was shown in Fig. 1. Pure aluminum sheets have been selected as the substrate due to the hydrophilic film is mainly applied on aluminum fins of heat exchanger. Aluminum sheets were cleaned first in 5 wt% sodium hydroxide solution for 10 min. Then, they were rinsed with deionized water for three times and dried under a thermal blower.

ATO film was synthesized on the surface of aluminum sheets through spray pyrolysis method. Firstly, Tin (IV) chloride pentahydrate was dissolved in dilute solution of 10 wt% hydrochloric acid. Antimony (III) chloride was added into the above solution following with magnetic stirring until the solutes dissolved absolutely, and made the molar ratio of Sn: Sb = 8: 2. The solution was transferred into medical atomizer then. When the aluminum sheets

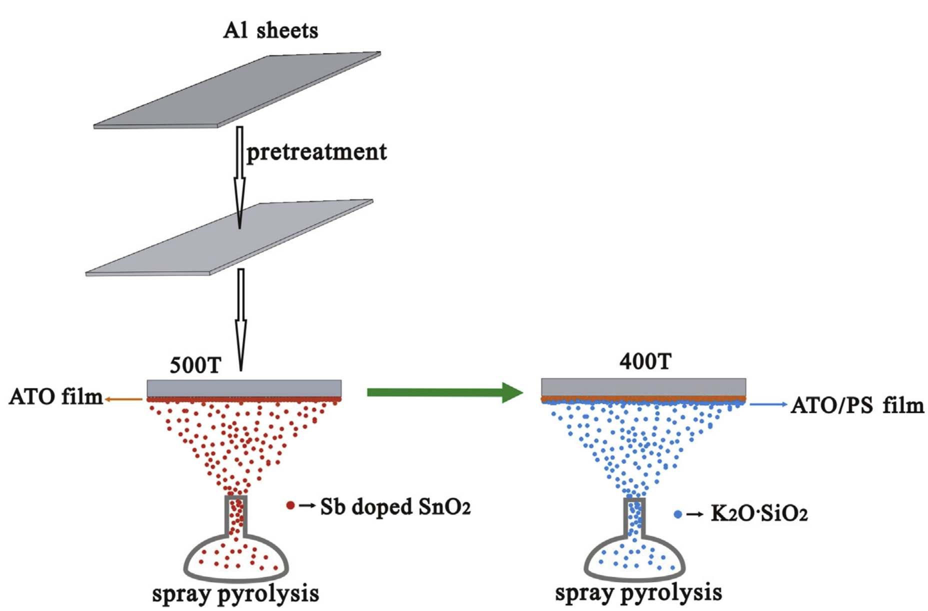

Fig. 1. The schematic diagram of preparation for the ATO/potassium silicate film by twice spray pyrolysis.