Available online at www.sciencedirect.com

ScienceDirect

Ceramics International 41 (2015) 1595–1601

CERAMICS INTERNATIONAL

www.elsevier.com/locate/ceramint

Fabrication of high infrared reflective ceramic films on polyester fabrics by RF magnetron sputtering

Dagang Miao[a], Hongmei Zhao[b], Qingxin Peng[a], Songmin Shang[a], Shouxiang Jiang[a,*]

[a]Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Kowloon, Hong Kong, China
[b]Department of Prosthodontics, The Affiliated Hospital of Qingdao University, Qingdao, China

Received 18 July 2014; received in revised form 16 September 2014; accepted 17 September 2014
Available online 28 September 2014

Abstract

In this project, AZO/Ag/AZO and AZO/Cu/AZO multilayer films were deposited on polyester fabrics with radio frequency (RF) magnetron sputtering technology. The prepared samples were systematically investigated with X-ray diffraction (XRD), Scanning Electron Microscope (SEM) and Fourier Transform Infrared Spectroscopy. Physical properties of the coated fabrics were evaluated by infrared reflection rate, contact angle (CA), air permeability and UPF value. The results indicated that the AZO/Ag/AZO coated polyester fabrics presented a high infrared reflection rate of 95–96% and CA of about 92.5°/93.5°, air permeability of 17.1/15.4 ml/s/cm^2 at 100 Pa and UPF values of 40.64/46.67. The AZO/Cu/AZO coated polyester fabrics exhibited an infrared reflection rate of 50–60%, CA of about 88°/88.5°, air permeability of 18.1/17.5 ml/s/cm^2 at 100 Pa and UPF values of 41.96/48.437.

Keywords: AZO/Ag/AZO; AZO/Cu/AZO; Polyester fabric; Infrared reflection; RF magnetron sputtering

1. Introduction

In recent years, researches on near-infrared (NIR) reflective thin films have attracted considerable attention and interest, particularly the ones related to highly visible transparent films. Such films have found a broad range of usages. For example, when coated on glass, they help to substantially reduce energy consumption of buildings. Transparent conductive oxides (TCOs) are promising materials for energy conservation films due to their high transparency level and high concentration of free electrons [1–4]. Of them, Al-doped ZnO (AZO) is an emerging TCO material and has been extensively investigated, because of its ability to substitute the widely used but expensive Indium Tin Oxide (ITO), and its rich reserve on the earth, non-toxic nature, reduction stability to hydrogen plasmas, and the relative easiness of its synthesis and processing [5]. However, the best NIR reflectance of AZO films can only be obtained when heating treatments are employed during or after the deposition process, which increases the overall cost of solar materials fabrication. Recently, TCO/Metal/TCO multilayer film has received a renewed interest as a highly promising route in fabricating solar materials [6–9]. It has been reported that the infrared reflective property of the TCO/Metal/TCO multilayer films is proportional to the metal's electrical conductivity [10–12]. Of all the metals, Ag and Cu have the highest electrical conductivity, thus AZO/Ag/AZO and AZO/Cu/AZO multilayer films have been intensively investigated, and a considerable amount of results have been reported.

Miao [10–12] has investigated the high infrared properties of AZO/Ag/AZO trilayers deposited on polyester film and glass substrate. Sahu [13] has prepared AZO/Ag/AZO trilayers by electron beam evaporation. Zhu [14] has studied the infrared emissivity of AZO thin films. Wu [15] and Crupi [16] have investigated the optimization of AZO/Ag/AZO structures. Lin [17] has studied the optoelectronics and microstructures of AZO/nano-layer metals/AZO. Jung [18] has characterized the AZO/Cu/AZO films prepared on polyethersulfone substrate. Wang [19] investigated the transparent, conductive and NIR reflective properties of Cu-based Al-doped ZnO multilayer films. However, most of infrared reflective thin films are deposited on rigid glass

*Corresponding author. Tel.: +852 2766 6430; fax: +852 27731432.
E-mail address: kinor.j@polyu.edu.hk (S. Jiang).

http://dx.doi.org/10.1016/j.ceramint.2014.09.096
0272-8842/

or polyester films to fabricate heat shielding glasses and window-films. These studies have enriched and deepened our understanding of these films. However, most of the infrared reflective thin films studied are deposited on rigid materials such as glass or polyester films to form heat shielding glasses and window-films.

Textiles possess unique properties, such as flexibility and permeability. Traditional heat shielding textiles are developed by coating a layer or layers of substance on the surface, and are widely used in various products such as curtains, tents, and umbrellas. However, these products have some limitations, such as low transparency, high visible light reflection, low air permeability and stiff hand feeling. To solve these problems, radio frequency (RF) magnetron sputtering technology was used in this project to deposit AZO/Ag/AZO and AZO/Cu/AZO multilayer films on polyester fabrics to form innovative heat shielding textiles. It has been proved that the nanostructure has a profound effect on the hydrophobic properties of the materials, that hydrophobic materials can be obtained by depositing nanostructured materials and the hydrophobic properties can be evaluated by the measurement of contact angle (CA) [20–22].

The surface morphology of the multilayer films coated polyester fabric was analyzed by a Scanning Electron Microscope (SEM). X-ray diffractometer (XRD) analysis was conducted to analyze the crystal structure of the multilayer films. In addition, the ultraviolet (UV) protection, contact angle, air permeability and infrared radiation properties of the coated polyester fabrics were also evaluated.

2. Experimental

AZO/Ag/AZO and AZO/Cu/AZO multilayer films were deposited on polyester fabrics (75D/180T 90✻90, 64.50 g/m^2) by a RF magnetron sputtering apparatus. Prior to deposition, the fabric substrates were ultrasonically cleaned in a detergent bath first and washed in acetone solution later, and then dried in nitrogen. The polyester samples were cut into 6 cm by 6 cm pieces and conditioned in accordance to ASTM D1776-08 before sputtering. Deposition parameters are shown in Table 1. Film thickness was controlled by an online measurement system which was calibrated by post-deposition measurements in a surface profile system (Alpha-Step 500) and film cross section measurement by Scanning Electron Microscope (JEOL-7100F). The accuracy of the film thickness was better than $\pm 5\%$. Both of the bottom and the top AZO layers were fixed at 30 nm, while the Ag and Cu inner layers were deposited at 15 and 20 nm, respectively.

The surface morphology of the coated fabrics was investigated by using a Scanning Electron Microscope (JEOL-7100F). Surface morphology was obtained by Atomic Force Microscopy (Bruker Nanoscope 8). Crystal structure of the AZO/Ag/AZO and AZO/Cu/AZO coated fabrics was characterized by $\theta/2\theta$ X-ray diffractometer (Rigaku SmartLab) using Cu Kα radiation ($\lambda = 0.154$ nm) (45 kV at 200 mA) at X'celerator normal mode. The XRD spectra were obtained at 2θ angles range of 30–70° with a scanning increment of 0.02°/step and the scanning speed was 5°/min. Contact angle measurements were conducted by using a contact angle meter (Model CAM-Moric; Tantec Inc.). Samples (2.0×2.0 cm^2) were taken from the coated fabrics and placed on the observation platform. A water drop of 5 μl was placed on the tested sample and the CA was taken by manual manipulation of the protractor on the apparatus. The measurements were taken on side of the water droplet 1 min after its placement. Air permeability measurements were taken by using an air permeability tester (SDL international, M021S) according to ISO 9237:1995. The testing area was 5 cm^2 and pressure drop across the testing area was 100 Pa. UV radiation penetration of the coated fabrics was evaluated with a UV–visible spectrophotometer (Varian, Cary 300 Conc) over wavelengths ranging from 280 to 400 nm. The ultraviolet protection factor (UPF) results were calculated by using the methods described in AATCC 183-2004. Infrared radiation properties of the coated samples were evaluated by Perkin Elmer Spectrum 100 Spectrophotometer ranging from 1.5 to 20 μm.

3. Results and discussion

3.1. XRD analysis

XRD spectra of the AZO/Ag/AZO and AZO/Cu/AZO coated polyester fabrics are shown in Fig. 1. In the AZO/Ag/AZO coated samples, both ZnO (002) and Ag (111) peaks can be observed in the XRD spectra. These results proved the well defined wurtzite ZnO structure and the crystallization of Ag inner layer in the multilayer films. Intensity of Ag (111) peaks increased with the increase of Ag layer thickness as expected. In the AZO/Cu/AZO coated samples, only ZnO (002) peak can be detected, which also proved that the wurtzite ZnO structure was formed in the AZO/Cu/AZO multilayer film. However, no obvious Cu peak was present in the XRD spectra, which may indicate that either the Cu particles were deposited in amorphous form in the multilayer film or the weak Cu peak diffraction was covered by the diffraction from the top AZO layer. The result is similar to that in other report [23] that Ag film presented higher intensity than that of Cu film under the

Table 1
Deposition parameters.

	AZO layers	Ag layer	Cu layer
Target	AZO (ZnO: Al_2O_3=98 wt%: 2 wt%) 99.99%;Φ9 cm	Ag 99.99%; Φ9 cm	Cu 99.99%; Φ9 cm
Base Pressure (Pa)	5×10^{-4}	5×10^{-4}	5×10^{-4}
RF power (W)	150	30	50
Ar flow rate (sccm)	40	25	30
Working pressure (Pa)	0.5	0.25	0.3
Target-substrate distance (cm)	10	10	10