Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 105 (2017) 4836 – 4841

Energy Procedia

The 8th International Conference on Applied Energy – ICAE2016

Antimony doped tin oxide/multi-walled carbon nanotubes: highly near-infrared blocking coating used for heat conservation windows

Xu Xingyu [a,b], Wang yuanhao [c,*], Wangshujun[a,†] ,Lu Lin [b]

[a]China University of Petroleum(Beijing),Beijing 102249,China
[b]The Hong Kong Polytechnic University, Kowloon 999077,Hong Kong
[c]Technological and Higher Education Institute of Hong Kong

Abstract

In this work, antimony doped tin oxide (ATO)/multi-walled carbon nanotubes (MWNTs) composite coating was prepared by introducing MWNTs and ATO nanoparticles into waterborne polyurethane matrix. This composite coating can be coated effectively on glass substrates with high near-infrared blocking property, which demonstrated a great potential for practical application in energy-saving windows used on modern buildings. The morphology, optical properties and mechanical hardness of coating film were investigated. Compared with blank glass substrates, the coating film retained high transmittance in the visible region but strong shielding in the near-infrared region. Meanwhile, by introducing MWNTs, the coating film was provided the mechanical hardness of 2H-3H.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.

Keywords: antimony doped tin oxide, multi-walled carbon nanocubes, near-infrared blocking, coating

1. Introduction

Nowadays, glazing materials have been widely used to replace conventional building envelopes for the purpose of aesthetic in modern buildings. However, the large area glazing materials on roofs and curtain walls will lead to the dramatic increase of electricity consumption of air-conditioning system, resulting to more energy consumption and carbon dioxide emissions. At present, considerable attentions are drawn for

* Wangyuanhao. Tel.:852-34003885;
E-mail address: yuanhaowang@yahoo.com.
† Wangshujun. Tel.: +8618901267897.
E-mail address: bjwsjbj@sina.com.

Peer-review under responsibility of the scientific committee of the 8th International Conference on Applied Energy.
doi:10.1016/j.egypro.2017.03.958

the objectives of meeting the increasing demands of environmental comfort and reducing the energy consumption of buildings[1-6]. Low-E glass reflects infrared light and thereby reduces the radiation of solar light. It consequently dominates the current market owing to its remarkably thermal insulation ability. However, it is still not at desired level because of the significantly high fabrication cost and light pollution [7].

Antimony doped tin oxide (ATO) is a well-known and promising semiconductor materials, due to its optically transparency and the intrinsic NIR absorption derived from surface plasma resonance[8, 9]. It has been deeply studied for a long time because of its wide applications ranging from solar filters, transparent electrodes, displays, gas sensors, catalysts to transparent thermal insulation coatings[10-14]. The heat insulation coating prepared by combining dispersed ATO into suitable resin has demonstrated to be an alternative to Low-E glass. However, the ATO particles are in nano scale and easy to aggregate due to high specific surface energy. It is very important to prepare highly stable ATO dispersions for keeping its special electrical and optical properties[15].

Carbon nanotubes (CNTs) with remarkable mechanical strength, excellent electrical conductivity and special optical properties have drawn increasing interests and been developed for a wealth of applications in nano-electronics, optics, and materials[16]. Combining MWNTs and ATO dispersions, the composite coating will exhibit better mechanical strength and NIR blocking effect.

In the present work, ATO dispersions was prepared by ball-milling using novel silane coupling agents. The final composite coating was prepared by introducing MWNTs and ATO nanoparticles into waterborne polyurethane matrix. The characterization of morphology, optical properties and mechanical hardness showed that the composite coating provides excellent NIR blocking property and good mechanical strength.

2. Experiment

The ATO nanoparticles were purchased from Huzheng Nanotechnology (Shanghai, China) Co., Ltd. The purchased Multi-walled carbon nanotubes were provided by Hengqiu Graphene Technology (Suzhou, China) Co. Ltd. Two silane coupling agents SIM6492.72 and SIB1824.82 were purchased from Gelest, Inc., (Morrisville, PA, USA) and the molecular structures were shown in Fig. 1. Waterborne polyurethane came from Jinan Huakai resin (Shandong, China) Co., Ltd. Concentrated nitric acid (HNO_3), concentrated sulfuric acid (H_2SO_4) and polyvinyl pyrrolidone (PVP) were all purchased from Aladdin Chemical Reagent (Shanghai, China) Co., Ltd. The glass substrates came from Sail Brand Company were used.

The ATO dispersions were prepared by dispersing the ATO nanoparticles in water with silane coupling agents SIM6492.72 and SIB1824.82 at concentration of 4wt%. Then the suspensions were transferred to a planetary ball mill (zirconia ball diameter of 0.6mm, rotation speed of 5000rpm) and milled for 6h. The dispersions contained a final concentration of 40wt% ATO nanoparticles.

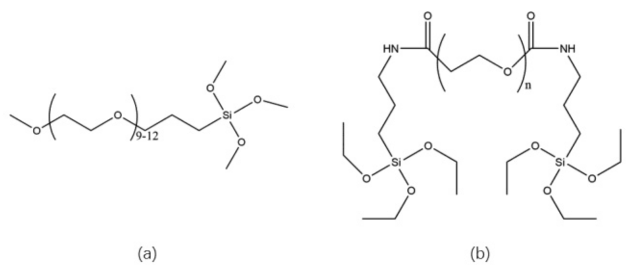

Fig. 1. The molecular structure of (a) SIM6492.72; (b) SIB1824.82

The acid mixture consists of concentrated nitric and concentrated sulfuric acid in a certain volume ratio of 3:1 was used to modified MWNTs. Then, the modified MWNTs were dispersed in water with surfactant PVP at concentration of 1wt%.

The composite coating was prepared by addition of MWNTs dispersions and ATO dispersions into waterborne polyurethane matrix. The final concentration of ATO was keep at 10wt%, corresponding a final concentration of MWNTs of 0.20wt%,0.15wt%,0.05wt% and 0wt%, respectively.

The glass substrates were washed by ultrasonic cleaner. All coated samples were prepared by dip coating method and the coated samples were carried out in a furnace in air at 75˚C for 15mim.

The morphology and thickness of coating film were studied by scanning electron microscopy (SEM). The morphology of the ATO dispersions and MWNTs dispersions were supplied by transmission electron microscopy (TEM). The hardness of the coating film was measured with pencil hardness tester. The optical transmissions were determined with a UV-VIS-NIR spectrophotometer.

3. Results and discussion.

3.1. Morphology of ATO/MWNTs composite coating film

The morphology and thickness of the composite film were studied using SEM images presented in Fig. 2. As shown in Fig. 2 (a), the left part is glass substrate and the right part is the surface of the coating film which was uniformly formed. Fig. 2 (b) illustrates that the thickness of the film was approximately 5um.

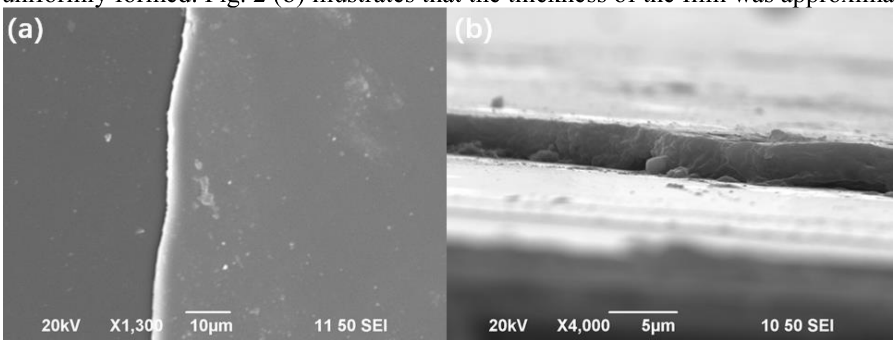

Fig. 2. SEM micrograph of surface (a) and section (b) of coating film with 10wt% ATO and 0.20wt% MWNTs.

3.2. Dispersion stabilization of ATO dispersions and MWNTs dispersions

As shown in Fig. 3, the dispersions of ATO nanoparticles and MWNTs in water were supplied by TEM. It can be clearly seen that there was no visible agglomeration of particles in dispersions. In Fig. 3 (a), single ATO particles of about 7-12nm in diameter can be detected, indicating the stability of the ATO dispersions. In Fig.3 (b), a single MWNT about 8nm dimeter was observed.

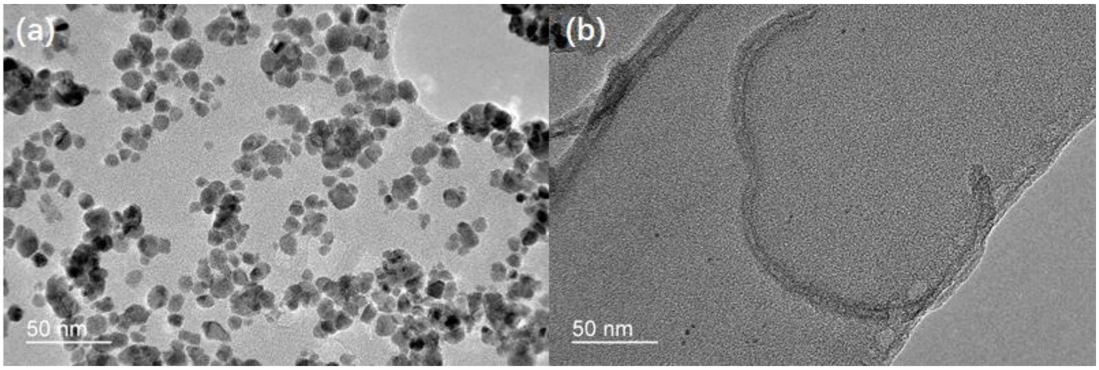

Fig. 3. TEM micrograph of ATO dispersions (a) and MWNTs dispersions (b).

3.3. Mechanical properties of ATO and ATO/MWNTs coating film

The addition of the MWNTs increased the hardness of the coating film from HB to 2H-3H, as shown in Table 1.

Table 1. Classification of coating film based upon standard mechanical tests.

Coating film	Pencil test classification
ATO	HB
ATO/0.05wt%MWNTs	2H
ATO/0.15wt%MWNTs	2H
ATO/0.20wt%MWNTs	3H

3.4. Optical performance of ATO and ATO/MWNTs coating film

The UV-VIS-NIR transmittance spectra of coating film was shown in Fig. 4. All the films had high visible transmission, while the ATO film and ATO/0.20wt%MWNTs film had a sharp fall of transmission in NIR region. It can be observed that the NIR blocking property of the coating film showed a significant improvement just only adding a really small amount of MWNTs at the content of 0.20wt%.

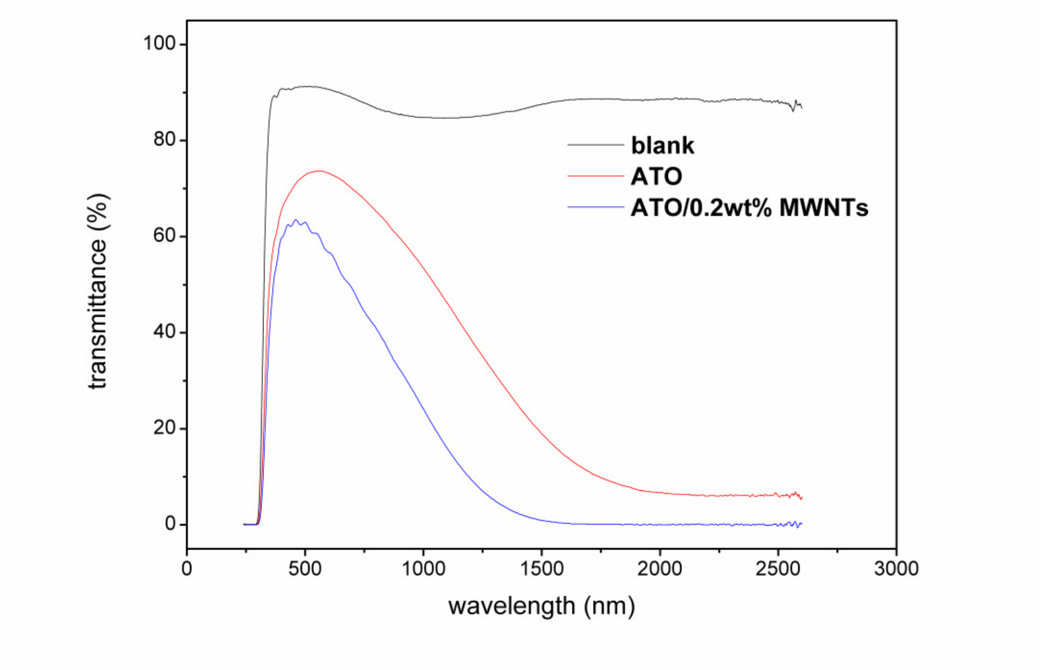

Fig.4. Transmittance of ATO and ATO/MWNTs coating film.

4. Conclusion

In summary, a transparent coating with NIR blocking property was developed using waterborne polyurethane matrix with addition of ATO and MWNTs nanoparticles. The composite coating film with 10wt% ATO and 0.20wt% MWNTs exhibited high transmittance in the visible region but strong shielding in the near-infrared region. At the same time, the hardness of the coating film was improved from HB to 2H-3H with the application of MWNTs. Thus, ATO/MWNTs composite coating with high near-infrared blocking property, demonstrated a great potential for practical application in energy-saving windows used on modern buildings.

5. Copyright

Acknowledgements

This study was funded by Hong Kong Innovation and Technology Fund.

References

[1]. Baetens, R., B.P. Jelle and A. Gustavsen, Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A state-of-the-art review. *Solar Energy Materials and Solar Cells*, 2010. 94(2): p. 87-105.

[2]. Schultz, J.M., K.I. Jensen and F.H. Kristiansen, Super insulating aerogel glazing. *Solar energy materials and solar cells*, 2005. 89(2): p. 275-285.

[3]. Fang, Y., et al., Low emittance coatings and the thermal performance of vacuum glazing. *Solar Energy*, 2007. 81(1): p. 8-12.

[4]. Manz, H., et al., TIM – PCM external wall system for solar space heating and daylighting. *Solar energy*, 1997. 61(6): p. 369-379.

[5]. Han, K. and J.H. Kim, Reflectance modulation of transparent multilayer thin films for energy efficient window applications. *Materials Letters*, 2011. 65(15 – 16): p. 2466-2469.

[6]. Chiba, K., et al., Low-emissivity coating of amorphous diamond-like carbon/Ag-alloy multilayer on glass. *Applied surface science*, 2005. 246(1): p. 48-51.

[7]. Cuce, E. and S.B. Riffat, A state-of-the-art review on innovative glazing technologies. *Renewable and Sustainable Energy Reviews*, 2015. 41: p. 695-714.

[8]. Wang, L., et al., Preparation and characterization of NIR cutoff antimony doped tin oxide/hybrid silica coatings. *Materials Letters*, 2012. 87: p. 35-38.

[9]. Li, Y., et al., Preparation and characterization of transparent Al doped ZnO/epoxy composite as thermal-insulating coating. *Composites Part B: Engineering*, 2011. 42(8): p. 2176-2180.

[10]. Volosin, A.M., et al., One-pot synthesis of highly mesoporous antimony-doped tin oxide from interpenetrating inorganic/organic networks. *Journal of Materials Chemistry*, 2011. 21(35): p. 13232-13240.

[11]. Santos-Pena, J., et al., Antimony doping effect on the electrochemical behavior of SnO 2 thin film electrodes. *Journal of power sources*, 2001. 97: p. 232-234.

[12]. Coleman, J.P., et al., Antimony-doped tin oxide powders:: Electrochromic materials for printed displays. *Solar energy materials and solar cells*, 1999. 56(3): p. 375-394.

[13]. Xu, J., et al., Antimony doped tin oxide modified carbon nanotubes as catalyst supports for methanol oxidation and oxygen reduction reactions. *Journal of Materials Chemistry A*, 2013. 1(34): p. 9737.

[14]. Zhou, H., et al., Preparation and properties of waterborne polyurethane/antimony doped tin oxide nanocomposite coatings via sol-gel reactions. *Polymer Composites*, 2013: p. n/a-n/a.

[15]. Li, N., Q. Meng and N. Zhang, Dispersion stabilization of antimony-doped tin oxide (ATO) nanoparticles used for energy-efficient glass coating. *Particuology*, 2014. 17: p. 49-53.

[16]. Sun, Y., et al., Functionalized carbon nanotubes: properties and applications. *Accounts of Chemical Research*, 2002. 35(12): p. 1096-1104.

Biography

Mr. Xu Xingyu is currently a PhD candidate in China University of Petroleum (Beijing) and a research assistant in The Hong Kong Polytechnic University. His research interests include energy science and chemical engineering and technology.