

The 7th International Conference on Applied Energy – ICAE2015

TEOS/Silane-Coupling Agent Composed Double Layers Structure: A Novel Super-hydrophilic Surface

Hu Yan^a, Wang Yuanhao^b, Yang Hongxing^{c*}

^aThe Hong Kong Polytechnic University, Hong Kong

^bThe Hong Kong Polytechnic University, Hong Kong

^cThe Hong Kong Polytechnic University, Hong Kong

Abstract

In order to increase the anti-dust and self-cleaning property of photovoltaic cells, this paper proposes a simple way to synthesis a novel self-cleaning, super-hydrophilic coating material based on double layers structure. The first layer is made from TEOS for gaining the number of Si-OH bond on the surface of the glass, and then the second layer, which is a special silane-coupling agent, is attached on the TEOS layer firmly. Since the silane-coupling agent has a super-hydrophilic chain, after the reaction, such kind of chain would go towards to the outside surface of the glass substrate and make the surface super-hydrophilic.

© 2015 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: Super-hydrophilic, double layers, silane-coupling agent

Instruction

Greenhouse gas emissions due to burning fossil fuels are the great challenge to human beings nowadays. For decreasing fossil energy consumption, renewable energy should be used. Solar energy application is an effective method. And an effective way to use the solar energy is to generate solar power from photovoltaic (PV) cells. ^[1] However, a lot of factors affect the energy efficiency of solar PV panels, such as the temperature, orientation, solar radiation intensity, front surface soiling ^[2-5] and so on. Among them, front surface soiling could influence the efficiency a lot if the PV cell is soiled badly. For example, the dust accumulation on the front surface is a major factor, which cause the huge decrease of the cell

* Corresponding author. Tel.: +00852-2766 5863; fax: +00852-2774 6146.

E-mail address: hong-xing.yang@polyu.edu.hk.

efficiency.^[6] In this case, self-cleaning material is applied. And this paper is to present a research delivery for producing a cheap and easy to made self-cleaning material for solar PV applications.

Contact angle (CA) is a closely related concept with self-cleaning material. As shown in Fig. 1, it is defined as the angle between the solid surface and the tangent line of liquid at the contact point between the three phases. CA represents the wettability of a particular surface. The bigger the CA is, the worse the wettability is. Generally speaking, it could be described as hydrophilic if the CA is less than 90° and if more than that, it is called hydrophobic. Moreover, if CA is less than 10° , it could be named as super-hydrophilic, and when it is more than 150° , it is super-hydrophobic. Both super-hydrophilic and super-hydrophobic material could be call self-cleaning materials.

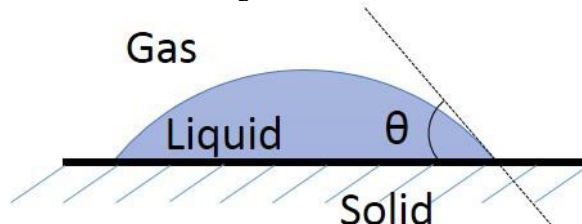


Fig. 1. Contact angle θ

For super-hydrophobic surface, the hydrophobic property derive from the micro-nano structure and some special coating like polytetrafluoroethylene.^[7-8] However such micro-nano structure is too sophisticated to maintain easily. And the polytetrafluoroethylene is not very economical. Thus, in self-cleaning field, much and much attention is attracted by the super-hydrophilic material.

Generally, two main kinds of materials are used to form the super-hydrophilic surface: the inorganic and organic. The inorganic subjects consist of TiO_2 ^[9], SiO_2 ^[10], $\text{In}_2\text{O}_3\text{-SnO}_2$ ^[11], Cu_2O and CuO ^[12]. And the organic subjects include PNIPAAm/PLLA (poly(N-isopropylacrylamide)/ poly(L-lactide))^[13], DMAEMA/MMA (2-(dimethylamino)-ethylmethacrylate/methyl methacrylate)^[14]. Those materials require some special processes to achieve the super-hydrophilic property, such as the sol-gel method, electro spinning, plasma technique, vapor deposition. In this paper, a simple method which forms two layers structure (the first layer is hydrophobic and the second is hydrophilic) is applied. TEOS (tetraethoxysilane) is applied as the hydrophobic layer and a special kind of silane-coupling agent is used as the hydrophilic layer. Since the front surface of most photovoltaic cells are made from glass, glass sheets are used to simulate the front glass of photovoltaic cells in this work.

The silane-coupling agent used in this work is named as 2-[acetoxypoly(ethyleneoxy)propyl]triethoxysilane (SIA0078.0, abbreviated as SIA), and the molecular structure is shown in Fig. 2. It could be seen clearly that it has a long hydrophilic chain (repeated ether bonds, and a carbonyl group) and at the other side, there are three silicon hydroxyl groups. In the ideal reaction, the $-\text{SiOCH}_2\text{CH}_3$ group would be hydrolyzed into $-\text{SiOH}$, and then it will condense with the $-\text{SiOH}$ which is on the surface of the glass and forms the Si-O-Si bond. In this case, the hydrophilic chain would go toward the outside of the substrate so that the surface would turn into hydrophilic.

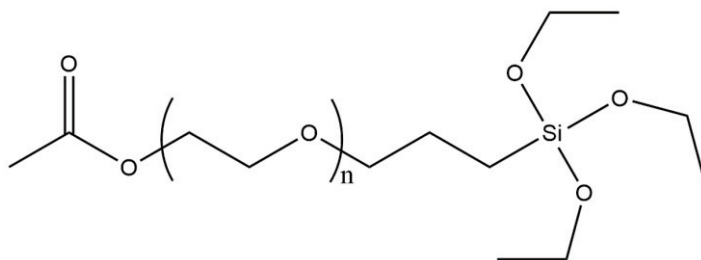


Fig. 2. The molecular structure of SIA0078.0

However, in practical situation such kind of SIA would be washed away from the surface easily. The probable reason is that there are not enough Si-OH bonds on the glass surface. Thus, in order to increase the number of Si-OH bonds, a layer of TEOS (Tetraethylorthosilicate) is pre-coated on the surface. In this case, the TEOS would form a dense membrane firstly which creates more Si-OH bonds on the surface. Finally the SIA would be attached on the TEOS membrane strongly. The scheme structure is shown in Fig. 3.

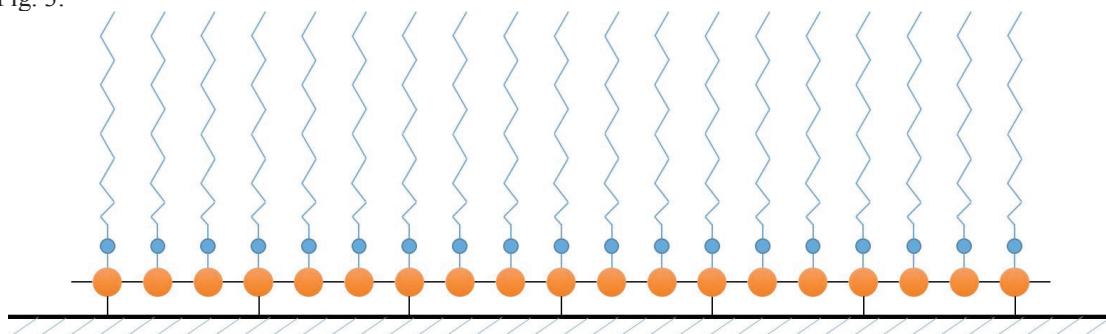


Fig. 3. The scheme structure of the super-hydrophilic surface



Experiment

The silane-coupling agent (SIA0078.0) comes from the Gelest, Inc (Morrisville, PA, USA). The TEOS (analytical pure) comes from Sigma-Aldrich. The acetic acid comes from Sigma-Aldrich. The glass sheets come from Sail Brand Company is used.

In this paper, the glass sheets are firstly cleaned with cleaning compounds. After dried in room temperature, they are soaked in the TEOS for 10 minutes. When dried again, they are merged into the SIA solution (mass concentration is 1% and adjust the pH around 5.5 with acetate acid). Heat the solution to 75°C for 10 minutes.

The FT-IR charts are obtained via Nicolet iS50 FT-IR, Thermo Scientific. The contact angle data is measured by Contact Angle Goniometer Sindatek Model 100SB.

Results

The FT-IR image of glass coated with single layer TEOS is shown in Fig. 4, and the FT-IR image of glass coated with TEOS and SIA is shown in Fig. 5. It could be seen from Fig. 4 that the peaks at 2974, 2890, 1448, 1395, 1166 cm^{-1} represent the characteristic peak of $-\text{CH}_3$ and the peak at 2927 cm^{-1} represents the existence of $-\text{CH}_2-$. The peaks at 1077 and 946 cm^{-1} demonstrate that the Si-O-Et bonds exist. And the peak at 792 cm^{-1} is the stretching peak of Si-C bond. According to the information from Fig. 4, the conclusion could be drawn that TEOS does be grafted on the glass surface.

Fig. 5 is the FT-IR of the sample which has double-layers structure. The first layer is the TEOS, and the second layer which is grafted on the TEOS is the SIA. Similarly, the peaks at 2975 and 2884 cm^{-1} reveal the $-\text{CH}_3$ groups in the sample. However, the concentration is much less than what is shown in Fig. 4. The peak at 1736 cm^{-1} represents the C=O bond, and the peak at 1136 cm^{-1} reveals the C-O bond. The Si-O bond is shown by the peaks at 1007 and 909 cm^{-1} . And the existence of Si-C bond is demonstrated by the peak at 774 cm^{-1} . From the characteristic peaks above associated with the molecular structure of SIA used in the work (Fig. 2), it could be seen that the SIA is coated on the surface.

Then, the contact angles of such surfaces are measured. It is shown in Fig. 6. For the original glass, the contact angle is 52.15° and for the coated glass which is shown in Fig. 6b, the contact angle is 4.7° .

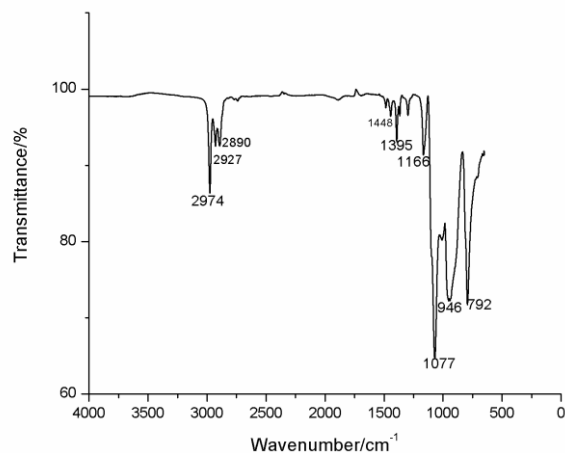


Fig. 4. The FT-IR image of glass coated with TEOS

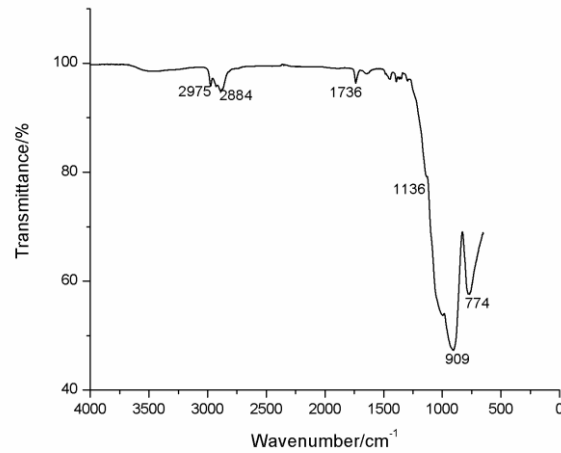


Fig. 5. The FT-IR image of glass coated with TEOS and SIA

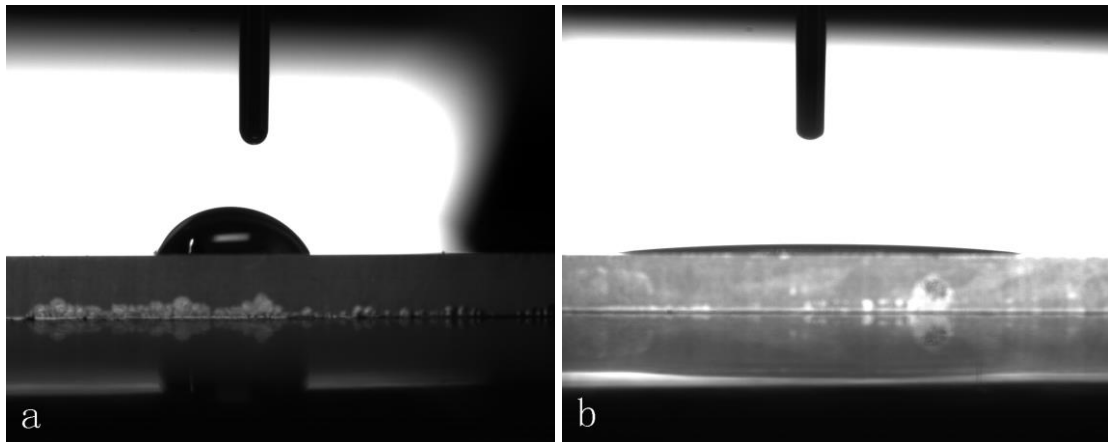


Fig. 6. a: The contact angle of blank glass; b: The contact angle of glass coated with double layers structure

Conclusions

From the FT-IR chart and the contact angle pictures, conclusions could be drawn that such kind of TEOS/SIA double layers structure is formed successfully on the glass surface which makes the surface a good super-hydrophilic property. However the coating could be used not only on the PV cell glass surface, but also on any other glass surface, such as the glasses on vehicles, curtain walls and so on.

Copyright

Authors keep full copyright over papers published in Energy Procedia

Acknowledgements

The work described in this paper was supported by a grant from the CII-HK / PolyU Innovation Fund.

References

- [1] Bube R H, Bube R H. Photovoltaic materials[M]. Amsterdam: Imperial College Press, 1998.
- [2] Ito S, Murakami T N, Comte P, et al. Fabrication of thin film dye sensitized solar cells with solar to electric power conversion efficiency over 10%[J]. Thin solid films, 2008, 516(14): 4613-4619.
- [3] Kim J Y, Kim S H, Lee H H, et al. New Architecture for high-efficiency polymer photovoltaic cells using solution-based titanium oxide as an optical spacer[J]. Advanced Materials, 2006, 18(5): 572-576.
- [4] Hanna M C, Nozik A J. Solar conversion efficiency of photovoltaic and photoelectrolysis cells with carrier multiplication absorbers[J]. Journal of Applied Physics, 2006, 100(7): 074510.
- [5] Peet J, Kim J Y, Coates N E, et al. Efficiency enhancement in low-bandgap polymer solar cells by processing with alkane dithiols[J]. Nature materials, 2007, 6(7): 497-500.
- [6] Mekhilef S, Saidur R, Kamalisarvestani M. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells[J]. Renewable and Sustainable Energy Reviews, 2012, 16(5): 2920-2925.
- [7] Feng L, Li S, Li H, et al. Super-hydrophobic surface of aligned polyacrylonitrile nanofibers[J]. Angewandte Chemie, 2002, 114(7): 1269-1271.
- [8] Feng L, Li S, Li Y, et al. Super-hydrophobic surfaces: from natural to artificial[J]. Advanced materials, 2002, 14(24): 1857-1860.
- [9] Wang R, Hashimoto K, Fujishima A, et al. Light-induced amphiphilic surfaces[J]. Nature, 1997, 388: 431-432.
- [10] Machida M, Norimoto K, Watanabe T, et al. The effect of SiO₂ addition in super-hydrophilic property of TiO₂ photocatalyst[J]. Journal of Materials science, 1999, 34(11): 2569-2574.
- [11] Premkumar J R, Khoo S B. Electrochemically generated super-hydrophilic surfaces[J]. Chemical communications, 2005 (5): 640-642.
- [12] Tang K, Wang X, Yan W, et al. Fabrication of superhydrophilic Cu₂O and CuO membranes[J]. Journal of membrane science, 2006, 286(1): 279-284.
- [13] Gu S Y, Wang Z M, Li J B, et al. Switchable Wettability of Thermo - Responsive Biocompatible Nanofibrous Films Created by Electrospinning[J]. Macromolecular Materials and Engineering, 2010, 295(1): 32-36.
- [14] Zhao J, Meyer A, Ma L, et al. Acrylic coatings with surprising antifogging and frost-resisting properties[J]. Chemical Communications, 2013, 49(100): 11764-11766.