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ANTI-SOILING COATING OF SOLAR PANELS TO INCREASE THEIR EFFICIENCY

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Abstract

Dust accumulation on the protective glass of solar photovoltaic (PV) modules gradually decreases the power output especially in many cities of Pakistan due to the dusty environment. The transmittance of sunlight through the glass of solar panel can be reduced by 90% in a single month due to dust deposit, this phenomenon is also known as soiling effect. To overcome this problem, a hydrophobic coating by sol-gel process is indigenously prepared and coated on solar panel glass. Initially, the silica nano-particles prepared by Stober's method, then silica solution treated with (3-Aminopropyl)Triethoxysilane (APTEOS) for the formation of particle network followed by treatment with Hexadecyltrimethoxysilane (HDTMS) to attain desired hydrophobicity while maintaining transparency. To acquire information on hydrophobicity the contact angle of coated glass was measured using IMAGEJ software, and transmittance was measured by spectrophotometer. In addition, SEM surface micrograph of coated specimens was taken to observe the size of the nano-particles. Similarly, AFM test was carried out to know the surface roughness of the nano-coating glass substrate.

Keywords: Hydrophobic; Nano-particles; Transparency; Surface roughness.

1. INTRODUCTION

Solar irradiance from the sun can be harness in the form of electricity by the converting photos to electrons by solar PV modules. Conventionally, PV modules are made of semiconductors and the P-N junction plays critical role in transforming energy of photons to push electrons across the P-N barrier. The performance characteristics of solar PV modules largely dependent on flux of solar radiation falling on modules surface, module tilt angle, properties of materials from which modules are made and gradual degradation of modules efficiency due to dust accumulation over the exposed surface. Over the last decade studies have been done to find degradation parameters of solar cells efficiency due to soiling effect. Dust accumulation is a severe problem for solar PV modules that attributes to 17%-32% reduction in the performance of solar PV [1]. Similarly, the transmittance of sunlight through the glass of solar panel can be reduced by 90% in one month [2]. The dust accumulation process is natural as it initiates by a dust layer deposition over the glass surface until surface is covered by the dust. Then a second layer pile up on the top of firs layer and so on. To avoid soiling effect a regular cleaning of solar panels is required. Water based cleaning is a firsthand solution, which is labor intensive with a challenge of optimum use of water. For economical and effective cleaning of protective glass, the hydrophobic coating is proposed in this research, which will repel the accumulated dust layer when water drops gets in contact with the surface of glass.

In this study, the hydrophobic coating is prepared by sol-gel process [3] in which silica particles were prepared by stober's method [4]. Dip coating method is used for hydrophobic nano-coating. APTEOS was used to form particle network of silica nano-particles due to which arthimatic mean roughness of 2.80 nm is achieved. Increase in surface roughness improves the hydrophobicity [5], therefore surface roughness is increase by the use HDTMS to gain hydrophobicity. This action ultimately increase the arithmetic mean roughness up to 3.85 nm. The prepared hydrophobic nano-coated glass substrates posse the static contact angle (>100°) and transmittance (> 74%).

2. Experimental procedure

2.1 Materials

Tetraethoxysilane (TEOS, 99%), ethanol absolute (99.9%), ammonia solution 32% concentrated, oxalic acid, 3-Aminopropyl)Triethoxysilane (APTEOS), hexadecyltrimethoxysilane (HDTMS), sulphuric acid and deionized water.

2.2 Preparation of hydrophobic coating

Hydrophobic nano-coating was prepared by sol gel method. At first silica solution prepared by using Stober's method to control the growth of silica nano-particles. The silica solution mole ratio consists of TEOS: ethanol: NH_3: H_2O = 0.24 & 0.35: 17: 0.81: 6.25. The silica solution was stirred at 50 °C for 1 hour. The as prepared silica solution was kept on stirring for further 2 hours to remove NH_3 and to achieve stable silica sol.

Then the pH of silica solution was lowered from 8 to 3 by adding oxalic acid to increase the rate of hydrolysis and condensation reaction that occurs in a solution between TEOS and ethanol. After preparing silica solution a few drops of APTEOS (0.1 vol. %) was added, which acts as an aggregating agent to form the silica nano-particles network. The solution was continuously stirred for 30 min and maintained at 60 °C during the addition of APTEOS and Oxalic Acid followed by cooling in cold water immediately. The APTEOS modified silica sol was denoted as AP-sol. The AP-sol was basically a gel due to the formation of silica particle network.

The glass substrates were cleaned in sulphuric acid for 15 min to remove the contaminated surface. The cleaned substrates were then immersed in AP-sol for 5mins. After that, the coated substrates were annealed at 150 °C for 1 hour for the firma adhesion of nano-coating. Later, HDTMS (2 vol. %) is mixed with ethanol (96 vol. %) and deionized water (2 vol. %). The AP-sol substrates were immersed in HDTMS solution for 30 min at 50 °C to further to increases roughness which helps in gaining hydrophobicity. The coated samples were annealed at 150 °C for 90 min to improve the bonding characteristics.

3. Results and discussion

3.1 Reaction system

For the preparation of silica solution, the mole ratio of TEOS: Ethanol: NH_3: H_2O = 0.28: 17: 0.81: 6.25 and 0.35: 17: 0.81: 6.25are prepared in a two separate containers. The concentration of TEOS was altered to observe the behavior of hydrophobicity of nano-coating. The variation in coating concentration is presented in Table 1.

Table 1 Concentrations of chemicals used in the preparation of silica solution.

Mole Ratio TEOS: Ethanol: NH_3: H_20	TEOS vol.%	Ethanol vol.%	Ammonia Sol. 32% concentrated vol.%	Deionized H_2O vol.%
0.28: 17: 0.81: 6.25	5.28	83.92	4.01	6.78
0.35: 17: 0.81: 6.25	6.51	82.83	3.95	6.69

Similarly the concentration of APTEOS in AP-SOL was 0.1 vol. % of the silica solution.

The concentration of HDTMS, ethanol and deionized water for the preparation of HDTMS solution are mentioned in Table 2.

Table 2 HDTMS solution

HDTMS	2 vol. %
Deionized water	2 vol. %
Ethanol	96 vol. %

3.2 Contact angle and transmittance of hydrophobic nano-coating

The static contact angle of hydrophobic nano-coating was measured using IMAGEJ software as shown n Figure 1 and Table 3. It has been observe that change in concentration of TEOS with in a range of 0.25M-0.35M produce significant results [6]. For hydrophobic coating the contact angle should be greater than 90°.

Table 3 Contact angle of hydrophobic nano-coating

Mole Ratio TEOS: Ethanol: NH_3: H_20	Contact Angle	Standard Deviation
0.28: 17: 0.81: 6.25	98.08°	1.89
0.35: 17: 0.81: 6.25	103.30°	2.24

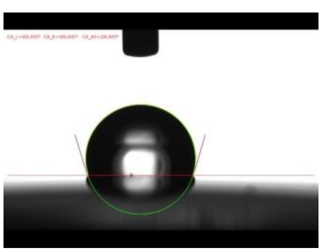


Figure 1 contact angle measured using IMAGEJ software

Similarly the transmittance of coated substrates was measured using spectrophotometer. It has been observe that uncoated substrate has a maximum transmittance of 90.48%, while the coated substrates have transmittance of 75.07%. Transmittance of uncoated and coated glass samples is plotted in Figure 2. Importantly, any change in the concentration of TEOS in the preparation of silica solution does not significantly alter the transmittance of coated substrates.

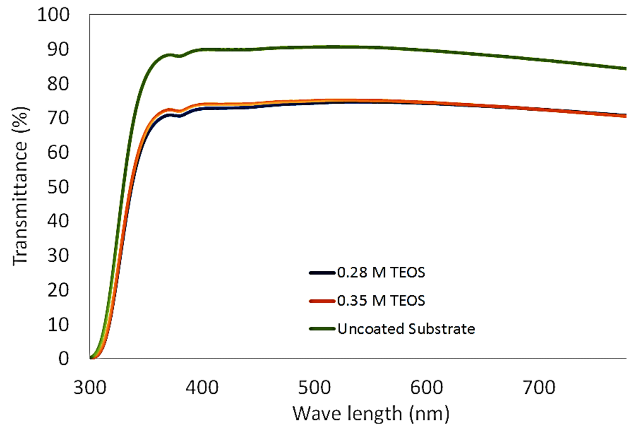


Figure 2 transmittance of hydrophobic nano-coating

Table 4 the transmittance of coated and uncoated substrates in three visible wavelengths.

Samples Concentration of TEOS	Transmittance (%)		
	400 nm	550 nm	700 nm
0.28 M	72.65	74.65	72.49
0.35 M	73.88	75.07	72.47
Uncoated Substrate	89.82	90.48	86.93

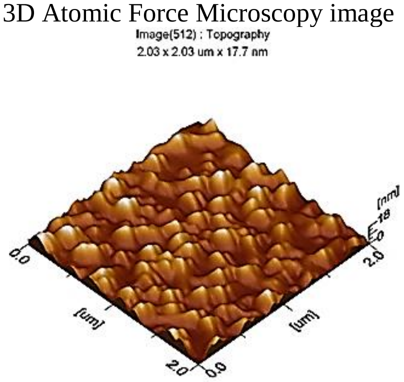
3.3 AFM analysis of hydrophobic nano-coating

The AFM measurement of AP-sol Nano coating and HDTMS solution coating is shown in Table 6 and Table 7, respectively. A large number of peaks and valleys stand on the surface of AP-sol nano-coating and HDTMS solution coating. The height profile curves verify the results of 3D AFM images, from which frequently fluctuant height profiles can be seen for AP-sol and HDTMS-sol coating. The RMS roughness (R_q) value of AP-sol Nano coating is about 3.40 nm, indicating the sub 18 nm roughness and after HDTMS solution coating the RMS roughness (R_q) value is about 4.70 nm, indicating the sub 23 nm roughness. It has been observe that the surface roughness increases significantly due to HDTMS solution coating due to which hydrophobicity is achieved.

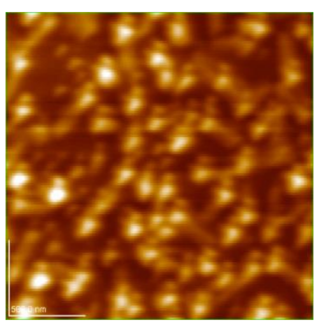
Table 5 surface roughness of AP-sol Nano Coating and HDTMS solution coating.

Roughness parameters	AP-sol Nano Coating, nm	HDTMS solution coating, nm
R_a	2.80	3.85
R_{RMS}	3.40	4.70
R_z	17.7	22.9

(a) 3D Atomic Force Microscopy image



(b) 2D AFM image



(c) Height profile curve of AP-sol nano-coating

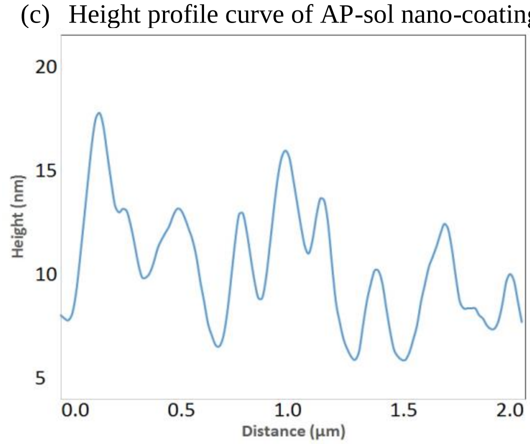
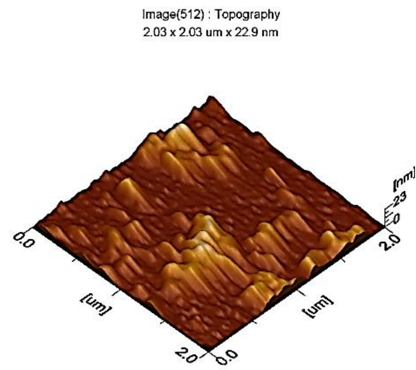
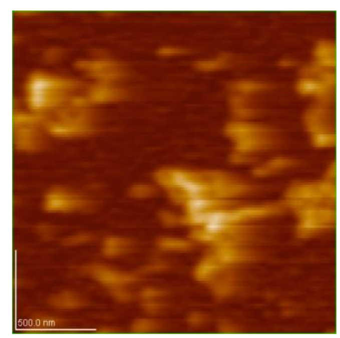


Figure 3 AFM of 0.35 M TEOS AP-solution coated substrate.

(a) 3D Atomic Force Microscopy image



(b) 2D AFM image



(c) Height profile curve of HDTMS solution coating

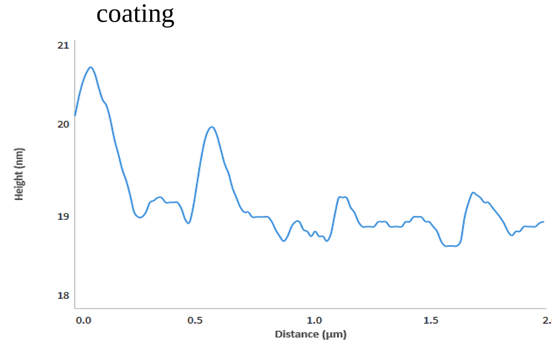


Figure 4 AFM of 0.35 M TEOS HDTMS solution coated substrate.

CONCLUSIONS

Transparent hydrophobic nano-coating prepared by sol-gel process possess arithmetic average value roughness (R_a) of 3.85 nm and water contact angle of 103.3°. The moisture resistance of coating is attain by treating with Hexadecyltrimethoxysilane (HDTMS). The maximum transmittance of as-obtained nano-coating is 75%. The as prepared transparent hydrophobic nano-coating can maintain its hydrophobicity even after exposing to ambient condition.

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