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Silica based nano-coating over the Glass Substrate Enhancing its Optical Properties in order to Increase the Efficiency of Solar PV

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Abstract—*ARC over the glass surface of a solar cellcan provide a smooth advance in the optical properties by increasing the proportion of light transmitting, thereby minimizing reflection losses. In this work, glass was taken as a simulated solar cell and Silica has been layered over glass by using TEOS as a precursor via sol-gel dip coating technique, where most of the experiment was conducted at room temperature. The transmittance was increased by 3%, which suits well for the expected result. Analysis of the surface roughness shows that the surface coating is smooth with the RMS value of ~30 nm. In addition to enhancing the anti-reflection properties, TMCS was used to modify the terminal OH group with non-polar group, converting the surface from hydrophilic to hydrophobic, making it self-cleaning in nature. Analysis of the functional groupswere also examined with the help of FTIR spectroscopy.*

Keywords*: ARC, TEOS, TMCS, sol-gel dip coating.*

1. INTRODUCTION

Renewable energy sources are the future of our world, among which solar energy is the most efficient one. It is responsible for the other renewable energy sources too, such as, solar irradiation induces temperature differences in the environment resulting in the formation of wind, wind generates waves, water evaporation because of sunlight initializes clouds and rain formation, and so on. Therefore, solar energy is the only real energy source and is used by two methods, either as solar thermal or photovoltaic (PV).

PV technology is a kind of technique where the conversion of light energy into electrical energy is conceivable specifically with no impedance of heat engines. PV devices are basic in design which requires very less maintenance and their greatest advantage is providing large outputs with solitary construction systems. These systems are used for various applications like, space vehicles, remote buildings, water pumping, power source, satellites, communications, solar systems for home, etc. The need for photovoltaic has been increased a lot so far, and still increasing on a large scale with an immense range of applications.

The percentage of light energy converted into electrical energy by PV, i.e., the efficiency of this technology is very low, up to 22% [1], and efforts are being put on all over the world to enhance it. Researchers and scientists had been involved in a tremendous amount of research activities to develop and propose various methods to effectively use the Sun's energy, increasing the performance of a photovoltaic system. One method is the choice of materials holding the property to absorb the light, generating electron-hole pairs to be separated and extracted to an external circuit in order to generate electricity.The conversion efficiency is pertained to the efficiency of PV modules which are comprised with a number of small solar cells. These cells are made up of different kind of materials, which primarily includes silicon; polycrystalline, monocrystalline and amorphous [2, 3], copper-indium-gallium-sulfide [4, 5], copper-indium-gallium-selenide [6], and cadmium-telluride [7]. The inventions of new materials to be used for making a solar cell occurred because of the need to enhance its efficiency, but are limited either due to the availability of such elements or the cost of manufacturing. Second, the orientation of the mounting structures of suchmodules, depending upon the area's angle of latitude, also supports to entrap more radiation, but the angle and the height of such structures above the ground level are fixed for a particular location.

The working of a solar cell is dependent not only on the semiconductor materials, but also on the glass placed on top of the surface. Hence, the other strategy to heighten the functioning of PV found out to be to improve the optical properties of the glass. Glass is an integral and important element of photovoltaic. The sun rays are transmitted through the glass where the photons of light transfer their energy to the electrons, thereby producing electricity. To achieve better efficiency, there should be high transmission with very low reflection of the light energy and for that anti-reflective coatings (ARC) play a remarkable role in obtaining such desirable properties.

Different kind of techniques have been used to deposit ARC, for instance, PVD, CVD, spray coating and spin coating method. When compared with these processes, Sol–Gel is a flexible and inexpensive process commercialized on an industrial scale apart from being the most profitable technologies to develop crystalline or amorphous oxide coatings [8]. Final coatings with better homogeneity is conceivable under the standard environmental conditions. By controlling the temperature and in addition the chemistry of the reacting materials, especially their molar proportions, the parameters of ARC can be effectively controlled [9, 10].

A solar panel is also vulnerable to the natural and environmental factors like dust, rain, deposition of soil, bird droppings, etc., resulting in the inefficiency of these operating systems. Coatings with hydrophobic nature has a self-cleaning effect [11, 12] which can ultimately reduce the power losses. This is one of the best solutions by which it is possible to get rid of the need to clean the surface of a solar panel on a regular basis and helpful for industries to save a lot of money.

In this work, a single layer transparent ARC was prepared over the glass substrate via sol–gel dip coating technique, based on the formulation of silica gel, which is in the nanometer range consisting macroscopic networks. In addition, the final product of the sol-gel process was hydrophobized before the coating to be fabricated on the glass surfaces. The samples were then characterized to obtain the optical properties, hydrophobicity and surface properties.FTIR spectrophotometer aided the analysis of the chemical bonds present on the surface.

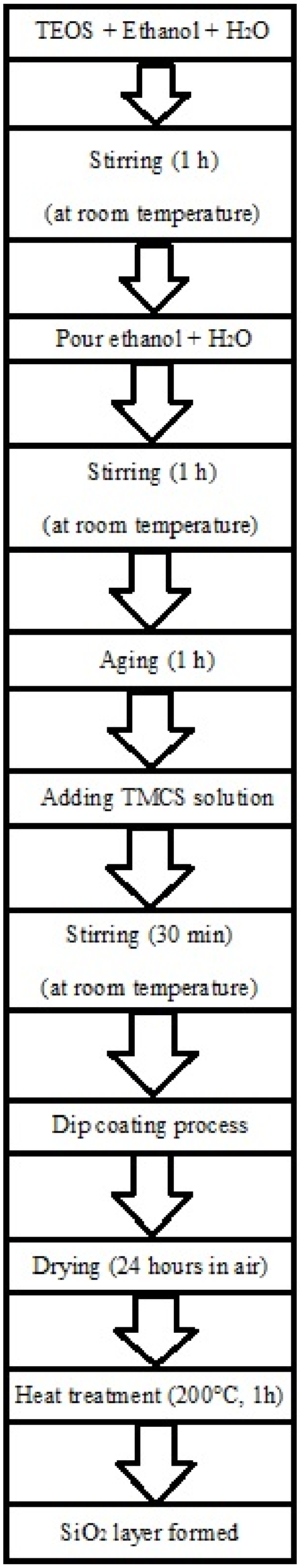


Figure 1: Flow chart of sol-gel dip coating process

2. EXPERIMENTAL DETAILS

2.1. Materials

The glass substrates used for the preparation of hydrophobic ARC were the ordinary glass slides mainly utilized for the optical microscopic analysis and biological experiments. Thelength, breadth and height of these specimens considered were 75 mm, 25 mm and 1 mm respectively. Also, the chemicals taken into account were utilized as obtained. Tetraethyl orthosilicate (TEOS) was supplied by Alfa Aesar (98% purity). Trimethylchlorosilane (TMCS) was obtained from SRL (99% purity), while ethanol (99.9% purity) and dilute hydrochloric acid (35%) were received from Merck. Deionized water was used throughout the work.

2.2. Preparation of TMCS Modified Silica Sol

In the process to coat the glass substrates, first the preparation of SiO_2 sol was carried out by the hydrolysis of tetraethyl orthosilicate (TEOS) in the presence of ethanol, followed by condensation reactions. Typically, to prepare a particular sol, the equivalent weights of TEOS, solvent and deionized water were considered in the ratio 1:2.5:1, respectively. So, accordingly 21.2766 ml of TEOS was collected in a 50 ml beaker and 14.9 ml of ethanol with 1.838 ml of deionized water were taken in a separate beaker, mixed with dil. HCl, which worked as a catalyst. The solvent mixture was poured into the precursor of silica drop by drop while stirring it for one hour with the help of magnetic stirrer. Then, the same solvent mixture was prepared again to be added into the stirring solution for another hour. After stirring, the solution was kept for aging for an hour, which allowed it to turn into a gel like formation. Separately, a solution containing 25.9 ml TMCS mixed with 1.838 ml deionized water was prepared. This solution was poured into the formed gel drop by drop along with stirring magnetically until half an hour to make a TMCS modified silica sol. The whole process was conducted at room temperature.

2.3. Formation of Hydrophobic ARC

The pre-treatment of the glass substrates is very essential task to achieve better wettability and adhesion of the ARC. The cleaning of the glass slides was carried out by washing them with water, followed by acetone and kept for drying at 100°C. After that, the specimen was dip coated with SiO_2. The glass slide was dipped into the container filled with TMCS modified silica sol and allowed to stay for 20 seconds. The thickness and homogeneity of the coating are mainly derived from the withdrawal speed, which is a crucial step in the dip coating technique [13]. So, the substrate was drawn out from the beaker very slowly with the speed of 12 cm/min. After drying it at ambient temperature for a day, the glass with a hydrophobic silica layer was formed. The final step was to perform the heat treatment process at 200°C for 1 hour in order to toughen the adhesion force among the silica layer and the glass. Flow chart of the complete process is shown in figure 1.

2.4. Characterization

UV-visible spectroscopy is a powerful tool for characterization of the optical properties. The transmittance of the soda lime glass substrates as well as TMCS functionalized silica coated glass samples were obtained with UV-Vis diffuse reflectance spectrometer [Shimadzu, UV-Vis Spectrophotometer - A116651]. Graph plotted for T% against the wavelength from 200 nm to 1400 nm were acquired with the help of a digital software. Contact angle was measured through goniometer using 5 µL water droplets in the standard environmental condition. Water contact angle (WCA) values, noted down, were estimated by the digital software attached with the system. To investigate the surface roughness of the coated samples,Talysurf CCI scanning white light interferometer with lateral resolution of 0.3 µm and vertical resolution of 0.1 nm was employed by using 20 × objective lens, where 0.8 mm × 0.8 mm area of the surface was assessed in the measurement.A graph depicting the absorption spectra of the coating surfacewas put down using a Perkin Elmer-spectrum one Fourier-transform infrared (FTIR)spectrophotometer.

3. RESULTS AND DISCUSSION

In the preparation of silica gel, tetraethyl orthosilicate (TEOS) was subjected to some reactions represented below [14], when mixed with the solvent and water; hydrolysis and condensation, to form the final product.

Hydrolysis:

$$Si(OC_2H_5)_4 + H_2O \rightarrow Si(OC_2H_5)_3OH + C_2H_5OH$$

Condensation:

$$\equiv Si - O - H + H - O - Si \equiv \rightarrow \equiv Si - O - Si \equiv + H_2O$$

$$\equiv Si - OC_2H_5 + H - O - Si \equiv \rightarrow \equiv Si - O - Si \equiv + C_2H_5OH$$

The gel contains OH group, which are hydrophilic in nature [15]. When this gel was functionalized with trimethylchlorosilane (TMCS) solution, the polar (OH) groups were exchanged with the non-polar trimethylsilyl ($OSi(CH_3)_3$) groups, according to the reaction below [16]:

$$\equiv Si - O - H + Si(CH_3)_3Cl \rightarrow \equiv Si - O - Si(CH_3)_3 + HCl$$

The reaction above results in the formation of TMCS modified silica sol. This sol was used to coat the surface of the glass substrate. The coated glass specimen with a water droplet is shown in the figure 2.Moreover, the transparency of the glass substrates was maintained.

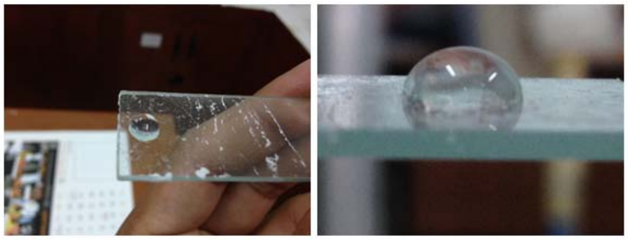


Figure 2. SiO_2 coated glass with a water droplet

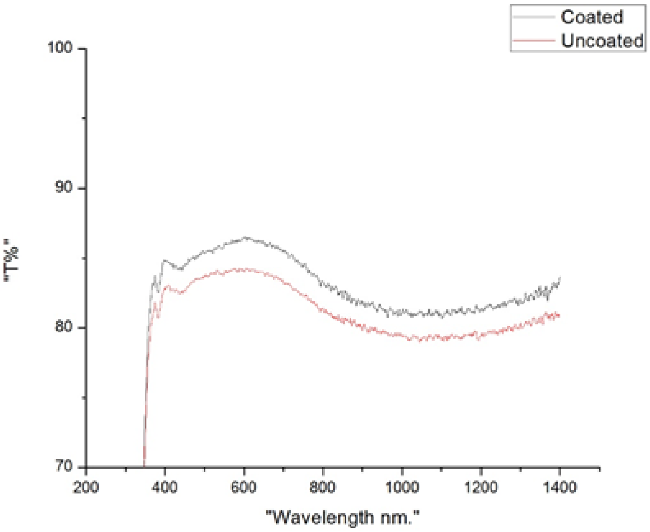


Figure 3. Plot for T% vs. wavelength in nm

3.1. Optical Properties

To start with, the glass substrate was taken for characterization under UV-visible spectrophotometer to find out its transmittance. The glass slides considered were having transmittance around 84% in the visible range of wavelength. At the point when the substrates were coated with TMCS functionalized SiO_2 film, these anti-reflective coatings were able to transmit sunlight about 3% superior to the uncoated samples. The graph appeared in figure 3 provides the information of the transmittance for both surfaces on the basis of wavelength of the rays falling on the surface ranging from 400 nm to 1400 nm.

3.2. Hydrophobicity

The silica coatings are hydrophilic due to the presence of hydroxyl groups on the surface. The key factor to produce a hydrophobic film is to successfully replace the OH groups to the alkyl ones, which are in this case, trimethylsilyl. With the help of TMCS functioning as a hydrophobic agent, the surface energy of the substrates was scaled down and the water contact angle was made sufficiently high (>90°), attaining a self-cleaning as well as water-repellent property. The figure 4 indicates the WCA of 109.1° of the coated surface.

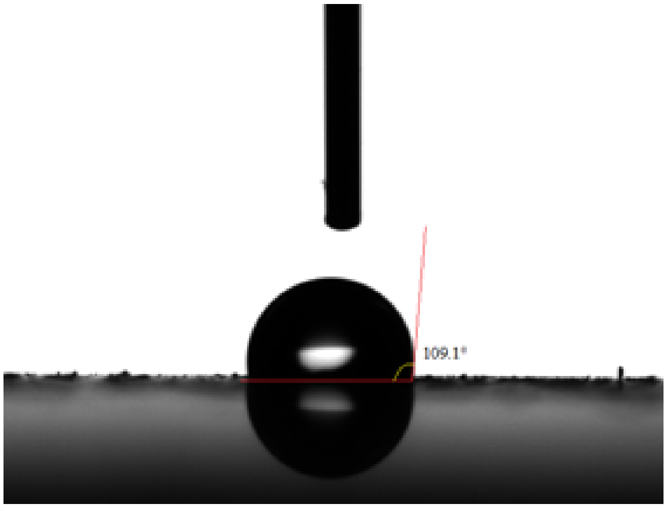


Figure 4. Water contact angle image of the coated surface

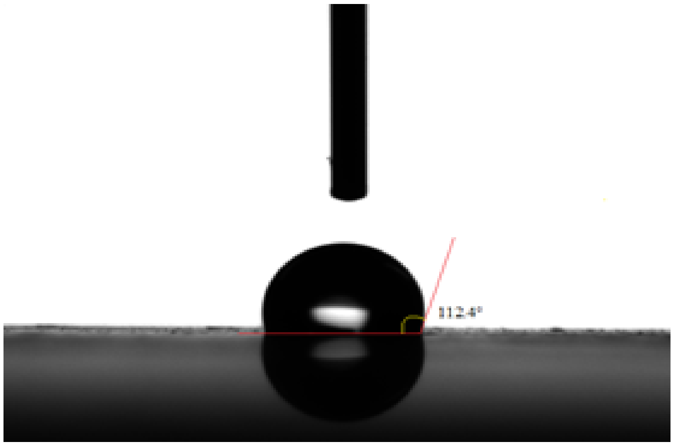


Figure 5. WCA increased due to high reaction time

Furthermore, in order to exchange the OH groups completely with the trimethylsilyl groups, raising the amount of modifying agent is very necessary or rather increase the time for reaction to happen.

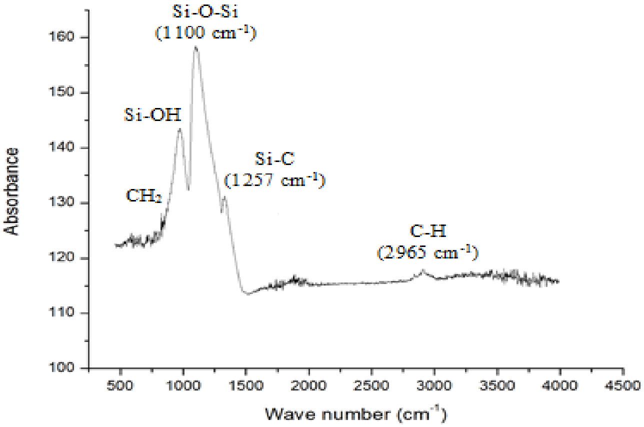
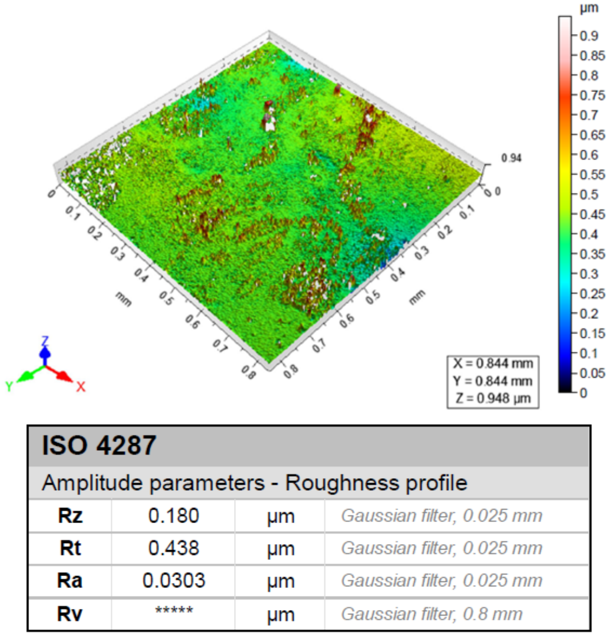


Figure 6. FTIR spectrafor TMCS modified silica film deposited over glass substrate

Hence the increment in the contact angle from 109.1° to 112.4° was viable, which describes the potential to reach superhydrophobicity (>150°). Figure 5 depicts the image with water contact angle 112.4°, illustrating the result of allowing the TMCS solution to react with wet silica gel for a little longer while preparing the hydrophobic anti-reflective silica layer over the glass substrates.



ISO 4287			
Amplitude parameters - Roughness profile			
Rz	0.180	µm	Gaussian filter, 0.025 mm
Rt	0.438	µm	Gaussian filter, 0.025 mm
Ra	0.0303	µm	Gaussian filter, 0.025 mm
Rv	*****	µm	Gaussian filter, 0.8 mm

Figure 7. Profilometer image showing the surface topography of the coated sample

3.3. FTIR studies

The chemical bonds established by the functional groups present in the hydrophobic anti-reflected layers, fabricated over the glass substrates, were examined by the FTIR spectroscopy. In the investigation of the TMCS modified silica film, the FTIR spectra shown in figure 6 illustrates the existence of various peaks related to $Si(CH_3)_3$ group. The strong peak of Si-O-Si asymmetric stretching is visible at 1100 cm^{-1}, Si-C at 1257 cm^{-1}, CH (stretching) at 2965 cm^{-1} and CH_2 at 755 cm^{-1} and 845 cm^{-1} [17]. In addition, through the Si-OH peak, available at 965 cm^{-1}, it was inferred that some silanol groups were left over, which did not able to exchange themselves by the alkyl groups due to low concentration of the TMCS solution.

3.4. Surface roughness

Looking into the perspective of roughness, transparency and hydrophobic nature contradict each other. Hydrophobicity increases along with the increment of surface roughness, though the transparency diminishes. Hence, on the way controlling the surface roughness to fulfil both the requirements, the roughness value ought to be below 100 nm for a transparent layer as the visible range lies between 400 nm to 700 nm [18]. The image shown in figure 7 was acquired with the assistance of optical profilometer. The picture concludes a sufficiently smooth surface of the coated glass substrate due to the root mean square (RMS) value of 30.3 nm, which is less than the wavelength of the rays falling on it. Also, the spiky topography favors the hydrophobicity of the film.

4. CONCLUSION

The above studies were emphasized to coat the glass substrates, demonstrated by considering the glass samples as the simulated solar cell. The hydrophobic anti-reflective coatings were fabricated through sol-gel dip coating technique and characterized to evaluate the optical properties, hydrophobicity, surface roughness and the chemical bonds present on the surface. The study revealed that the transmittance was increased by around 3% in the visible range of wavelength, when compared the uncoated samples with coated ones capturing more radiation. The water contact angle of the coated surface achieved was 109.1° making it hydrophobic in nature. Moreover, the contact angle was scaled up to 112.4° when providing more time for reaction, which delineates the potential to attain superhydrophobicity after controlling the parameters; concentration of functionalized groups to be exchangedwith silanol groups or the reaction time. The smooth surface was sufficient enough depicted by the RMS value, including its spiky nature supporting the hydrophobicity of the film. Also, the chemical bonds related to Si $(CH_3)_3$ yields better performance of the hydrophobic anti-reflective layer on the glass substrates. Hence, it is very beneficial to cover the top surfaceof a solar cell with the water-repellant silica layer. The method used for coating is a cost effective one, ultimately enhancing the efficiency of the photovoltaic.

5. ACKNOWLEDGEMENTS

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