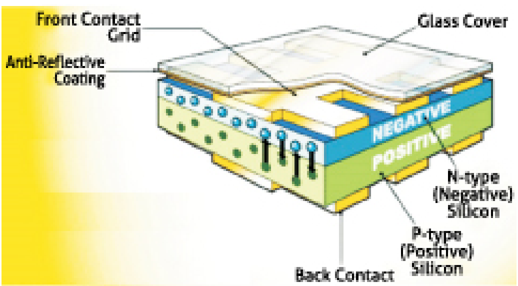
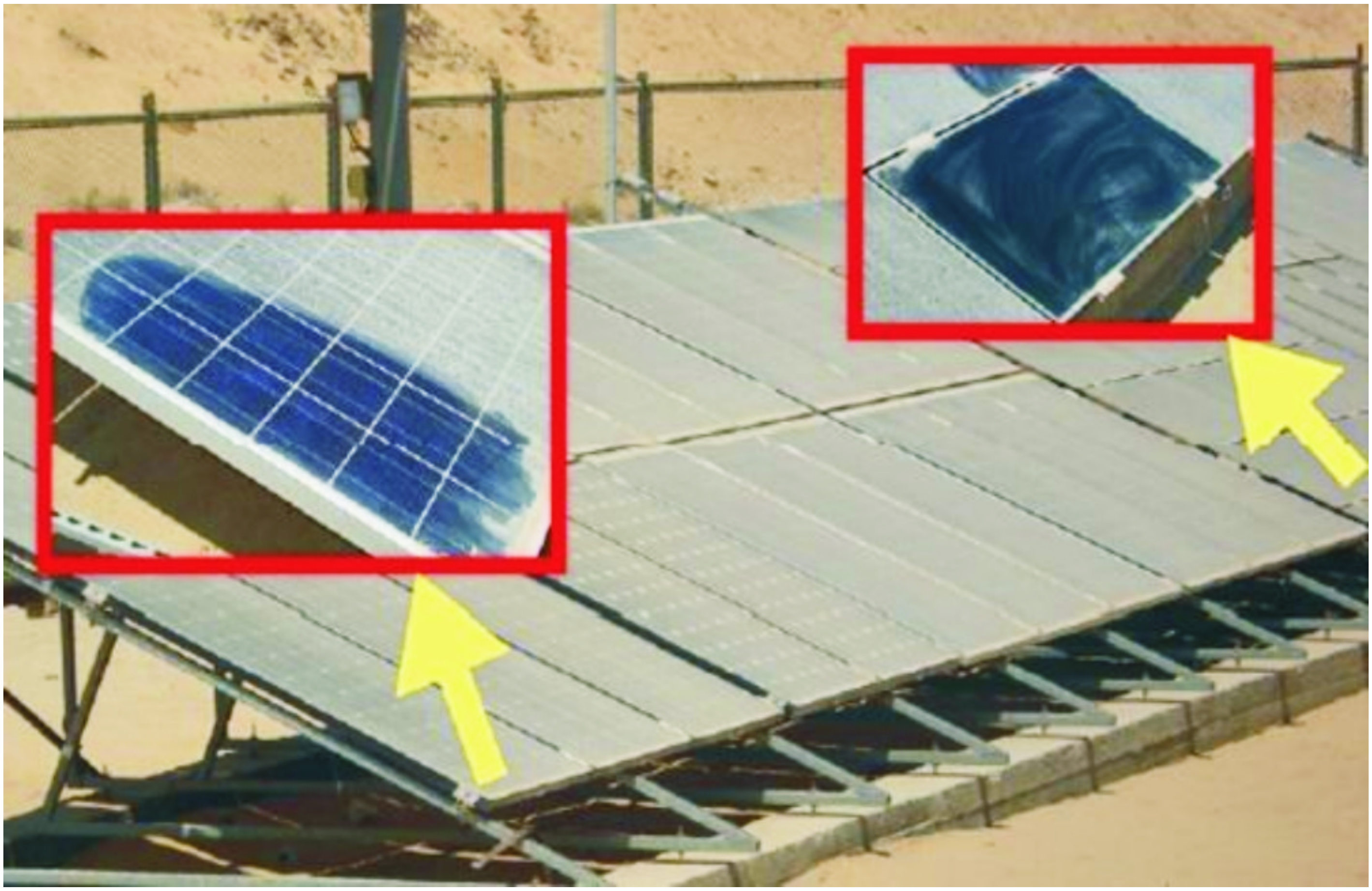
Self-Cleaning Coating for Solar Panel Applications

Introduction

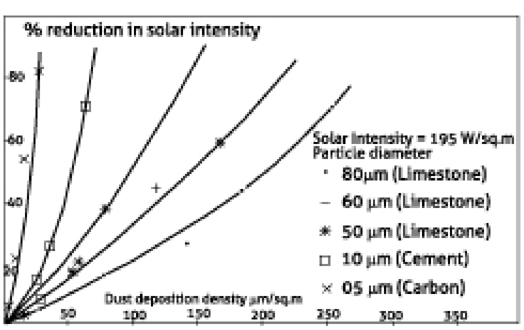
Solar energy is the most abundant renewable energy source and the technology to harness the solar energy includes the use of photovoltaic systems and solar thermal systems. Particularly, Photovoltaic systems are playing a crucial role in meeting our future energy demand and it has been considered as an environmental benign and eco-friendly source of electrical power. Figure 1 shows schematic on cross sectional view of solar panel protected with cover glass.



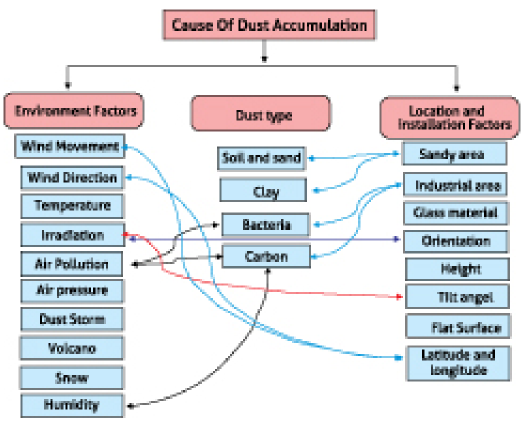
A photovoltaic system (protected with cover glass) for harvesting solar energy is usually installed in sun-drenched desert areas, outdoors and roof tops of urban and rural areas, where dry weather and winds sweep dust and deposit onto the surface of the solar panel. Hence, the glass covering system is commonly used to protect the solar cells from moisture, rain, traffic dust, heat, ultraviolet radiation, bird excrement and corrosive acidic rain in real outdoor environments. During the course of time, the glass surfaces of the solar panels become contaminated with the dust particles from transport vehicles, industrial chimney wastes and pollution(Figure 2)[1]. Such dust particles deposited over the cover glass of the panels hinder the incident light photons to reach the working part of the solar cell and consequently reduces the output electrical power.



There has been a wide range of studies reported previously regarding the investigation of dust deposition and its effect on solar panel efficiency. In brief, Garg [2] conducted experiments to study the effect of dust deposition on average transmittance on rainless days and observed that there was 8% decrease in transmittance at a tilting angle of 45° after 30 days of exposure. Nahar and Gupta [3] carried out a detailed learning to quantify the influence of dust accumulation on average transmittance with respect to tilting angle. It was observed that average transmittance increased with tilting angle and transmittance loss was higher for weekly cleaning cycle when compared to daily cleaning cycle. Al-Hasan [4] was analyzing mathematically the effect of dust deposition and proved that there was up to 50% reduction in transmittance. El-Shobokshy and Hussein[5] conducted a study which reported that the impact of finer particles have a greater impact than coarser particles on solar performance, for thesame type of dust (Figure 3). Therefore, it can be concluded that the accumulation of dust particles on the solar panels has negative significance on the transmittance of incoming light radiation and overall cell efficiency; thus making photovoltaics as an unattractive energy source for harnessing solar radiation.



The characteristics of dust settlement on PV systems are dictated by two primary factors that influence each other, viz., the property of dust and the local environment. The local environment comprises site-specific factors influenced by the nature of prevailing (human) activities, built environment characteristics (surface finishes, orientation and height of installation), environmental features (vegetation type) and weather conditions. The high pollution level of India is extremely dangerous and coat existing solar panels with dust, requiring almost daily cleaning. An approximate statistics of dust accumulation from various sources are shown in Figure 4. Soiling of solar panels can occur as a result of dust and dirt accumulation. In many cases, the dirt is washed off the panel surface by rainfall or water sprinkling; however dirt like bird droppings may stay even after heavy rains. The most critical part of a module is the lower edges. Usually, large-scale solar power plants are being installed in desert and dry areas across the India. But, dust accumulation is an unavoidable problem in these areas as it forms as layers and decreases the solar power conversion of 40% and these plants may lose nearly 30% energy output within short period [6]. Hence, it is highly essential to maintain the solar cell panels with frequent cleaning with the installation of automatic cleaning systems like solar wash or, manually which may increase the cost of panel and its maintenance.



Conventional methods for cleaning of solar panel

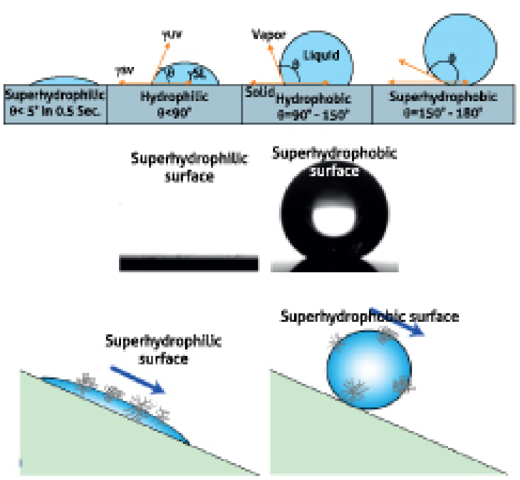
In considering the issues presented above, it is strongly insisted that cleaning of cover glass of the solar panels is mandatory and obligatory part of the maintenance. There have been several methods suggested for maintaining the solar panel efficiency, which includes manual cleaning, natural source of cleaning and by mechanical mode of cleaning via wipers and robotic arm.

– Manual cleaning represents a high peril for cleaning persons who works at a height of 12 – 30 feet from the ground level and a tiresome work in the case of large area surfaces (Figure 5).
– Natural sources of cleaningincludeswind and rain storms will effectively clean the solar panel cover glasses. Cleaning with wind is reported as a non- feasible technique, as there is a need of high wind velocity to clear off the dust particles and the velocity will vary according to different geographical locations and seasonal conditions. Cleaning with rain is whispered as a method of effective cleaning, but actually it is a method of cleaning with low efficiency and if the pollution of the local environment is high, leaves debris over the surface of the solar panel after rainfall.
– Mechanical mode of cleaning includes the use of wiper and robotic arm (Figure 6). The wiper type

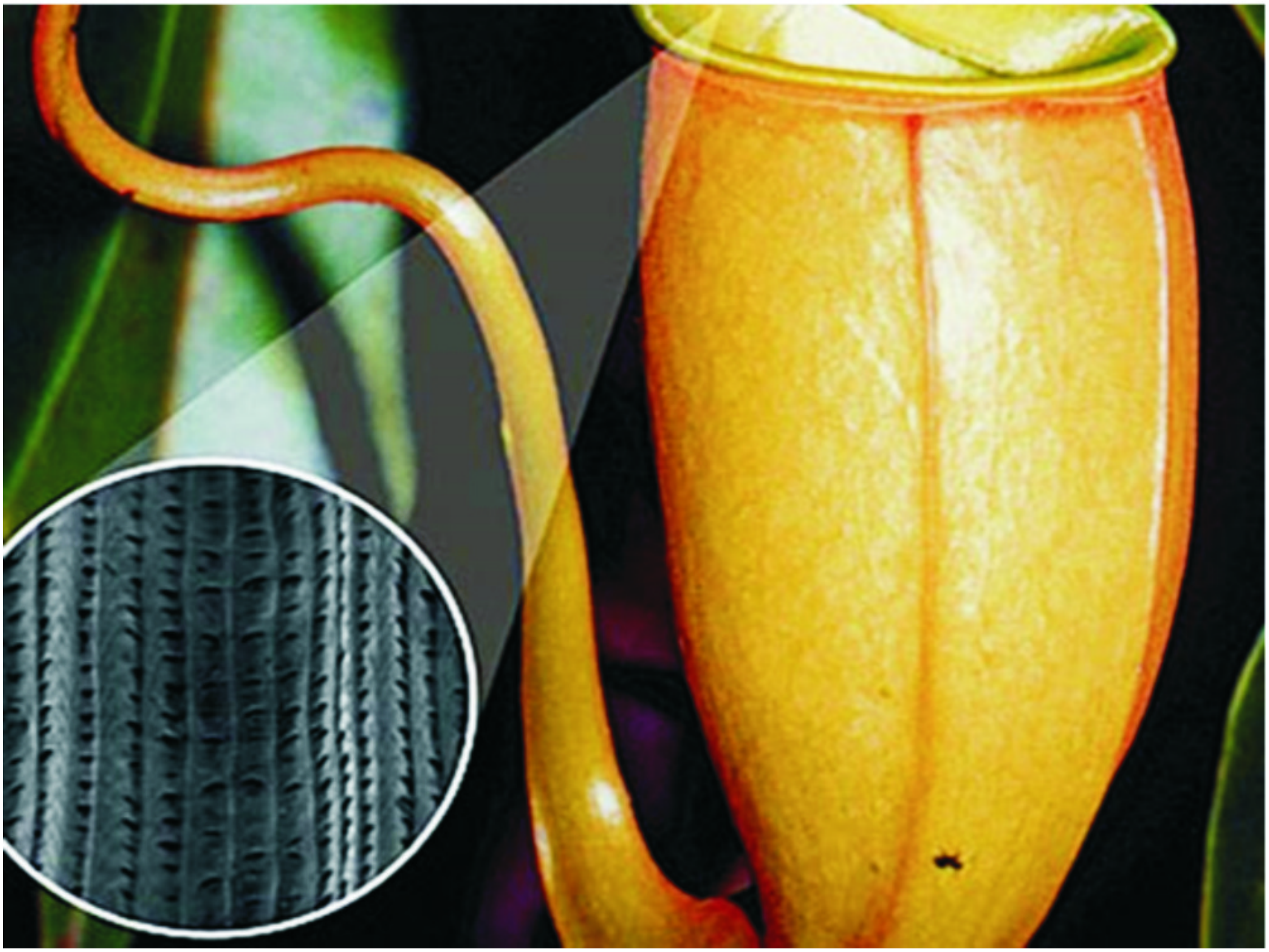
cleans the solar panel cover glass with a device just like automobile windscreen-wiper. The wiper consists of an electrostatic cloth which needs to be charged and difficult to be scaled for large area surfaces. The robot type seems efficient in cleaning strongly adhered dust particles and large area surfaces, but it requires high voltage for operation and human intervention is required to start the operation and while moving from one row to another.

Superhydrophilic Self-cleaning coating

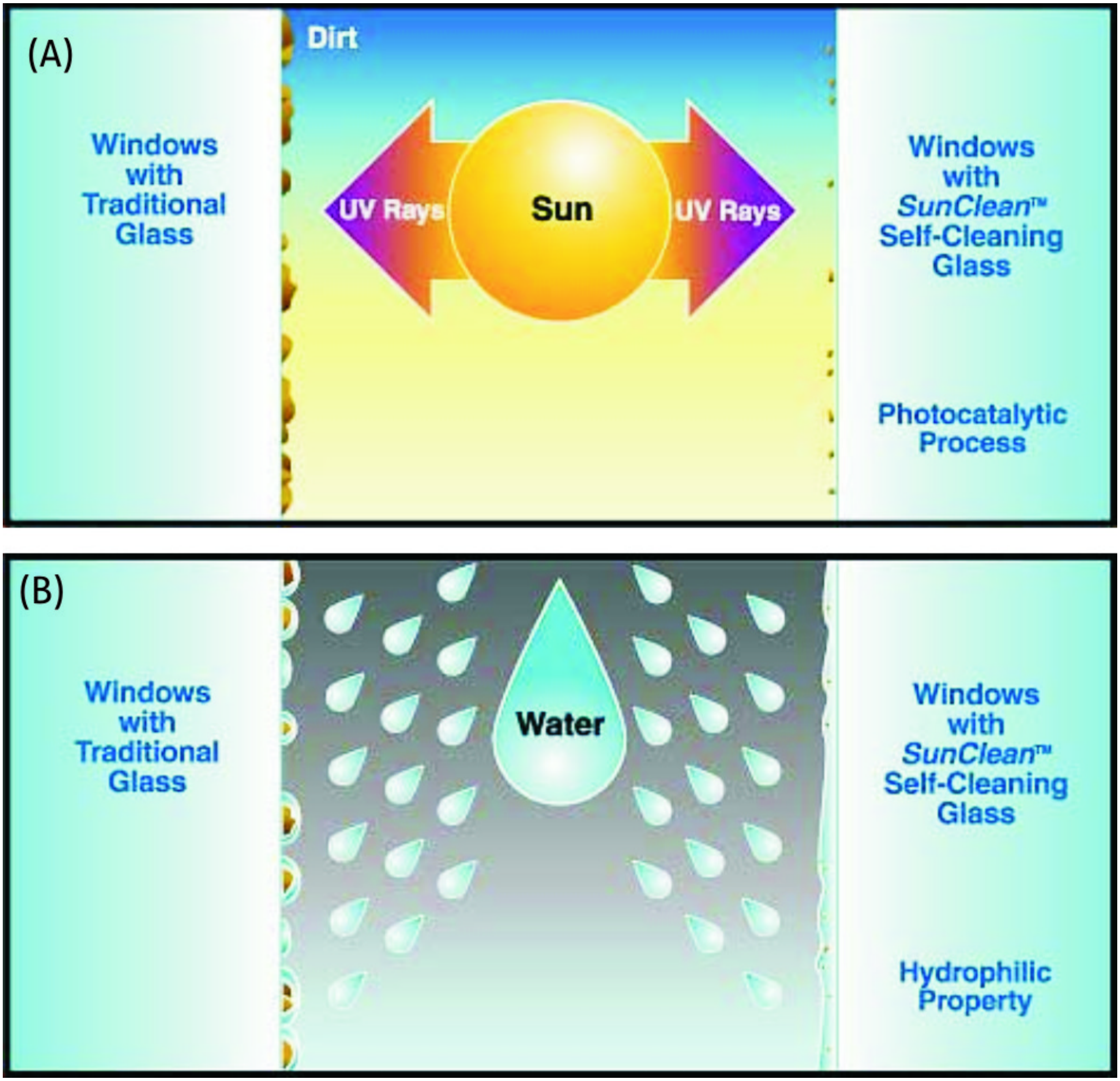
Self – cleaning coatings based on superhydrophilicity is generally defined as exhibiting a water contact angle is almost 0°. On such a surface, water droplets spread very quickly and the water runs off the surface with considerable velocity. Pitcher plants, also known as carnivorous plants, possess pitcher-shaped leaves to capture prey (primarily insects). Like insect – pollinated flowers, the pitchers attract insects by presenting visual and olfactory signals and offering food rewards.



However, the insects trapped on the pitcher rim (peristome) fall prey to the bottom part of the pitcher, filled with a digestive fluid to make the captured prey drown and subsequently decompose. One of the most important features of the pitcher plant for capturing the insects is considered to be its slippery surface. The surface of the peristome shows superhydrophilicity due to the surface micro-topography and secretion of hygroscopic nectar. As a result, stable water films are formed under humid conditions. This water film causes the insects that step on it to slide from the rim into the bottom of the pitcher plant by repelling the oils on their feet. Inspired by the system seen in the pitcher plant slippery surface, lot of synthetic liquid-repellent surfaces were fabricated.

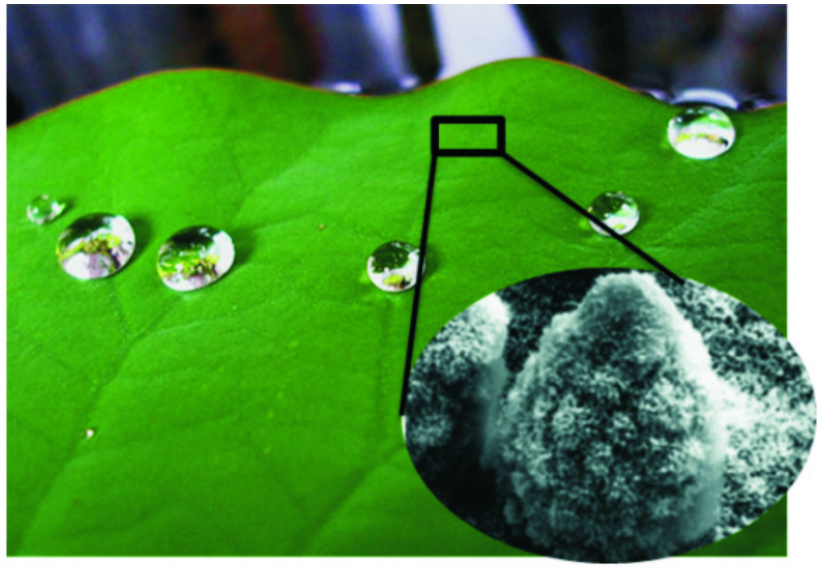


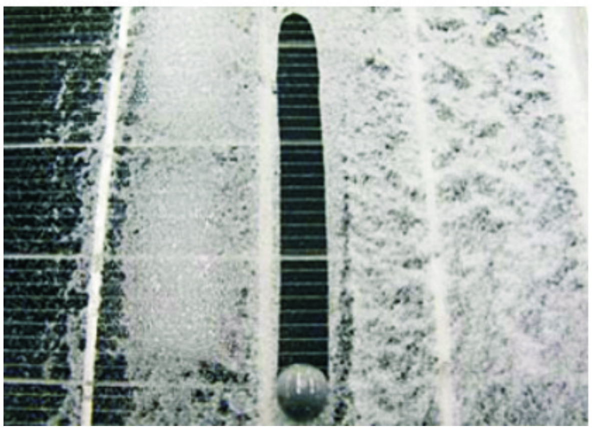
Superhydrophilicity is also realised by the photo catalytic activity and hydrophilicity. The photo catalytic activity of coated film reacts under ultraviolet light, break down the organic dirt (Figure 9(a)). This is known as the ‘photocatalytic’ stage. The reaction also causes the glass surface to become superydrophilic. This forces water to spread across the surface like a sheet, rather than beading, thereby washing away the loosened debris on the surface of the glass as it falls (Figure 9(b)). This is the ‘superhydrophilic’ stage. Generally, ultra-pure water, ensuring the absence of corrosive chemicals, should be used for cleaning the solar panels, because the tap water contains minerals that can leave white lime deposits. This will be difficult to wash off and inhibit the power output of the panels. Hence, the superhydrophilic type of self-cleaning coatings cannot be used for large area surfaces and in water scarce areas, since the huge volume of purified water is needed for making the surface clean.

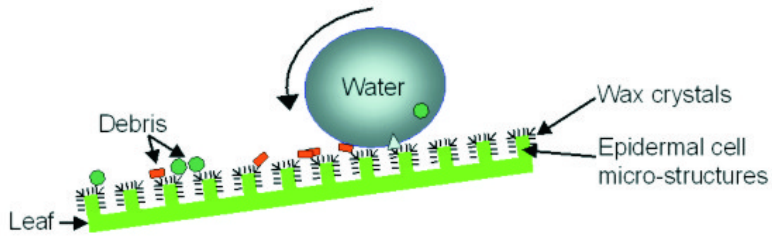


Superhydrophobic Self-cleaning coating

Self-cleaning coatings based on superhydrophobicity are inspired from the outstanding structural and functional properties of sacred lotus leaves. The combination of micro-nano structured roughness and low surface energy wax crystals on the surface of the lotus leaves reduced the contact area between water droplets and the leaf's surface (Figure 10). If the surface is tilted to about 5°, the water droplet begins to roll-off from the surface, collects and removes the dust particles; thus demonstrating the 'self-cleaning effect' [7]. The self-cleaning coatings based on superhydrophobicity offer several advantages over the other mentioned cleaning methods, which includes no requirement of large amounts of water for cleaning; hence can be used for water scarce areas, low cost in terms of maintenance and does not accompany heavy equipment during cleaning.







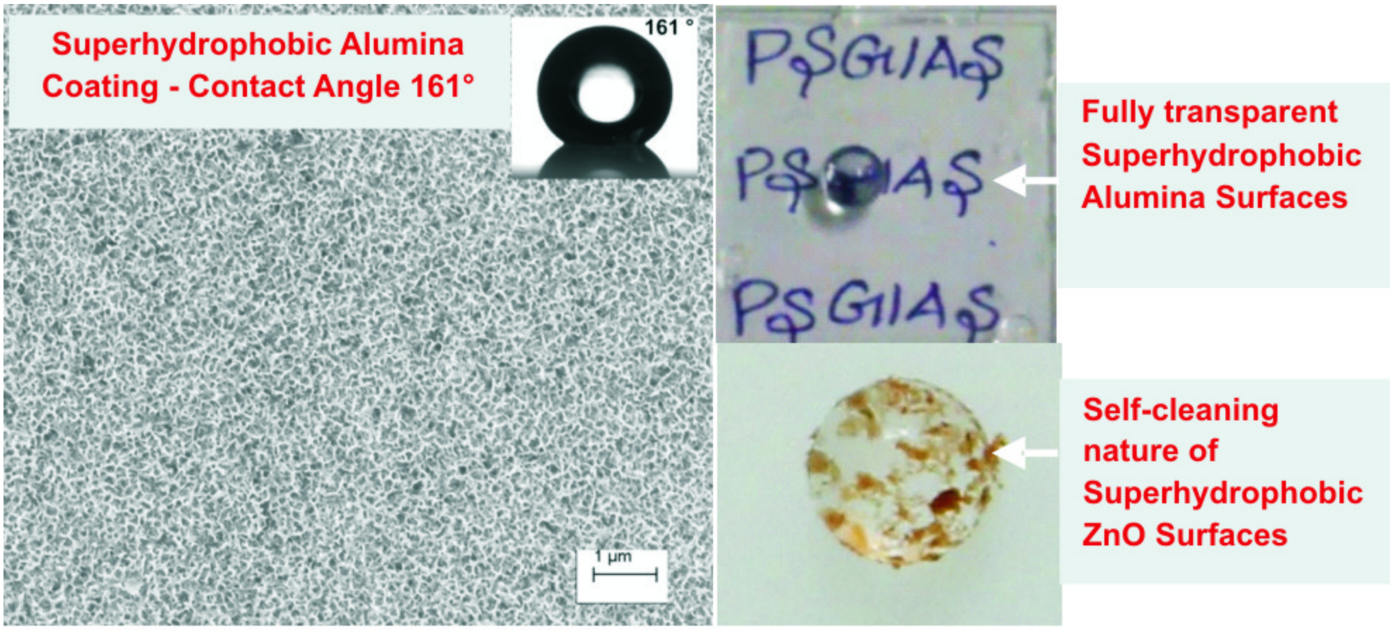
The unique properties of biological microstructures bring some interesting findings which are used for active research in the fabrication of the superhydrophobic surface. Mimicking the properties of the multifunctional biological structures is called biomimetics, which inspires the designing and fabricating of various devices and materials for human beings. Various plant leaves and flowers and insect wings and legs exhibit a low adhesion, self-cleaning property. This property is termed as the lotus leaf effect, in which water rolls off the surface and removes dust particles. This property is not only seen in biological structures but also stimulates research on the development of artificial superhydrophobic surfaces. Nature has always inspired humans in developing ideas for making new objects. For example, biological surfaces like lotus leaves, rose petals, butterfly wings, water-strider legs, and mosquito eyes show superhydrophobicity, which comes from their hierarchical, chemical compositions and multi-functional structures. The surface structure of the lotus leaf exhibits superhydrophobicity and the self-cleaning property due to the presence of arrays of micropapillae. From this surface, water can roll off in each direction with a sliding angle of 2° and a contact angle of 162°. However, the morphology of the lotus leaf reveals the amount of roughness present on the leaf surface. This roughness is due to the presence of papillae epidermal cells. Along with roughness, 3D epicuticular wax is also present on the surface. This epicuticular wax structure looks like tubular wax crystalloids whose diameter is around 100 nm. These two structures not only improve superhydrophobicity but also increase the advancing angle of the water droplet and reduce surface tension for better repelling properties.

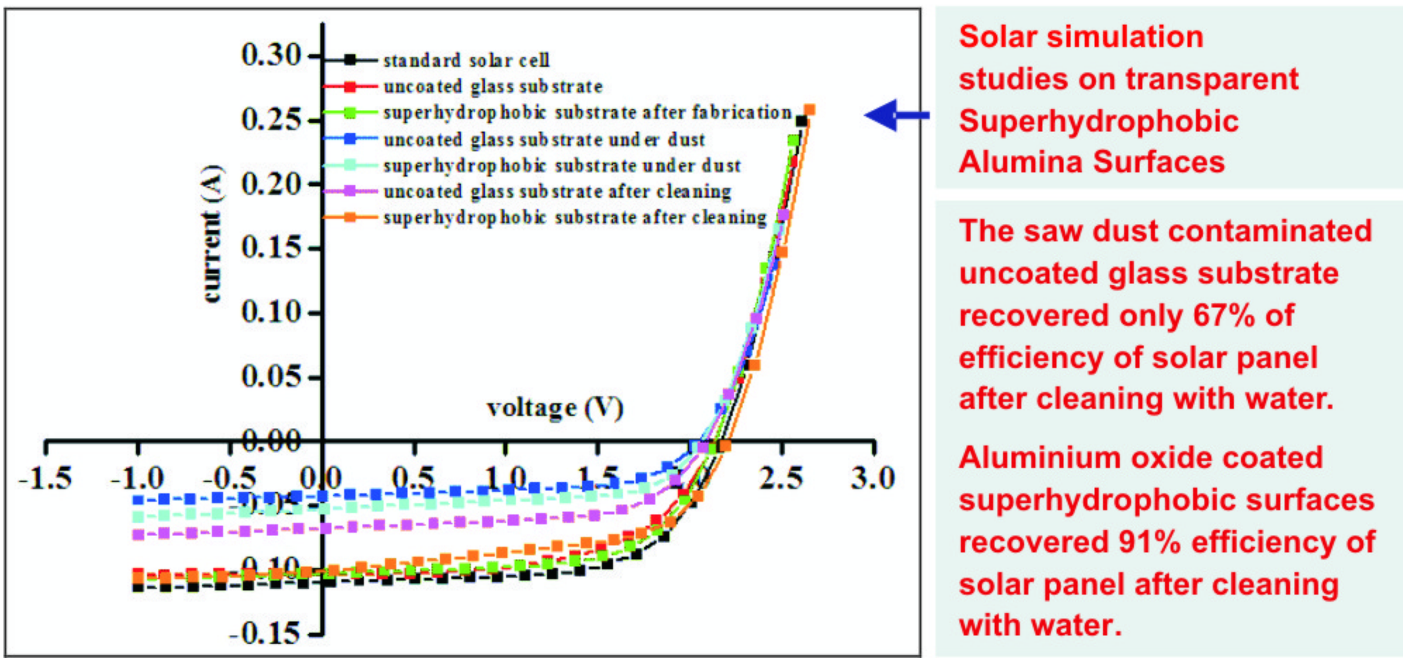
At present, the potential nanocoating companies across the world are Nanopool ® GmbH, NanoShell ltd, UK, P2i, UK, NanoSonic, USA. The potential users for superhydrophobic coatings could be the solar PV manufactures, as the coating has to be performed during their fabrication. There are no potential nanocoating companies at India and the solar panel manufactures has to import the coating materials which causes additional costs to the solar panels. Moreover, the suitability of these products for long term applications are not validated till now.

Currently, authors at PSG Institute of Advanced Studies, Coimbatore developed superhydrophobic surfaces based on ZnO [8,9] and aluminium oxide [10]coating on glass substrates via solution based approach for solar panel cover glass applications (Figure 11).The fabricated surface was amorphous with an interconnected porous network of nanoflakes. The static contact angle of the prepared coatings was 161° and exhibited superior self – cleaning behaviour at a tilting angle less than 10°. The interconnected network of coatings exhibited average transmittance level of 95%.

The photovoltaic performance of commercially available solar cells covered with uncoated glass substrate and superhydrophobic glass substrate was measured under various conditions (such as – fabricated, artificially contaminated and self – cleaned conditions) and the results were compared. The uncoated glass substrate and aluminium oxide coated superhydrophobic glass substrate recovered the efficiency of saw dust contaminated solar panel by 67% and 91%, respectively, thereby enabling the fabricated superhydrophobic glass substrate to be effectively useful for self – cleaning cover glass applications.

Further, the prepared coating with average optical transmittance and self – cleaning superhydrophobic nature recovered the efficiency of the dust contaminated solar cell by more than 90% after being cleaned with water. These results suggested that the fabricated coating will be effectively used for self – cleaning solar panel cover glass applications.Despite these advantages, practical issues like optical transparency and mechanical robustness should be satisfied to apply superhydrophobic coatings for outdoor applications. Increasing the surface roughness leads to improvement in superhydrophobic property, while acting as a deteriorating source for scattering incident light radiation as well as poor mechanical stability.





It is believed that the development of transparent, mechanically robust superhydrophobic coating will eventually solve the challenging issues regarding dust accumulation in near future.1 In view of that research scientist in PSG Institute of Advanced Studies, Coimbatore in collaboration with Indira Gandhi Centre for Atomic Research, Kalpakkam are in the process of “Development of Scalable Self-Cleaning Coatings Based on Superhydrophobicity for Solar Panel Applications” funded byONGC Energy Centre Trust, New Delhi.

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