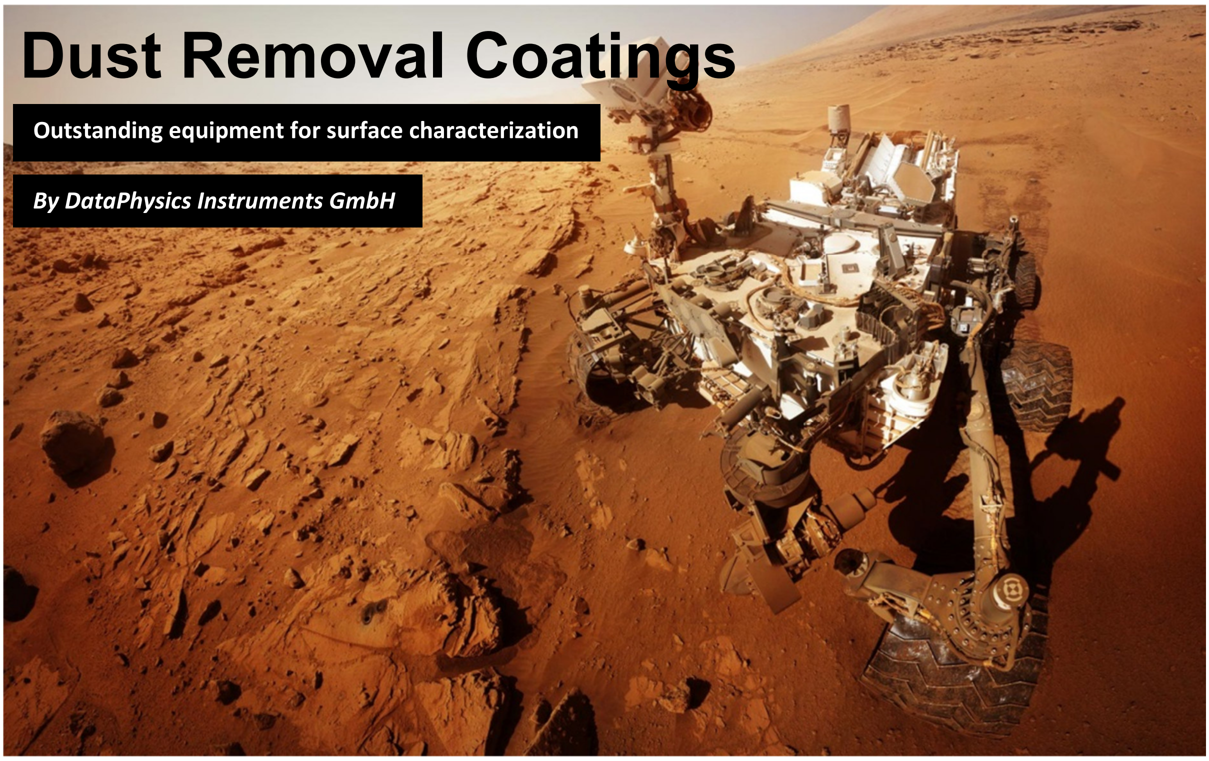
How Contact Angle Measurements Can Help Explore Mars



Photovoltaic power generation is still a hot and attractive topic for scientists with the increasing requirement for clean energy generation. This holds especially true when thinking about sending satellites or space exploration vessels out for which the sun through solar cells are the most abundant source of power. In open space it is fairly simple to run a solar cell as no disturbances from particles will occur. However on planet surfaces such as Mars, dust and other pollutants, which stain on the solar devices' surface, seriously affect the sunlight transparency and decline the efficiency of solar cells.

Picture 1: *Picture from the surface of Mars showing the dusty atmosphere in the aftermath of a dust storm which frequently occurs on Mars and can even cover the whole atmosphere of the planet*

From now on, there are many methods to clean the dust adhering on the surface of solar cells, such as high-pressure water jets, robotic devices etc. Unfortunately, most of them are labour-intensive, too expensive, time-consuming, and most importantly unfit to be applied to the solar panels of devices in outer space. Although scientists have already developed some self-cleaning coatings, such as superhydrophobic and superhydrophilic coatings, the self-cleaning can only work efficiently with rainwater cleaning the surface or at the certain wind velocity, which make it impossible to be used on Mars (no rain and usually low wind speed). Based on the literatures, gravity-induced dust removal coatings should be a good candidate for solar cells on Mars. It is well known that low adhesive force between the dust and surface is crucial for good gravity-induced dust removal performance, which could be realised by proper surface roughness, high hardness and low hydrogen bonding interaction. Particularly, surface roughness has an extremely critical effect on adhesive force. According the common wetting theory, we know that surface roughness strongly affects the water contact angle (WCA). In the following we will explain how to use contact angle measurements can be sued to evaluate the dust removal performance of solar cell coatings for Mars?

Picture 2: *Dusty surface of a solar cell illustrating the need for a good cleaning mechanism to maintain efficiency.*

Recently, Zhang *et al.* first reported about gravity-induced and good durable dust removal coatings for the solar cells on Mars. In their research, they studied on a series of hybrid coatings, which were fabricated from colloidal silica nanoparticles (SiO_2) and methyltrimethoxysilane (MTMS) though a sol-gel process. In order to achieve suitable surface roughness, they investigated systematically the MTMS Hydrolysate/Silica Sol (MH/SS) mass ratio, aging time and curing. The results showed that, high mass ratio of MH/SS (for example, 4:1 and 3:1) will get low WCA coatings (around 88°), which are not effected by aging time. However, the WCA dramatically increased to 109.5°, when the MH/SS mass ratio was lowered to 2:1 (7 h aging). Especially after longer aging time (20 h), the WCA could be further increase to 116.6°. During the study, they found that lower MH/SS mass ratios (1:1, 1:2, and 1:3) could fabricate higher WCAs at short aging time (up to 120°). The coatings showed a poor adhesion behaviour on the glass slides at lower MH/SS mass ratios, resulting in the coatings peeling off or cracking on the slides after curing, which can be avoided after a certain aging period. To get a deeper understanding for the wetting behaviour, they studied the dynamic contact angles of the hybrid coatings with different MH/SS mass ratios (13 h aging time). As shown in Table 1, a decrease of the MH/SS mass ratio led to a decline in the receding contact angle while the advancing contact angle got bigger leading to an increase of the contact angle hysteresis. This can be explained by the easier chain flipping under aqueous conditions, due to less hydrophobic groups (CH_3) at lower MH/SS mass ratios, which was also supported by measurements with Atomic force microscopy and X-ray photoelectron spectroscopy.

Table 1: *Dynamic water contact angles on the hybrid coatings with different MH/SS mass ratios (13 h aging time)*

MH/SS	Advancing angle(°)	Receding angle(°)	Contact angle hysteresis (°)
4:1	94.5	79.0	15.5
3:1	96.0	76.7	19.2
2:1	108.7	51.6	57.1
1:1	112.2	25.7	86.5
1:2	124.1	23.0	101.2
1:3	116.1	28.4	87.7

Besides, they also found that by carefully adjusting the MH/SS mass ratio at 2:1 or 1:1 high WCAs (over 110°) and high pencil hardness (4–5 H) could be achieved. The different coatings were tested by using volcanic ash as the standard dust to look into the coatings' dust removal performance. They found that coatings with a nanometer-scale surface roughness (Ra no less than 1.5 nm) have outstanding gravity-induced dust removal properties, independent of the ash quantity. Furthermore, O_2 plasma etching investigations showed that the coatings without CH_3 groups almost had no dust-removing performance under the humid conditions. In contrast, they had excellent dust-removal property in the absolute dry chamber. As Figure 1 shows, that surface roughness is the key point to the dust removal property, since it efficiently diminishes the adhesive force by reducing the contact points between the dust and surface. In addition, the hydrophobic groups (CH_3) could also contribute to the low adhesive force since their steric interaction blocks the formation of a water adsorption layer only leaving weak Van de Waals forces between CH_3 groups and the dust.

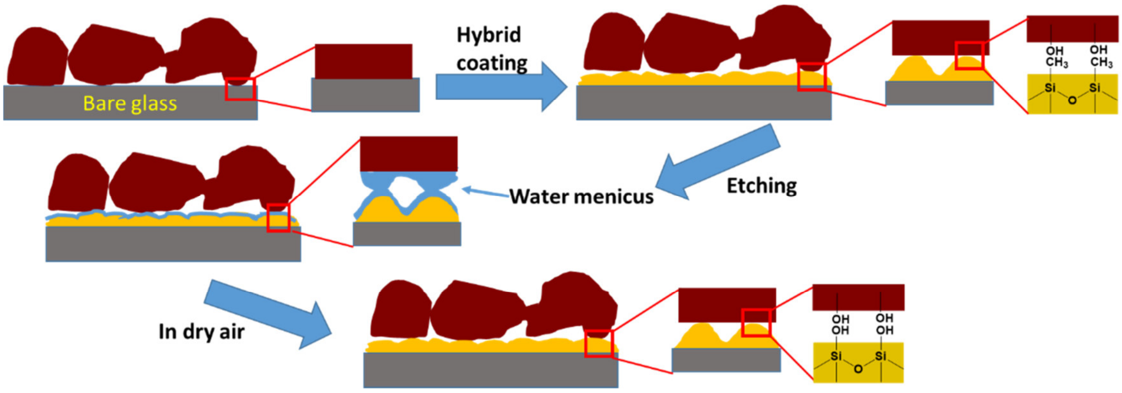


Figure 1: *The possible dust removal mechanism of coatings*

Moreover, they also studied the durability of the coatings in thermal shock/humidity series (THS) tests and high-low temperature cycle/electron beam radiation/vacuum ultraviolet radiation series (HEVS) test to simulate the thin air (close to vacuum), hugely changing temperature (−16~+30 °C to −103~-60 °C) and serious electron/UV irradiation on Mars. After the HEVS test, the dust removal percentage could still keep up to 75.8%, which ensure the reliable dust removal performance for solar cells on Mars.

This research shows the developed of coatings with good gravity-induced dust removal performance for solar cell coatings that can be used on Mars. The authors also clarified the mechanism of the dust removal performance of the coatings, which indicated that rough surfaces improved with hydrophobic methyl groups is the vital factor for the excellent dust removal property.

OCA 25 Contact Angle Analyser (DataPhysics Instruments GmbH, Germany) was used in this research.

For more information, please refer to the following article:

Transparent dust removal coatings for solar cell on mars and its Anti-dust mechanism; Jiawei Zhang, Wenqiang Wang, Shuxue Zhou, Hongdong Yang, Cheng Che; *Progress in Organic Coatings* **2019**, 134, 312–322