Synthesis of hydrophilic silica nanoparticle and its application as self-cleaning coating for solar cell panels

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Abstract. In past decades, nanotechnology has attracted much attention among researchers and industries due to its high potential of adding significant values to the original materials. Thin film coating with nanomaterial can provide new properties and enhance performances of pristine surfaces for certain applications. In this research, we investigated the development of superhydrophilic self-cleaning coatings for solar panels using colloidal silica nanoparticles. The coatings consist of colloidal silica nanoparticles with the average size of 30 nm, sodium dihydrogen phosphate and boric acid under various formulations. The coatings can be applied by simple painting or fine spraying. The light transmittance of the coated samples was characterized by UV–visible spectrophotometer. The water contact angle (WCA) was measured by a contact angle instrument. It was observed that the optimum weight ratio of silica nanoparticles : sodium dihydrogen phosphate : boric acid was 22:1:1 with contact angle of 1.83º and transmittance of 65%.

1. Introduction

In past decades, nanotechnology has attracted much attention among researchers and industries due to its high potential of adding significant values to the original materials. Thin film coating with nanomaterial can provide new properties and enhance performances of pristine surfaces for certain applications. In this research, we investigated the development of superhydrophilic self-cleaning coatings of the so-called mirror (material made from glass) with colloidal silica nanoparticles [1]. The mirror can be melted and easily formed into various shapes. When cooled down, it has a solid state that is amorphous and transparent, thereby making it popular for interior decoration that increases the brightness inside a building. Today it is also widely used in automotive, residential, and general industrial applications. However, one common problem associated with its use is that the glass is dirty from dust and water stains caused by rain, storm, air pollutants, PM2.5 from industrial plants, vehicles with combustion engines, and so on dirt gets out. Therefore, it is necessary to hire people to clean up the dirt. The mirrors installed on the exterior of high-rise buildings are much more difficult to clean.
Self-cleaning coatings may be classified into two major categories: hydrophobic and hydrophilic [2]. In this research, we aimed to develop superhydrophilic self-cleaning coatings for mirrors in general and solar cell panels in particular, [3] which consist of colloidal silica nanoparticles with an average size of 30 nm, sodium dihydrogen phosphate and boric acid in various formulations for testing and selection. The coatings can be applied by spraying. To save cost of material, the ideal coating should have a minimum thickness while displaying superhydrophilicity with strong surface adhesion and durability [4, 5]. The thickness of the applied coating and the microstructure of the nanoparticles in the coating were observed and characterized with a Scanning Electron Microscope (SEM). Its degree of hydrophilicity was represented by the water contact angle (WCA) of a static droplet on the coating measured with a contact angle meter. The transmittance spectra of the coated and uncoated samples were evaluated using a UV–vis spectrophotometer and assessment of the adhesion strength of the coating film, by the standard tape test method. In this investigation, microscope glass slides, which have excellent transparency, were used as substrate for the coating. The main objective was to develop an optimum spray-coating material formulation that would display excellent superhydrophilicity with strong adhesion, acceptable film thickness and reasonable transmittance. The durability and long-term characteristics of the optimized coating will be investigated and reported in the near future.

2. Materials and methods

2.1 Materials

Colloidal silica nanoparticles, 3%wt in isopropyl alcohol (IPA), were synthesized at NANOTEC using the Stöber process. Colloidal silica nanoparticles, 3%wt in water, were purchased from Nissan Chemical, Japan. Boric acid was purchased from ACROS, USA. Anhydrous sodium dihydrogen phosphate was purchased from QRëC, New Zealand.

2.2 Measurements

Characterization of microstructure, film thickness, water contact angle and adhesion strength

The static contact angle between a water droplet and the film surface was measured with a Contact Angle Meter (Model TC/TPC150, Dataphysics Instruments GmbH, Germany). At least 3 independent angle measurements were conducted for each thin film sample. The average contact angle and its standard deviation were reported. The microstructure of the thin film of hydrophilic nanoparticles was observed through scanning electron microscopy (SEM) (Model SU8230, Hitachi, Japan). The transmittance spectra of the coated and uncoated samples were evaluated using a UV–vis spectrophotometer and assessment of the adhesion strength of the coating film, by the standard tape test method

3. Results and discussion

Preparation of superhydrophilic coating solution

Table 1 lists the composition of all 18 formulations investigated. Taking the case of formulation no. 1 as example, 1 g of anhydrous sodium dihydrogen phosphate as additive agent and 1 g of boric acid for pH adjustment were put in a stainless-steel heating container, mixed with 10 ml of deionized water, and then heated at 80 °C under stirring [6]. After the heated mixture achieved complete dissolution, it became transparent and colorless. Then its weight was measured and the evaporated water was compensated, so as to gain the desired additive compound. Next 16 g of IPA containing 3%wt of silica nanoparticles was added to the additive compound and sufficiently stirred at room temperature to gain an inorganic aqueous coating solution having a final pH of 5. The other formulations in Table 1 were prepared in a similar manner.
Table 1 Composition of all 18 formulations

| Formulation (no.) | 3% wt Silica nanoparticles in IPA (g) | 3% wt Silica nanoparticles in water (g) | Boric acid (g) | Sodium dihydrogen phosphate (g) | pH |
|-------------------|--------------------------------------|----------------------------------------|----------------|---------------------------------|----|
| 1                 | 16                                   | -                                      | 1              | 1                               | 5  |
| 2                 | 18                                   | -                                      | 1              | 1                               | 5  |
| 3                 | 20                                   | -                                      | 1              | 1                               | 5  |
| 4                 | 22                                   | -                                      | 1              | 1                               | 5  |
| 5                 | 24                                   | -                                      | 1              | 1                               | 5  |
| 6                 | 26                                   | -                                      | 1              | 1                               | 5  |
| 7                 | 28                                   | -                                      | 1              | 1                               | 5  |
| 8                 | 30                                   | -                                      | 1              | 1                               | 5  |
| 9                 | 32                                   | 16                                     | 1              | 1                               | 5  |
| 10                | -                                    | 16                                     | 1              | 1                               | 5  |
| 11                | -                                    | 18                                     | 1              | 1                               | 7  |
| 12                | -                                    | 20                                     | 1              | 1                               | 7  |
| 13                | -                                    | 22                                     | 1              | 1                               | 7  |
| 14                | -                                    | 24                                     | 1              | 1                               | 7  |
| 15                | -                                    | 26                                     | 1              | 1                               | 7  |
| 16                | -                                    | 28                                     | 1              | 1                               | 7  |
| 17                | -                                    | 30                                     | 1              | 1                               | 7  |
| 18                | -                                    | 32                                     | 1              | 1                               | 7  |

**Thin film coating on substrate**

Microscope glass slides were used as substrate for thin film coating by spraying. Then newly coated microscope glass slides were dried at 80 °C for 30 min.

**4. Water contact angle on the thin film coatings**

To evaluate the hydrophilicity of the sprayed coating, static water droplet contact angle was measured for each of the 18 formulations and the measurement results are summarized in Table 2. To enhance the reader’s understanding, photos of a droplet lying on a blank slide (without coating) and the slide coated with formulation no. 4 are shown in Figure 1. [7]

![Figure 1](image-url)

**Table 2** Average contact angles and standard deviations

| No. | Average contact angle (º) |
|-----|----------------------------|
| 0 (blank) | 70.87 ±13.43 |
| 1 | 6.73 ±2.71 |
As seen from Table 2, the WCA on the blank slide was widest at 70.86°. Among formulations no. 1-9 which used IPA containing 3%wt silica nanoparticles, it was found that formulations no. 3, 4 and 5 have the three smallest contact angles of 5.86, 1.38 and 3.10 degrees, respectively [4]. Similarly, among formulations 10-18 which used water containing 3%wt silica nanoparticles, formulations no. 15, 16 and 17 have the three smallest contact angles of 16.50, 15.87 and 13.97 degrees, respectively. Therefore, it was decided to characterize formulations no. 3, 4, 5, 15, 16 and 17 with the other above-mentioned analytical tools.

5. Light transmittance through the thin film coating [8, 9]

As shown in Table 3, the transmittance spectra of the uncoated and 6 coated samples were evaluated using the UV–vis spectrophotometer [10].

Table 3 Transmittance spectra of the uncoated and 6 coated samples.

| No. (blank) | Transmission values (%) |
|-------------|-------------------------|
| 0 (blank)   | 100                     |
| 3           | 35                      |
| 4           | 65                      |
| 5           | 60                      |
| 15          | 75                      |
| 16          | 75                      |
| 17          | 85                      |

The blank case (uncoated slide) had transmission value of 100%. The 3 selected IPA-based formulations no. 3, 4 and 5 were found to have lower transmittance than their 3 selected water-based counterparts. A similar trend was reported by Liu et al. [11]. More specifically, formulation no. 3 exhibited the lowest transmittance of 35% whereas formulations no. 4 and 5 showed transmittance of 65% and 60%, respectively. In contrast, formulations no. 15, 16 and 17 showed transmittance values of 75%, 75% and 85%, respectively.

6. Conclusion
Based on the above experimental results, it may be concluded that formula no. 4 is the optimum formulation of the coating because it displayed excellent superhydrophilicity (the smallest contact angle of 1.83º) [7] with strong adhesion, acceptable film thickness 300 nm and reasonable transmittance of 65%.

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8. References

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