Recent study on TiO₂ based Self-Cleaning Coating

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Abstract. Coating is a way of protecting the surface of the materials as glass, metal, clay, wood, and cementitious from pollutant, dust. self-cleaning coating can be achieved by modifying the surface to have super-hydrophobic, super-hydrophilic, and photocatalytic properties. This paper summarizes the recent studies on TiO₂ based self-cleaning coating. The scope of this article is in the mechanism and fabrication route of TiO₂ based self-cleaning coating, application technique such as spin coating, spray coating dip coating and chemical vapour deposition (CVD) and characterization. Self-cleaning coating can be characterized using many methods in order to determine their quality and feasibility. The characterization of the surface applied by self-cleaning coating can be in the form of numerical data and morphological images such as X-ray diffraction (XRD), Scanning Electron Microscope (SEM), Atomic Force Microscopy (AFM), contact angle, hardness, and scratch resistance are also analysed and discussed.

1. Introduction

Coating is a way to protect the surface of the materials as glass, metal, clay, wood, and cementitious from pollutant and dust [1]. There are various materials in this nature to be coated, such as glass, wood, metal, clay, and cementitious materials. By the rapid growth of the materials field and the avid production of multipurpose materials, self-cleaning coating is developed. Self-cleaning coating is defined as a coating that consists of compounds which either have a super-hydrophilic or super-hydrophobic property with the addition of photocatalytic effect. The former properties gives the self-cleaning effect by utilizing the action of water (rolling the droplet or sheeting water) to remove dirt or dust, while the latter activated its charges upon sunlight excitation that able to degrade the chemicals bonding of the dirt or dust absorbed by the water into smaller molecules [2].

The compound that is often used as a photocatalyst in the self-cleaning layer is TiO₂. The photocatalytic properties of TiO₂ results from the formation of photogeneration (hole and electron) charge carriers that occur in the absorption of ultraviolet (UV) in accordance with the band gap. The photogeneration hole in the valence band diffuses to the surface of TiO₂ and reacts with absorbed water molecules, forming hydroxyl radicals (·OH). Hydroxyl radicals and the photogeneration holes oxidize organic molecules on the surface of TiO₂. The electrons in the conduction band play a role in the reduction process, which reacts with molecular oxygen in the air to produce superoxide radical anions (O₂•−) [2].
Coating, as mentioned previously is also expected to have hydrophilic and hydrophobic properties. On the surface of super hydrophilic material, the surface energy is high and sufficient to make the water spread or sheeted to the surface of the substrate or the contact angle of the water on the surface is very low [3]. In 1997, Wang et al. showed a super hydrophilic effect on glass slides coated with TiO₂ thin films. The distribution of water is produced by the hydrophilic properties of anatase exposed to UV radiation and submicroscopic roughness from the coating respectively, although the effect of the spread of water was entirely due to photoinduced self-cleaning ability of TiO₂ with the contact angle \( \theta < 90^\circ \) [4]. Meanwhile, it was stated that generally a surface with contact angle larger than 150° and a shear angle lower than 10° is known as a superhydrophobic surface [5]. If the surface of the material is in the form of droplets and the composition of the organisms such as dust, water droplets will roll to the surface to degrade organic compound [6]. Barthlott and Neinhuis, (1997) have carried out microscopic examination of lotus leaves (Nelumbo nucifera) which showed a roughness of about 10 \( \mu \text{m} \) protruding bulge with a gap of 1030 \( \mu \text{m} \) covered with a small waxy crystal of about 0.22 \( \mu \text{m} \). Hydrophobic materials must have high roughness and low surface energy. High roughness reduces mechanical properties and other properties such as transparency [7].

Self-cleaning based TiO₂ coating can be the alternative solution for materials protections that require minimum maintenance and effectiveness in removing the dust, dirt, organic component even unwanted microorganism on the surface of the materials. Thus, assessing the development state of the self-cleaning based TiO₂ coating is necessary. This article covered the mechanism and fabrication route of TiO₂ based self-cleaning coating, application technique such as spin coating, spray coating dip coating and chemical vapour deposition (CVD) and characterization.

2. TiO₂ Based Coating

TiO₂ is one of the self-cleaning materials that has photocatalytic properties. This ability is beneficial for keeping a surface free of dirt and microorganisms. Besides a self-cleaning property, the other properties such as anti-reflectivity and photocatalysis are very important in many applications such as solar cells coating and smart phones or personal computers (PC) coating. Very high porous and low-density materials have combined the advantages of high surface area and high pore volume as well as larger pore sizes with accessible diffusion paths associated with nanopore structures. Helsch et al. (2006) found that borosilicate glass light transmission at 550 nm increased from 92 to 97% with a film thickness of 110 nm and porosity of around 35%. Self-cleaning TiO₂ film on glass has high potential for various applications such as windows in buildings, vehicles, and others [8].

Titanium dioxide can be produced from various Ti precursor such as TiCl₄ or Ti(SO₄)₂. Titanium dioxide can have three different crystals structures called brookite, anatase and rutile. Brookite is rare and not used for any industrial application. Rutile is the most extensive use a white pigment because it has a slightly higher refractive index than anatase and is less photoactive. Anatase can be formed at various temperatures depending on the process. Several reports make anatase at temperatures below 100°C and up to 900°C. Generally, though anatase does not thermally stable at high temperatures and converted to rutile. TiO₂ is a good photocatalyst because the rate of recombination of electrons, freed by photo excitation, and positive holes is slow compared to other photocatalytic materials. Although routine has a smaller band gap than anatase, and therefore absorption a wider range of wavelengths, anatase is a much more effective photocatalyst due to a slower recombination rate [9].

In addition, TiO₂ is common materials that is easy to produce, non-toxic and has a good thermal and chemical stability. Furthermore the effect is long lasting as the TiO₂ act as a catalyst and not consumed during the reaction [10]. Photocatalytic properties of TiO₂ has been applied on optically transparent glass materials have been used in many applications, including window glass, automobile windshields, cover of solar cell panel, microscopes, eyeglasses, screens of many electronic devices, and optical instruments [11]. Many researches have been conducted for TiO₂ coating preparation which includes its combination to other components in order to improve the coating properties.
Hwang et al. (2003) have prepared organic-inorganic nanocomposite coatings on PC with simple spray coating. A coating solution was prepared by inserting a nanosized TiO$_2$ sol into a polymer silica sol. This nanocomposite layer also protects the PC from photo degradation under UV illumination [12].

Table 1. Various kinds of TiO$_2$-based coating recipes from various studies

| Based                    | The coated object       | Results (Parameters)                                                                 | References |
|--------------------------|-------------------------|-------------------------------------------------------------------------------------|------------|
| Ce doped TiO$_2$ nanopowder through reflux method. | Glass                   | Sample HM-T20 with contact angle at water 118$^\circ$ and at n-hexadecane 57$^\circ$ | [13]       |
| TiO$_2$/reduced Graphene Oxide (rGO) | Glass                   | GT 0,5:1 after keeping the sample in ambient for 5 min, then water contact angle reverts to $\sim$34$^\circ$ from 48$^\circ$ | N/A        |
| TiO$_2$–SiO$_2$ mixtures | Polycarbonate substrates | With oleic acid under UV irradiation. A WCA 33$^\circ$ was observed on the surface of the TS-3 sample, after deposition, it became 45$^\circ$ | N/A        |
| TiO$_2$/poly(dimethylsiloxane) (PDMS) nanocomposites | Glass                   | Nano-TiO$_2$ was measured in the UV chamber for 60 seconds. All layers showed hydrophobic characteristics with an angle above 80$^\circ$. | N/A        |
| TiO$_2$–CCDP             | Glass                   | PEG-TiO$_2$ irradiated UV for 5 hours yield contact angles 11$^\circ$, 12$^\circ$ and 11$^\circ$ for CCDP content of 15, 30 and 50 units, respectively, | N/A        |
| TiO$_2$                  | Ordinary Portland Cement (OPC) pastes | The decrease was observed after UV irradiation for 6h hours with autoclave curing. | N/A        |

Kesmez, (2020) investigated TiO$_2$ nanoparticles doped by Ce were made by the reflux method added to the obtained hybrid polymer network, it is dispersed solvent at varying rate. The obtained transparent coating solution is applied to the glass surface [13]. Meanwhile, Kavitha, et al (2020) combined TiO$_2$ and reduced graphene oxide (rGO) by vacuum-assisted filtration and transfer method for self-cleaning application on glass. The presence of rGO in the hybrids can reduce the TiO$_2$ band gap and thereby increase visible light photo response. However amount of the loading rGO must be controlled in the TiO$_2$/rGO hybrid to resist catalytic property as well as hydrophilic [14]. The other research conducted by Adachi, et al (2018) studied a TiO$_2$/SiO$_2$ coating on polycarbonate using a dip coating technique [11]. Tavares, et al (2014) was synthesized TiO$_2$/poly (dimethyl siloxane) (PDMS) nanocomposites for further application in spraying to obtain thin films with photocatalytic properties and self-cleaning on glass [15]. Another research has also been conducted by Kim, et al (2016) which explored catechol conjugated polymers coated to the glass film by chemical route, and then the TiO$_2$
nanoparticles are immobilized on the surface of the polymer-coated glass film for make hydrophilic surfaces with photocatalytic activity and self-cleaning properties by changing the number of catechol parts (2-chloro-3,4-dihydroxyacetophenone), CCDP and TiO₂ nanoparticles [16]. The TiO₂ layer can also be deposited on materials containing cement, as was done by Constantino, et al (2020). In their research, TiO₂ for self-cleaning of cementitious materials is developed, where they used Ordinary Portland Cement (OPC) [17]. The details TiO₂-based coating recipes from various studies are summarized in Table 1. The measured parameter compared in each study is water contact angle (WCA).

3. Self-Cleaning Coating Application

Self-cleaning coating can be applied by using various methods, such as spin coating, dip coating, spray coating, and chemical vapor deposition.

3.1. Sol-Gel Process

In general, the sol-gel process involves the transition of a liquid system from a liquid "sol" (mostly colloid) to a solid "gel" phase. Long-lasting thin films with various properties can be stored on the substrate by spin-coating or dip coating. When "sol" is inserted into the mold, "wet gel" will form. With further drying and heat treatment, the "gel" is converted into a dense material. If the liquid in the wet "gel" is extracted under supercritical conditions, a very fragile and very low-density material called "air gel" is obtained. Because the viscosity of the "sol" is adjusted to within the range of viscosity given, the fiber can be pulled from the "sol". Ultrafine and uniform powders are formed by precipitation, spray pyrolysis, or emulsion techniques [18]. The application of sol-gel in nanotechnology is the same as mentioned above but in the nanoscale. Sophisticated devices in telecommunications, biology, and micro machinery, require new protective nanocoating and thin films. Thin films (typically <1μm thick) are formed by dipping or spinning slightly using raw materials and can be processed quickly without cracking, overcoming most of the losses from sol-gel processing. In addition to reflective or colored coatings, oxide coatings on glass and silicon substrates (single layer, multilayer, and porous layer) have been widely used as antireflective (AR) surfaces in solar-related applications.

3.2. Spin Coating

Spin coating is a procedure used to apply uniform thin films to a flat substrate. A typical process involves storing a small puddle of liquid resin into the middle of the substrate and then spinning the media at high speed (around 3000 rpm) [19]. The centrifugal force will cause the resin to spread to, and ultimately, the edge of the substrate leaving a thin layer of resin on the surface.

![Figure 1. Four distinct stages to spin coating, a) Dispense, b) Substrate acceleration, c) A stage of substrate spinning at a constant rate and fluid viscous forces dominate fluid thinning behaviour, d) A stage of substrate spinning at a constant rate and solvent evaporation dominates the coating thinning behavior [19].](image-url)
According to Fig. 1, there are four stages to the spin coating process, that is dispense, substrate acceleration, a stage of substrate spinning at a constant rate and fluid viscous forces dominate fluid thinning behaviour and a stage of substrate spinning at a constant rate and solvent evaporation dominates the coating thinning behavior. The first stage is dispense. A typical spin process consists of a dispense step wherein the liquid resin is deposited onto the surface of the substrate (Figure 1 (a)). Two methods of expenditure are static dispense, and dynamic dispense. Static dispense only stores small puddle of fluid on or near the center of the substrate. Dynamic dispense is the process of removing while the substrate rotates at a low speed. Speeds of around 500 rpm are generally used during this step of the process [20-21]. The second stage is substrate acceleration. This stage characterized by the expulsion of aggressive fluid from the surf ace of the water by rotational movements (Figure 1 (b)) [19-22]. The general rotation speed for this stage ranges from 1500-6000 rpm, depending on the properties of the fluid and the substrate. This step can take anywhere from 10 seconds to several minutes. The third stage is spinning the substrate with constant rate and fluid viscous force dominates the fluid depletion behavior This stage is characterized by gradual fluid depletion. Fluid depletion is generally quite uniform (Figure 1 (c)), although with solutions containing volatile solvents, it is often possible to see interference colors "spin", and doing so progressively more slowly because the thickness of the coatings decreases [23]. The fourth stage is spinning the substrate at a constant rate and evaporation of the solvent dominates the coating depletion behavior. When the previous stage advances, the thickness of the liquid reaches the point where the viscosity effect yield only in rather small net fluid flow. At this point, evaporation of volatile solvent species will be the dominant process (Figure 1 (d)) that occurs in the layer [22-24].

3.3. Dip Coating
The dip coating process can be defined as the deposition of a water-based liquid phase coating solution to the surface of each substrate. In general, the target material is dissolved in a solution that is directly coated on the surface of the substrate, then a wet layer of sediment has been evaporated to obtain a dry film [25-27]. This approach involves soaking the substrate into the solution of the coating material, therefore ensuring that the substrate has been completely infiltrated and then leaving the solution tank. One of the most important aspects of the dip coating process is the thickness of the deposited film [28], which is the basis of various properties, chemical properties, and applications. Shokuhfar et al. (2012) have examined that automotive wind shields with nano SiO2-TiO2 films can be coated with a dip sol-gel coating. The effect of annealing temperature was studied. In the dark (without UV irradiation), SiO2-TiO2 films are annealed at 500 ℃ with an almost hydrophilic anatase phase with a contact angle of 45°, annealed at 700℃ with a relatively hydrophobic rutile phase with a contact angle of 65°. This change in contact angle is clearly caused by an increase in heat treatment temperature, thereby reducing photocatalytic activity [29].

3.4. Spray Coating
The spray coating process can be applied to any object with complex shapes, where colloidal soles are sprayed on the media. The spray coating process is faster, and less sol waste occurs. Segota et al. (2011) studied the synthesis of TiO2 thin films on glass substrates by the sol-gel coating method, the effects of surface roughness were studied. It was found that the roughness was higher with the addition of polyethylene glycol (PEG) [30].

3.5. Chemical Vapour Deposition
Chemical vapor deposition (CVD) is the process by which thin solid films are deposited on the substrate through chemical reactions from gas species. For structural component applications, deposits usually occur at temperatures around 1000 ℃. This is a reactive process that distinguishes the CVD process from the physical vapor deposition (PVD) process, such as the physical evaporation...
process, sputtering and sublimation processes [31]. Lee et al. (2011) deposited TiO2 nanoparticles on glass bead with the CVD process. CVD-coated bead has a relatively uniform and regular surface. Catalytic activity was investigated using TiO2. The results showed that the coating time was less and the amount of TiO2 deposited was controlled through the coating time [32].

4. TiO2 based Self-Cleaning Coating Characterization

Preparation of self-cleaning coating based on TiO2, then characterized using several methods to determine the quality and feasibility. There are various types of characterization methods that can be performed, such as X-ray diffraction (XRD), Scanning Electron Microscope (SEM), Atomic Force Microscopy (AFM), contact angle, hardness and scratch resistance.

4.1. X-Ray Diffraction

X-ray diffraction (XRD) consists of 3 stages of work, namely: production, diffraction, and interpretation. At the production stage, electrons produced when the filament (cathode) is heated will be accelerated due to the difference in voltage between the cathode and the target metal (anode) so that collisions with the anode occur. The collision will produce X-ray radiation that will come out of the X-ray tube and interact with the crystal structure of the material being tested. In the diffraction stage, the X-ray radiation that produced will interact with the crystal structure of the material being tested. The material to be analyzed for its crystal structure must be in the solid phase because the atomic positions are arranged very regularly to form a crystal field. When X-rays are directed at the crystal plane, a diffraction pattern will appear when the X-ray passes through the small gaps between the crystal planes. The diffraction pattern resembles a dark and light pattern. Dark patterns are formed when destructive interference occurs, whereas light patterns are formed when constructive interference occurs from reflected X-ray waves that meet each other. Constructive disturbance occurs according to the following Bragg's Law:

\[ n\lambda = 2d \sin \theta \]  

(1)

where \( \theta \) is the diffraction angle, \( d \) is the distance between the crystal planes, \( \lambda \) is the X-ray wavelength, \( n \) is the diffraction sequence (1, 2, 3, ...).

Analyzing the top of the graph, the crystal structure of a material can be determined. Characterization using XRD aims to determine the crystal system. X-ray diffraction method can explain the lattice parameters, type of structure, different arrangement of atoms in a crystal, crystal imperfections, orientation, grain, and grain size [33]. Kavitha (2020) has researched that Figure 2 shows the XRD pattern of Graphene Oxyde (rGO) / TiO2 films differently after hydrothermal treatment and transfer. The XRD pattern of all samples has two characteristic diffraction peaks, one at \( \sim 25^\circ \) with d-spacing of 3.6 Å corresponding to (002) reflection from rGO and the other at \( \sim 10.5^\circ \) with d-spacing of 8.16 Å corresponding to (001) reflection from rGO. This shows a partial reduction in rGO during hydrothermal treatment. In GT 0.5:1, reflections from TiO2 crystallites are seen. Because (002) reflections from rGO stand out in all samples which show reduction and reordering of graphene sheets during hydrothermal reaction and filtration [14].
Figure 2. XRD pattern of rGO/TiO₂ hybrid film. Marked peaks (black dots) represents TiO₂ [14].

4.2. Scanning Electron Microscope

Scanning Electron Microscopy (SEM) can be used to determine the surface morphology of materials. Material characterization using SEM is used to see the surface topographic structure, grain size and structural defects [34]. Kesmez (2020) has researched that the surface of the film layer with various nano TiO₂ content was examined by Scanning Electron Microscopy. No cracks or similar defects were observed on the surface of the film image, and an optimal surface was obtained. Although the amount of TiO₂ in the inorganic part increases, the surface of all layers is smooth and uniform (Figure 3) [13].

Figure 3. SEM images of the coatings on polycarbonate surface: a. HM-T0, b. HM-T20, c. HM-T60, d. Cross-section of HM-T20 [13].
Kavitha (2020) has researched that the surface of the film layer with various rGO (graphene oxide)/
TiO₂ content was examined by SEM. Figure 1.4 gives information of SEM images of different
rGO/TiO₂ films (a) GT 0.1:1 (b) GT 0.5:1 and (c) GT 1:0.1. In the surface of the film, TiO₂
nanoparticles is observed like nodules. When the amount of GO is increased, the nodules merge
together to form continuous film with evenness on the surface as observed in Figure 4 (c) (GT 1:0.1)
[14].

![Figure 4. SEM images of different rGO/TiO₂ films (a) GT 0.1:1 (b) GT 0.5:1 and (c) GT 1:0.1 (scale 1 μm) [14].](image)

### 4.3. Atomic Force Microscope

Atomic force microscopy (AFM) is a technique that is used to map the topography and to study the
properties of material on a nanoscale. AFM uses a probing tip at one end of a spring-like cantilever
to interact with the material (sample). The interaction between the tip and the sample gives attractive
or repulsive forces. These forces give information about the topography of the sample [35]. Kim
(2016) deposited TiO₂ onto the C-PEG surface which was studied by measuring the thickness of the
coating using Atomic Force Microscope (AFM), as shown by the image in Figure 5. The average
thickness of the C-PEG coating was nearly 18.1 nm, then was increased to 44.3 nm after TiO₂ were
deposited. Considering the increased 26 nm thickness, it is assumed that the TiO₂ were successfully
deposited onto the composite as C-PEG / TiO₂. Additionally, the AFM image of C-PEG/TiO₂ was
suggesting homogeneous shape and fairly uniform size that could maintain effective interaction
between PEG and TiO₂ [16].
4.4. Contact Angle

The deposition of coating on solids produces new interfaces between different materials and involves considerations of wetting, dispersing, interface evolution, and adhesion. The wettability of a solid by a liquid is characterized in terms of the contact angle made by the liquid in that solid. The contact angle, $\theta$ is obtained from the balance of the interface tension (Figure 6) and is defined from the Young equation, according to it

$$\sigma_{sv} = \sigma_{lv}. \cos \theta + \sigma_{ls} \quad (1.2)$$

where $\sigma_{sv}$, and $\sigma_{lv}$ and $\sigma_{ls}$ are are the interface tensions at the boundary between vapor (v), solid (s) and liquid (l). Here, it represents the force required to stretch the interface to the distance of the unit (or, equivalent, the energy needed to make the surface area of the unit from the given interface, provided, in the case of $\sigma_{sv}$, mechanical distortion and strain can be ignored). The conditions $\theta < 90^\circ$ indicate that the solids are wet by liquid, and $\theta > 90^\circ$ indicate nonwetting, with limits $\theta = 0$ and $\theta = 180^\circ$ defining complete wetting and total wetting, respectively [36].

For rough surfaces, Wenzel (1936) introduced the following relationship [37]:

$$\cos \theta_w = r \cos \theta \quad (1.2)$$

where $r$ is the surface roughness parameter; $r$ is defined as a rough area / smooth area. The Wenzel relationship shows that if the intrinsic contact angle for liquids on a solid surface is below $90^\circ$ (hydrophilic), then this additional roughening of the surface will reduce the effective contact angle.
Kim (2016) has researched that in Figure 7 shows the sample water contact angle for CCDP content of 15, 30 and 50 units, respectively. Bare glass film shows a contact angle of 72°. When CCDP content in C-PEG the contact angle increases to 57°, 58° and 65°, respectively, which shows an increase in hydrophobicity. When the same amount of TiO$_2$ nanoparticles was immobilized on the surface of a C-PEG coated glass film, the contact angle changed to 42°, 39° and 26°. These results indicate the success of immobilization of TiO$_2$ nanoparticles which become hydrophilic on the C-PEG coated glass surface. UV irradiation for 5 hours results in contact angle of 11°, 12° and 11°, indicating that the surface becomes more hydrophilic. A more hydrophilic surface may be caused by the decomposition of organic species adsorbed on C-PEG/TiO$_2$ through conventional photocatalytic oxidation processes [16].

![Figure 7. The water static contact angle optical images of C-PEG, C-PEG /TiO$_2$ (50 wt%), coated surface in response to UV irradiation [16].](image)

4.5. Hardness and Scratch Resistance

Hardness is defined as the ability of a material to resist penetration or abrasion by other materials. Hardness can be evaluated by dividing it into three main types: rebound hardness, indentation and scratch. Rebound hardness is evaluated by measuring the reflection of a hammer dropped from a fixed height to the material. The indentation is evaluated according to the indent dimension left by the indenter. In engineering field is the most common Vickers, Brinnel, and Rockwell test. Scratch hardness is often assessed in the case of film surfaces or as a comparison method. Hardness can be evaluated based on three different scales: macro, micro and nano scale. Specimens tested on a macro scale typically experience test loads higher than 10 N and this scale also includes the Vickers, Brinnel, and Rockwell tests mentioned above [38]. According to the Table 2. Kesmez (2020) has researched that the values of pencil and Newton hardness on HM-T0 surfaces that didn’t contain Nano TiO$_2$ were each determined as 6 H and 2.4 N. The hardness value obtained increases with reduced organic film content, and, in words others, it was determined that the hardness value of Pencils and Newton increased respectively to > 9H and 4.0 N, with an increase in inorganic parts (TiO$_2$ nanoparticles) in the film [13].
Table 2. The results of mechanical tests of the obtained samples.

| Sample     | Hardness | Pencil Hardness | Scratch Resistance |
|------------|----------|----------------|--------------------|
| HM-T0      | 6H       |                | 2,4 N              |
| HM-T10     | 8H       |                | 2,8 N              |
| HM-T20     | 9H       |                | 3,4 N              |
| HM-T40     | >9H      |                | 3,6 N              |
| HM-T60     | >9H      |                | 4,0 N              |

5. Future Development TiO$_2$ based Self-Cleaning Coating

TiO$_2$ based self-cleaning coating is very potential for further development as it can be one of alternatives approach to prevent the pollution accumulation on daily used materials or structures which cause technical and economical problem. Many researches have been conducted related to the materials combination and also application technique to bring out the optimum coating that can gives maximum advantages. The combination of TiO$_2$ and graphene oxide seems to have an extensive development as the addition of graphene to the TiO$_2$ film results transparent and high conductivity yields a promising increase in photocatalytic activity in visible light excitation. Thus, can extend the potential of TiO$_2$ based self-cleaning coating in various indoor applications. As graphene is conductive material, the electroconductivity of TiO$_2$ based self-cleaning with a graphene will add additional function through its antifouling effect against particulate contaminants.

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