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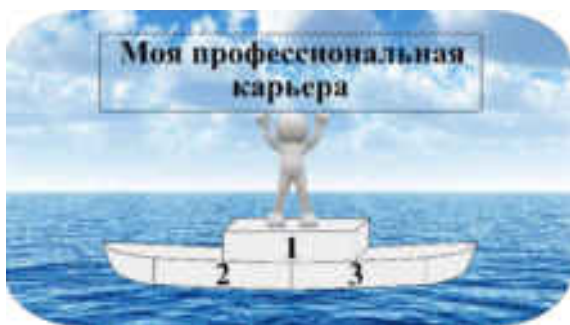


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«ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ»

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**Международный научно-образовательный электронный журнал
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OGUZ HAN ENGINEERING AND TECHNOLOGY UNIVERSITY OF TURKMENISTAN

Название публикации: «SURFACE FUNCTIONALIZATION OF SiO₂ AND TiO₂ NANOPARTICLES FOR SELF-CLEANING AND ANTI-FOULING SURFACES»

Introduction

In recent years, nanotechnology has become one of the most rapidly developing fields in material science and engineering. Nanoparticles possess unique physical and chemical properties because of their extremely small particle sizes and large surface area-to-volume ratios. Among various nanomaterials, silicon dioxide (SiO₂) and titanium dioxide (TiO₂) nanoparticles are especially important for advanced coating technologies.

Self-cleaning and anti-fouling surfaces are innovative materials designed to reduce contamination, microbial growth, and surface pollution. These surfaces are widely used in construction materials, solar panels, medical devices, marine engineering, textiles, and automotive industries. Surface functionalization of nanoparticles improves their compatibility, hydrophobicity, photocatalytic activity, and durability, allowing the production of highly efficient protective coatings.

SiO₂ nanoparticles are mainly used to create rough hydrophobic surfaces, while TiO₂ nanoparticles provide strong photocatalytic and antibacterial properties. The combination of these nanoparticles enables the development of multifunctional coatings with excellent self-cleaning and anti-fouling performance.

Nanoparticle Characteristics

Silicon Dioxide (SiO₂) Nanoparticles

Silicon dioxide nanoparticles possess:

- High thermal stability
- Chemical inertness

- Optical transparency
- Large specific surface area
- Mechanical durability

The nanoscale size of particles is generally expressed as:

$$1 \text{ nm} \leq d \leq 100 \text{ nm}$$

Where:

- d = particle diameter

The small particle size increases surface roughness and enhances hydrophobic behavior when applied to coatings.

Titanium Dioxide (TiO₂) Nanoparticles

Titanium dioxide nanoparticles are widely known for:

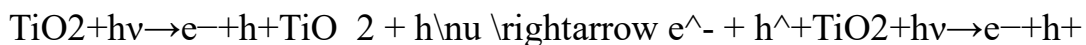
- Strong photocatalytic activity
- UV absorption capability
- Antibacterial performance
- Chemical resistance
- Environmental stability

TiO₂ exists mainly in three crystalline forms:

- Anatase
- Rutile
- Brookite

Among these, anatase TiO₂ demonstrates the highest photocatalytic efficiency.

Under ultraviolet radiation, TiO₂ generates electron-hole pairs:



Where:

- $h\nu$ = photon energy
- e^- = electron
- h^+ = positive hole

These charge carriers initiate oxidation-reduction reactions that decompose contaminants and microorganisms.

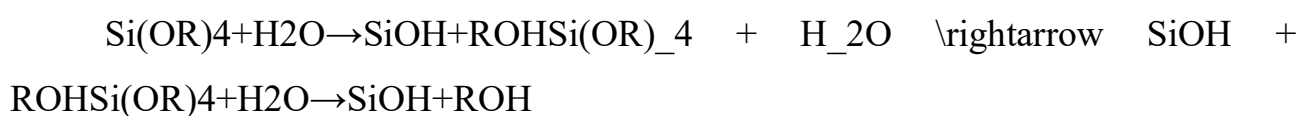
Surface Functionalization Techniques

Surface functionalization refers to the modification of nanoparticle surfaces using chemical or physical methods to improve their properties.

1. Silane Modification

Silane coupling agents are commonly used to functionalize SiO₂ and TiO₂ nanoparticles.

The hydrolysis process can be represented as:



The generated silanol groups bond strongly to nanoparticle surfaces, improving:

- Adhesion
- Hydrophobicity
- Dispersion stability

Functional groups such as fluorinated alkyl chains can create superhydrophobic surfaces.

2. Polymer Functionalization

Nanoparticles may be coated with polymers including:

- Polyurethane
- Polydimethylsiloxane (PDMS)
- Polyethylene glycol

Polymer layers improve:

- Mechanical strength
- Chemical resistance
- Surface flexibility

Functional polymers also reduce nanoparticle agglomeration.

3. Plasma Surface Treatment

Plasma treatment modifies nanoparticle surfaces by ion bombardment and surface activation.

Advantages include:

- Increased surface energy
- Improved wettability
- Enhanced coating adhesion

Plasma technology is widely used in biomedical and electronic industries.

Self-Cleaning Mechanisms

Self-cleaning surfaces mainly operate through two mechanisms:

1. Superhydrophobic effect
 2. Photocatalytic degradation
-

Superhydrophobic Effect

Superhydrophobic surfaces strongly repel water droplets. Dust and contaminants are removed when water rolls across the surface.

The hydrophobic behavior is determined by the water contact angle:

$$\theta > 150^\circ$$

Where:

- θ = contact angle

A contact angle greater than 150° indicates superhydrophobicity.

SiO_2 nanoparticles create nanoscale roughness that enhances water repellency.

Photocatalytic Self-Cleaning

TiO_2 nanoparticles decompose organic contaminants under UV radiation through photocatalytic reactions.

The hydroxyl radical formation reaction is:



Hydroxyl radicals are highly reactive and destroy:

- Organic pollutants

- Oils
- Bacteria
- Biofilms

This process keeps surfaces clean without manual washing.

Anti-Fouling Properties

Anti-fouling surfaces prevent accumulation of:

- Microorganisms
- Algae
- Dust
- Proteins
- Marine organisms

Biofouling is a major problem in marine and biomedical industries because it causes:

- Corrosion
- Increased fuel consumption
- Infection risks
- Reduced material lifespan

Functionalized TiO₂ nanoparticles provide antibacterial effects through oxidative stress mechanisms.

The reduction of bacterial population may follow exponential decay behavior:

$$N = N_0 e^{-kt}$$

AAA

kkk

$$y = A e^{-kt} \approx 6 e^{-0.6t}$$

yt

Where:

- N = bacterial population
- N_0 = initial population
- k = decay constant

- $t_{tt} = \text{time}$

This equation demonstrates the antimicrobial efficiency of photocatalytic surfaces.

Industrial Applications

Construction Industry

Self-cleaning coatings are applied on:

- Glass windows
- Ceramic materials
- Building facades
- Concrete structures

These coatings reduce maintenance costs and improve durability.

Solar Panels

Dust accumulation decreases solar panel efficiency. Nanoparticle coatings help maintain clean surfaces and improve energy conversion efficiency.

Marine Engineering

Anti-fouling coatings protect:

- Ship hulls
- Offshore platforms
- Underwater pipelines

These coatings reduce biological growth and corrosion.

Medical Applications

Functionalized nanoparticle coatings are used in:

- Surgical instruments
- Medical implants
- Hospital surfaces

Their antibacterial properties help reduce infection risks.

Textile Industry

Nanoparticle-treated fabrics exhibit:

- Water repellency
- Stain resistance
- Antimicrobial activity

These textiles are widely used in healthcare and sportswear industries.

Advantages of Functionalized Nanoparticles

1. Excellent self-cleaning ability
 2. Strong anti-fouling performance
 3. High chemical stability
 4. UV resistance
 5. Antibacterial properties
 6. Long-term durability
 7. Reduced maintenance costs
-

Challenges and Limitations

Despite their advantages, several limitations still exist:

- Nanoparticle agglomeration
- Limited visible-light photocatalysis
- High manufacturing costs
- Environmental concerns regarding nanoparticle release

Current research focuses on:

- Green synthesis methods
 - Visible-light-active TiO₂
 - Eco-friendly coating technologies
 - Improved mechanical durability
-

Conclusion

Surface functionalization of SiO₂ and TiO₂ nanoparticles represents an important advancement in nanotechnology and material engineering. SiO₂ nanoparticles contribute to surface roughness and hydrophobicity, while TiO₂ nanoparticles provide photocatalytic and antibacterial activity.

Functionalized nanoparticle coatings enable the production of highly efficient self-cleaning and anti-fouling surfaces used in construction, marine engineering, medicine, solar energy systems, and textiles. These materials reduce contamination, improve durability, and minimize maintenance requirements.

Future developments are expected to focus on environmentally sustainable synthesis methods, multifunctional coatings, and enhanced photocatalytic performance under visible light conditions. As nanotechnology continues to evolve, self-cleaning and anti-fouling surfaces will play an increasingly important role in modern industrial and environmental applications.

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