Proceedings of the 5th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/124/2025.20145

Research on the Light Absorption Properties of Nanoparticles in the Cosmetics Industry

Minjun Luo[1,a,*]

[1]*Wuhan University of Technology, Wuhan City, China*
a. 336032@whut.edu.cn
**corresponding author*

Abstract: Cosmetic materials can directly affect the performance, safety and user experience of products. High quality materials can ensure that cosmetics can effectively improve skin conditions, maintain makeup for a long time, reduce the risk of allergy, and improve overall beauty and comfort. With the progress of science and technology, the R&D and application of cosmetic materials are increasingly rich, and strive to meet the needs of different skin types and styles. However, the light absorption performance of traditional materials is poor, which is not enough to achieve the desired cosmetic effect. In contrast, nanomaterials have unique structural characteristics, such as high surface area volume ratio and enhanced optical properties, which can significantly improve the absorption and utilization of light. The paper studies the exploration and application of nano materials in cosmetics, and their potential to change the industry. In addition, the potential disadvantages and hazards of these nanomaterials are also discussed. The significance of this work is to summarize the current situation of nanomaterials in the cosmetics industry and new possibilities for more effective and innovative cosmetics products.

Keywords: light absorption, nanoparticles, cosmetics industry

1. Introduction

Cosmetics refer to a kind of daily-use chemical industrial products used to smear, spray or other methods on the human body surface to achieve the purpose of cleaning, maintaining, beautifying, modifying or changing the appearance. Among them, sunscreen, whitening and anti-aging are the most common efficacy categories in cosmetics.

The application of traditional particles in cosmetics is slightly insufficient. Traditional particles, due to their large size, are difficult to form a uniform and dense sunscreen layer on the skin surface, resulting in relatively weak sun protection effects. Compared to nanoparticles, traditional particles such as titanium dioxide or zinc oxide with larger particle sizes may not perform well in ultraviolet radidation b protection and cannot effectively block the damage of ultraviolet rays to the skin [1]. The application of traditional particles in whitening cosmetics is relatively limited because they are difficult to penetrate deep into the skin to exert whitening effects. Compared to nanoparticles, traditional particles have poor permeability and absorption in the skin, making it difficult to achieve ideal whitening effects. The application of traditional particles in anti-aging cosmetics is also limited because they are difficult to penetrate deep into the skin to exert anti-aging effects. Nanoparticles can penetrate deeper into the skin, promote collagen production and cell metabolism, thereby achieving anti-aging effects [2]. However, traditional particles may not be able to achieve this effect due to their large size.

The emergence of nanoparticles has brought new breakthroughs to the cosmetics industry. Nanoparticles have unique optical properties due to their special structural properties, such as small size effect, surface effect and quantum size effect. These characteristics make nanoparticles have better dispersion, stability and absorption in cosmetics, which can significantly improve the effect of cosmetics.

In this paper, the excellent optical absorption properties of titanium dioxide, zinc oxide, gold/silver and other major nanoparticles are discussed. Titanium dioxide and zinc oxide can reflect and scatter ultraviolet rays, effectively preventing skin sunburn. Gold/silver nanoparticles can absorb light at a specific wavelength and produce photothermal effect or photodynamic effect, thus exerting antibacterial and antioxidant properties. The light absorption properties of these nanoparticles make them widely used in cosmetics such as sunscreen, whitening and anti-aging. This paper emphasizes the great significance of the light absorption properties of nanoparticles for the possibility of the innovation of the cosmetics industry in the future.

2. Discussion

2.1. Types of Nanoparticles Used in Cosmetics

According to different light effects, nanoparticles used in cosmetics can be roughly divided into three categories.

One is nano particles based on scattering effect, such as nano titanium dioxide (TiO_2). The particle size of nano titanium dioxide is much smaller than the wavelength of visible light, so it has weak scattering ability to visible light and high transparency. However, it has a strong scattering and absorption effect on ultraviolet. With the decrease of particle size, the reflection and scattering of ultraviolet radiation a are not obvious, while the absorption of UVB is obviously enhanced. At the same time, nano titanium dioxide has high refractive index, which can effectively reflect and scatter ultraviolet rays and play a role in sunscreen. In addition, its surface is usually charged, which can interact with the oil and water on the skin surface to improve the adhesion and durability of sunscreen products. The second is nanoparticles based on absorption effect, such as nano zinc oxide (ZnO). It can reflect, scatter and partially absorb ultraviolet rays, and has a shielding effect on UVB and UVA. Third, nanoparticles based on special light absorption and scattering effects, such as gold, silver and other metal nanoparticles. Metal nanoparticles will exhibit strong light scattering and absorption effects under the irradiation of specific wavelength electromagnetic waves, which is called local surface plasmon resonance (LSPR). This phenomenon makes metal nanoparticles become the best scatterers and absorbers in the visible region. These nanoparticles play an important role in cosmetics and provide a variety of functions and effects for products.

2.1.1. Titanium Dioxide Nanoparticles(TiO2 NPs)

Titanium dioxide is one of the most widely used inorganic UV filters in sunscreens. The UV shielding performance of nano-TiO_2 is mainly achieved by the absorption and scattering of UV light [3]. When exposed to UV light, the electrons in the valence band of nano-TiO_2, as a semiconductor, are excited to transition to the conduction band, and corresponding holes are generated in the valence band, forming photogenerated electrons in the conduction band. In this way, it can absorb ultraviolet light larger than its band gap energy (about 2.3 eV). UV is an electromagnetic wave. When UV irradiates nano-TiO_2 particles, the size of nano-TiO_2 particles is far smaller than the UV wavelength, and the electrons in them will be forced to vibrate at the same frequency, becoming a secondary wave source to radiate the original incident UV light. TiO_2 nanoparticles are optimal for sunscreen formulations

DOI: 10.54254/2755-2721/124/2025.20145

also because they possess outstanding transparency and dispersion, making them effective as protective filters.

The ability of TiO_2 particles to absorb and scatter light depends on the particle size. In contrast, when the UV wavelength is long, the shielding ability of nano-TiO_2 depends more on its scattering ability while the shielding ability depends more on its absorption ability when the wavelength is short [4]. For near UV light with the wavelength of 400nm, the shielding ability of nano-TiO_2 almost completely depends on its scattering ability. For ultraviolet light with a wavelength of 375nm, the scattering ability and absorption ability of nano-TiO_2 are basically equal. For ultraviolet light with a wavelength of 350nm, nano-TiO_2 has great absorption capacity, but its scattering effect cannot be ignored. For ultraviolet light with a wavelength of 300nm-325nm, the shielding ability of nano-TiO_2 almost completely depends on its absorption ability. Therefore, there is an optimal particle size of nano-TiO_2 [5], which is conducive to comprehensive protection against UV radiation.

2.1.2. Zinc Oxide Nanoparticles (ZnO NPs)

Zinc oxide is another important inorganic UV filter used in sunscreens. Compared to TiO_2, ZnO demonstrates superior UVA absorption [6]. ZnO nanoparticles enhance both UV absorption and transmission. When TiO_2 and ZnO nanoparticles are mixed, the dispersion and stability of relatively single particles can be improved. Also, the brightness of zinc titanium composite slurry is higher than that of TiO_2 and ZnO mixed powders at the appearance stage. At the application stage, the spreading property is good, the moisture feeling is strong, and the whiteness is significantly improved. After application, the brightness, smoothness and moisture retention are higher, and the whiteness is significantly improved [7].

The application of ZnO in sunscreen cosmetics also makes the system convergent and has the effect of absorbing the oil that human skin secrets [8]. The antibacterial properties of nano ZnO come from two aspects. First, $Zn2^{+}$is a heavy metal ion, which can inhibit the activity by combining with thiol groups on bacterial and viral proteins. Second, ZnO will produce hole (h^+) - electron (e^-) pairs under UV irradiation, and the active holes and electrons will migrate from the valence band (VB) and conduction band (CB) of nano ZnO to the particle surface, converting the water or hydroxyl (OH) adsorbed on the surface to hydroxyl radicals (·OH), and the oxygen to atomic oxygen ($\cdot O_2^-$).Hydrogen and oxygen free radicals with strong oxidation can kill most bacteria and viruses. Due to the small particle size of nano ZnO, holes and electrons move faster from the inside of the crystal to the crystal surface, reducing the probability of hole and electron recombination, so nano ZnO has stronger antibacterial ability than micro ZnO [6].

2.1.3. Gold and Silver Nanoparticles (Au NPs/Ag NPs)

Gold nanoparticles can adjust the texture of cosmetics, making them more delicate and easy to apply and absorb. By using gold nanoparticles, cosmetics can form a uniform film on the skin and improve the stability of the product. Gold nanoparticles also have significant anti-aging and antioxidant effects which can produce photodynamic effects and stimulate cell metabolism and repair process after absorbing visible and infrared light. This photodynamic cosmetic effect helps to improve skin quality, promoting collagen production and skin firmness.

Nano silver material has a very effective inhibition and killing effect on bacteria and mold. One component of nano silver antibacterial agent can build a cosmetic anti-corrosion system, eliminate the impact of microorganisms on the quality of cosmetics, and avoid the harm of cosmetics caused by secondary microbial pollution. The introduction of nano silver antibacterial agent into cosmetic composition can achieve high-efficiency and broad-spectrum antibacterial effect with a small amount of addition, and achieve a high degree of unity of antibacterial, anti-corrosion, safety and stability of cosmetics [9].

2.2. The Importance of Nanomaterials in Enhancing Light Absorption Performance

2.2.1. UV protection in Sunscreens

Sunscreens have evolved significantly over the years, with advancements in technology leading to more effective and safer products. One of the key innovations in sunscreen technology is the incorporation of nanomaterials. These materials, due to their unique properties, have revolutionized the sunscreen industry by enhancing light absorption capabilities and providing superior protection against harmful UV rays.

In the context of sunscreens, nanomaterials such as ZnO and TiO_2 are commonly used. These nanomaterials possess exceptional light absorption and scattering properties, making them ideal for blocking UV radiation. ZnO, in particular, is a widely used nanomaterial in sunscreens due to its broad-spectrum UV protection. It can reflect, scatter, and partially absorb UV rays, providing shielding against both UVA and UVB radiation. The small particle size of ZnO nanoparticles allows them to be easily dispersed in sunscreen formulations, creating a transparent and lightweight product. The light absorption properties of ZnO nanoparticles are enhanced by their large surface area and small size. When UV rays strike the surface of ZnO nanoparticles, part of the energy is converted into heat and dispersed, reducing the potential for skin damage. Additionally, the scattering of UV rays by ZnO nanoparticles further reduces the intensity of radiation reaching the skin. TiO_2 nanomaterials also play a crucial role in sunscreens by providing effective UV protection. Like ZnO, TiO_2 can scatter and absorb UV radiation, making it a valuable component in broad-spectrum sunscreens. The combination of ZnO and TiO_2 in sunscreen formulations often results in enhanced UV protection, covering a wider range of wavelengths [7].

Of course, with the use of modern sun protection technology, the sun protection efficiency may be further improved. The active sunscreen ingredients of microcapsules can be trapped in a silica shell [10]. Jun Zhang et al. have studied and demonstrated that encapsulating hydrophobic UV absorber MBBT within silica vesicles can improve the UV attenuation efficiency and skin safety of sunscreen formulations [11].Using this technology, as the active ingredient does not directly contact the skin, it can reduce allergic or irritating reactions. Microencapsulation can further solve the problem of incompatibility between different components. In addition, polymer materials that only enhance the effectiveness of active ingredients but do not absorb UV radiation can be used, even if they scatter UV radiation [12].

2.2.2. Brightening in Color cosmetics

A key aspect of nanotechnology in cosmetics is to use the light absorption characteristics of nanoparticles to enhance the color, durability and overall performance of products.

Color cosmetics, such as foundation cream and lipstick, usually use nanoparticles to achieve ideal color effect and improve texture. In particular, Au NPs, due to their strong absorption and scattering properties, have been used to create vibrant and lasting colors. The color of gold nanoparticles varies from red to purple depending on their diameter and the surrounding chemical environment. When the size of nanoparticles is reduced, their absorption and emission spectra are blue shifted, and when the size of nanoparticles is increased, they will be red shifted. Therefore, the color of nano gold varies with its diameter and surrounding chemical environment [13]. Nano-TiO_2 particles are fine and easy to scatter blue light with short wavelength in visible light, which will make the skin blue when added into sunscreen cosmetics. In order to match skin color, red pigments such as iron oxide are often added to cosmetic formulas in the early stage [5]. The current iron oxide cosmetics pigments have

DOI: 10.54254/2755-2721/124/2025.20145

achieved the advantages of fine and smooth powder, good covering power, easy coloring, uniform particle distribution and good safety [14].

Secondly, nanoparticles can adjust the optical properties of cosmetics, making them present a more natural and three-dimensional appearance. By scattering and reflecting light, nanoparticles can create a soft-focus effect, minimize defects and improve skin luster. This is particularly useful for foundation and Concealer products, where a perfect and radiant complexion is ideal.

Nano particles can also optimize their light absorption properties through the construction of layered structure. Research shows that the layered distribution of nanoparticles with different sizes can enhance the light absorption effect of single particles, and particles with different sizes can play their respective light absorption advantages, so as to improve the overall light absorption performance of the coating [15]. This strategy not only improves the extinction performance of the coating, but also enhances the thermal stability and optical properties of the coating, which makes it have broad prospects in the application of high temperature solar selective absorption coating.

In addition, the use of nanoparticles in color cosmetics can enhance the spreading and wear resistance of products and provide smoother and more uniform applications.

2.2.3. Anti-aging treatments

Nanoparticles exhibit excellent optical properties. The most important is their ability to absorb light with a wide spectrum, including UV. UV radiation is the main factor of skin aging, which will damage DNA, protein and lipid, and lead to the formation of wrinkles, fine lines and pigmentation [16]. By absorbing ultraviolet rays, nanoparticles play a shielding role and protect the skin from this harmful radiation. ZnO and TiO_2 are two kinds of nanoparticles commonly used in sunscreen because of their excellent UV absorption properties. For example, ZnO has been proved to be effective in blocking UV-A rays, which penetrate deeper into the skin and are more destructive than UV-B rays. When formulated into cosmetics, these nanoparticles can provide broad-spectrum protection and reduce the risk of photoaging.

In addition to UV protection, the light absorption characteristics of nanoparticles can also indirectly promote the anti-aging effect by enhancing the transmission of active ingredients. By absorbing light, nanoparticles can generate heat, which helps to open the pores of the skin, so as to better penetrate anti-aging active substances, such as peptides, antioxidants and retinoids. This enhanced delivery system ensures that these ingredients reach the deeper layers of the skin, where they are most effective.

In addition, some nanoparticles, such as cerium oxide (CeO_2), have been found to have antioxidant properties. They can remove free radicals generated by UV radiation [17] and other environmental pressures, thus protecting the skin from oxidative damage, which is the key driver of skin aging. AgNPs is included in skin care products because of its antibacterial and anti-inflammatory properties [9]. These nanoparticles can help reduce the appearance of fine lines and wrinkles by promoting collagen synthesis and inhibiting the growth of bacteria that can cause skin infections. Its ability to absorb and scatter light can also provide a mild exfoliation effect and improve skin texture and luster. By incorporating these antioxidant nanoparticles into cosmetics, manufacturers can create products that not only protect the skin from external damage, but also promote internal skin health.

2.3. Problems and challenges

Despite the numerous advantages of nanoparticles in cosmetics, there are several challenges that need to be addressed to ensure their safe and effective use. One of the primary concerns is the potential health risks associated with nanoparticle exposure. Because of the small particle size, nanoparticles can enter the human body through infiltration or simple diffusion. He Pingting et al. studied the effects of nano TiO_2 on lung tissue and serum biochemical indicators in mice by exposing them to an environment containing 1500 mg/m^3 of nano TiO_2 aerosol. They finally found that nanoparticles were present in the alveolar spaces after 28 days of exposure in this environment, and lung inflammation gradually increased [18].Yuan Jinhua et al. used MTT assay to detect the effect of zinc oxide nanoparticles on the survival rate of somatic cells, evaluated the morphological changes of cells using optical microscopy, and observed the changes in surface microstructure before and after the interaction between cells and nano zinc oxide using electron microscopy, thus obtaining the result that high concentration of nano zinc oxide can lead to apoptosis of HELF cells [19].

3. Conclusion

The article summarizes the application of the four common nanoparticles: zinc oxide NPs, titanium dioxide NPs, gold NPs, and silver NPs, in the cosmetics industry, and outlines the role and advantages of nanoparticle light absorption properties from three aspects: sunscreen, cosmetics, and anti-aging. Finally, the potential hazards of nanoparticle application in cosmetics to human health and the environment were proposed.

The light absorption properties of nanoparticles have a crucial role in developing advanced cosmetic products, offering enhanced functionalities and improved performance. From UV protection to color cosmetics and anti-aging treatments, nanoparticles have demonstrated their potential to revolutionize the cosmetics industry. However, the safe and effective use of nanoparticles in cosmetics needs a thorough understanding of their mechanisms, potential risks, and regulatory considerations. Future research should focus on addressing these challenges and developing innovative solutions to harness the full potential of nanoparticles in cosmetic applications.

Future research in this field should focus on developing safer and more sustainable nanoparticles for cosmetic applications. Green synthesis methods, which use plant extracts and other natural materials, offer a promising approach to reduce the environmental impact and improve the biocompatibility of nanoparticles. Additionally, the development of multifunctional nanoparticles can lead to the creation of more effective and versatile cosmetic products.

References

[1] *Li Y H, Li J F, Li M C, et al.Study on the influence of nano ingredients in sunscreen cosmetics on its performance[J]. StandardandQuality of Light Industry, 2019(3):4.DOI:10.19541/j.cnki.issn 1004-4108.2019.03.010*

[2] *Yang G Y,Cui Y L,Zhong S. Applications of Nanotechnology in Whitening and Anti-aging Cosmetics[J]. Journal of Capital Medical University,2009,30(6):862-865. DOI:10.3969/j.issn.1006-7795.2009.06.032.*

[3] *Smijs T G,Pavel S.Titanium dioxide and zinc oxide nanoparticles in sunscreens:focus on their safety and effectiveness[J].Nanotechnology,science and applications,2011,4: 95.*

[4] *MASACHI SAKAMOTO,HARUO OKUDA.Influence of particle size of titanoum dioxide on UV-ray shieding property[J].Iap Soc Colour Mater,1995,168(4):203.*

[5] *Yao C,Zhang Z H,Lin X P,et al. Nanosized titanium dioxide in sunscreen preparations[J]. China Surfactant Detergent & Cosmetics,2003,33(5):333-336. DOI:10.3969/j.issn.1001-1803.2003.05.018.*

[6] *Yao C,Wu F Q,Lin X P,et al. Application of nanosize zinc oxide in sunscreen cosmetics[J].China Surfactant Detergent & Cosmetics,2003,33(6):393-397. DOI:10.3969/j.issn.1001-1803.2003.06.015.*

[7] *Chen X Y, Wang C, Yu J, et al. Application of titanium dioxide/zinc oxide composite slurry in sunscreen formulation[J]. China Surfactant Detergent & Cosmetics, 2018, 48(4):221-226. DOI:10.13218/j.cnki.csdc.2018.04.008.*

[8] *KOICHI DHTSU,NORIAKI SATO. Ultraviolet rays-absorbing composition and process for producing the same [P]. US:5976511. 1999-11-02.*

[9] *Wang J C,Yi G B. Synthesis and application of silver nanoparticles as antimicrobial agent in cosmetics[J]. Applied Chemical Industry ,2018,47(10):2094-2096,2102. DOI:10.3969/j.issn.1671-3206.2018.10.012*

[10] *Gogna D, Jain SK, Yadav AK, Agrawal GP. Microsphere based improved sunscreen formulation of ethylhexyl methoxycinnamate. Curr Drug Deliv 2007; 4: 153–159.*

DOI: 10.54254/2755-2721/124/2025.20145

[11] Zhang, J., et al. (2014). "Nanodispersed UV blockers in skin-friendly silica vesicles with superior UV-attenuating efficiency." J Mater Chem B 2(44): 7673-7678.

[12] Antoniou, C., et al. (2008). "Sunscreens – what's important to know." Journal of the European Academy of Dermatology and Venereology 22(9): 1110-1119.

[13] Preparation and Application of Colored Gold Nanoparticles[Z]. Institute of Chemistry Chinese Academy of Sciences. 2005.

[14] Colored nano titanium dioxide and its applications[Z]. Shanghai University. 2012.

[15] Yuan X P, et al. (2023). Effect of Nanoparticles on Solar Selective Absorbing Characteristics of Cermet Coatings for Photothermal Conversion[J]. Acta Optica Sinica 43(7).DOI:10.3788/AOS221652

[16] She J M,Che J,Chen C Y,et al. Advances in research on ultraviolet-induced skin photoaging and photocarcinogenesis[J]. Chinese Journal of Plastic Surgery,2021,37(2):220-224. DOI:10.3760/cma.j.cn114453-20200608-00343.

[17] Jiang Y C,Wang D J.Preparation Technology and UV Absorption Application of Nano CeO_2[C]. //Proceedings of the 3rd National Conference on Nanomaterials and Technology Applications.Beijing:Chinese Materials Research Society, 2003:792-795.

[18] Pingting H,Jie T,Yanyan Z,et al.Effect of inhaled nano-$Ti0_2$ on lung and serum biochemical indexes of mice[j].Journal of Nanjing Aerospace University,2010, 27(4):338-344.

[19] YUAN J H,LI G,CHEN H Z,et al. ytotoxicity on Human Embryonic Lung Fibroblasts of ZnO Nanoparticles in Cosmetics[J]. JOURNAL OF SUN YAT.SEN UNIVERSITY(MEDICAL SCIENCES),2009,30(2):170-173,178. DOI:10.3321/j.issn:1672-3554.2009.02.010.