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Antibacterial effect of titanium-oxide particles under white-photon irradiation

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Abstract

We observed the antibacterial effect of titanium-oxide (TiO_2) particles under white-photon irradiation from a light-emitting diode (LED). The crystal structure of rutile-type TiO_2 is tetragonal, and the color is white. The band gap and the excitation wavelength are 3.0 eV and 412 nm, respectively, and TiO_2 molecules are excited by photons with wavelengths below 412 nm. The TiO_2 suspension was sprayed on an agar medium, and the Bacillus-natto solution was dropped onto the TiO_2 particles four hours after spraying. In the measurement of LED spectra, photons with wavelengths of below 412 nm were absorbed, and photons of beyond 412 nm were scattered by the TiO_2 particles. Using white-photon irradiation from a 5.6 W white LED, we observed the weak antibacterial effect of TiO_2 particles.

***Keywords*:** TiO_2 particles, TiO_2 suspension, photocatalyst, short-wavelength photon excitation, antibacterial effect

1. Introduction

Metallic oxide particles are applied to various researches, and we made a gadolinium oxide (Gd_2O_3) suspension for visualizing the active cancerous region using magnetic resonance imaging [1]. In this experiment, Gd_2O_3 nanoparticles remained in the cancerous region. Subsequently, a zinc-oxide (ZnO) crystal was used for counting X-ray photons, and a CT scanner utilizing megacounts per second was developed [2,3].

Titanium oxide (TiO_2) particles are known as a photocatalyst material [4] and produce electron-hole pairs by the excitation. Photons with wavelengths below 412 nm are absorbed by the particles, and the holes killed various bacterias and viruses. In addition, TiO_2 particles can be easily coated by spraying the suspension utilizing super hydrophilic [5]. Lately, since the TiO_2 suspension is sprayed on various things in the room, the antibacterial effect of TiO_2 particles should be investigated. Although the antibacterial-test method is determined by Japanese Industrial Standard, it is not easy to perform the test at home.

In the present research, major objectives are as follows: to make the TiO_2 suspension for antibacterial, to measure spectra irradiated from a white LED, to measure spectra scattered by TiO_2 particles, and to observe Bacillus-natto coronies on the agar medium with and without irradiating white photons. Therefore, we conducted the experiment for antibacterial effect of TiO_2 using Bacillus natto and white photons.

2. Materials and methods

Table 1 shows characteristics of TiO_2 particles. In this experiment, we used rutile-type white microparticles of 5 μm in average diameter, and the particles scatter various-wavelength photons. The band gap and the excitation wavelength are 3.0 eV and 412 nm, respectively, and the photons below 412 nm are absorbed effectively by TiO_2 particles. TiO_2 molecules are then exited, and electron-hole pairs are produced. In particular, the holes are useful for killing various bacterias and viruses.

Table 1. Various characteristics of TiO_2 microparticles.

Characteristics	
Type	Rutile
Crystal structure	Tetragonal
Band gap (eV)	3.0
Excitation wavelength (nm)	412
Molar mass (g)	79.87
Melting point (°C)	1,870
Density (kg/m^3)	4,252
Color	White
Average particle diameter (μm)	5

A method for making TiO_2 suspension is shown in Table 2. Using a glass beaker, a suspension with a concentration of 1.0 mg/mL was made with a pure water volume of 500 mL. The suspension was heated to a boiling point of 100 °C, and the point was maintained for 10 min to kill bacterias. After lowering the suspension temperature to 30 °C, the TiO_2 particle mass were dispersed using an ultrasonic cleaner (Citizen, SWT710).

Table 2. Method for making a TiO_2 solution.

TiO_2 solution	
TiO_2 mass (g)	0.5
Pure water volume (mL)	500
Boiling time (min.)	10
Dispersion time (min.)	20

We made a Bacillus-natto solution to observe the antibacterial effect (Table 3). A natto bean was put into a shale, and 4 ml pure water was poured. After stirring, a drop of solution was dropped onto the particles using a 3 mL dropper.

Table 3. Method for making a Bacillus-natto solution.

Bacillus-natto solution	
Number of natto beans	1
Pure water volume (mL)	4.0
Dropping tool	3 mL dropper
Number of drops	1

Figure 1 shows methods for measuring spectra using a high-sensitivity spectrometer (Hamamatsu, C10083CA) with a 1.5-m-length fiber. To measure spectra produced from a 5.6 W LED bulb (Iris Ohyama, LDR6N-H-SE25) and to reduce the incident photons, the fiber was set in a direction 20° from the irradiation axis, and the distance from the LED to fiber end was 0.9 m [Fig. 1(a)]. To measure scattered photons from TiO_2 particles, the fiber was set in a direction of 30° from the irradiation axis, the particles were placed 0.35 m from the LED, and the fiber end to particle distance was 5 mm [Fig. 1(b)].

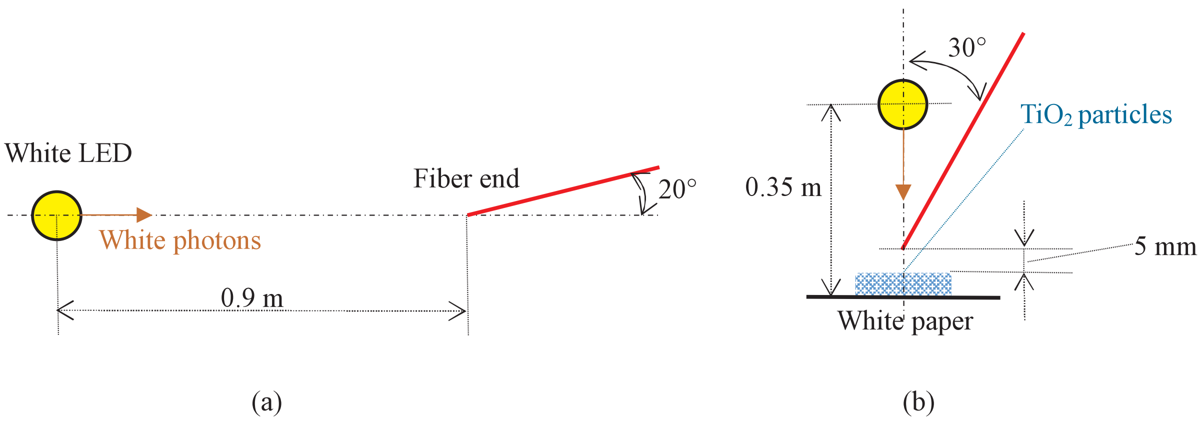


Fig. 1. Experimental setups for measuring spectra using a high-sensitivity spectrometer (a) for reducing white photons without saturation and (b) for detecting scattered photons from TiO_2 particles.

The experimental setup for the antibacterial test is illustrated in Fig. 2. After spraying the TiO_2 suspension four times on the agar medium from a distance of 0.3 m, the sample was dried for 4 hours with the lid open. A drop of natto solution was dropped, the lid was closed, and white photons were irradiated [Fig. 2(a)]. The white photons were shaded using a black vinyl film in Fig. 2(b). Without spraying the suspension, the natto solution was dropped on to the agar media with and without photon irradiation [Figs. 2(c) and 2(d)]. A photon-irradiated control sample was used for comparison with the previous four samples [Fig. 2(e)].

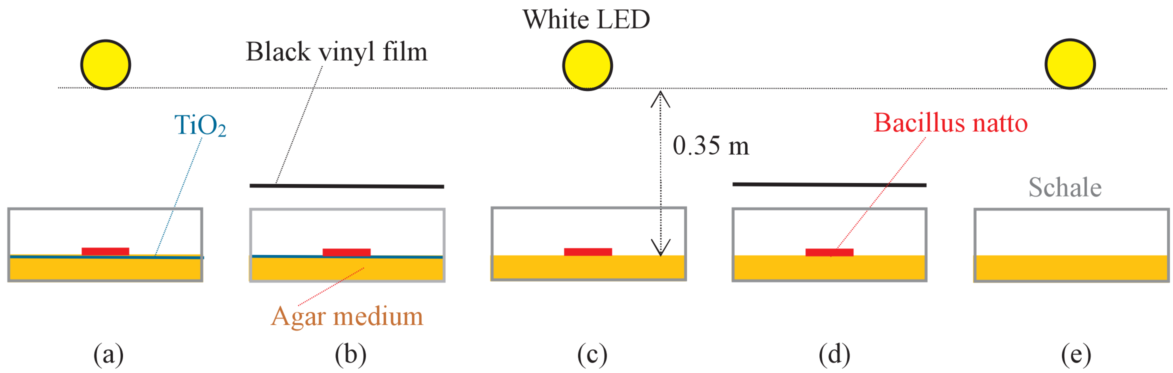


Fig. 2. Five samples for observing the antibacterial effect of TiO_2 particles using a drop of Bacillus-natto solution. Agar medium was covered with TiO_2 particles when (a) irradiating or (b) shading photons. Agar medium was not covered with TiO_2 particles when (c) irradiating or (d) shading photons. (e) Agar medium was irradiated when using a control sample.

3. Results

Figure 3 shows the spectra irradiated from the LED bulb. The spectra had two wavelength peaks of 450 and 570 nm [Fig. 3(a)], and the photon number below the excitation wavelength 412 nm was quite small [Fig. 3(b)].

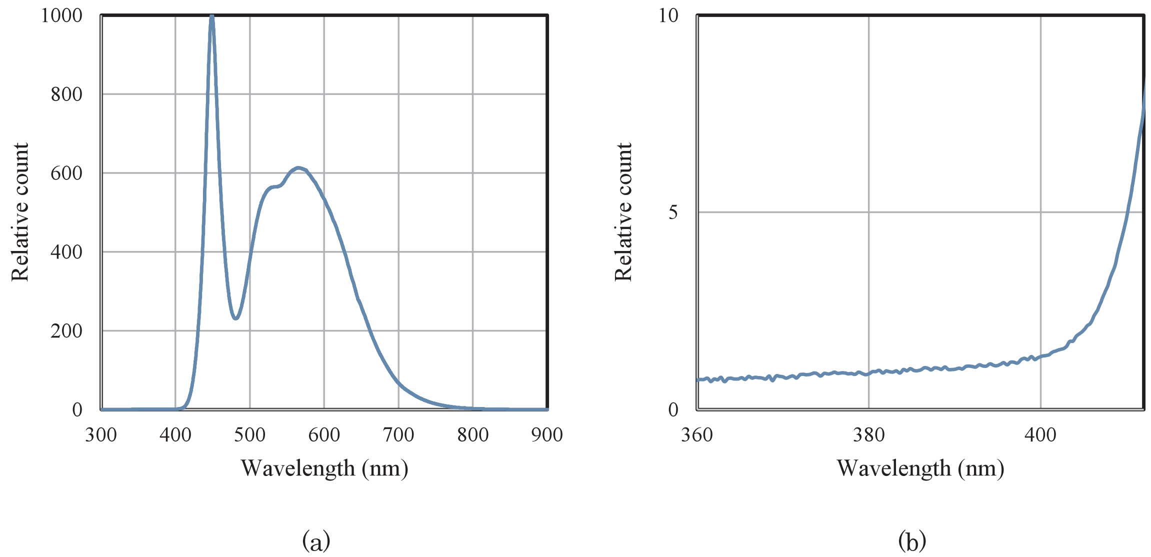
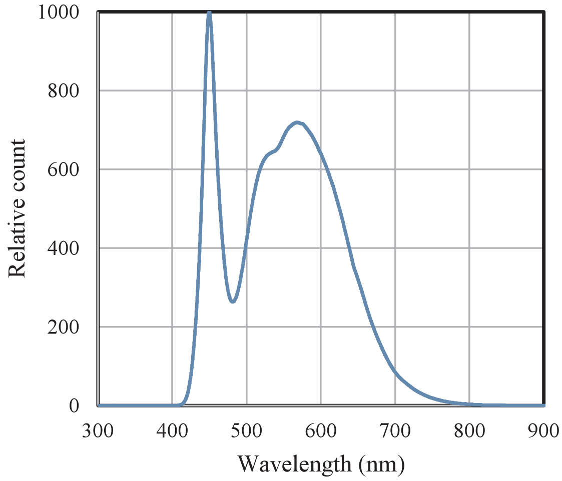


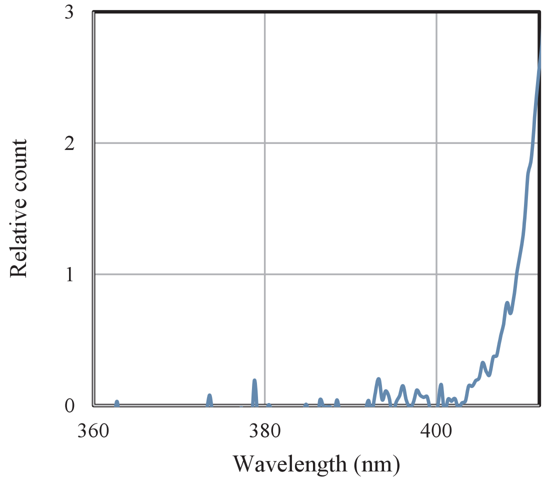
Fig. 3. White LED spectra. (a) Entire photons and (b) selected photons below 412 nm for TiO_2 exciting.

The scattered spectra from the TiO_2 particles are shown in Fig. 4. The spectra also shows two wavelength peaks, and the peaks shifted slightly to long-wavelength region [Fig. 4(a)]. Most short-wavelength photons were absorbed and not scattered by the particles [Fig. 4(b)].

Figure 5 shows the results in the antibacterial test. Using the TiO_2 suspension, the colony dimensions around a large central colony when irradiating white photons are smaller than those when shading. However, the dimension of the central colony seldom varied with the suspension. Without the suspension, the central-colony dimension did not change. In the control sample, no colonies were observed.

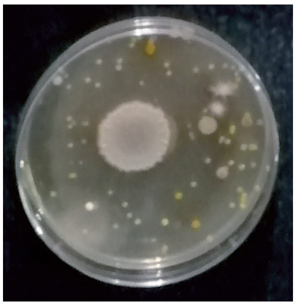


(a)

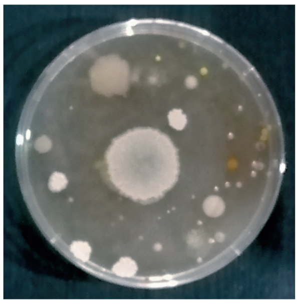


(b)

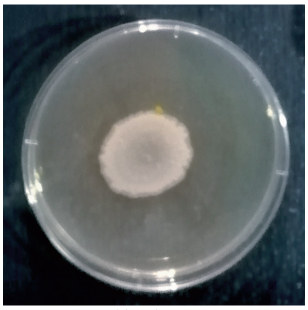
Fig. 4. Scattered LED spectra. (a) Entire photons and (b) selected photons below 412 nm.



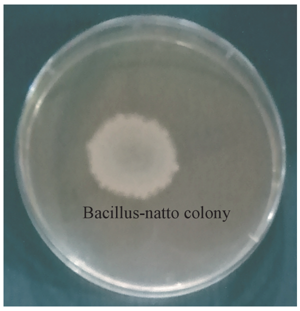
TiO_2+white photons



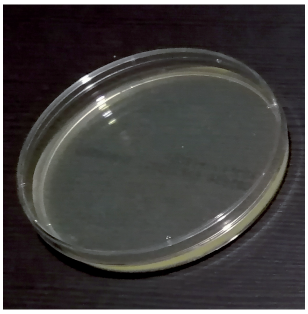
TiO_2+shading



White photons



Shading



Control (white photons)

Fig. 5. Results in the antibacterial test three days after dropping the natto solution.

4. Discussion

The TiO_2 particle is known as a photocatalyst material. The antibacterial property of TiO_2 particles is effective under sunlight-photon irradiation, since a large amount of short-wavelength photons below 412 nm are irradiated. However, few short-wavelength photons for excitation are obtained under the white LED bulb, and a black-light LED is useful for producing effective photons for improving the photocatalyst effect.

The TiO_2 particles absorb high-energy short-wavelength photons for the antibacterial effect. Although low-energy long-wavelength photons are scattered and effectively irradiate bacterias, it is difficult to kill bacterias using photons beyond 412 nm.

In this experiment, we used TiO_2 microparticles with an average diameter of 5 μm, the microparticles remained well on the sprayed object and were difficult to remove. Therefore, we are interested in the effect of TiO_2 nanoparticle, and the TiO_2 concentration for antibacterial effect may be minimized.

5. Conclusion

We made the TiO_2 suspension with a concentration of 1.0 mg/mL. After dispersing the TiO_2-particle masses using an ultrasonic cleaner, we carried out the antibacterial test with Bacillus natto. Using a white LED bulb, short-wavelength photons below 412 nm were absorbed by the TiO_2 molecules, and positive-charge holes were produced. Therefore, we observed weak antibacterial effect of TiO_2 particles when irradiating white photons.

Acknowledgments

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