2025/02/18

Sakura-Science

at Nakamozu campus, Osaka Metropolitan University

Development of a small droplet remover for infectious disease control

Masafumi Akiyoshi

Graduate School of Engineering, OMU.

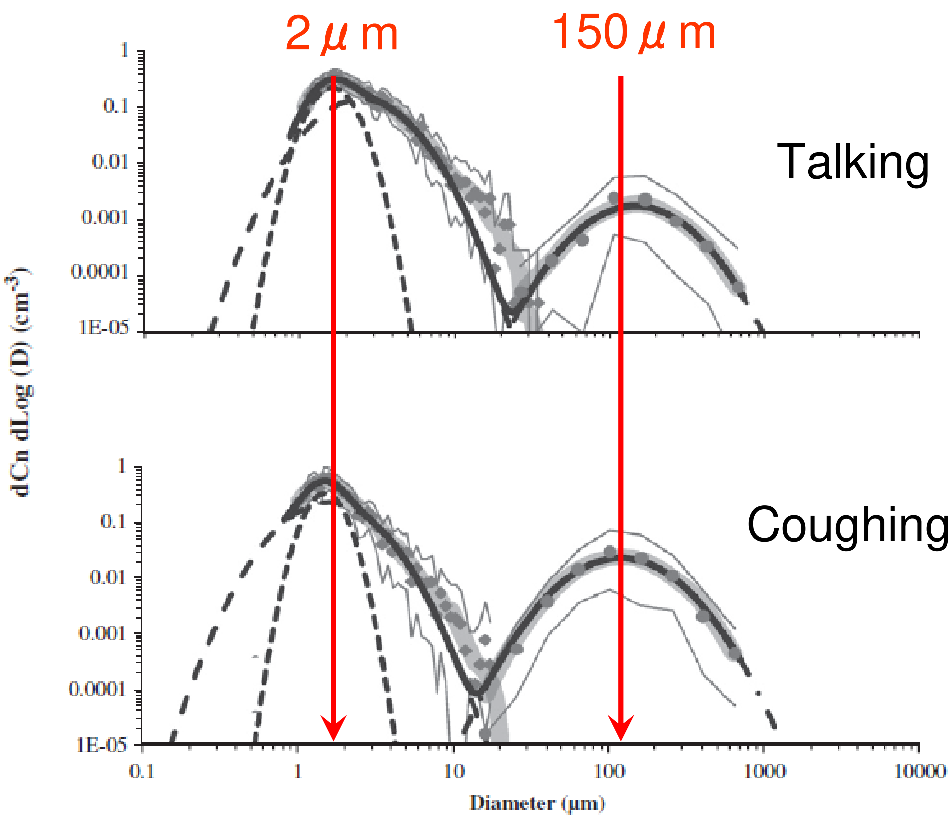
* akiyoshi-masafumi@omu.ac.jp

Web sute:

http://bigbird.eng.omu.ac.jp/AntiCovid19/

（In Japanese）

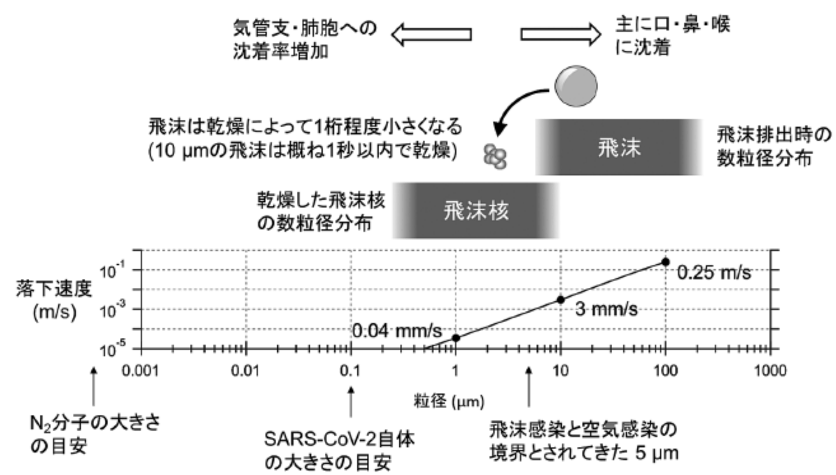
Particle size distribution of droplets released from the oral cavity



G.R. Jhonson et al., Modality of human expired aerosol size distributions, J. Aerosol Science, 42(2011)839-851.

The actual distribution of particles sizes released from the oral cavity is two-peaked, with 150 μ m "**droplets**" falling in about two seconds and reaching only about two meters, while 2 μ m "**aerosols**" drift in the air for a long time.

In some cases, the droplets evaporate to form aerosol-sized droplet nuclei.

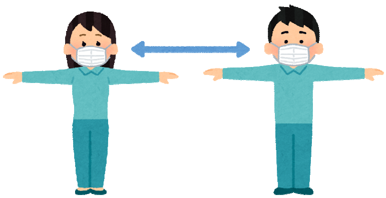


Nobuyuki Takegawa, Aerosol, Droplet Transmission, and Airborne Transmission, Earozoru Kenkyu, 36 (2021) 65-74.

Investigation of Engineering Countermeasures against COVID-19 (1)

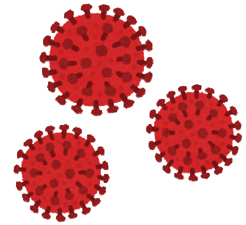
~~Crowded places~~

Social distance



Since the droplets only travel about 2 meters, you can protect yourself from flying droplets by keeping a distance from others.

Droplets



Large droplets with large amounts of virus

Stay Home

Wet particles larger than 5 μm emitted from the oral cavity are called **droplets** and actually have a distribution peak at about 150 μm. These large **droplets** can be scattered over a distance of up to 2 meters in a few seconds.

To prevent the release of **droplets**, wear mask is effective. Non-woven or cloth masks can stop about 80% of the droplets, but the remaining 20% are dispersed through gaps. Therefore, there is a risk of infection when meeting within the range of droplets. Furthermore, it is difficult to wear a mask during meals and drinking.

Wear Mask

Requirement for Droplets Remover

Investigation of Engineering Countermeasures against COVID-19 (2)

Enough Ventilation

Carbon dioxide concentration is one indicator of ventilation status.

~~Closed Space~~

Aerosol

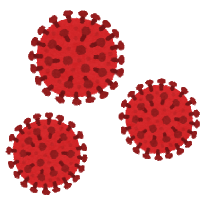
Air Purifier

△Active disinfection with Chlorine dioxide or Ozone is not recommended

Various types air purifier are available, including those using photocatalyst, UV-C, and high-performance filters, which collect aerosols and inactivate viruses contained in aerosols.
Inactivation is also possible with fan heaters and stoves, which are subject to high temperatures. (Air conditioners cannot be used for this purpose.)

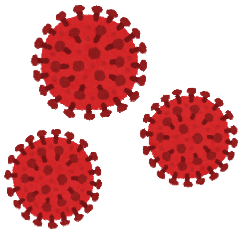
Particles smaller than 5 μm are called **aerosols**, and the solids that remain after the droplets have dried are also called droplet nuclei. They stay in the air for several minutes and can spread over a wide area. It can be dispersed even by talking.

Fly around in the air for long periods of time.



Even if you wear a mask, nearly half of the aerosol is dispersed between fibers and gaps. Since they stay in air for a long time, their concentration gradually increases if ventilation is poor.

Investigation of Engineering Countermeasures against COVID-19 (3)



~~Close-contact settings~~

Wash Hands

Disinfection

Coronaviruses are the type that have an envelope, a lipid membrane, on their surface, so it is important to dissolve the lipid. Just physically washing it away is effective.

Falled droplets cause contact infection

Contact infection from object surfaces

Depending on the environment, a virus attached to the surface of an object may retain its infectivity for several days. Dispersed droplets fall in several second, but the virus contained in the droplets remains on the rurface.

UV-C irradiation to PPE

Since the risk of removing personal protective equipment (PPE) is high in medical fields dealing with infectious diseases, UV-C irradiation to PPE at the boundary to the Cold area will reduce the risk of infection.

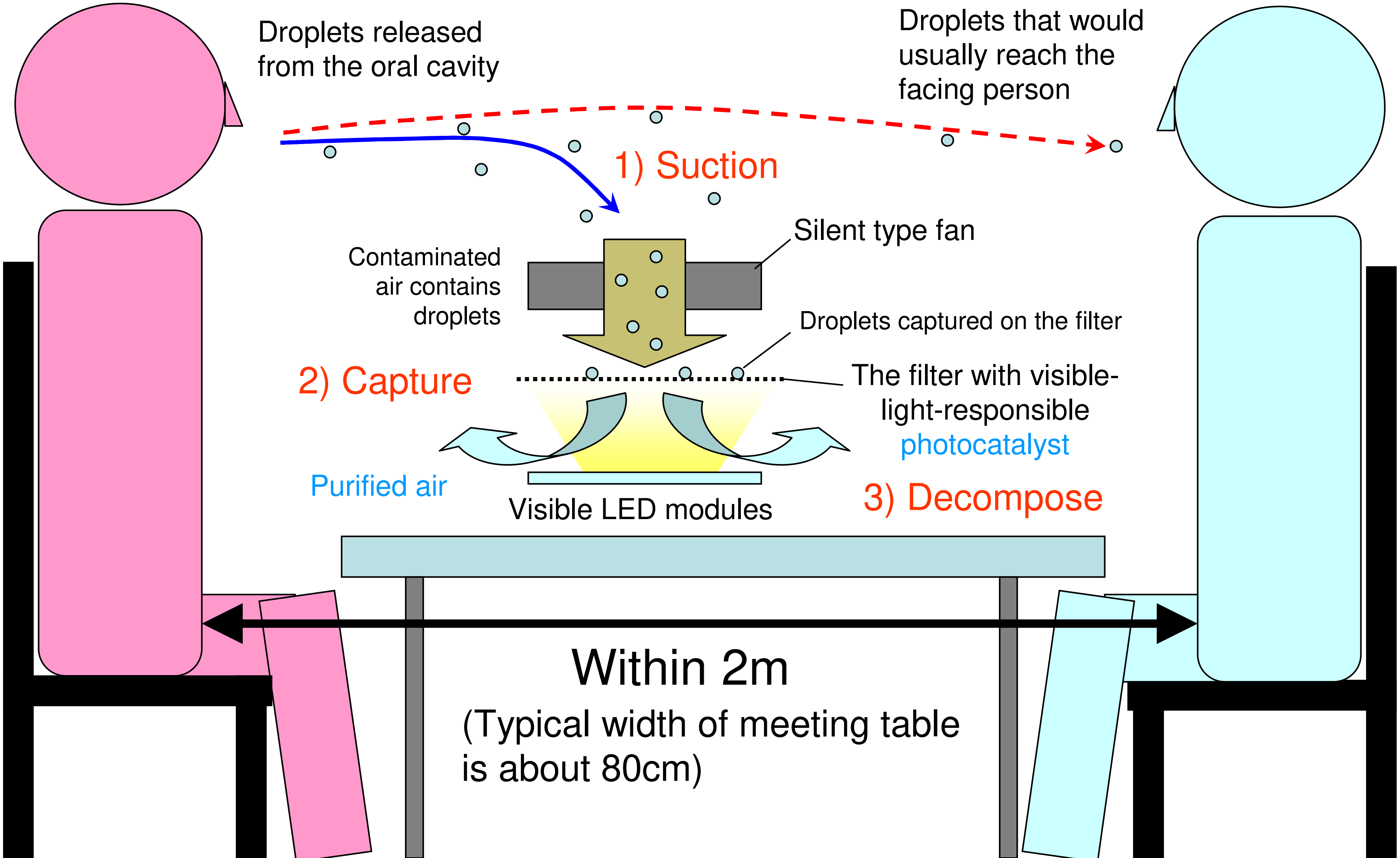
UV-C irradiation to object surfaces

Various papers have confirmed that it is possible to inactivate SARS-CoV-2 in a short time.
It cannot be used in the presence of people because it is harmful to the human body. There are some products using 222 nm UV that have very little effect on the human body, but they have not yet been certified as completely safe.
It is necessary to understand various problems before using these products.

Application of photocatalysts and metal particles such as copper and silver to the surface of shared items

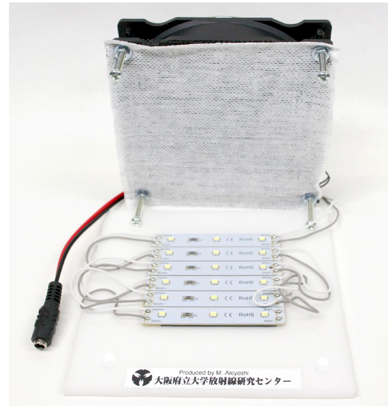
The application of photocatalyst to the surface of an object always produces a gradual deactivation effect. Some metal-containing photocatalysts, such as copper, are effective for a certain period of time even after dark. The simplest way is to apply copper foil tape.

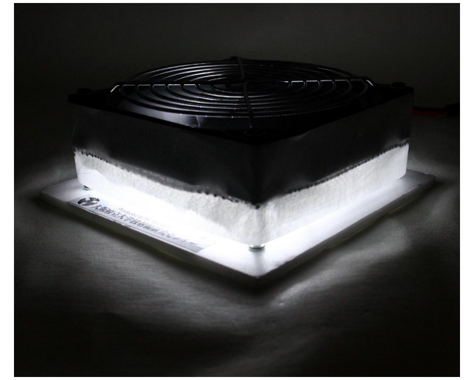
A specialized device that removes droplets flying between facing persons



Ultra-low-cost droplet removal system "Hikari Cleaner" using visible light responsive photocatalyst

NOT commercial product





Shading leaked light with Japanese paper

The size is 12 cm square and 5 cm high. Fan noise is only 19 dB. Power consumption is less than 5 W, and can be powered by a mobile battery

Luminary light between person-and-person

Using visible light-responsive photocatalyst, it does not need to be completely shielded from leaking light and can be made with a simple structure. It is made by combining commercial PC parts, therefore it cost only 1200 yen per unit. The photocatalyst filter can be manufactured with a simple non-woven fabric filter and Toshiba's "Renecat" spray, which is commercially available. The suction performance can be improved by using a more powerful fan.

What is photocatalyst?

・In addition to visible light, there are also other types of light with various photon energies, such as infrared rays, ultraviolet rays, X-rays and gamma rays, which are invisible to the human eye.

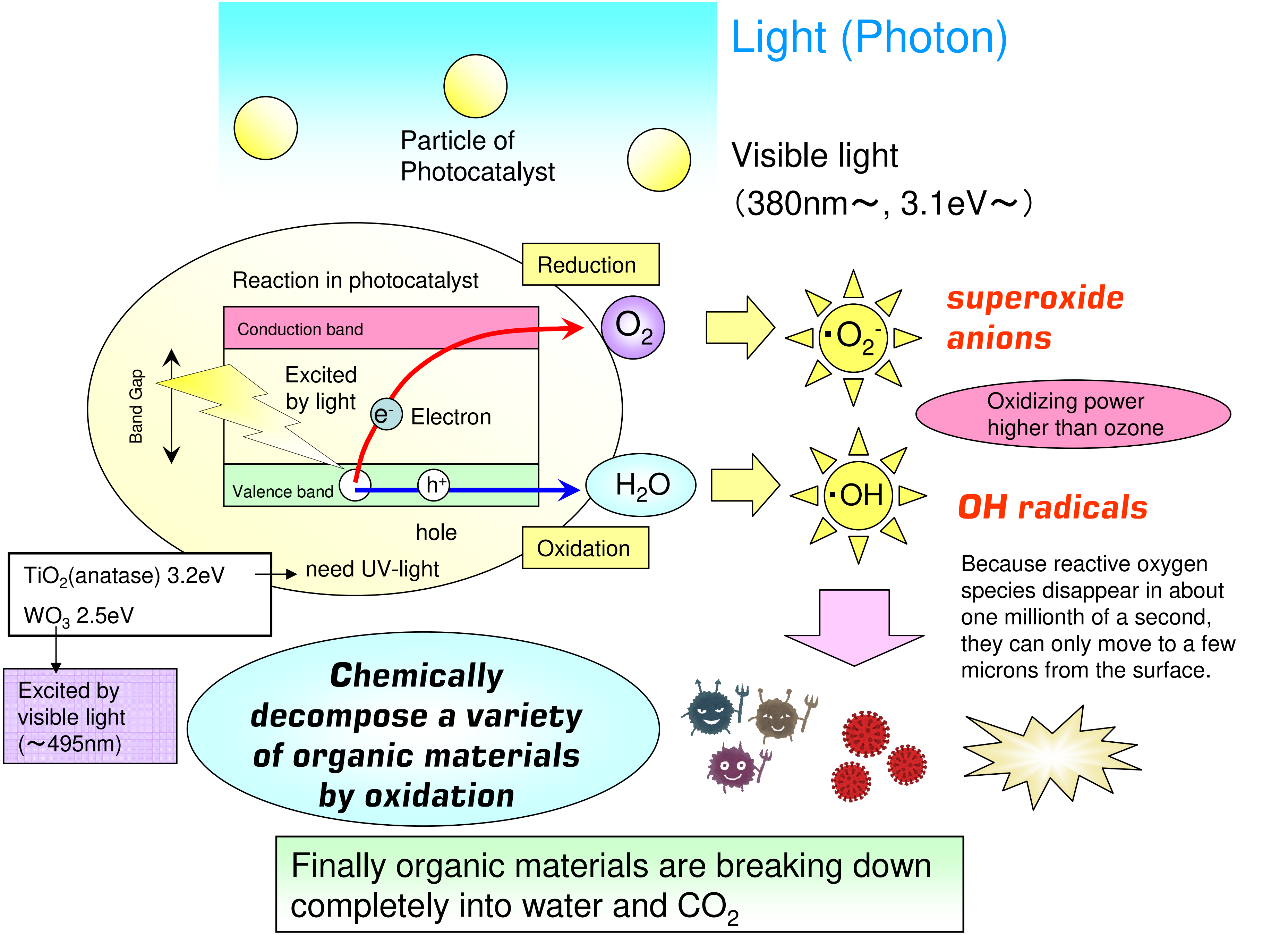
・Visible light also plays a very important role in processes such as photosynthesis in plants and the generation of electricity in solar cells.

・Since the discovery in 1967 that water can be broken down into oxygen and hydrogen using the Honda-Fujishima effect, **photocatalysts** have attracted attention as a technology developed in Japan, and their development has continued. Photocatalysts are a type of semiconductor that generate electrical energy when exposed to light, in the same way as solar cells. Photocatalysts do not use this energy as an electric current, but it creates active oxygen such as superoxide anions and OH radicals on the surface of small particles, and then breaks down organic matter using its extremely strong oxidizing power, ultimately completely decomposing it into water and carbon dioxide. Viruses and bacteria are no exception, and there have been no reports of it not being effective.

・Conventionally used titanium dioxide (anatase type) has a band gap of 3.2 eV, so it has a low response to visible light and requires ultraviolet light irradiation. On the other hand, the tungsten trioxide-based photocatalyst that has recently been put into practical use responds to light with wavelengths of 480 nm (green to blue visible light region) or less.

・The effectiveness of both titanium dioxide and tungsten trioxide in inactivating SARS-CoV-2 has already been reported in academic papers.

・By combining this visible-light-responsive tungsten-based photocatalyst with a cheap visible-light LED, we have achieved the production of a simple, safe air purifier.


Light (Photon)
Particle of Photocatalyst
Visible light
(380nm～, 3.1eV～)
Reaction in photocatalyst
Reduction
Conduction band
Band Gap
Excited by light
e^-
Electron
Valence band
h^+
hole
O_2
H_2O
Oxidation
need UV-light
TiO_2(anatase) 3.2eV
WO_3 2.5eV
Excited by visible light (～495nm)
$\cdot O_2^-$
superoxide anions
Oxidizing power higher than ozone
$\cdot OH$
OH radicals
Because reactive oxygen species disappear in about one millionth of a second, they can only move to a few microns from the surface.
Chemically decompose a variety of organic materials by oxidation
Finally organic materials are breaking down completely into water and CO_2

Inactivation of viruses by visible light responsive photocatalysts

from Toshiba RENECAT™ Website

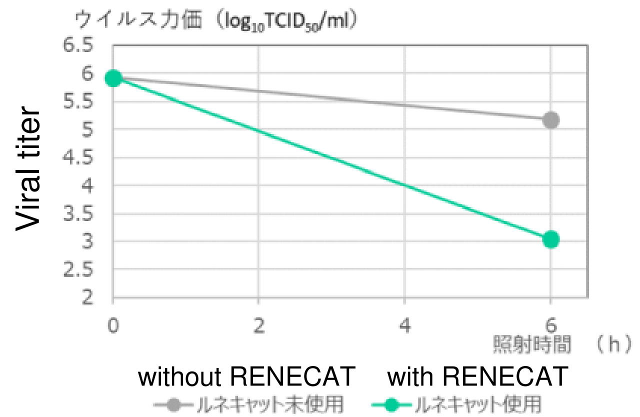
新型コロナウイルス
(SARS-CoV-2)

Masashi Uema et al., "Effect of Photocatalyst under Visible Light Irradiation in SARS-CoV-2 Stability on an Abiotic Surface", Biocontrol Science, 26 (2021) 119-125.

・ウイルス力価：実験的に測定されるウイルスの細胞感染能力
（数値が低いほど感染能力があるウイルスの存在が少ない）

試験条件

抗ウイルス性試験方法	フィルム密着法 ISO 18071:2016ファインセラミックス(先進セラミックス，先進技術セラミックス)－屋内照明環境下の半導体光触媒物質の抗ウイルス活性の求め方－ バクテリオファージQ-ベータを使用する試験方法を参考に実施
光源	白色蛍光灯 3000lx （380nm以下の紫外光はフィルターでカット）
作用時間	6h
試料塗布量	4g/m^2
サンプルサイズ	30mm×30mm

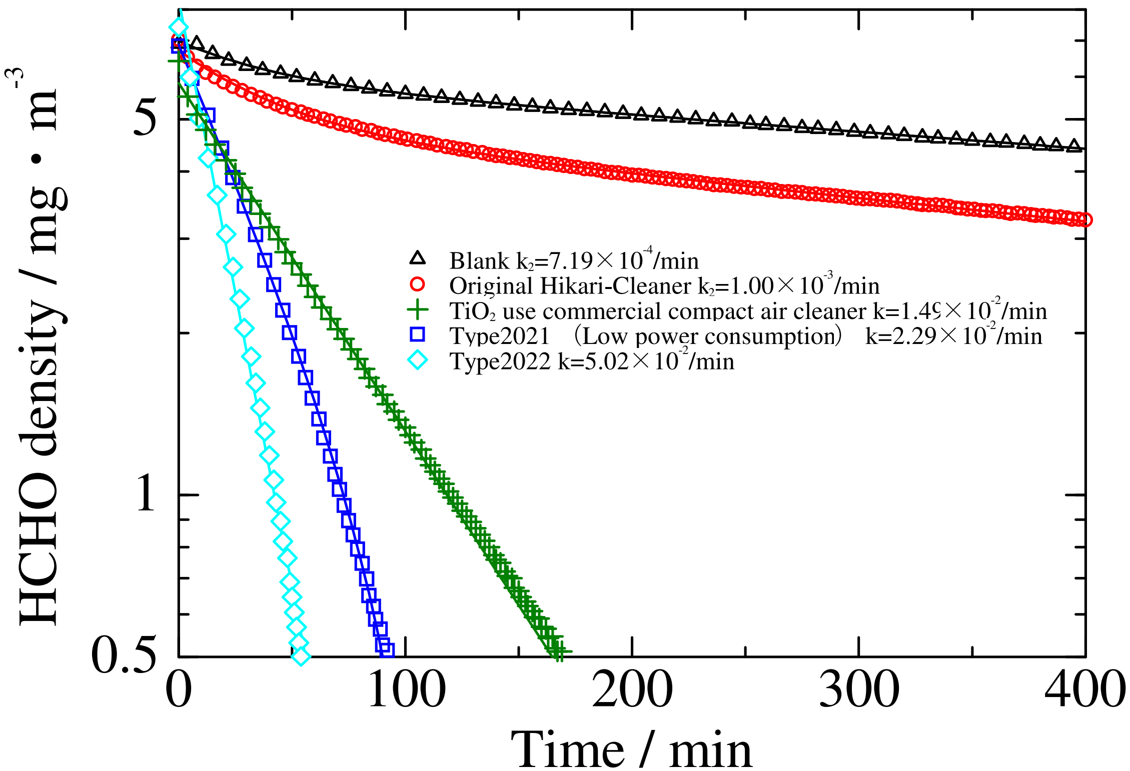


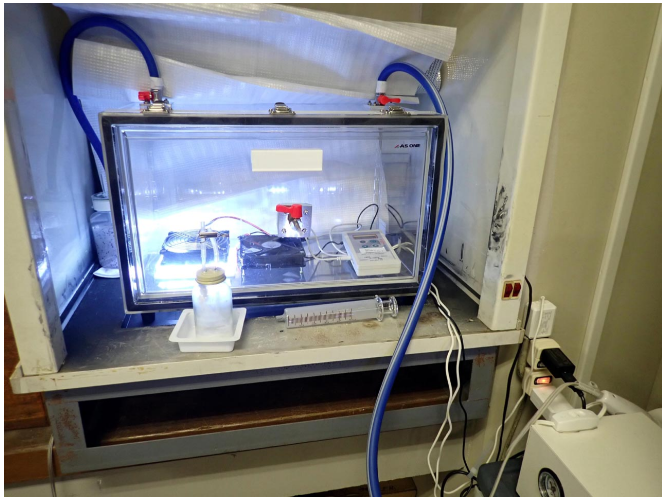
※グラフは下記論文データから当社にて作成しました
「Biocontrol Science 2021 Volume 26 Issue2 ,p.123 FIG.2 (A) 」

The amount of photocatalyst applied is about 0.7 g/m^2 in the standard specification of Hikari Cleaner, but it is about 14.3 g/m^2 in the high-performance filter that can be mass-produced.

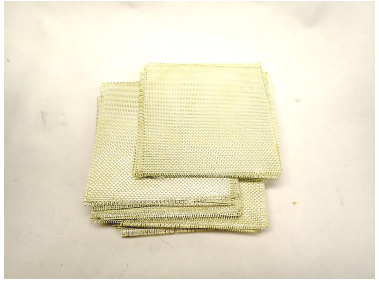
The illuminance on the filter surface of the Hikari cleaner is more than 68,500 lux. Therefore, the Hikari Cleaner is expected to inactivate at a faster rate than the above conditions.

Formaldehyde decomposition experiment





38L-sized decomposing chamber using acrylic desiccator

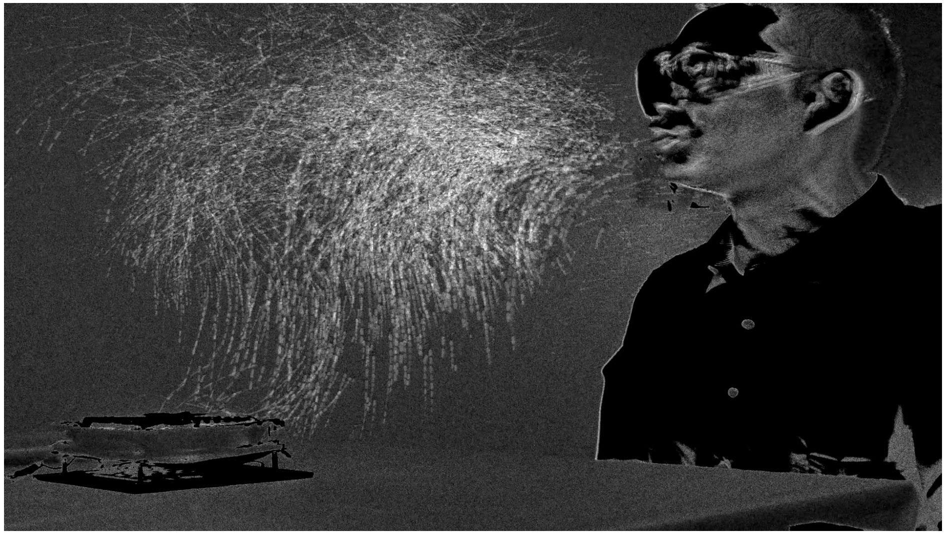


High performance inorganic filters

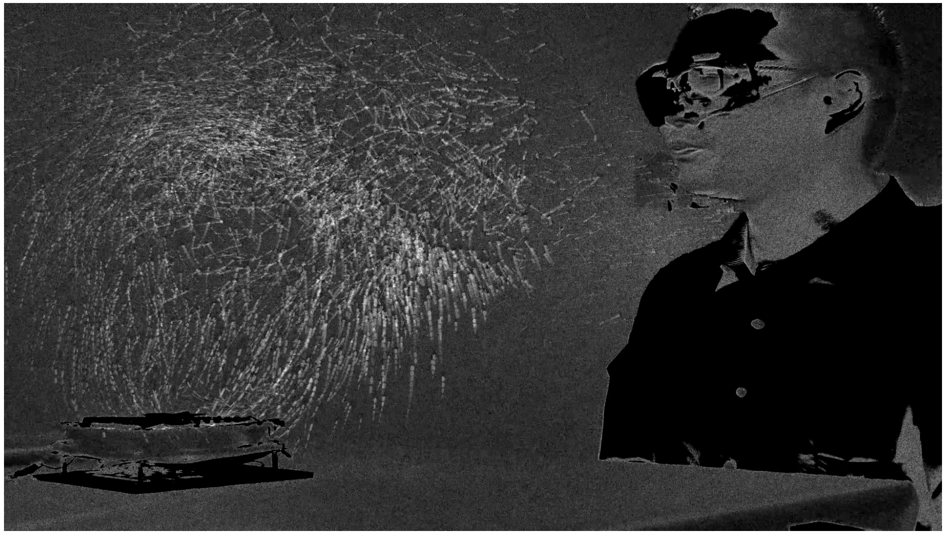
Using a 38L-sized acrylic desiccator, we measured changes in the concentration of formaldehyde (HCHO), a type of organic gas, using a formaldehyde meter (htV-m).

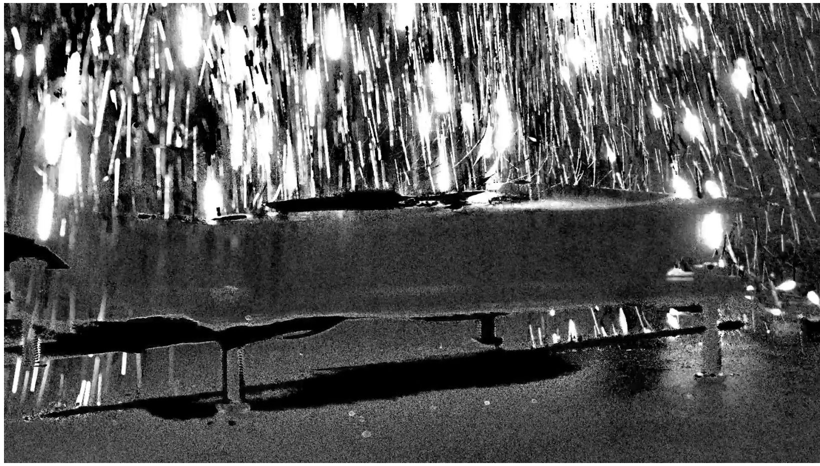
The simple structure and low price of the device make it suitable for use in educational fields, and the prototype device, which uses a filter with a higher concentration of photocatalyst and inorganic materials, demonstrated performance that far higher performance that of existing commercially available photocatalytic compact air purifier.

Visualization of droplet suction by special imaging system

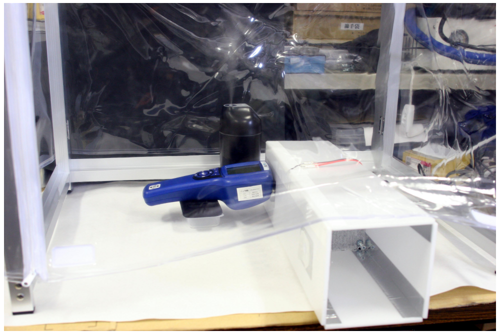


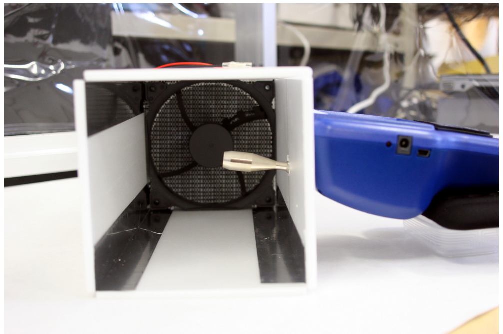
Special video recording was conducted to visualize droplets in the air. Within a range of about 50cm, we can see that droplets emitted by speech from the oral cavity with a "booming" sound are inhaled and stopped by the filter in the same way as a mask.





Transmittance rate of droplets to a filter

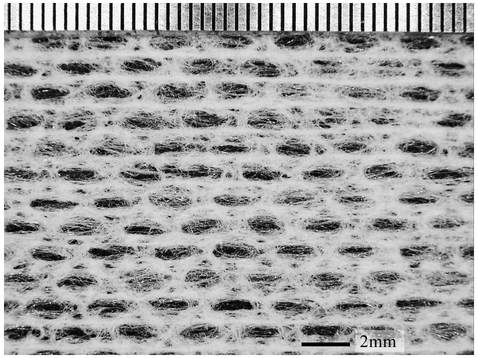




A duct was set up in a clean booth using HEPA filter unit, and the rate at which ultrasonic sprayer mist, simulating droplets from the oral cavity, was captured by a non-woven fabric filter was evaluated. As a result, it was confirmed that droplets of 5 μm or larger could be almost completely captured.

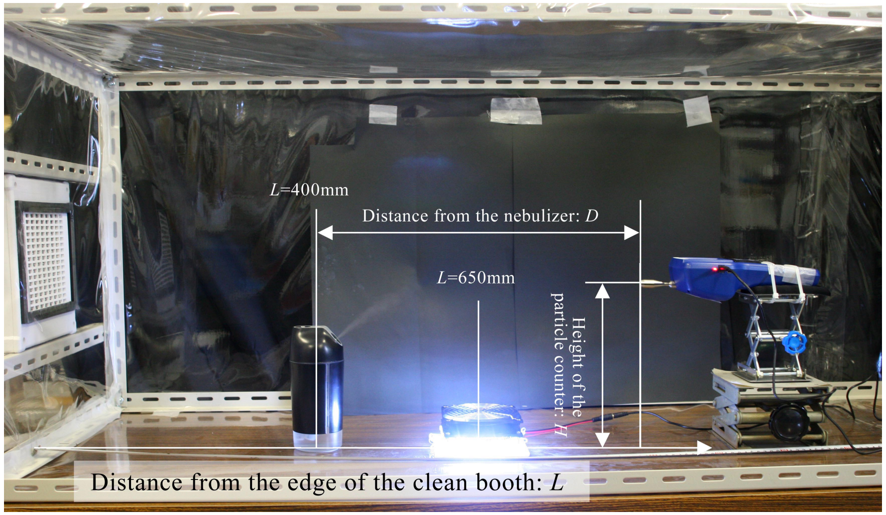
Condition	Diameter of Particles	Particle consentration		Transmittance
		Before filter	After filter	
	μm	m^{-3}	m^{-3}	
Dual nozzle spray	0.3～1	4.1×10^{8}	4.6×10^{8}	1.14
	1～5	1.2×10^{7}	3.6×10^{6}	0.30
	5～25	3.7×10^{6}	2.1×10^{2}	5.8×10^{-5}
Single Nozzle Splay 1st	0.3～1	2.8×10^{8}	2.5×10^{8}	0.87
	1～5	2.6×10^{6}	1.0×10^{6}	0.40
	5～25	3.0×10^{5}	1.8×10^{1}	6.0×10^{-5}
Single Nozzle Splay 2nd	0.3～1	2.7×10^{8}	2.7×10^{8}	0.99
	1～5	2.0×10^{6}	1.5×10^{6}	0.76
	5～25	1.1×10^{5}	5.3×10^{1}	4.7×10^{-4}

Catching and slowly decomposing

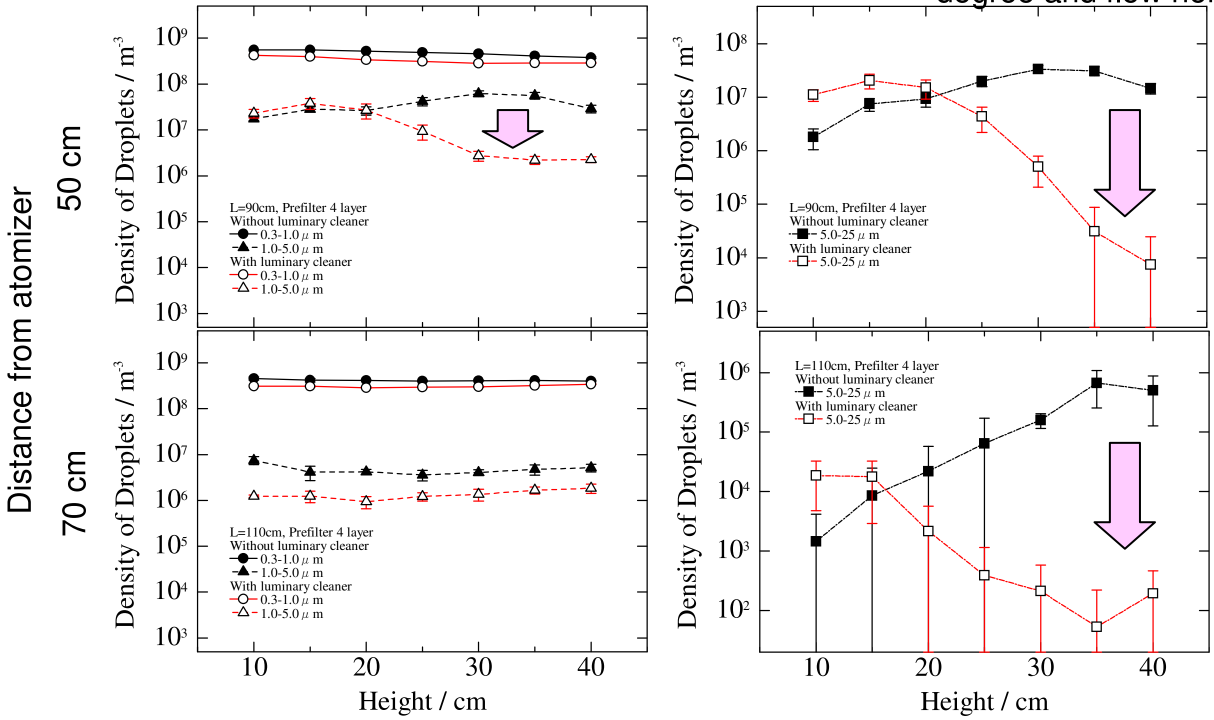


The non-woven fabric filter used in this study

Collection rate of droplets flying in space(1)



A droplet collection test was conducted in a clean bench with a wind speed of approximately 0.6 m/s. The droplets of water from the ultrasonic humidifier were measured using a particle counter installed downstream. The droplets were sprayed at 45 degree and flew horizontally at a height of approximately 40 cm.



A particle counter was placed at a distance of 50 cm and 70 cm from the atomizer, and it evaluate the height dependence of the particle count.

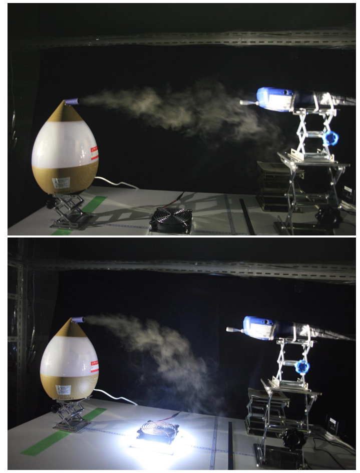
At both distances, it was confirmed that the large droplets with a particle diameter of 5.0 to 25 μm were greatly reduced due to the operation of the droplet removal device at a height of about 40 cm, which is the height of a center of a person's face when seated.

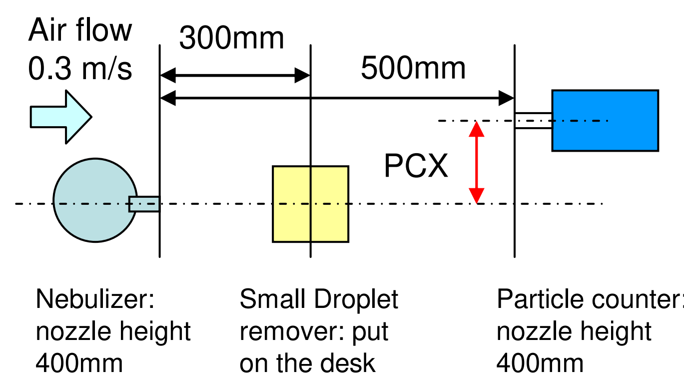
For aerosols of 1.0 to 5.0 μm that corresponding to the smaller peak of particle size released from oral cavity, a decrease of about one order of magnitude was observed.

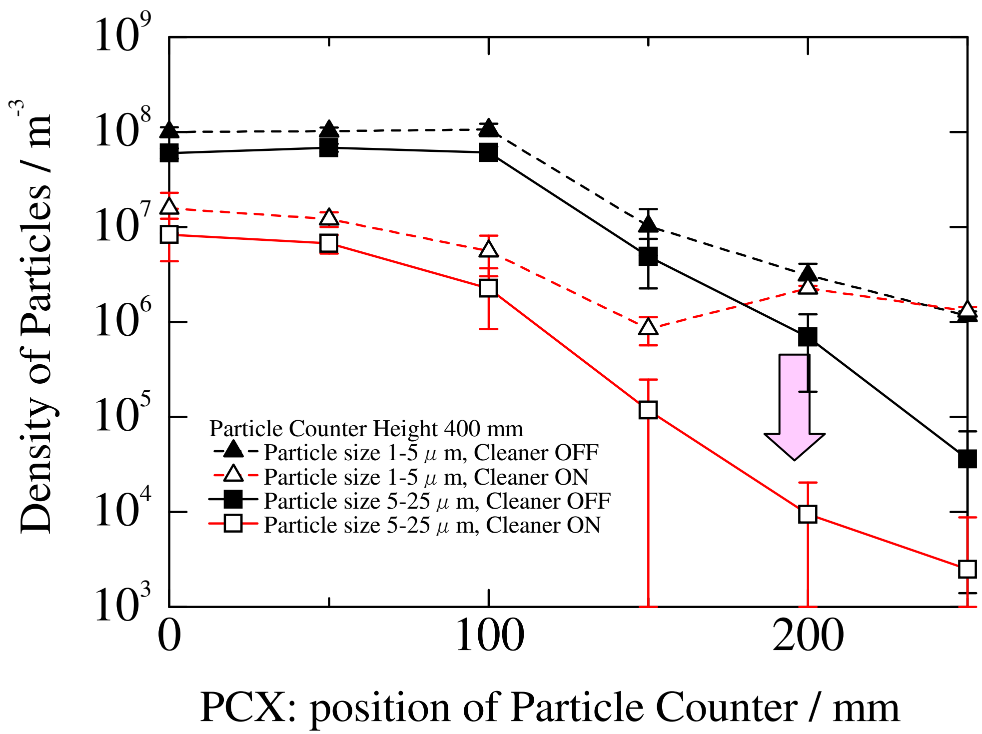
Aerosols of 0.3 to 1.0 μm (sub-micron) were not evaluated because the number of particles was beyond the measurable range, but even in separate measurements with a reduced particle count, no decrease was observed.

Collection rate of droplets flying in space(2)

Large clean booth: 1.5 × 1.5 × 2.4m





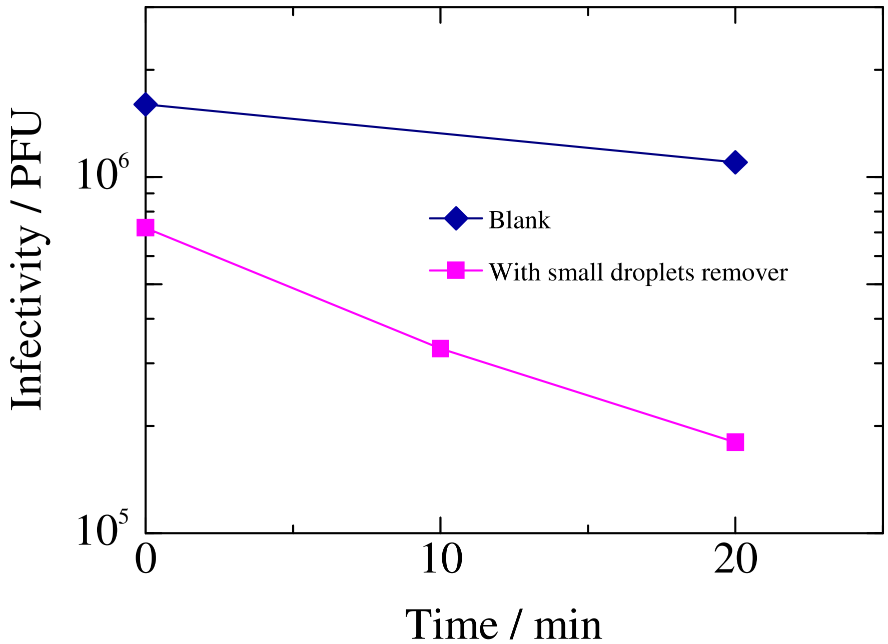


Performance of the small droplet remover in open space was estimated using large clean booth. Particle counters were placed off-center axis of nebulizer and the remover. The nozzle of the nebulizer was set horizontally and the mist flied almost straight with a following wind of 0.3 m/s from air purifier units.

Large droplets with diameters of 5.0 to 25 μ m were reduced to about 1/10 in all position. **Aerosols** of 1.0 to 5.0 μ m, which are close to the peak diameter of the aerosol emitted from the actual oral cavity, were also reduced to about 1/10 from center to 15cm, but at 20 and 25cm almost no reduction was observed.

Removal performance for virus in aerosol

A solution containing bacteriophage Qβ was sprayed with a nebulizer in a 370 L glove box to make an aerosols. At the measurement time, 10 L air was sampled through a gelatin filter and the infectivity was evaluated by the plaque method.
As a result, the infectivity decreased in the blank from 1.6×10^6 PFU to 1.1×10^6 PFU in 20 minutes, a decrease of about 30%.
On the other hand, the use of the small droplets remover with an inorganic high-performance filter resulted in a decrease from 7.2×10^5 PFU to 3.3×10^5 PFU after 10 minutes and 1.8×10^5 PFU after 20 minutes, approximately half in every 10 minutes.



Although aerosols suspended in the air for long time cannot be caught by the filter, it was suggested that viruses contained in aerosols can be removed by the small droplet remover using a photocatalyst.