
Here's How Nanotechnologies Tailor Face Masks for Coronavirus Era

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Since the spread of COVID-19, quite a lot of nanotechnologists all over the world, in both academia and industry, have been focusing their studies, research work, and production lines on the development of coronavirus-trapping and -killing face masks to control this pandemic. These days, diverse nano-based technologies are in hand to fight the new coronavirus, among which nanofibers, nanoparticles, nanocomposites, and graphene are of great importance. Here, the most active nano-based organizations in enabling or enhancing face masks against this devastating virus along with the properties of their products are reviewed.

The ongoing coronavirus taking over the world has put many countries in a terrible predicament of lockdowns which can barely continue in many societies. People are required to commence a new form of corona-adapted social lie; however, it needs time to assimilate into the daily routine. According to the World Health Organization (WHO) and the data from epidemiology studies, COVID-19, which can persist in aerosol form, is primarily transmitted among people through respiratory droplets within a few feet away.

In line with all researchers in every corner of the world, nanotechnologists are employing their both relevant experience and cutting-edge achievements to find a panacea for ceasing this pandemic in general and to diminish its airborne risks in particular. Diverse face masks such as N95, N99, surgical masks, and technical respirators, being now available or close-to-market, leverage nano-related technologies to enable or enhance their performance against COVID-19, some of which – namely – nanofibers, nanocomposites, nanoparticles, and graphene technologies are the most paramount ones.

To begin with, nanofiber membranes technology, the most plausible and universal approach, is based on the dense spiderweb-like 3D network of extremely thin nanofibers (e.g., polyacrylonitrile and nano-coco-carbon™), provides high surface area for super-high trapping properties. These membranes are incorporated into respiratory masks, providing high breathability and filtration efficiency thanks to their strong and durable structures.

Nanocomposite membranes technology is a proper substitute for nanofibers to improve the performance of face masks in battle against COVID-19. This technology uses an active filtration system including nanoparticles-incorporated nanofibers (e.g., polypropylene impregnated with 5% copper oxide nanoparticles), ensuring maximum capture and containment within the structure. The functionalization of nanofibers, before being incorporated into the masks, is another approach at hand to enhance virus filtration potential through the simultaneous addition of nanoparticles to the hot nanofibers during the synthesis process.

As an effective solution for killing coronaviruses captured in the masks filters, nanoparticles technology provides the field with tremendous supports. Nanoparticles such as copper oxide and diamond can make self-cleaning sanitizing masks through either incorporation into fibrous membranes or deposition as an ultra-thin layer on the respirator. Nanoparticles can also use as hydrophobic coatings to protect the respirators against transmission of the virus by making them impervious to water. Self-regenerating germicidal TiO₂-based face masks show efficient germ-killing power under zero light conditions and with self-regeneration capability by light.

The face mask can provide effective protection as the first-hand defense against air-transmitted germs, bacteria, and viruses. The TiO₂ layer can be refreshed by direct sunlight (UV) exposure to kill off accumulated germs. Moreover, nanosilver-improved masks can help protect users so that the nanoparticles continuously release ions, which are able to kill viruses and bacteria.

Last but not least, graphene technology contributes to fighting against coronavirus through the bacteriostatic properties of graphene-introduced membranes. However, the most eye-catching application of this technology in the field is likely killing the trapped microorganisms in the mask's filter with the aid of laser-induced graphenes through conducting electrical charge, which is a close-to-market respirator developed by some companies. A low-level electrical charge passes through the membrane when it is plugged into a portable battery pack via a USB port, which can repel any particles trapped in the mask.

A broad spectrum of companies and researchers has pitched in to benefit the merits of the aforementioned nanotechnologies in developing proficient face masks, some of which are summarized in the table below.

Companies involved in developing nanotechnology-based face masks

No.	Organization	Country	Technology	Nano insights	Properties
1	RESPILON	Czech Republic	nanofibers membranes	patented ReSpimask® technology based on an extreme density of nanofiber filters	protection against inhalation of PM _{2.5} and PM _{1.0} smog and dust particles, virus removal, bacteria removal, anti-smog, anti-pollution, anti-fungi, anti-spore, anti-mildew
2	YAMASHIN-FILTER CORP	Japan	nanofibers membranes	YAMASHIN Nano Filter™ containing a 3D structure of extremely thin synthetic polymer-based nanofibers	disposable, virus removal, super-high virus trapping
3	Metamasks	New Zealand	nanofibers membranes	natural, organic, and sustainable nanofibers using an exclusive nano-coco-carbon™ filter technology, containing the unique combination of naturally produced coconut shell carbon and nanofiber matrix	breathable, eco-friendly, recyclable, 99.99% filtration efficiency
4	Nanopoly	Taiwan	nanofibers membranes	four layers of filter protection, including a water-repellent layer made of non-woven fabric, two layers of nanofibers providing high filtration efficiency, and a silky skin-friendly layer which cares for facial skins	breathable, virus removal, bacteria removal, 98.75% filtration efficiency
5	NanoSPACE s.r.o.	Czech Republic	nanofibers membranes	on the basis of ReSpimask® technology	virus removal, allergens-free, bacteria removal, chemicals-free
6	Kim Il-Doo Research Institute	South Korea	nanofibers membranes	aligned nanofibers with a diameter of 100~500 nm in orthogonal or unidirectional directions	washable for more than 20 times, water-resistant, 94% filtration efficiency
7	Profit Royal Pharmaceutical Limited	China	nanofibers membranes	smart masks which can kill 99% of bacteria within 5 minutes	breathable, virus removal, bacteria removal, bacteria-killing
8	Nanovia Ltd	Czech Republic	nanofibers membranes	fabric laminates with a nanofiber layer, forming a barrier against penetration of microorganisms on the principle of mechanical detection	anti-bacterial activity, anti-microbial activity, moisture permeability, virus removal, anti-dust, breathable, disposable
9	Queensland University of Technology (QUT)	Australia	nanofibers membranes	highly breathable cellulose nanofiber-based material	nanoparticle removal, virus removal, anti-pollution, breathable, disposable, biodegradable
10	Oxin Sabz Espadan	Iran	nanofibers membranes	multiple-layer mask comprised of a layer of 20g PP spunbond as a supportive inner layer (for more comfortability), a layer of 40g spunbond, a layer of nanofibers coated on spunbond in order to filter nanoparticles, a layer of 17g meltblown as a filter for microparticles, a layer of 40g spunbond, a layer of polyacrylonitrile nanofibers is coated as the middle layer of the mask and can absorb 80-100% of particles bigger than 300 microns	virus removal, nanoparticle removal, breathable
11	Nano Tar Pak	Iran	nanofibers membranes	multi-layer mask: one of the middle layers contains nanofibers with nanometric diameters to prevent harmful particles from entering the respiratory system	high filtration efficiency
12	Nano Fanavaran Khavar	Iran	nanofibers membranes	enhanced performance thanks to a large surface-to-volume ratio and high porosity, provide by nanofibrous network	high filtration efficiency, large surface-to-volume ratio, high porosity
13	Modiran Tosee Salamat Iranian	Iran	nanofibers membranes	produced by three layers which the second layer is consist of polymeric nanofiber, being under 100 nm	anti-bacterial activity, anti-microbial activity, virus removal, anti-pollution, breathable, impermeable
14	Copper3D	Chile	nanocomposite membranes	made of a novel modular filtration system manufactured with the innovative nanocomposites of PLACTIVE® and MDflex®, including three layers of a non-woven polypropylene impregnated with 5% copper oxide nanoparticles	anti-bacterial activity, virus removal, recyclable, antiviral, reusable

15	Verdex Technologies Inc.	USA	nanocomposite membranes	a proprietary process technology to functionalize nanofibers, before being incorporated into the masks, which enhances virus filtration potential. This functionalization process allows you to feed in powders/particulates at the same time the fibers are being formed. This means that as the hot fibers are being formed, the powders/particulates naturally stick to the hot fibers ensuring maximum capture and containment within the structure.	bacterial removal, virus removal, breathable
16	ZEN Graphene Solutions Ltd.	Canada	nanocomposite membranes	developing a potential virucidal graphene-based composite ink in collaboration with Graphene Composites Ltd to fight COVID-19, containing silver nanoparticles functionalized graphene oxide nanocomposites that can be applied to fabrics including N95 face masks and other personal protective equipment (PPE) for significantly increased protection through both trapping and killing the virus.	anti-fungal activity, antiviral, virucidal, virus-killing
17	MVX Prime Ltd. (rebranded to Invisi Smart™)	UK	nanoparticles technology	a self-cleaning sanitising surgical mask treated with an ultra-thin invisible layer (Protex) ranging between 1-2 micrometers in thickness, enough to protect from viruses	anti-bacterial activity, self-cleaning, anti-microbial activity, anti-fungal activity, anti-viral, proven to kill 99.9% of all viruses and bacteria that come into contact
18	Promethean Particles Ltd	UK	nanoparticles technology	embedded nano-copper into polymer fibers, such as nylon, via a melt extrusion process, it was found that the antimicrobial effect lasted longer than other similar antimicrobial fabrics on the market.	anti-microbial activity, anti-viral
19	RESPILON	Czech Republic	nanoparticles technology	ReSpimask® VK is made of a three-layer nanofiber membrane containing copper dioxide (CuO) nanoparticles into the nanofiber matrix	virus filtration, virus-killing, 99.9% filtration efficiency, natural skin-like color
20	Integricote Inc.	USA	nanoparticles technology	a hydrophobic nano-coating, developed in collaboration with the University of Houston, to improve the ability of surgical masks to protect against transmission of the virus by making them impervious to water	anti-viral, hydrophobe
21	Sonovia Ltd.	Israel	nanoparticles technology	an anti-pathogen fabric that could be used in masks using a patented nanotechnology process, containing zinc oxide nanoparticles	anti-pathogen, virus removal, washable, anti-bacterial activity, anti-microbial activity
22	University of Central Florida (UCF)	USA	nanoparticles technology	a protective coating on masks that would include a new nanoparticle to catch COVID19 and kill it within seconds through triggering a chemical reaction using ultraviolet light to destroy it	virus removal, virus-killing
23	Master Dynamic Limited	China	nanoparticles technology	a nanodiamond coating to be employed in a new generation of the non-woven material of surgical masks	virus-killing, anti-viral, breathable, waterproof, anti-bacterial activity
24	Anson Nano-Biotechnology (ZhuHai) Co.Ltd	China	nanoparticles technology	patented nanosilver technology	anti-bacterial activity, environmentally-friendly, reusable
25	X.TiO2 Inc.	USA	nanoparticles technology	the world's first self-regenerating germicidal TiO2Ag face mask based on XTI's revolutionary Active-Nucleus Nano-Particle Technology	anti-bacterial activity, moisture resistance, non-allergenic, anti-viral, germs removal, self-regenerating, 99.999% germ-killing power under zero light
26	Directa Plus PLC	UK	graphene technology	Made of the patented graphene material (i.e., G+® graphene)	anti-bacterial activity, non-toxic, anti-microbial activity, bacteriostatic
27	LIGC Applications Ltd.	USA	graphene technology	Guardian G-Volt masks based on laser-induced graphene that can conduct electrical charge to kill the trapped microorganisms in the mask's filter	anti-bacterial activity, self-sterilizing, anti-viral, reusable, virus-killing