COVID-19 Pandemic Has Spurred Materials Researchers to Develop Antiviral Masks

Dinsa Sachan

Scientists around the world are developing a new breed of masks that can both trap and destroy viruses.

When Jiaxing Huang, a materials scientist at Northwestern University, heard that Wuhan, China, was entering a lockdown to contain the spread of the novel coronavirus, SARS-CoV-2, he immediately began thinking of ways to contribute to the global response to the impending COVID-19 crisis. Initially, he was frustrated because drugs and vaccines were not in his scientific wheelhouse. But then he made an astute observation: a virus spends a lot of time in the material world before reaching a human. “That’s our territory,” Huang says of his research group. “That’s what we [study] as physical scientists. So there’s got to be something we can do about it.”

What these materials scientists decided to do was try to develop a reusable add-on layer for face coverings that could kill viruses. The team landed a U.S. National Science Foundation (NSF) Rapid Response grant to work on the project for a year.

Huang’s group is not alone. The pandemic has propelled researchers around the globe to work on similar antiviral mask technologies. Their common goal: build a mask that does not just trap the novel coronavirus, but also destroys it.

Some of these researchers think such antiviral mask technology could help protect health-care workers. During the pandemic, these workers have had to reuse surgical masks and N95 respirators due to supply shortages. “The problem with current surgical masks or N95 respirators is they are not designed to destroy the virus, and that’s why the virus can survive a long time on the surface of masks,” says chemical and materials engineer Hyo-Jick Choi of the University of Alberta, who began working on an antiviral face mask filter years before the new coronavirus appeared.

For example, in a 2019 study, researchers reported that they could isolate DNA and RNA from viruses such as adenovirus and influenza virus from 10% of surgical masks discarded by medical staff during 6–8 h shifts at three Beijing hospitals. Similarly, a 2013 study showed that viable H1N1 virus, which caused the 2009 influenza pandemic, lurked for 6 days on the exterior of N95 respirators, which trump surgical masks at filtering out aerosols and airborne particles.

These lingering viruses could infect workers who reuse the equipment. To combat that issue during the current pandemic, hospitals around the world have been decontaminating masks and other personal protective equipment (PPE) before reusing

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them. But Praveen Vemula, a materials scientist working on antiviral masks at the Institute for Stem Cell Science and Regenerative Medicine (inStem), an autonomous institute under the Indian Department of Biotechnology, thinks a mask that destroys viruses may be a better option than disinfection. “As long as [the virus] is there on the mask, it’s still active,” and can infect staff who come in contact with the discarded PPE during the cleaning or washing process, Vemula says. Moreover, decontamination can damage masks. For example, a non-peer-reviewed study posted earlier this year on the medRxiv preprint server showed that multiple cycles of decontamination by ethanol and dry heat reduced the ability of N95 masks to capture fine particles. Vemula and others think that antiviral masks could get around these issues with existing face coverings.

**Antiviral Strategies**

The idea of designing a mask material to destroy viruses did not just pop up during the COVID-19 pandemic. In 2017, Choi and colleagues published a design for an antiviral mask filter. They applied a layer of NaCl to the middle filter from a surgical mask. Choi came up with the idea for such a design while working on solid vaccines that could be administered through microneedles. These vaccine formulations contain inactivated virus in a sugar-based coating. The sugars in the formulation can sometimes crystallize and destroy the protective outer lipid envelope of the virus. “I wanted to use that principle to destroy the virus” trapped on masks, Choi says.

For the mask filter, Choi decided to replace sugar with salt, because salt crystallizes more reliably than sugar. He and his team tested the salt filter against two strains of H1N1 and one strain of H5N1 influenza viruses in experiments with mice. They first passed aerosols containing the viruses through either a salt-coated filter or a noncoated filter to calculate how much virus escapes each filter. Mice infected with amounts of viral particles that escaped from the salt filters survived, while animals infected by amounts leaving noncoated filters died.

As for this mask’s antiviral mechanism, Choi thinks that the aerosols, which are ∼5 μm wide water droplets containing virus particles, dissolve the salt crystals. Then as the droplets evaporate, the salt recrystallizes, piercing through the virus like in the solid vaccine formulations. In studies of this process, Choi says the viruses “were mostly destroyed in 30 min.”

Choi is interested in using the salt filter for the COVID-19 pandemic and is seeking funds to test face coverings with salt filters in a pilot study involving COVID-19 patients and health-care workers.

Not all the materials scientists developing antiviral mask technology are focused on the surgical masks and N95 respirators used by health-care workers. Northwestern University’s Huang and his team are proposing a sticker-like product that could be added to lower-grade face masks or face coverings that patients can wear. “We want to make a complementary chemical barrier to reduce the infectiousness of patients or carriers,” Huang says.

The team’s hope is that, when an infectious person sneezes or coughs into the mask, the antiviral substances in this add-on layer will interact with the droplets and disrupt the structure of the virus, so if even a few aerosol-sized droplets escape through the mask, they’re rendered harmless.

Currently, his group is testing masks with layers of various antiviral substances using droplet and aerosol generation techniques. These setups basically produce simulated coughs or sneezes. So far they’ve had some success with containing outgoing droplets with acids and copper ions. Breathability is also a top priority for his group’s sticker design—the add-on cannot significantly disrupt air flow through the mask. Huang says his team’s lab results show that a low-density mesh coated with these antiviral substances can significantly alter the chemical composition of outgoing droplets and have no measurable hindrance on air flow.

“The usefulness of this is not just in a pandemic,” Huang says. “In general, reducing the infectiousness of a patient is very important and effective way to control and mitigate any infectious disease.”

Meanwhile, Saikat Basu, another NSF Rapid Response grantee and a mechanical engineer at South Dakota State University, has joined forces with Sunghwan Jung, a biological and environmental engineer at Cornell University, and Leonardo Chamorro, a mechanical engineer at the University of Illinois at Urbana—Champaign, to create a mask inspired by animal noses.

Animals like pigs, dogs, and quolls—small marsupials native to Australia—have a better sense of smell than humans, Basu explains. The nasal pathways of some of these animals are tortuous, which allows them to trap water droplets better than our simpler nasal passages can. These droplets can often contain smell compounds. “We knew that better smellers can capture droplets better,” Basu says.

The team wants to design a mask based on these winding animal nasal passages to trap droplets created by coughs and sneezes and then inactive the trapped viral particles with copper filters. Scientists have known about copper’s microbe-zapping properties for some time. For example, in a letter to the editor this year in the New England Journal of Medicine, researchers reported that SARS-CoV-2, the virus behind the COVID-19 pandemic, was inactivated after...
sitting on copper for 4 hours, while it continued to thrive on plastic for up to 3 days.

Scientists have recently begun to understand that copper destroys virus mostly through copper ions jetisoned from its surface. For example, scientists have observed that these ions can deactivate HIV’s protease, which the virus uses when creating copies of itself. In other viruses, the ions can disrupt the outer envelope and dismantle proteins sitting in that layer.

Basu’s colleague Jung is conducting computed tomography scans on the nasal passages of some of these super-smelling critters. Once Basu has the scans, he will do computational modeling to create three-dimensional (3-D) printed designs of these cavities that could be incorporated into a detachable respirator filter on some types of masks. Chamorro will then take the 3-D printed designs and run airflow experiments on them, passing liquid droplets or air containing water aerosols through them to see if the designs can trap particles effectively.

In India, inStem’s Vemula along with colleagues from the National Centre for Biological Sciences, a Bangalore-based institute, are harnessing the antimicrobial powers of quaternary ammonium salts to attack the novel coronavirus. These salts are membrane disruptors, which means they could work against all viruses that feature a lipid membrane envelope, like SARS-CoV-2. “These molecules interact with the membrane and just rip it off,” Vemula says. The salts contain positively charged nitrogens that can interact with negatively charged ions on virus membranes, as well as greasy hydrocarbon tails that can poke into and disrupt the membranes.

Vemula’s lab has impregnated cotton fiber with the best-performing quaternary ammonium salt. In lab tests, the treated fabrics kill 99.99% of viruses like SARS-CoV-2 and those that cause influenza on contact, Vemula says.

**Addressing the Tough Questions**

Physicians and medical device experts see advantages and disadvantages for antiviral mask technologies. Thomas Russo, chief of the infectious disease division at the University at Buffalo’s Jacobs School of Medicine and Biomedical Sciences, says such masks could reduce the chances of accidental infection for health-care workers. For example, he says, workers can contaminate their hands with viral particles if they do not take off their masks properly.

“I suspect it would cost more,” Russo says, adding that these masks could be more complicated to manufacture if adding the antiviral element involves an additional step in the process. Vemula does not think that antiviral masks would cost significantly more than conventional masks, but did not offer a ballpark price for his team’s masks at this stage.

Jeremy Biggs, an occupational and environment medicine physician at the University of Utah, is concerned about the fit of masks with antiviral add-ons. “It would be important to have a mask that is comfortable because we wear masks a lot longer now than we have in the past.” But he points out that reusable masks could potentially reduce hospitals’ contribution to landfills.

The other main concern is the safety of adding an antimicrobial element into the mask. “People could inhale chemicals that can be exceptionally harmful to the lungs,” says Kim Trautman, executive vice president for medical device international services at NSF International, an independent public health and safety consulting organization. “So that’s why it’s very important that the science is understood and you’re not actually inducing harm.” For example, although quaternary ammonium salts, which Vemula’s mask designs rely on, have been used as disinfectants for decades, some scientists have recently raised concerns about their systemic toxicity.

The researchers working on all these antiviral mask technologies have not yet conducted safety tests. However, Vemula says that his antimicrobial small molecules are integrated into fibers so well they cannot be inhaled. “They become just a part of the fiber,” he says.
As for how such mask technologies could reach hospitals, a spokesperson from the U.S. Food and Drug Administration explains that face masks, surgical masks, or N95 respirators with antiviral or antibacterial elements would normally undergo a clearance process. As part of that process, manufacturers would submit a variety of data, including results from clinical studies, and technical information to prove that the technology is as safe and effective as a similar device already approved for use in the U.S. However, recently the FDA has issued several emergency use authorizations (EUAs) for masks that are not FDA cleared, but still meet some general safety and efficacy norms, to fulfill demand during the COVID-19 pandemic. The spokesperson adds that manufacturers of antimicrobial or antiviral face masks “may request an EUA if the device is intended for use to diagnose, treat, or prevent COVID-19.”

Back in the lab, the technology that Vemula’s team developed has been licensed to a textile company called Color Threads, which has started to make masks with that design. The masks, called G99+, will be available soon in India. South Dakota State University’s Basu hopes to have a prototype out in 3–4 months. His team then hopes to collaborate with a biosafety lab to test the prototype against the novel coronavirus.

On the Northwestern University campus, lockdown-related restrictions have eased up, and Huang’s team of postdocs and graduate students is hard at work on its antiviral add-on. Huang is touched by the team’s spirit. They’re working during a pandemic and tackling a subject unrelated to their regular research. “They could have sat at home and just waited it out but they decided to come,” Huang says. “So that’s quite remarkable.”

Praveen Vemula developed a mask based on fibers coated with quaternary ammonium salts to destroy virus particles. The company Color Threads is using the technology to make G99+ masks, which will be available soon in India. 

Dinsa Sachan is a freelance contributor to Chemical & Engineering News, the weekly news magazine of the American Chemical Society. A version of this story appeared in C&EN.