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UV Lights the Way

The COVID-19 outbreak brought with it an almost immediate and unprecedented national shortage of personal protective gear needed by health-care workers and others seeking to prevent the spread of the virus. N95 masks intended for single use by front-line health workers were being cleaned and reused. Questions arose: Were they clean? Were they safe? Were they still effective?

As cases of COVID-19 spiked wherever large groups breathed recirculated air in closed spaces, such as ships, hospitals, churches and prisons, it became ever clearer that solutions are needed to disinfect masks for reuse, as well as to decontaminate shared surfaces and spaces and neutralize the virus in recirculated air.

UV lights — those emitting in the very short, ultraviolet, wavelengths — are promising on both counts. Already, some jails and prisons are using robots topped by a cylindrical bank of UV lights to decontaminate cells and shared spaces, such as dining halls. UV light damages human skin and eyes, so the rooms are emptied before the robots go through, sanitizing everything in them.

For the past 20 years, the Solid State Lighting and Energy Electronics Center (SSLEEC) in UC Santa Barbara's College of Engineering has been a world leader in developing powerful and energy-efficient solid-state LED lighting. Smaller SSLEEC research efforts over the past 15 years have centered on developing LEDs that emit in ultraviolet wavelengths of 200-280 nanometers (UVC), primarily with an eye toward water purification in areas of the world lacking water-treatment infrastructure. UVC lights have been used for decades by municipal water plants

because they destroy the DNA of many microbes, rendering drinking water safe.

While we receive ultraviolet light in the form of UVA and UVB from the sun, UVC, the ultraviolet light of choice for purifying air and water and for inactivating microbes, can be generated here only via man-made processes. According to materials professor and SSLEEC co-director Steve Denbaars, the center's UVC work has intensified over the past four years. Meanwhile, with government funding for UV LED extremely limited, many other U.S. universities have stopped working on them altogether.

Until recently, UVC decontamination systems — whether in municipal water-treatment plants or devices like the SteriPEN, which backpackers use to purify water — have been enabled not by semiconductor-based LEDs, but by mercury-vapor lamps. If the glass breaks in the SteriPEN, mercury is released, rendering the device useless.

One big drawback to using mercury lamps for disinfection of enclosed spaces is that they require a lot of voltage to operate, which is difficult to achieve for a portable device should it need to run on battery backup during a power outage. But LEDs, which are small, non-toxic, run on little power and are essentially shatter-proof “can go everywhere,” says Denbaars. “You could even imagine having a UV LED on your cellphone to decontaminate it if someone else touches it.”

When campus labs were ordered to temporarily shutter in response to the outbreak, a limited number exceptions were made for what was deemed “essential research.” SSLEEC's UV projects were among them. “Pre-COVID, we had one [PhD] student working on it; now we have five,” Denbaars noted. “Once we got declared essential research, we shifted people from the white-LED projects to the UV LED projects.”

With COVID, Denbaars said, “You have a tipping-point application, because you can't decontaminate an entire room by spraying, and you can't decontaminate your food by spraying it with Clorox. You can't even decontaminate your mask with Clorox, or with alcohol. But you can decontaminate it with UV light. The other way to decontaminate masks is to use vapor hydrogen peroxide, but to do that you have to buy a special reactor made for hydrogen peroxide, which is expensive, and that process allows you to use the mask only about three times.”

A preview of a study — not by UCSB researchers — soon to be published by The National Institute of Allergy and Infectious Diseases compared four methods for

decontaminating N95 respirators: treating them with UV light, with heat (150 degrees Fahrenheit), with a 70-percent ethanol solution and with vaporized hydrogen peroxide (VHP).

VHP and ethanol had the highest rate of inactivation of SARS-CoV-2, which causes COVID-19; however, after two rounds of usage the VHP- and ethanol-treated masks showed marked drops in filtration performance. The heat-treated masks constantly underperformed compared to the UV-treated masks and did not function effectively after two decontaminations.

Further, said Chris Zollner, a fourth-year Ph.D. student in SSLEEC, “In this study, the researchers placed the mask far from the UV LED, resulting in a low ‘dose’ of UV radiation, so they needed a lot of time to get UV disinfection to work well. I suspect that, had they placed the UV LED closer to the mask, it would have been disinfected much more quickly.”

At their current efficiency and power, the UVC LEDs are able to decontaminate masks without damaging them, and as power and efficiency increase, Denbaars said, he expects to see sanitization times come down to a few seconds of exposure. And, in fact, in April, Seoul Semiconductor, an SSLEEC industry sponsor, received hundreds of orders after reporting that its UVC LED lights had achieved 99% sterilization of coronavirus in thirty seconds.

According to Denbaars, the pandemic has ignited the conversation around UV LED research funding. “I think the funding landscape is going to change,” he said. “Government people are calling us now and asking what it will take to get UV LEDs to be really efficient.”

Currently, LEDs emitting UVC light are only about 3% efficient, making them most effective for low-power portable applications, as seen in some UV LED-equipped water bottles, while the LED light bulb you buy at the store is about 60% efficient. “So, we have a twenty-fold improvement we can do,” said Denbaars, adding, “It’s a complicated process in materials science. To increase the power, we need to increase the efficiency of the LED, and that involves doing a lot of the same things we did to increase the efficiency of LED lightbulbs, but doing it all over again for UV wavelengths.”

The team spearheaded by Denbaars uses metal organic chemical vapor deposition (MOCVD) to grow the semiconductor materials; UCSB materials professors James

Speck characterizes the new materials; and Nobel Laureate Shuji Nakamura designs the device. Together they have developed a new material, made by depositing a thin film of the semiconductor alloy aluminum gallium nitride (AlGaN) on a silicon substrate.

“Current UVC disinfection lamps, such as mercury vapor lamps, have fixed light emission of 254 nanometers,” said Denbaars. “However, many bacteria, fungi and viruses are killed more efficiently at different wavelengths. The AlGaN material system being developed at UCSB allows for greater flexibility in fine-tuning UVC light emission from an LED, which would make targeting specific microorganisms a real possibility. Aluminum gallium nitride is the only semiconductor that provides light of the correct wavelength, and UCSB is a world leader in developing it.”

According to Zollner, the materials challenge in UVC LEDs lies in the fact that a lot of aluminum is needed to increase the energy of the conducting electrons, which can then recombine with positively charged holes to release high-energy photons as UV light. But aluminum atoms bond very strongly to nitrogen atoms within the crystal, making atomic-scale control of crystal growth more difficult, so that expensive and time-consuming methods are often required to make a functioning UV LED on sapphire. While many other labs and a number of companies work in that space, UCSB has developed a new process: by replacing sapphire with silicon carbide, the team is able to use much simpler traditional epitaxy methods to grow high-quality AlN and AlGaN materials. (Unlike sapphire, which is an insulator and structurally dissimilar to AlN, SiC is a semiconductor material with a close structural similarity to AlN.)

Heating and air conditioning systems that recirculate air are another big target for improved decontamination. State of the art high-efficiency particulate (HEPA) filters are made to filter out particles down to three microns in size. However, once captured by the filtration system, viruses can shrink as they dry out, possibly enabling them to pass through the filter and be recirculated into an airplane or ship or operating room, where they may infect people. In environments lacking HEPA filters, such as on aircraft carriers, the viruses are simply being redistributed.

With powerful, efficient UVC LEDs, Denbaars said, “You could pass air through a light tunnel to decontaminate it; you just need enough photons to hit enough of the air. It used to be that people thought it would be nice to have contamination devices on subways and ships and other enclosed spaces where people gather in large

numbers. The coronavirus has made it priority one.”

Long term, Denbaars said, “The goal is to shift to certain shorter wavelengths of UV that are safe for skin and eyes, so you could have safe decontamination even in the presence of people. You could leave the lights on all the time for applications like hospital operating tables, Navy ships and submarines, airplanes, prisons and so on. I think we’re years, not decades, away from that.”

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