Wearable, printable, shapeable sensors detect pathogens and toxins in the environment

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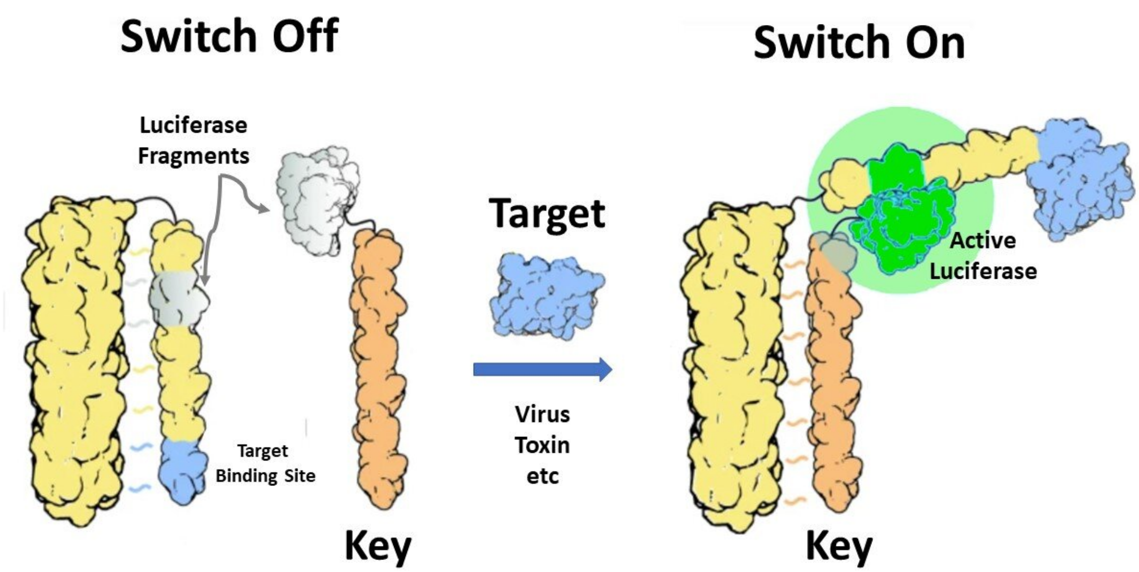


The molecular switch in the biopolymer sensor consists of a protein that acts like a lock and key. When a target molecule or pathogen (blue) binds to the switch, it uncovers the "lock" allowing a molecular key (red) to combine and form a complete luciferase enzyme (green) with the lock. Luciferase, found in fireflies and glowworms, can then emit a green light indicating the presence and quantity of the target. Credit: Alfredo Quijano, University of Washington

Researchers at Tufts University School of Engineering have developed a way to detect bacteria, toxins, and dangerous chemicals in our environment using a biopolymer sensor that can be printed like ink on a wide range of materials, including wearable items such as gloves, masks, or everyday clothing.

Using an enzyme similar to that found in fireflies, the sensor glows when it detects these otherwise invisible threats. The new technology is described in the journal *Advanced Materials*.

The biopolymer sensor, which is based on computationally designed proteins and silk fibroin extracted from the cocoons of the silk moth *Bombyx Mori*, can be embedded in films, sponges, filters, or molded like plastic to sample and detect airborne and waterborne dangers, or signal infections or even cancer in our bodies.

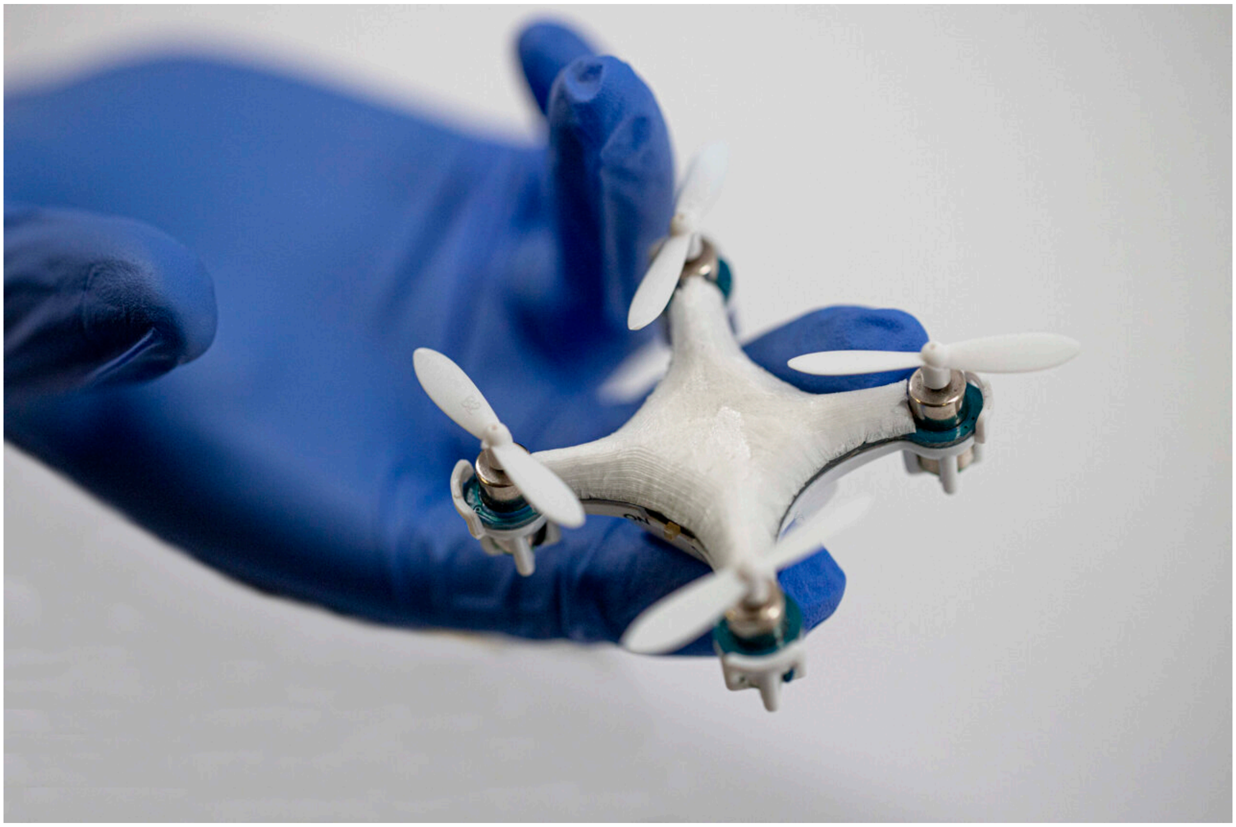
The researchers demonstrated how the sensor emits light within minutes as it detects the SARS-CoV-2 virus that causes COVID, anti-hepatitis B virus antibodies, the food-borne toxin botulinum neurotoxin B, or human epidermal growth factor receptor 2 (HER2), an indicator of the presence of breast cancer.

Currently, once exposed the sensors require a quick spray with a non-toxic chemical. If the target is present, then the sensor generates light. The intensity of emitted light provides a quantitative measure of the concentration of the target.

"The combination of lab-designed proteins and silk is a sensor platform that can be adapted to detect a wide range of chemical and biological agents with a high degree of specificity and sensitivity," said Fiorenzo Omenetto, Frank C. Doble Professor of Engineering at the Tufts University School of Engineering, and director of the Tufts Silklab where the bio-responsive materials were developed. "For example, SARS-CoV-2 and anti-hepatitis B antibodies can be measured at levels that approach clinical assays."

The sensing element is modular, so developers can swap in newly designed proteins to capture specific pathogens or molecules to measure, while the light emitting mechanism remains the same. "Using the sensor, we can pick up trace levels of airborne SARS-CoV-2, or we can imagine modifying it to adapt to whatever the next public health threat might be," Omenetto said.

He noted that, although it's in a conceptual stage, the application to detect breast cancer is particularly interesting. His team created a proof-of-concept silicone bra pad that when worn can absorb secreted fluid, report the levels of HER2 hormone, and provide an indication whether breast cancer may be present. "While further development will be required to improve and clinically validate the assay, the opportunity for such diagnostics in everyday garments is certainly compelling," Omenetto said.



A drone fuselage was embedded with a biopolymer sensor capable of detecting airborne SARS-CoV-2. During flight, the propellers direct airflow through the porous body of the drone which will emit light if virus was present. The drones could enable monitoring environments from a remote, safe distance. Credit: Fio Omenetto, Tufts University SilkLab

The sensors can assume a seemingly endless variety of forms. To demonstrate this, the research team created viral sensing drones in which their fuselage was embedded with the sensor material. During flight, the propellers direct airflow through the porous body of the drone which can be examined after landing. The drones, which in the example reacted to airborne pathogens (SARS-CoV-2), could enable monitoring environments from a remote, safe distance.

Lock and key mechanism

The active component of the biopolymer sensor, which was developed by Professor David Baker at the Institute for Protein Design at the University of Washington (sites.uw.edu/biochemistry/faculty/david-baker/), is a molecular switch made of proteins that act like lock and key, but with a cover. When a virus, toxin, or other target molecule comes near, it binds to the switch and opens the cover. Another part of the switch—a molecular key—can then fit into the lock, and the combination forms a complete luciferase enzyme, similar to the enzyme that lights up fireflies and glowworms. The more virus, toxin, or other chemical that binds to the sensor, the brighter the glow.

The molecular glow-switch is embedded in a mixture of protein that is derived from silk cocoons, called silk fibroin. The silk fibroin is the inactive component of the biopolymer sensor, but has unique features, including the ability to be processed and manufactured using safe, water-based methods, and a remarkable versatility to be fabricated into different materials, such as films, sponges, textiles, or dispersed onto surfaces through an inkjet printer. Additionally, the silk fibroin stabilizes the molecular glow-switch and greatly extends its shelf life.

These biopolymer sensors are a big leap from other approaches to measuring pathogens or chemicals in the environment, which often rely on biological components that degrade quickly over time and require careful storage. The sensors also do not depend on electronic components that can be difficult to integrate into flexible wearable materials.

Extended shelf life

The Tufts researchers tested the shelf life of materials embedded with SARS-CoV-2 sensors after storing them at 60 degrees Celsius for four months and found very little change in performance. The breast cancer sensor shaped into a sponge was kept on the shelf at room temperature for one year, and still performed near its original sensitivity.

"This means we can manufacture, distribute, and store these sensing interfaces for long periods of time without losing their sensitivity or accuracy and without the need for refrigerated storage, which is remarkable due to the fact that they are made of protein," said Luciana d'Amone, a graduate student in Omenetto's lab who co-led the project with Giusy Matzeu, a research professor at Tufts' Silklab.

This approach could make sensors widely available in different formats. "For example, you could make surgical masks capable of detecting pathogens, package them in boxes, and use them over time just like conventional masks," said d'Amone. "We also showed that you can print the sensor inside of food packaging to track spoilage and toxins. You can modify so many products that we use every day to include sensing, and store and use them as you normally would."

The Tufts research team envisions applications for the biopolymer sensors ranging from personal and patient monitoring and infection control in health-care settings to environmental sensing in home, workplace, military, and disaster settings.

More information: Luciana d'Amone et al, Reshaping de Novo Protein Switches into Bioresponsive Materials for Biomarker, Toxin, and Viral Detection, *Advanced Materials* (2022). DOI: 10.1002/adma.202208556

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