SYNTHETIC BIOLOGY

Synthetic Biologists Design 'Living Materials' That Build Themselves

Organisms are master builders. Crabs assemble shells, corals amass reefs, and our own tissues build bone. Now, synthetic biologists are taking control of the construction process. Researchers in Massachusetts reported this week in *Nature Materials* that they've reprogrammed the genetic circuitry of bacteria to construct electronic and optical materials, complete with living cells in their midst.

The new materials can't yet compete with conventional electronic devices. Nevertheless, outside researchers say the feat opens a new door to using genetically engineered organisms to assemble complex materials from the ground up, with minimal help. "It's fantastic work," says Lingchong You, a biomedical engineer at Duke University in Durham, North Carolina, who was not involved in the research. Traditional manufacturing is typically energy-intensive, polluting, and often hazardous for workers. "But if we can harness the power of cells [to build structures], we can make the entire process 'green,' " You says. Moreover, because organisms are adept at engineering materials at many different size scales—the way our bodies imprint bone with structure on the nanoscale, microscale, and meter scale—the new work holds the potential for adding new levels of complexity to engineered materials.

The new work isn't the first foray into marrying engineered organisms with materials. In 1999, for example, Angela Belcher, a chemist now at the Massachusetts Institute of Technology (MIT) in Cambridge, and her colleagues engineered viruses to assemble semiconductor nanoparticles on their surfaces. Belcher's group has since gone on to program viruses to construct everything from electrodes for lithium-ion batteries and photovoltaics to catalysts that split water to generate hydrogen fuel. But because viruses don't harbor their own cellular machinery, the materials they make aren't alive. That means, for example, that they can't respond to their environment the way bacteria can: by organizing themselves in groups or healing themselves.

The new work, from Timothy Lu, a synthetic biologist at MIT, and colleagues, brings these previously disparate fields together. "Our idea is to put the living and nonliving worlds together to make hybrid materials that have living cells in them and are functional," Lu says. They started with *Escherichia coli* bacteria that naturally cooperate to produce sheetlike biofilms atop different surfaces. The bacteria bind these films together by secreting proteins called curli fibers. Made up of repeated protein subunits called CsgA, the fibers glue the bacteria to surfaces and to one another.

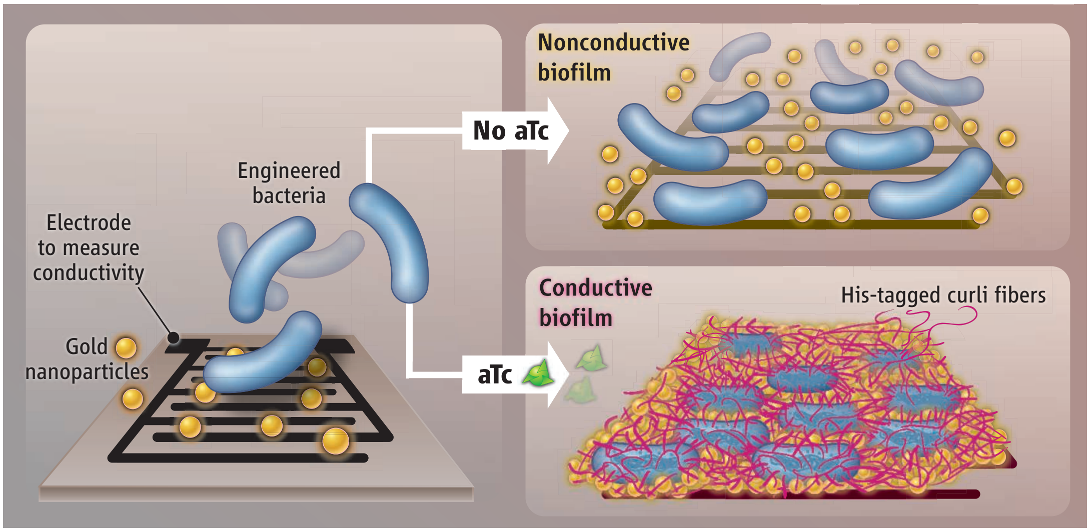
For their experiments, Lu's team first disabled the genetic pathway that allows bacterial cells to produce CsgA. They replaced it with an engineered genetic circuit that produces CsgA only when the researchers add a chemical trigger, a molecule called AHL. The team then engineered a separate batch of *E. coli* to produce altered CsgA tagged with short protein strands, or peptides, containing multiple histidine amino acids, which bind metal particles. These bacteria expressed the histidine-tagged CsgAs only in response to another chemical trigger, called aTc. When aTc was present, the bacteria settled into a film and latched on to gold nanoparticles that the researchers had sprinkled into their beakers, creating a network that conducts electricity (see figure, below).

By growing both batches of *E. coli* together, Lu's team could vary the composition of the film just by adding AHL and aTc at different times. In this case, the varying composition didn't add new function. But it sets the stage for doing so by binding other materials, for example. In a separate experiment, they used different peptide tags and chemical triggers to create bacteria that could trap tiny semiconductor particles called quantum dots, which altered the optical properties of the biofilm.

Lu now hopes to take advantage of recent advances in synthetic biology, in which researchers have programmed bacteria to form colonies in the form of rings, bars, and other shapes. That could lay the groundwork for more complex architectures that could serve as electrodes, environmental sensors, and artificial tissues. Ultimately, the living materials might be fashioned into devices that repair themselves when damaged.

The technique might also be used to sponge up environmental toxins such as cadmium and recycle the material into complex optical and organic devices. It may even prove useful in prospecting: Designer bacteria, for example, might harvest gold from their environment and concentrate it in mats that could be scooped up. Such tests remain a ways off, however. Regulators would need to be convinced that engineered bacteria don't pose risks when released into the environment.

–ROBERT F. SERVICE



Filmmaker. When exposed to a chemical called aTc, bacteria produce fibers (pink) that cause them to attach to a surface and to one another. Amino acids called histidines on the fibers then grab gold nanoparticles, forming an electrically conducting film.

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