Mechanical metamaterials roll off the 3D printing press

Researchers are exploring applications that extend beyond optical invisibility cloaks.

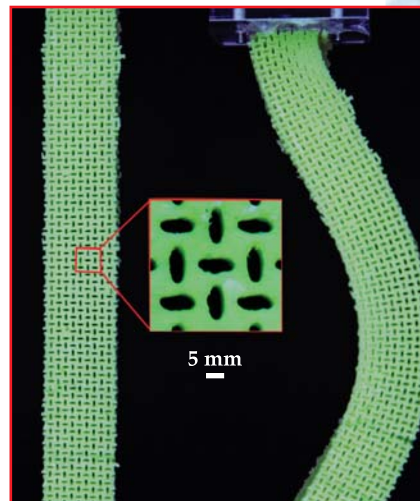
A powerful fabrication tool has found its way into the labs of scientists who study metamaterials and their bizarre behaviors. Researchers are now using three-dimensional printers to churn out invisibility cloaks, spongy ceramics, and ultralight, ultrastiff materials with architectural features inspired by the Eiffel Tower.

For metamaterials—engineered materials with exotic properties governed by their structural features, not their chemical composition—the benefit of 3D printing is design freedom. In the 3D printing process, also known as additive manufacturing, an object, regardless of its complexity, is constructed layer by layer via the curing, sintering, or fusing of raw materials, each layer being just a few microns thick. A limited set of plastics and metals, and even fewer ceramics, can be used as the "ink" for a 3D printer (see PHYSICS TODAY, October 2011, page 25).

In particular, 3D printers are being used to fabricate periodic microstructures that unusually affect a bulk material's elastic properties. Examples of such so-called mechanical metamaterials include auxetic materials, which contract in the transverse direction when compressed and expand in the transverse direction when stretched, and pentamode metamaterials, which, like liquids, are hard to compress but easy to shear. Potential commercial applications range from acoustic dampeners to "unfeelability" cloaks (the elastic analogue of optical invisibility cloaks) to athletic footwear.

With 3D printing, "you can choose the behavior you want and go design the system," says physicist Martin van Hecke, who is heading a new designer matter program at the FOM Institute AMOLF (Institute for Atomic and Molecular Physics) in Amsterdam. "We have no idea how much functionality we can put into these structures," he adds. Van Hecke and Harvard University materials scientist Katia Bertoldi have designed a 3D-printed "metabeam" containing precisely arranged elliptical holes; past its buckling point, the metabeam counterintuitively bends more as the load is reduced.

Physicist Martin van Hecke and his research group in Amsterdam use 3D printers to fabricate metamaterials that exhibit unusual elastic properties—the elliptical holes in the "metabeam," shown in the inset, cause it to bend more when the load is reduced.



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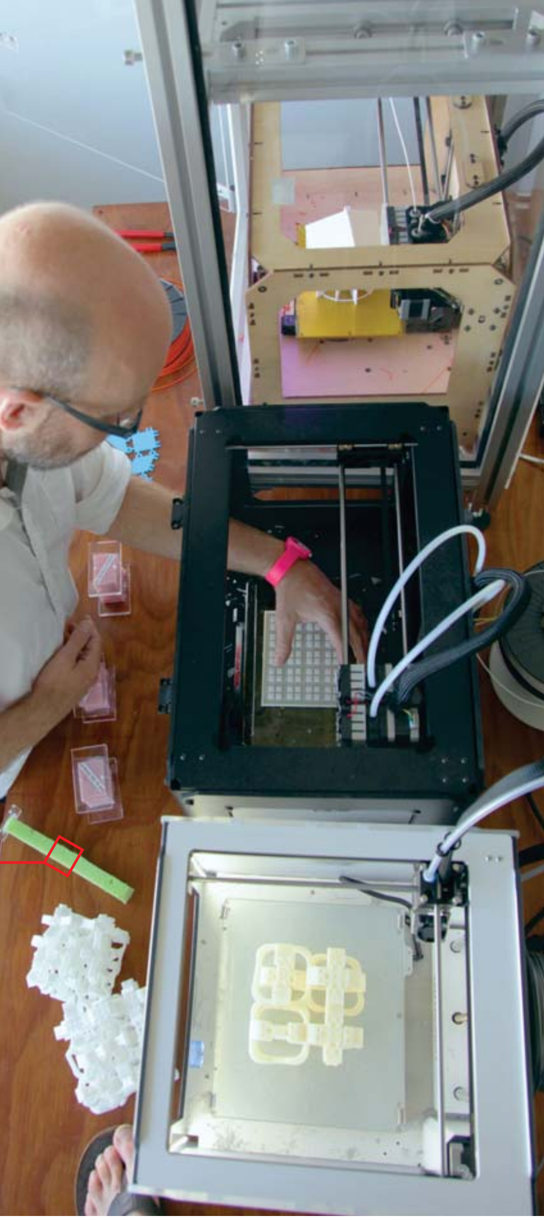
In general, for mechanical metamaterials, the unit-cell architecture of the underlying structure determines the behavior, says Xiaoyu Zheng, a staff scientist at Lawrence Livermore National Laboratory. Zheng and colleagues at Livermore and MIT have developed a metamaterial that remains stiff even at very low densities. The material's underlying structure is an array of hollow microscale unit cells, similar to the ones that make up the Eiffel Tower and the Golden Gate Bridge. (See also the related story, PHYSICS TODAY, January 2012, page 13.)

Zheng lists potential commercial applications for the collaboration's lightweight and ultrastiff metamaterial: vehicle parts, battery electrodes, medical implants, energy-absorbing helmets, and more. MIT nanophotonics researcher Nicholas Fang, a principal investigator with Zheng on the project, says several companies have contacted them, including the chemicals manufacturer BASF; he says they are "interested in an impact-resistant lightweight composite with good acoustic absorption and low thermal conductivity."



By all accounts, the modern era of metamaterials research was launched 15 years ago, when *Physical Review Letters* published theoretical physicist John Pendry's landmark paper on negative refraction and physicist David Smith and his colleagues proved the concept experimentally. (See the article by Pendry and Smith in PHYSICS TODAY, June 2004, page 37.) Those events kicked off the growing quest for artificial materials that could interact strongly and unusually with electromagnetic waves—for example, a material that could bend light in such a way that it renders itself and anything behind it invisible. (See the article by Martin Wegener and Stefan Linden in PHYSICS TODAY, October 2010, page 32.)

According to a 2014 report from market research firm Lux Research, widespread commercial implementation of metamaterials depends in part on the development of cost-effective manufacturing methods. The report notes that 3D printing could become "the tool of choice for most metamaterial manufacturing" as the technology continues to improve in speed, resolution, materials selection, and the ability to combine multiple materials in a single object.

Next month van Hecke is hosting a conference on "4D" printing and metamaterials at AMOLF. The fourth dimension is the programmed and spontaneous response to such external stimuli as temperature and pH by a 3D-printed multimaterial object. In 4D printing, structure and chemical composition both matter. **Jermey N. A. Matthews**

Spotting coincidences in astronomical signals

Perhaps a dozen times a year, the IceCube Neutrino Observatory at the South Pole alerts NASA's *Swift Gamma-Ray Burst Mission* to follow up on neutrino detections. "That's infrequent enough that a telescope like *Swift*, whose time is valuable, is willing to slew and take a look," says Doug Cowen of the Pennsylvania State University (PSU).

But IceCube spots five or six neutrinos per hour, Cowen says, and useful data may be lost in the winnowing process. "We don't want to overwhelm [telescopes] with alerts," he says, but researchers don't like to throw away data either. That's what led him and some colleagues to create the Astrophysical Multimessenger Observatory Network, or AMON.

With AMON, which is gearing up to go live, participating observatories send their data to a hub at PSU. There, the data are queried in real time, and when they collectively meet given criteria, alerts are sent out to telescopes to follow up with imaging. The process is fully automated. Alerts go out within five minutes of the initial detection, says Gordana Tešić, a PSU postdoc who joined the project in 2012, about a year into its development, and has been key in setting up its database and real-time infrastructure.

The network lowers the threshold for identifying useful data, says Cowen. In the IceCube–*Swift* example, IceCube sends alerts only when two neutrinos are detected within 100 seconds and