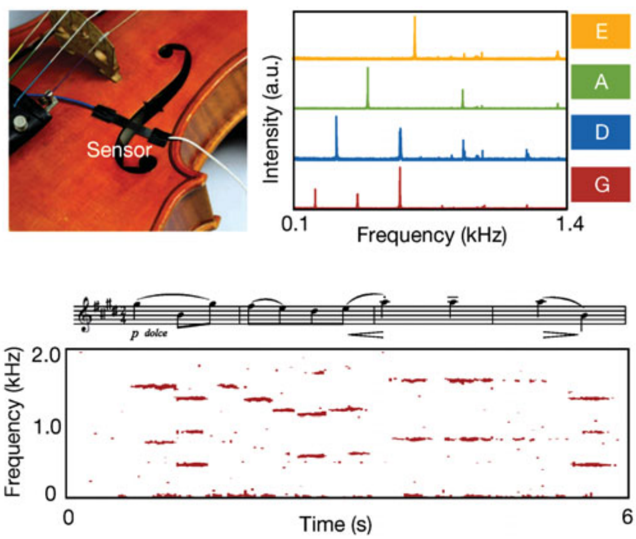
Bio Focus

Spider-inspired vibration sensor detects music

Spiders use crack-shaped slit organs near their leg joints to detect minute mechanical vibrations. This inspired Mansoo Choi and his team from Seoul National University to design their own version of a mechanical sensor based on nanoscale crack junctions. As the researchers describe in their December 2014 *Nature* publication (DOI: 10.1038/nature14002), they fabricated their sensors by depositing a stiff 20-nm thin film of electrically conductive platinum on a flexible polymer (polyurethane acrylate). The material is then wrapped around glass rods of different diameters to induce controlled directional cracking with different spacing between the individual zigzag cracks. While signal transductions through the spiders' neurons are responsible for the extraordinary vibration sensitivity of their slit organ, changes in electrical resistance as the zigzag crack edges of the platinum gaps pull apart or reconnect are the underlying cause of the artificial sensor's operation. It is the gap geometry both devices have in common, which is crucial to achieve the remarkably high sensitivity to mechanical stress.



Nanoscale crack junction-based sensor attached to a violin for sound wave recognition (top left), recorded wave functions of E (yellow, fundamental frequency of 659 Hz), A (green, 440 Hz), D (blue, 294 Hz), and G (red, 196 Hz) strings (top right), measured sound waves of music playing ("Salut d'Amour"; excerpt shown in the bottom panel). Reproduced with permission from *Nature* **516** (7530) (2014), DOI: 10.1038/nature14002; p.178. © 2014 Macmillan Publishers Ltd.

Among other tests to prove the functionality and reversibility of their mechanosensor, the research team attached it to a violin (see Figure). Not only were they able to register sound waves, but they could also observe unique sensor responses to different frequencies. Additionally, the flexible sensor was mounted on skin and successfully detected speech or heartbeats with superior signal/noise ratios. The publication's supplementary information includes a real time–peak spectrogram of Elgar's "Salut d'Amour" played on the violin, a special treat for music lovers.

Throughout their study the researchers show that their sensor pixel array outperforms other mechanosensors in the 0–2% strain range, including recently reported sensors based on graphene platelets, carbon nanotubes, or organic semiconductors. "Precise engineering of crack formation" says Choi, "might be the future of ultrasensitive mechanosensing."

Birgit Schwenzer

Bio Focus

Spinning artificial spider silk remains a challenge

Although spider webs can be torn apart with one well-aimed sweep of a broom, the silk that forms them is, by weight, one of the strongest materials found in nature. It's also lightweight, biodegradable, sticky, and slightly stretchy—all properties that make it desirable for a variety of applications.

Humans have been collecting silk from silkworm colonies for thousands of years to create textiles. However, using the same strategy to harvest natural spider silk—which is stronger and lighter than that of silkworms—isn't a practical option. Spiders can become territorial and even cannibalistic when kept in close proximity to each other, and the labor required to harvest their silk is too great to make the process commercially viable. Instead, scientists are studying the molecular basis for spider silk's valuable properties with the hopes of eventually creating a commercially viable biomimetic synthetic silk fiber.

"One of the main obstacles to synthesizing true, biomimetic spider silks was, and still is, a lack of understanding about the natural material and processes by which it is created," said Cameron Brown of the University of Oxford and an author of a review paper on synthetic silk in the January 14 issue of the *Journal of Materials Research*. "We are getting much better at making proteins similar to the natural proteins, yet our processing capabilities lag behind."

The two main proteins believed to be responsible for silk production are large molecules called Spidroins, but over a hundred secondary proteins might help finesse the silk's properties. Researchers have turned to a variety of organisms, from bacteria to goats, to recombinantly express these relevant proteins. None, however, has yielded synthetic fibers on par with natural ones in strength. Recombinant silk protein expression has suffered from low protein yield—making the process inefficient—and low molecular weight, weakening the resulting product. It seems that while spiders are well suited to efficiently express these large proteins critical to their survival, other species are not.

Scientists at Utah State University turned to silkworms as an alternative, engineering them to create a hybrid spider-silkworm protein. "This was a great idea, as most expression systems aren't well suited to making proteins of the size of the main silk proteins," said Federico Rosei, a researcher at INRS University in Quebec, Canada, and another contributor to the review.

Once the proteins are expressed, the resulting slurry must be spun into a thread. Spiders have specialized equipment for this task: glands in the abdomen release a molten protein mixture, which flows through ducts that reorder the proteins into a fiber before releasing it through spinnerets. For humans, it has proven to be more of a challenge. One promising solution uses microfluidics, where fiber assembly takes place at the interface of a fluid protein stream and a water-insoluble liquid like oil.

It's too soon to call spider silk the next miracle material—many of the technologies being developed, though promising, are still in their nascent stages, and the exact properties of a given spider silk depend on the complex interplay between its molecular makeup and the fiber structure. Nevertheless, opportunities for its eventual use abound.

Randy Lewis, a Utah State University researcher who was not involved in the review article but has been studying spider silk for 25 years, points out that the potential for the material goes beyond the strong, lightweight fabrics one might expect. "We have found that we can make a variety of things other than fibers from spider silk," he says, like adhesives, coatings, and highly absorbent sponges.

The authors of the review agree. "We think some of the most exciting applications aren't the ones that follow the obvious properties of spider silk—applications in biophotonics and sensing, for example," said Brown.

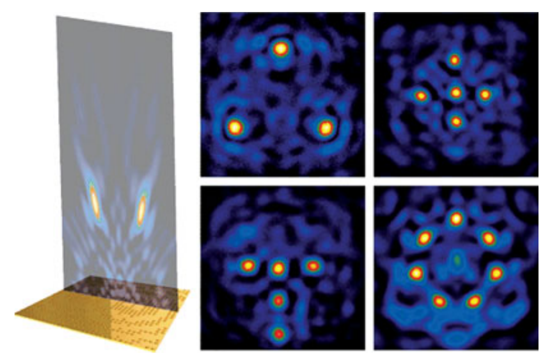
Laurel Hamers

Nano Focus

New optical materials manipulate light into 3D profiles

The discovery of new materials is being rapidly accelerated through the use of computational methods that can screen the constituent elements for a desired application. While simple materials systems and structures can be easily predicted using these methods, more complex systems can prove challenging due to the increased number of potential configurations. Evolutionary algorithms, a sort of "survival of the fittest" methodology that sequentially generates and weeds out potential solutions to converge on an optimized result, offer the possibility to accurately predict complex systems while reducing computation time. These design methods have been used in the past to predict metamaterial structures that can operate at terahertz frequencies but encounter problems at optical frequencies that require a finer computational grid to account for losses, leading to prohibitively longer computation times.

Teri W. Odom and colleagues at Northwestern University now report a bottom-up strategy that uses a custom-built evolutionary design algorithm to predict a new class of optical materials. These new "lattice opto-materials" are detailed in the November 7, 2014, issue of *Nano Letters* (DOI: 10.1021/nl5040573; p. 7195). Lattice opto-materials can be used to concentrate light into discrete focal points in the optical far-field and produce arbitrary three-dimensional (3D) light profiles. They function based on the discretization of a plasmonic film into a two-dimensional (2D) subwavelength grid of holes with diameters in the range of 100–200 nm. The researchers were able to design lattice opto-materials for a specific design criterion with vastly reduced computation time.



Lattice opto-materials can manipulate visible light to produce a variety of three-dimensional profiles from two-dimensional grids of nano-sized holes milled into a substrate. Reproduced with permission from *Nano Lett.* **14** (12) (2014), DOI: 10.1021/nl5040573; p. 7195. © 2014 American Chemical Society.

A number of optical systems were simulated based on this new design algorithm before being experimentally validated in the laboratory. The researchers used a focused ion beam to mill a 2D grid of holes and they measured 3D optical profiles using confocal scanning optical microscopy. They found that experiments matched simulations accurately in a number of configurations. The researchers were able to generate a variety of 3D far-field light profiles with focal points varying in x, y, and z positions. These lattice opto-materials grant exceptional control over visible light, surpassing the capabilities of current microlenses, metalenses, and plasmonic lenses. With the inclusion of polarization-sensitive hole shapes, the possibility of dynamic control without physical alteration of the substrate is also possible. This new class of materials holds incredible potential for current and future applications, paving the way for enhanced flat optics for new imaging modalities.

Ian McDonald