by Ted Lynch

Smart Ceramics Transform Structural Shapes

In the early days of smart materials, fantastic visions of aircraft changing wing shape, much like birds flexing their wings, were touted as one of the big payoffs. Unfortunately, the limitations of the key technology for smart materials—piezoelectric materials that stretch and contract in response to an electric field—have frustrated progress. Most piezoelectrics are ceramics that are too brittle and have too small a stroke displacement to do much more than damp small, high-frequency vibrations or produce and sense ultrasonic waves for imaging applications.

Materials advances, such as new macrofiber composites developed at the National Aeronautics and Space Administration's Langley Research Center (Hampton, VA), may help speed progress in applications ranging from aerospace to consumer products. The composites, known collectively as LaRC-MFCs, are designed for inexpensive, automated manufacturing. They are flexible enough to conform to almost any surface and provide the large displacements needed for the active control of structural shapes.

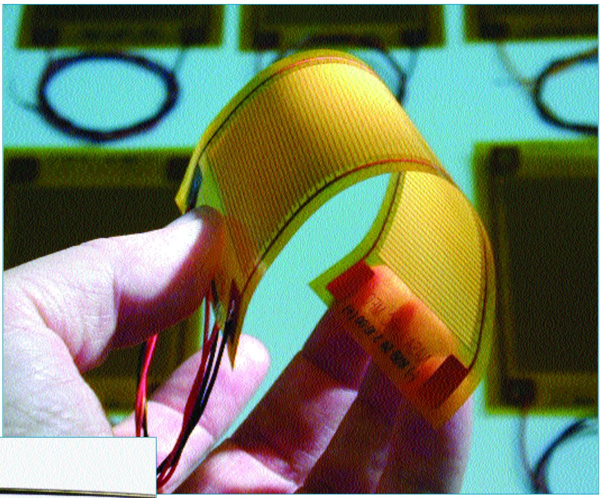

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Figure 1. This piezoelectric strain actuator produces controlled motion when stimulated by a driving voltage and may be embedded in or attached to the surface of a flexible structure (such as a helicopter rotor) to distribute deflection, control vibration, and sense strain.

Boeing Co.

Aerospace challenges

One of the benchmark applications in smart materials is controlling vibrations in helicopter rotors, which can shorten their lifetimes (see The Industrial Physicist, December 1996, p. 13). In scale-model tests conducted in the early 1990s, conventional piezoceramics attached to rotors doubled the weight of the blades, says Keats Wilkie, principal investigator for Langley's macrofiber-composite research program. LaRC-MFC, in contrast, is thin and lightweight, and it can control strong vibrations. The real challenge for the new composites is producing 10% changes in rotor-blade pitch so that the blades' aerodynamics can be adjusted for hovering or forward motion.

"We're about halfway there," says Wilkie, referring to preliminary tests of the Langley composites. If the materials are successful, the result will be faster helicopters with greater range that can hover longer because of higher fuel efficiency. "That is something that will get a general really excited," says Wilkie, "because it improves the operational capabilities of his forces."

Performance enhancement makes composite piezoceramics "the most exciting new material to hit the white [unclassified] aerospace industry since the introduction of composites 30 years ago," says Robert Derham, leader of aeromechanics at Boeing's Philadelphia division. His research group is currently characterizing the Langley materials' structural, mechanical, electrical, and actuation properties, primarily for rotorcraft blades. Although it is still too early to give definitive answers about performance, "we have nothing but a favorable reaction," says Derham.

In NASA's space programs, the technology could give a boost to inflatable space mirrors, proposed as a cost-effective way to make space telescopes that can image terrestrial planets around distant solar systems. Using conventional technology, these large telescopes are simply too costly because they would be several times bigger and orders of magnitude more expensive than the Hubble Space Telescope. Inflatable space structures, with their light weight and compact deployment size, would dramatically reduce costs. But to make mirrors that would unfold and inflate in space, a material such as LaRC-MFC is needed to force support beams and mirror parts into position during deployment and to eliminate vibrations that would ruin a mirror's resolution.

How does it work?

In its packaged form, LaRC-MFC consists of diced piezoceramic fibers embedded in an epoxy matrix, which is covered by copper electrodes etched on a polymer film. The copper electrodes form a pattern of alternating positive and negative electrodes that extend across the fibers. The fibers make the composite flexible, and the interdigitated electrodes help increase displacement, because the piezoelectric effect is stronger in plane than through the plane, as most piezoelectrics are designed to operate.

Although others have used interdigitated electrodes and fibrous composites, what makes LaRC-MFC unique is its method of

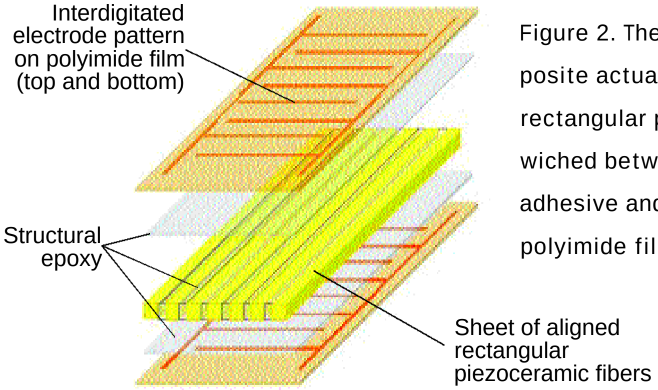

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Figure 2. The macrofiber composite actuator consists of rectangular piezofibers sandwiched between layers of adhesive and electroded polyimide film.

manufacture. Earlier attempts to make composite piezoceramics used extrusion-produced fibers, which meant that they had to be laid out by hand, a time-consuming and expensive process. The fibers also needed to be round because sharp edges cut into electrodes if they turned on their sides during packaging. Round fibers, however, provide less surface area for the electrodes to contact, which means that these composites had to be driven by very high voltages—in the range of 1,000 to 4,000 V.

In contrast, Langley's fibers are made by cutting a piezoceramic wafer with a computer-controlled dicing saw. The commercially obtained ceramic wafer is attached to a sticky polymer so that the fibers can be handled as a unit after dicing. Next, an epoxy bonds the polymer sheets to the fibers. "This bonding is the only part of the process we haven't automated," says Wilkie. As a result, hand-size patches—pieces of the material meant for use on airplanes, for example—could be made for less than $100 in small batches. This is only one-tenth the expense of other composite patches, and the price should come down with volume manufacturing.

A second advantage of the process is that dicing produces flat fibers that allow more uniform electrical contact between electrodes and fibers. The result is more strain per volt and greater flexibility in the design of the electrode patterns. With closer electrode spacing, "we can drive the patches with just 250 V, which means that the control electronics are much simpler to design," says Wilkie.

High-volume markets

In addition to the aerospace applications—which will demand composite sheets as large as 3 ft^2 and in which performance will outweigh cost in importance—Langley is seeking higher-volume commercial licensees. Although Wilkie says that potential users are taking samples as fast as NASA can make them, finding licensees is not easy. According to Marisol Garcia of NASA Langley's Technology Commercialization Program Office, no one has yet designed systems around flexible patches. "We have been in contact with many companies, and they are excited because this can open up new applications for them," Garcia says.

Some uses envisioned by potential licensees include immersible pumps (the polymer encapsulation protects the patches), and patches that conform to pipe surfaces for actuating valves. Toys are another possibility, as are more traditional vibration-suppression applications such as positioning sensors. But the flexibility of these patches is new, says Garcia. As a result, the big payoffs will likely come after systems designers put in the necessary research to learn what the composites can do and start dreaming up clever new uses.

BIOGRAPHY

Ted Lynch is a senior technologist with the National Technology Transfer Center, where he helps coordinate the Ballistic Missile Defense Organization's technology transfer program (tlynch@as.wm.edu).

Further reading

Ouellette, J. How Smart are Smart Materials? The Industrial Physicist 1996, 2 (4), 10.

Wilkie, W. K., et al. Low-Cost Piezocomposite Actuator for Structural Control Applications. Proc. SPIE's 7th Annual International Symposium on Smart Structures and Materials, Newport Beach, CA, March 5–9, 2000.