AEROSPACE engineering & manufacturing MaterialsFeature
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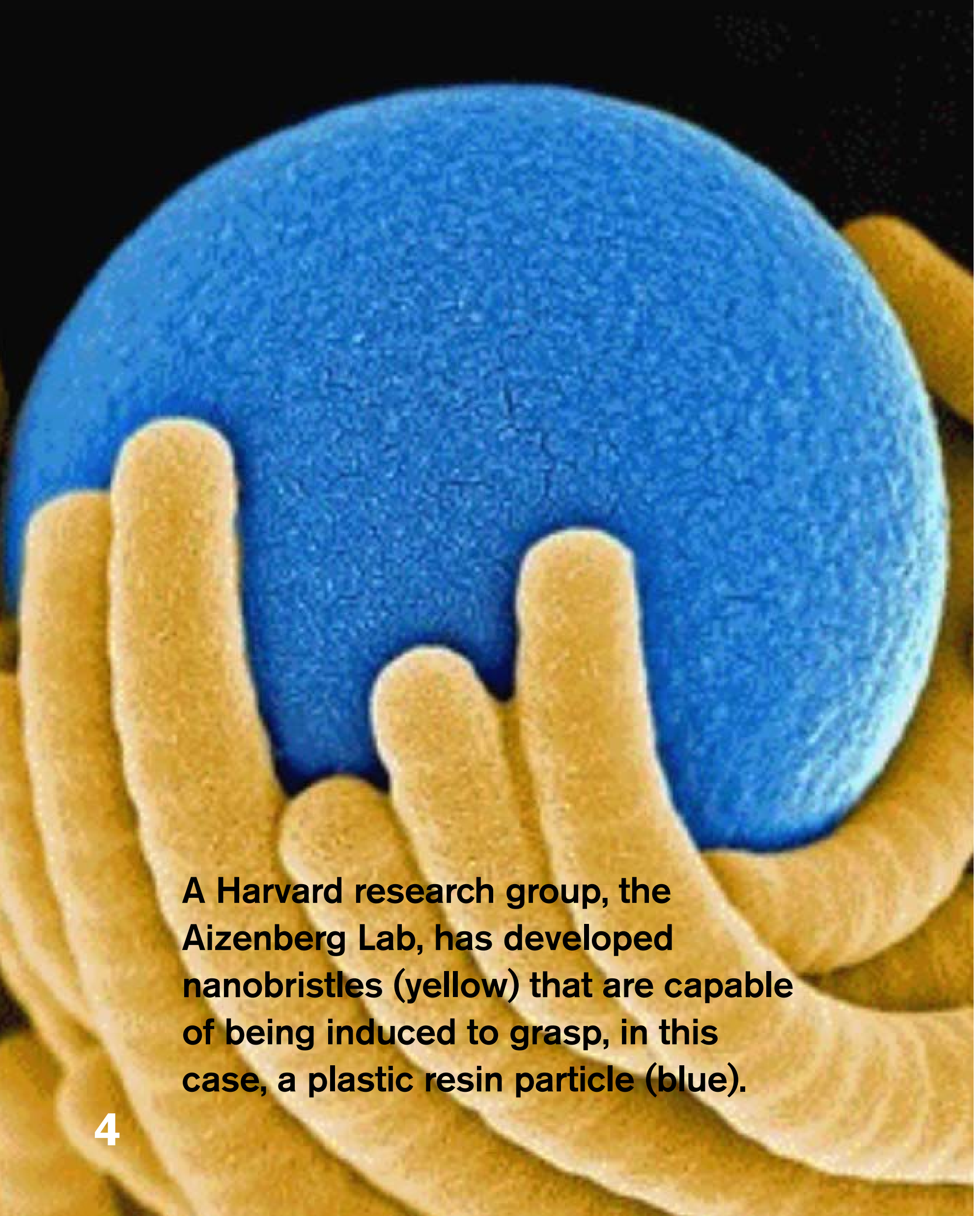
A smarter future



A Harvard research group, the Aizenberg Lab, has developed nanobristles (yellow) that are capable of being induced to grasp, in this case, a plastic resin particle (blue).

Smart materials have been around a long time; some have made it to market, but the real promise is still to come.

by David Gehman

Smart materials—materials that respond to, or report on, their environment—have been researched at universities and technical think tanks for decades. But where are they in the real world?

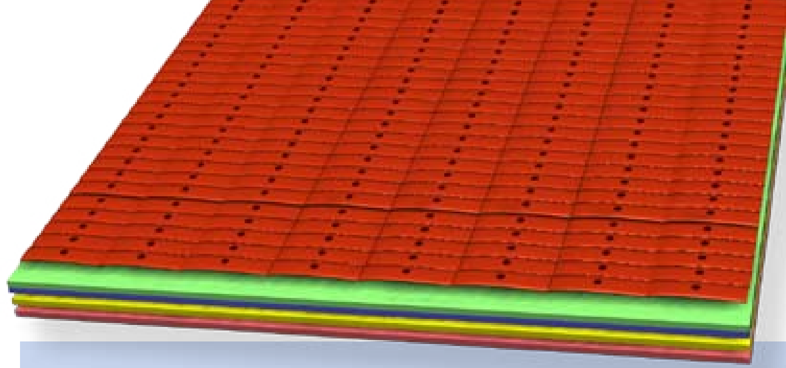
It is tempting to say nowhere, but that characterization is unfair. For example, if you own a **Cadillac** or Corvette automobile made since 2003, the car's ride damping is controlled via a magnetorheological (MR) shock absorber system that includes fluid incorporating micrometer-sized iron spheres. Supplied by **Lord** Corp., the fluid's flow properties change dramatically depending on external magnetic forces.

Shape memory metal alloys (SMAs) provide a second area of real-life applications, a key example being the jet engine variable-geometry engine nozzle chevrons developed by **Boeing** and involving **GE Aviation**, **Goodrich**, **NASA**, and **All Nippon Airways**. All of Boeing's new aircraft will be equipped with the technology.

SMAs have been with us since the 1930s, with seminal work in nickel-titanium (Tinel) alloys in the **Naval Ordnance Laboratory** in the early 1960s. A similar technology is found in thermoplastic polymers. Applications range from pipe connections to medical stents in blood vessels, from eyeglass frames to dental braces.

Then there are smart materials based on piezoelectric phenomena, suitable for damping, noise sensing or control, flow control, and other applications where controlled vibration handles a given need. **Smart Materials** Corp. makes: piezoceramic fibers and tubes in 105 to 800-µm diameters, with lengths under 150 µm; piezo composites for ultrasound transduction; and soft-mold composites and macro-fiber composites.

Finally, there are applications going on behind a veil of secrecy: defense projects, anti-terrorist initiatives, and the like. Details are sketchy, of course, but the **Defense Advanced Research Projects Agency** (DARPA) has actively supported research into smart materials since the early 1990s. In addition to pure research into generic materials, DARPA has focused on materials that adapt intelligently to aerodynamic, hydrodynamic, and protection needs.



Harvard researchers have developed ways to seed and grow cardiac muscle cells on thin-film polymers. Patterns on the substrate help determine how the cells align—in this case, rows.

Secrecy is also the stance for companies outside of defense that are currently making smart materials—several opted not to participate in this article, citing competitive issues.

Hurdles increase time to market

You could say that, in their purest sense, smart materials incorporate dynamic actuations or reactions in ways that replace externally controlled systems. In this sense, Lord's MR material is only semi-smart, since it relies on external sensors and controllers.

Truth is, the line where smart materials are truly self-actuating is a gray one. For example, inclusion of fiber optics that act as strain gauges in composites (or literal inclusion of strain gauges) obviously relies on external devices to do something with the strain information—if not to take immediate action, then to at least store it for later recall and use.

Whether self-actuating or dependent on external sensors and controls, smart materials offer at least some reduction of ancillary devices, and most react more quickly or more directly to environmental inputs.

"If smart materials are slow to reach commercial viability, it's because the third stage of any development is the hardest," said Steven Luby, President and CEO of **Vistagy** Inc. "The first is research into functionality, and there's been a lot of that. Thousands are studied, and a few prove themselves as viable. The second is gaining the ability to make a proven smart material repeatably. The third stage is making a smart material with methods and materials that are cost-effective—can I make it at cost and still meet performance objectives?"

Intelligence builds on intelligence, Luby added, citing an example drawn from composite fiber layup design.

"Designers learned how to create fiber orientations and types to handle aircraft wings under stress," he said. "Now it's possible to use the same basic engineering knowledge, take it a step forward, and use it to design a wing that changes its angle of attack depending on the stress it is undergoing. When you know enough to design a structure that avoids unwanted twisting, in effect, you know almost enough to build a structure that automatically and selectively induces twisting, such as a windmill blade that automatically de-loads when wind pressure rises to certain point."

In addition to learning-curve issues, Luby sees a couple other circumstances that have slowed the progress of smart materials. The first is a lack of available engineering tools and instrumentation.

"Smart materials generally are highly tunable materials, and any tunable material can have multiple pockets of localized attributes. This is especially applicable to composites, whose behaviors are engineered into each structure," said Luby. "Every local attribute has to do its own thing and also work in harmony with all the other attributes, including the overall function of the part as a whole. That is far from easy, and requires highly sophisticated simulation augmented with equally sophisticated testing."

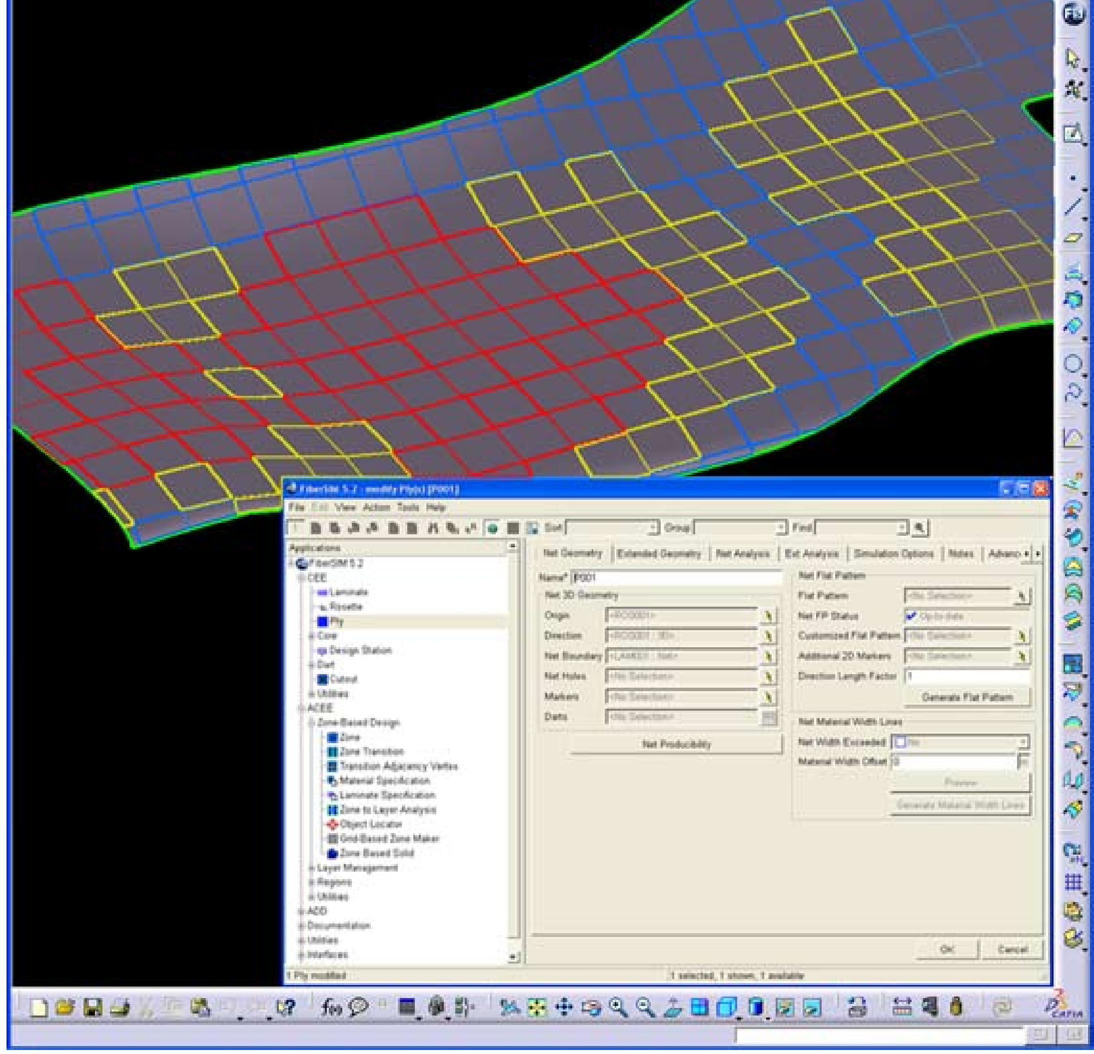
The second issue is the flurry of questions around adding and managing new information flows. "You can embed sensors to report on conditions, for example, but you immediately face new questions," Luby said. "The first one is, how will you use the data generated by the sensors? Then, how will you embed physical elements without adversely affecting the structure? And how do you prevent, say, false positives?"

A promising future

In the research community, a discipline that has generated much interest is that of biomaterials, which in the simplest form combines biological molecules with more traditional molecules of materials like polymers. More properly, the discipline is called biomimesis, the mimicking of biological processes in nonbiological organic or inorganic materials.

The target is a material that responds in ways similar to the responses of biological organisms. That is, they are capable of being actuated by tiny electrical currents, or can sense heat and cold and take action to cope, or even compute and return data.

The **Massachusetts Institute of Technology** (MIT) recently announced a textile that detects light. In research, a swatch "took" a "picture" of a smiley face, acting as a camera without a lens. The new fibers, less than a millimeter in diameter, are composed of layers of light-detecting materials nested one within another. Those layers include two rings of a semiconductor material that are light-sensitive, each ring only 100 billionths of a meter across.



Readily available tools for design and analysis of composite structures permit simulation of forces. This enables designers to build in resistance to stress and strain, or, more interestingly, to design structures to automatically flex in predictable ways. *Vistagy*

Four metal electrodes contact each of the rings, extending along the length of the fiber, for a total of eight. Each semiconductor ring with its attached electrodes is in turn encased in rings of a polymer insulator that separate it from its neighbor. The fabric is thus something like the sensor in a digital camera, but (a) spread over an area several magnitudes larger and (b) without a lens or focus mechanism. Projected uses include military garb that looks in all directions, potentially allowing a controller to identify threats.

At **Harvard University**, Kevin Kit Parker, Associate Professor of Biomedical Engineering, and his group are working on biohybrids—part biological, part synthetic materials. Experiments center on placing seed cells—specficially rat heart muscle cells—on specially prepared thin-film polymer sheets. A tissue of muscle cells is then grown across the thin film, either aligned in a regular pattern or arrayed in a more random pattern. Tiny stamped patterns in the polymer layer help determine which growth pattern will occur.

Researchers then can cut the film into shapes. Since the motive power (or if you will, molecular motor) is living cardiac muscle tissue, the resulting biohybrid responds to electrical stimulation when placed in a salt solution, contracting and relaxing on cue just as it would in a beating heart. The type of contraction, and thus the type of motion, depends on the type of muscle cell pattern; the type with aligned cells can bend, for example.

"Our first product was an artificial fish that we folded from a small triangle of the biohybrid. Then we actuated it through electrical pulses at one kilohertz," said Parker. "We enjoyed watching it swim around."

Potential applications are more serious, including an underwater soft robot capable of traversing a port, exploring for toxins or other chemicals, including explosives. Sensors could listen to sounds, as well.

"And we can combine it with other microorganisms—conceivably making a device that roams oil or gas tanks, consuming contaminants," Parker said.

"The ultimate smart materials are biological. Living organisms fuse data, and respond to their environment such that they survive. You get both smart material and computational capabilities for multiple kinds of data, and multiple kinds of actuation or sensing."

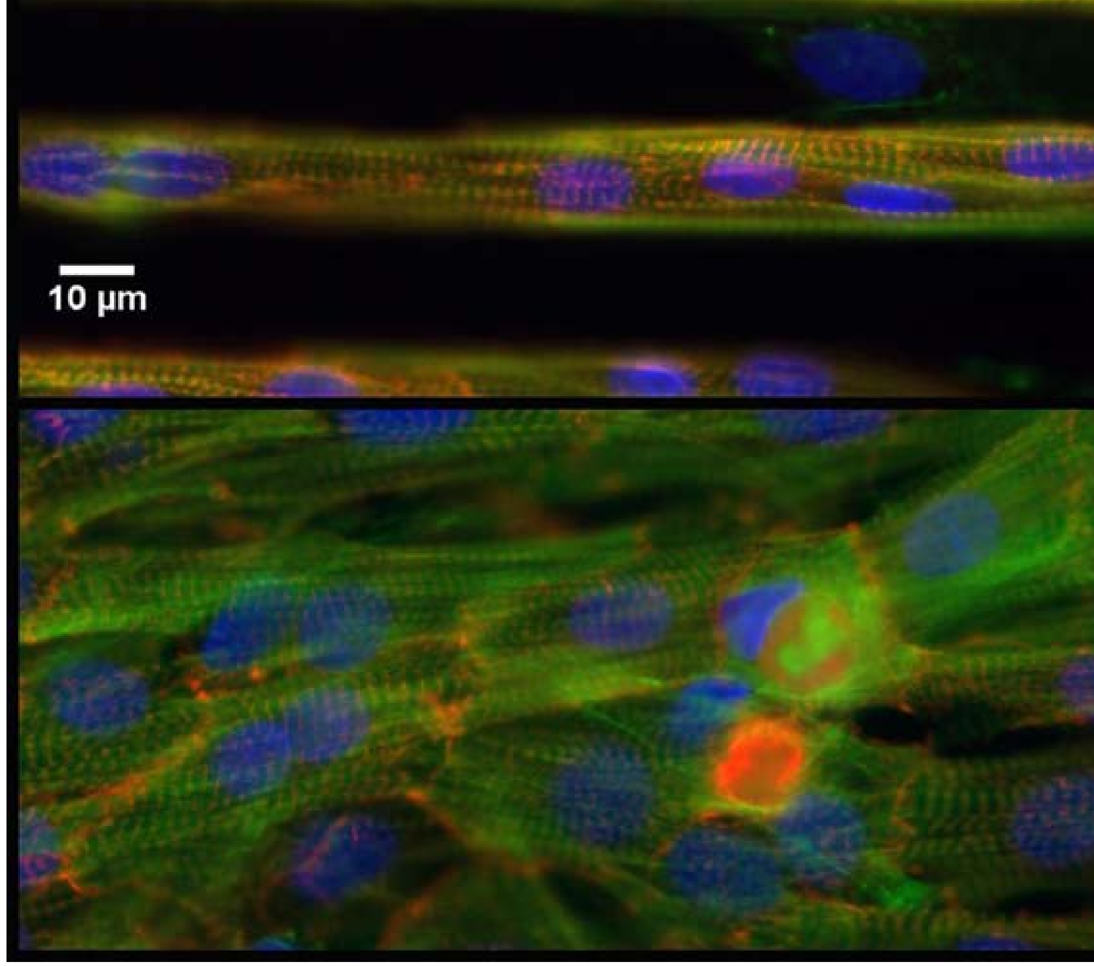
Elsewhere in Harvard's engineering school, a team in the Aizenberg Biomineralization and Biomimetics Lab led by Joanna Aizenberg has most recently created a helical nanofiber construct capable of literally reaching out and grasping other material. Aizenberg is Gordon McKay Professor of Materials Science at the Harvard School of Engineering and Applied Sciences.

The project team can synthesize and control the formation of nanobristles, akin to tiny hairs, into helical clusters and have demonstrated the fabrication of highly ordered clusters, built from similar coiled building blocks, over multiple scales and areas.

Aizenberg is quoted as saying: "We demonstrated a fascinating phenomenon—how a nanobristle immersed in an evaporating liquid self-assembles into an ordered array of helical bundles. This is akin to the way wet, curly hair clumps together and coils to form dreadlocks—but on a scale 1000 times smaller."

Potential applications of the technology include storage of elastic energy and information embodied in adhesive patterns that can be created at will. It may also induce chiral (asymmetric) flow patterns that enhance mixing and transport of particles at the micron and submicron scale.

Globally, major companies dependent on engineered products, universities large and small, and government/defense are all coming together to pound away at a hugely rich array of projects. Ultimately, the entire spectrum of smart materials will evolve into design solutions hardly conceivable today. The bad news is that they take a long time to reach a real market. The good news is that the impediments pointed out by Vistagy's Luby are slowly diminishing.



Two different muscle tissue architectures for biohybrids that create molecular motors. Top: cells organized into lines of tissue. Bottom: tissue layer of loosely aligned cells. Here, the nucleus is blue, filaments (the tension-bearing elements of the cell) are green, and red designates the molecular motors, that is, the force-generating elements inside the muscle cells.

Harvard School of Engineering and Applied Sciences

Academia's fascination with them means more and more waves of students with appropriate kinds of knowledge will be joining companies. More and more design tools and production equipment are in process. Bottom line: the future looks smart.