



# FABRICS GET SMART

ELECTROACTIVE TEXTILES SERVE AS SWITCHES, SENSORS, AND MORE.

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If your idea of smart fabrics is a pair of khaki pants that sheds food stains, think again. The smartest fabrics are becoming electroactive, allowing them to address far more important engineering problems than whether you wear your lunch to an afternoon meeting. These textiles can help you build flexible sensing systems, detect chemicals, generate mobile power, and perform other tasks. “More than 70% of the surfaces we interact with daily are textiles. Once those textiles can carry data and electrical power, it opens up a huge new world of applications,” says Stacey Burr, president of Textronics Inc, a developer of smart-fabric technology.

Rather than just a single material, electroactive smart fabrics encompass many combinations of textiles and electrically conductive materials. Though manufacturers often base smart fabrics on elastomeric fibers, such as Lycra, they can also create them from a wide variety of synthetic and even natural fibers. Various knit, woven, and nonwoven fabrics can all be smart, too. As for the electrical properties, smart fabrics most commonly

contain fine metal wires, either in the yarn of the fabric or in the fabric alongside ordinary textile fibers. Other smart fabrics get their electrical properties from ICPs (inherently conductive polymers) or nanocomposites deposited as coatings on the fabric’s fibers.

All of these electroactive smart fabrics have a way to go before they become commonplace engineering materials. Some of the textiles, particularly those

that rely on nanotechnology, are available only in quantities suitable for development work. Others, although fully commercial, may not have enough of a track record to alleviate the kinds of technical concerns that design engineers bring up within minutes of evaluating a technology. “Smart fabric is still something of a black art,” says Maggie Orth, president and founder of International Fashion Machines, a developer of smart-fabric products.

Smart-fabric suppliers, for example, all make compelling arguments for the use of their technologies in various sensing systems. But only one company, NanoSonic Inc, provides technical data about sensor performance—in this case, strain range, linearity, and hysteresis.

This lack of basic engineering information may somewhat limit the use of smart fabrics. Spyros Photopoulos, an analyst who studies the smart-fabric market for Venture Development Corp ([www.vdc.com](http://www.vdc.com)), recently surveyed OEMs regarding their plans for using smart fabrics and

## AT A GLANCE

- Smart fabrics encompass many combinations of textiles and electrically conductive materials.
- Physically integrating fabrics with traditional rigid electronics requires new approaches to interfaces and interconnections.
- Carefully look at and test the current-carrying capability of prospective textiles. Fibers may burn up when you subject them to harsh electrical environments.
- One of smart fabrics' biggest potentials is their ability to sense strain and serve in pressure-monitoring systems.



Figure 1 Users can roll, crumple, or fold Eleksen's textile pressure sensor, which finds use in keyboards for mobile electronics.

found that many expressed doubts about the durability and performance of smart fabrics. "Price is also a big issue," he says. "Many OEMs wouldn't consider smart-

fabric technology without strong consumer demand."

Smart fabrics may also suffer from a division within the design community. "Electrical engineers and textile designers don't speak the same language," says Textronics' Burr. And bringing these two

groups together goes beyond semantics. Engineers need to know how to physically integrate fabrics with traditional rigid electronics, which requires new approaches to interface and interconnect designs (see sidebar "Proceed with caution").

## PROCEED WITH CAUTION

Few people know more about working with smart fabrics than Maggie Orth. She did her doctoral work on them at the Massachusetts Institute of Technology (Cambridge). She consults on smart fabrics for OEMs. She founded International Fashion Machines, which makes smart-fabric products, and she has created smart-fabric art. Another electronic-textile supplier even calls her the godmother of smart-fabric technology.

So it's probably worth listening to her when she says that design engineers need to move cautiously when considering whether they want to use electronic smart fabrics. "The thing about textiles is that there are lots of ways to do things," she

says. "There are also a lot of ways to mess up." To avoid messing up, Orth asks some tough questions at the beginning of any application she works on. Here are three important ones:

*How will you connect the textiles to the other electronics?* "I don't even start a project if I don't know how I'm going to connect all the electronics," she says, before noting that traditional connections sometimes won't work with "fussy" e-textiles. Take soldering, for instance. "Most textiles won't stand up to soldering temperatures." And rigid connectors can interfere with the design goals that pushed you into textiles in the first place. Over the years, she has had to come up with

a number of nontraditional ways to marry electronic textiles with rigid electronics. She has even tied knots onto pc boards.

*Have you accounted for unfamiliar failure modes?* "Remember that the 'e' in 'e-textile' stands for 'electronic,' which means that you're putting electronics into products that didn't formerly have them," she says. E-textile products often need to be machine-washable, for example, or they need to be ironed. They may also go through extreme flex cycles that could break the continuity of the conductive material. Remember, too, that flexibility in textiles goes beyond understanding a minimum radius as you would for a flexible circuit.

"Flexibility in textiles is different," Orth says, explaining that users can often fold, crumple, and twist textiles in ways that a flex circuit need not endure.

*How much juice can the textile really handle?* Orth advises engineers to carefully look at—and test—the current-carrying capability of prospective e-textiles. They currently have no standard electrical ratings, and the suppliers don't or can't reveal the gauge of the tiny wires in a given textile. "Some of these wires are no bigger than the fiber itself," Orth says, adding that, in some cases, yarns burned up when designers subjected them to electrical loads similar to what they'd see in use.



**Figure 2** The ElekTex sensor contains a proprietary e-textile that senses pressure. It works by measuring voltage drop across the sensor surface.

The smart-fabric applications that have moved the furthest commercially have involved switches and controls for consumer electronics. The leader in this field, Eleksen Ltd, has supplied touch-sensitive fabric controls for products ranging from electronics cases to ski jackets with integrated, machine-washable controls for audio players. The company has also developed portable, wireless fabric keyboards that you can roll, fold, or even crumple (**Figure 1**).

Eleksen makes these fabric controls from a multilayered fabric containing three electroactive layers. Two outer conductive layers surround an inner resistive layer that separates the conductive layers until someone presses them together, says Andrew Newman, product manager at Eleksen and one of the technology's developers. Eleksen then measures the voltage drop at various points on the surfaces to determine where and how hard someone presses the fabric. "We measure the interaction in the x, y, and z directions," says Newman, who adds that the z-axis measurement gives a relative, rather than an absolute, pressure reading.

The company can supply a variety of configurations, including single switches or arrays of switches on a given fabric surface. The company's keyboards, for example, use the array-of-switches approach. Newman notes that Eleksen's fabric, ElekTex, and the related electronics, output an analog signal (**Figure 2**). So, you can apply the same technology to

sliding control buttons, such as those for volume or scrolling on a computer display.

Although ElekTex applications currently focus squarely on consumer electronics, Newman sees some potential for a variety of human-to-machine interface applications. In automotive interiors and appliances, the technology could find use in software-configurable control panels that can cover even deeply curved surfaces. In one of the only indications of smart-fabric durability, Eleksen has performed ex-



**Figure 3** International Fashion Machines' reimagined household light switch costs \$129 and is UL-approved.

tensive mechanical testing of its products, including subjecting them to 10 million press cycles and hysteresis tests after 30,000 roll-up and folding cycles. "That's far in excess of what they would see in real life," says Newman (**Reference 1**).

Another switch application comes from International Fashion Machines. Orth has reimagined the ordinary household light switch as a capacitive touch sensor in the shape of a pom-pom (**Figure 3**). At first glance, pom-pom switches may seem frivolous. But consider that Orth gets \$129 for her light switch, which has appeared in museum shows, compared with approximately \$2 for the ugly, plastic commodity versions at the hardware store. "Smart fabrics allowed me to create a premium product," she says. She's also got UL approval—no easy task—for her switch.

## SENSE STRAIN AND MORE

For engineers, one of the biggest technological potentials for smart fabrics relates to their ability to sense strain and serve as the basis for pressure-monitoring systems. Both broad types of smart fabric—those based on metal wires and those based on ICPs or nanocomposites—can perform some sensing. Whatever the type of fabric, they tend to operate on the fabric equivalent of the piezoresistive principle. With fabrics based on metal wires, such as those from Textronics, the movement of the fabric itself brings conductive metal fibers closer together or farther apart, altering the resistance of the fabric. Something similar happens with fibers incorporating ICPs or nanocomposites, in that strain changes the electron transport between conductive clusters on the fabric fiber. With some signal processing, these resistance changes translate into pressure measurements. "In theory, you can turn all kinds of resistive materials into strain sensors," says Orth.

Two of the newest ways to create fabric sensors rely on nanotechnology to make polymer-fabric fibers conductive to varying degrees. NanoSonic has recently developed smart fabrics it based on an electrostatic self-assembly process (**Reference 2**). The developers of this process initially created it to make free-standing elastomeric sensor films. The self-assembly process can infuse the surface of textile

fibers with various nanocomposites—combinations of polymers and metals or metal oxides. Fabrics incorporating these fibers have high conductivity, with bulk resistivity values of  $10^{-5}$   $\Omega$ -cm, according to Andrea Hill, a NanoSonic researcher who helped develop the conductive fabrics.

They also can tolerate extreme elongations. Rick Claus, NanoSonic president and founder, notes that the original sensor films, metal rubber, can measure strains as high as 1000% with full-scale linearity of 1%. At lower strains, they can tolerate thousands of flex cycles and exhibit low mechanical hysteresis, he adds. The new fabric versions, metal-rubber textiles, can tolerate similarly large strains.

Another twist on inherently conducting fibers comes from Eeonyx. The company has a proprietary process for coating textiles with ICPs based on doped polypyrrole. The company polymerizes the materials on the surface of the fabric itself so that the coating material fills interstices in the surface and forms a physical bond with the fibers. Jamshid Avloni, the company's president, reports that the ICP's conductivity doesn't match the level that metal wires offer. But, then again, it doesn't have to.

"There are orders of magnitude of difference between the conductivity of, say, polyester and copper," says Avloni. "We occupy a middle ground." The company can deliver fabrics, for example, with surface resistivities ranging from 10 to 106  $\Omega/\square$ , controllable to within 10%. Avloni says that the textiles have seen some use in piezoresistive-pressure-sensing applications, including a dynamic

pressure sensor for biomedical and custom-footwear applications.

Neither the NanoSonic nor the Eeonyx technology changes the fabric properties much, if at all. "You still get the drape and feel of a fabric," Avloni says of Eeontex. The conductive treatments can also be translucent enough to avoid much of a visual impact, though some versions of the Eeonyx-coating formulations are black.

The two nanotech approaches have a downside, too. Metal-rubber textiles and Eeontex are currently available in quantities that many large OEMs would consider developmental. What's more, Eeontex has issues with long-term stability owing to the hydrolysis of polypyrrole when you expose it to heat and humidity. The company recently developed a third-generation product that improves stability by a factor of 20, according to Avloni. And laminate can protect the fabrics. But environmental conditions still represent the chief failure mode for ICPs, and design engineers need to account for them, he acknowledges. "Metal wires have their problems, too," he adds. "If you bend them enough, they'll break."

In many sensing applications, smart fabrics don't likely represent a low-cost alternative to an array of pressure transducers. Yet, even if they aren't the cheapest way to sense pressure, fabric sensors can potentially offer value by bringing more freedom to the design of sensing systems. Fabrics can cover large areas, including civil structures, such as bridges, roads, and buildings. They can conform to a wide variety of surfaces, including a human body in motion. And they may be

## FOR MORE INFORMATION

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[www.eeonyx.com](http://www.eeonyx.com)

Elksen Ltd  
[www.elektex.com](http://www.elektex.com)

International Fashion  
Machines  
[www.ifmachines.com](http://www.ifmachines.com)

NanoSonic Inc  
[www.nanosonic.com](http://www.nanosonic.com)

Textronics Inc  
[www.textronicsinc.com](http://www.textronicsinc.com)

able to measure large strains. Textronics' Burr notes that elastomeric smart fabrics tolerate repeated elongations.

These fabric attributes may result in the development of other types of unique sensors. Textronics, for example, is working on electro-optical movement sensors for medical-monitoring applications. As Burr explains, these sensors integrate a light source and a photodetector into the fabric. As the fabric stretches and returns to its initial shape, different amounts of light pass through the fabric's woven or knit structure. One application for such an optical sensor would be a garment that monitors a patient's breathing or heart. Textronics also recently introduced a bio-monitoring product for the consumer market (**Figure 4**).

She also sees the potential for both optical- and strain-based measurements of movement and vibration. And NanoSonic's Claus reveals that the company has come up with a proprietary chemical sensor based on smart fabrics. He's not ready to disclose much about it, other than to say that it works based on electrochemical reactions of a nanocluster on the fabric surface. EDN

## REFERENCES

1. ElekTex Reference Design Licensing, <http://rbi.ims.ca/4922-562>.
2. "Electrostatic Self-Assembly," NanoSonic, [www.nanosonic.com/esa/esa.html](http://www.nanosonic.com/esa/esa.html).

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**Figure 4** Textronics added a heart-monitor electrode to the lower band of a sports bra.