Flexible, thin, elastic, washable, scalable and cost-efficient, printed electronics are coming forward as the technique of choice for the integration of smart components into clothing.

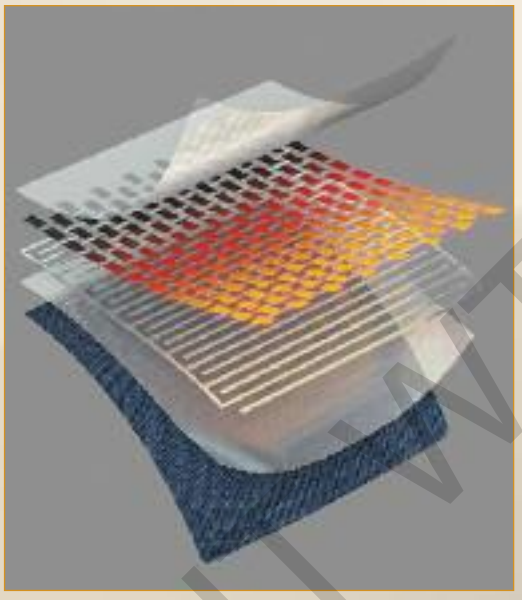
Wearables in print

In just a few years, the shift from conductive cables to printed ones has enabled smart wearable clothing to become, well, wearable. "Three or more years ago, when the first smart clothing concepts became commercially available, we were seeing heavily engineered clothing. Many of the fabrics and components were not soft to the touch, and the amount of engineering made them uncomfortable to wear," says Michael Burrows, venture leader for smart clothing at DuPont Advanced Materials. This division is the latest in a long history of divisions of DuPont to devote itself to innovative textiles (as Mr Burrows points out, Textronics was a DuPont company before being spun off and later acquired by adidas in 2008).

This latest arm of the company develops stretchable electronics inks and films for smart clothing applications under the Intexar brand. The platform has been designed for the easy integration of these components into the garment manufacturing supply chain, as the ink is delivered ready for screen-printing on a roll of film. "It is both scalable and cost-effective, which is what makes it so attractive," says Mr Burrows, mentioning Beijing-based brand Body Plus and Canadian smart clothing maker OMsignal as having used the platform.

In mid-2017, the company introduced a new material with higher recovery, for applications in close-fitting fitness wear. When the overlay film is pulled, it will spring back, says Mr Burrows, making it more comfortable to wear and even offering the wearer some support. The company believes a garment made for everyday use, running or cycling, requires around 10% to 20% elasticity. "The magic is in the ink," he says, the reult of a resin matrix in which the conductive particles can move.

At Holst Centre, a Dutch innovation hub located in Eindhoven that specialises in printed electronics, these products are some of the many different smart solutions it works with. The centre seeks specifically to develop processes that are scalable. Among these, printing and bonding electrical and electronic components on a film substrate has many advantages. "It offers a flat, non-porous carrier that stretches and requires a minimum of conductive material," Margreet de Kok, senior scientist at the Holst Centre, tells *WSA*. She believes that this is the most cost-effective solution for the integration of conductive circuits and sensors as the carrier film can easily be heat-pressed to a garment, without requiring new machinery or competences in today's cut-and-sew manufacturing processes. "It's as simple as applying a logo," she says.



Intexar printed electronics developed by DuPont Advanced Materials encapsulate conductive elements inside two films and can be cut to shape and bonded to a garment. Various sensors can be integrated into the system.

DuPont Intexar

The conductive inks themselves can either be screen-printed or ink-jet-printed onto a film. "Printing is a flexible technology that allows changes in design and can cover a large surface area," says Ms de Kok. Several collaborative research projects are under way at the Holst Centre, and subject to non-disclosure agreements, but she lets it be known that many major sports brands are working with this technology.

Comparing options

Printing is a relatively new technology compared to other methods of integrating conductive components into textiles. Embroidery, a fabric adornment technique that has been using metallic wiring and yarns for centuries, has the ability to apply conductive circuitry in intricate patterns and shapes. Swiss embroidery specialist Forster Rohner uses this technology to make smart textiles. It may however require more complex processing and expertise than printing.

It is also possible to weave or knit a conductive yarn into a fabric, a technique used in a smart commuter jacket launched this year by Levi's and Google. All of the above can be useful for

certain applications and are not at all incompatible with printing. Ms de Kok mentions weaving a conductive yarn into a fabric as an appropriate solution to make bed sheets for sleep monitoring purposes.

The founder and technical lead of NY-based Loomia smart textile consultancy, Madison Maxey, has worked with all of these smart textile solutions. "Knitting with a Shima or a Stoll machine can be used to pattern circuitry, but the traces cannot be easily separated in the machine, requiring post-processing," she says. Printing conductive elements allows more freedom and is easier to adjust. "We see patterning conductivity as a critical part of making an e-textile and digital printing allows patterning on a small scale or a large scale. Being able to lay out a circuit on your computer and quickly print it in a repeatable way makes it easy to iterate on a circuit design and go from prototype to scalable design," she says.

Flexible designs

Printed electronics have many advantages for Dutch fashion tech designer Marina Toeters, including design flexibility, scalability and cost-effectiveness. A printed overlay film is "so flat, you can barely feel it. It is also washable and can be seamlessly integrated into current industrial processes. There is no soldering as was required for first generation smart clothing." She appreciates the technique for the design freedom it allows, including the possibility of showing the technology itself. "The electronics have a cool metallic look," the designer says.

For the most recent project at her design

The electronics and pressure sensors are printed on the Arion smart insoles developed by Dutch company Ato-gear. They measure a user's running technique.

Ato-gear

The Closed Loop Smart Athleisure Fashion concept developed by Dutch fashion tech designer Marina Toeters monitors a wearers' key vital signals using printed and laminated sensors.

by-wire.net

studio, by-wire.net, Ms Toeters created an angel wing design to capture ECG signals on a top she is calling Closed Loop Smart Athleisure Fashion (CLSAF). As its name implies, it combines electronics and sustainability. It won an innovation award at Munich Fabric Start earlier this year. The fabric is made in Econyl recycled nylon, manufactured by Italian knitter Aquafil. The concept was developed thanks to technical support from the Holst Centre. "Marina Toeters has designed the printed pathways and ECG and EMG sensors in such a way as to add aesthetic value to the electronics without compromising the signal quality," says Ms de Kok, who participated in the project.

The matter of aesthetics comes up more often than we anticipated, says Mr Burrows. "Some want the technology to be invisible, others want to show it. Design options are varied, and this is one of the strengths of our technology," he says.

Printed electronic components are present in Wearable X's Nadi X smart yoga pants, which send haptic signals to the wearer to adjust the body's alignment or position. It is one of last year's more notable smart garments to come to market. "With our partners, we tested many variations, including printing directly on the textile and adding a second film for durability," says Wearable X chief executive, Billie Whitehouse. Launched in 2017, with the first pants being delivered in November, they are currently being sold at Selfridges in London.

Smart sustainability

The need for a clean end of life for all clothes, whether smart or not, is top-of-mind for many of today's fashion tech designers. Ms Whitehouse weighed the environmental impact of each stage of the development process of the Nadi X pants, deciding not to add a second protective film layer. Wearable X will also be setting up a take-back system for its products.

Ms Toeters has made sustainability a central element of the CLSAF project, developing a special delamination process to separate the electronic components from the garment when it comes time to dispose of it. "These contain various metals, including silver, that need to be removed so as not to end up in landfill," the designer says. The smart top can actually be delaminated and relaminated five times, she says. With regards to sustainability, and compared with other conductive textile processes, Ms Toeters believes printing is a better option: "Once a conductive yarn is woven or knitted in the fabric, how do you get it out?" she asks. With her project now finalised, she is currently in discussions with other parties to see how she can hand the project over to a company that can bring it to market.

Direct printing

Printing conductive inks directly onto a textile surface is not seen as a durable solution, especially for garments that will be washed often. The three-dimensional surface of textiles is a challenge when it comes to obtaining electrical continuity, and the "result will be quite fragile," says Ms de Kok.

But here, too, change may be under way. This March, Creative Materials, a supplier of conductive inks and coatings based in Ayer,

Loomia's Electronic Layer is a flexible smart e-textile solution developed by the Brooklyn-based start-up founded by Madison Maxey. It is designed to be embedded into clothing and to offer heating (shown here), lighting, sensing or data-tracking applications.

Loomia

Massachusetts, introduced a new offering allowing the application of printed electronic circuits on what the company calls "washable textiles". These are said to be able to withstand 50 machine-wash and heated dryer cycles. The company also claims that they enable direct printing onto synthetic fabrics, including polyester, spandex and nylon, with "no need for dielectric encapsulation to ensure wash durability".

A research team working for the University of Southampton in the UK is also working on a process to print conductive materials and connectors directly on tapes. These can be used to power sensors, LEDs and electroluminescent panels. As printing is a relatively low-cost solution, the electronics and electrical engineering group believes it could be useful for medical monitoring. "These products do not always need to last long, printed electronics could thus help people and save money," a research associate told *WSA*.

"We have found that direct deposition methods to textiles are very cool for prototypes, but aren't rugged enough to scale," says Ms Maxey. "Insulation is an important part of any e-textile, not just for performance, but because we do not want ink touching the skin." She adds that conductive pathways will not work without some form of insulation and that the polymer layer provides protection during washing and wearing.

Yet another technology that involves a form of printing, or deposition, solar cells may also soon be making appearances in clothing, the result of work done by Pvilion, a Brooklyn-based company that develops lightweight photovoltaic materials. The company worked with Tommy Hilfiger to develop Solar-powered jackets in 2014 and a device-charging tote bag more recently. The company's solar panels are said to be lightweight and flexible because a special lamination process and metallic substrate that allows pliability. "Our technology is applicable to wearables now," states Pvilion chief executive, Colin Touhey. The next step, he says, is to print the photovoltaic cells directly onto a textile and thus eliminate the metallic element, a prospect he sees as coming in just three to five years. Pvilion's technology has attracted the attention of outdoor brands, for applications where solar charging makes good sense. Lead times being long, the earliest a commercial product may come to market is 2019.

Though cost-effective, as the suppliers in this market like to emphasise, printed electronics may still represent an expense not readily acceptable in a price-sensitive sportswear industry. There is also, as Ms de Kok points out, the issue of consumers' expectations: "These can be quite different for an item of clothing or electronics. A consumer will accept a certain amount of variation in a piece of clothing that will fade or change with time. With electronics, the situation is not at all the same-either the device works, or it doesn't. The last case is unacceptable to a consumer." Simplifying the manufacturing process, as printing does, is a step forward, but many other challenges remain in the world of smart clothing.

Launched in 2017, WearableX's Nadi X smart yoga pants come with an app that is slated to be upgraded to offer push notifications and the possibility of creating one's own flow or sequence of poses. The electronic components and haptic signals it sends to a user are powered by printed components.

Masha Maltsava for Wearable X