with the primers used by dentists to bond restorative materials to our teeth, as these also provide for the formation of strong chemical bonds between the restorative and the native tooth structure[10]. Wang and colleagues functionalized chondroitin sulphate, which is one of the components of native cartilage, with two distinct organic moieties: methacrylate and aldehyde groups. The aldehydes form a covalent bond with the native cartilage tissue (presumably reacting with the amine groups of the collagen). At the same time this adhesive can bind to the biomaterial, as the methacrylate groups participate in the polymerization reaction used to solidify the biomaterial once it is introduced in the tissue defect. Together, these modifications yield a unique architecture illustrated in Fig. 1. Notably, this tissue primer provides a strong mechanical bond to the native cartilage, and does not damage the cells delivered through the biomaterial or the native cartilage. Ultimately, this approach led to significantly greater tissue repair of cartilage defects in two different *in vivo* experiments using rabbits and goats.

Future studies will clearly be required to determine if these specific chemistries and procedures can lead to long-term functional cartilage repair in animals, and ultimately humans, but this general concept seems to be full of promise. It may be further extended by the incorporation of specific cytokines or growth factors that direct the metabolic activity of cartilage cells, potentially enhancing cross-talk between the host and new tissue. The work of Wang *et al.* will most likely be applicable, not only to orthopaedic tissue repair, but also more broadly to any situation in which separate tissues (native or engineered) need to be adhered. It is an excellent example of the high level of sophistication that can be achieved in tissue engineering, and introduces the perspective that native tissue is to be considered as a partner in determining the fate of new tissues.

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ELECTRONIC TEXTILES

A logical step

The integration of electronics and clothing promises a variety of new technologies, but constructing electronic circuits on fabrics is complex. Coating fibres to create electrodes and forming transistors at their crossing points offers an elegant solution.

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The concept of multifunctional — electronic or 'smart' — fabrics was suggested several years ago[1], but only recently has their true potential to make life safer, healthier and more comfortable been recognised. Multifunctional fabrics are conceived as innovative and high-knowledge-content apparel, integrating sensing, actuation, processing and power functions into a single garment[2]. Perhaps the most compelling application is that of providing quality health care in modern society, delivered by means of easy-to-use wearable interfaces, to enable prevention, diagnosis, therapy and even rehabilitation[3].

Although considerable progress towards these goals has been made in some areas, the realization of viable textile fibres endowed with active electronic functions has proved to be more elusive. On page 357 of this issue, Olle Inganäs and colleagues take a step in this direction[4]. By coating fibres with conducting polymer, they can join them with solid electrolyte at cross-points to form micrometre-sized organic electrochemical transistors (OECTs). They then use the OECTs as components for logic circuits, offering an alternative approach to organic field effect transistors (OFETs) commonly used in flexible electronics[5]. The wire OECTs provide an easier route to weaving electronics directly into fabrics.

Common OFETs operate like electrical valves, with the flow of current between the source and drain electrodes controlled by the voltage of the gate electrode. Increasing the gate voltage injects charges into the conducting polymer next to the gate electrode, creating a conduction channel, through which the source-to-drain current flows (Fig. 1a). The magnitude of the voltage applied by the gate controls the size of this conduction channel. OFETs can be flexible, but printing them onto fibres[6,7] is a complex process — their successful operation depends on the accurate control of the electric field applied to the polymer by the gate electrode, which in turn requires a very thin and uniform insulating layer to be deposited between the gate and active polymer. Precise micropatterning of source drain and gate electrodes on a fibre is therefore needed. These requirements make the implementation of OFET-based knitted or woven structures very impractical.

In the OECTs used by Inganäs and colleagues, the conducting channel is made by ions being injected from or removed to a solid electrolyte reservoir (Fig. 1b), which is in turn controlled by the gate electrode. This means very large conductivity changes can be easily induced, and these conductivity changes control the source-to-drain current in the same way as the injected charges from the gate electrode in the OFET. Because of the differences in the way the devices work, the need for accurate dimensions and precise positioning of the transistor subparts is greatly relaxed in OECTs compared with OFETs. OECTs also benefit from needing very low operating voltages — of the order of a couple of volts.

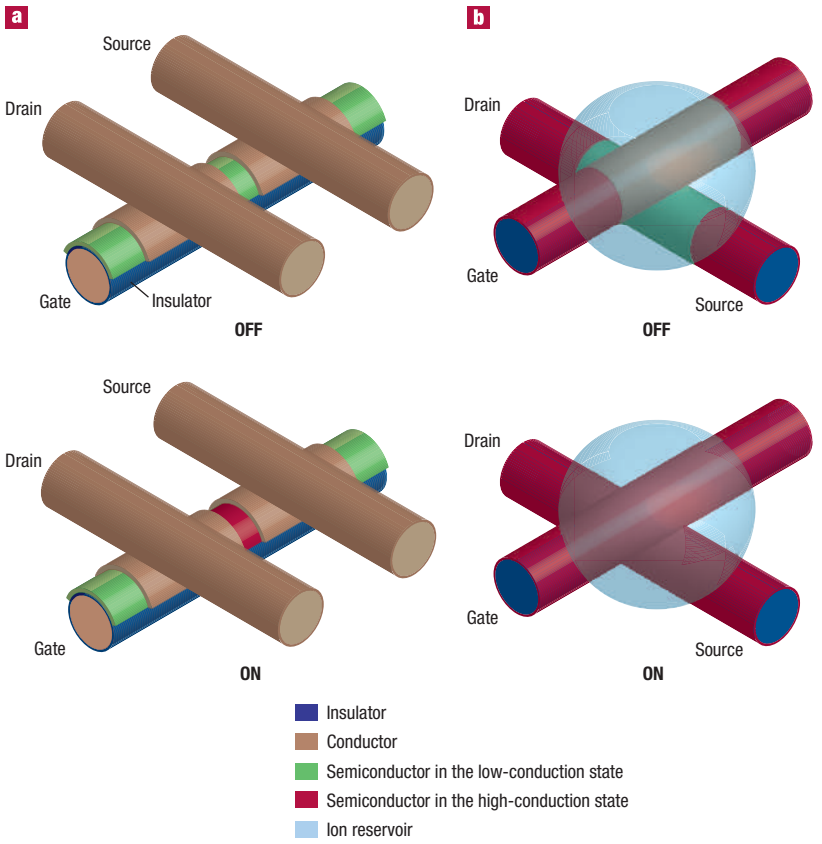

Figure 1 Working principles of OFET and electrochemical WECT transistors. **a**, OFET on fibres; switching from the OFF to the ON state operates through charge accumulation in the polymer channel under the action of the electric field from the gate electrode, which increases the polymer conductivity in the conduction channel. **b**, WECT switching from the ON to the OFF state occurs when ions are depleted from the polymer semiconductor channel by electrodiffusion through the solid electrolyte under the action of the gate voltage. The WECT structure is symmetrical; the source–drain fibre and gate fibre can be interchanged, which adds flexibility to circuit design.

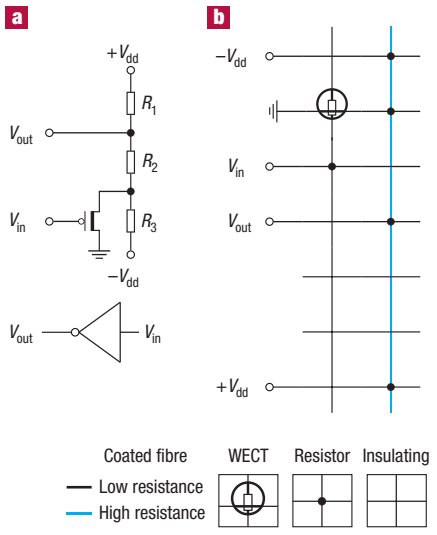

Figure 2 Logic circuits constructed from WECTs. **a**, Classical circuit diagram of an inverter, consisting of a transistor and three resistors. **b**, Illustration of how this circuit can be realized using WECT technology.

OECTs have previously been reported in a planar configuration, but Inganäs and colleagues instead coat wires with conducting polymer to create cylindrical electrodes. At junctions where the wires cross each other, a drop of solid electrolyte is used both as a physical joining method and as the ion reservoir to create a transistor (Fig. 1b). The authors dub these 'wire electrochemical transistors', or WECTs. If a polymer with lower conductivity is used to join the wires instead, a resistor is made. The authors then go on to show that logic circuits can be made using arrays of wires crossed and connected in these ways (Fig. 2).

Despite all the positive features outlined there is a major intrinsic constraint on performance of OECTs that is highly relevant to their implementation on fibres. The rate-limiting process of OECT operation is electrodiffusion of ions within the solid electrolyte; ionic charge carriers have very low mobility, which does not allow speeds of operation comparable to either inorganic or conventional organic transistors. The long response time and the consequent low switching frequency of WECT-based logic circuits will certainly limit the dynamic characteristics of any application. Dimensional scaling to speed up operation is an option because the time characteristics of electrodiffusion processes scale with the inverse square of characteristic lengths. However, other rate phenomena might be dominant, limiting operations to very low frequencies and hence confining WECT technology to quasi-static applications. This aspect will need to be carefully investigated to assess the full potential of WECT woven logic in the field of e-textiles and wearable technology. Body signals with slow dynamics, such as sweat rate and composition changes, body surface temperature mapping and surface-strain field mapping for posture recognition and respiration monitoring, are therefore likely to be ideal targets in the area of wearable monitoring systems for health, sport and ergonomics using this technology.

Chemo-, piezo- and thermo-resistive fibres are now available in textile-compatible form[8], and their integration into fabrics and garments is actively pursued[9,10] — something that could be enabled by this work. Using simple and elegant solutions, the Inganäs team has interwoven WECTs with passive electronic components on fibres for local signal acquisition and early conditioning in e-textiles, paving the way for a revolution in existing wearable technology.

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