Research summary

Making large-scale, functional, electronic textiles

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Large-area display textiles can be produced by weaving transparent conductive weft and luminescent warp fibres using an industrial rapier loom. The integration of interactive functionalities, such as a keyboard and power supply, with the display textile forms an electronic textile system that can serve as a communication tool.

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The problem

Displays are a core component of many modern electronic devices, and they help people to interact with machines. Integrating displays into textiles to render the materials smart, interactive and responsive could transform how we interact with electronic devices[1,2]. Light-emitting textiles have been developed by attaching thin-film light-emitting devices to a textile[3], as well as by inserting light-emitting fibres into it[4]. However, thin-film devices easily degrade or fail, because the films are relatively rigid and do not conform with the rough and deformable surfaces of textiles. And although light-emitting fibres can be woven into textiles with high flexibility and breathability, they generally show pre-designed patterns. This makes it difficult for the light-emitting textiles to meet the requirements of display applications such as computers and mobile phones, and limits their use. The challenge of obtaining small illuminating units that are both durable and easy to assemble over a large area meant that display textiles consisting of an array of pixels had not been achieved.

The solution

We developed a large-area display textile by weaving transparent conductive weft and luminescent warp fibres with cotton yarn in an industrial rapier loom (warp and weft are the basic components used in weaving and refer to the orientation of woven fabric; Fig. 1). The electroluminescent units are constructed directly at each weft–warp contact point during weaving, and can be independently controlled by sending electrical signals through the fibres. To produce the display textile, we chose electric-field-driven devices based on zinc sulfide (ZnS) phosphor, which is activated by alternating electric fields across a polymer matrix when it is dispersed in an insulating polymer[5]. Such devices require spatial contacts only between wefts and warps to illuminate[6], making them intrinsically durable and suitable for large-area production. Our weft fibres were prepared by melt-spinning ionic-liquid-doped polyurethane gel. The warps were prepared by dip-coating silver-plated conductive yarn in a slurry of commercially available ZnS phosphor and passing it through a scraping micro-pinhole before drying. This solution-based method of coating is a simple way to obtain continuous lengths of uniformly coated luminescent warp fibres.

Our weaving strategy allowed us to produce a 6-metre-long, 25-centimetre-wide display textile consisting of approximately 5×10^5 electroluminescent units, each of which is micrometres in size. The narrowest spacing achieved between the electroluminescent units is ~800 μm, which provides the resolution required for display applications. The brightness between electroluminescent units deviates by less than 8%, and remains stable even when the textile is bent, stretched or pressed. The display textile is flexible and breathable, and withstands repeated machine-washing in detergent-containing water at 60 °C, making it practical for use. Other interactive functionalities, such as a keyboard and power supply, can also be built into the textile, forming an integrated system that can function as a communication tool and has potential in the 'internet of things'.

Future directions

Our approach unifies the fabrication and function of electronic devices with the practicality of textiles, and we hope that woven-fibre materials will shape the next generation of electronic devices by changing how we interact with them. For example, our display textile could function as a real-time communication tool, and might be able to help individuals with voice, speech or language difficulties to express themselves. However, several limitations need to be overcome first. For example, because ZnS phosphor can be only green, blue or orange, a high-efficiency red luminescent material will be needed to achieve a full-colour display. Moreover, the resolution of the display textile could be improved by making smaller electroluminescent units. Standardized coating equipment and finer ZnS phosphor are both required to obtain luminescent warp fibres with smaller diameters.

Finally, because the control signals require all fibre ends to be individually connected to addressing circuits, new weaving technology is needed to accurately arrange the conductive lines and produce a high-resolution display textile. The connecting points between the fibre ends and conductive lines will also need to be both firm and flexible to replace rigid soldering.

EXPERT OPINION

"There are several elements of this work that stand out: the deceptive simplicity of the underlying emissive principle, the apparent ease by which it has been woven using an industrial loom into centimetre-scale functional textiles, and the versatility and durability of the resulting optoelectronic platform. It is not hard to imagine such textiles finding a range of practical and aesthetic uses."
Karl Ziemelis, Chief Physical Sciences Editor, *Nature*.

FIGURE

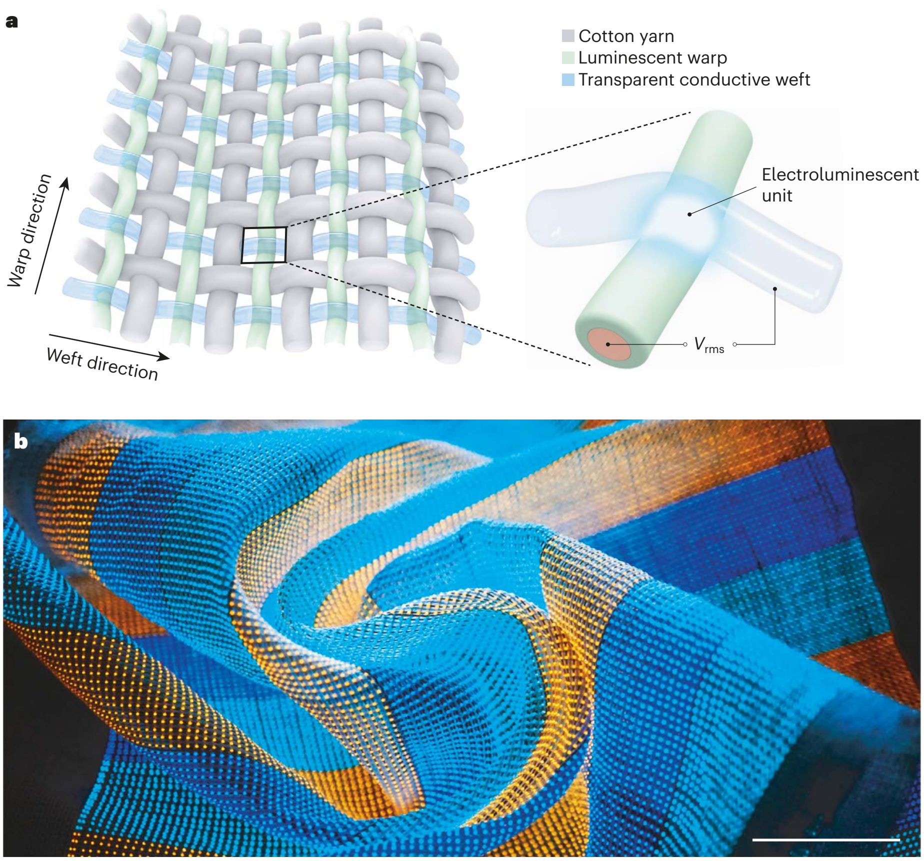

Figure 1 | Structure and appearance of the large-area display textile. a, A schematic showing the weave diagram of the display textile. Each contacting luminescent warp and transparent conductive weft forms an electroluminescent unit (right). An applied alternating voltage (V_{rms}) turns on the electroluminescent units. **b**, A photograph of a functional, multicolour display textile under complex deformations, including bending and twisting. Blue and orange colours are achieved by doping ZnS with copper and manganese, respectively. Scale bar = 2 cm. Figure adapted from Figure 1a and Figure 1h of full paper.

BEHIND THE PAPER

The selection and optimization of the transparent conductive weft required to make a large-area display textile has troubled us for a long time. The most commonly used materials are indium tin oxide (ITO) and silver nanowires. However, ITO is prepared by magnetron sputtering, so it is difficult to deposit continuously on the fibre surface, and the thin silver nanowire coating on fibres is vulnerable to friction during weaving. Our ionic liquid-doped polyurethane gel, which served as a highly uniform and transparent weft fibre, could deform to fit the surface of the luminescent warp and formed a stable surface contact during weaving. The elastic surface contact meant that the electric field at the curved surface was as uniform as that achieved by planar devices, facilitating the formation of a homogeneous and stable display textile, and confirming that our search for a suitable transparent conductive weft was over.

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