Device physics

A smart sensor that can be woven into everyday life

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A hybrid design combines sensitivity and flexibility to create an acoustic single-fibre sensor that can be knitted into fabric. The future of tracking our health and fitness looks wearable — or even implantable

Imagine a future in which your clothes are embedded with sensors and electronics that are designed to improve your lifestyle and health care[1]. This idea might become a reality with fabrics woven from piezoelectric fibres, which generate electricity in response to mechanical stress. Several studies have already demonstrated the potential of using piezoelectric materials to develop wearable devices[2], but so far performance has been limited by the materials' properties. Writing in Nature, Yan et al.[3] report an innovative approach to fabricating hybrid piezoelectric fibres that can act as flexible, robust acoustic sensors — pushing audible sensing to a new high. The family of piezoelectric materials includes inorganic compounds, organic compounds and polymers that generate electrical signals on mechanical vibration, and these materials have long been used to measure stress or pressure. Most piezoelectric inorganic materials show high piezoelectricity, but they are typically rigid, brittle and difficult to fabricate into fibres. By contrast, flexible polymers are readily processed into fibres, with shapes and sizes that can be tuned, but often have much lower piezoelectric properties — as much as 200 times lower — than those of inorganic compounds (with piezoelectric coefficients exceeding 2,100 picocoulombs per newton)[4–6].

Scientists and engineers have attempted to develop piezoelectric composite materials that combine inorganic particles and polymers to exploit their advantages and overcome their limitations. Despite some success, the piezoelectric performance of these hybrid materials is still far below expectations [7,8]. A 'rule of mixtures' is often used to predict the properties of an ideal composite material, but it seems that this rule has been broken in the design and development of functional piezoelectric hybrids, for which either piezoelectricity or flexibility and fibre processability are compromised. The problem is that even the uniform distribution of the inorganic particles, and the fact that they bind strongly to the polymer matrix [OK?], cannot improve the material's piezoelectric properties substantially enough for practical applications, while retaining its flexibility6. The high piezoelectric performance of the nanoparticles is thought to be largely shielded by the insulating polymer matrix4. Most flexible piezoelectric acoustic sensors that are made from either polymers or a composite can convert sound signals into electrical output, but their performance is limited for real wearable electronics. One easy and effective strategy for making polymer fibres that have optimal piezoelectric properties is called thermal drawing. In this process, the material is heated until soft, and then pulled at a constant speed until it elongates into a fibre with a uniform diameter. This method was developed by researchers in the same team as Yan and colleagues[9]. The next step is known as stepwise poling, in which an external electric field is applied to the fibre in multiple cycles to generate stable, electrically polarized domains (electric dipoles) at the surface of the material and inside it. The combination of drawing and poling can have the synergetic effect of orienting macromolecular chains and their crystalline structures along the axis of the fibre as it forms, as well as inducing the electric dipoles. This results in increased flow of electrical charge in response to mechanical stimulation. With that in mind, instead of drawing a single piezoelectric polymer, Yan and colleagues stretched an entire multilayered device by combining thermal drawing and stepwise poling. The resulting single-fibre sensor consists of piezoelectric barium titanate nanoparticles dispersed in a layer of well-aligned piezoelectric polymers that is sandwiched between electrodes encased in rubber.

The device was shown to be highly sensitive to stimulation with audible sound. Its piezoelectric coefficient, which is the degree of s the electric charge generated per unit area in response to stress, is twice that of the polymer material itself. Yan et al. attributed the high piezoelectric coefficient to tiny voids that form along the aligned polymer chains, surrounding the well-dispersed barium titanate nanoparticles (Fig. 1). Electric dipoles are induced at the interfaces between the polymer matrix, the particles and these elongated voids. The authors inferred that this increased number of dipoles enhanced the spontaneous electrical charges generated by sound vibrations. Yan et al. demonstrated that their flexible single-fibre sensor can be woven into fabrics that can receive and emit sounds, recognize the direction from which a sound originates, and even monitor a heartbeat. The fabrics are machine washable, robust and reproducible, which suggests that these piezoelectric fibres might have applications in wearable consumer electronics, acoustic communications and acoustic energy harvesters — as well as in devices designed for the security, automobile, aerospace, robotics and biomedical industries. Specific applications might include wireless fibre microphones, fitness-tracking vests, hearing aids, and implants that can sense and monitor bodily functions in real time. Such innovations will increase the ways in which the human body interfaces with devices, opening new channels for emerging technologies in artificial intelligence.

Despite the promising applications of Yan and colleagues’ acoustic fibres, a number of challenges remain before such sensors can be used in marketable products. The conditions outside the authors’ well-controlled laboratory environment will certainly affect the sensor’s performance. Key factors influencing the response to external conditions include the method by which the fibre sensor is woven or knitted into fabrics, and the type, texture and stiffness of other materials used. And because the environment and the movement of the fabric cannot be controlled in the real world, a substantial increase in noise is unavoidable, which might limit the device’s sensing capacity and hamper the processing of incoming data.

A wearable device performs like a miniaturized computer, and so must be integrated with other electronics, including a data processor, storage core, communication interface and power source. These additions are not trivial — they require components that are small and flexible enough to keep the integrated device compact and lightweight. A self-powered piezoelectric- fibre sensor that can interact with high-speed wireless communication, other smart devices and cloud computing facilities could potentially overcome these challenges. Yan and colleagues’ device takes us a step closer to a future in which wearable electronics are integrated into our everyday lives.

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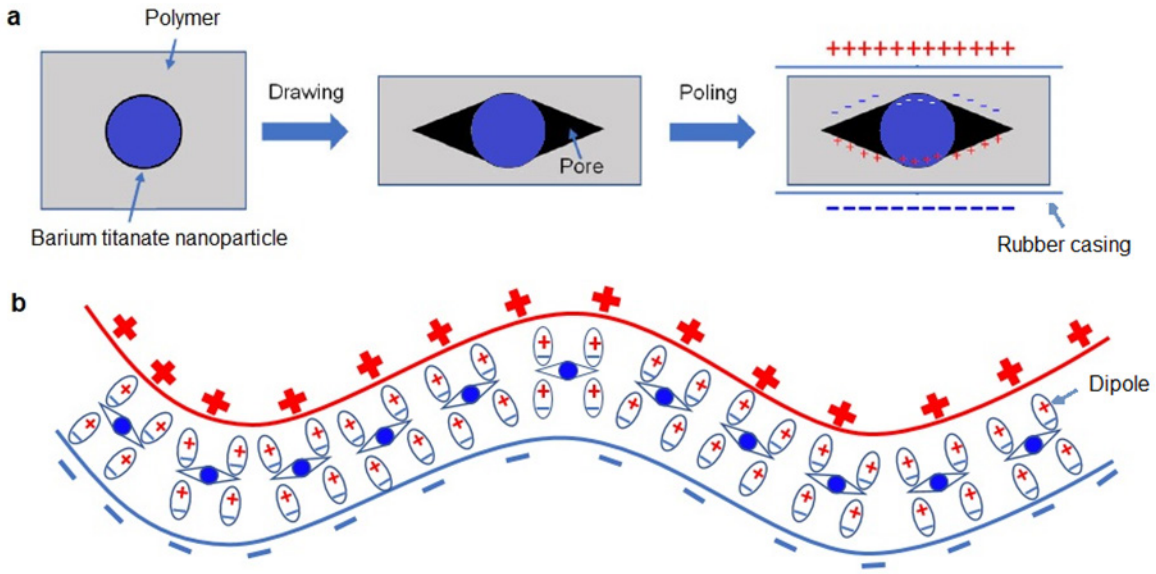

Figure 1 | A single-fibre sensor with high sensitivity and flexibility. Piezoelectric materials generate electrical signals in response to mechanical vibration, and can be used to build sensors. Yan et al.3 fabricated a flexible-fibre sensor with high piezoelectricity, comprising barium titanate nanoparticles embedded in a well-aligned polymer matrix, which is sandwiched between two electrodes. a, The authors attributed the high piezoelectricity to pores that form next to the nanoparticles in a process known as thermal drawing, which elongates the material (forces shown as black arrows). These pores induce electrically polarized domains (dipoles) in a subsequent process called poling. The increased numbers of dipoles improve the output of the electrical charges that are formed through sound vibrations. b, Because the sensor is made of polymers, Yan et al. were able to shape it into a fibre that could be woven into fabric. The fibre is expected to have applications in wearable devices for health monitoring, entertainment and communications. (Adapted from Supplementary Fig. 9 of ref. 3.)