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# Scalable production of stretchable conductive fibers for textile electronics

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**Stretchable conductive fibers are key building blocks for constructing textile electronics. In this Preview, we highlight the scalable production of stretchable conductive fibers based on multimaterial thermal drawing and chemical deposition. The resulting fibers exhibit initial electrical conductivities up to 4,415 S/cm while retaining more than 500% stretchability. They can be further made into multifilaments, driving the development of textile electronics toward real-world applications.**

Wearable electronics are of increasing importance in health management, virtual reality, and information interaction, which have undergone rapid development in the past decades.[1] Textile-based wearable electronics are one of the most promising innovations because they are well-suited to current textile technologies and offer more human-friendly characteristics, such as flexibility, breathability, and conformability, as well as the convenience of multifunctional integration.[2] Stretchable fiber devices are the cornerstones for building these textile electronics. While many of these devices, such as stretchable fiber solar cells, fiber lithium-ion batteries, and fiber supercapacitors, have been widely developed in labs,[3–5] these stretchable devices measure centimeters in length and have yet to be mass-produced. One of the main challenges lies in the continuous fabrication of stretchable fiber electrodes with high electrical conductivities.

The current continuous fabrication strategies of stretchable conductive fibers can be classified into two main types. The first involves blending elastomers and conductive components and extruding them together in a single step. But there are trade-offs between electrical conductivity and stretchability, i.e., high conductivity requires more conductive fillers to obtain more conductive pathways according to percolation theory, which can compromise the stretchability and processibility of the elastomer. For example, increasing silver (Ag) content in polyurethane can yield conductivities exceeding 10,000 S/cm, comparable to metal wires, but at the cost of reduced stretchability (only 50%).[6] The second strategy involves extruding elastomer fibers and subsequently coating them with conductive components for high conductivity without sacrificing stretchability. However, the interface between coating and elastomer fiber is often unstable, leading to significant degradation of conductivity during complex deformations.[7] Chemical deposition of conductive components onto elastomer fibers can combine the advantages of both strategies and reconcile the contradictions between stretchability and conductivity.[8] Therefore, the continuous fabrication of stretchable conductive fibers based on chemical deposition represents a promising direction.

In a recent issue of *Cell Reports Physical Science*, a research team led by Professor Zijian Zheng reported continuous production of highly stretchable and conductive fibers based on multimaterial thermal drawing and chemical deposition processes (Figure 1A).[9] They adapted a thermal drawing technique originally used for traditional optical fibers to produce kilometer-scale stretchable fibers in one single drawing. Specifically, a multimaterial preform of poly(styrene-block-butadiene-block-styrene) (SBS) core and poly(methyl methacrylate) (PMMA) sheath was heated above softening temperature and then drawn into fibers. The PMMA sheath was used to aid in molding and prevent thermal decomposition of SBS and could be subsequently removed by glacial acetic acid to obtain stretchable SBS fibers. It is worth noting that thermal drawing is an optimal choice for fibers with customized cross-sectional shapes and high purity compared with wet spinning process for elastomers.

Then, the SBS fibers achieved electrical conductivity by chemical deposition of Ag nanoparticles. The above process was carried out in a continuous roll-to-roll fashion, thus allowing for scalable production of conductive fibers (Ag-SBS). The repeatable chemical depositions enabled Ag nanoparticles to effectively interact with SBS matrix to enhance electrical conductivity to 4,415 S/cm after seven cycles of deposition while maintaining more than 500% strain. The combined high conductivity and stretchability is sufficient for most wearable applications (Figure 1B). Furthermore, it is necessary to carefully evaluate the textile compliance, as moduli of these fibers would be increased by high loading of Ag. Notably, the conductivities of stretchable fibers are not only affected by the penetration depth of Ag ions, but also by the density of the deposited Ag domain. In fact, it may be better to balance modulus, stretchability, and conductivity when Ag

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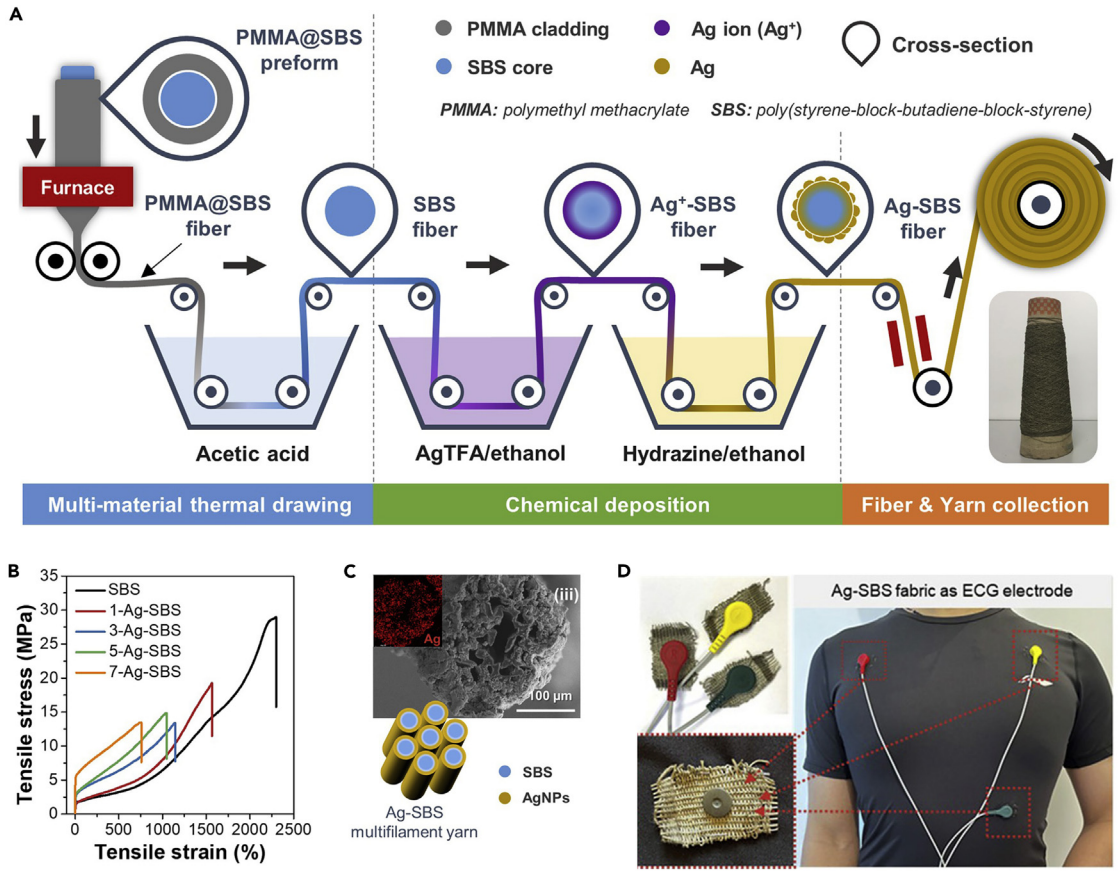


**Figure 1. Continuous fabrication and application of stretchable and conductive fibers**

(A) Schematic showing the continuous fabrication of Ag-SBS fiber.

(B) Tensile stress-strain curves of Ag-SBS fibers.

(C) Ag-SBS multifilament yarns.

(D) Photographs showing a typical application of Ag-SBS fabric as an ECG electrode.

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is only concentrated on the exterior part of the fiber.[8] Therefore, regulating the solvents in Ag precursor solution to control permeability of Ag ions may be effective to further optimize performance of Ag-SBS fibers.

The versatile preparation strategy of Ag-SBS allowed for continuous production of multifilament yarns with tunable filament numbers and twisting levels, which improved tensile strengths and strains (Figure 1C). Surprisingly, multifilament yarns exhibited better electrical conductivity than monofilaments owing to larger loading areas on the fiber surface and inside the yarn. Besides, the more twisting numbers of bundles there were, the more multifilaments that interacted with each other there would be, which inhibited crack propagation in the conductive pathway and contributed to less resistance variations during stretching. With this twisting strategy for stretchable fibers at scale, the resulting yarns could be loaded with more active materials and are promising for use in various fields such as energy storage, sensing, and luminescence.

The as-made Ag-SBS fibers and yarns with superior mechanical and electrical performances could therefore be adapted to modern textile technologies such as weaving, knitting, and braiding. Thus, they could be more flexible for integration into textiles by combining aesthetic considerations and target functionalities. The textiles also showed comparable air permeability (<0.8 kPa $s{\cdot}m^{-1}$) and moisture permeability (>540 g $m^{-2}$ $day^{-1}$) to commercialized fabrics.

Specifically, the Ag-SBS yarns were attached to the finger positions of a glove, and the resistance change could realize the highly sensitive detection of human finger movements. The rapid response to voltage further made Ag-SBS fabric useful as an electrothermal heater for joint therapy. It was shown that the change in output temperature at 30% stretching was less than 10%. Besides, Ag-SBS fabric-based ECG electrodes showed both high reliability in signal collection and washing endurance (Figure 1D).

Although the stretchable conductive fibers produced through this simple, scalable, and versatile fabrication strategy have well demonstrated their high electrical and mechanical properties, there remain a few concerns that need to be addressed for satisfying real applications in the future. The mechanical stability, biosafety, and photostability of the above fibers under harsher conditions and industry standards need to be further characterized.[10] For example, how do sweat or washing procedures affect the electrical and mechanical properties of Ag-SBS? Will the Ag on the surface be oxidized after contact with sweat or air? Moreover, additional active materials need to be loaded onto conductive fibers to realize more functions of fiber electronic devices; thus, the effective loading methods are expected. In addition, there is an urgent need to find continuous encapsulation methods for them to fit application scenarios.

It is also important to deeply investigate the generality of such a scalable strategy. More efforts should be made to expand the multimaterial thermal drawing and chemical deposition method to many other material libraries. For instance, it is promising to chemically deposit Ag or other conductive particles onto commercially available elastomer fibers such as elastolefin and elastomultiester to produce stretchable conductive fibers. This strategy might be used to prepare elastic conductive substrates suitable for fabric displays or fiber lithium-ion batteries.

In summary, this work has successfully achieved the scalable fabrication of highly stretchable and conductive fibers, providing reliable building blocks for moving toward real-world applications of textile electronics. It is necessary to further reveal the relationship between their structures and properties and the repeatability at large scale to guide the advance of these stretchable and conductive fiber materials.

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## DECLARATION OF INTERESTS

The authors declare no competing interests.

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