COMMENTARY

Chipless textile electronics enable wireless digital interactions

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Fibers and fabrics have been closely related to the daily life of humans for millennia. With the advancement of the artificial intelligence of things (AIoT) and wearable technology, functional fibers came into being and underwent revolutionary progress and development.[1] Today, fibers have transcended the traditional concept of clothing, being no longer limited to shelter for the body, individual privacy protection, and the aesthetic expression of ourselves but moving in the direction of high-performance, high-end intelligence and green development.[2] We are on the verge of an era of all-textile electronics following the first, second, and third generations. Textile electronics, a high-tech carrier of future AI, enable interactions between individuals and their surroundings via stimuli sensations, executive feedback, energy harvesting and storage, display, computation, and communication functions, wherever and whenever possible.[3] Textile electronics are responsible for integrating human society, the information space, and the physical world. Their subversive and revolutionary nature promises to promote the integration and development of materials, communications, AI, healthcare, and other forms of multi-disciplinary integration, leading humankind toward a more civilized, intelligent society.

All-textile electronics are considered indispensable alternatives to traditional wearable devices owing to their thermal-wet comfort, light weight, dynamic bending elasticity, and other features, especially over the long term. However, current advancement is mostly dominated by third-generation hybrid fiber/fabric electronics, which depend on the heterogeneous integration of microelectronics into normal textiles via traditional circuit boards and adapted electrical connections.[4] These hybrid fiber electronics' design and fabrication are based on the conventional "Von Neumann architecture"—that is, taking silicon-based chips as the core of information processing for developing various fibrous functional modules, such as sensing fibers for signal acquisition, optical fibers for visual transmission, and power-generation fibers for energy supply (Figure 1, top left). Although fibrous units can be initially combined into fabric forms, seamless integration technology for complex multi-modules in textiles still faces non-negligible challenges. Further, textile electronics based on the traditional system architecture contain inherent rigid integrated circuit chips (wireless modules, microprocessors, and analog-to-digital converters), which require high electricity consumption, thus struggling to meet both the low power and comfort requirements of smart wearable electronics.[4]

Proactively integrating multiple electronic components into a single fiber and equipping it with self-powered wireless sensing, transmission, processing, and feedback functions is the key to overcoming the above obstacles and achieving a groundbreaking paradigm shift in modular textile electronics. The latest study published in *Science* by Yang et al. reported exciting progress in successfully converting the interaction functions of conventional silicon-based chip textile systems into an energy-autonomous wireless chipless form, which breaks through Von Neumann architecture limitations in energy and wearability.[5] Electromagnetic fields and electromagnetic waves are everywhere in daily life. Yang et al.

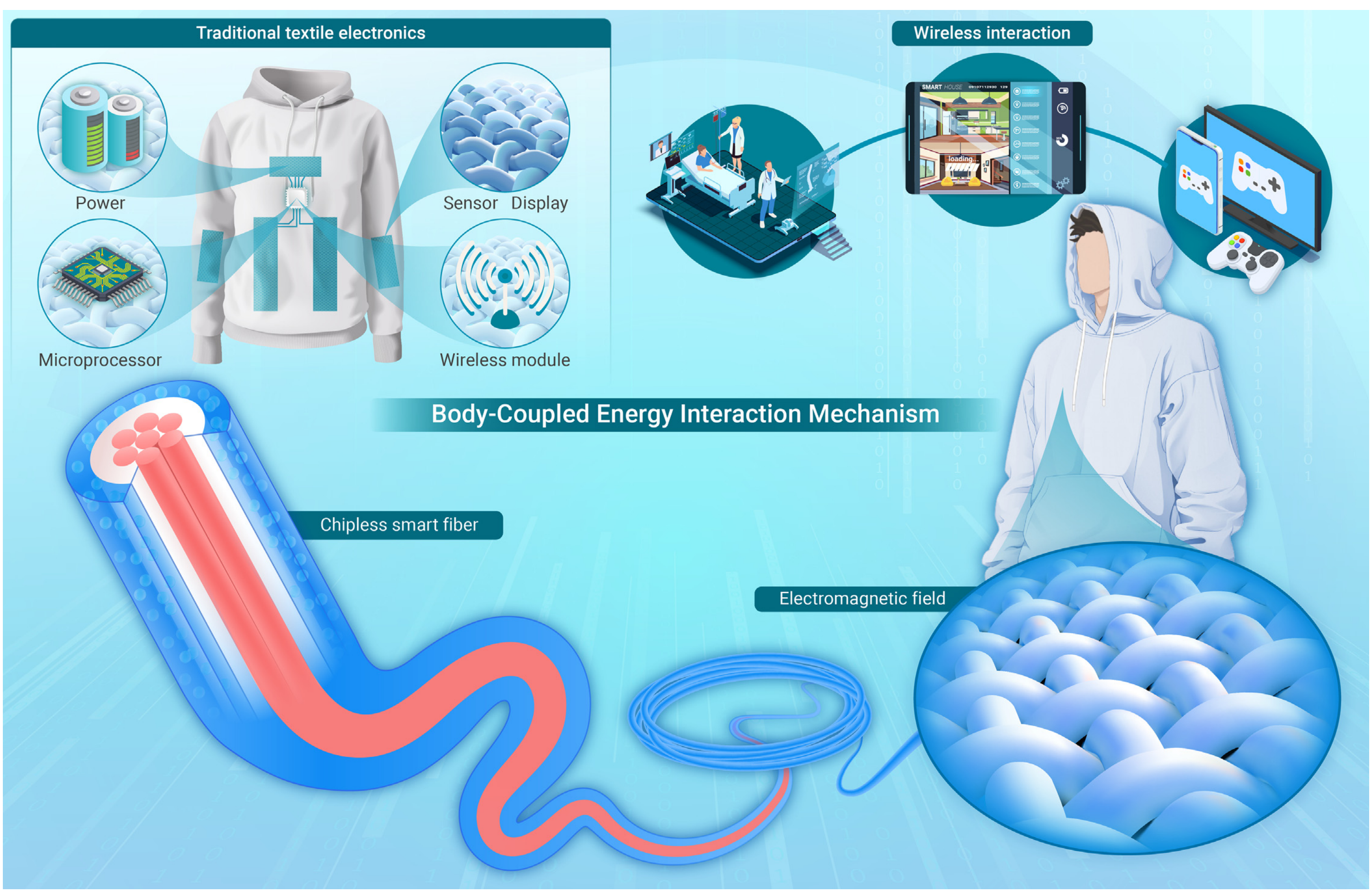

Figure 1. The body-coupled chipless textile electronics and their interaction application

had the foresight to use the human body to couple these energies as the driving force for realizing self-powered wireless tactile sensing, visual signal transmission, and logic interaction functions in a single fiber (Figure 1).

The proposed interactive fiber was coaxially designed through a continuous layer-by-layer coating technique. The single fiber is composed of the antenna core, which induces an alternating electromagnetic field; the dielectric layer, which stores the body-coupled electromagnetic energy; and a photoactive layer, which is sensitive to the electric field. The contact between the fiber and human body can lead to the formation of interface contact capacitance, thus exciting the photoactive layer to emit visible light. Once the electric field intensity of the interface capacitance has surpassed the air breakdown threshold, the wireless transmission of pressure-response electrical signals becomes possible. The interactive fibers are compatible with traditional textile techniques (e.g., digital embroidery, large-area weaving, and knitting), which is crucial for scalable production and large-area applications. Additionally, the chipless wireless textiles woven with interactive fibers offer better breathability and wearing comfort, as well as better washing resistance and durability, than traditional chip-based textile electronics, which are comparable to the conventional daily textiles in wearable serviceability.

The chipless textile electronics invented by Yang et al. can be used in various living scenarios to realize intimate interactions between the human body and its surroundings. For example, the chipless textile-based touchpad and display are capable of providing assisted optical signal communication for the deaf. Also, the team revealed that wireless interactive textiles could enable real-time remote manipulation for virtual games and that haptic carpets could perform wireless control for household appliances. These results in auxiliary communication, virtual reality, and smart homes confirm the application feasibility of interactive fibers in wearable electronics and smart clothes.

Yang et al. pioneered a body-coupled fiber-electronics technology that eliminates the need for traditional components in textile electronics, such as chips, batteries, and other rigid modules. This principle, while simple, is an attractive breakthrough in wearable technology. This advancement in fiber electronics offers new design concepts for the innovation of functional fibers, smart clothes, and wearable electronics, and it simultaneously advances fundamental models of human physical interaction and promises to bring sensorless information interaction to the way people communicate with each other and interact with their surroundings. Nonetheless, the body-coupled chipless fiber-electronics technology remains to be further studied in order to approach the future vision of human-cyber-physical intelligence integration based on all-textile electronics. For example, it is necessary to pursue structural design and advanced material innovation to enhance ambient electromagnetic energy-collection efficiency and examine reliable encapsulation technology to free fibers from moisture-oxygen environments and ensure signal transmission stability. It is important to simultaneously integrate a wider range of electronic functions and interactions into a single fiber to imbue the fibers with wisdom similar to that of a human. The high level of integration of more advanced features in the fibers, including photoreception, information storage, brain-like computation, and emotional expression, will enable them to adapt to complex and variable application scenarios in the real world, thus promising smart all-textile electronics in a real sense. Follow-up work on using chipless fibers in active information interaction is also worth exploring. A systematic study on the integration of fiber with the AIoT, big-data analysis, and AI algorithms will enable chipless textile electronics to realize more accurate and real-time data collection, processing, analysis, and feedback, thus providing users with an all-around senseless smart life experience. There are numerous hidden gems in the underlying materials science, textile science, and information technology of fiber electronics. We look forward to further research to optimize the quality and performance of fibers and to expand their wider applicability for exciting future functional fibers, thus heralding a new era of human-centered information interactions based on chipless textile electronics.

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DECLARATION OF INTERESTS

The authors declare no competing interests.