Smart materials and devices for electronic textiles

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Electronic textiles (e-textiles) have attracted a significantly increasing amount of interest in recent years. A wide variety of e-textile devices, systems, and applications have been reported. The development of smart materials and devices has played a critical role in this rapid progress of e-textiles. This article provides a concise review of the development of e-textiles and their applications. It introduces the three articles included in this issue. Finally, it discusses the challenges of this field.

Introduction

Electronic textiles (e-textiles) generally refers to textiles that are integrated with electronic components and systems, and provides electronic active functions.¹ In particular, fiber- and textile-based materials and devices outperform thin films because of their high surface area, good wearing ability, easy integration, and processing flexibility.² These attributes may provide higher sensitivity and efficiency, improve mechanical flexibility and stretchability, lengthen the lifetime and serviceability, enhance the wearing comfort and long-term wearing biocompatibility, and enable new functionalities of the wearable devices and systems.³

The development of e-textiles may be traced back to the original idea and development of fabric circuit board prototypes in the 1960s, even though the technology was apparently too advanced to be realized at that time. The research in e-textiles has not stopped since then, and bloomed into a hot topic in the recent decade as a result of the rapid progress in novel nanotechnologies, smart materials, miniaturization of devices and chips, low power communication strategies, and perhaps more importantly, the pursuits for an intelligent human-machine interface. According to the Web of Science, the total number of publications searched using the keyword “electronic textiles” in the past five years (2016–2020) is 1238,

with a total citation more than 20,000. More than half of them focus on new materials and devices.

The first generation of e-textiles is represented by the simple addition of electronic circuits to a garment with hidden wires and soft interconnects. Although it provides a proof-of-concept shift from a rigid circuit board to an on-body type of electronics, the disadvantage is obvious: the electronic garment consists of many rigid parts so that it is heavy, not comfortable, and difficult to realize functions.⁴

The second generation of e-textiles majorly develops functional fabrics such as sensors and switches. Thin-film-based devices can be attached onto conventional textile fabrics by thermoplastic adhesives using lamination technology. Besides, electronic devices can also be directly fabricated on textile substrates via printing technologies such as screen printing and inkjet printing with the use of solution-processable functional materials. This phase of development significantly improves the conformability of the electronics to textiles, yet reaches the level of pliability of common textiles because of the use of thin-film electronics. Moreover, these thin-film devices are normally sealed by packaging materials to prevent the wear-induced loss of the functional materials, so that the permeability, which is critical to long-term wearing, is of great concern.⁵

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The recent decade witnesses the emergence of the third generation of e-textiles, where functional smart fibers and yarns are developed as building blocks to assemble smart devices, circuits, and systems. This bottom-up approach can maximize the advantages of the highly scalable and mature textile technologies, such as braiding, weaving, knitting, and embroidery, to create complex patterns and architectures desirable in different areas while retaining the textile properties.⁶ To date, the applications of e-textiles have now spanned from small-sized implantable and surgical devices, wearables and on-body electronics, to mid-sized smart interiors, interactive surfaces, and robotics, and to large-scale built environment, transportation, landscape, and beyond.^{7–11}

This issue aims to highlight some of the latest developments in smart materials and devices of e-textiles. The Lund et al. article¹² reviews the recent development in advanced conducting fibers as building blocks of a wide variety of wearable devices. They discuss how metals, conducting polymers, carbon nanotubes, and two-dimensional materials, including graphene and MXenes can be used in concert to create e-textile materials, from fibers and yarns to patterned fabrics. They also provide examples of how these materials are combined to construct a range of semiconducting, conducting, and electrochemically active functions.

In their article in this issue, Xia et al.¹³ discuss the smart wearable thread-based wearable devices, including sensors, energy devices, and displays. In particular, physical sensing stimuli such as strains and biological total analysis systems. They also cover the examples of wearable sweat-sensing patches and smart bandage/smart sutures. It shows the promise of wearable thread-based sensing and delivery platforms for next-generation biondiagnostics.

The final paper by Dong et al.¹⁴ discusses the latest development of textile triboelectric nanogenerators (TEGs), a triboelectric technology originally developed by the same research group. Textile TENG is a kind of smart textile technology that integrates traditional flexible and wearable textile materials with emerging and advanced TENG science, which not only embraces the capabilities of autonomous energy-harvesting and active self-powered sensing, but also maintains original wearability and desired comfortability. The authors provide the fundamental knowledge and core elements of TENG, including the operational modes and corresponding service occasions, charge generation and transfer mechanisms, and analyze the five major developing trends and 10 remaining key challenges. They also draw a roadmap toward further scientific research and large-scale commercial application of textile TENGs in the next decade.

Discussion

It is no doubt that there are many more exciting examples of progress, apart from those included in this issue, in the past few years in this field. Several aspects important to e-textiles, for example, packaging,¹⁵ energy supply,¹⁶ and safety of materials,^{17,18} are not discussed in this issue. Therefore, it is our sincere hope that this issue can serve as an introductory doorway to bring the interest in e-textiles to a broad range of researchers, and trigger sparks contributing to the development of advanced materials, devices, and systems for e-textiles.

Besides the technological challenges, there is also a serious concern of the sustainability and lifecycle of e-textiles, especially when they are heading toward large-scale commercialization in the future.^{11,19} E-textiles contain not only a variety of valuable materials, but also a number of hazardous heavy metals and halogenated organic compounds that can harm human health and create ecological risks. These hazardous materials can be released into the environment while leaching from landfills, during incineration if mixed into municipal waste streams, or during recycling. As also argued in Lund et al.¹² it should be challenging to recycle these materials from a total energy recovery point of view. Instead, they advocate that future research efforts should concentrate on the design of hybrid materials that can be easily separated into their individual components without compromising their electrical, electronic and electrochemical properties. In order to facilitate truly sustainable e-textile materials, it may be advantageous to limit the number of different materials that are combined.

Ultimately, the success of the e-textile market will be on the utilization of these new material methods in commercially viable applications. Use cases for e-textiles will need to be established beyond niche applications and demonstrations, but to those that have validated return on investment for the consumer, fabricator, and seller. This will require materials scale-up to meet the pricing and product quantity demands of these markets. Historically, textiles have been considered as a consumable item, but the inclusion of smart technologies necessitates the ideological shift toward being durable consumer goods. Parallel advances in automated and human-assisted automated manufacturing will soon support textile manufacturing, promoting new business and costing strategies for advanced textiles, such as e-textiles.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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