Extended Abstract

Multifunctional Graphene-Based Wearable E-Textiles †

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Wearable electronics are becoming increasingly popular, since such technology makes life safer, healthier, and more comfortable. Among them, smart wearable electronic textiles (e-textiles) have been going through significant evolutions in recent years, through the innovation of wearable electronics, due to the miniaturization of technology and the wireless revolution. This has resulted in personalized wearable garments that can interface with the human body and continuously monitor, collect, and communicate various physiological parameters such as temperature, humidity, heart rate, and activity monitoring. Such a platform would potentially provide a solution to the overburdened healthcare system, resulting from a rapidly growing aging society, as well as maintaining and encouraging healthy and independent living for all, irrespective of time and location. However, current technologies for wearable garments are associated with a number of challenges that other electronic technologies do not face, such as the complex and time-consuming manufacturing process of e-textiles, and the use of expensive, non-biodegradable, and unstable, metallic, conductive materials.

Graphene is considered to be one of the most promising materials for next-generation wearable electronic applications, due to its outstanding electrical, mechanical, and other performance properties [1–4]. However most of the previously reported graphene-based textiles require time-consuming and multi-stage manufacturing processes, which are neither scalable nor suitable for large scale production. Additionally, many of them suffer from poor electrical conductivity, washability and flexibility. Therefore, we have been focusing on developing a simple, scalable, and sustainable process of fabricating graphene-based textiles via industrial yarn dyeing [5], padding [6], screen printing [7], and inkjet printing [8,9] techniques for multifunctional, non-toxic, machine washable smart wearable e-textiles applications. We then demonstrated various applications for such graphene textiles including a supercapacitor, an Electrocardiogram (ECG) device, an activity monitoring device, an eye tracker, a temperature sensor, and flexible heating elements [5–11].

In a recent work [5], we demonstrated a highly scalable and ultrafast yarn dyeing technique that can produce 1000 kg of ultra-flexible, graphene-based, coated conductive yarn in an hour, Figure 1a,b. Such graphene-based yarns were then integrated into a knitted structure as a flexible sensor that could send data wirelessly to a device via Bluetooth. The graphene textile sensor, thus produced, shows excellent temperature sensitivity, very good washability, and extremely high flexibility. In another study [6], we reported a simple, scalable and cost-effective method of producing graphene-based wearable fabrics via a simple pad–dry technique, Figure 1c. This application method allows the potential manufacture of durable and washable conductive graphene e-textiles fabrics at commercial production rates of ~150 m/min. The reduced graphene oxide (rGO) coated cotton fabric thus produced, demonstrate enhanced tensile strength and flexibility due to the increase
ultimate failure strain of the fabric. A potential application of this rGO coated textile as an activity monitoring device was also demonstrated.

We also demonstrated the first all-inkjet-printed graphene onto a rough and porous textile surfaces for wearable electronic applications, Figure 1d [8]. Due to the porosity, surface roughness, and texture of textile material, it is highly challenging to produce a continuous conductive track onto textiles by using low viscosity graphene-based inkjet printable inks. Therefore, we have inkjet-printed an organic nanoparticle-based surface pre-treatment onto textiles which presents a smooth, hydrophobic, breathable coating on textiles, and eventually reduces the sheet resistance of graphene-based conductive prints. We then demonstrated the application, of such conductive graphene prints, as an ECG monitoring device on a garment. Additionally, we reported inkjet printing of graphene–silver composite inks on similar surfaces, pre-treated (via inkjet printing) to enable fully inkjet-printed highly conductive graphene-based wearable e-textiles [9]. Furthermore, a flexible textiles supercapacitor was screen-printed onto textiles via printing graphene oxide on the fabric first, and then reduced using an electrochemical process, Figure 1e [7].

One of the challenges with current reduced graphene oxide (rGO)-based electronic textiles (e-textiles) is that they suffer from poor electrical conductivity and higher power consumption. In a recent study, we reported highly conductive, ultra-flexible, and machine washable graphene-based wearable e-textiles. Our approach involved the coating of textiles fabrics by micro-fluidized graphitic dispersion, and then subsequently dried and compressed to improve the connection between the flakes. We also applied a fine encapsulation on graphene-based textiles in order to improve the wash stability of such fabrics, Figure 1f. We achieved the lowest sheet resistance (≈11.9 Ω sq⁻¹) ever reported on graphene e-textiles, which is also highly conductive even after 10 home laundry washing cycles. It could potentially be applied for various other wearable electronics applications, where high electrical conductivity, washability, and flexibility are desired.

In our studies, we demonstrated potential application of our graphene-based e-textiles for multifunctional and high-performance wearable electronics applications. We believe our scalable production method of producing graphene-based wearable e-textiles is an important step toward moving from R&D-based e-textiles to actual real-world applications. Such textiles could potentially be used to manufacture next generation smart and sustainable clothing for various applications [12].

Figure 1. Scalable production of multifunctional graphene-based wearable e-textiles: (a) A batch of untreated cotton yarn [5], (b) Scalable graphene yarn via yarn dyeing technique [5], (c) scalable pad–dry–cure process for producing conductive graphene fabric [6], (d) All-inkjet-printed graphene-based wearable e-textiles [8], (e) Screen-printed flexible textiles supercapacitors [7], and (f) Highly conductive and machine washable graphene-based wearable e-textiles [10].
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