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MINI REVIEW

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Development of Graphene Coated Wearable Electronic Textiles for Biomedical and Health Monitoring Devices

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ABSTRACT

Graphene-based highly, conductive, flexible, washable, and breathable textile electrodes have been developed using the pad-dry-cure method. It is found that the electrical conductivity of the graphene-coated textile electrodes was significantly improved by padding process. The deposition of poly(3,4-ethylenedioxythiophene) polystyrene sulphonate (PEDOT:PSS) was acquired on reduced graphene oxide (rGO) coated substrate using layer by layer (LbL) technique. The resultant electrodes showed decreased sheet resistance from 150 to 50 kΩ for PEDOT: PSS with a low impedance of 40–150 Hz over the electric potential of 1.0 mV for the detection of high-quality electrocardiograms (ECG) and pulse rate response in different conditions such as rest, walking and running. Consequently, the effect of post-treatment was also analyzed using 5.0 wt% of ethylene glycol (EG) and dimethyl sulfoxide (DMSO), respectively. The sheet resistance was further decreased from, which is appropriate for the detection of highly sensitive pulse rate response. The study demonstrates that the pad-dry-cure method can potentially be used for the development of graphene-coated wearable electronic textiles for biomedical and health monitoring devices.

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Introduction

An arrhythmia is a problem with the rate or rhythm of the heartbeat. During an arrhythmia, the heart beats very fast, or slow, with an irregular rhythm. The most commonly used test to detect and diagnose the arrhythmia is an electrocardiogram (EKG or ECG). Arrhythmia is caused by the changes occured in heart tissues activity or in the electrical signals that controls the heartbeat [1]. Such physiological heart diseases require intensive care and advanced techniques to detect the human health conditions at an early stage, using high precision devices such as electrocardiography (ECG) and pulse rate detection devices [2]. Electrocardiograph (ECG) is the most common and widely used technique for several decades [3]. Whereas, the first photoplethysmography (PPG) was introduced by the Hertzman in 1938 [4]. The electrophysiological signs are the complicated diagnosis response, which requires special care, and proper positioning of the electrodes on the human body with low impedance and higher contact with the human skin to improve the electric signal response [5]. The determination of such medical signs is highly sensitive and sophisticated, which requires several considerations such as the type of skin, and variable conditions during diagnosis [6]. Although, most widely used conventional devices are made up of metallic wires such as silver and silver chloride (Ag/AgCl) electrodes in the shape of monopolar disks. The use of highly flexible and stretchable electrodes is very rare. Therefore, existing prototypes such as ECG, pulse rate, and breathing rate in health monitoring devices [7]. Whereas, the metallic electrodes are complex and complicated due to their low flexibility, breathability, and higher rigidity which may cause skin irritation [8]. In this context, different types of textile-based wearable sensors have been investigated during the last several decades, due to the increasing demand of health monitoring devices [9]. The textile-based electrodes have been used with higher progression in recent years due to their exceptional qualities, for example, ultra-thin, light-weight, flexibility, stretch ability, and conductivity [10-13]. Whereas, the metal electrodes such as silver, steel, copper, aluminium wires have also been embedded in textile fabrics by weaving, stitching, and development of 3D spacer fabrics [14]. However, the use of such metal electrodes in conductive textiles become limited due to their low binding, fixation, poor washing, rubbing, and degradation through oxidation-reduction, when exposed to water and human sweat [15]. Furthermore, these electrodes may also cause some problems such as skin irritation and allergy when directly exposed to human skin, which is another limitation of their end-use. In this concern, several studies have been reported using highly flexible, stable, user-friendly and eco-friendly materials such as carbon nanotubes (CNT), graphite, graphene, and reduced graphene oxide (rGO) with the addition of some binders and thickeners to improve the binding and adhesion properties with textiles [16]. These binders and thickeners include polyurethane (PU), polystyrene (PS), polystyrene sulphone (PSS), polyamide (PA), polyvinylpyrrolidone (PVP), propylene glycol methyl ether

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acetate (PMA), and poly methyl methacrylate (PMMA), has also been used with graphene, reported in previous studies for biomedical and health monitoring devices [17-23]. Therefore, there is a great demand of wearable conductive e-textiles, for personal health care gadgets as well as real-time health monitoring devices used in medical hospitals [24]. Graphene-based textile electrodes are considered as an ideal and novel material used for wearable sensors due to their better contact with the skin, improved washing ability, and stable for long-time used [25]. The graphene-coated textile-based electrodes are highly efficient and promising materials due to their higher stretch ability, bendability, and hydrophobicity, which develops a higher contact with the human skin [26]. However, the use of graphene, and highly conductive polymer (3,4-polyethylenedioxy: polystyrene sulphonate (PEDOT:PSS) coated textile electrodes can potentially replace the metal-based electrodes used in biomedical and health monitoring devices such as electrocardiograph, (ECG), electroengography (EEG), electromyography (EMG), and physiological activities (pressure and pulse rate) [27]. These wearable conductive textiles have been developed through different techniques such as direct deposition by dip coating, spin coating, spray coating, drop-casting of conductive materials with metal oxides, graphene, conductive polymers, and their composites [28]. Whereas, some advanced techniques have also been practiced by using conductive inks of these materials through roll to roll, heat transfer, screen, and stencil printing for the fabrication of biomedical and health monitoring devices [29]. The primary motivation of this research work is based on the design and development of such a flexible and breathable device, which covers the higher skin contact with low impedance to reduce distortion of electrical signals during diagnosis [30]. In this study, the textile fabric was coated with GO using the production scale dyeing (pad-dry-cure) method. The graphene oxide GO coated textile fabric was chemically and thermally reduced into rGO using a green reducing agent to develop highly conductive graphene-based textile electrodes. Finally, the as rGO coated textile electrodes were coated with conductive polymers using drop-casting as layer by layer (LbL) approach to develop highly flexible, washable and breathable textile electrodes for biomedical and health monitoring devices.

Among the various developed materials and fabrication processes for wearable sensors, carbon-based materials and textile-based configurations are considered as promising approaches due to their outstanding characteristics such as high conductivity, lightweight, high mechanical properties, wear ability, and biocompatibility. Despite these advantages, in order to realize practical wearable applications, electrical and mechanical performances such as sensitivity, stability, and long-term use are still not satisfied.

Technical Details

Pure graphite of (Grade 3061) with a particle size of (45.0-µm) has been used as primary material for the conversion of graphite into graphene oxide and finally reduced into rGO after fabrication on textile substrate. The highly conductive grade polymer poly (3,4-ethyelenedioxythiophne polystyrene sulfonate) PEDOT: PSS dispersed in water with weight percent of (1.2%) has been used. Mindray patient Monitor (MEC-1000) device was used for performance analysis of ECG response. The pulse rate detection analysis was performed using a digital voltmeter (Key-sight) Model. Number, connected with LabVIEW software version (5.0).

The following procedures have been followed

a) Synthesis of Graphene Oxide (Go) And Pad-Dry-Cure

b) Preparation of Textile Electrode

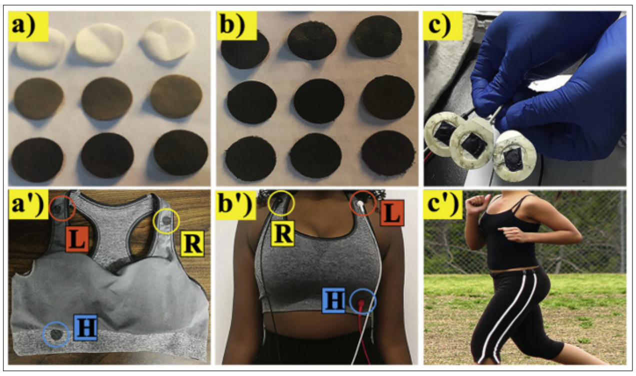

Figure 1: (a) Cutting of textile fabric electrodes (Cotton, GO coated, rGO coated samples), (b) P-rGO-1 and P-rGO-2(DMSO) and P-rGO-3 (EG) treated fabric, (c) placing of conductive textile electrodes on metal Probes attached to ECG device, (a') placing and positioning of textile electrodes in a sports bra (left straps (L), right straps (R), and bottom rib electrode (H), (b') female volunteer student wearing sports bra for ECG, performance analysis during rest and (c') performance analysis during running.

Later on, both identical sizes and shapes of the textile electrodes were placed on the ECG electrodes with the help of adhesive silver paste and completely covering the metal electrodes. As the coated textile substrate comes in direct contact with human skin instead of metal electrodes, as shown in Figure-1 (a), (b), and (c) respectively and attached to the sports bra, as shown in Figure-1 (a). The developed electrodes were used for (ECG) performance without any exterior masking. The experimental trials were made after attaching the textile electrodes to the sports bra. The designed wearable sports bra was worn by the female volunteer, and the performance of the electrodes was measured in different conditions such as normal position (sitting/ rest) and during running and walking conditions, as shown in Fig. 1(b') and (c') respectively. The response was recorded several times with different time spans of 1 min, 5 min, 10 min, 20 min, and 30 min for consistent monitoring, which could potentially be useful in sports activities, such as running and jogging. The real-time ECG monitoring was accomplished without any deflection/ distortion occurred against wear and tear of the developed textile electrodes when placed in the sports bra and worn by the female volunteer for rapid succession during analysis.

The following studies have been carried out

a) FTIR

b) Raman spectroscopy

c) XPS spectroscopy

d) Scanning electron microscopy (SEM)

e) Water contact angle (WCA)

f) Tensile strength

g) Electrical conductivity

h) Color fastness to rubbing (wet and dry)

i) ECG response

j) Pulse rate response

k) Pressure sensor response

Conclusions

The execution of the ECG, Pulse rate, and pressure responses were accomplished using rGO and PEDOT: PSS coated textile electrodes as resistive type sensors. The developed wearable textile electrodes were found to be suitable to measure the ECG, pulse rate, and pressure response in variable conditions. The results also demonstrate that the impedance and electrical conductivity were not influenced by human sweat when developed textile electrodes were directly exposed to sweat with maximum skin contact due to the hydrophobic nature of graphene. The study reveals that the graphene-coated textile electrodes are highly efficient and can be used as an alternative material towards better detection of human pulse rate, ECG, and pressure response with low impedance for long term use. The study also demonstrates that the used commercial scale (pad-dry-cure) method is highly efficient and suitable for the mass scale production of graphene-based wearable sensors and actuators with higher flexibility and breathability without compromising the comfort properties. With the introduction of the intellectualization and active matrix of wearable sensor arrays, a health monitoring system with carbon/textile-based sensors will become a new paradigm for diagnosing and treatment of medical conditions beyond the current clinical applications.

The authors hereby state there are no conflicts of interest

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