Research on Wearable Sweat Sensor Based on Graphene

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Abstract. Sweat is a biofluid of great significance, 99% of which is water, while the rest consists of ions, metabolites, hormones and other substances, which provide extremely rich chemical information about biological metabolism and can be used to reflect the state of the body's bodily functions, making it an ideal sample of body fluids for monitoring. Graphene-based wearable sensor technology obtains unique metabolic information through continuous detection of sweat, enabling personalized application to the human body. The intention of this paper is to first introduce the concept of sweat sensor and its working principle by introducing the extraction method of glucose from sweat, which exposes the shortcomings of the current situation of scientific analysis of the human body, i.e., low personalization of detection, low sensitivity of detection, and high cost of detection. The advantages of carbon-based materials such as graphene are then introduced, leading to the derivation of methods to further improve the sweat sensor and seek to optimize its performance.

Keywords: Sweat, graphene, biosensors, human metabolism.

1. Introduction

Glucose is one of the main sources of energy for the body's cells, especially for the brain. Maintaining good blood glucose levels helps provide the energy the body needs to function properly. Glucose is a long-lasting and essential brain fuel that accomplishes many critical functions including ATP production, management of oxidative stress, synthesis of neurotransmitters, neuromodulators and structural components [1]. At the same time the maintenance of blood glucose levels is critical to metabolic homeostasis, and excessively high or low blood glucose can lead to problems in the body. When athletes exercise, glycogen in muscle tissue is broken down into glucose, which serves as the primary source of energy. At the same time, the breakdown of fat due to exercise produces ketone bodies and lactic acid, some of which are converted to glucose, which in turn provides the body with energy.

Therefore, real-time monitoring of blood glucose changes in the body of athletes to ensure normal blood glucose concentration is of great significance in protecting the life of athletes and improving the level of sports. It is worth noting that the loss of sweat and electrolytes, these manifest as changes in sweat parameters (rate, composition) and other changes, and often vary from person to person [2].

The traditional method of blood glucose testing for traumatic testing, that is, by puncturing the skin to obtain samples, the steps are cumbersome, the patient's painful wounds are susceptible to infection, and cannot realize the dynamic, continuous detection of blood glucose concentration. Optical non-invasive blood glucose detection technology is still in the research stage in the world, and there is still a large distance from the clinical application [3]. Therefore, researchers need to develop a collection method that is minimally invasive and sensitive enough for blood glucose detection so that blood glucose can be detected with minimal harm.

So, A. Martı´n, J. Kim et al. designed and fabricated a real-time wearable flexible sweat detection sensing system. A sweat-sampling microfluidic platform was used to integrate with a flexible wireless electronic device for the detection of lactate and glucose in sweat, and the sensing system with a layered microfluidic system on the skin is shown on the left side of Fig. 1. The most sophisticated battery-free sweat sensor to date was announced by John A. Rogers et al. This device allows real-time monitoring of lactate, glucose, chloride concentration, pH, sweat rate, and sweat volume as shown on the right side of Fig. 1 [4].



Figure 1. Flexible microfluidic wireless sweat detection system [1]

2. Principle and Application

2.1. Working Principle of Graphene Based Wearable Sweat Sensor

A sweat sensor is a sensor device used to detect human sweat. The main function of such a sensor is to measure specific chemicals or physiological indicators in sweat, which can be displayed and aggregated via a Bluetooth-connected mobile application to provide data about an individual's health status, exercise level, or other physiological information. Distinguishing from traditional bio-detectors that can only detect superficial skin information such as temperature and humidity, the sweat sensor can obtain deeper information such as human metabolic substances, glucose, lactic acid, etc. By analyzing changes in the concentration of these components, sweat sensors can provide important information about the state of the body. With the direction of research towards integration and sensitivity, scientists have proposed a mechanized and fully integrated sensor array for multiple primary sweat analysis. The sensor array can be used to simultaneously and selectively measure sweat metabolites (e.g., glucose and lactate) and electrolytes (e.g., sodium and potassium ions), as well as skin temperature (to calibrate the sensor response). Their work fills the technological gap between signal transduction, fragment tuning (amplification and filtering), processing, and wireless transmission in wearable biosensors. The approach combines a plastic-based sensor with a skin interface with a silicon integrated circuit integrated on a flexible circuit board for complex signal processing. For outdoor devices, it is crucial to minimize the effects caused by temperature changes. While the effect of temperature on the sensor electrodes is small, the effect on the performance of enzyme sensors is dramatic. In response to this, they concluded experimentally that the response of the glucose and lactate sensors increased rapidly as the solution temperature increased from 22 degrees Celsius to 40 degrees Celsius, reacting to the effects of increased enzyme activity. So they integrated the system to allow to realize real-time compensation by calibrating the readings by the change of temperature [5].

In addition to this, in practical applications, sweat has a complex composition and contains a large number of molecular groups, which if attached to the sensor will definitely cause the resistance to become large, which will lead to difficulties in signal transmission and inaccuracy. This problem is solved by using high contact area materials as electrodes. For example, the electrodes of dry sensors are usually made of metals or metal polymers, and nanomaterials are utilized to increase the interfacial contact area of the dry electrodes, thus reducing the contact impedance [6].

Graphene is a new type of nanomaterial with a two-dimensional honeycomb lattice structure formed by the close-packing of a single layer of carbon atoms. The basic structural unit of this nanomaterial is a benzene six-membered ring formed by the Sp2 hybridization of carbon atoms, which is only one carbon atom thick, and it is the thinnest two-dimensional nanomaterial discovered so far, with the thickness of only 0.34 nm, and its large specific surface area can reach up to 2630 m^2/g [7]. Nanocomposites of graphene have been utilized by scientists for electrochemical applications. The metrics of sweat sensors are: sensitivity, selectivity, response time, and stability. the use of graphene modified electrode can perfectly solve the problems caused by uncertainties such as temperature, resistance, and environment. Graphene and its derivatives not only have excellent electrical, mechanical, and electrochemical properties, but are also capable of forming nanocomposites with metal nanoparticles, metal oxides, metal-organic frameworks, polymers, and ionic liquids [7].

Compared to conventional carbon electrodes, graphene electrodes offer higher sensitivity, lower detection limits and faster electron transfer kinetics [8].

The preparation methods of graphene are abundant and can be categorized into two groups depending on the principle. The first category is by applying an external force, which causes the van der Waals forces between the graphite layers to disappear, resulting in the detachment of graphite flakes and the appearance of a small amount of graphene. This method can be realized by mechanical stripping method, while the use of redox method and supercritical fluid can be realized. The other is the use of chemical synthesis methods, involving chemical vapor deposition, epitaxial growth and other related methods. It is worth noting that most of the methods have drawbacks. For example, the mechanical stripping method can only meet the needs of basic research, but cannot cope with large-scale manufacturing. Or for the epitaxial growth method, high-quality graphene can be produced, but it requires a process that is extremely difficult and difficult to produce technology. The method that has been used more often is the redox method [9]. For example, Malla et al, studied and synthesized AuNPs modified magnetically reduced graphene oxide (Au-decorated magnetically reduced graphene oxide, AMRGO) and used it as the electrode of the sensor, or Alafeef et al. used electrochemical deposition method to deposit AuNPs uniformly on the surface of the electrode. Both of these experimental methods for modifying electrodes are the more classical and highly utilized modification methods, which are easy to operate and highly realizable [7]. As in Figure 2, the approximate flow of the redox method is explained, which is, the function of strong acids and strong oxidizing agents are used to realize the processing of the electron conjugate structure of graphene, which makes the defective planar graphene and introduces changes in the layer structure of the oxygen-containing group.

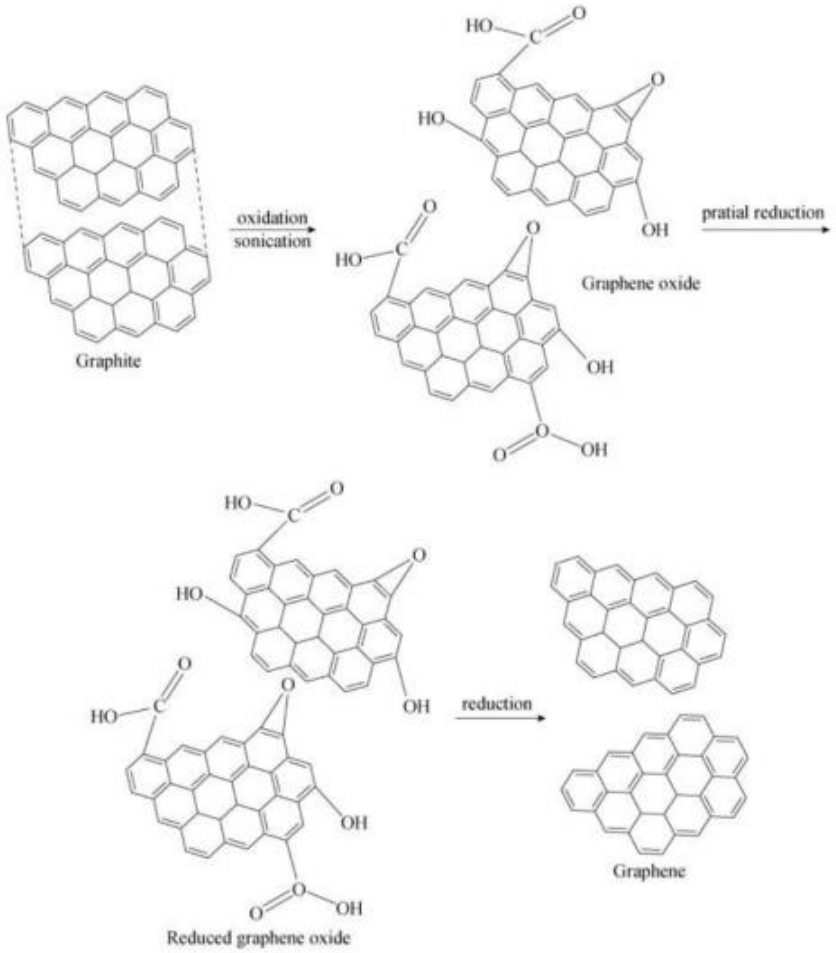


Figure 2. Flow chart of graphene preparation by redox method [2].

The use of graphene materials as electrodes can lead to signal amplification, sensitivity and recognition specificity for biomolecule detection, which can give these hybridized nanocomposites a wide range of biomedical applications [10]. The use of graphene-modified electrodes can dramatically

improve the stability of real-time monitoring of athletes' movements, effectively reducing the low time lag such as that associated with carbon electrodes. The detected chemical and electrical signals are transmitted to the processor through digital-to-analog conversion in a timely manner to make appropriate feedback. The emergence of flexible electronics with high sensitivity and high reliability has revolutionized the development of soft electronics, biological and chemical sensor technology and promoted the development of sports medicine [11]. The use of wearable sensors for clinical research in sports medicine can enable researchers to access a wide range of data, which can then be modeled and analyzed to accurately and efficiently predict the risk of injury in athletes and provide data support for sports medicine personnel [12].

2.2. Applications for Sweat Sensors

With the development and progress in the field of high-precision technology in recent years, as well as the maturity of graphene technology, many perspiration-based biosensors have been applied in the market. For example, in the medical industry, by wearing wearable biosensors on recovering patients, people can immediately observe the condition of their physical indicators, and timely feedback to avoid deterioration of the condition. In the sports industry, the intelligence and immediacy of wearable biosensors can enable coaching teams to accurately analyze an athlete's muscle and body metrics down to the second, avoiding injury due to issues such as electrolyte imbalances or low blood sugar. Su Bingtian is a top sprinter in China, but compared with the powerful sprinters in the world, his backward speed of 80-90 meters is still a short board in China, which requires accurate analysis of his stride length, stride frequency and body condition, so as to make in-depth adjustments [13].

Biosensors include a wide range of areas of human life, whether it is medical treatment, sports, planting, production, are inseparable from biosensors. As one of them, sweat sensors naturally play a role that cannot be ignored. The growing number of "smart bands" and "smartwatches" that can monitor a person's physical condition is the best example of this technology. In addition to these direct applications, sweat sensors also have a partial crossover with the field of biofuel cells. In other words, sweat is used as fuel to convert chemical energy into electricity. This sweat sensor can collect and store energy, and can be used to provide electricity for electronic watches such as Apple Watch. By using wearable sweat sensors to monitor and track physiological parameters in human daily activities, combined with artificial intelligence and Internet of Things systems, portable and effective data basis and technical support can be provided for telemedicine detection, timely diagnosis and treatment of potential patients, early intervention of auxiliary means and other fields [14].

3. Conclusion

Wearable sweat sensors are devices that detect human sweat with high timeliness, sensitivity, and integration, and are capable of extracting trace amounts of useful information from sweat through a small device, which can be effectively analyzed through electrical signals. Unlike conventional sensors, sweat sensors can simultaneously measure skin-deep information such as metabolic substances and ion concentrations.

The purpose of this paper is to introduce the working principle of sweat sensors as well as the current development status, hoping that readers can understand what sweat sensors are and where they are all applied. With the introduction of the concept of fully integrated sensor arrays, the gap in sweat sensor technology was bridged.

After this domestic and foreign scholar to sweat sensor more in-depth research, that graphene modified electrode is the key to future development. Graphene has excellent electrical, mechanical and electrochemical properties. By modifying the electrode with graphene to increase the interface contact area, effective information can be collected to the greatest extent. Although sweat sensors have many unprecedented advantages and seem to be perfect, the process has also revealed many problems that still need to be improved, such as how to reduce the impact of uncertainties such as outdoor temperature on the sensor's operation, or how to reduce the pollution of the environment and industrial

waste emissions when producing graphene on a large-scale industrial scale. With the continuous improvement of the technology, sweat sensors will surely play a significant role in personalized medicine, sports, and daily life, and have great significance for the progress of mankind that cannot be ignored.

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