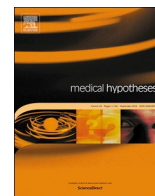




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Role of graphene in biosensor and protective textile against viruses

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ABSTRACT

Coronavirus disease (COVID-19) is a recently discovered infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Graphene is an emerging material due to its extraordinary performance in the field of electronics and antimicrobial textiles. Special attention devoted to graphene oxide-based materials due to its surface to volume ratio is very high which make it easy to attach biomolecules by simple adsorption or by crosslinking between reactive groups and the graphene surface. In response to the COVID-19 pandemic, we have summarized the recent developments of graphene and its derivatives with possible virus detection and textile applications. Moreover, graphene strain sensors can be executed on high-performance textiles and high-throughput drug efficacy screening.

Introduction

The widespread of coronavirus disease (COVID-19) has become a global public health issue in the whole world. The World Health Organization (WHO) declared that COVID-19 is vastly infectious and pathogenic caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1,2]. Many researchers have researched vaccines as well as protective products for public health care. COVID-19 is formed by spherical envelope particles enclosing single-stranded positive-sense RNA associated with a nucleoprotein within a capsid comprised of matrix protein as shown Fig. 1 [3,4].

Graphene is playing a vigorous role in the field of medical and electronics projects due to its potential role as an effective antibacterial and sensing capabilities [5]. In the last few decades, graphene-based nanomaterials are the most attractive materials for the design of biosensor due to its high affinity, cost-effective, and ease of fabrication [6]. Graphene oxide (GO) can be converted into reduced GO (rGO) after removing the oxygen groups by reducing agent to attain materials with properties very close to graphene. Compared to the platelet-like surface of graphite, wrinkled, layered flakes, and crumpled thin sheets were observed on the surfaces of GO and rGO, respectively [7,8]. Being a single layer sp^2 hybridized carbon atoms; graphene has a high specific surface area to volume ratio [9,10]. Due to this unique characteristic, it can easily detect a single biomolecule as it comes in contact with the graphene surface. This level of sensitivity is due to the changes in electrical resistance, making these nanoscale material perfect sensors as well as implantable devices [11]. Optical absorption of one atom thick

carbon layer is about 2.3%, which is 50 times more than that of gallium arsenide (GaAs) of the same thickness [12], this property is very essential for making an object free from live microorganism. The presence of oxygen groups in GO makes it hydrophilic in nature compared to graphene and rGO. Moreover, these groups provide active sites for adsorption or functionalization with enzymes, protein, and nucleic acids. Thus, we can think that how graphene exploration can take part against COVID-19.

In this paper, authors exposed that the graphene and its derivatives have good surface integrity towards capturing viruses [13,14]. Most of the disease-related researchers focused on the advancement of graphene sensors but the effects on viruses have been less characterized. It has been proven that antibody-conjugated GO can promptly detect the targeted virus and can be coupled to nanomaterial electronic properties for signal amplification [15]. This can help in screening a large population and also for the progress of low-cost environmental sensors.

Graphene sensors to detect virus

Many researchers are working to develop a graphene-based sensor for the detection of virus combat COVID-19. In the past few years, numbers of researchers have been proved that the graphene sensors to be capable in advanced detection and testing such as respiration rate, blood glucose, and pressure, real-time body temperature, small molecules, and protein interactions and virus detection as well as allergen sensing [16]. Recently, a group of researchers in the Republic of South Korea has successfully developed a transistor-based biosensor that

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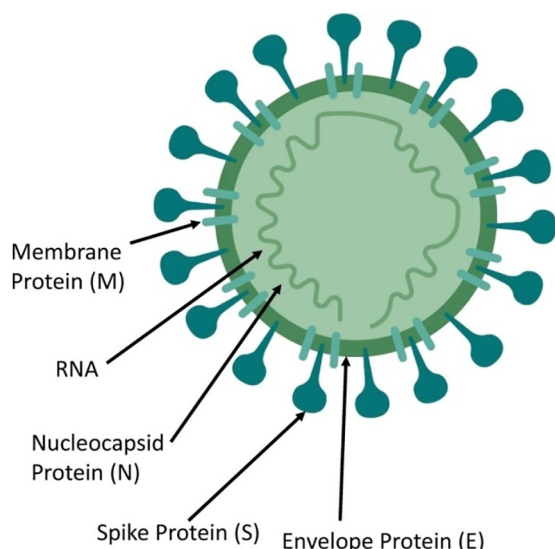
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| Structural Protein | Function of Protein |
|--------------------------|---|
| Nucleocapsid Protein (N) | <ul style="list-style-type: none"> Bound to RNA genome to make up nucleocapsid |
| Spike Protein (S) | <ul style="list-style-type: none"> Critical for binding of host cell receptors to facilitate entry of host cell |
| Envelope Protein (E) | <ul style="list-style-type: none"> Interacts with M to form viral envelope |
| Membrane Protein (M) | <ul style="list-style-type: none"> Central organiser of CoV assembly Determines shape of viral envelope |

- It has been noted that some CoVs do not need to have the full ensemble of structural proteins to make virions, highlighting that certain proteins may be dispensable or compensated by the function of non-structural proteins.

Fig. 1. Main structure of Corona viruses [4]. Reprinted under the terms of the Creative Commons CC BY license.

detects SARS-CoV-2. The biosensor was fabricated by coated graphene sheets of field-effect transistor (FET) with a specific antibody against the SARS-CoV-2 spike protein. They have reported that the addition of SARS-CoV-2 or viral protein on the surface of graphene, the sensor detects a change in electrical current [17].

Graphene and functionalized graphene is more compatible with different biomolecules such as DNA, antibodies, enzyme, and cells [18]. These biomolecules have incorporated on the larger surface area of graphene for the development of biosensors (Fig. 2). In recent research, it was reported that the graphene has unique nanostructures that can be used as nanodevices for DNA sequencing [19,20]. It has been reported that the crumpling in graphene makes biosensor more sensitive to DNA by creating an electrical hot-spot. This sensor could detect ultra-low concentration molecules on the basis of the markers of disease, which is important for early diagnosis [21,22].

Curcumin functionalized GO composite showed great biocompatibility with the host cells and highly efficient inhibition for respiratory syncytial virus (RSV) infection [23]. This composite was also used in

biological imaging due to its low cytotoxicity, better photostability, and outstanding tumor-targeting ability [24]. Bugli et al. [25] reported about the applicability of GO-curcumin composites as an antibiotic resistant against methicillin-resistant *Staphylococcus aureus*. A graphene-polymer based biosensor electrochemical was proposed to detect the early stage dengue virus (DENV) and antibody screening. GO-polymer surfaces were functionalized by the DENV component using a self-assembly process that makes the polymer surface more selective and sensitive to the virus [26]. Omar et al. [27] developed a -NH₂ functionalized GO based optical sensor for the DENV E-protein. They have explored the sensing behavior for the identification of monoclonal antibodies to the DENV. In another work, immobilized monoclonal antibodies were covalently linked with graphene to detect Zika virus. The low cost field effect biosensor (FEB) with anti-Zika NS1 can detect early stage disease in presumptive Zika infection [28].

It has been demonstrated that the gold nanoparticle decorated rGO nanocomposites can be used as an antigen functionalized surface to detect the existence of the hepatitis B virus core antigen [30]. Similarly,

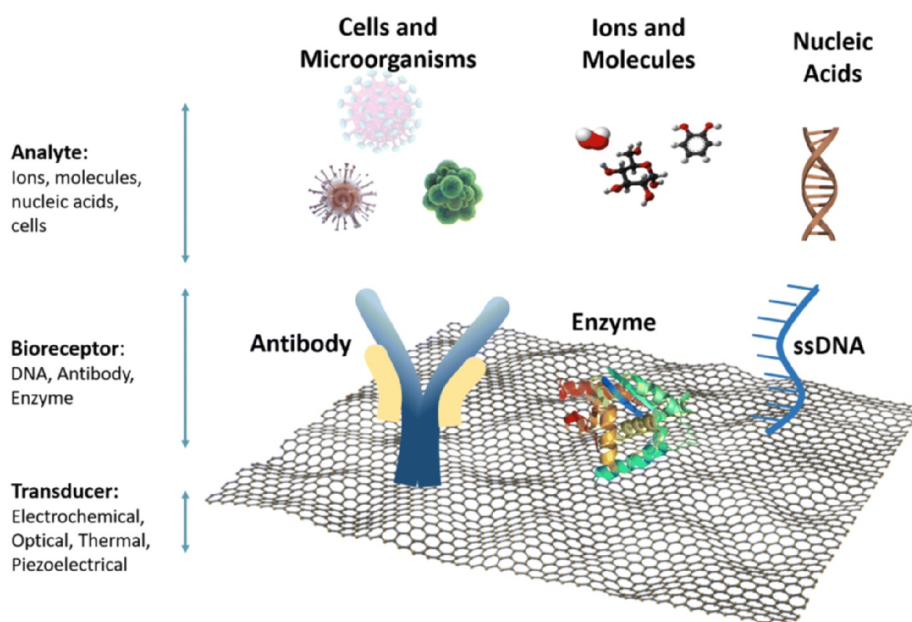


Fig. 2. Examples of biosensors and components on a graphene platform [29]. Reprinted under the terms of the Creative Commons CC BY license.

DNA assisted magnetic rGO-copper nanocomposite was proposed to sense the presence of the hepatitis C virus. This ultrasensitive detection of the virus was accomplished via the electrochemical signal response of the copper ions catalyzed oxidation of o-phenylenediamine [31]. An electrochemical immunosensor was fabricated using shaellac derived thermally rGO flakes for the detection of the influenza virus H1N1. These thermally rGO based sensors used to fabricate variety of immunosensors and have high stability and reproducibility [32]. In another work, silver nanoparticles graphene-chitosan nanocomposites based sandwich-type immunoassay was designed to quantify avian influenza virus H7 (AIV H7) [33].

Graphene textile for protection against virus

Graphene, a new 2D and advanced nanomaterials can fight against COVID-19 by developing high-quality protective equipment such as gowns, gloves, and face masks for corona warriors. As of now, several teams are taking advantage of graphene's antistatic, antimicrobial, and electrically conductive properties to fabricate protective equipment which can be washable and reused. Tang et al. [34] fabricated cotton fabric with the dispersion of coated graphene oxide (GO) nanosheet on the surface of fabric via vacuum filtration deposition method (Fig. 3). Further, the obtained fabric was assembled with polyaniline (PANI) by the in-situ chemical polymerization process. The results showed that the ultrastrong UV radiation protection and higher electrical conductivity compared to control cotton. They have also reported that the cotton fabric performs efficiently after 10 times water laundering without losing any properties.

In the healthcare sector, conductive textiles are used for clinical purpose. Graphene can act as a filter in between the body and external environment to ensure ideal temperature for the wearer. In recent news, it has been reported that the virucidal graphene-based composites ink can be incorporated into the fabric of face mask and other PPE for better protection. Few tests have already been conducted to verify Ag nanoparticles functionalized GO based ink kills the SARS-CoV-2.

The integration of graphene materials family was a reasonable step to attain not only conductive fabrics but also multifunctional wearables [35]. Fig. 4 shows the multifunctional properties of graphene-modified

protective clothing. Kowalczyk et al. [36] have used sol-gel method to modified cotton fabric by xerogel coatings containing 0.5–1.5 wt% of graphene and rGO. They have obtained the best anti-static properties with increased conductivity of fabric due to the flattening and smoothening of graphene flakes. In another research, GO modified N-halamine coated cotton fabrics were fabricated via the conventional dipping-drying method. Further, the obtained fabrics were in-situ reduced by treating with L-ascorbic acid [37]. Hu et al. [38] developed ions implanted GO-based cotton fabric by radiation-induced cross-linking under microwave and bombardment by different doses of Fe^{+3} ions. The ion bombardment has created a whirlpool structure on the GO-cotton, which further increased its washing durability and anti-bacterial activity.

A medical grade polyviscose textile pads were formed by impregnation of Ag nanoparticle decorated rGO nanocomposite through wet chemical solution dipping process. It is also reported that rGO increasing the stability of Ag nanoparticles onto textile fabric substrates which enhanced rinse-reuse capabilities and antimicrobial properties [40]. Many companies have claimed that graphene can be used to make gloves, masks and gowns for medical staff. LIGC applications developed graphene filtration based Guardian G-Volt face mask that can be self-sterilizing, virus killing and reusable. In comparison with a N95 face mask, G-Volt is effective 99% against viruses of $0.3 \mu m$ [41]. Zhao et al. [42] conducted a skin irritation experiment to evaluate safety of GO modified cotton fabric. They have not found any evidence of irritation from the test.

Conclusion and future outlook

Graphene and its derivatives (GO and rGO) have several diverse applications. WHO regularly updates the need for PPE for frontline healthcare warriors and graphene-coated face mask for self-protection as well as others from the spread of COVID-19. Graphene based textiles for filtering and for epidemiological exposure detection are possible accomplices of health systems against epidemic spreading. Furthermore, graphene sensors have been effectively demonstrated for drug screening as well as high-throughput diagnostics. In response to the worldwide pandemic of COVID-19, we have brief the recent

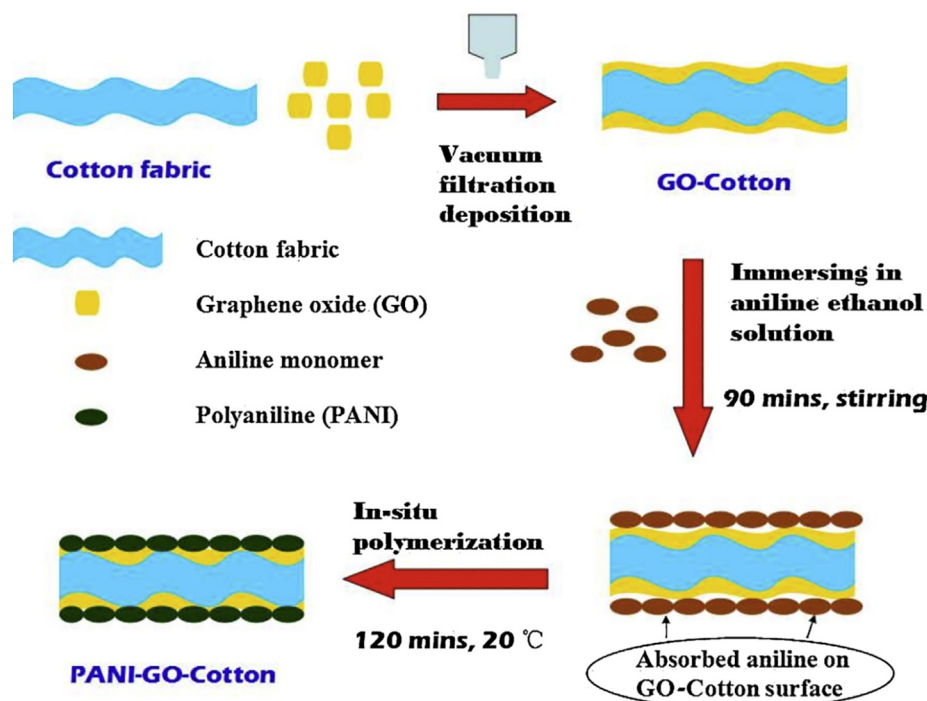


Fig. 3. Preparation procedure of PANI-GO-cotton fabric [34]. Reprinted with permission from Elsevier.

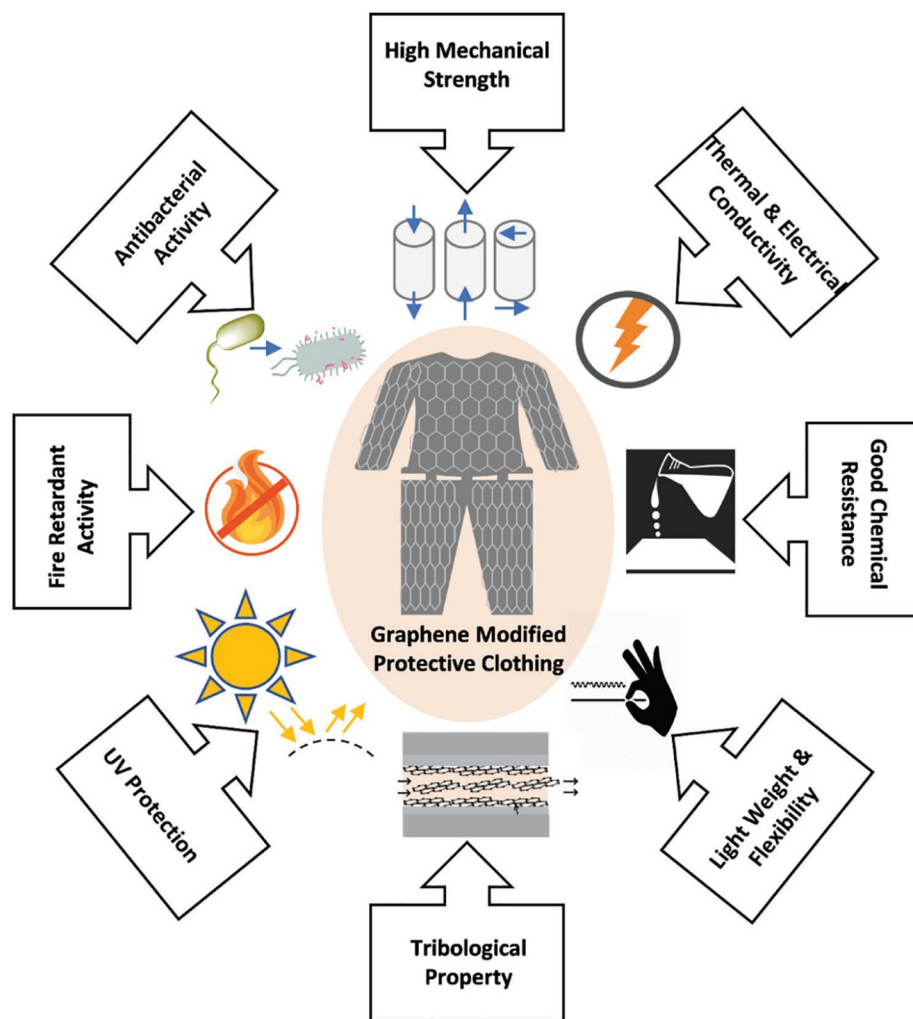


Fig. 4. Schematic representation of multifunctional properties of graphene modified protective clothing [39]. Reprinted with permission from Wiley.

development of graphene in virus detection as well as protective clothing. Likewise, more advancement and research is required against the diagnosis and treatment of SARS-CoV-2. Thus, we can say that graphene may have a leading role against COVID-19.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.mehy.2020.110253>.

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