IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Graphene and Graphene-based Materials: Potential to combat against COVID-19 Pandemic

M. Chakraborty

Assistant Professor
Department of Electronic Science
Sarsuna College, Kolkata, India

Abstract: Graphene and graphene-based materials have recently gained enormous importance in biological domain besides its multifarious applications in other domains like electronics, robotics, material science, sensing etc. The extraordinary physicochemical properties possessed by this wonderful nanomaterial have paved the road to find its utilities in biological field. Moreover, the sudden COVID-19 pandemic caused by Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) has immensely widened the research on graphene and graphene-based materials. This short review presents the potentials of graphene and graphene-based materials that can play a vital role to combat against the current COVID-19 and future pandemics. In this regard application of graphene and graphene-based materials as bio-sensors, wearable devices, PPEs and face masks, antiviral surfaces and coatings, filters and membranes, 3D printing etc are briefly discussed. Further the limitations of these materials are pointed out.

***Index Terms* - Graphene, graphene-based materials, COVID-19 pandemic.**

I. Introduction

The outbreak of the highly infectious coronavirus disease 2019 (COVID-19) due to Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) has been the greatest challenge to the mankind in the present century due to its worldwide spread and severity. The first case of COVID-19 was reported in December 2019 at Wuhun city, China [1]. As of August 26, 2022 there have been ~ 596,873,121 confirmed cases of COVID-19 globally in 170 countries and ~ 6,459,684 deaths, reported to WHO [2]. COVID-19 is an acute respiratory disease with preliminary symptoms of headache, fever, gastrointestinal pain, breathing problem, skin rashes and sometimes pneumonia [3]. The disease has not only affected the worldwide health scenario, but it also impacted global economy as well as social life. Scientists have started to focus their research into developing novel technologies to combat against COVID-19. Several vaccines are already developed and launched. As of 23 August 2022, a total of 12,449,443,718 vaccine doses have been administered [2]. More time is needed to complete the vaccination program worldwide. Also, the short-term immunity provided by the vaccines and emergence of new variants of COVID-19 viruses has made the situation complex and demanded robust technologies to eradicate this deadly virus from our world. Therefore, development of smart nanomaterial is extremely required to combat against this global pandemic beside development of medicines and vaccines.

Graphene, the wonder material, since its discovery in 2004, has drawn tremendous interest among the researchers due to its multifarious fascinating properties like mechanical, electrical, optical, thermal etc [4]. Moreover, other graphene-based materials also have excellent properties. Graphene-based materials include single layer graphene (SLG), bi-layer graphene (BLG), multi-layer graphene (MLG), graphene oxide (GO), reduced graphene oxide (rGO) and its composites with metals, polymers and ceramics [5]. Graphene is a sp^2 hybridized two-dimensional honeycomb lattice structure. The high conductivity and mobility of the SLG layers owes to zero band gap of the material. Stacking of two or more SLG layers produces BLG or MLG graphene. With increase in number of layers the electronic structure of graphene modifies giving rise to different incredible properties. Graphene oxide (GO), the oxidized form of graphite is having a bandgap though its electrical conductivity, mobility etc. are inferior compared to graphene. Reduction of GO through thermal, chemical and electro-chemical means develops reduced graphene oxide (rGO) having a few oxygen functional groups than that of GO. Graphene and graphene-based materials have already shown prospective in various bio-medical applications like bio-sensing [6-8], wearable technology [9-11] etc. It can be used to manufacture improved personal protective equipment (PPE) to fight against COVID-19. Also, graphene is used as antimicrobial element in tissue engineering and in drug delivery [12-14]. In this article, we investigate how graphene and graphene-based materials could play a major role as a potential alternative to detect and monitor COVID-19 virus (Fig.1) and also explore future research directives for graphene-based technologies to combat against COVID-19 and other infectious viruses.

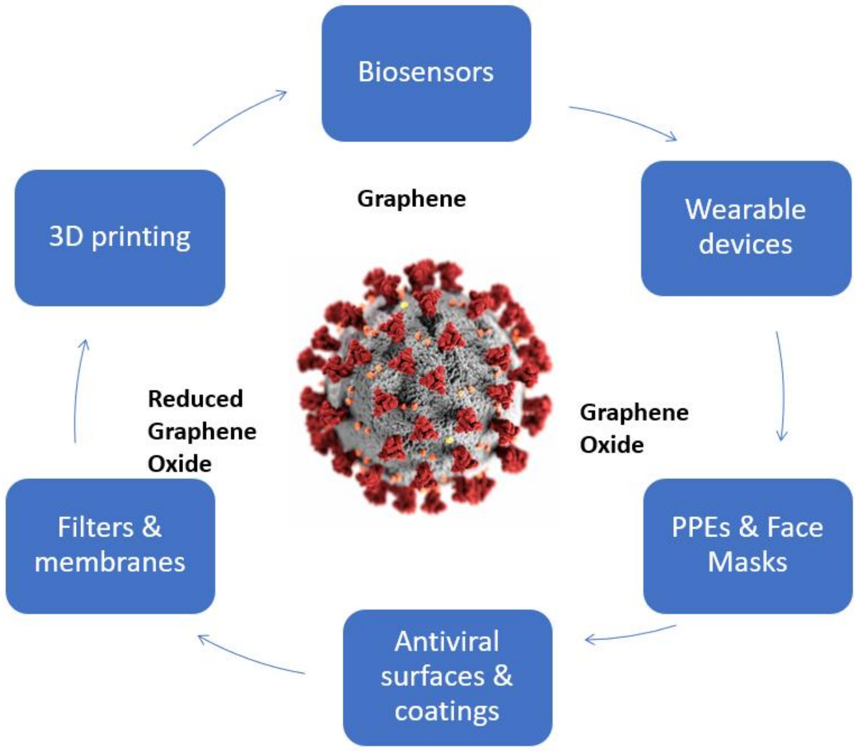

Figure 1: Application of graphene and graphene-based materials to combat against COVID-19

II. APPLICATIONS OF GRAPHENE AND GRAPHENE-BASED NANOMATERIALS AGAINST COVID-19:

During the last two years rapidly spreading COVID-19 pandemic has created a lot of troubles to mankind and it took several lives throughout this period. Presently there is no specific treatment procedure except a few conventional medications to improve our immunity level. Moreover, there is lack of detection and diagnosis system for COVID-19. Precise, fast, sensitive and easy detection methods are needed to overcome the present problem. Worldwide, currently, the most common test methods for diagnosis of covid-19 patients are RT-PCR kits, serological tests etc. But these testing methods have certain drawbacks like RT-PCR requires much longer time to get its result, expensive laboratory procedure and expert technical person to analyze the results etc. Nanotechnology is playing a vital role for rapid detection and diagnosis of COVID-19. Nanoparticles have emerged as a powerful tool for the detection of different virus species due to surface modification and functionalization. Graphene-based nanomaterials are being extensively explored in recent years for numerous bio-medical applications like delivery of drugs, therapeutic carrier, detection and diagnosis of various viruses etc.

BIOSENSORS: Graphene has proved itself as a novel sensing element due to its unique chemical construction, high surface area and excellent thermal, mechanical, optical, chemical and electrical properties. Sensors immobilized with biological molecules like proteins, antibodies, enzymes, cells etc. are called biosensors. They provide simple, fast, sensitive, miniaturized, inexpensive and portable means to detect virus and pathogens [15]. During last decade, next generation nanoscale biosensors are fabricated using graphene and graphene-based materials unaided or modified with nanoparticles or polymers [16-20]. These biosensors provide rapid detection, high selectivity & sensitivity, excellent conductivity and good accuracy. They help to detect the diseases at a primary stage and needs minimal invasive methods. The loading capacity for the biomolecules and drugs of graphene is very high. Also, the high mechanical strength and strong adsorptive property of graphene make it most suitable for biosensors. Fabrication of graphene layer is the critical step in the development of graphene-based biosensors. Also, they can be combined easily in one multilayer stack to build heterostructure devices with tunable properties. Further using defect engineering or modifying surface functionalities graphene and graphene-based materials can be tailored to respond selectively to specific analytes with very high sensitivity. Among the developed graphene-based biosensors, graphene-based field effect transistors (FET) are very promising due to their ultra-sensitivity even in the presence of small quantity of analyte [21]. Recently a graphene-based FET biosensor is developed for detection of COVID-19 [22] (Fig. 2) For biosensing, 2D composites can be fabricated using, GO, polyelectrolytes and electroconductive 2D materials as GO has similar ionic transport properties as that of polyelectrolytes [23]. Surfaces made of cationic polyelectrolytes are positively charged and allow biological samples including COVID-19.

WEARABLE DEVICES & TECHNOLOGIES: To provide quality healthcare services to the mass population use of wearable technologies is an important step. Wearable devices like activity trackers, smart watches etc. will provide early prediction and continuous detailed monitoring and tracking of diseases. These devices will help in getting detailed analysis of one's health by the collection of real-time physiological data instead of data obtained during medical appointment. The potential of these devices can be felt more during the covid-19 pandemic. Readily available consumer grade wearable devices could be used potentially for continuous monitoring of vital symptoms like skin temperature, respiratory rate, oxygen saturation, relative change in systolic blood pressure, heart rate, body movement [24] etc. though they have limitations in accuracy and measurement techniques. Researchers have started using this technology for quick detection of asymptomatic and pre-symptomatic cases of covid-19 since its outbreak. Several studies are performed though the scientists fail to distinguish between covid-19 and other viral infections. Moreover, such devices are massive, rigid and uncomfortable to wear. To enhance patient's comfortability, scientists are trying to develop skin-integrated sensors (soft electronic patch coupled to body) that can track and continuously monitor various physiological data of patients like temperature, heart rate and respiratory rate.

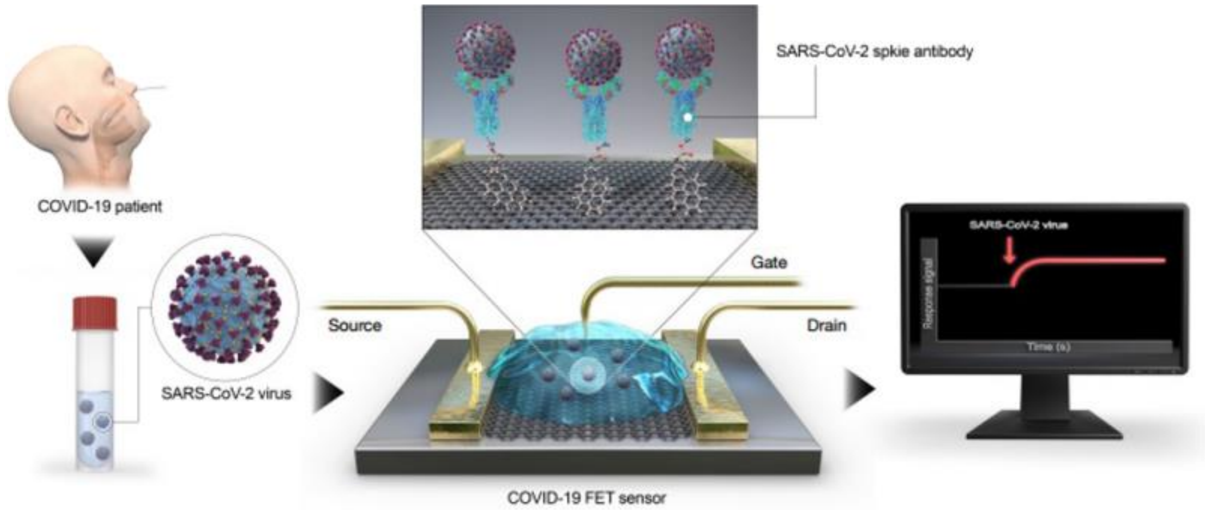

Figure 2: Schematic diagram of COVID-19 graphene-based FET sensor. Reproduced from [22], Copyright © 2020, American Chemical Society

Present day metal-ink (Ag, Cu and Au) based wearable e-textiles are more flexible and comfortable to the wearer compared to the bulky, rigid conventional devices though they have certain disadvantages as the metal-inks are non-biocompatible, expensive and harmful to the environment [25]. So, there is a need among the scientists to develop alternative wearable technologies. Graphene based wearable e-textiles [26] have recently gained profound interest among researchers due to extraordinary electrical and thermal properties of graphene and graphene-based materials. rGO based wearable textiles [25-29] are most prominent among them due to stronger adhesion to textiles as a result of covalent and hydrogen bonding between the textile and rGO. rGO based textiles have improved washing stability but it suffers from poor electrical conductivity. The problem of poor electrical conductivity could be overcome by fabricating highly conductive and machine washable graphene-based e-textiles via pad-dry-cure method with subsequent roller compression and a fine encapsulation of graphene flakes [30].

PERSONAL PROTECTION EQUIPMENT (PPE) AND FACE MASKS: To physically protect the respiratory systems and other vital organs from SARS-CoV-2 and other deadly viruses, use of personal protection equipment (PPE) like masks, face shields, respirators etc has increased worldwide. Surgical face masks are not suitable to resist COVID-19 virus due to bigger pore size. Also, their surfaces are hydrophobic in nature that helps to stick the deadly virus in it. Further these masks cannot be sterilized or reused. N95 respirators are also effective against the virus whose average size is 300nm. For below 300 nm size virus the efficiency of N95 respirators reduced to 85% [31-32]. Therefore, it does not provide enough protection against SARS-CoV-2 virus whose size belongs in the range of 65-125 nm [33]. It is therefore urgently needed to develop better quality and efficient respirators, masks and PPE for medical applications. Due to smooth molecular arrangement and self-lubricating properties, graphene can intervene as a solid lubricant in the preparation of PPEs, which are light-weight and flexible and has high chemical resistance, excellent thermal and electrical conductivity, UV-protected and has high anti-microbial and anti-bacterial property.

Recently, graphene based self-cleaning and sterilizing masks have been developed to tackle COVID-19 outbreak considering the excellent properties of graphene and graphene related materials. Li et al [34] have deposited laser induced graphene (LIG) onto commercial surgical mask with improved superhydrophobic and photothermal properties that can be reused and recycled. Further, some companies like Bonbouton have also developed reusable graphene masks [35] which has reported to effectively block virus-containing microdroplets. Also, graphene-based composite inks for face masks and other PPEs are developed [36]. Recently, a graphene-based respirator mask named 'Guardian G-Volt' developed by LIGC Applications is in competition with gold standard N95 respirator masks [37]. They can be washed and reused up to 10 times without losing its special properties and damaging the graphene coating. It also has portable battery for self-sterilization and an LED light system that alerts the user when the mask needs to be replaced [37]. Fig. 3 shows the representation of a three-layered mask whose main constituent is graphene that offer great protection against COVID-19 virus and similar deadly pathogens. In this mask the outer layer is made of graphene, inner layer is made of 100% cotton and the middle layer is of polypropylene based fabric layer having excellent filtration property. The inner cotton layer is highly hydrophilic and great virus blocking capacity.

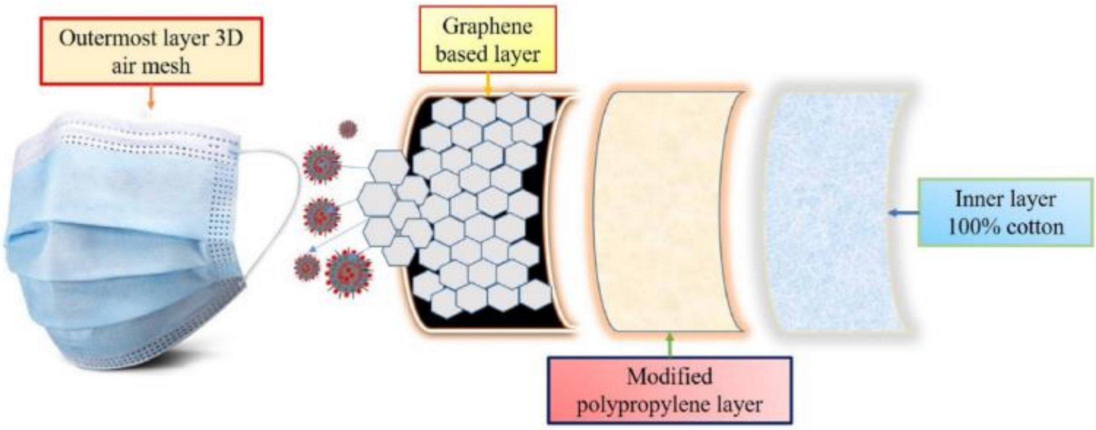

Figure 3: Representation of Graphene-based three-layer face mask to protect against SARS-CoV-2 virus. Reproduced from [49] . CC BY 4.0.

ANTIVIRAL SURFACE AND COATINGS: It is reported that COVID-19 virus remains active on various surfaces like glass, metal, plastic etc even after many days after exposure. The survival time depends on number of factors like type of surface, temperature and relative humidity of the surroundings, type of virus etc. Graphene and graphene-based derivatives have already shown its potential of its anti-bacterial action. Therefore, they can be used to develop antibacterial and antiviral surfaces and coatings to prevent the spread of harmful bacteria and viruses. These coatings can be used profusely in hospitals, laboratories, offices and other public places. The GO/rGO-SO_3 composites with different metal ions also enhances the antibacterial and antiviral property of these materials and are used for antiviral surface and coatings [38,39].

FILTERS AND MEMBRANES FOR FILTRATION AND DECONTAMINATION OF COVID-19: Recently, a self-sterilize graphene-based air filter has been developed [40] by laser induced graphene (LIG) method. This filter is able to destroy any microorganisms including bacteria by using joule heating method. Also, this technology can be integrated with advance air filtration system (HEPA), ventilation and air conditioning system (HVAC), self-sterilization of surgical and N-95 masks.
Recently it was reported that SARS-CoV-2 is found in sewage in different countries like Italy, France, Netherland, Australia and US. Graphene based membranes are also effective in separation of virus and bacteria from water. By controlling the interlayer spacing, various ions, molecules, pathogens, micromolecules can be separated from water [41-43]. Extensive research is needed to throw light in this direction.

3D PRINTING:3D printing nowadays has become a useful technique in various fields like electronics, energy storage, healthcare etc due to lower production costs and higher speed and precision of printing. In this process, material is overlayed layer by layer that could be used to make any unpredictable shape in a very short time. This process could be used to develop graphene, graphene related material and graphene-nanocomposites based components and systems [44,45]. Highly electrically conductive 3D printable graphene inks are used [46]. Graphene and Graphene based material-based 3D printing could be used to develop various personal protective equipments (PPEs), ventilator parts etc. [47].

III LIMITATIONS OF GRAPHENE AND GRAPHENE-BASED MATERIALS:

Graphene and graphene-based materials have antibacterial and antifungal properties but it has certain cytotoxicity, according to Ye et al [48]. At low concentration, it is non-toxic, but at higher concentration it has low toxicity. As they are less hazardous compared to other carbon-based materials, they have good prospect for future. It is observed that the cytotoxicity is much reduced in presence of protein, therefore it is less hazardous to humans and other mammals compared to bacteria. Therefore, it has the potential to combat the deadly pathogens. Another way of reducing the toxicity of GOs/rGOs is to make polymer nanocomposites by diffusing them in polymers. Instability and aggregation in solution is among other challenges of this material. Moreover, while Graphene is used in manufacturing PPE kits, it shows difficulties in interfacial interactions between graphene and the textile that can be overcome by modifying the graphene surface. Also till now, high-quality large-scale production of graphene is not possible. Moreover, proper disposal protocol should be set up and communicated to the all the common people because graphene nanomaterials may cause cytotoxicity in both living cells and to the environment. Graphene based nanomaterials treated with any chemicals should be first neutralized and then disposed of. Also, they should not be mixed with common wastes.

IV CONCLUSION:

The COVID-19 pandemic has its worldwide devastating effect since the last two and half years with loss of millions of lives. The social and economic conditions of various countries have also become unstable. Still its effect is not over. The weak and strong various type of mutants are appearing suddenly. The vaccines that are resistant to the previous mutant may not work against the new one. Therefore, there is much need to develop the new vaccine and also the diagnostic devices to detect the new variants. In this context, graphene and graphene-based materials have revealed the potential to combat against the deadly virus like SARS-CoV-2. They are the suitable candidates to fight against the deadly virus due to their excellent properties. This wonderful material can be used to prepare biosensors and other medical components and devices like PPE, masks, antiviral coatings.

REFERENCES:

[1] W.C.W. Chan, 2020, Nano Research for COVID-19, ACS Nano, 14:3719–3720. https://doi.org/10.1021/acsnano.0c02540

[2]https://covid19.who.int/ (accessed last time on 27/08/2022)

[3] P. Zhou, et al.,2020 A pneumonia outbreak associated with a new coronavirus of probable bat origin, Nature 579 (7798) 270e273, https://doi.org/ 10.1038/s41586-020-2012-7.

[4] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, M. I. Katsnelson, I. V. Grigorieva, S. V. Dubonos, A. A. Firsov, 2005, Two-dimensional gas of massless Dirac fermions in graphene, Nature, 438, 197

[5] V. Palmieri, M. Papi, 2020, Can graphene take part in the fight against COVID-19? Nano Today 33, 100883, https://doi.org/10.1016/ j. nantod.2020.100883

[6] M. Pumera, 2011, Graphene in Biosensing, Mater. Today, 14, 308.

[7] E. B. Bahadır, M. K. Sezgintürk, 2016, Applications of graphene in electrochemical sensing and biosensing, TrAC, Trends Anal. Chem., 76, 1.

[8] M. S. Artiles, C. S. Rout, T. S. Fisher, 2011, Graphene-based hybrid materials and devices for biosensing, Adv. Drug Delivery Rev., 63, 1352.

[9] S. Afroj, S. Tan, A. M. Abdelkader, K. S. Novoselov, N. Karim, 2020, Highly Conductive, Scalable, and Machine Washable Graphene-Based E-Textiles for Multifunctional Wearable Electronic Applications, Adv. Funct. Mater., 30, 2000293.

[10] H. Kim, J. - H. Ahn, 2017, Graphene for flexible and wearable device applications, Carbon, 120, 244.

[11] N. Karim, S. Afroj, S. Tan, P. He, A. Fernando, C. Carr, K. S. Novoselov, 2017, Scalable Production of Graphene-Based Wearable E-Textiles, ACS Nano, 11, 12266

[12]Jin G, Zhao X, Xu F., 2017, Therapeutic nanomaterials for cancer therapy and tissue regeneration. Drug Discov. Today; 22(9):1285–7.

[13] Giordani S, Camisasca A, Maffeis V.,2019, Carbon nano-onions: A valuable class of carbon nanomaterials in biomedicine. Current Medicinal Chemistry; 26:6915–29.

[14] Kapat K, Zhou QTHSM, Leeuwenburgh S., 2020, Piezoelectric Nano-Biomaterials for Biomedicine and Tissue Regeneration, Adv. Func. Mater. 30:1909045.

[15] R. Samson, G. R. Navale, M. S. Dharne, 2020, Biosensors: frontiers in rapid detection of COVID-19,3 Biotech, 10, 385.

[16] E. Morales-Narváez, L. Baptista-Pires, A. Zamora-Gálvez, A. Merkoçi, 2017, Graphene-Based Biosensors: Going Simple, Adv. Mater., 29, 1604905.

[17] P. Suvarnaphaet, S. Pechprasarn, 2017, Graphene-Based Materials for Biosensors: A Review Sensors, 17, 2161.

[18] S. Taniselass, M. M. Arshad, S. C. Gopinath, 2019, Graphene-based electrochemical biosensors for monitoring noncommunicable disease biomarkers, Biosens. Bioelectron. 130, 276.

[19] T. Terse-Thakoor, S. Badhulika, A. Mulchandani, 2017, Graphene based biosensors for healthcare, J. Mater. Res., 32, 2905.

[20] J. Peña-Bahamonde, H. N. Nguyen, S. K. Fanourakis, D. F. Rodrigues, 2018, Recent advances in graphene-based biosensor technology with applications in life sciences, J.Nanobiotechnol. 16, 75.

[21] J. Sengupta, C. M. Hussain, 2021, Graphene-based analytical lab-on-chip devices for detection of viruses: A review,Carbon Trends 2, 100011.

[22] G. Seo, G. Lee, M. J. Kim, S. - H. Baek, M. Choi, K. B. Ku, C. - S. Lee, S. Jun, D. Park, H. G. Kim, S. - J. Kim, J. - O. Lee, B. T. Kim, E. C. Park, S. I. Kim, 2020, Rapid Detection of COVID-19 Causative Virus (SARS-CoV-2) in Human Nasopharyngeal Swab Specimens Using Field-Effect Transistor-Based Biosensor, ACS Nano, 14, 5135.

[23] S. Y. Chen, K. Yang, X. Y. Leng, M. S. Chen, K. S. Novoselov, D. V. Andreeva, 2020, Polym. Int., 69, 1173.

[24] H. Jeong, J. A. Rogers, S. Xu, 2020, Continuous on-body sensing for the COVID-19 pandemic: Gaps and opportunities, Sci. Adv. 2020, 6, eabd4794.

[25] S. Afroj, M. H. Islam, N. Karim, 2021, Multifunctional Graphene-Based Wearable E-Textiles,Proceedings, 68,11.

[26]N. Karim, S. Afroj, D. Leech, A. M. Abdelkader, In Oxide Electronics, Wiley, Hoboken, NJ 2021, pp. 21–49.

[27] N. Karim, S. Afroj, S. Tan, P. He, A. Fernando, C. Carr, K. S. Novoselov,2017, Scalable Production of Graphene-Based Wearable E-Textiles, ACS Nano, 11, 12266.

[28] S. Afroj, N. Karim, Z. Wang, S. Tan, P. He, M. Holwill, D. Ghazaryan, A. Fernando, K. S. Novoselov,2019, Engineering Graphene Flakes for Wearable Textile Sensors via Highly Scalable and Ultrafast Yarn Dyeing Technique, ACS Nano, 13, 3847.

[29] A. M. Abdelkader, N. Karim, C. Vallés, S. Afroj, K. S. Novoselov, S. G. Yeates, 2017, Ultraflexible and robust graphene supercapacitors printed on textiles for wearable electronics applications 2D Mater., 4, 035016.

[30] S. Afroj, S. Tan, A. M. Abdelkader, K. S. Novoselov, N. Karim, 2020, Highly Conductive, Scalable, and Machine Washable Graphene-Based E-Textiles for Multifunctional Wearable Electronic Applications. Adv. Funct. Mater., 30, 2000293.

[31] L. Liao, W. Xiao, M. Zhao, X. Yu, H. Wang, Q. Wang, S. Chu, Y. Cui, 2020, Can N95 Respirators Be Reused after Disinfection? How Many Times? ACS Nano, 14, 6348–6356. DOI: https:// doi.org/10.1021/acsnano.0c03597.

[32] N. El-Atab, N. Qaiser, H. Badghaish, S. F. Shaikh, M. M. Hussain, 2020, Flexible Nanoporous Template for the Design and development of Reusable Anti-COVID-19 Hydrophobic Face Masks, ACS Nano, 14, 7659–7665. DOI: https:// doi.org/10.1021/acsnano.0c03976.

[33] S. Kumar, R. Nyodu, V. K. Maurya, S. K. Saxena, 2020, Coronavirus Disease 2019 (COVID-19): Epidemiology, Pathogenesis, Diagnosis, and Therapeutics, (Ed: S. K. Saxena), Springer Singapore, 23–31.

[34] H. Zhong, Z. Zhu, J. Lin, C. F. Cheung, V. L. Lu, F. Yan, C.-Y. Chan, G. Li, 2020, Reusable and Recyclable Graphene Masks with Outstanding Superhydrophobic and Photothermal Performances, ACS Nano, 14, 6213–6221. doi: https:// doi.org/10.1021/acsnano.0c02250.

[35] www.bonbouton.com/graphene-mask
[36]https://statnano.com/news/67657/A-COVID-19-Virucidal-Graphene-based-Composite-Ink-for-More-Effective-PPE
[37]https://grapheneindustry.org.au/2020/05/g-volt-mask/
[38] A.C. Ferrari, et al., Science and technology roadmap for graphene, related two-dimensional crystals, and hybrid systems, Nanoscale 7 (11) (Mar. 2015) 4598e4810, https://doi.org/10.1039/C4NR01600A.
[39] Virus Capture and Destruction by Label-Free Graphene Oxide for Detection and Disinfection Applications - Song - 2015 - Small - Wiley Online Library'. https://onlinelibrary.wiley.com/doi/abs/10.1002/smll.201401706
[40] M. G. Stanford, J. T. Li, Y. Chen, E. A. McHugh, A. Liopo, H. Xiao, J. M. Tour, 2019,ACS Nano, 13, 11912–11920. doi: https://doi.org/10.1021/acsnano.9b05983
[41] Y. L. F. Musico, C. M. Santos, M. L. P. Dalida, D. F. Rodrigues, ACS Sustainable Chem. Eng. 2014, 2, 1559–1565. doi: https://doi.org/10.1021/sc500044p
[42] Z. Song, X. Wang, G. Zhu, Q. Nian, H. Zhou, D. Yang, C. Qin, R. Tang, Small 2015, 11, 1171–1176. doi: https://doi.org/10.1002/smll.201401706
[43] K. A. Mahmoud, B. Mansoor, A. Mansour, M. Khraisheh, Desalination 2015, 356, 208–225.doi: https://doi.org/10.1016/j.desal.2014.10.022.
[44] J.K. Tiwari, A. Mandal, N. Sathish, A.K. Agrawal, A.K. Srivastava,2020, Addit. Manuf. 33, 101095, https://doi.org/10.1016/j.addma.2020.101095.
[45] M. Fischer, D. Joguet, G. Robin, L. Peltier, P. Laheurte,2016, Mater. Sci. Eng. C Mater. Biol. Appl. 62,852e859, https://doi.org/10.1016/j.msec.2016.02.033.
[46] A.E. Jakus, E.B. Secor, A.L. Rutz, S.W. Jordan, M.C. Hersam, R.N. Shah, 2015, ACS Nano 9 (4) 4636e4648, https://doi.org/10.1021/acsnano.5b01179.
[47] 3D Printing Service for on Demand Manufacturing', 3D Systems, Mar. 01, 2017. https://www.3dsystems.com/on-demand-manufacturing
[48] S. Ye, et al., 2015,Antiviral activity of graphene oxide: how sharp edged structure and charge matter, ACS Appl. Mater. Interfaces 7 (38) 21571- 21579, https://doi.org/10.1021/acsami.5b06876
[49] Hashmi, A. et al. 2022,Potentialities of graphene and its allied derivatives to combat against SARS-CoV-2 infection", Materials Today Advances, 13, p. 100208.https://doi.org/10.1016/j.mtadv.2022.100208