# Graphene-based Flexible and Stretchable Bioelectronics in Health Care Systems

**Abstract**

The objective of this short review is to summarize the recent applications of graphene in the field of flexible and stretchable bioelectronics. The review highlights the current developments in graphene and graphene hybrid based bioelectronics and their properties (in terms of stretchability and conductivity), challenges and future perspectives.

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## Introduction

Nanomaterials are playing a vital role to meet increasing demand of bioelectronics devices in health care system. In this context, different kind of nanomaterials has been examined. In recent years emergence of 2-D nanomaterials like graphene have been largely explored in various technological application including bioelectronics. Current mini review provides a meaningful insight towards potential application of graphene in developing efficient flexible and stretchable bioelectronics devices in healthcare system.

Efficient bimolecular detection is very important for biomedical, environmental, as well for security purposes. This has been become possible by means of efficient analytical devices or by biosensors. In recent years, biosensors research has been largely explored in the area of biomedicine, environmental screening in safety. Although the existing biosensing technology is contributing well in the concerned area, even though there is large scope to improve their performance for better outcomes. The application of biosensors in general public health care system needs to be largely addressed. Since the discovery of field effect transistor in the 1920s, there is tremendous efforts have been made in electronic industries to develop devices with high speed and large capacity (such as microprocessors and random access memories). Recent growth of personalized and mobile electronics has expanded and tuned the research domains in electronics from performance-oriented to more in human health care topics [1]. Thus, further expansion of electronics in developing flexible and stretchable biomimetic systems have been initiated [2]. As results, in short period of time, the market size of health care gadgets is significantly increased with further expectations of more improved medical devices [3].

The high expectations of the flexible electronics in healthcare system are due to their high flexibility, inexpensive substrate material and low-cost of manufacturing etc. However, the stretchability was the only limitations with flexible devices [4], which have been overcome by incorporating inorganic and organic nanomaterials [5-9]. Thus flexible and stretchable devices have become a powerful alternatives to bulky health-monitoring devices. Nanomaterials enabled flexible and stretchable bioelectronics devices have attracted significant interest in healthcare applications. It is due to the several unique features of nanomaterials including medical multifunctionality, mechanical deformability, and other excellent properties etc [9]. Nanomaterials with superior properties for e.g. large surface areas, high mechanical strength, and high electronic conductivity, are highly compatible for developing more efficient and large-scale flexible and stretchable electronic devices [10,11]. Till date, application of nanomaterials as stretchable interconnects or conductors is reported, while stretchable and flexible active device components based on nanomaterials [12,13] remains as an emerging area of research. Continuous efforts are being made to utilize novel properties of nanomaterials in health care bioelectronics. Several nanomaterials have been explored in developing efficient diagnostic systems [14] and other are under exploration. The currentshort note provides a summary of application of graphene, a 2-D carbon nanomaterial, in flexible and stretchable electronic devices.

## Graphene-Based Stretchable and Flexible Devices

Polydimethylsiloxane (PDMS), an elastomer has been widely used in the substrate for incorporation of nanomaterials for developing flexible and stretchable bioelectronic devices. A composite of nanomaterials and PDMS can also be made to enhance the stretchability and flexibility of the devices.

Graphene, a 2-D layered material (an allotrope of carbon), possesses unique features, have made a tremendous impact in the field of nanoscience and technology. Discoverer of graphene received Nobel Prize in Physics in the year 2010. Since its discovery by mechanical exfoliation of graphite [15,16], graphene has become a material of central interest due to its unique 2-D layered structure, and its unique physic-chemical properties, for e.g. excellent electron mobility, high chemical and thermal stability, ultra-high strength, large specific 2-D surface area, and low contact resistance with organic electronic devices [17]. Innumerable applications of graphene have been demonstrated, such as in electrochemical sensors and biosensors, polymer composites, field-effect transistors and organic electronic devices, and energy conversion and storage devices [18]. Numerous methods have been established for e.g. epitaxial growth on SiC [19,20] and metal surfaces [21], reduction from graphite oxide [22], liquid-phase exfoliation [23] and Chemical Vapor Deposition (CVD) [24]. However, CVD is comparatively simple and feasible method for large scale production high-quality graphene. Synthesized graphene can be transferred onto random substrates with the help of range of polymers like PDMS [25], poly(methyl methacrylate) (PMMA) [26] or thermal release tape [27]. The transferred graphene films displayed a high quality and sheet resistance of ca. 30Ω $sq^{-1}$ at ca. 90% transmittance was realized for p-doped 4-layered graphene.

## Fabrication of Graphene Devices and Properties

Comparatively high transparency and good electrical conductivity of graphene make it a promising candidate as transparent electrodes [28]. Large-scale, patterned synthesis of high-quality graphene by CVD method and its effective transfer onto different substrates is reported [25]. The graphene film was transferred to biaxially prestrained PDMS (ca. 12% strain) to enhance electromechanical stability. Both longitudinal and transverse resistance remained stable within 11% tensile strain and increased by one order of magnitude at ca. 25% strain after releasing the PDMS. Alternatively, to make stretchable graphene film, one need to grow the graphene on wavy Cu foil (instead of the planar one), followed by drop-casting PDMS and etching the Cu foil [29]. The resulting graphene/PDMS showed transmittance between 50% and 60%. Coating of another layer of PVA on top of the graphene largely suppresses the creation of cracks during stretching and thus enhanced the stretchability. The resistance of PVA coated graphene/PDMS is increased by ~2 times under tensile strain of 40%. Self-organized, crumpled hierarchical structures can be formed by sequentially releasing the biaxially prestrained VHB 4905 substrate with a graphene film on top along the two prestrain directions [30]. The crumpled structure can be "unfolded when stretching the substrate back in both directions. The crumpled graphene conductor can accommodate an extreme strain of 450% along the direction with the higher prestrain, with unequal prestrains of 10% and 500%.The crumpled make graphene super hydrophobic. And the wettability and optical transmittance of the graphene can be tuned by reversible crumpling–unfolding process. Further, 3-D macroscopic graphene foams (GFs) were synthesized by a template-directed CVD using nickel foam as a template [31]. The well-interconnected 3D conducting network in GFs, the GF/PDMS composite with low graphene loading of ca. 0.5 wt% have shown good conductivity of ca. 10S $cm^{-1}$ and high fracture stain of ca. 95%. After being treated by five cycles of stretching, the resistance increased ca. 30% under 50% tensile strains.

## Fabrication of Devices using Graphene–Hybrid Materials and their Properties

Doping of foreign atoms in graphene improves its electrical properties. Several methods of doping have been introducing, to enhance the conductivity of graphene, such as chemical doping [32], introducing CNTs [33] and metal nanostructures (e.g. depositing on top of graphene or mixing with graphene) [34] etc. Moreover, Graphene–Ag hybrid fibers were synthesized by the wet-spinning process and subsequent chemical reduction, and they exhibited enhanced conductivity and current capacity ([35]. Ag-doped graphene fibers transferred onto PDMS pre-strained by 150%, the conductivity was maintained for strains within 150%. Conductivity of graphene has been further enhanced by spin-coating a thin layer of AgNW network on its top, where the conducting pathways of the graphene and AgNWs function complementary to each other, and overcome to charge scattering by defects in grapheme [36] and as results, a low resistance of 33Ω $sq^{-1}$ at a high transmittance of 94% was obtained. Graphene–AgNW on PDMS have shown a large strain tolerance of 100% with negligible resistance degradation, in addition, the hybrid structure showed a much higher breakdown electric field and better stability against thermal oxidation compared with pure AgNWs. Apart from the graphene, other 2-D layered materials like $MoS_2$, $WS_2$, and $VS_2$ are under evaluation for their further application in flexible and stretchable devices.

## Challenges

For efficient application of graphene in developing flexible and stretchable bioelectronics systems, some specific challenges need to be thoroughly addressed:

a. Facile integration technology of graphene in bio-electronic devices.

b. Through interaction study of graphene with supporting substrate.

c. Through characterization of graphene-based bioelectronics devices in extreme conditions.

## Conclusion

Increasing demand for flexible and stretchable electronic devices in health care system accelerated the development of more efficient bioelectronics devices. Incorporation of nanomaterials for developing novel bioelectronics devices provides immense opportunities for advanced diagnostics and drug delivery. 2-D layered materials like graphene along with other upcoming materials have huge potential for significantly improving the performance of existing devices. The Huge potential of nanomaterials based flexible and stretchable bioelectronics needs to be thoroughly investigated especially for health biosystem. Nanomaterials enabled flexible and stretchable bioelectronics devices may lead to significant expansion and application of these devices in healthcare system.

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Dr. Vinod Kumar is a postdoctoral scientist at Ben-Gurion University of the Negev, Israel. He received his PhD in Nanobiotechnology from Banaras Hindu University, India in 2014. His current research interest focuses on design and development of nanomaterial based high efficient flexible and stretchable point of care devices for early and accurate screening of disease biomarkers.

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