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Bioapplications of graphene constructed functional nanomaterials

Arif Gulzar [a, *], Piaoping Yang [a, b, **], Fei He [a], Jiating Xu [a], Dan Yang [a], Liangge Xu [a], Mohammad Omar Jan [b]

[a] Key Laboratory of Superlight Materials and Surface Technology, Ministry of Education, College of Material Sciences and Chemical Engineering, Harbin Engineering University, Harbin, 150001, PR China
[b] Harbin Medical University, Harbin, PR China

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ABSTRACT

Graphene has distinctive mechanical, electronic, and optical properties, which researchers have applied to develop innovative electronic materials including transparent conductors and ultrafast transistors. Lately, the understanding of various chemical properties of graphene has expedited its application in high-performance devices that generate and store energy. Graphene is now increasing its terrain outside electronic and chemical applications toward biomedical areas such as precise bio sensing through graphene-quenched fluorescence, graphene-enhanced cell differentiation and growth, and graphene-assisted laser desorption/ionization for mass spectrometry. In this Account, we evaluate recent efforts to apply graphene and graphene oxides (GO) to biomedical research and a few different approaches to prepare graphene materials designed for biomedical applications and a brief perspective on their future applications. Because of its outstanding aqueous processability, amphiphilicity, surface functionalizability, surface enhanced Raman scattering (SERS), and fluorescence quenching ability, GO chemically exfoliated from oxidized graphite is considered a promising material for biological applications. In addition, the hydrophobicity and flexibility of large-area graphene synthesized by chemical vapor deposition (CVD) allow this material to play an important role in cell growth and differentiation. Graphene is considered to be an encouraging and smart candidate for numerous biomedical applications such as NIR-responsive cancer therapy and fluorescence bio-imaging and drug delivery. To that end, suitable preparation and unique approaches to utilize graphene-based materials such as graphene oxides (GOs), reduced graphene oxides (rGOs), and graphene quantum dots (GQDs) in biology and medical science are gaining growing interest.

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* Corresponding author.
** Corresponding author.
E-mail addresses: arifgulzar@hrbeu.edu.cn (A. Gulzar), yangpiaoping@hrbeu.edu.cn (P. Yang).

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1. Introduction

Ever since its first serendipitous, nevertheless historical discovery by British scientists in 2004[1], graphene has engrossed momentous attention of researchers from all fields of science for exploiting many of its unique properties. One of the key research concentrations have been replacing indium tin oxide (ITO) with large-scale, high-quality chemical vapor deposition (CVD) graphene for macroscopic applications such as flexible thin films for transparent electrodes. Further studies in the fields of electronics, physics, and materials science have also been broadly explored [2]. In recent times, given a growing consensus on graphene's environmentally-friendly features, researchers have deliberated engaging graphene in other branches of science such as biology and medicine. Researchers have predominantly concentrated on utilizing the capability of graphene oxides (GOs) to quench fluorescence and the readiness of their functional groups for molecular conjugation for several optical bio-sensing studies. In 2009, Lu et al. efficaciously detected fluorophore-labeled DNA on/off the basal plane of GOs [3]. This work was followed by spotting other small molecules such as phosphate containing metabolites, protein kinases, trypsin and neurotransmitters with appropriate surface modulations [4]. A latest report by Mei et al. demonstrated that logically designed GO gates could discriminate Fe^{3+} and Fe^{2+} in living cells by take advantage of the difference in fluorescence quenching [5]. Various researchers dedicated special courtesy to uncommon characteristics of stem cell growth and differentiation on graphene film substrates, which could probably open new venues in stem cell engineering [6]. Besides, extraordinary optical absorbance of GOs, reduced graphene oxides (rGOs) and graphene quantum dots (GQDs) in the near-infrared (NIR) region expedite selective photothermal/photodynamic applications, making graphene a favorable multipurpose therapeutic tool. Especially, researchers have demonstrated that malignant tumor cells can be directly ablated using NIR-responsive photothermal therapy [7]. Graphene centred materials have also been engaged to assist in several photodynamic therapies, certain display the chance of combining graphene-based photodynamic agents with either photothermal therapies or chemotherapies [8]. Further studies have employed graphene hyperthermia as an external prompt for efficient and controlled gene/drug delivery either by disrupting an endosome or a drug containing matrix [9]. Graphene materials comprising of exclusively carbon are acknowledged to be non-toxic; still, it is a matter of grave concern to know how carbon derivatives like graphene decay in a biological system and how long it takes to excrete them from the biological system [10]. Though, throughout fabrication, graphene or sources of graphene commonly experience numerous chemical treatment progressions for functionalization, comprising doping with metals, oxidation introduction of functional groups and also reduction [11]. This designates that some of the graphene derivatives deliberated for bio-applications contain metals and/or impurities other than carbon. For example, graphene quantum dots contain around 10%–40% oxygen and 60% carbon. The presence of excess oxygen is one of the standard features that augments the solubility of graphene quantum dots and impart optical properties to them. Furthermore, different graphene derivatives have different chemical properties with different functionalities and applications, thus they exert different toxicities [12]. Yet very inadequate studies have recently been conducted to detect the mechanisms of toxicology of graphene derivatives, especially of GO due to oxidative stress; no universal mechanism has been established yet [13].Table 1

Besides the studies deliberated above, dispersed graphene derivatives are recognized to demonstrate exceptional characteristics suitable for multipurpose imaging applications. Even though technical innovations in science have generated different ways for appreciating diverse cellular/subcellular proceedings on highly sophisticated levels, the real time imaging with sufficiently high temporal and spatial resolutions still remains reasonably thought-provoking in many aspects. Simultaneously developing effective and stable fluorescent probes has been and remains to be one of the most important tasks in fluorescence bioimaging. Similarly, other imaging tools such as Raman spectroscopy, which exploits scattered light derived from the vibrational excitation mode of molecules, necessitates adequate imaging agents for creating clear and sharp signals. By the virtue of the exclusive properties of graphene-based materials, they are becoming gradually spotlighted as versatile imaging tools for assisting in both optical and nonoptical imaging studies. Our goal here is to review the status of current research on graphene-based imaging studies and drug/gene

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