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Review

Insights Focused on Hybrid Graphene Modifications within the Nanoscale for Opto-Electronics Perspectives

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Abstract

This brief letter presents this Special Issue nominated as "Hybrid Graphene-based Materials: Synthesis, Characterization, Properties, and Applications". This intends to show and discuss the main properties of Graphene and its derivatives; and how it could be synthesized, modified and tuned for Optics, Electro-Optics, Electronics, and Quantum characteristics. In this context, the synthesis and chemical modifications were highlighted for the design of Hybrid composites, platforms. In this context, it was afforded to varied developments within Multidisciplinary fields for high-impact Research and applications. In this manner, Graphene joined to other organic and inorganic materials showed different properties compared to free and non-modified Graphene. This fact, permitted to tune of electronic properties through materials that were transferred to applications. For example, the high electronic density could generate pseudo-electromagnetic fields and other phenomena such as luminescence, electronic conductions, and specific Quantum states that could be joined to optical active materials. Thus, it was afforded to the discussion and introduction in this other Research field as well. In this manner, it was intended to afford an overview of the high-impact Research and potential perspectives of Hybrid Graphene materials.

Keywords

Design of hybrid materials; quantum emissions; nanoelectronics; hybrid nanomaterials; graphene derivatization; graphene properties; carbon allotropes; carbon-based materials

1. Insights of Graphene Properties towards Tuning Optical Active Materials

Graphene is a highly conjugated chemical structure with highly dense and close electronic orbitals interacting with their close surroundings. It affords electronic waves moving on both sides of planes that show interesting chemical and physical properties [1]. Similarly, benzene, anthracene and related compounds with their sp2 orbital are responsible for the major number characteristics associated with chemical reactivity and interactions [2]. However, Graphene and derivatives with a major extension of a periodic and well-ordered carbon-based structure could lead to additional properties and different Optical and electronic behaviors [3]. Thus, theoretical calculations modeled unities of excited cells with spectra schema in terms of Optical fields and scattering field formulations. In this manner, Graphene itself showed sub-cell types for a complex surface conductivity defined by several quantum mechanics equations. These properties showed time domain dependencies and promising coincidence with those acquired from analytical close expressions and experimental recordings.

In this way, and in order to understand how these periodical properties of multi-quantum energy modes are generated, the particular properties of reduced sizes of conjugated benzene rings and derivatives should be first be known. In this manner, the Electromagnetic fields produced from electronic densities in the movement are a pole of attraction and induction of electronic modification in their close sour rounding. And, in this context, improved explanations and effects of aromaticity are still being discussed based on recent experimental and theorical studies. Therefore, it could be highlighted a recent report focused on the well-known property of aromaticity related to highly dense and conjugated electronics on cyclic planar carbon-based structures. It was shown that this property is not as homogeneous as it is believed. This new characteristic was inferred from the Huckles rule not being completely applied to structures such as polycyclic systems such as pyrene and larger chemical structures such as Nanograpehene.

These larger surfaces from thin Carbon based slides permitted tuning other 3D structures generating new chemical and physical properties. Thus, wrapped graphene Nanostructures affected the local and global aromaticity generating electronic circuits within their structures [4]. Key indicators to measure the extent of aromaticity were calculated. Therefore, it was determined the aromatic fluctuation index (FLU), the harmonic oscillator model of aromaticity (HOMA), the electron density of delocalized bonds (EDDB), and the gauge including the use of magnetically induced current (GIMIC) method. By the analysis of FLU, related with values close to zero to be the greatest aromatic characteristics, abnormal electronic delocalization was observed and described as molecular circuits. It should be mentioned that Aromaticity cannot be measured directly by any physical or chemical experiment because it is not a well-defined magnitude. However, it could be quantified by Aromaticity descriptors [5] determined from different properties usually found in aromatic compounds such as bond length equalization, energetic stabilization, and particular magnetic behavior associated with induced ring currents. These properties have been used to set up the myriad of structural-, energetic-, and magnetic-based indices of aromaticity known to date. And these studies are relatively new, highlighting the last decade that electron delocalization measures have been widely employed to quantify aromaticity, reevaluate properties, explain them, and predict new ones.

In addition, the flexible characteristics of these 2D carbon-based materials led to electronic encountering and interferences between them. Thus, 2D dimensional quantum materials offer a robust platform for investigating broken ordered phases that could lead to highly controlled and tuneable electronics and quantum properties. This, control of thin molecular slide dimensions created new electronic band structures in graphene through moiré superlattices [6] interactions between stacked and twisted forms [7]. Therefore, it led to the discovery of new topological phases and correlations between them. In brief, and as an example, a topological quantum state of Graphene that were different and modified by just twisting their planar structure [8]. But, it should be noted the elastic properties from C-C bonds are described by expressions of Young's modulus contemplating mechanical deformations mechanism. These properties explained the capability of special tips to manipulate them and finally generate different properties and opened further queries about this material.

So, Graphene with a zero bandgap energy structure provided superior optical and optoelectronics uses. But, in addition, from twisted twisted and bilayer forms formed twisted angles and asymmetrical lattices generated augmented optical absorption with consequent better photoelectrical performances [9], faster photochemical reactions [10], and Nanoscale photonic crystal structures [11].

Moreover, the generation of pseudo-Electromagnetic fields in controlled conditions from varied Graphene-based materials produces additional mechanisms of physical interactions with consequent electronic modifications in its surrounding [12]. It studied electronic interactions between graphene and reagents within typical reactions from where it was inferred that strong electromagnetic fields in the order of $\times 10^7$ V/cm were responsible for enzyme catalytic effects.

In addition, different strategies and Optical setups were shown enhanced electronic and quantum conductions through tuned materials [13]. In this context, it should be highlighted that pure Graphene as well as joined to other Optical active materials [14], always played the main role where electronic flow showed particular behaviors improving and enhancing tracked properties.

From the perspective of tuning new properties of Graphene materials, it should be noted that quantum emissions from Graphene Quantum dots [15, 16] could be coupled to other different Optical properties. In this manner it could be produced new Optical miniaturized instrumentation such as Organic Light Emitter Devices (OLEDs) [17] and related non-classical light emitters [18]. In addition, and tuning electronic densities towards other applications, their applications to chemical catalysis showed interesting perspectives [19]. Moreover, it showed as well the impact of electronic densities on other molecular electron active species within variable intervals of lengths from the molecular level towards the Nanoscale. Thus, after being measured spectroscopical signal modifications from these close interactions by combining different Optical active materials, new strategies and perspectives in Nano-Optics were opened. This mention could appear from a brainstorming node. However, it is the beginning of the actual state of knowledge to begin new proposals and thinking in new molecular and Nanostructured approaches. Further studies, even considering this material as inert and non-reactive, permitted the first insight into non-covalent interaction with ions and related charged molecular structures for potential applications towards new analytical chemistry methods [20].

Conceptually, the design of new Graphene structures could be resumed in different manners and varied strategies. For example, joining different sizes of high conjugated carbon-based structures, with molecular tails and varied atomic compositions to achieve and control de Nanoscale (Figure 1a). This is the ongoing challenge from the prototyping point of view to the bench of the Laboratory. Then, these Nanoarchitectures could be added on modified substrates to test new approaches within Optoelectronic devices (Figure 1b). In this way, there are many ongoing Research works and high-impact expectations within Metamaterials.,

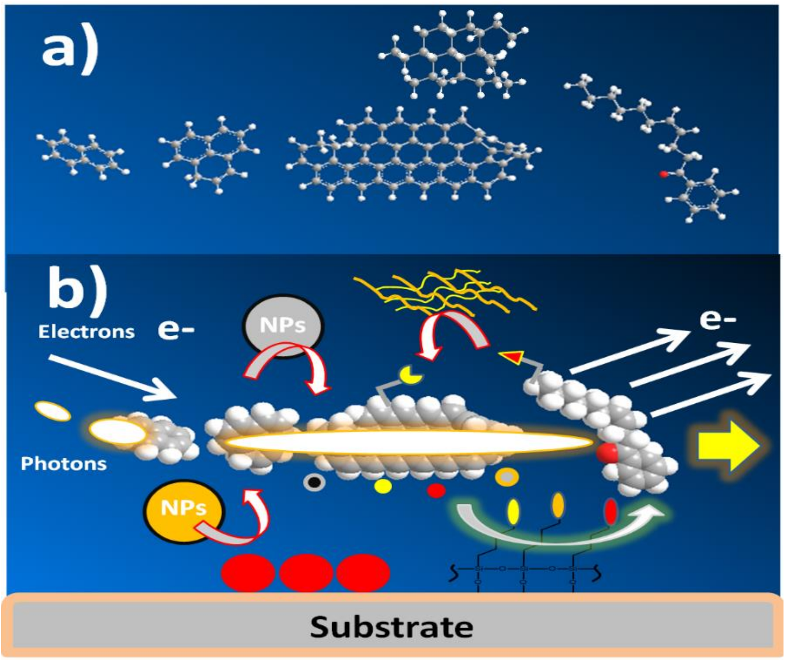

Figure 1 Schematic Hybrid Graphene design: a) varied high conjugated Carbon based structures could be considered to be added on different Graphene structures within the Nanoscale. Prototyping the tuning of Nano-graphene; b) Modifications of Nano-graphene structures with Nanoparticles (NPs), Polymers, high conjugated Carbon based structures, and molecular spacers joined to Optical active molecules. These modified could be attached on modified substrates with Nanostructure patterns and Opto-electronic active materials. Different colors represent different Opto-active properties and functions. From these modified structures it is expected varied Optical active behaviors as well as the generation of new properties and applications. Reprinted with permissions from A. G. Bracamonte et al. 2023 (cite Research work in progress).

So, the well-known properties and the new ones developed open innovative expectations within the knowledge transferred to the next generation of related experiments and studies. And, these characteristics are highlighted for potential developments within varied Research fields and related applications. However, it should be noted that not so many fundamental Research studies were transferred to real applications, but this is the current state of the art looking for new properties generated from the atomic and molecular level towards larger sizes and dimensions.

In this direction, it is very important to know about the experimental part and design of Nano architectures that could afford new carbon based materials [21]. And, it should be noted that today, there is a large view toward Hybrid Nanomaterials [22, 23] from where the synthesis and modifications of Graphene and derivatives [24] are required upon needs. In this regard, the next section showed and discussed Research developments focused on these interests. And, how it could be translated from the Laboratory Book to the bench, and then towards applied Optical active materials [25, 26].

2. Development of Functional Materials Based on Graphene and Derivatives

In this section it was discussed about applications of Graphene properties from the current status of recent publications. In this regard, it is intended to show how it was possible to transfer properties discovered from fundamental studies within varied applications available on the market [27]. Thus, it is also assayed to highlight the impact of Graphene as a semiconductor [28] with a particular chemical organic structure in conjunction with other electro-active materials [29]. In this manner, it looks like it is fundamental Research, but it is not all. They are already incorporated within materials for the fabrication of support materials [30], functional devices [31], conductors [32], and instruments [33, 34]. Therefore, Graphene-based composites are beyond expectations from characterization and discussion related to generating new properties. In this regard, recent reports in the market, could be highlighted; i) Graphene-based materials for energy [35], ii) storage and harvesting applications [36]; iii) incorporation within paints [37], iv) modified coating [38], v) INKs applications such as wireless connections [39], vi) conductive INKS [40], vii) Nano-electromechanical systems [41], viii) Electronic applications within micro-electronics devices and instruments [42], ix) Graphene supplies for batteries [43], x) Nanomaterials and materials for catalysis uses [44], and due to their inert properties and high resistive characteristics as well incorporation within support type materials as xi) tire fabrications and rubber industry [45, 46]. And in this context, it should be highlighted the awarded Nobel in Prize in Chemistry for the United Kingdom (UK) 2010 “for groundbreaking experiments regarding the two-dimensional material graphene” [47]. From this discovery and knowledge based on fundamental Research, another source of opportunities was opened worldwide that provided new and further developments. This huge open window of opportunities was based on properties such as transparency (up to nearly 98%), conductivity of electricity, pseudo-Electromagnetisms, and quantum properties. In this manner, later it was proposed to be incorporated into the next generation of technology.

In this regard, the production of transparent touch screens, light panels and solar cells is noted. And these incorporations could be considered the strongest insights with daily technology used worldwide in continuous expansion. Similarly, plastics could be made into electronic conductors if only 1% of graphene is incorporated. So, just by mixing a fraction of graphene per mile, the heat resistance of plastics would increase by 30°C; while at the same time, it makes them more mechanically robust. This resilience could be utilized in new super-strong materials, which are also thin, elastic and lightweight [48].

In this long-standing way it is highlighted as well the incorporation of Graphene in the automotive Industry thinking to light weigh cars and incorporation of new energy fuels and related technology, as well as advanced electronics semiconductive circuits [49]. In this context, it should be highlighted aerospace technology [50], military and defense, by varied materials such as from support to optical wearables and sensing applications [51]. These themes and topics are mentioned to open readers' interest. It is not intended to afford a detailed discussion in this article; however, these key points of development must be communicated in progress. Thus, the young and advanced Researchers that expect to work with Graphene and derivatives could have an overview and expectations of these materials.

3. Discussions and Future Perspectives

As it could be shown from previous insights of new studies focused on already well-known properties such as aromaticity, there is existing current fundamental Research looking for potential transfer of knowledge towards real applications. In this way, it should be noted that the incorporation of Carbon-based materials within Microelectronics related to electron transfers through spaces and time was very well accomplished from the market. However, at the same time, this material could be considered very strong and non-reactive against other materials. Thus, it is found within support materials, paints, and flexible polymeric films. In all the mentioned examples, the cohesion of atoms by their electronic waves provided the particular properties and interactions with their media that generated homogeneous electronic movements improving by this manner of electronic conductions. .Similarly, incorporating very stable lattices with controlled sizes and shapes provided particular behaviour to liquid and in flow products. Moreover, as expected electronic waves afforded to non-covalent interactions with the surrounding media permit molecular adsorption and catalysis of reactions as well as molecular detection based on variation of electrical signalling. In this context, electrical signal modifications should be highlighted to track single DNA aptamers within low genomic concentrations in optimal conditions for sequencing applications. So, there are still existing possibilities none explored yet from fundamental Research towards high-impact Research applications. Similarly, the generation of non-classical light and visible classical light showed higher performances in the presence of semiconductive materials. Thus, Graphene with its intrinsic high rigid chemical structures accompanied by size and shape control could generate varied quantum properties and emissions. The most well-known light devices used today are LEDS and O-LEDs which are very well placed on the market. However, there are still existing many challenges and limitations related to quantum yields . Thus, Graphene could be incorporated to test new non-classical light pathways.

In order to improve and propose new Opto-electronics behaviors in the different mentioned applications based on new properties; there is a focused interest on the control of the Nanoscale and the Quantum scale. From these scales, varied chemical structures could be joined considering the design from the molecular tuning towards multi-layered additions and formation of 3D Nanostructures (Figure 2). Optical interferences, electronic modifications and enhanced Photonics are being developed, as well as metamaterial signalling where the origin of the recorded signal phenomenon is not clearly defined.

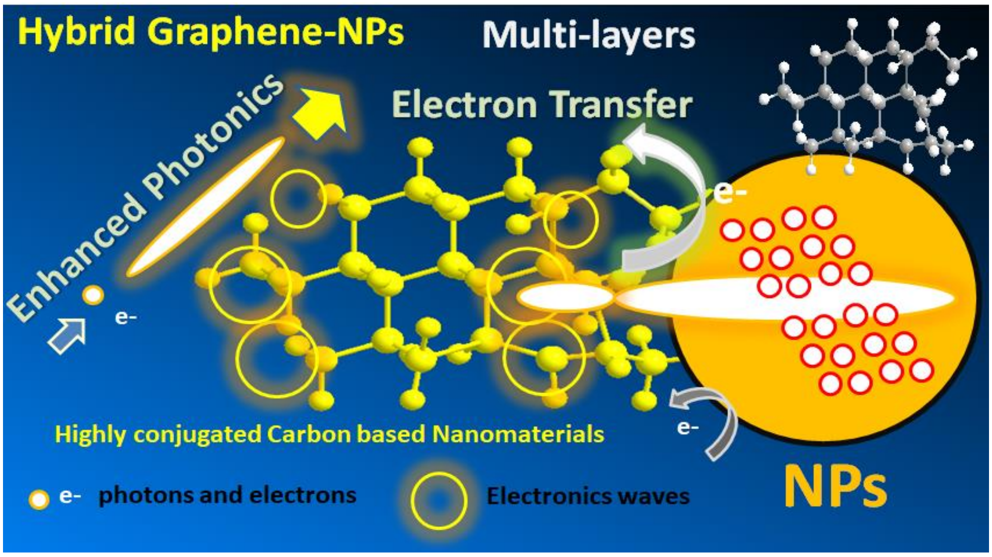

Figure 2 Small Nano-graphene deposition on Optical active Nanoplatforms to develop new Hybrid Graphene Nanoarchitectures. The design here is focused on the Nanoscale and beyond but considering the design from the molecular modification towards the Nanoscale by multi-layered modifications. Optical interferences, electronic modifications and enhanced Photonics are expected to develop. Reprinted with permissions from A. G. Bracamonte et al. 2023 (cite Research work in progress).

It is important to know about Enhanced phenomena that the interaction of Electromagnetic field with matter could produce enhanced spontaneous emissions, as described early by Purcell et al. from metallic micro-particles [52]. Then, the development of the Nanoscale and tuning Nano-Optics afforded to confined Micro-, and Nano-Resonators [53] where enhanced high Electromagnetic Energy fields were generated from their interactions. In this regard, Hybrid Organic/Inorganic composites could lead to new and improved Optoelectronic properties such as by incorporating Graphene and derivatives as electron shuttles and additional sources of Pseudo-Electromagnetic fields within modified Photonics substrates.

In this manner, the perspectives generated from real products and needs, with the incorporation of Graphene, open new opportunities and hypotheses of work in Fundamental Research but with direct consequent use. And from this idea, or observation the proposal to breakthroughs is large. And that is considering the previous mentions and associated challenges. In this regard, the manipulation of Graphene layers to Multi-layered depositions on surfaces, layer wrapping, and all other types of physical manipulations was afforded with external tip interactions. In these types of non-covalent interactions are involucred the polarization of Graphene by inhomogeneous electronic distributions is produced when tips are in close contact [54]. Therefore the modifications afforded to planar inter-layer interactions and wrapped structures. These electronic interactions showed enhanced properties based on constructive electronic waves from which photo-chemical processes and quantum phenomena are not produced as expected [55]. So, new phenomena could be generated as it is a new and different material. These previous mentions could be considered a summary of high-impact recent Research studies that could be found by searching the scientific literature.

Moreover, suppose it analyzed the development of electronic distribution in different Research studies. In that case, it is quickly concluded that these properties were produced by interactions of different Optical active components or chemical species that produces new energy modes very different in comparison to original atoms isolated as well as forming part of molecular components [56]. It could be tuned and made a different material such as a meta-material by joining targeted Optical active materials. In this regard the future perspectives and ongoing Research in many Research fields are focused on the Next Generation of properties and applications [57].

In these perspectives it should be highlighted as well the versatility and chemistry of surfaces that could be tuned towards covalent linking, non-covalent interactions, and further modifications (Figure 3). This control could allow proposing new fundamental Research and applications. In this context, it is highlighted that Life Sciences focused on Bioelectronics and High Technology developments could be led.

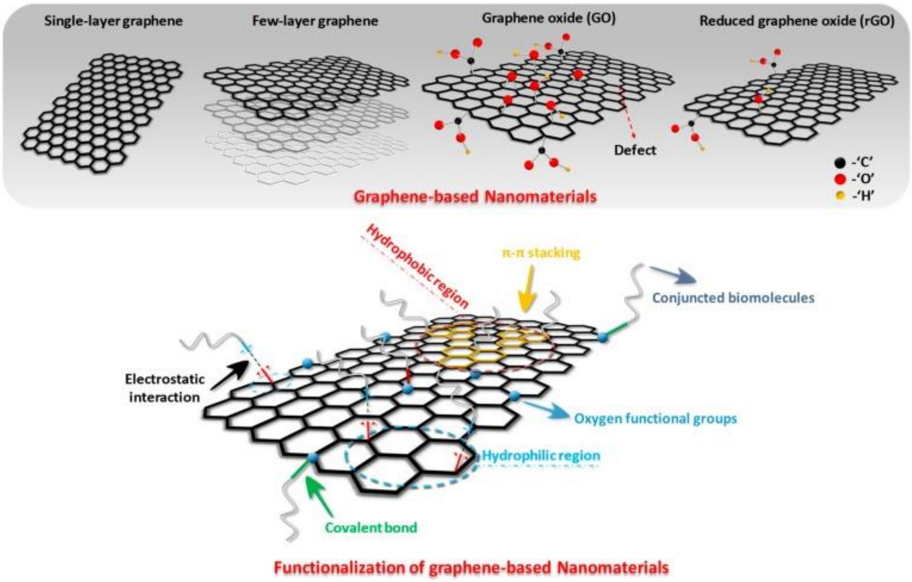

Figure 3 Overview of the various structures of graphene-based nanomaterials and the illustration of covalent/non-covalent functionalization of these nanomaterials. Reprinted with permissions from X. Zhao et al. 2019 [55].

It is noted that the Graphene-Based Nanocomposites for Neural Tissue Engineering [58] using their electrical conductivity properties, biocompatibility, mechanical strength, and high surface areas within Life Sciences. In these perspectives, an increasing number of studies have been reported showing that combining graphene with other materials to form nanocomposites can provide exceptional platforms for stimulating neural stem cell adhesion, proliferation, differentiation and neural regeneration. And, in order to achieve that Bioconjugation techniques were afforded by simple organic chemical reactions on modified and activated surfaces to link varied Biomolecules and Biostructures up on needs [59]. In the middle there are many challenges to overcome that opened new Research lines exploiting Optoelectronic properties to be incorporated within Biological media; and even arriving to develop Quantum Biology studies [60].

Finally, focusing on Technology perspectives, it is highlighted semi-metallic and semi-conductive properties that also afford unusual electronic behaviors and quantum conductions [61]. Improved electronic conductions in the presence of one of the most common conductors such as Cooper showed insights within current materials for Opto-electronics [62]. Moreover, Graphene-based materials due to their high sensitivity against low Opto-electro-stimulations, lead to be transferred towards reduced sizes devices and flexible wearables [63].

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Author Contributions

The author did all the research work of this study.

Competing Interests

The author has declared that no competing interests exist.

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