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Review

Quantum Semiconductors Based on Carbon Materials for Nanophotonics and Photonics Applications by Electron Shuttle and Near Field Phenomena

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Special Issue: Hybrid Graphene-based Materials: Synthesis, Characterization, Properties, and Applications

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Abstract

This review intended to resume key Research reports and publications that open many themes and topics related to Carbon-based semiconductors and Quantum emitters. The Design and synthesis of highly pure materials such as Graphene, Carbon Nanotubes, fullerenes, and other Carbon-based allotropes were shown. They presented their most important and promising properties concerning new studies and developments in photonics. Carbon-based Quantum dots, semiconductors, and higher sized Nanoplatforms allowed us to discuss fundamental studies and perspectives within varied applications. In this context, relevant developments from literature related to electron transfer within various targeted processes, where energy and light transfers occurred through different optical active materials and platforms, were highlighted and discussed. Therefore, many approaches that tuned the desired Optical active properties were shown. Thus, Hybrid materials from single Quantum and Nanoplatforms towards modified substrates were incorporated within varied media such as colloidal dispersions, solid devices, and waveguides. Moreover, Heterojunctions and applications such as energy harvesters and emitter devices were also presented. This manner highlighted varied topics of Photonics' leading current status, perspectives, and implications in Nanophotonics, Quantum photonics, and Optical lenses. Further views and commentaries about Green Photonics were presented as well.

Keywords

Quantum semiconductors; quantum dots; quantum emissions; hybrid nanomaterials; carbon-based materials

1. Introduction

Carbon-based Nanomaterials [1] provide many properties and applications. Still, from the beginning, semiconductors [2] and varied emissions such as quantum, luminescence, and improved luminescence phenomena range from single conjugated molecules to higher carbon-based molecular structures [3]. In this context, many variables affected the development of these Research topics depending on challenges, needs, trends, and costs at different time intervals. However, the Nobel Prize in Chemistry in 2010 was awarded to the UK for the “groundbreaking experiments regarding the two-dimensional material graphene” [4], opening the knowledge to a broad Research staff with particular interest and needs focused on these materials. It is mentioned pure materials such as Graphene [5], Carbon Nanotubes [6], fullerenes [7, 8] as well other Carbon-based allotropes [9] based on Carbon that show unique Opto-electronic [10], conductive [11], and Quantum emissions properties [12]. In this regard, these materials are exposed to those with high performances. Much research and development are focused on Nano-Optics and Quantum-Optics, showing trends and future perspectives looking for Nanotechnology and technology transfer. It is highlighted that semiconductive properties could be developed from varied types of materials within different scales, but the majority target a few high-tech applications and functions. In this regard, other phenomena such as conduction [13], harvesting [14], signal translation and transductions, [15] encryption [16] of different modes of energy [17] are studied. Within these functions are involved physical and chemical properties such as thermal [18], electronic [19], photonics [20], quantum [21], and luminescence mechanism [22]. In this context, it is noted that semiconductor materials are related to the dual properties of conductors, such as copper, and insulators, such as glass, depending on their intrinsic electronic constitutions and media. As an example, it is known that Silicon Nanomaterials show lower energies than Carbon-based semiconductors for electronic conductions. However, improved optical properties are also being developed in different formats and scales based on carbon allotropes and hybrid materials. In this regard, combining both materials based on their chemical properties, compatible material interactions, and different Optical responses contributes to adding a higher versatile optical value to study and exploit for further applications.

From these perspectives, synthesizing carbon-based nanomaterials and quantum dots shows impressive advances in this field. Thus, emerging Trends of Carbon-Based Quantum Dots varying in Nanoarchitectonics and related applications were recently reported [23].

Carbon-based Nanomaterials, Nanoparticles, and Quantum Dots could be considered stable and Green Photonic materials with already approved performances in many applications, such as within solar cells, waveguides, and Optoelectronic materials. Similarly, sunlight-driven water splitting using two-dimensional carbon-based semiconductors was recently reported [24]. Harvesting sunlight using photocatalysts to split water into hydrogen and oxygen is practical. This improved efficiency makes graphene a low-cost photon source based on 2D and 3D structures with superior charge transport. Tunable energy levels and bandgaps, visible light absorption, high surface area, easy processability, quantum confinement effects, and high photocatalytic quantum yields are recorded in this manner. Moreover, these properties are still being modified and studied based on the modification of their structures.

The CdSe/ZnS Quantum Dots were incorporated within micro-beads with unique properties based on their confinement into the particle; thus, unique optical properties were developed, such as good efficiency, very stable, and narrow excitonic emissions. The approach was developed by the encapsulation in situ of the Quantum material by polyisobornyl methacrylate and covalent linking with active carboxyl-modified QDots [25]. This simple strategy permitted the control concentrations and tuning of confined Quantum properties within the Nano-and Microscale. In this context, the modification of the Quantum properties by additional new interactions within short spacer lengths that tune from the surface to inside the Quantum dimension was highlighted. It is known how sensitive the Quantum properties are to molecular stabilizers; for this reason, modifying their media and close environment with Optical active components produces new and different properties at the Quantum level and macroscale. Therefore, the confinement of Quantum materials within confined volumes in the Nanoscale and beyond could provide new approaches to developing new Quantum materials. From these perspectives, this communication could be discussed using organized systems, such as vesicles, micelles, and varied nanomaterials, to generate quantum-confined volumes with different characteristics and potential applications. In this regard, the aggregation-induced emission of matrix-free graphene quantum dots via selective edge functionalization of rotor molecules could be highlighted [26]. This advanced Nanoarchitecture based on Nanoaggregates of Quantum Graphene materials showed interesting Optoelectronics applications due to their stable particular photoluminescence and blue light emissions. In their development was highlighted the use of two different rotor molecules nominated as benzylamine (BA) and 4,4′-(1,2-diphenylethene-1,2-diyl) diphenol (TPE-DOH), both were selectively functionalized by substituting carboxylic acid and carbonyl functional groups. It controlled the quenching effect caused by bigger aggregates diminishing their sizes to close 1 nm diameters. Thus, it was shown how different strategies could be tuned to new Quantum properties, as mentioned.

Moreover, as it is known, carbon-based materials are stable and quickly react in variable media. However, Hybrid composites with varied materials could be proposed, such as using platforms of graphene oxides, reduced graphene oxide, carbon nitrides, modified 2D carbon frameworks, assemblies, and composites.

Therefore, based on these trends and needs, this article intended to show and discuss recent reports focused on semiconductive and quantum properties developed by tuning carbon-based materials of varied compositions where confinements and electron shuttles were involved in the strategy applied.

2. Carbon-based Electron Shuttle Structures for Energy and Electron Transfer

This section shows how carbon-based materials could be confined within the molecular and the Nanoscale to transduce electronic signaling, electron conductions, Electron Transfer (ET), Energy Transfer, and Luminescence [27]. This statement could be simple if all these properties are well known; however, their study, which aims to develop new approaches to improve the mentioned phenomena, is not evident. This is part of the challenge as well. New optical setups and study strategies are needed. In these perspectives, different levels of complexity are taken into account dif. This means that it should be contemplated in designing Carbon-based Nanoarchitectures or Hybrid Nanoplatforms and Optical setups for the excitation and detection of electronic events [28]. These approaches could be based on i) soft materials and ii) complex matter incorporated mainly within high technological materials. Carbon-based materials are suitable to be incorporated in both types of materials. This versatility could be attributed to their solid and stable mechanical properties and respective photophysical properties. Thus, from varied studies and applications, soft matter types are highlighted as molecular assemblies [29], and complex matter or modified substrates are highlighted as heterojunctions [30]. Both examples have different kinds of studies and applications; however, both have a factor in typical electro-active dynamics within complex Opto-electro-active systems. Moreover, iii) high precision optics of reduced-sized substrates such as optical waveguides incorporated in high technological devices such as Light emitter devices, intelligent mobile telephones, and other fine technological systems today used daily as chips could be contemplated in future studies by incorporation of Carbon-based materials and electron shuttle applications (Figure 1) [31].

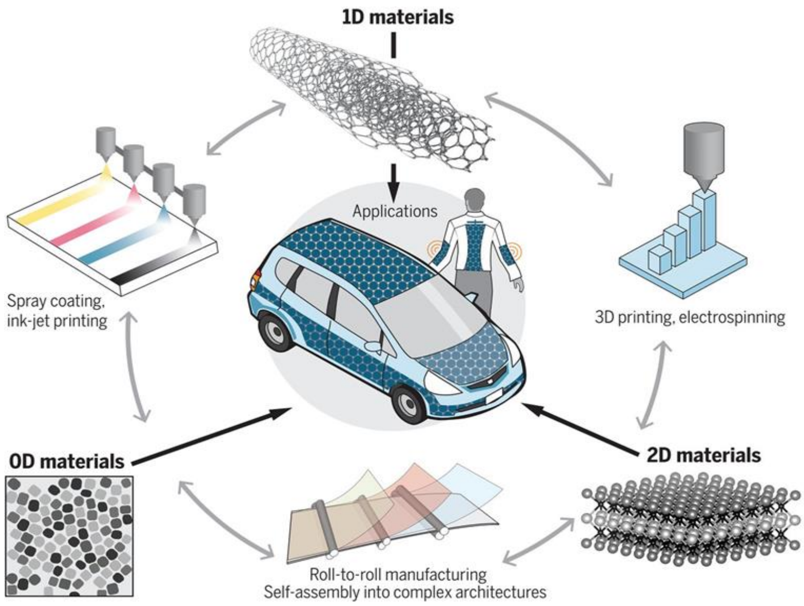

Figure 1 Nanomaterials for energy storage applications. The high surface-to-volume ratio and short diffusion pathways typical of nanomaterials provide a solution for simultaneously achieving high energy and power density. Furthermore, the compatibility of nanomaterials with advanced manufacturing techniques such as printing, spray coating, roll-to-roll assembly, and so on allows for the design and realization of wearable, flexible, and foldable energy storage devices. Reprinted with permission from [31] (Y. Gogotsi et al.). Copyright 2019 Science, Sci.

In these perspectives and developing the first soft matter approach, the use of organized systems could be highlighted by different Carbon-based chemical structures. These Carbon-based materials are supported or used as platforms to incorporate inorganic components; therefore, organized systems are obtained.

Modifying the media platforms or support through electron transport conduction is highly desired for Optoelectronics studies and applications. In this regard, different phenomena and effects could propose modifications in the electronic flow. It is noted the control of i) ionic media, ii) applied organic and inorganic substrates, iii) multilayered composites, and iv) doping or incorporation of carbon-based materials such as graphene and derivatives and carbon allotropes. Yet, even with much-related research, many other studies and developments have not been accomplished.

Examples of colloidal dispersion of modified vesicles, such as synthetic liposomes for varied optoelectronic developments, could be provided to understand the complexity of these systems based on the proper tuning of organic molecules and inorganic materials. Depending on their media, vesicles with variable sizes and shapes are formed by non-covalent interacting amphiphilic molecules [32]. These amphiphiles have a polarized chemical structure with hydrophilic heads joined to hydrophobic tails [33]. In this manner, vesicles have different physical and chemical properties that could interact with variable surrounding media [34]. Different types of chemical reactions could also be applied to modify their properties [35]. Therefore, the other parts of the amphiphiles and nanostructure could be tuned to have the desired properties. It should be highlighted based on their intrinsic constitution, different environments, polarities, and chemical reactivities. The polar head, as hydrophilic, could interact with polar solvents and be chemically modified with varied and controlled functional groups, polymeric chains, Biomolecules, and Nanoparticles. Thus, it is a key part of the functionality from where further modifications can be developed. However, the lipidic bi-layer showed strong apolar characteristics [36] that permit other types of interactions, such as highly conjugated organic chemical structures such as cholesterol [37], tiny Organic Nanoparticles such as Graphene Quantum Dots [38], and different types of inorganic Nanomaterials as well [39]. Moreover, the hydrophobic tails could be chemically modified with double bonds and chemical, organic modifications such as cross-linkers [40]. In this manner, inter-crossed linking of seats could be obtained, leading to a higher stability of the Nanoarchitecture [41]. In addition, the vehicle's interior has an accessible volume that could be filled as the container [42]. So, there is a large variety of strategies and possibilities to generate new Nanostructures based on organic compounds with high impact within fundamental Research towards Optoelectronics and new Quantum materials (Figure 2) [43-45].

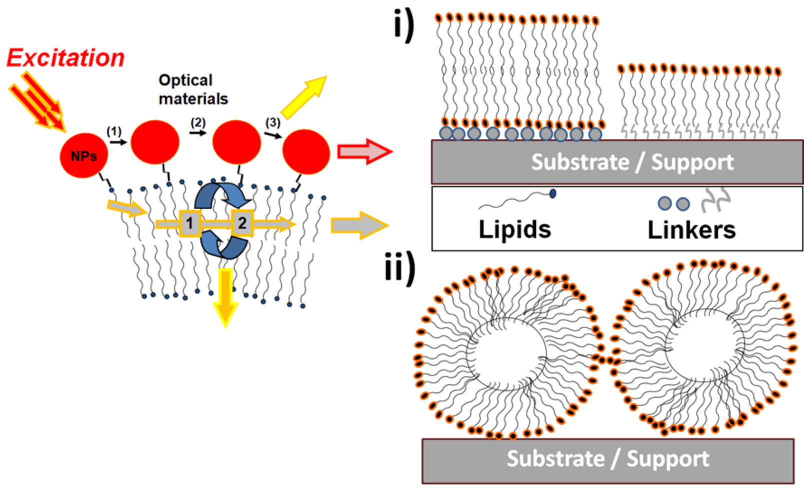

Figure 2 Schema of Optical active, organized systems and bottom ups. Bi-lipidic layers modified with Optical functional Nanoparticles (red NPs) on their surfaces that record Opto-electronics stimulations and generate varied energy pathways reflecting, emitting, and waveguiding different energy modes and passing through the membrane. The hydrophobic bi-lipidic layer could incorporate other Optical active materials such as energy transductors, wires, conductors, amplifiers, etc., nominated as 1 and 2. Insert Figures: i) bi- and mono-lipidic layers deposed on substrates; ii) Micelles or vesicles attached on substrates. The substrates that could participate in the targeted function are supported. Reprinted with permissions from [28] (A. G. Bracamonte et al.) Copyright 2023 Recent Progress in Materials, LIDSEN Publishing Inc.

For example, artificial photosynthetic reaction centers were developed for converting light energy to protons [46]. In this case, within the double lipid bilayer, an electronic wire was added based on an unsaturated organic chain with a porphyrin for the covalent linking of a donor/acceptor pair crossing the bilayer. Here, a reduction potential near the outer surface of the bilayer and an oxidation potential near the outer surface of the bilayer were generated by photoexcitation, accompanied by an oxidation potential near its inner surface. Thus, a free shuttle Quinone alternated between its oxidized and reduced forms to ferry protons across the bilayer with a measurable quantum yield and pH gradient between the inside and outside of the liposome in aqueous media. These phenomena without any of these components showed no electron transfer. As a result, these phenomena are susceptible to the electronic properties of the chemical structures involved, as previously discussed for other electronic transferences that occur through highly conjugated carbon structures. In addition, these electron transfer phenomena across bilayers [47] were shown to be highly sensitive to other variables such as the charge of liposomes [48], constitutive donor/acceptor pairs [49], as well as the incorporation of a more efficient electron shuttle [50]. This field also motivated research into the origins of life [51], where protocells constituted by small organic molecules [52], carbon-based materials [53], and minerals could be part of efficient photosynthetic centers. However, from the knowledge to control synthetic biology, Nanotechnology [54] could be developed for Biotechnology [55] applications. Therefore, by joining optimized manufactured nanomaterials with excellent degrees of purity, conductions, and pseudo-electromagnetic properties, such as graphene, its derivatives, and other carbon allotropes, new approaches could be proposed and developed with potential applications in different fields.

Recently, the transport of a graphene nanosheet sandwiched inside cell membranes was reported [56]. This simple observation is part of a complex organized system that significantly impacts the future development of bioelectronics and optoelectronics. It studied the transport of graphene oxides sandwiched inside cell membranes that vary from Brownian to Lévy and directional dynamics. Specifically, experiments evidenced sandwiched graphene-cell membrane superstructures in different cells. Incorporating Graphene oxides within membranes produced porous cell membrane leaflets spanning unstable, metastable, and stable states. These other states and 3D nano-bio architectures are essential to studying ET processes. However, it was highlighted by the authors' insights by sandwiching graphene for the applied enhanced efficiency of membrane-specific drug delivery uses. Thus, the perspectives were even broader towards Biophotonics and Biomedical applications were opened [57]. However, these perspectives are not the only ones. The capability to be incorporated within apolar media permitted to be included in complex membrane cellular Opto-regulated force mechanics through membrane to receptors using as intermediates molecular motors [58]. This approach was inspired by non-invasive methods for manipulating forces at a molecular scale in physiological environments, such as cellular mechanisms for force applications. These complex mechanisms use motor proteins pulling on cytoskeletal fibers, for example. Thus, applying Graphene permitted light harvesting and Energy transfer within a unique molecular machine that can apply forces at cell-matrix and cell-cell junctions. Thus, the light-driven actuation of the molecular motor is converted into mechanical twisting of the entangled polymer chains, which will, in turn, effectively “pull” on engaged cell membrane receptors. These results revealed the potential of nanomotors for manipulating living cells at the molecular scale and demonstrated a functionality that, at the moment, cannot be achieved by other Nanotechnologies. This innovation opened to other applications new perspectives due to the high precision capability achieved.

Another example focused on the importance of incorporating Quantum semiconductors Carbon-based Quantum and Nanomaterials; was the Mechanical penetration of beta-lactam-resistant Gram-negative bacteria by programmable nanowires [59]. It was observed that the beta-Lactam-resistant (BLR) Gram-negative bacteria had cell stiffness values almost 10× lower than that of gamma-lactam-susceptible bacteria, caused by reduced peptidoglycan biosynthesis. Therefore, this Research work demonstrated that these stiffness findings can be used to develop programmable, stiffness-mediated antimicrobial nanowires that mechanically penetrate the BLR Gram-negative bacterial cell envelope. Thus, It was anticipated that these stiffness-related findings could assist in the discovery and development of novel treatment strategies for BLR Gram-negative bacterial infections. It should be noted the importance of the bacteria implication associated with nanomechanical properties of a range of Gram-negative bacteria (Salmonella, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella pneumoniae) with different degrees of gamma-lactam resistance.

In this context, the importance of the interaction of Carbon-based Quantum dots and Nanomaterials within membrane forming part of complex Biomachineries that produce targeted Opto-responsive functions was highlighted. Further future perspectives are attended to due to their implications in high-precision mechanisms. The idea is simple, but it should still be developed to modify the media to transduce electrons and energy through a confined molecular spacer, nanometer scale spacer, trough substrates, and across modified surfaces contemplating Quantum phenomena involucred as well.

These previous examples showed improved performances based on the interaction of electrons and Quantum semiconductors. This strategy could be tuned to develop new approaches and properties as well. It means that Electron Transfer (ET) is part of a mechanism to transfer energy, interact, conduct electrons, and confine electron densities within confined volumes that produce different quantum and electronic behaviors. Consequently, these new Quantum and Nanoplatforms are potential new materials to be evaluated and applied for emitters and Optoelectronics. For example, it could be noted that the performance of Quantum Dot Light-Emitting Diodes Using a ZnMgO Electron Transport Layer with Core-Shell Structures improved (Figure 3) [60]. An improved version was generated by employing ZnMgO nanoparticles as electron transfer platforms and templates to tune core/shell structures by incorporating Quantum dots. Thus, new properties in the far field were generated from the Quantum level by generating non-classical light. Therefore, a maximum current and power efficiency of the QLED with ZnMgO NP core/shell was noted by as much as 156.3% and 113.8%, respectively, compared with control QLEDs in the absence of the Electron Transfer strategy.

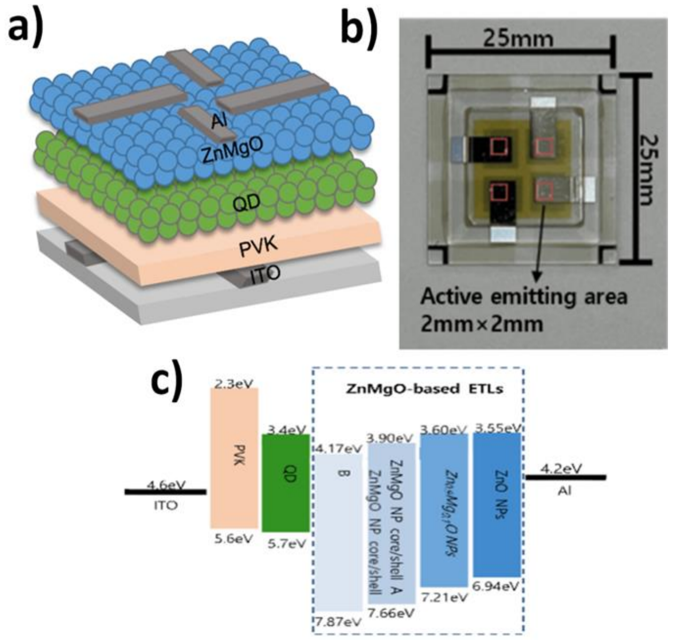

Figure 3 a) Schematic diagram of the QLED configuration; b) Photographic image of device showing four active-light-emitting areas; c) Schematic energy band diagram of the quantum dot light-emitting diodes (QLEDs). Reprinted with permission from [60] (C.-Kyo Kim et al.). Copyright 2023 Materials, MDPI.

Similarly, other phenomena related to the transference of varied energy modes could be used as a strategy to develop new mechanisms for tuning new Optical properties, such as Fluorescence Resonance Energy Transfer (**FRET**) (Figure 4) [61]. The confinement of Laser dyes controlling concentrations improved Quantum Yields and different and tuneable properties with potential applications in Optoelectronics and Metamaterials [62] approaches. Therefore, It could produce other electronic and quantum properties with exciting perspectives for further studies and developments towards new Quantum properties, semiconductor emitters, and Opto-electronics behaviors. In this regard, the following section shows the impact of these Research fields and Current Research in progress, presenting recent reports and discussions.

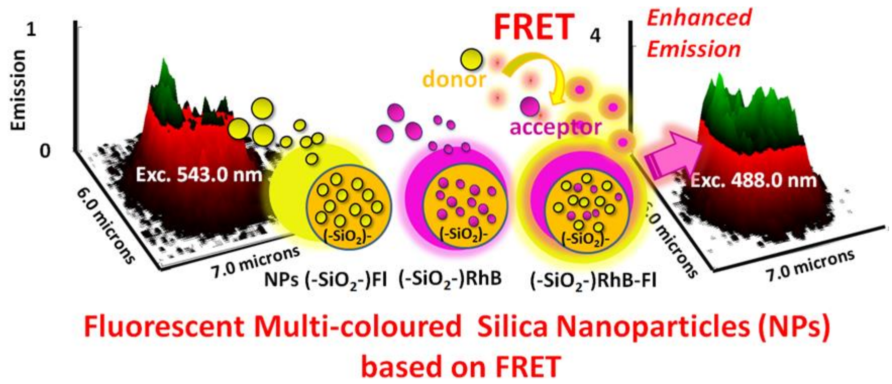

Figure 4 3D fluorescence surfaces from multi-colored SiO_2-RhB-Fl nanoparticles with only optimal excitation of RhB as a fluorescent energy acceptor at 543 nm and only optimal excitation of Fl as a fluorescent energy donor at 488 nm and coupling with RhB as a fluorescent energy acceptor. Inset images show the laser dyes incorporated within the silica nanoplatforms. Reprinted with permission from [61] (C. Salinas-M. Amé-A. G. Bracamonte et al.). Copyright 2020 Journal of Nanophotonics, SPIE.

3. Quantum Carbon-based Semiconductor Emitters and Opto-electronics

The carbon-based nanomaterials in close dimensions with Quantum sparked interest in explaining different behaviors non-explained by classic electronic explanations [63]. Quantum phenomena from these materials showed unusual semiconductor properties, such as electronic conductions within energy gaps between the LUMO and HOMO levels [64]. This was the beginning of further studies of varying optical setups considering the quantum sizes and materials involved and the application of optical instrumentation [65]. Both sides' control showed in recent years, augmenting publications on these themes and Optics. These facts were accompanied by communications focused on Quantum computing developments, challenges related to faster and improved signaling, and encryption of the Information, and in this regard, the use of Graphene in these types of studies appeared to be one of the best in the last time with the development of miniaturized circuits and Chips (Figure 5) [66].

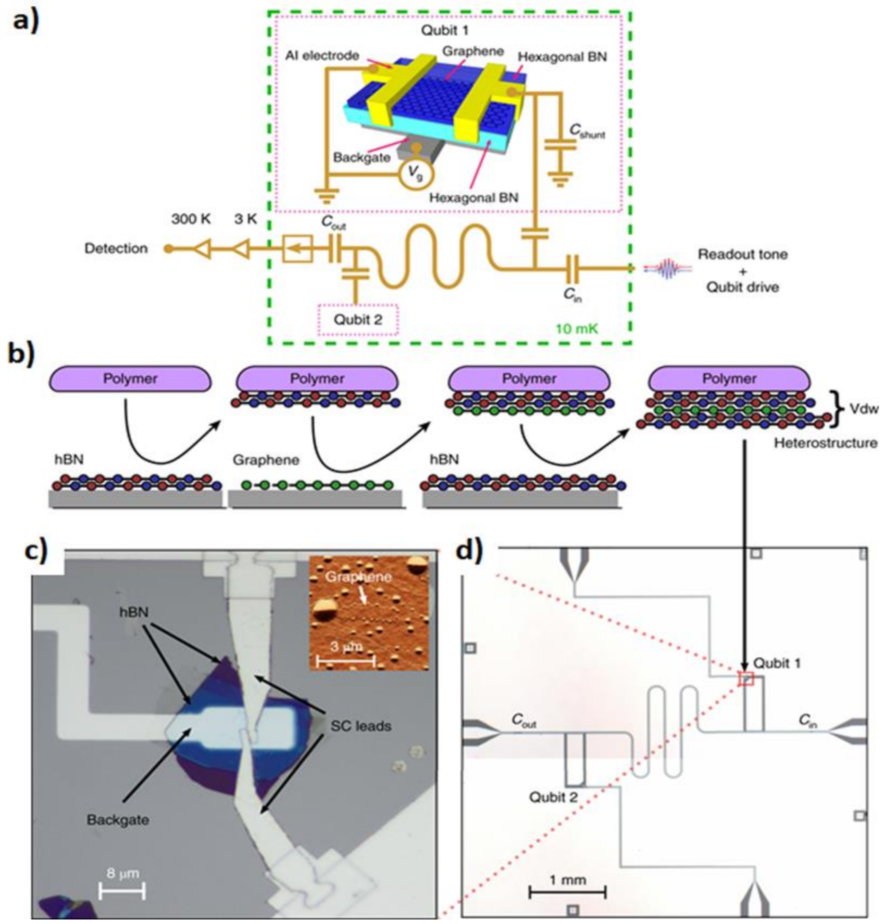

Figure 5 a) Schematic of the hexagonal boron nitride (hBN)-encapsulated superconductor-graphene-superconductor (S-G-S) junctions embedded in a circuit quantum electrodynamics (cQED) system. b) Assembly of van der Waals (vdW) heterostructures using a dry polymer-based pick-up and transfer technique. c) Optical micrograph of the graphene transmon qubit. SC, superconducting. Inset, atomic force microscopy image of the encapsulated graphene before making electrical contact with the superconducting electrodes. d) Qubit chip made of high-quality aluminum. Each shunting capacitor is cut out at the corner (red box; see c) to host the assembled vdW stack. Bonding pads on the top and bottom of the chip are used for backgate control. Reprinted with permissions from [66] (Wang-Bretheau et al.) Copyright 2019 Nature Nanotech, Springer Nature.

In this manner, the aims are similar in some cases to those of Optoelectronic applications; however, many others are not directly related due to the different intrinsic phenomena involved based on other energy modes. How the Quantum phenomenon occurs is not always well understood. For this reason, many studies in progress focused on Quantum Mechanics and related. These phenomena are associated with the improved and enhanced quantum conductions recorded by many carbon-based materials such as graphene, fullerenes, and derivatives. These experimental situations are focused on tracking electrons through hybrid materials, modified substrates, heterojunctions, and other Optoelectronic setups.

Therefore, conductors and semiconductors nanomaterials based on their particular electronic band gaps permit the mobility of the mentioned varied energy modes. These band gaps related to electronic energy levels could be tuneable, controlled, modulated, and affected differently depending on the nanomaterial in the study [67]. Thus, for example, within the mentioned material groups, it could be highlighted: i) highly conjugated carbon-based chemical structures such as graphene [68], carbon nanotubes [69], derivatives, and carbon allotropes [70]; and in particular, it is highlighted quantum dots [71, 72].

In these perspectives, Graphene with a zero bandgap energy structure provided superior optical and optoelectronics uses. The properties are based on structural characteristics to highlight related flexible layers that could be tuned. Thus, twisted and bilayer forms formed twisted angles, and asymmetrical lattices generated augmented optical absorption with consequent better photoelectrical performances [73], faster photochemical reactions [74], and Nanoscale photonic crystal structures [75]. The generation of pseudo-electronic fields in controlled conditions from varied graphene-based materials produces additional mechanisms of physical interactions with consequent electronic modifications in their surroundings [76]. It studied electronic interactions between graphene and reagents within typical reactions from where it was inferred that strong electromagnetic fields in the order of ×107 V/cm were responsible for enzyme catalytic effects.

In addition, different strategies and Optical setups were shown to enhance electronic and quantum conductions through tuned materials [77]. In this context, it should be highlighted that pure Graphene, as well as joined to other Optical active materials [78], always played the leading role where electronic flow showed particular behaviors improving and enhancing tracked properties. Thus, high electromagnetic fields within the near area showed potential uses in solar cell technology, such as plasmonic materials. Moreover, other sources of electromagnetic fields, such as graphene [79], and modified carbon-based chemical structures, such as carbon nanotubes [80], were shown and discussed. In addition, quantum-coupled properties [81] and electron shuttles [82] were contemplated too. As it is being developed, many materials are based on hybrid composites, incorporating varied semiconductive nanomaterials to tune new properties and applications. So, it is afforded not only to improved solar cell approaches such as perovskites solar cells; there are studies towards optoelectronics [83], Nanoelectronics [84, 85], and nano-, micro-circuits [86] that show interesting perspectives as well to long term.

The innovation focused on the different and varied synthetic methods that could produce further physical interaction, chemical surfaces, sizes, shapes, and quantum properties should be highlighted in these perspectives. Thus, Optoelectronics and Bioelectronics applications are of high interest. Recent trends focus on the green synthesis of biomaterials to be transferred towards bioelectronics, miniaturized bioelectronics devices, and wearables. For example, it is mentioned that green synthesis uses relatively easy hydrothermal reactions of Carbon-based materials to tune fluorescent properties and surface chemistries for varied interactions with different targeted materials. In this manner, it was recently developed as carbon quantum dots from biocompatible materials such as lemon juice [87]. The synthesized Quantum Dots had an excellent blue-green emission extending up to the infrared region with high quantum yield (Φ) in the interval of 14-41% values. The material used showed different chemical surfaces that permitted new perspectives for Bioapplications. In this regard, molecular interactions with well-known laser dyes such as Methylene Blue were evaluated. The results indicated excellent adsorbent properties with a removal efficiency of 60%-82% and high-speed adsorption rates around 6×10^{-2} min^{-1} for the dye studied.

4. Current Trends and Future Perspectives on Optoelectronics and Bioelectronics

The trends shown in recent years have opened exciting perspectives toward soft materials such as bioelectronics, focusing on optoelectronics within biological systems and miniaturized devices, electronic patches, and wearables. As observed from these perspectives, there is a broad band of potential developments with multi-disciplinary studies to generate fundamental knowledge for targeted applications. Thus, the particular structure of 3D organized Carbon structures, such as from Benzene to Graphene, showed a high sensitivity for electronic conductions. From these perspectives, the electron transport in single molecules from Benzene to Graphene was studied [88]. This Research showed the importance of Electron movement within and between molecules for many chemical, electrochemical, and biological processes. This was afforded by the use of scanning electrochemical microscopy (SECM), scanning tunneling microscopy (STM), and atomic force microscopy (AFM), which permitted the study of electron movement with single-molecule resolution. This research highlighted the differences between electron transport from a semiconductor physics point of view and electron transfer related with a more general term considering the electron movement between donors and acceptors. The study was developed between two electrodes controlling the deposition of single layers of electron shuttle. In this manner, the electron transport was more efficient when the electron transmission probability via a molecule reached 100%; the corresponding conductance should be 2e2/h, with e being the electron's charge and h being the Planck constant. Thus, it measured the ideal conduction in a single metal atom and a string of metal atoms connected between two electrodes. However, often the perfect situation is not present. Other variables, such as molecular lengths, are involved in improving electronic processes through the electrodes. Therefore, the presence of conjugated double bonds and the inclusion of possible redox centers, such as ferrocene, within the molecular wire have a pronounced effect on the conductance. So, the Polycyclic aromatic hydrocarbons (PAHs) afford a unique insight into electron transport in single molecules. The simplest one, benzene, has a conductance much less than $2e^{2/h}$ due to its large LUMO-HOMO gap. These results showed how sensitive the electronic processes are to chemical structures, dimensions of molecules, and spacer lengths. Logically, Graphene layers, Carbon Nanotubes, related derivatives, and other Carbon-based Nanomaterials, such as fullerenes, are composed of infinite benzene rings with zero energy gaps between the conduction and valence bands. However, the incorporation within varied media did not explore other intermediate sizes to optimize Optoelectronics properties. So, other molecules and derivatives such as naphthalene, perylene, and various polyaromatic chemical compounds known as PAHs could be mentioned. Therefore, the possibility of studying electron transfer between molecules and electron transport within the Nanoscale is highlighted.

In addition, It should be mentioned that highly conjugated Carbon chemical structures such as Carbone allotropes, different from Graphene, were used within interesting optical active approaches due to their unique properties. This is the case of fullerenes with high electronic densities generated from spherical Carbon-based chemical structures within the nanoscale [89]. Therefore, it was recently reported that a different mechanism explained non-fullerenes acceptors with reduced non-radiative voltage losses (ΔVnr) compared to fullerenes. In this manner, another agent of non-radiative voltage losses in organic solar cells [90]. Thus, it was discussed in contrast to the energy gap law that by non-fullerenes acceptors it did not show a correlation with the energies of charge-transfer electronic states at donor/acceptor interfaces as described for fullerenes. This explanation was based on the role of the thermal population of local exciton states in low-ΔVnr systems. The pristine no-fullerene material determined the photoluminescence yield of the lower limit of ΔVnr, reducing charge generation losses. A new design was proposed by incorporating donor-acceptor materials with improved Quantum Yields (QY) and overlapped optical absorption/emission bands until the Near-Infrared Region (NIR). Similarly, the addition of varied Opto-electrical active materials could be tuned to each part of the Multilayered materials, such as electron shuttle, metallic conductive materials, and organic semiconductive materials, from where there is a generation of new Optical active properties and logically innovative, responsive, functional platforms to develop new materials as well (Figure 6) [91]. These facts open the analysis to optimize and maximize performances depending on the application. Larger surfaces should require different conditions compared to confined or reduced sizes volumes below and beyond the Nanoscale. In this context, the evaluation and optimization during the scale-up of the phenomenon under study should be highlighted, and the way to transfer towards applications.

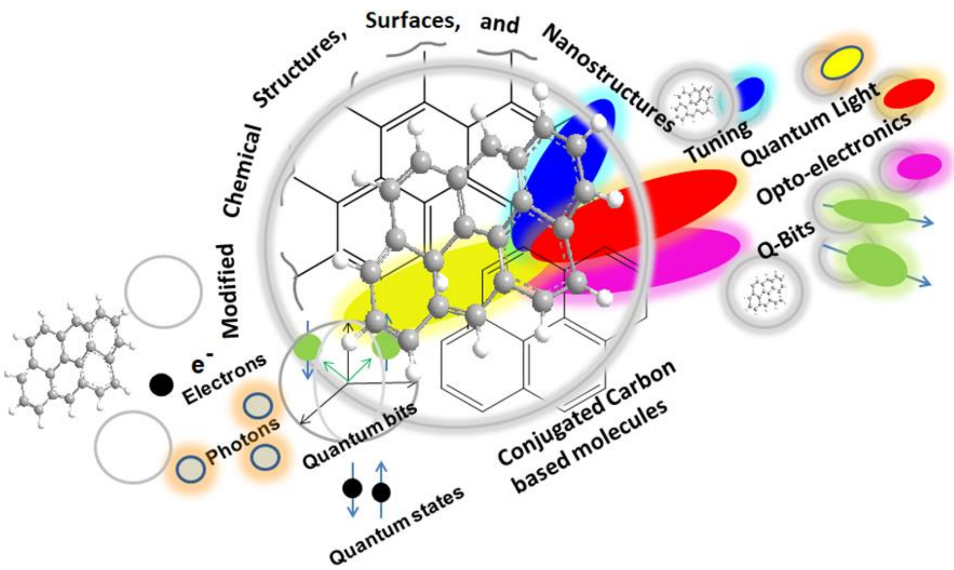

Figure 6 Scheme of confined Opto-electrical active materials with incorporation of Multilayered Carbon-based materials as electron shuttle, conductive materials, and organic semiconductive materials; from there are generation of Photonics, Optoelectronics, and Quantum modified properties. Reprinted with permissions from [28] (A. G. Bracamonte et al.) Copyright 2023 Recent Progress in Materials, LIDSEN Publishing Inc.

Thus, it should be mentioned that electronics, catalysis, energy harvesters, and conductors have impacted fundamental and applied perspectives in the development process accompanying the market as well.

In this way, coupling varied phenomena [92, 93] could produce enhanced electron conduction and harvesting. These enhanced coupling could be afforded by incorporating varied nanomaterials and properties. Thus, high electromagnetic fields within the near area showed potential uses in solar cell technology, such as plasmonic materials. Moreover, other sources of electromagnetic fields, such as graphene [94], and modified carbon-based chemical structures, such as carbon nanotubes [95], also showed exciting perspectives. In addition, quantum-coupled properties [96] and electron shuttle [97] were developed and highly required. Therefore, hybrid composites were afforded by incorporating varied semiconductive nanomaterials to tune new properties and applications. So, it was designed not only to improve solar cell approaches such as perovskites solar cells but also to show studies towards optoelectronics [98], Nanoelectronics [99, 100], and nano-, micro-circuits [101]. In these perspectives, Graphene as a high Opto-electro-active organic material with similar conductive properties of Copper and enhanced properties joining both materials within composites [102], was applied as a back surface material in solar cells. This phenomenon is related to the diminution of electron recombination and energy loss from the back layer of the substrate. In this manner, a numerical investigation of Graphene as a back surface field layer was reported on the performance of Cadmium Telluride solar cell (Figure 7) [103]. The results showed very high commissions with the highest short-circuit current (ISC) of 2.09 A), power conversion efficiency of 15%, and quantum efficiency (QE) of 85% with a carrier Lifetime of 1×10^3 µs. These values are just examples to show how it could be tuned to optoelectronic materials from tuning properties within the Quantum scale and beyond.

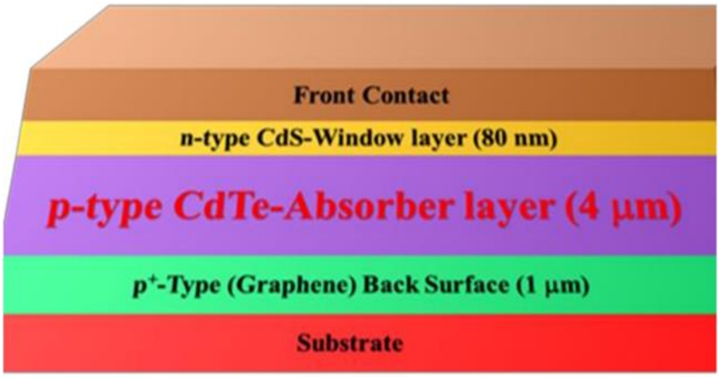

Figure 7 The device structure of graphene back surface-based CdTe solar cell. Reprinted with permission from [103] (B. Pant et al.). Copyright 2021 Molecules, MDPI.

In this manner, the feasibility of structural and chemical modifications to optimize visible light absorption and charge separation makes carbonaceous semiconductors promising candidates to convert solar energy into chemical energy and further uses. In the bottom-up of 2D and 3D materials, incorporating hybrid composites and using Carbon allotropes with Quantum Optical properties is of high interest and novelty because this Research field is under development.

5. Discussion and Conclusions

About the discussion and concluding remarks on the importance of Quantum phenomena and uses to tune new material properties and applications. Electronic confinement's critical contribution and essential role in producing quantum phenomena and semiconductive properties with varied energy levels incorporated within controlled mixed-organized systems generate different optoelectronic behaviors. From this simple concept, the new properties could not be predicted. These are the potential variables that will afford to tune new properties. Therefore, electron shuttle from the molecular level towards the Nanoscale with the contribution of quantum and semiconductive properties afforded to exciting perspectives such as improved electron transfer, harvesting, and energy generation by Opto-stimulation only focusing application in the solar cell energy domain. However, other views are on development, focusing on non-classical light generation and Green photonics. In addition, highly sensitive developments focused on the molecular detection level based on electron and varied energy modes transfers should be noted. These strategies add high selectivity and sensitivity to the mechanism and the application.

In these regards, it is essential to highlight some of the critical variables to control. Thus, the intrinsic selectivity based on the Quantized energy involved plays a vital role in applications requiring targeted uses. Molecular detection and Biomolecule targeting and tracking require this analytical performance. Moreover, it could be extended towards bioelectronics applications focusing light on targeted organelles within higher-sized biostructures to tune biodetection and other uses such as generating non-classical light. Thus, the perspectives of tuning Opto-electronics and quantum properties by electron shuttle participation and considering pseudo-electromagnetic field interactions and coupling could provide essential insights and strategies to develop new Quantum and photonics materials.

In the same way, it could be mentioned that bioelectronics is essential, but synthetic studies are needed to translate electronic and quantum signaling to record metabolites with Optoelectronic active properties. For example, variable-modified substrates are tuned for detecting targeted analytes recorded by thin films incorporated in wearable devices. In this context, quantum phenomena as crucial material for the event of detection take a vital role by adding their semiconductive properties as well as other unknown potential pathways considering new matter properties such as meta-materials. In addition, considering recent trends in quantum research, quantum biophotonics and quantum biology could also be mentioned in this context. So, the use of advanced Optical Set ups focusing light within Biological structures permits the evaluation of how quantum phenomena are involucred within well-known functions such as photosynthesis, transmembrane electronic signaling, generation of Bioluminescence and unique phenomena such as Biolasing within confined luminescent dyes within proteinic cages. All these previous mentions related to critical topics were associated with a common factor focusing on the signal's selectivity; however, it is not the only variable on which to focus the study. Other ones could be of interest and attention at the same time. This is the high Sensitivity of Quantum Optics shown in well-known phenomena, for example, the Graphene Quantum quenching that could be developed within colloidal dispersions. Other Quantum phenomena could also be designed for high sensitivity in modifying electronic waves and chemical species involved in the study. This modification of quantum states could be afforded by coupling electronic densities, non-classical light, luminescence, and joining varied Optoelectronic matter constitutions (Figure 8) [104].

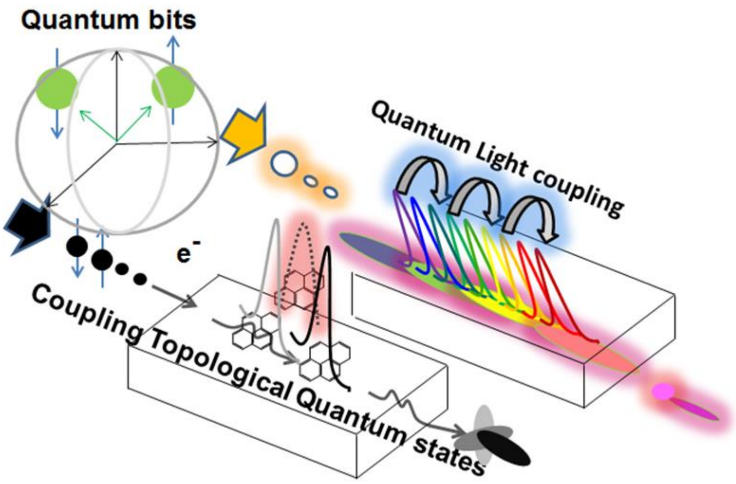

Figure 8 Scheme of modified substrate with optical active nanomaterials, including quantum graphene dots within a metamaterial substrate for coupling and waveguiding varied Quantum and Photonic phenomena. Reprinted with permissions from [104] (A. G. Bracamonte et al.) Copyright 2021 Current Material Sci. Bentham.

This approach to the study of Optical-active matter is closely related to the generation of Meta-material Engineering [105]. In this context, potential enhanced developments exploiting not only Quantum emissions and highlighting Pseudo-electromagnetic field interactions produced by Carbon-based materials with their close surrounding could be tuned [106]. These studies' approaches could be adjusted by coupling varied materials. Still, the design of hybrid Plasmonic materials, where organic and inorganic matter are joined for interesting perspectives for Quantum and Photonics studies and applications, is highlighted. Finally, the importance of developing new materials in the bottom-up of Nanotechnology, Micro technology, and miniaturized instrumentation is noted. Thus, the chemical surface modification by depositions of controlled Opto-active multilayers could generate a new open window of potential developments.

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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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