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Review

Plasmon Inspired 2D Carbon Nitrides: Structural, Optical and Surface Characteristics for Improved Biomedical Applications

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Abstract: In the past few years, noble metal-based 2D nanomaterials particularly Ag and Au enriched carbon nitrides have seen advanced catalytic actions and reactivity. These composite nanostructures' chemical and physical characteristics have been applied to improve the targeted functionalities in healthcare and medical sciences. Many scientists and experts were inspired to study their foundational technologies in the medicinal industries via architectural and surface modifications by doping of noble nanoparticles. Here, we have provided fundamental ideas for structuring Ag and Au decorated CNs (carbon nitrides) by studying their morphological and modified surface properties for biomedical applications. There is a vast spectrum of publications that discusses the peculiarities of CNs and noble metal's key discoveries. The impact of surface plasmons resonance (SPR) is an essential factor for noble metals and that is why it is focused extensively for better performance in biomedical sectors. The elemental combinations on the CNs surfaces and their morphological status were found to be much more efficient which is broadly discussed. The fabrication techniques, structural characterizations, and SPR role of Ag and Au are addressed including fundamental concepts followed by many suitable examples under this review.

Keywords: carbon nitrides; nanoparticles; noble metals; structural characteristics; biomedical uses

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1. Introduction

Unique electromagnetic and physicochemical functionalities of conductive nanostructures along with suitable polymeric frameworks have been employed as a multifunctional tool in the field of nanoscience and technologies range for a variety of applications, including photovoltaic, therapeutic, and photocatalyst. [1–3]. Noble metals in the class of metallic nanostructures were used as individual and also as co-doped ions to enhance the work quality and efficiency. Several inorganic nanoparticles (NPs) such as Pt, Pd, Ag, and Au have been appreciated due to their surface plasmon properties in materials research and nanoelectronics. The most studied metals are Ag and Au nanostructures which have distinctive photonic excitation regions in the electromagnetic spectrum due to their specific conduction bands electrons and nano range sizes. These optical and electronic characteristics provide an outstanding catalytic action against targeted applications. [4,5]. The associated electronic configurations of both the Ag and Au NPs found much better as bimetallic nanocatalysts due to their intra-bands structure and combined surface plasmon resonance (SPR, produced by the combined fluctuation of the valance band electrons after irradiated by electromagnetic wave) and that is why both candidates are mainly focused for biomedical uses as compared to other noble metals. When the particular incident light interacts with Ag and Au particles, the conduction bands electron promotes to the valance bands and combined fluctuates with the similar frequencies of incident wavelength of light. This phenomenon is called SPR which is studied in noble metal surfaces [5–7]. Variety morphologies offer fascinating chances for biomolecules or microbes to disperse and come into interaction with one another at the surface, enabling individuals to properly manage their specific functions. Plasmon metal nanoparticles exhibit an optical absorption band having a maximum plasmon resonance frequency which is known as localized surface plasmon resonance (LSPR). This LSPR value is found to be 520 nm for a spherical Au NPs with a confined 10 nm size. These metal nanoparticles also enhance the electromagnetic field close to their surfaces. The LSPR of the colloidal suspension is significantly influenced by the noble Ag and Au NPs width (confined sizes) and geometry, altering the optical bands at visible and near infrared range means at confined wavelength. Such type of spectral shifting might be caused by the simple clustering or random distribution of spherical particles. Nanomaterials might infiltrate organelles owing to a property exploited in biosystems assurance their widths are contained within the nanometer scale. Likewise, molecules with larger sizes as compared to nanometer NPs have several advantages as compared to other preventative medicines when used as reducing treatments and Ag and Au can moderate structurally for the efficient performances [8,9]. The addition of both AgAu NPs felicitates an advanced antibacterial impact with minimum side effects inside the living cells. However, the narrow sizes and engineered surfaces of the noble nanostructures have been targeted to use as bio markers due to their easy processing and less toxic nature, resulting an improved biomedical aspect in the medical and health environments. [10–12].

Gold nanoparticles are coveted for their wide range of uses in medical chemistry, pharmacology, and diagnostics, as opposed to some other nanomaterials. In vivo experiments have focused more on Au metal nanoparticles (Au NPs) over the past few years. The detrimental effects of gold chloride and photosynthesized nanomaterials utilizing Cassia roxburghii leaf extract on the African green monkey normal kidney Vero cell line and three cancer cell lines, including MCF7, HepG2, and HeLa, were studied by Pannerselvam Balashanmugam and coworkers [13]. Silver is generally a long-lasting product with antimicrobial qualities and historical qualities. Due to its dispersion nature, silver nanoparticles have a wide range of industrial applications. They are heavily utilized by the aquaculture industry. In order to lessen or completely eliminate the dangers associated with managing chemical reduction agents, production rates, and cytotoxicity, better environmentally friendly methods for creating metallic NPs were chosen [14,15]. In the past, they have been employed for a wide range of therapeutic diagnoses associated with anti-inflammatory and antioxidant actions [16,17].

2. Characteristics and Importance of SPR and 2D CNs

Since complete miscibility of Au and Ag can be obtained at any composition in both bulk materials and NPs, combinations of Au and Ag are notably crucial to study about their coupled elemental-sensitive optical characteristics. Au NPs have an intense SPR band at the visible spectrum at a certain wavelength that is distinct from the pure Ag NPs. The LSPR (localized surface plasmon resonance) spectra of Au/Ag composite NPs showed increasing blue- or red-shifting when the Ag or Au proportion changed, according to Mallin et al. [18]. When Au core-Ag shell nanoparticles are created through the process of gastric ripening followed by annealing, they become Au-Ag hybrid nanoparticles. Figure 1 illustrates the clear SPR shift that R. Kuladeep et al. [19] suggested for Au and Ag NPs at various concentrations. Ag, Au, and mixed alloy AgAu NPs, which had spherical shapes with diameters of less than 20 nm, respectively, showed LSPR bands located at about 410, 526, and 459 nm.

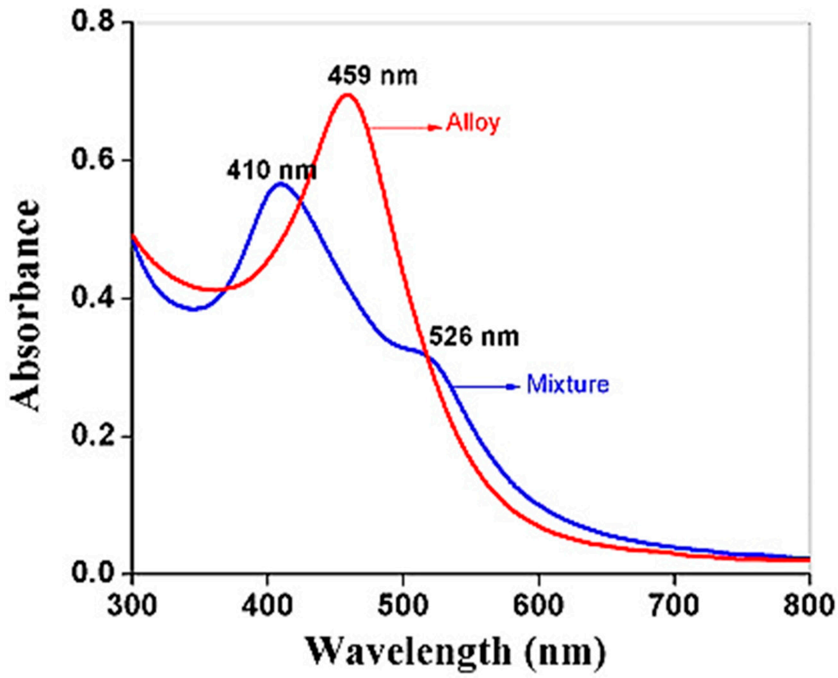

Figure 1. UV-Vis absorption spectra (SPR) of AgAu (0.5:0.5) concentration.

The geometries of the Au and Ag have been altered by the lab conditions and the selection of primary compounds taken for the synthesis reactions, which also affects the SPR bands. Therefore, these mixed plasmon nanostructures' morphology, dimensions, and stoichiometry are investigated both as pure Ag and Au NPs along with the mixed composite materials.

Utilizing nanocrystals of various sizes and forms, including nanocrystals, thin films, and spherical arrays, the electrochemical performance of hybrid CNs could be altered especially by modifying the surface properties [20,21]. The g-C_3N_4-based (graphitic carbon nitrides) catalysts device applications to its pp-stacked heterocyclic thicker systems of heptazine (tri-s-triazine) or triazine heterocycles produce better results thanks to the core covered component of g-C_3N_4 [22]. Using proper techniques, major advances in the physicochemical features of composites such as carbon nanotubes, graphite, and other 2D (two-dimensional) configurations are produced in the form of one- and two carbon nitride sheets. To separate two metal-based semiconductors with acceptable topologies, nanostructures, g-C_3N_4, and nano ranged thick polyheptazine films were typically employed. There is a significant demand for exfoliated g-C_3N_4 and its analogs to form quickly in extended surfaces, such as 2D g-C_3N_4 (two-dimensional graphitic-carbon nitrides) and 3D g-C_3N_4 sheets [23]. Since doped concepts could be utilized to change the structural and electrical framework of these nanomaterials, a considerable of studies have been carried out in this area [24,25]. In the realm of mixed nanocomposites, however, defined in various conducting polymers have developed and changed substantially. Multiple combination types of 2D structures, such as nanocrystals, metals doped graphene, r-GO (graphene-oxides), CNT, and carbon nitrides (C_3N_4), were discovered and utilized in biomedical, energy conservation, and environmental sensors [26]. Here we explained a fundamental and descriptive overview of 2D carbon allotrope known as CNs including structural, surface associated with based on Ag and Au NPs and its use in healthcare areas.

2.1. SPR Properties of Ag and Au Nanostructures

When electromagnetic radiation interacts with plasmonic metals such as Pt, Cu, Ag, and Au NPs, the surface plasmons response (collective motions of the valance bands free electrons) changes which influences the optical absorption band intensities of the particles. However, the Ag and Au plasmonic quality are considered valuable for potential prospective in therapeutic diagnosis, and drug delivery. Whereas an Au displays red and an Ag exhibits greyish, depending on their size and form, Au and Ag nanoparticles can display any color in the spectrum, from red to green to violet. Due to the localized surface plasmon resonance (LSPR) particles on the surfaces of Ag and Au nanoparticles, they have a wide variety of colors [27,28]. In essence, elements are composed of positively charged that is encircled by an electron-free conduction band. An additional electric field is created on particle surfaces as a result of the migration of metallic electrons during illumination, which results in the production of an electric dipole [29–31]. The electric field created by SPR on the metal atom's surfaces and the electric field created by the applied electromagnetic field combine to form the overall electric field. Although higher-level plasmon phases could also be produced in anisotropic nanostructures, dipole plasmons are primarily synthesized in narrow-sized nanospheres. Therefore, the distinctive bands of the ultraviolet absorption spectrum of Ag nanoprisms produced by plasmon-driven change were 340 nm (out of plane quadrupole resonance), 470 nm (in-plane quadrupole resonance), and 640 nm (in-plane dipole resonance) [32,33]. It is crucial to highlight that changing the absorption bands in spherical Ag and Au nanostructures is incredibly difficult based on experimental considerations. For instance, the size of Ag NPs is likewise influenced by pH levels, and this affects how they respond to SPR (Figure 2a) [34,35].

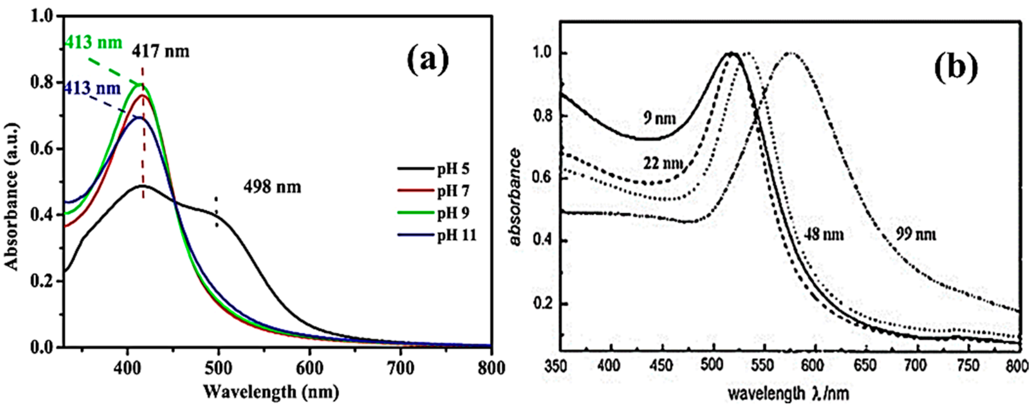

Figure 2. LSPR bands of the Au NPs with different sizes (**a**) SPR of Ag NPs, (**b**) SPR bands for Au NPs [34,35].

2.2. Surface Modification and Determinations of Carbon Nitrides

Due to bare g-CNs specific surfaces and fast photoexcited coupling, a strong note can alter its architecture and banding sites. These g-CNs' particular geometric configurations may be used to accelerate charge recombination, increasing kinetic and chemical efficiency [36–38]. Researchers are very interested in graphitic carbon nitride (g-C_3N_4), a pretty modern type of carbonaceous material including a band-gap of about 2.7 eV, owing to its excellent intrinsic optoelectronic characteristics, including high surface and photo-responsiveness, semiconductive nature, and chemical and thermal resistance. They have improved optical absorption, photocatalyst, and storage capabilities due to optimum band gap values. Using Ag or Au nanocrystals of different sizes and forms, such as wires, cylinder configurations, and nanotubes, the catalytic activity of hybridized g-CNs is altered. Due to the core enclosed element, g-CN-based photocatalytic device applications to its pp-stacked heterocyclic bulkier systems of heptazine (tri-s-triazine) or triazine heterocycles produce better results. Runxue Liu used a straightforward one-step calcination process in his research to examine the effects of calcination time on the morphology, surface composition, and catalytic performances of Ag loaded g-C_3N_4 (Ag/CN-x) composites [39]. The Ag and Au loaded hybridized g-CNs were studied by Marta Jiménez-Salcedo [40] using TEM and XPS techniques. (Figures 3 and 4). The almost spherical nanoparticles of the Ag were dispersed into the CNs surfaces using one-pot self-reduction of organometallic compounds, which were having a maximum 9.8 nm sizes. Figure 4 show a XPS spectra for the Ag and

Au dispersed CNs hybrid materials where the full survey scan is showed in Figure 4a with all expected elements such as C, N, O and Ag.

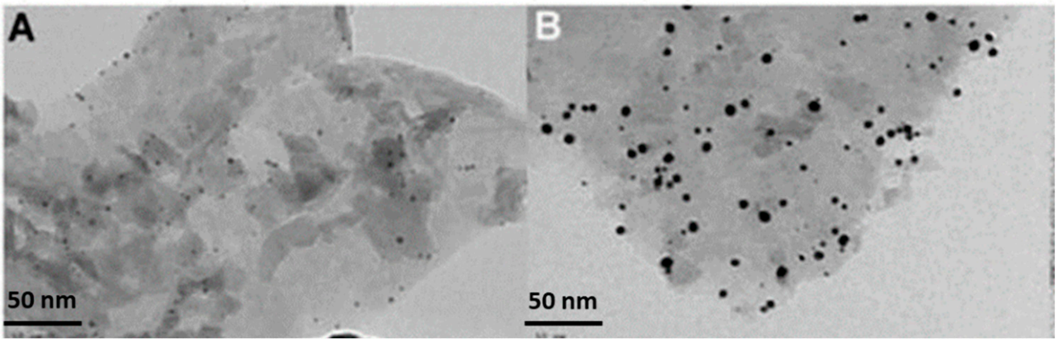

Figure 3. TEM images of Au and Ag loaded g-C_3N_4 nanomaterials (**A**,**B**) [40].

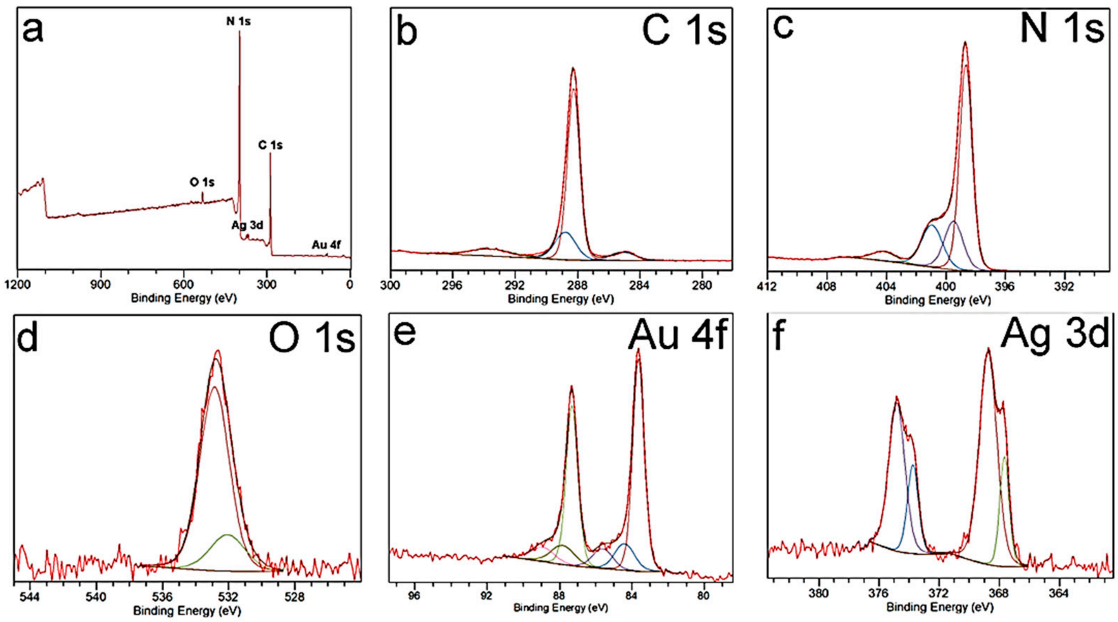

Figure 4. XPS analysis of AuAg loaded g-C_3N_4 nanomaterials (**a**). XPS Full survey, high-resolution of C 1s (**b**), N 1s (**c**), O 1s (**d**), Au 4f (**e**) and Ag 3d (**f**) [40].

The C1s peak observed around 284 eV, N 1s at around 285 eV, and the O 1s found near to 530 eV. Here, the C and N peaks confirmed the CNs atomic presence along with atmospheric N. The high resolution of the Au 4f and Ag 3d spectra were also confirmed around 84 and 87.7 eV for the Au $4f_{7/2}$ and Au $4f_{5/2}$ binding energy states, while the Ag $3d_{5/2}$ and $3d_{3/2}$ levels were observed at around 368 and 374 eV.

An AFM, TEM, or SEM technique is usually used to explore the structural account of the CN, which has previously been used to illustrate the typical membranous nanosheets with multiple mesoporous structures. Under particular environmental conditions, urea polycondensation is frequently used to create an atomic structure that is graphitic. While hybrid graphitic carbon composite materials can have a variety of topologies depending on the production, pure graphitic carbon frequently has nanosheets-like architectures. [41]. Numerous procedures were suggested to look into the characteristics of CN and nanomaterials, including FTIR, XRD, Raman, XPS, and many more. Theoretical approaches could be used to investigate the electrical characteristics, ionic conductivity, and surface composition of such conducting polymers. [42,43].

3. Morphologies and Optical Functionalities of Ag and Au Doped Carbon Nitrides Nanocomposites towards Medicinal Aspects

The structure and elemental content of nanoscale materials determine their physical and chemical properties. Due to the unusual SPR, thin geometries, and electrical topologies of the composite nanomaterials and its doped counterparts, they were used for better medical applications [44]. Ag and Au NPs are primarily emphasized throughout this perspective for creating considerably more effective nanomaterials for enhanced monitoring and healing reasons.

3.1. Structural Modified Plasmon-Carbon Nitirides for Enhanced Bomedical Uses

The Ag and Au NPs' absorption spectra and conformational changes have a significant effect on the kinetic efficiency and actions. Ag and Au doped highly conductive nanomaterials, including multilayered films, transition metals, nanostructures were exploited as a substantial catalyst, especially in clinical field [45,46].

Numerous studies have been conducted for all this particular job employing nanobiosensors and structured activities on metallic nanoparticles. The plasmon frequency for Ag and Au was examined at the nanoscale and was found to be 425 nm and 550 nm, correspondingly [47]. Yu Fan has successfully created a novel "on-off" electrochem-iluminescence (ECL) sensor for the sensitive and precise detection of concanavalin (ConA) [48]. For the purpose of immobilizing phenoxy dextran (DexP) by p-p interface and achieving the "signal-on" state with a strong positive ECL output, Ag-doped Ag-g-C_3N_4 was modified out onto the glassy carbon electrode (GCE). A carbohydrate-ConA interface was then used to affix the particular ConA to the DexP/Ag-g-C_3N_4 altered film. Polyani-line-3,4,9,10-perylenetetracarboxylic acid-DexP conjugate (abbreviated as PANI-PTCA-DexP), an ECL signal quenching probe, was repeatedly incubated onto the electrode via the carbohydrate-ConA connection to provide the "signal-off" state. With the greater dosage of PANI and DexP, PTCA was used as a host and PANI and DexP served as quenchers for the Ag-g-C_3N_4 system and sensing platforms for binding ConA. A satisfactory quenching ECL signal was seen with the creation of the sandwiched architecture of DexP, ConA, and PANI-PTCA-DexP using S2O82 as the co-reactant of Ag-g-C_3N_4. Using an "on-off" approach, ConA identification was achieved with a broad linear region of 0.001 ng/mL to 50 ng/mL and a detection limit of 0.0003 ng/mL (Figure 5). Using S2O82 as the co-reactant of Ag-g-C_3N_4, an acceptable quenching ECL signal was observed with the construction of the sandwiched architecture of DexP, ConA, and PANI-PTCA-DexP. ConA identification were obtained with a large linear region of 0.001 ng/mL to 50 ng/mL and a detection limit of 0.0003 ng/mL using such a "on-off" method.

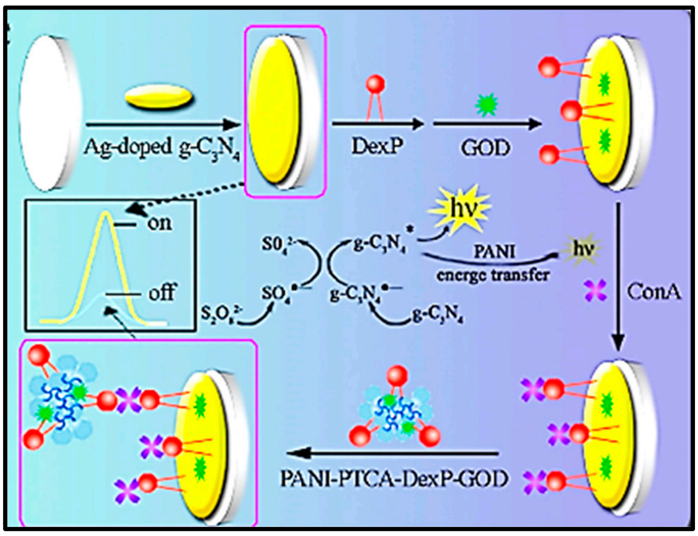

Figure 5. The functionalized Ag-g-C_3N_4 and PANI-PTCA-DexP-GOD for the ECL biosensor [48].

3.2. Improved Biomedical Properties Using Metal and Metal-Based Nanocomposites

It has been investigated into if Ag ions may be incorporated on g-C_3N_4 to increase the efficiency of its photo-response. Pt, Ag, and Cu are just a few of the ionic metals that can be transported by the elastic structural framework known as the g-CNs nanomaterial. By exploiting the various properties of these free ions, it is also possible to identify certain substances in the atmosphere. A range of biomaterials that were combined with g-CNs nanomaterials are displayed in Table 1. By adding noble metals, the reaction rate of g-C_3N_4 for the eradication of dangerous bacteria and diseases might be increased [49,50].

Table 1. Metal based CNs biomaterials for medical uses [51].

Metal Ions	Targeted Biomolecules	Detection Procedures	Years
Au/Cu	Sudan I	lectrochemiluminescence	2018
Au NPs	DNA	Electro-chemiluminescence	2018
ZnO	e (SMZ)	Electrochemiluminescence	2018
Au/Gox	Glucose	Electro-chemiluminescence	2017
Cu NPs	DNA	Electrochemiluminescent	2017
Palladium (Pd)	OPs and HupA	Electrochemiluminescence	2016
Au NPs	Lactate	Electro-chemiluminescence	2014
Ag NPs	Glutathione	Persistent-luminescence	2013

To altering the excitation wavelength, the researchers used Au nanostructures (Au25) to enhance the results of photodynamic treatment (PDT). Upconversion nanoparticles (UC-NPs) are coated with a mesoporous g-C_3N_4 coating, and then ultrasmall Au25 nanocrystals and PEG polymers are applied (UCNPs@g-C_3N_4-Au25-PEG), to form a novel dual-photosensitizer nanosystem [52]. In view of the excellent valence band of Au nanoclusters, the absorption zone of g-CNs is consistent with the emission band of Au nanoparticles. The therapeutic effects of g-CNs are strengthened by their surface plasma resonance (SPR) features. Both g-C_3N_4 and Au25 nanoparticles can be initiated by UV-Vis light and the powerful near-infrared (NIR) emission bands emitted by UCNPs to produce ROS, enabling the two types of photosensitizers for improved PDT capability when activated by conventional NIR light.

4. Antibacterial Impacts of Ag and Au Based CNs

Interest has been sparked by the basic elemental composition of g-C_3N_4, a metal-free conductors with a structure reminiscent of carbon allotropes [53]. To increase chemical and photonic capacities, designed and synthesized nanomaterials with essentially different components could be successfully produced. Numerous applications of the g-C_3N_4 have been researched, such as biological, chemical, and nano biomaterials. Numerous techniques, including the production of nanostructured materials and the modification of hybrid ions, have already been developed to improve biological responses qualities [54–56].

The plasmonic nature of nanoscale Ag and Au is also observed to have a significant impact on the changed structures due to its small size, dispersion, and support at hosts or substrates. Typically, the surface of nanostructures with a nano ranged metal (such Ag and Au) nitride substrate would improve microbe adsorption. Plasmon nanoparticles' greater surface allows for the rapid spread of bacterial colonies, makes it simple to enter microscopic membranes, which rapidly kills bacteria. In a study, M. A. Wahab et al. [57] created an Ag NPs-loaded NCN material (NCN@Ag) that was employed as an antimicrobial agent against *E. coli*. A systematic illustration showed in Figure 6 for the Ag functionalized CNs nanomaterials for the antibacterial biosensors.

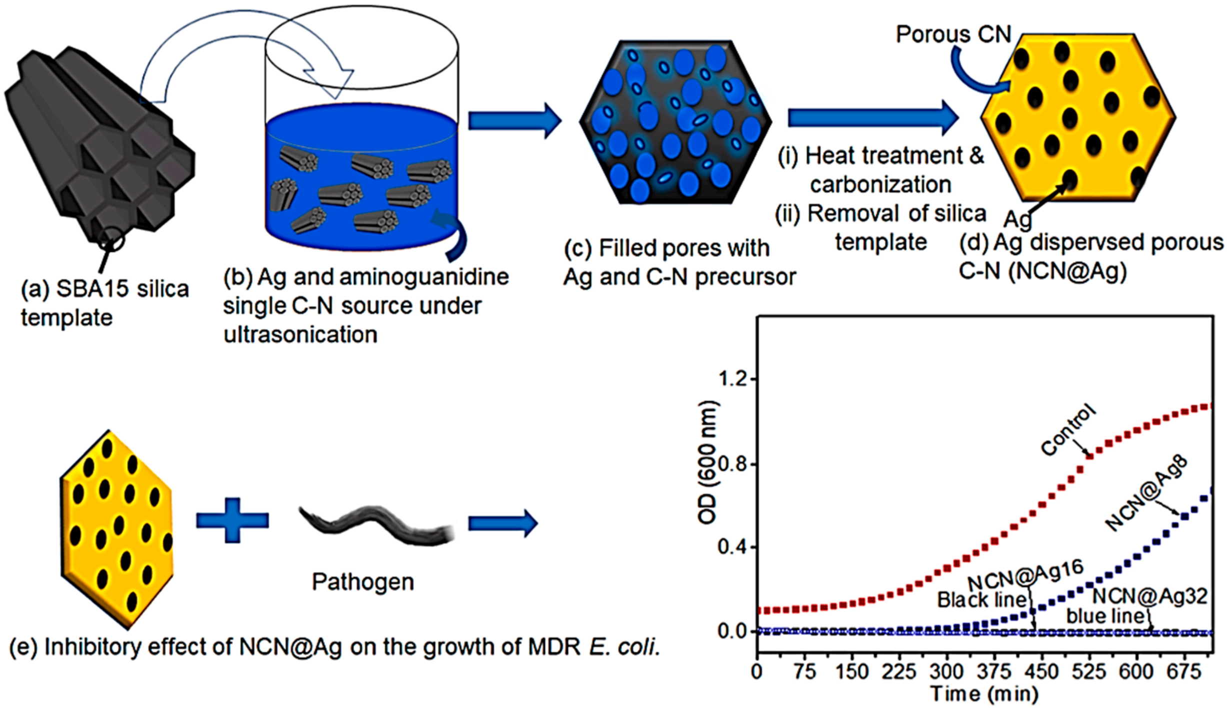

Figure 6. Ag NPs doped CN, (**a**) SBA15 silica substrate; (**b**) Ag and C-N with SBA15 silica; (**c**) Ag doped C-N; (**d**) Ag doped porous CN; and (**e**) Inhibitory action against MDR *E. coli*. [57].

An Fundamental Assessment toward Biomedical Importance

Research is still being carried out on evenly disseminated dispersion plasmon Ag or Au NPs in nanostructured carbon nitrides (NCN), particularly from single carbon-nitrogen substrates, and their interaction with microbial cells. The precise atomic populations and morphologies of nanoscale particles have been discovered to be crucial for the development of biologically based nanosensors and tools for bioimaging, and antibacterial protection. Wei Bing [58] developed a very efficient framework to generate modified g-C_3N_4 substrates with included Ag NPs (Ag/g-C_3N_4). Ag/g-C_3N_4 nanohybrids significantly outperformed pure g-C_3N_4 nanosheets in terms of ROS production in the visible area. They also showed superior antimicrobial qualities and had the ability to disintegrate bacterial biofilms. When exposed to visible sunlight, the Ag/g-C_3N_4 nanohybrids have once again been shown to be powerful antibacterial inhibitors.

Figure 7 shows the development of bacterial colonies on LB agar supplemented with Ag/g-C_3N_4, Ag NPs/g-C_3N_4, and g-C_3N_4 over the course of 24 h. The plates containing Ag/g-C_3N_4 (50 g mL^{-1}) showed a considerable improvement over the control in the visible region. Colony growth was nearly completely inhibited whenever bacteria were cultured on LB-agar stained with Ag/g-C_3N_4, but Ag NPs/g-C_3N_4 or g-C_3N_4 only produced high colony-forming units [58]. These results show that Ag/g-C_3N_4 is the most effective inhibitor of both G^- and G^+ bacteria.

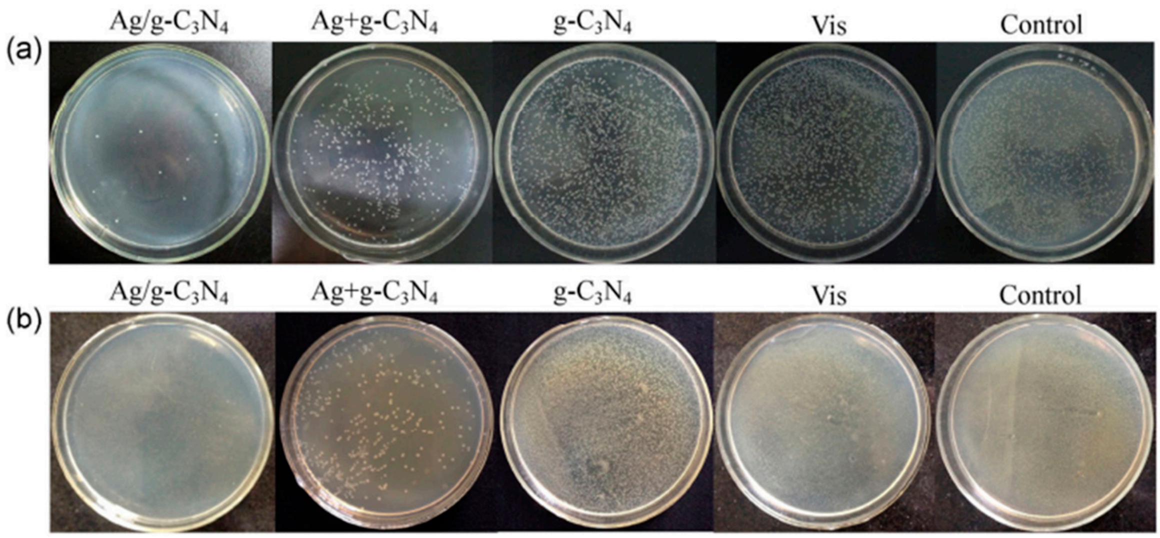

Figure 7. Antibacterial studies of $g\text{-}C_3N_4$, Ag NPs: $g\text{-}C_3N_4$ or $Ag/g\text{-}C_3N_4$ against (**a**) *E. coli* and (**b**) *S. aureus*.

By retaining photo-induced electrons in heterostructures, nanocrystals may be able to enhance carrier separation. UV light could also be used by Au NPs to complete the inter-band electron transfer. By ultrasonically processing g-CNQDs and $HAuCl_4$, Bhowmik et al. [59] created Au-CNx composites without using an additional reducing agent. Au NPs could also accomplish the inter-band electron transfer using ultraviolet light. Owing to an increase in ROS production activity. Au is one of the most durable nanostructured materials, making it one of the safest for biological systems. Table 2 lists the numerous plasmon-associated nanostructures for medical uses.

Table 2. Metal-based biosensors for biomedical applications [60].

Targets	Nanomaterial	Activities	Outputs	Samples
SARS-CoV-2	Au NPs	N gene	Electrochemical	Coronaviruses infectious Human
Cu^{2+} and histidine	Au nanoclusters	Peroxidase	Colourimetric	Human serum blood
Placental cellderived exosomes	Au doped Fe_2O_3 nanocubes	Peroxidase	Colourimetric, electrochemical	Cell culture media 8
Spermine	Ag–Au NP	Oxidase, Peroxidase	Fluorescence	Urine
Dopamine	Au nanoclusters	Peroxidase	Fluorescence, colourimetric	PC12 cells
Pseudomonas aeruginosa	Au NPs	Peroxidase	Electrochemical	Drinking water
Heparine and heparinase	Au nanoclusters	Peroxidase	Colourimetric	Diluted serum

The release of therapeutic drugs bound to Au NPs could be accomplished by heating the nanoparticles by employing a particular frequency of light. The heated Au nanostructures caused by the plasmons phenomenon can be used to deliver treatments to targeted biomolecule nuclei and organelles. The 5-fluorouracil (5-FU) (an anticancer) was discovered to be released from Au NPs by Agasti et al. [61] with the use of light. For improved dispersion and regulated cellular uptake, zwitterionic mediators were employed. When it is exposed to light with the 365 nm wavelength, the orthonitrobenzyl molecule cleaves and released 5-FU out from conjugate systems. Likewise, employing DNA-wrapped Au NRs infused by DOX (GNR@DOX), chemotherapy and photothermal treatment were conducted to cure metastatic melanoma. While spherical Au NPs exhibit plasmon resonance in the middle of the visible spectrum, their real positions could be shifted towards the infrared (IR) spectrum for rods and shells shaped structures. These nanostructures studied are highly effective for in vivo medication because biological tissues are more permeable to NIR wavelengths of sunlight [62]. These designed Au-based nanomaterials could be widely used as the building blocks for effective light-dependent controlled medication release reactions for the handling of several disorders. So, the nanoscience and technologies have played an advanced impacts on improving the catalytic functions towards optoelectronic, environments and biomedical uses [63–66].

5. Future Scopes and Conclusions

Noble metals such as Ag and Au NPs have received a lot of praise for their enhanced functionality in therapeutic and clinical applications due to their surface and narrow sizes. In the medicinal sector, their combination of these metal nanostructures with CNs was additionally applied to design the medical tools, sensors, and markers. Graphitic CNs have already been employed along with desired metal ions, having larger surface sites, stabled 2D orientations, and exceptional catalytic reactivity. Thus, to explain the physicochemical properties and chemical stabilities of Ag and Au doped CNs, we have highlighted the fundamentals of surface, 2D rearrangements of CNs units, and chemical bandings by reporting acceptable methodologies and techniques. Additionally, Ag, Au, and doped CNs might be integrated as effective catalysts in the healthcare industry to offer essential properties for enhanced biomedicine applications. Ag/Au-g-CN nanomaterials would be employed in physiological entities as therapeutic tools for antimicrobial and anticancer, uses. Further, various metal ions such as Pt, Cu, and Pd are also incorporated into the CN surface for enhancing the catalytic activities which is an essential task in the field of drug designing and developments in medical sciences. In addition, other concepts of these plasmonic materials such as photochemical and plasmonic near-field also explored to improve the biosensing uses in medical sciences. Experimentally, the thermo-induced alteration of the refractive index was used to evaluate the thermoplasmonic activities, which gave the optimum temperature for NA (nucleic acid) hybrid, Endo-IV breaking, and cyclical fluorescent probes. The highest absorbance of the 2D uniformly dispersed nanoabsorbers (AuNI) with a normal incidence angle was created specifically for 532 nm. The heated electron–hole combinations within the AuNI nanoabsorbers were photoexcited after exposed to the homogenized 532 nm pulse. The photoexcited plasmon moved to the metallic lattice in a matter of nanoseconds and later produced the heat energy to the surround aqueous environment via electron-phonon interactions. This suggested biosensing device could also be a promising technology for quick medical disease detection and serious ecological surveillance in the COVID-19 pandemic and post-pandemic period, supporting interventions in public health [67,68]. The combined effect of SPR and 2D surface of CNs could be regulated by the changing stoichiometric ratios of doped metal ions and their nano ranged sizes which directly affect the drug delivery in terms of the increasing rate of physicochemical kinetics. Therefore, these advanced nanomaterials could be highly appreciated for various areas such as biomedical, optoelectronics, and environmental applications due to their SPR spectral characteristics and surface qualities of the functionalized CNs.

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