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Gold Nanorods - An Overview

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Abstract:

This article provides an overview of current research in structure, synthesis, properties, application of gold nanorods. Interest in rod- shaped nanoparticles steam of unique optical properties, A gold nanorod is defined as nanometer-sized gold particles that are rod shaped. These solid, cylindrical nanoparticles have uniform diameters ranging from a few nanometers to hundreds of nanometers, with aspect ratios (length/diameter) larger than 1 but typically smaller than 10. The most popular and successful method for creating high-quality gold nanorods is seed-mediated development. optical properties of gold nanorods, absorption spectrum of colloidal dispersion of gold nanorods, local field effect and sensing application, color of colloidal dispersion of gold nanorod, polarization dependent color and absorption in polymer gold. Gold nanorods are utilized in a range of applications including biosensing, photothermal therapy, bioassays, biomedical imaging, and drug delivery. All these properties make gold nanorod a good candidate for future nanoelectronics in this article, we will describe the preparation and characterization of gold nanorods.

Keywords: Gold nanorods, Nanometered, Seed-mediated, Nanoelectronics.

Introduction:

In nanotechnology, nanorods are one morphology of nanoscale objects. Each of their dimensions range from 1–100 nm[(1)]. They will be synthesized from metals or semiconducting materials. Standard aspect ratios (length divided by width) are 3-5. Nanorods are produced by direct chemical synthesis. A blend of ligands act as shape control specialists and bond to distinctive features of the nanorod with distinctive qualities. This empowers diverse faces of the nanorod to develop at distinctive rates, creating a prolonged question. One potential application of nanorods is in display technologies, because the reflectivity of the rods is often changed by changing their orientation with an applied field. Another application is for microelectromechanical systems (MEMS). Nanorods, alongside other metallic element nanoparticles, also function as the agnostic agents. Nanorods absorb within the near IR, and generate heat when excited with IR light. This property has led to the utilization of nanorods as cancer therapeutics. Nanorods are often conjugated with tumor targeting motifs and ingested. When a patient is exposed to IR light (which passes through body tissue), nanorods selectively haunted by tumor cells are locally heated, destroying only the cancerous tissue while leaving healthy cells intact [(2)].

Gold Nanorods:

Gold nanorods are considered excellent candidates for biological sensing applications because the absorbance band changes with the refractive index of local material [(1)] allowing for extremely accurate sensing. In addition, nanorods with near-infrared absorption peaks can be excited by a laser at the absorbance band wavelength to produce heat, potentially allowing for the selective thermal destruction of cancerous tissues [3]

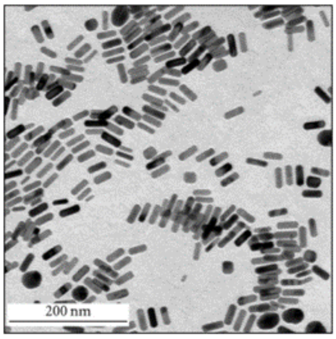

Figure 1: Microscopic structure of gold nanorods

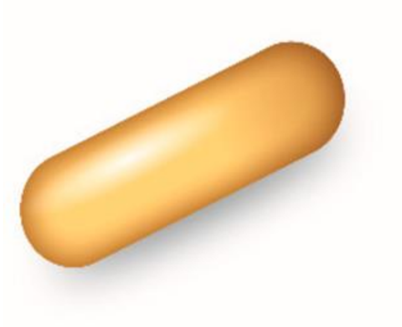

Figure 2: Gold nanorod

Nanoscale materials such as fullerenes, quantum dots and metallic nanoparticles have unique properties, because of their high surface area to volume ratio. Gold nanospheres and nanorods also have unique optical properties, because of the quantum size effect. Gold nanorods are cylindrical rods which range from less than ten to over forty nanometers in width and up to several hundred nanometers in length. These particles are typically characterized by their aspect ratio (length divided by width). [4]

Nanoscience is the exploration of materials on nanometer length scales. The wet-chemical synthesis of such novel materials is a field at the crossroads of conventional inorganic cluster chemistry and classical colloid chemistry. These new materials will lay the foundations for a whole set of technological developments which are commonly termed nanotechnology, and that have in common the use and manipulation of objects with at least one dimension in the nanometer size range (typically 1–100 nm). Although quite a few approaches have been developed for the creation of such objects, wet chemistry promises to become the preferred choice, because of its relative simplicity and use of inexpensive materials. The aim of such synthesis is generally the preparation of various kinds of nanoparticles of controlled composition, shape and size, so that the influence of particle radius on the physical, chemical, optical, electronic and catalytic properties of the material can be studied and correlated with modern quantum theory. To date the most widely studied nanoparticles have been those made of metals, semiconductors and magnetic materials. Once size control and monodispersed have been reasonably achieved, the next level of sophistication is shape control, i.e., synthesis of non-spherical nanoparticles where not only the size, but also other topological aspects can be controlled through judicious choice of experimental conditions and additives. For example, materials may be fashioned as rods, tubes or concentric core-shell structures, as hollow capsules or alloys. To move beyond conventional spherical growth, additives are used which bind to the nanoparticle surface. Such "coordination chemistry" between surfactants, ligands, adsorbates, passivants, chelating agents or polymers and nanoparticle surface atoms is of fundamental importance in achieving shape control. To date, the specific mechanisms governing morphology and geometry control over particle growth are still far from being well understood, this is expected to stimulate considerable the research over the next decade. It is immediately apparent that such basic studies of crystal morphology will lead to models for the more complex processes involved in biomaterial synthesis and the development of sophisticated skeletal architecture in living systems. This review will focus on the latest advances in the chemical synthesis of metal nanorods, in particular of gold nanorods, as well as their properties and some applications. These particles are primarily interesting from the point of view of their optical properties, which strongly depend on both the particle size and shape. Such optical properties are related to the interaction between the metal conduction electrons and the electric field component of incident electromagnetic radiation, which in the case of a few metals, such as gold and silver, leads to strong, characteristic absorption bands in the visible part of the spectrum, and in turn to unusual bright colors, not observed in the bulk material. The basic elements of the theory behind this phenomenon are described in Section 2, since the optical spectrum is directly correlated to the aspect ratio of the particles. Consequently, the formation of nanorods in solution can be easily monitored using standard UV–vis–NIR spectroscopy, which enables the mechanism behind the growth of these particles along a preferred orientation to be investigated. The current synthetic methods are then thoroughly described, including a review of the structural characterization that has been performed on them. Section 5 describes experiments on surface modification of gold nanorods, as well as the influence of surface-active compounds on the rod properties, while Section 6 focuses on ultrafast optical studies of the mechanical properties of nanorods and the physical effects of irradiation with intense laser beams. Section 7 summarizes the few reports available on the incorporation of gold nanorods within solid matrices to form nanocomposites, and finally, Section 8 briefly describes some applications for these materials [(5)].

History:

Gold Nanorods. Gold nanorods are gold nanoparticles that are elongated along one direction. The most popular method for synthesis of gold nanorods is the seeded growth originally developed by Niko Bakht and El-Sayed and Murphy et al. in the early 2000s. [(6)]

Gold nanorods have been the first successful example of anisotropic plasmonic nanostructure synthesized by wet chemistry.1 Since the early 2000s, they have received increasing attention because of their tunable optical (plasmonic) properties, which render them ideal candidates for a wide range of applications, such as solar harvesting,2 photovoltaics,3 surface enhanced spectroscopies,4,5 sensing,4,6,7 and therapy,2,8 to name a few. A direct consequence is that a broad variety of researchers with a wide range of backgrounds are currently interested in exploiting their optical properties. Therefore, fast, easy, scalable, and reliable methods for the synthesis of gold nanorods are necessary for their actual implementation in new technologies, which could have a direct impact on our future every-day life. During the past 2 decades, a huge effort has been made to decrease the size dispersity of colloidal gold nanorods; unfortunately, we have not achieved sufficient reproducibility of the synthetic protocols, understood as the possibility of reproducing them in a different working environment. The reason is that small details and "tricks" are generally left out in the experimental section of dedicated publications. In this Viewpoint, we highlight all of the synthetic aspects that generally remain in the shadows in order to provide the scientific community with a user-friendly guide for the production of gold nanorods. We present in Scheme 1 an informal representation of the optimization of synthesis methods to achieve the required quality. [7]

Structure: -

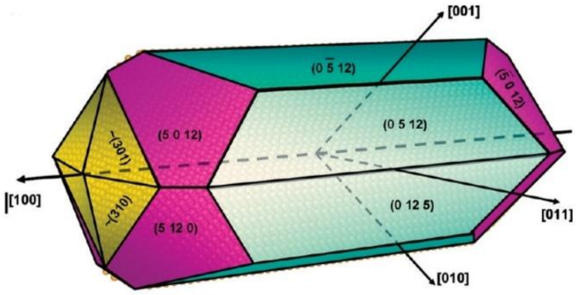

Figure 3: Schematic of the gold nanorod morphology. (For simplicity, slight differences in octagonal side lengths and facet angles have been ignored.)

Understanding the mechanisms that determine crystal morphology is a major challenge in materials science. [8] Since the ground-breaking demonstration of nanocrystal shape control via surfactant templating, gold nanorods have become the model system for understanding the growth of highly anisotropic, thermodynamically unexpected shapes. These nanocrystals exhibit a variety of properties, which are exquisitely sensitive to shape, such as the optical response. This has driven an intense effort over the past decade to understand and control their morphology. [9]

Theoretical studies of morphology and current models of growth mechanisms and shape transformations are underpinned by a consensus that gold nanorods, grown in the presence of silver ions, are bound by the same facets as bulk gold, namely, the closely packed atomic planes: {1 0 0}, {1 1 0}, or {1 1 1} facets. Specifically, the current morphological model describes these nanorods as an octagon formed by four {0 0 1} and four {0 1 1} side facets and terminated by {1 0 0}, {1 1 0}, or {1 1 1} facets [10]. The growth of a rod-like shape implies that the rod ends grow at a faster rate than the sides, [10] so the identification of the rod end-facets and some of the side facets as belonging to the same {1 0 0} family has been problematic. It is difficult to understand why the rods grow preferentially along only one of the three symmetry equivalent ⟨100⟩ directions. Similarly, it is difficult to understand why the octagon should have side-facets belonging to symmetry-inequivalent atomic planes, which might be expected to have different surface energies [12].

Transmission electron microscopy (TEM) has been used to analyze nanorod morphology; however, it is difficult to obtain quantitative information about the specimen in the third dimension using conventional methods. [13] For example, a single-atomic-resolution TEM image permits the identification of only a vector parallel to the facet plane. Images in several different projections are required to determine the orientation of the plane itself. [14]

Here we have undertaken an analysis of the three-dimensional shape (3D) and crystallography of gold nanorods using scanning transmission electron microscope (STEM) images acquired with a high-angle annular dark field (HAADF) detector. We have derived complementary 3D information from these images using two methods: HAADF-STEM to myography and a novel HAADF-STEM "thickness profile" method. [15]

Synthesis of Gold Nanorods: -

Based on their sizes and morphologies, gold nanomaterials display photophysical and novel optical properties. Au nanomaterials exhibit Localized Surface Plasmon Resonance (LSPR) when their dimensions exceed a critical size (2nm). The most extensively studied one-dimensional nanomaterials AuNR, exhibit two modes in additament to their transverse and longitudinal axes. The longitudinal LSPR mode's wavelength can be adjusted over a wide range, from visible to IR regions. In addition to the morphology of the nanomaterials, other factors such as surrounding environment and the surface modification also influence the LSPR wavelengths. By utilizing this LSPR bands' high tunability AuNR offer potential applications in a variety of domains, including imaging, photothermal treatment, biomolecule sensing, and photovoltaics. Recently, AuNR was also used to detect the lysine amino acids of specific viruses. When 11- mercaptoundecanoic acid is present, a chain of AuNR linked to each other at their end's forms, leading to this detection. [15]

1] Template method: -

The layout technique for the planning of gold nanorods was first presented by Martin and associates [16]. The technique depends on the electrochemical statement of Au inside the pores of nano porous polycarbonate or alumina format films. The bars could be scattered into natural solvents through the disintegration of the suitable film followed by polymer adjustment [17]. The technique can be made sense of as follows: at first a modest quantity of Ag or Cu is faltered onto the alumina layout layer to give a conductive film to electrodeposition. This is utilized as an establishment onto which the Au nanoparticles can be electrochemically developed. Thusly, Au is electrodeposited inside the nanopores of alumina. The following stage includes the particular disintegration of both the alumina layer and the copper or silver film, within the sight of a polymeric stabilizer, for example, poly (vinyl pyrrolidone). In the last stage, the poles are scattered either in water or in natural solvents through sonication or unsettling. The length of the nanorods can be controlled through how much gold saved inside the pores of the film [18]. The distance across of the gold nanoparticles in this way blended agrees with the pore breadth of the alumina film. In this way, Au nanorods with various measurements can be ready by controlling the pore width of the layout [19]. The major restriction of the format technique is the yield. Since just monolayers of bars are ready, even milligram measures of poles are exhausting to plan. In any case, numerous fundamental optical impacts could be affirmed through these underlying spearheading studies.

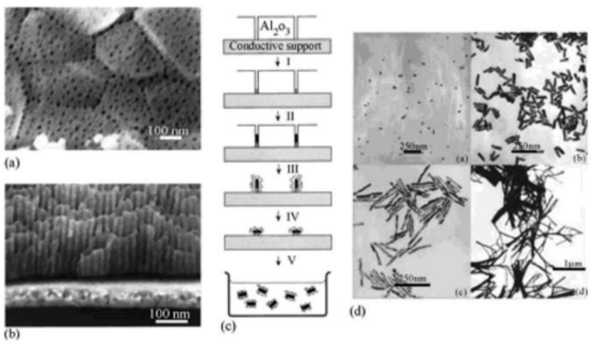

Figure 4: (a and b) Field emission gun-scanning electron microscopes images of an alumina membrane. (c) Schematic representation of the successive stages during formation of gold nanorods via the template method. (d) TEM micrographs of gold nanorods obtained by the template method.

2] Electrochemical Method: -

An electrochemical course to gold nanorod development was first shown by Wang and colleagues [(20)]. The strategy gives an engineered course to planning significant returns of Au nanorods. The combination is directed inside a basic two-cathode type electrochemical cell.

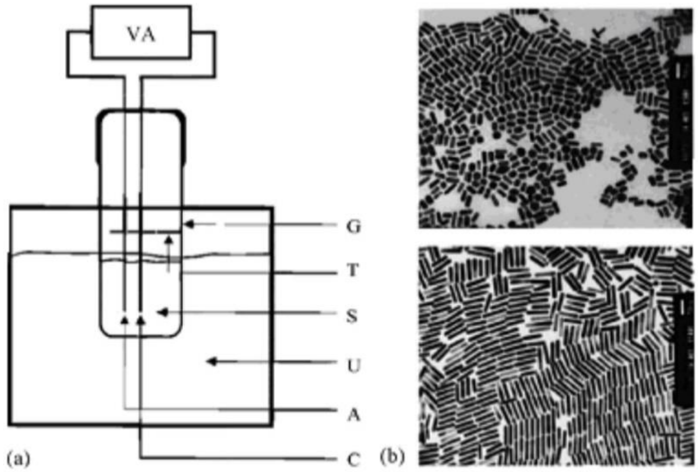

Figure 5: (a) Schematic diagram of the set-up for preparation of gold nanorods via the electrochemical method containing; VA, power supply; G, glassware electrochemical cell; T, Teflon spacer; S, electrode holder; U, ultrasonic cleaner; A, anode; C, cathode. (b) TEM micrographs of Au nanorods with different aspect ratios 2.7 (top) and 6.1 (bottom). Scale bars represent 50 nm.

In the agent electrochemical cycle, the accompanying circumstances are essential and significant:

1. A gold metal plate (3 cm×1 cm×0.05 cm) as a conciliatory anode
2. A platinum plate comparable as a cathode (3 cm×1 cm×0.05 cm)
3. A regular current of 3 Mama and a commonplace electrolysis season of 30 min
4. Electrolytic answers for submerge the two cathodes at 36 ℃, it contained:

A cationic surfactant, for instance: hexadecyltrimethylammonium bromide (C16TAB) to help the electrolyte and to act as the stabilizer for the nanoparticles to forestall conglomeration. A limited quantity of a tetra dodecyl ammonium bromide (TC12AB), which goes about as a rod inducing cosurfactant. Proper measure of CH3)2CO added to the electrolytic answer for slackening the micellar structure to help the consolidation of the round and hollow shape-inciting cosurfactant into the C16TAB micelles. Reasonable measure of cyclohexane to upgrade the arrangement of lengthened bar like C16TAB micelles. A silver plate is steadily drenched near the Pt terminal to control the viewpoint proportion of Au nanorods [(21)].

3] Seeded growth method: -

Cultivated development of monodisperse colloid particles traces all the way back to the 1920s. Ongoing examinations have effectively prompted control of the size conveyance in the reach 5-40 nm, though the sizes can be controlled by fluctuating the proportion of seed to metal salt [22]. Within the sight of seeds can make extra nucleation happens. Nucleation can be tried not to by control basic boundaries like the pace of expansion of lessening specialist to the metal seed, metal salt arrangement and the compound decrease capability of the diminishing specialist. The bit-by-bit molecule growth is more viable than a one stage cultivating technique to stay away from optional nucleation. Gold nanorods have been helpfully manufactured utilizing the seeding growth technique [23]. The arrangement of 3.5 nm seed arrangement can be made sense of as follows: C16TAB arrangement (5.0 mL, 0.20 M) was blended in with 2.0 mL of 5.0×10-4 M HAuCl4. To the blended arrangement, 0.60mL of super cold 0.010 M NaBH4 was added, which brought about the development of a tannish yellow arrangement. After lively mixing of the seed answer for 2 min, it was kept at 25 °C minus any additional blending. The seed arrangement was utilized somewhere in the range of 2 and 48 h after its readiness [24]. By controlling the development conditions in fluid surfactant media, it was feasible to hinder auxiliary nucleation and orchestrate gold nanorods with tunable viewpoint proportion. Some researchers showed expansion of AgNO3 impacts not just the yield and angle proportion control of the gold nanorods yet in addition the system for gold nanorod arrangement, correspondingly its gem structure and optical properties [25]. As of now, it is consequently advantageous to separate seed-interceded approaches acted in the nonattendance or within the sight of silver nitrate.

3.1] Preparation of gold nanorods without AgNO3: -

Murphy and collaborators had the option to combine high viewpoint proportion tube shaped nanorods utilizing 3.5 nm gold seed particles arranged by sodium borohydride decrease within the sight of citrate, through cautious control of the development conditions, i.e., through streamlining of the grouping of C16TAB and ascorbic corrosive, and by applying a few stages cultivating process [26].

3.1.1] Preparation of 4.6±1 Aspect Ratio Rod: -

In a perfect test tube, 10 mL of development arrangement, containing 2.5×10-4 M HAuCl4 and 0.1 M C16TAB, was blended in with 0.05 mL of 0.1 M newly arranged ascorbic corrosive arrangement. Then, 0.025 mL of the 3.5 nm seed arrangement was added minus any additional mixing or disturbance. Inside 5-10 min, the arrangement tone changed to rosy brown. The arrangement contained 4.6 angle proportion poles, circles, and a few plates. The arrangement was steady for over one month [27].

3.1.2] Preparation of 13±2 Aspect Ratio Rod: -

A three-step cultivating strategy was utilized for this nanorod planning. Three test tubes (named A, B, and C), each containing 9 mL development arrangement, comprising of 2.5 ×10-4 M HAuCl4 and 0.1 M C16TAB, were blended in with 0.05 mL of 0.1 M ascorbic corrosive. Then, 1.0 mL of the 3.5 nm seed arrangement was blended in with test A. The shade of A became red inside 2-3 min. After 4-5 h, 1.0 mL was drawn from arrangement An and added to arrangement B, trailed by careful blending. The shade of arrangement B became red inside 4-5 min. After 4-5 h, 1 mL of B was blended in with C. Arrangement C became red in variety inside 10 min. Arrangement C contained gold nanorods with viewpoint proportion 13. The arrangements were all steady for over a month [28].

3.1.3] Preparation of 18 ±2.5 Aspect Ratio Rod: -

This system was like the technique for getting ready 13 viewpoint proportion bars. The main distinction was the planning of seed expansion in progressive advances. For 13 viewpoint proportion poles, the seed or arrangements An and B were added to the development arrangement after the development happening in the past response was finished. Be that as it may, to make 18 perspective proportion poles, particles from An and B were moved to the development arrangement while the particles in these arrangements were all the while developing. Normally, arrangement A was moved to B after 15 s of adding 3.5 nm seed to A, and arrangement B was moved to C after 30 s of adding arrangement A to B. In the above strategy, the yield of the nanorods in this manner combined is ca. 4 % [(29)]. The long poles can be focused and isolated from the circles and abundance surfactant by centrifugation. Afterward, a similar gathering detailed a better technique to deliver monodisperse gold nanorods of high viewpoint proportion in 90 % yield [(30)]. simply through pH control. In the new proposed convention, addition of sodium hydroxide, equimolar in focus to the ascorbic corrosive, to the development arrangement raised the ph. The pH of the development arrangement was changed from 2.8 to 3.5 and 5.6, which prompted the arrangement of gold nanorods of perspective proportion 18.8±1.3 and 25.1±5.1, separately. The fresher strategy likewise, brought about an emotional expansion in the general extent of nanorods and decreased the division steps important to eliminate more modest particles.

164 Nanorods The system of arrangement of pole formed nanoparticles in watery surfactant media stays muddled. In view of the possibility that C16TAB retains onto gold nanorods in a bilayer style, with the trimethylammonium headgroups of the first monolayer confronting the gold surface [(31)]. Murphy and collaborators [(32)]. recommended that the C16TAB headgroup specially ties to the crystallographic countenances of gold existing at the edges of pentahedral twinned poles, when contrasted with the appearances at the tips. The development of gold nanorods would consequently be represented by special adsorption of C16TAB to various gem faces during the development, as opposed to going about as a delicate micellar layout [(33)]. The impact of CnTAB analogs wherein the length of the hydrocarbon tails was differed, keeping the headgroup and the counterion consistent was additionally contemplated [(34)]. It was found that the length of the surfactant tail is basic for controlling the length of the nanorods as well as the yield, with more limited chain lengths creating more limited nanorods and longer chain lengths prompting longer nanorods in better returns [(35)]. Taking into account the special adsorption of C16TAB to the different precious stone countenances in a bilayer style, a "zipping" component was proposed considering the van der Waals connections between surfactant tails inside the surfactant bilayer, on the gold surface, that might advance the development of longer nanorods from more steady bilayers [(36)].

As of late, Pérez-Juste et al. researched the elements influencing the nucleation and development of gold nanorods under comparative circumstances. They demonstrated the way that the viewpoint proportion, the monodisperses and the yield could be impacted by the soundness of the seed, temperature, the nature and convergence of surfactant. The yield of nanorods arranged from C16TAB covered seeds is a lot higher than that from bare (or citrate balanced out) seeds. This demonstrates that the more colloidally stable the gold seed nanoparticles are, the higher the yield of bars [(37)].

3.2] Preparation of Gold Nanorods with AgNO3: -

The presence of silver nitrate permits better control of the state of gold nanorods orchestrated by the electrochemical strategy, and Murphy and collaborators proposed a variety of their underlying method for long nanorods. To expand the yield of pole molded nanoparticles (up to 50 %) and to control the angle proportion of more limited nanorods and spheroids. Under indistinguishable exploratory circumstances, a limited quantity of silver nitrate is added (5×10−6 M) preceding the development step. The viewpoint proportion of the spheroids and nanorods can be constrained by fluctuating the proportion of seed to metal salt. The presence of the seed particles is as yet essential in the development cycle, and there is an expansion in viewpoint proportion when the grouping of seed particles is diminished. The component by which Ag+ particles alter the metal nanoparticle shape isn't exactly perceived. It has been estimated that Ag+ adsorbs at the molecule surface as AgBr (Br− coming from C16TAB) and confines the development of the AgBr passivated gem features [38]. The likelihood that the silver particles themselves are decreased under these exploratory circumstances (pH 2.8) can be dismissed since the lessening force of ascorbate is excessively sure at low pH. This shape impact depends on the presence of AgNO3, yet in addition on the idea of the seed arrangement. By essentially changing how much silver particles in the development arrangement, a tweaking of the perspective proportion of the nanorods can be accomplished, with the goal that an expansion in silver fixation (keeping how much seed arrangement steady) prompts a redshift in the longitudinal plasmon band. Strangely, the viewpoint proportion can likewise be constrained by changing how much seed arrangement added to the development arrangement within the sight of consistent Ag+ fixation [39].

4] Photochemical method: -

Yang and collaborators fostered a photochemical technique for the union of gold nanorods [40]. which is acted in a development arrangement like that depicted for the electrochemical technique, within the sight of various measures of silver nitrate and with no substance lessening specialist. The development arrangement containing gold salts and others like surfactants and lessening specialists, was illuminated with a 254 nm UV light (420 µW/cm2) for around 30 h. The subsequent arrangement was centrifuged at 3000 rpm for 10 minutes, and the supernatant was gathered, and afterward centrifuged again at 10,000 rpm for 10 minutes. The hasten was gathered and redispersed in deionized water. The shade of the subsequent arrangement fluctuates with how much silver particles added, which is characteristic of gold nanorods with various perspective proportions [41].

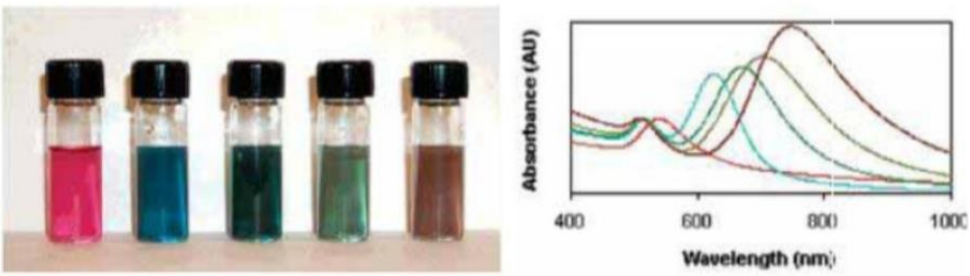

Figure 6: (a) Image of photochemically prepared gold nanorods solution, and (b) corresponding UV-vis spectrum.

The left most solution was prepared with no silver ion addition. The other solutions were prepared with addition of 15.8, 31.5, 23.7, 31.5 µL of silver nitrate solution, respectively. The middle solution was prepared with longer irradiation time (54 h) compared to that for all other solutions (30 h), and the transformation into shorter rods can be seen. two retention tops were acquired, which came about because of the longitudinal and cross over surface plasmon (in the UV-vis range) that demonstrates gold nanorods are framed when silver particles are added. The viewpoint proportion increments when more silver particles are added, and this is joined by a lessening in bar width, while without any silver particles, round particles are gotten. In this manner, the chance of a bar like micellar layout system can be disposed of and these trials show the basic pretended by silver particles in deciding the molecule morphology [42].

5] Other methods: -

Markovich and associates adjusted the seed-interceded strategy without even a trace of silver nitrate proposed by Murphy and collaborators for the development of gold nanorods straightforwardly on mica surfaces [43]. The technique includes the connection of the circular seed nanoparticles to a mica surface, which is then plunged in a C16TAB surfactant development arrangement. Around 15 % of the surface-bound seeds are found to develop as nanorods. This yield improvement of nanorods, contrasted with that acquired for the arrangement development strategy (ca. 4 %), was credited to an adjustment of the like hood of the developing seed to foster twinning imperfections. In this way, Wei et al. adjusted the technique to develop nanorods straightforwardly on glass surfaces. They concentrated because of the linker used to append the seed particles and the gold salt focus in the development arrangement on the framed gold nanostructures [44].

Properties: -

1] Optical properties of gold nanorods: -

Gold nanorods show unique optical properties depending on the size and the aspect ratio (the ratio of longitudinal-to-transverse length). Although the spherical gold nanoparticle (nanosphere) has only one surface plasmon (SP) band in the visible region, the nanorod has a couple of SP bands. One SP band corresponding to the transverse oscillation mode locates in the visible region at around 520 nm, while the other corresponding to the longitudinal oscillation mode between far-red and near-infrared (near-IR) region. This is the distinctive optical characteristic of the nanorod as compared with the nanosphere. So, nanosphere may have electronic, crystallographic, mechanical or catalytic properties that are different to the nanorods. Such differences may be probed through optical measurements. Spectroscopic measurements are often the easiest methods for monitoring surface processes such as dissolution and precipitation, adsorption and electron transfer. If nanocrystals of any specific geometry could be grown then it is conceivable that optical materials could be designed from scratch. Photonic devices could be created from molecular growth reactors. In the section, we will only describe the optical properties of gold nanorods. 3.1 Plasmon resonance for ellipsoidal nanoparticles for gold nanorods, the plasmon absorption splits into two bands corresponding to the oscillation of the free electrons along and perpendicular to the long axis of the rods [45]. The transverse mode (transverse surface plasmon peak: TSP) shows a resonance at around 520 nm, while the resonance of the longitudinal mode (longitudinal surface plasmon peak: LSP) occurs at higher wavelength and strongly depends on the aspect ratio of nanorods. As aspect ratio is increased, the longitudinal peak is redshifted. To account for the optical properties of Nanorods, it has been common to treat them as ellipsoids, which allows the Gans formula (extension of Mie theory) to be applied [46].

2] Absorption spectrum of colloidal dispersions of gold nanorods: -

The longitudinal and transverse plasmon resonance can be computed as a function of aspect ratio either by using analytical expression put forth by Gans in 1912 or by using one of numerical techniques [47]. Sharma et al. describe the how the absorption spectrum measured experimentally compares to the results from Gans theory and DDA simulations [48]. The gold nanorods cited from their research were synthesized using a seed-mediated method based on use of binary surfactant and all UV-vis-NIR spectra were acquired with a Cary 5G UV-visible-near IR spectrophotometer. Even though optical properties of pure water were used for calculating the spectrum, the peak resonance measured experimentally show a remarkable agreement with theoretical and simulation results . Several groups have observed similar trends [49].

It is well known though that the plasmon resonance is very sensitive to change in the dielectric constant of the medium, and in case of mixed solvents or in sensing applications, this effect must be taken into consideration. Theoretically predicted change in optical properties of colloidal gold suspensions expected upon changing medium has been observed experimentally by several groups. For the gold nanorods, the computed longitudinal plasmon peak increases with an increase in the dielectric constant of medium. The effect of medium seems more pronounced for longer nanorods, as is evident from the increase in slope observed for higher aspect ratios [50].

3] Local field enhancements and sensing applications: -

The electric field is the gradient of potential, and hence using the expression for potential derived earlier, the function electric fields inside and outside the sphere are: Resonance in polarizability leads to the resonant enhancement of both the internal and the external dipolar fields. The wavelength at which this resonance occurs depends upon the dielectric of the metal as well as the medium around it. Since the resonance condition and resulting enhancements of the fields are directly correlated with the shape and size of particle, the basic understanding of this relationship is crucial for their widespread use. The sensitivity of plasmon resonance to the local dielectric environment, implies that any changes within a few nanometers of the particles can be used in say biological or chemical sensing applications [51]. For the perfectly spherical particles that can be described by electrostatic approach (Rayleigh limit), only the dipole surface plasmon contributes to the localized enhancement, limiting the overall enhancement achieved. In rod-like particles, highly localized fields can be generated at the tips, providing a much stronger response function for sensing applications. The theoretical and experimental aspects of surface-enhanced Raman scatting and plasmonic based sensing are widely discussed and debated in literature and it forms one of the most anticipated applications of non-spherical gold and noble metal particles [52].

4] Color of colloidal dispersions of gold nanorods: -

Since the color of colloidal gold depends on both the size and shape of the particles, as well as the refractive index of the surrounding medium, it is important to independently account for the color change of gold nanorod suspension due to presence of either nanospheres or any substance that affects the refractive index of the solvent. Since color of the gold sols is traditionally linked to their shape or size, Sharma et al. characterized the dependence of perceived color on shape and dimensions of the nanoparticles using color science. The color was identified by positioning x and y values in the CIE chromaticity diagram. This visible light region consists of a spectrum of wavelengths, which range from approximately 700 to 400 nm. For the nanorods, the transverse plasmon resonance peak is not quite as sensitive to the change of aspect ratio, as the longitudinal peak, which shows noticeable shifts in the aspect ratio. which shows the UV-vis-NIR spectrum of gold nanorods dispersions. The relatively intensity of transverse peaks shows that mostly nanorods are present, which were obtained by optimizing synthesis and separation techniques. As predicted by theory, the transverse peak blue shifts with an increasing aspect ratio.

shows the photograph of the colloidal dispersions of gold nanorods and the color patches simulated using theoretical absorbance data equivalent to the aspect ratio of gold nanorods. The color of solution is basically the same beyond an aspect ratio of around 4. Therefore, in a visible region, the dramatic color change cannot be achieved by only changing aspect ratio. But once the longitudinal peak goes beyond 700 nm, (for aspect ratio ~3) the change in peak absorption cannot be detected by the human eye and color of gold nanorod dispersion does not change with further increase in aspect ratio. Therefore, the color change could be only observed for relatively short range of aspect ratios. But the tunability of optical properties gold nanorods as a function of aspect ratio provides potentials to use gold nanorods as an optical filter in near infrared region. Sharma et al. found that the color in a visible region is rather sensitive to the number of spherical particles included as byproducts since surface plasmon peak of sphere positions between 500 and 550 nm. The color changes from purple to brown as the number of byproducts decreases [(53)].

5] Polarization dependent color and absorption in polymer-gold nanocomposite films: -

The optical properties of gold nanorods are dependent on the state of polarization of incident light, on size and aspect ratio of the particles, and the dielectric properties of the medium. The optical response of a colloidal dispersion of nanorods, as revealed by UV-vis spectroscopy can be thought of as the response from randomly oriented rods. The polarization dependent response of nanorods can be observed by dispersing them in a gel or 173 polymer matrices, and then stretching the matrix uniaxially, thus aligning the dispersed rods. When the incident light is polarized in the direction of stretching or in the direction coinciding with the average orientation of long axis of nanorods, absorbance is dominated by the response due to the longitudinal resonance. As the angle between the stretching direction and polarization of incoming light is increased, the absorbance shows a marked blue shift. Thus, the composite films show a marked polarization dependent color and absorption, making them suitable for use as polarization dependent color filters and for other optical applications [(54)]. Caseri presented a very comprehensive historical perspective and discussion of optical properties of polymer/nanoparticle composites. Caseri and co-workers found that spherical gold nanoparticles can form “pearl necklace type arrays” by aggregating along the stretching direction and produce dichroic filters that have potential application in creating bicolored displays. Rawashdeh [(55)]. studied the linear dichroic properties of polyethylene/gold rods composites and studied how the local field enhancement could make these composite films impacts the infrared absorption of probe molecules attached to the surface of nanorods oriented to the polarizer [(56)]. The transmittance spectra as a function of polarizer angle for a nanocomposite with gold nanorods of aspect ratio 2.8, and draw ratio of 4 was used for this study. The longitudinal plasmon resonance blue shifts as polarization angle are increased, and the intensity of the peak drops, in accordance with the observations by other groups. The thickness of the film is 50μm and it has good flexibility. When the aspect ratio of nanorods is sufficiently large, the LSP shifts to the near-IR region. This indicates that the wavelength region displaying optical dichroism can be shifted from the visible to the near-IR. This enables the fabrication of thin film optical filter that respond to the wavelengths in the near-IR region [(57)].

Applications: -

Gold nanorods are utilized in a range of applications including biosensing, photothermal therapy, bioassays, biomedical imaging, and drug delivery. The sections that follow explain why gold nanorods are useful for these applications and provide guidance for applying Fortis Life Sciences products to develop new technologies and improve existing ones [(58)].

1] GNRs for sensing applications: -

GNRs' enticing qualities must be applied in practical ways before their full potential can be realized. The use of GNRs for the sensing and detection of numerous analytes in biological and other systems has been the subject of extensive research. Numerous methods that take use of the intriguing optical characteristics of GNRs are suitable for use in sensing applications [(59)].

The remarkable qualities of GNRs have inspired biomedical researchers to use GNRs for a variety of biomedical applications, particularly in the diagnosis, imaging, and treatment of cancer. Cancer biomarker detection, which was covered in Section 4, is a key component of cancer diagnosis. The specific concentration of GNRs inside the cancerous cells allows for the imaging of malignancy. The GNRs are then used in dark-field, two-photon luminescence as highly effective contrast agents [(60)].

2] GNRs for in vivo biomedical applications: -

The foundation for in vivo applications of GNRs is their potent, tunable longitudinal LSPR band since NIR light can penetrate deeper (10 cm) tissues with less attenuation than visible light. Additionally, GNRs have smaller line-widths (108-1010 M cm 1) and higher extinction coefficients (108-1010 M cm 1) than the majority of other types of nanostructures, which leads to superior photothermal and photoacoustic conversion efficiency [(62)].

3] Biomedical imaging: -

Optical imaging is a strong sub-atomic imaging strategy and is turning into a promising method for diagnosing illnesses like disease. In optical imaging innovation, fluorescence imaging is an optimal way for early disease recognition because of its minimal expense, high awareness and high spatial goal [(63)]. As of now, natural fluorophores and quantum specks are broadly utilized as differentiation specialists for fluorescent imaging applications. Nonetheless, natural fluorophores are more defenseless to photobleaching, and quantum spots have long haul harmfulness both in vitro and in vivo. Contrasted and natural fluorophores and quantum specks, AuNR enjoys significant benefits, like biocompatibility, no photobleaching or disintegration, upgraded ingestion and dissipating signals, and longitudinal plasmon assimilation movable from apparent light to NIR. Durr et al. directed TPL concentrates on involving AuNRs in profound tissues. The outcomes showed that the TPL sign of AuNRs was multiple significant degrees more splendid than the two-photon autofluorescence (TPAF) sign of cells and tissues which made it a proficient imaging test for disease determination [(64)].

4] Gene delivery: -

As of late, AuNR as a non-viral quality conveyance vector has gotten far and wide consideration. Takahashi and his colleagues contemplated phosphatidylcholine-adjusted AuNR to deliver plasmid DNA. Subsequent to being illuminated with NIR lasers of various powers, the state of the AuNR transformed from a pole shape to a circular shape, and DNA was delivered. Chen et al. directed a comparable report to target HeLa cells utilizing upgraded green fluorescent protein (EGFP) quality stacked AuNRs [(65)].

5] Drug Delivery: -

The optical properties, tunable surface science, and relative biocompatibility of gold nanorods loan them exceptional abilities as vehicles for designated drug conveyance. This can happen by means of biofunctionalization of the nanorod surfaces for designated drug conveyance, as well as by designing a photoinduced arrival of medication particles for focused on and site-explicit medication conveyance. Also, gold nanorods can be hybridized with different materials, for example, mesoporous silica, for designated and controlled drug discharge [(66)].

6] Photothermal Therapy: -

Gold nanorods are broadly utilized for photothermal treatment advancements, where close infrared (NIR) lasers specifically illuminate nanorods at their full frequencies to prompt nearby warming without making harm encompassing (IR straightforward) tissues. Stake covered gold nanorods are watery viable and ideal for working with nanorod pore infiltration for restorative treatments like skin break out treatment and laser hair expulsion [(67)]. Citrate-covered and Stake carboxyl ligands can likewise be further functionalized with different terminal gatherings or biomolecules for cell focusing on, empowering nanorod utility in disease treatments and growth removal [(68)].

7] Biosensors: -

Gold nanorods are collecting extensive consideration for their utilization as biosensors because of their tunable surface plasmon resonances and aversion to nearby refractive list, filling in as tests of their substance climate. Their surface science is handily adjusted for joining biomolecules, from antibodies and proteins, to catalysts and aptamers. These bioreceptors can be utilized to target particles of interest with high particularity, and their communication with gold nanorod surfaces can initiate a visual and quantifiable sign of sub-atomic discovery [(79)]. Gold nanorods have remarkable capacities as optical pointers because of the excellent tunability of their surface plasmon resonances, covering frequencies from the noticeable to the close infrared (NIR) district of the electromagnetic range. Moreover, their anisotropic shape offers two unmistakable plasmon modes which can be tuned by changing the viewpoint proportions (length to width) of the poles during manufacture. These characteristics empower detecting advances with exceptional control [(70)].

Their anisotropic shapes empower course of action of gold nanorods into superstructures, offering upgraded security from long-range requesting and extra methods of optical tunability. Development of situated game plans could actually be directed by surface collaborations delicate to biotin-streptavidin restricting, DNA hybridization, and immune response antigen acknowledgment worked with by surface functionalization of nanorod outfits [(71)].

After nanorod union, the surfaces of CTAB-covered gold nanorods are almost consistently altered for ensuing formation or superstructure arrangement because of the cytotoxicity of CTAB. At Fortis Life Sciences, our citrate-functionalized gold nanorods give uncovered, sans ctab surfaces for simple uprooting with thiols and other natural covering specialists to work with making of custom biosensors and apt sensors [72].

One more way to deal with making nanorod-based biosensors uses polyethylene glycol (Stake) surface alteration, which delivers the nanorods profoundly stable in watery circumstances to work with in vivo bioimaging. Fortis Life Sciences offers gold nanorods surface-functionalized with Stake for improved dependability in watery cradles and protic solvents, and Stake carboxyl for prepared EDC/NHS coupling or formation to proteins, antibodies, and peptides [73].

Conclusion:

This study focused on the history, structure, properties, synthesis, and applications of gold nanorods (GNRs), as promising candidates for utilization in nano-drug delivery systems (nDDS), photothermal therapy, rapid diagnostic and imaging, and theranostics applications. Among these applications, the capacity of GNRs in converting irradiation into heat has been considered the most distinctive feature in photothermal therapeutic strategies and localized drug release. Never the less, the interaction between GNRs and different chemical/biological elements and the possibility of unfavorable, irreversible changes in their physicochemical characteristics is an important issue that needs deep research and ex/in vivo experiments for nDDS and other potential applications, i.e., nanobiosensing and regenerative medicine. Manageable surface chemistry, high stability (less agglomeration and corrosion), low cytotoxicity and high biocompatibility, simple synthesis protocols with reproducibility in scaling up, strong signals for bioimaging, sustainability in delivery, and cost-effectiveness are also other concerns that need to be addressed in designing such hybrid systems.

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