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## Research Article

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# Performance Evaluation and Enhancement of Medical imaging using Plasmonic gold Nanostars

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## Abstract

This paper gives insights about examinations of plasmonic nanoparticles and particularly gold nanostar as sign enhancer and contrast agent for clinical imaging and the optical properties of (NPs) of different volume and morphology and the encompassing medium were stood out from affirm that the gold nanostars are the best shape that can Scatter the light, thusly obtaining better and all the most clear clinical imaging. Stars formed gold nanoparticles have a greater surface comparative with its volume and contact surface cross section than spherical and rods shaped nanoparticles, and accordingly act even more firmly as a radiation enhancer. At that point the wavelength of the (SPR) is in the body tissues transparence window, the laser can impact gold nanostars more profound inside the human body. Mathematical outcomes exhibit that the gold nanostar has more powerful Scattering cross section conversely with sphere and rod shaped gold nanoparticles. The largest nanostar displayed better contrast properties for imaging applications, for instance, confocal microscopy and optical coherence tomography.

## Keywords

plasmonic nanoparticles, gold nanostars, biomedical imaging, plasmon resonance, nanoparticles dimmers.

## I. INTRODUCTION

Optical imaging exemplifies one the very pinnacle of fundamental apparatuses in biological studies. Despite the fact that with incredible advances, optical imaging actually experiences hitches like resolution, sensitivity, speed, and penetration depth. Attributable to the selective optical properties of gold nanoparticles (AuNPs), in another meaning surface Plasmon resonance, AuNPs canister is promptly used to improve optical images set up on their absorption, scattering, fluorescence, Raman scattering, etc. and so on Here, we incorporate the most current accomplishments and provokes specialist with utilizing AuNPs to propel goal and affectability in medical imaging .Utmost biomedical applications requisite particle plasmon resonance wavelengths in the range from 700 to 1300 nm that resemble to the tissue transparency window. Altering the geometrical shape of nanoparticles is one of the ways to control the position of the plasmon resonance peak. Plasmon resonant for gold nanoparticles require usual significant attention as a potential technology in optical imaging, laser diagnostics and medication with the interesting property of (PR) ensuing in an upgraded electromagnetic fields on the metallic (NPs) surfaces (Kim EY et al. 2015; Ana B et al. 2016; Pang et al. 2016). Thus, exceptional consideration is as of now being paid to anisotropic AuNPs with a plasmon resonance which is tunable to the close by infrared (NIR) district inside the transparent range (700-1300 nm) with upgraded photons (light) entrance into biotissue. Remarkable to this property, lower toxicity, simple function and stability, anisotropic AuNPs can be utilized for treatment and diagnostics (Versiani AF et al. 2016; Sousa-Castillo et al. 2016; Bhamidipati et al. 2017). Anisotropic extended gold nanoparticles specially gold nanostars (AuNSts), have become especially fast approaching competitor for applications in biomedicine because of their wide plasmonic resonance peaks and extremely high electric field intensity concentrated at their branches

(Rodriguez-Lorenzo LA et al. 2009; Jana D et al. 2015; Vendrell M et al. 2013; Harmsen S et al. 2015). Exceptionally, at this moment of the presented study outstandingly, most of gold nanostar applications in medical imaging and detecting are restricted to surface enhanced Raman scattering (spectroscopy). In any case, due to extraordinary dispersing (scattering) properties, AuNSTs assurance to be splendid optical imprints for various imaging applications. For example, the usage of gold nanostar (AuNST) as contrast agent for (OCT) imaging is valuable for forward-dissipating (scattering) fluids since nanoparticles will increase backward reflected photons, making conceivable static fluid very well imaging, yet furthermore diversion of the fluid speed profile, which is critical for infection diagnostics. Another valuable resource for imaging cell and shockingly nuclear changes is confocal laser scanning microscopy (CLSM) that furnishes that furnishes 3D minuscule images with a bewildering sub-micron spatial resolution. The usage of AuNSTs CLSM builds the backscattered signal from the examples for the direct synchronized management of the take-up and localisation of nanoparticles in cells. The nonappearance of conceivably poisonous fluorescent dyes in the examples empowers zeroing in on the impact of the AuNPs on the cells solely, which is generally critical for biomedical applications. In this Paper the upsides of plasmonic nanostars are included interestingly with other nanoparticles for the application domains presented already. Likewise, the connection of the optical characteristics of metallic nanostructures fill in as a solid establishment for the as of late referred to application.

## **II. Design and Modeling Nanoparticles**

In this work initially, the particles of spheres, Rods and nanostars were recreated and modulated by using finite element method (FEM) (Hsiangkuo et al. 2012; Zhihua et al. 2015). Utilizing episode light source as found in mathematical equation (1). The model of nanostar and their optical properties will studies using RF Module of (COMSOL Multiphysics 5.0).

$$E = e^{-jk_0z} \hat{X} \tag{1}$$

The simulation was based on numerical solutions of a time- averaged Laplacian, seen in Equation (2), employing the widely used Finite Element.

$$\nabla \times \frac{1}{\mu_r} (\nabla \times \mathbf{E}) - \mathbf{k}_0^2 \left( \epsilon_r - \frac{j\sigma}{\omega\epsilon_0} \right) \mathbf{E} = \mathbf{0} \quad (2)$$

The geometry was based on three concentric areas. A completely absorption spherical layer, typically alluded to as perfect matching layer (PML), the layer appointed the dielectric properties of water, (Hale et al. 1973) and a center space including the different nanostar models allocated the dielectric characteristics of gold from the (Drude–Lorentz) just vaules from Christy and Johnson ( Johnson et al. 1972) The relative permeability ( $\mu_r$ ) taken to be one in all calculation areas. The angular frequency  $\omega$  determined from the input wavelengths values.

The models for nanostsr were also developed in Comsol Multiphysics using at most a spherical core, eccentric conical spikes with hemispherical, oblate, and prolate hemi ellipsoidal tips. The volume and surface areas of these models are defined by Equations (3) and (4) with  $i$  being the number of spikes.

$$V = \frac{4}{3}\pi a^3 + \sum_{i=1}^n \left\{ \frac{h_i}{3} \pi (R_i^2 + R_i r_i + r_i^2) + \frac{2}{3} \pi r_i^3 - \frac{\pi}{6} (a - a^2 - R_i^2 - 3R_i r_i + a^2 - R_i^2) \right\} \quad \mathbf{3}$$

$$A = 4\pi a^2 - \sum_{i=1}^n \{ 2\pi a (a - \sqrt{a^2 - R_i^2}) \} + \sum_{i=1}^n \{ \pi (r_i + R_i + 2\pi r_i^2) \} \quad (4)$$

Moreover, (a) is the radii of the (sphere core), (R) is the base radii of a (spike), (r) is the radii of the (hemisphere tip of a spike), and (h) is the (distance between R and r).

From the solution of Equation 2, provide plots of the normalized scattered electrical fields. Three dimensional plots of the electrical fields norm (Equation 5) on the surface of the various NSs along with two-dimension slice plots of the electric fields norm are presented. 2D slice plots are fundamental to study, at the same time, surface and bulk plasmons modes in these nanoparticles.

$$|E| = \sqrt{E_X^2 + E_Y^2 + E_Z^2} \quad (5)$$

In parallel, calculate the Scattering, Absorption and Extinction, as defined by Equations (6) and (7).

$$\sigma_{abs} = \frac{W_{abs}}{P_{inc}} \quad \sigma_{sca} = \frac{W_{sca}}{P_{inc}} \quad (6)$$

$$\sigma_{ext} = \sigma_{abs} + \sigma_{sca} \quad (7)$$

The Absorption and Scattering are definite by the energy rates (absorbed and scattered) by the nanostars due to its size, defined in Equations (8) and (9) respectively, and divided by the incident irradiance, given by Equation (10).

$$W_{abs} = \frac{1}{2} \iiint_{xyz} [Re [(\sigma E + j\omega D) \cdot E^*] + j\omega \mathbf{B} \cdot \mathbf{H}^*] dx dy dz (W) \quad (8)$$

$$W_{sca} = \oint [E \times H^*] \cdot n ds (W) \quad (9)$$

$$P_{inc} = \frac{1}{2Z_0} |E_0|^2 \quad (10)$$

$E_0$  is the amplitude of the episode electrical fields (1 V/m) and  $Z_0$  is the impedance of free space as found in Equation (1). Also, given the Extinction, we compute the morphology and concentration dependence Extinction coefficient by multiplying the Extinction with the number of density for nanoparticles as see in Equation (11):

$$\varepsilon_{dep} = \sigma_{ext}n \quad (11)$$

Similarly, the coefficient of Absorption is given by Equation (12):

$$a = \sigma_{abs}n \quad (12)$$

Au and Ag nanostructures are utilized as plasmonic bio-sensors for the discovery of explicit proteins in bio-molecules that are applicable for explicit infections (Haes AJ et al. 2002; Ginting et al. 2017). Extinctions bands of such nanostructures relies upon the refractive indices of the medium adjacent them; for the greater refractive index, it goes through a red shift (Anker JN et al. 2008). The capacity of Scattering is the example is pivotal for imaging applications, for example, optical coherence tomography (OCT). It is known, that for Nanospheres and Nanorods the Absorption is the main contributor in the Extinction cross section spectrum (Jain PK et al. 2006; Xianghua Meng et al. 2016; Swarnapali D. S. Indrasekara et al. 2015; Helena de Puig et al. 2015) that can be an issue for optical medical imaging techniques, While the Scattering is the main contributor in Nanostars Extinction cross section as Shown in Figure (1). Conversely, Nanostars possess a significant ability for scattering. The large enhancement of electromagnetic fields at the tips of the star is because of a collection of the enhancement in resonance and the effect of lighting rod correlating at the tips with the larger curvature. A bigger surface charges densities and thus a higher electrical fields Occurs because this curvature. Accordingly, we researched and thought about the optical characteristics of AuNSt of different sizes and different number of Spikes as attractive contrast agent, focusing on their scattering abilities and optical properties.

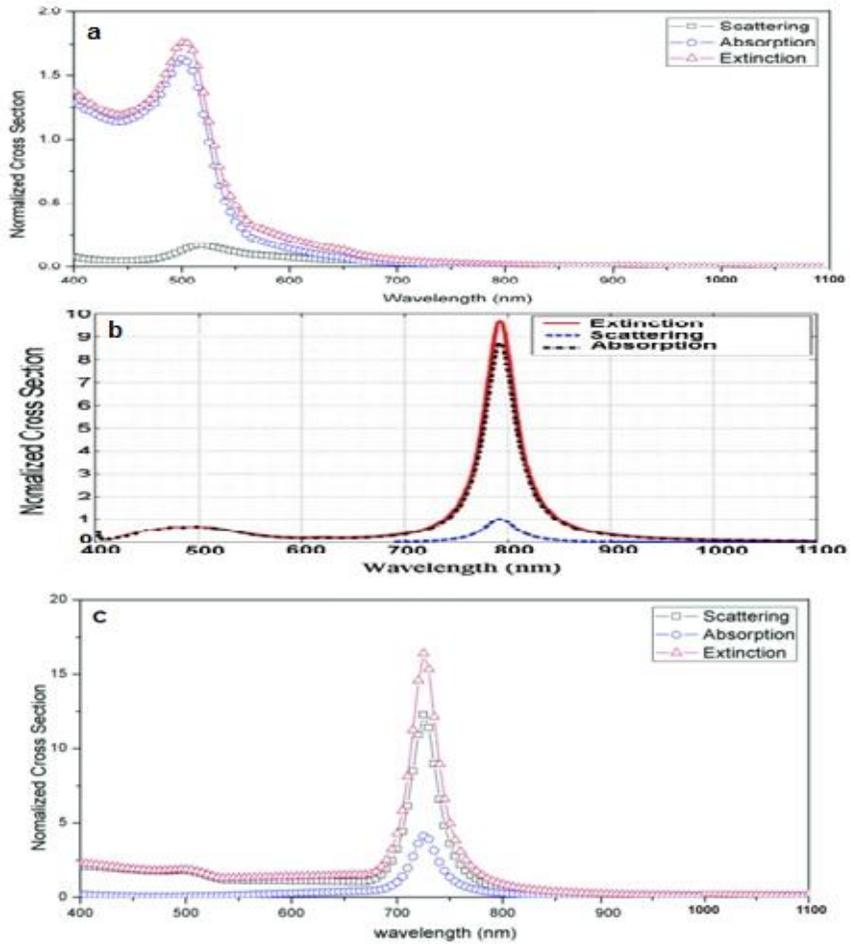


Fig 1: The (Extinction, Absorption and Scattering) Spectrum for gold (a)Nanosphere, (b)Nanorod and (c)Nanostar.

### III. Results

#### 1-Gold Nanospheres

The first and the simplest type of nanostructures are sphere gold nanoparticle. When diameters of AuNSps around (30-120) nm, the efficient for scatter light increased in the visual range of the spectra, approximately the power of six of Nanosphere linear size the intensity of scattered light will occurs. It is a well known fact, that smaller particle mostly absorbs light, while large ones scatters it, and the amounts of absorbed and scattered light are equals when the size of particle reached (80 nm) (Khlebtsov NG 2008; Georgios D. Barmparis et al. 2015). AuNSps with (LSPR) in the visible range at approximately the 530 nm wavelength as demonstrated in Fig (1-a).

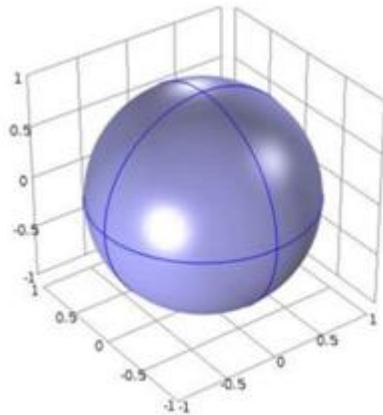


Fig 2: Representation of the nanosphere model .

#### I. Effect of increasing Nanosphere size on Scattering cross Section

By rising the gold spherical nanostructure size, there is a significant red shift in the wavelength corresponding to the maximum efficiency of extinction. Furthermore, this guide can also be perceived in efficiency of scattering range as demonstrated in Figure (3). These

results are identified with the reliance of free electron involvement in the dielectric function which can be adjusted by varying the volume of the structure (Megan A et al. 2013). As spherical nanostructures get bigger, the dipole reverberation tops red movements from (520 to 545) nm. In any case, it is tracked down that rising the size of nanostructures brings about a rise in the Scattering efficiency.

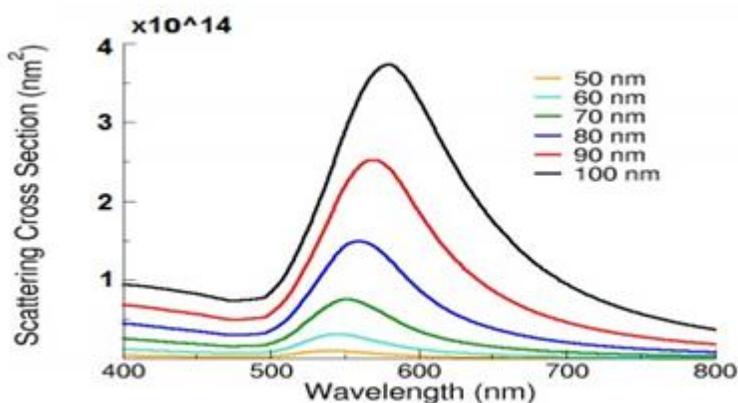


Figure 3: Normalized scattering cross-section profile for a metallic nanosphere as function of wavelength for different diameters (Size).

## II. Environment effect on the Scattering Cross Section

The scattered light from the nanosphere will be increase when the Refractive Indices of the adjacent Medium increased. Where there is an immediate connection between the refractive Indices of the adjacent medium and between the measurements of photons Scattered from the molecule as demonstrated in Fig (4).

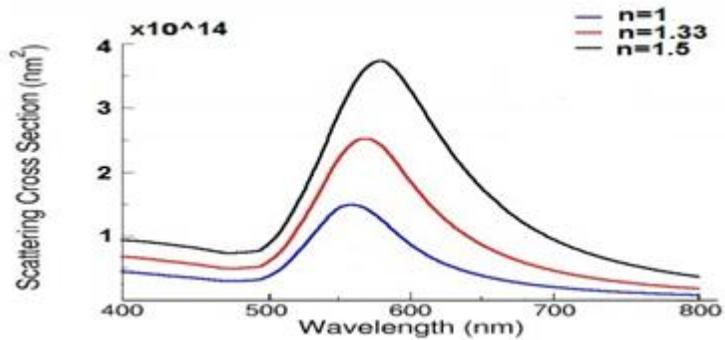


Fig 4: Shows effect of refractive indices for adjacent medium on Scattering Cross Section of Nanosphere.

### III. Effect of gap distance between two nanospheres (nanosphere dimer)

For Perpendicular (s-) polarized, for which the episode electrical fields are corresponding to the axis of dimer, the inter gap ( $g$ ) between structures has considerable effects on the dimer's dominant dipolar plasmon resonance. As the nanostructures come near one another, the resonance peak is red shifted from the visible to (IR) range accompanying the gradual increase of Scattering magnitude, as demonstrated in Fig(5). When the NPs are far away from one another, the resonance is close to the (LSPR) of a single particle, which is the situation of isolated single nanoparticle. Distance dependent in nanostructure dimers have been investigated with Alessia Polemi and Kevin L. Shuford (2012).

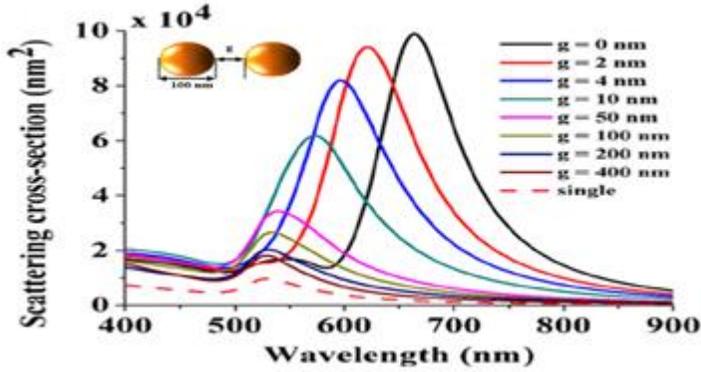


Fig 5: Shows the effect of gap distance between two gold nanospheres (100nm) on Scattering Cross Section (For s-polarization).

## 2- Gold Nanorod

A different Example of Anisotropic nanostructures is gold nanorod which are cylindrical shaped particles with hemispherical closures. Rather than AuNSps with (LSPR) in the noticeable reach at around the 530 nm wavelength As demonstrated in Figure (1-b), the longitudinal peak of (AuNRs) can be effectively tuning from (600 to 1100 nm) by the variety in their (length to width proportion) This effect has been widely studied (Babak Nikoobakht and Mostafa A. El-Sayed (2003); Mikhail Yu Tsvetkov et al. 2013). Specifically, great sensitive tune of the longitudinal resonance is clarified by the Equation (13):

$$\lambda_{||} = \lambda_p \sqrt{\epsilon_{ib} + \left(\frac{1}{\lambda_{||}} - 1\right) \epsilon_m} \quad (13)$$

(LSPR) is red shifted as we increment the aspect ratio of (AuNRs), where ( $\lambda_{||}$ ) is the wavelength for longitudinal resonance; ( $\lambda_p$ ) is the wavelength of the volume oscillations of an electron plasma; ( $\epsilon_m$ ) is the medium optical permittivity of; ( $\epsilon_{ib}$ ) is the contribution of inter band of electron transitions (Prashant K. Jain et al. 2006). It is known, that for AuNRs the absorption is the main contributor in the extinction spectra (Si Yue Li and Min Wang (2012); Saumyakanti

Khatua et al. 2014) that can be an issue for optical and medical imaging strategies.



Fig 6: Representation of the nanorod model .

### I. Effect of Nanorod Aspect ratio (length to width proportion )

One can see the red shift and strengthening of account of the scattering Cross Section when the aspect ratio gets higher as shown in fig (7).

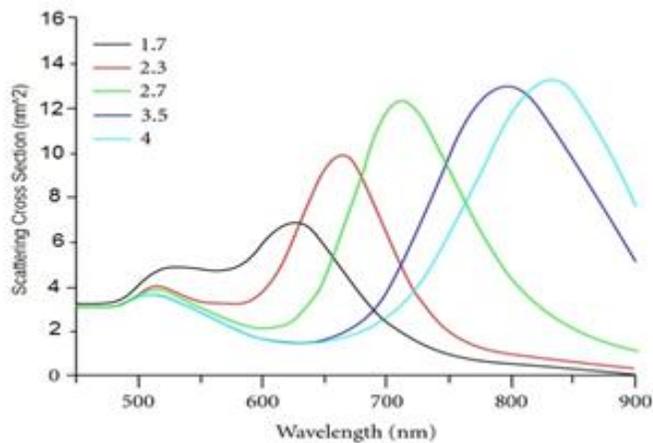


Fig 7: Shows the effect of increasing the aspect ratio of nanorod.

## II. Effect of Varying Surrounding medium (Refractive index)

With varying the Refractive indices of the adjacent medium, the scattering spectrum is red shifted and overlapped without any effect on amount of scattered light as shown in Fig (8).

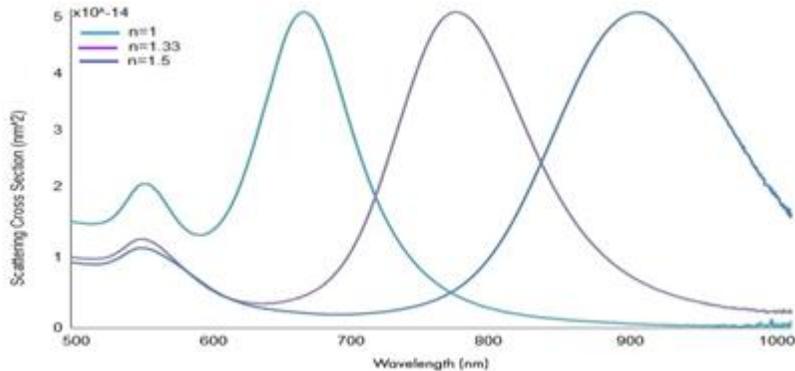


Fig 8: shows the effect of varying surrounding medium (refractive index).

## III. Effect of nanorod dimer on Scattering Cross Section

As the nanostructures approach one another, the resonance peak is red shifted from the visible to (IR) range accompanying the gradual increase in degree of Scattering, as demonstrated in Fig(9). When the nanorods are distant from one another, the resonance is close to the (LSPR) of a single particle, which is the situation of lonely single nanoparticle. With increasing the gap distance between two nanorod the scattering cross section will decreasing and blue shifted as shown in Fig (9).

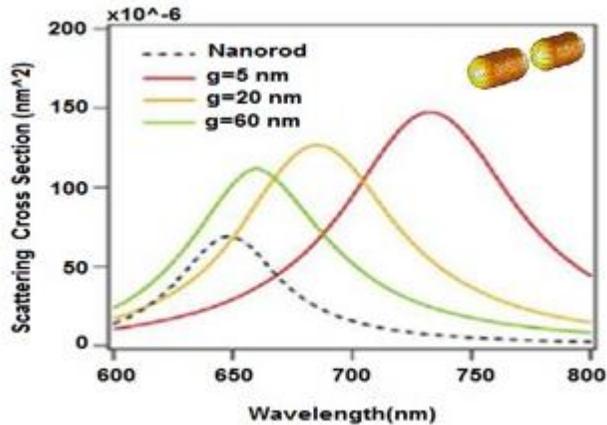


Fig 9: shows the effect of gap between nanorods on scattering cross section.

### 3- Gold Nanostars

As of late, branched and star formed nanostructures or gold nanostars (AuNSts) have pulled in a lot of significance in different medical applications because of the tunability of (LSPR) to the close to infrared (NIR) which is a diagnostic window. As demonstrated in Figure (1-c), and the presence of numerous sharp tips that can enormously improve occurrence electromagnetic fields (Feng Hao et al. 2007). The superposition of the plasmons modes at core and the plasmons modes of the tips drastically rising the excitation of the bonding plasmons and results in huge enhancements in electrical field compared with those that would be initiated for singular tip (Chirico et al. 2015). This observable fact is also called antenna effect and is responsible for an increment in the extinction (absorption and scattering), however in the respective electrical field upgrade too (Chang Soo Kim et al. 2009). Because of large scattering , (AuNSts) are ideal contender to serve as contrast agent for Doppler OCT and OCT imaging (Jung Heo et al. 2014; Vincenzo Amendola et al. 2017; Colleen L. Nehl et al. 2006).



Fig 10: Representation of the nanostar model as defined by the analytical equation for its volume for a numeral of 18 spikes.

### **I. The effect of varying Aspect Ratio of nanostar (Spike to core volume)**

The frequency of electron reciprocal trembling in metallic nanostructures is controlled via the nanostructures morphology and volume. Under the state of resonance, the free electron interaction between photons and metallic surface is strongest, and the greatest improvement in Scattering and local light effect are formed on the surface of metallic structure. The spherical core of the AuNSTs is set at Radius=30 nm. The relation between the tips volume and the resonance peak of the AuNSTs is calculated by varying the volume of the tip of the structure. while the tip long of (GNSs) changing, the position of the SPR peak shifted from (580 to 640 nm), the intensity of the resonance peak rises and the spectrum of resonance expand to some degree. The red shifts in the resonance peak are because of the size impact of nanostructure (Liu et al. 2015; Battulga Munkhbat et al. 2016; Ioannis G. Theodorou et al. 2018). As the tip turns out to be longer, potential photoinduced charge separation of the (GNSs) along the polarization direction of the electrical fields increases, and therefore, the attraction between the negative and positive charges reduced. Accordingly, the number of times of oscillating electric dipole is increased, resonance frequency reduced and resonance peak will red shifted. Furthermore, the intensity of the resonance peak is owing to lighting rod effect turns out to be more clear as the tip turns

out to be longer, and the charges stack at the tips with a higher concentration as demonstrated in Fig (11).

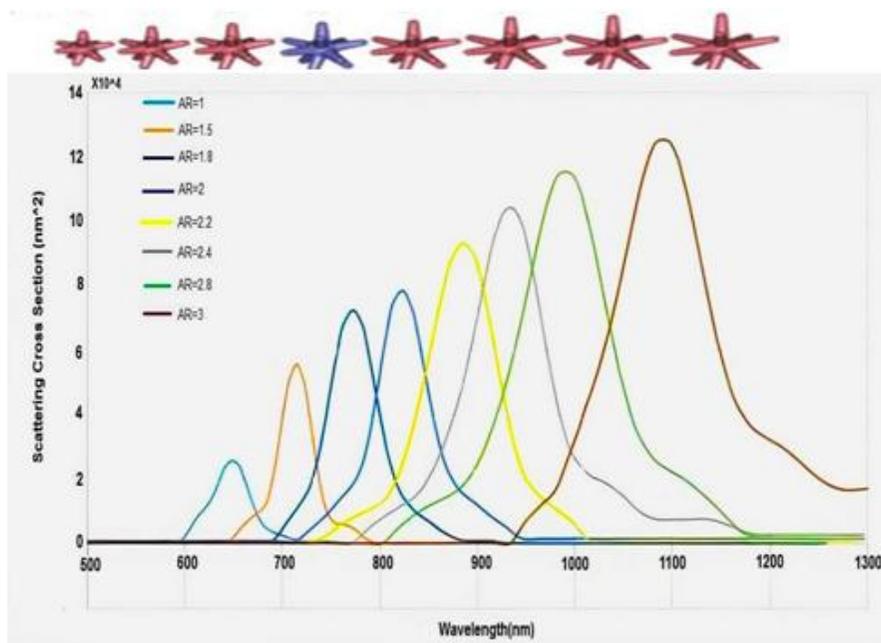


Fig 11: Shows the effect of increasing spike Size with fixed core volume ( $R=30\text{nm}$ ) on nanostar Scattering Cross Section.

## II. The effect of varying Spikes number of nanostar

When the number of Spikes in branched nanostars increases, then sharp points will increase. At sharp points for the nanostar the electrons accumulate will be increase. It is more owing to the impact of incoming radiation on the nanostars. Nanostar plasmons begin to oscillate further Plasma intensification occurs when nanostructure sharp points of the star increases due to those hot spots increase (Hsiangkuo Yuan et al. 2013; Andrew Fales et al. 2014; Wei Xiong et al. 2014). With increasing hot spots, the intensity of Scattering in the surface plasmon increases and the peak of Scattering the superficial red plasmon shifts as shown in Fig (12).

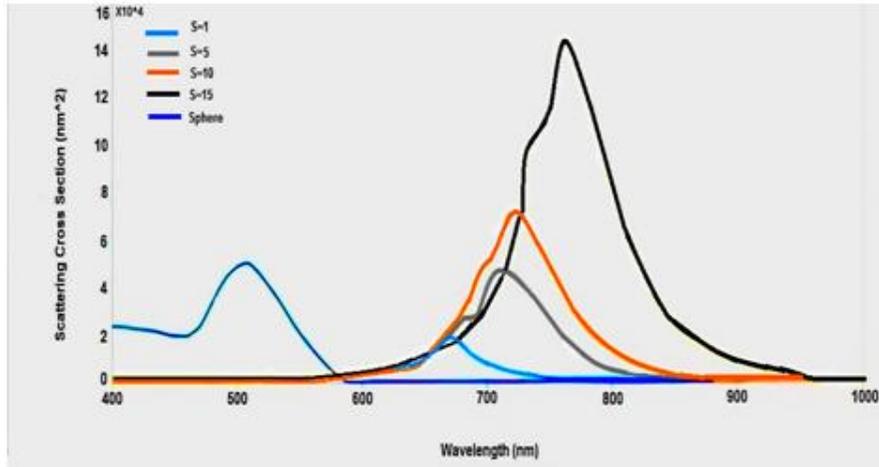


Fig 12: Shows the effect of number of spikes of nanostar on Normalized Scattering Cross Section.

### III. Effect of Varying Surrounding Medium (Refractive index)

The resonance spectrum of (AuNSts) is extremely sensitive to the dielectric medium environs around them. The efficiency of Scattering spectrum will be increase with increasing the refractive indices of adjacent medium and there are a red shifts in spectrum will be seen as shown in Fig (13) (Ioannis H et al. 2016; Kyle D. Gilroy et al. 2016; Ted V. Tsoulos et al. 2018). The peak of absorption in a dielectical environment of medium with (n=1.5) is larger than that of medium with (n=1.33) and (n=1) because the dielectric coefficient of medium with (n=1.5) is greater than that of medium with (n=1.33) and (n=1), according to the Equation ( $\omega(s) = \frac{\omega_p}{\sqrt{\epsilon-1}}$ ) As the dielectric coefficient increases, the resonant frequency decreases and the wavelength increases (Red shift in spectrum).

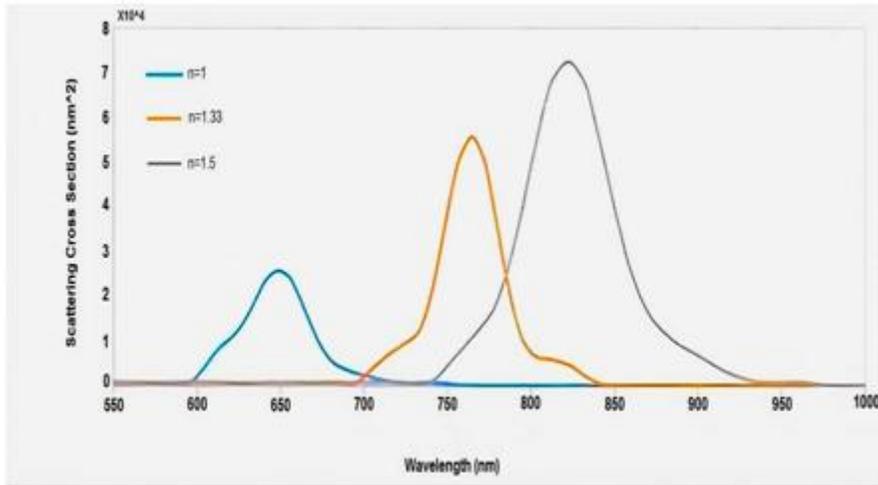


Fig 13: Shows the Effect of Varying Refractive index on Normalized Scattering Cross Section of gold nanostar.

#### IV. Effect of the gap between two nanostars dimer On Normalized Scattering Cross Section

As demonstrated in figure 13, the peak of resonance for a single AuNSt is about (600) nm. At the point when the two AuNSt are near one another, there is observable red shift in the peak of resonance with reduce the distance between particles, and the intensity of local field increases. As a result, by adjusting the AuNSt distance, the red shift in the near infrared band, and the intensity of local field can be efficiently increased by more than a hundredfold, which can be used in surface spectrum enhancement (T. V. Tsoulos et al. 2017; Stefan Harmsen et al. 2015). For the meantime, it can be seen that there are two peaks in resonance for the two AuNSts, in which the larger peak is due to the pairing effect between the AuNSts and the smaller peak is the inherent resonance peak of the AuNSt itself.

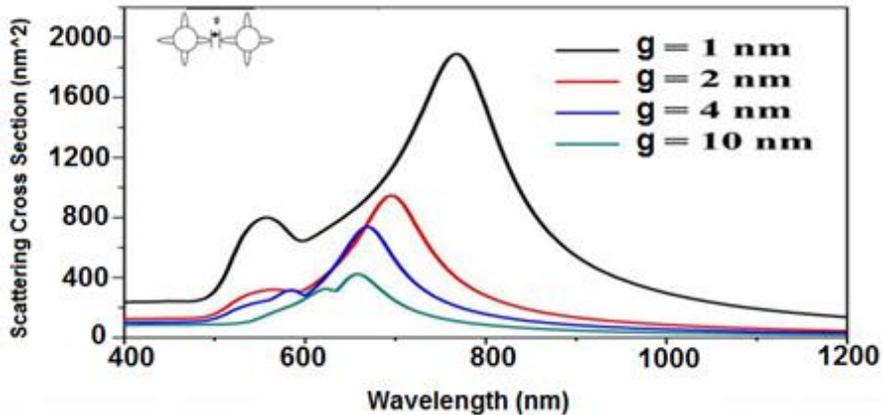


Fig 14: shows the effect of gap distance between two gold nanostars on normalized scattering cross section.

### Influence of GNSs number

As demonstrated in Fig (15) the spherical core in the center of the AuNSt has Radius around (20) nm, the tip volume is (80) nm and the gap distance around (0.5) nm. The increment in the number of AuNSts will bring about the red shift of the peak of resonance, and the most extreme intensity of resonance of the two AuNSts is (8000). Larger peak is because of the pairing impact between the AuNSts, and the smaller peak is the inherent resonance peak of the AuNSt itself. The exceptionally improved electromagnetic fields created by pairing the plasmons between sharp tips and cores of two AuNSts in the wide conjunction area allocate the accommodation and specific detection of big molecules.

So I propose utilizing gold nanostars dimers rather than single gold nanostars because of its improvement in light scattering thus it can to be gotten more clearly biomedical images.

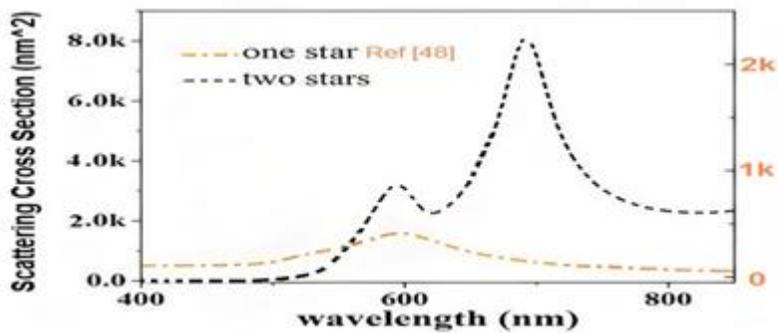


Fig 15: shows the effect of number of gold nanostars on normalized scattering cross section.

## Conclusions

A significant trend in modern medicine is the substantial increase of the role of diagnostics in disease treatment strategies, including early-stage diagnostics and accurate detection of molecules in small concentrations. In view of above, the signal and response enhancement for various detection and imaging applications is a main challenge for modern diagnostics. Using of the localised Plasmon resonance phenomena of plasmonic nanostructures is a future trend. Furthermore, the benefits of gold nanoparticles could be applied to increase the selectivity of therapy and Diagnosis on the cell and tissue levels. Spherical gold nanoparticles are the simplest possible nanostructures and have been used in the popular of investigations, whereas at the moment of research related to the paper the benefits of plasmonic nanostars were clearly demonstrated in selected diagnostic applications. In this Paper nanostars were adopted both for optical imaging, spectroscopy analysis and for cell treatment. The plasmon resonant properties of nanostars were manipulated by modifying their size and surface properties cover to match localised plasmon resonance and the operational wavelength of the used equipment. The effectiveness of nanostars and gold nanoparticles was compared for selected bioimaging and sensing methods. Significant advantages of nanostars were highlighted in the paper. Due to the higher scattering cross-section in comparison to gold nanoparticles, large nanostars

demonstrated better contrast properties for imaging applications for example confocal microscopy and optical coherence tomography. The broad peak and tunability of the nanostars' localised plasmon resonance allows the effectiveness of laser optoporation to be maximised. Thus, the results of this study on the efficiency of nanostars and nanostars dimers have a broad scope of application and this broadens the potential range of utilisation for nanostars in nano biophotonics and biomedicine.

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