Comparative Optoelectronic Modelling and Analysis of Metallic and Dielectric Spherical Nanoptennas

Abstract

This article reports on designing and analysis of gold, silver and silicon spherical nanoptennas, which are specially designed antenna at nanoscale for optical frequencies. The absorption, scattering and extinction efficiencies would indicate the suitable material for the device. The metal nanoparticle possesses the inherent surface plasmonic properties which help in enhancing the field of nanoptenna. When the incident light is interacted with the nanoparticle, it is either absorbed (refracted) or scattered (reflected) by the metallic nanostructure device. But metallic nanodevices suffer from losses at optical frequencies. So, dielectric material silicon is used to achieve high directivity with vanishing losses.

Keywords: Nanoptenna; Plasmonic; Dielectric

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Introduction

Nanoptennas are revolution in the field of digital and wireless communication technology. Plasmonics are capable of converting the concepts of microwave and radio frequency electronics to optical wavelengths by initiating faster, smaller and more efficient optical electronic interfaces. In other words, plasmonics build a bridge between photonics and electronics [1,2]. These plasmonics nanoptenna converts the propogating electromagnetic radiation into electrical signals which are plasmon (coherent oscillation of surface electrons) and vice versa [3-5]. Moreover, traditional microstrip antennas cannot be used at optical frequencies in the range of THz due to increased losses and inefficiencies. At GHz (radio frequencies) geometry of an antenna can be utilized to shrink their sizes, but at THz (optical frequencies) dispersive permittivity enables the shrinking of sizes. These are basically nanoantennas designed for working operations at optical frequencies.

These are so termed, in order to remove the confusion between radio frequency antenna and nanoantenna as the conventional antenna theorems cannot be applied at nanoscale. Nanoptennas are the most promising area of research from the technology point of view due to their capability to remove the impedance mismatch between nanodevices and free space along with the manipulation of light on the nanoscale which is much smaller than the wavelength of light. At optical frequencies, with certain conditions, these devices with specific geometries with metallic materials (such as gold or silver) show peculiar electromagnetic resonances known as surface plasmon resonances (SPR) [6]. These are related with the jump of conduction electrons to the upper valence band which creates a strong light scattering and absorption resulting the efficient enhancement of local electromagnetic field. In plasmonics, the scattering properties are of more importance in comparison to the conventional antenna responses [1]. In other words, the material, design and operating frequency of the nanoptenna, its plasmonic features determines the scattering properties. Eventually, the optical properties of most metallic nanodevices are greatly affected by the existence of surface plasmon resonances. But these plasmonic metallic nanodevices suffer from large dissipated losses resulting in low radiation efficiency [7]. To avoid such limitations, dielectric material such as silicon is used as the fabricating material with high dielectric constant [8]. These have low dissipated losses with enhanced magnetic responses in the visible spectrum.

Modelling of Nanoptenna

For designing and modelling of nanoptenna CST microwave studio is used [9]. In all studies, spherical shape is selected with radius of 50 nm. The design materials are chosen as gold, silver and silicon just to have the clear differences between metallic and dielectric nanodevices. In other words, simple optoelectronic model for light scattering and absorption can be evaluated from basic spherical shape. For excitation planewave which is linearly polarized and propogating in z- direction is used to generate the structure of nanoptenna. For the far field properties, a probe of E-field (far field) is located at a distance beyond the far field distance, from the centre of the sphere located at the origin. The solver is frequency domain solver, where the mesh type is tetrahedral to get the fine results.

Results and Discussion

The main results discussed here are extinction, absorption and scattering spectrum of spherical nanoptenna with three different materials viz. gold, silver and silicon. Generally at optical frequencies, the absorption and scattering properties plays a dominant role rather than conventional reflection and transmission properties. The extinction efficiency would evaluate the extinction cross function normalized by the geometry of the nanoptenna [6]. In other words, these properties are affected by certain parameters such as the optical material used, particle size, shape and the polarizability of its surrounding medium which result in characteristic changes of the optical properties of the nanodevice. The particle shape, size, the material's polarizability, separation of surface charges leading to strength of the attraction force, collectively determines the resonance condition of the nanoptenna. Any change in these properties results in a drastic shift in the oscillation frequency of the polarized electrons and thus different cross sections in the optical region (extinction, absorption and scattering cross sections) [10].

Metallic nanodevices greatly absorb and scatter light at the plasmon resonance condition which leads to a change in a color. The absorption efficiencies are shown in Figure 1-3 with wavelength ranging from 300 nm to 900 nm. From the Figure 1, it is clearly indicated that the resonance peak for gold occurs at the wavelength of 510 nm which is good for visible range applications. Figure 2 clearly demonstrates that the resonance peak of silver nanoptenna occurs at the wavelength of 380 nm which indicates a shift from the above spectrum. Finally, Figure 3 indicates the absorption efficiency of a dielectric nanoptenna which is quite different from the metallic nanostructures. Here, the resonance peak could have the value below 300 nm, somewhere in the range of 20nm-300nm. Figure 3-5 indicates the scattering efficiencies of gold, silver and silicon nanoptennas respectively. The forward scattering indicates the overall behavior of extinction cross section in a way that dispersive properties of the metallic structures would evaluate the resonances. During light scattering the noble metals such as gold and silver shows the changes in color such as silver has characteristic yellow color whereas gold has a characteristic red color [6]. The main reason behind color changes is the collective oscillation of the electrons in the conduction band. Figure 7-9 indicates the extinction efficiency of gold, silver and silicon nanoptenna respectively. Basically, the extinction efficiency represents the extinction cross section normalized by the geometrical cross section of the nanoptenna.

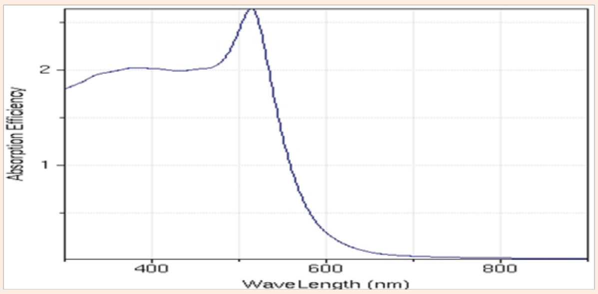

Figure 1: The absorption efficiency of gold.

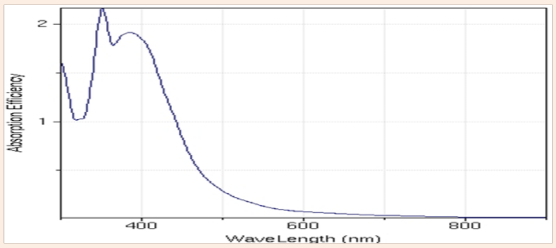

Figure 2: The absorption efficiency of silver.

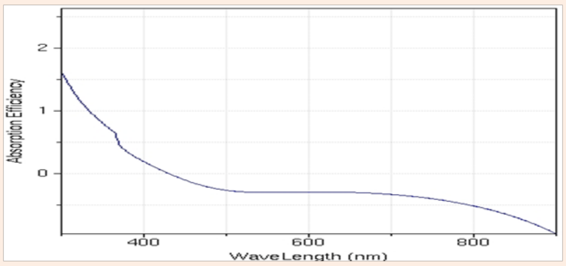

Figure 3: The absorption efficiency of Silicon.

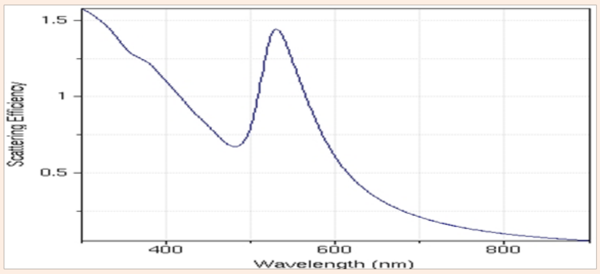

Figure 4: The scattering efficiency of gold.

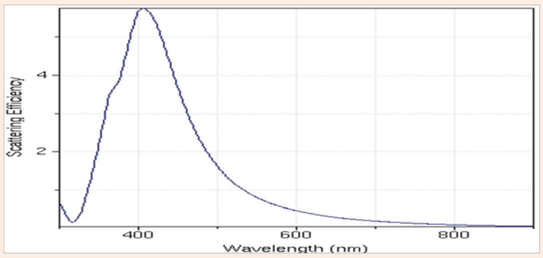

Figure 5: The scattering efficiency of silver.

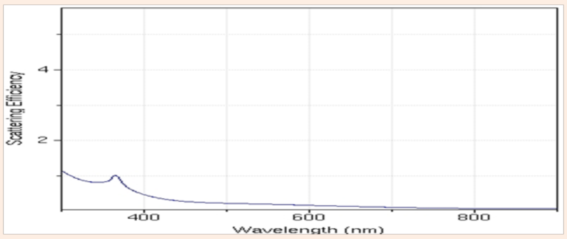

Figure 6: The scattering efficiency of silicon nanoptenna.

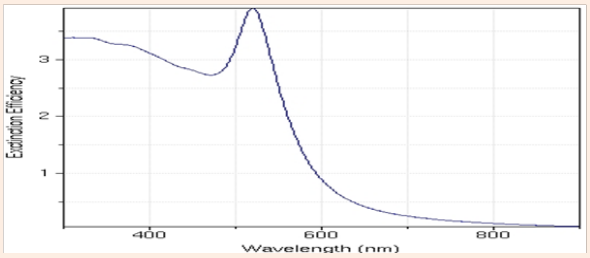

Figure 7: The extinction efficiency of gold.

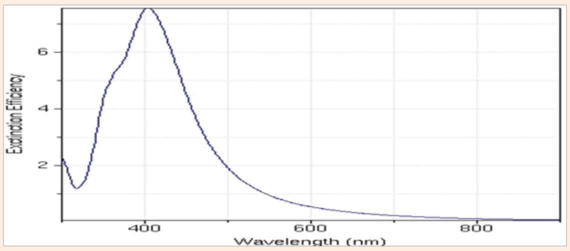

Figure 8: The extinction efficiency of silver.

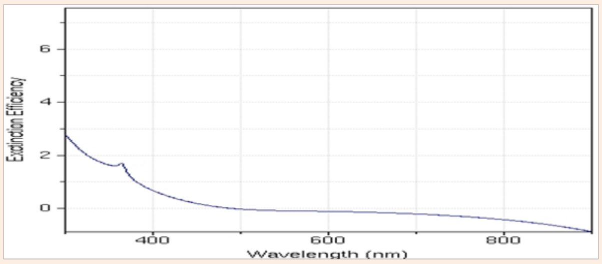

Figure 9: The extinction efficiency of silicon spherical nanoptenna.

Conclusion

This paper investigates the comparative design and analysis of spherical nanoptenna of three different materials viz. gold, silver and silicon. The gold and silver being the noble metals exhibit the peculiar property of surface plasmon resonance but suffers from great amount of losses. So, to overcome this disadvantage, the dielectric material silicon is used as the basic material for the nanoptenna. At optical frequencies i.e. in the range of THz absorption and scattering properties plays a dominant role than the conventional reflection and transmission characteristics in the traditional antennas. The shift in the spectrum characteristics of silicon nanoptenna proves that the nanoptenna of dielectric material can be of great importance rather than their metallic counterparts. These nanoptenna can have various applications such as efficient solar cells, near field microscopy, data storage, medical treatment such as cancer diseases and quantum communication [3,11].

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Conflicts of Interest

None.

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