Photonics and Nanostructures - Fundamentals and Applications 31 (2018) 107–114

Contents lists available at ScienceDirect

Photonics and Nanostructures - Fundamentals and Applications

journal homepage: www.elsevier.com/locate/photonics

Effect of graphene layer on the localized surface plasmon resonance (LSPR) and the sensitivity in periodic nanostructure

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ARTICLE INFO

Keywords:
Localized surface plasmon resonance
Gold nanoparticles
Graphene
Sensitivity

ABSTRACT

We study the interaction of gold nanoparticles with a graphene film. Graphene is used as a spacer, as thin as possible, between the gold nanoparticles and the detection dielectric medium, and one of the advantages of graphene is to protect the structure, which allows to avoid the oxidation of nanoparticles. We focus our study on the variation of the resonant structure (LSPR) depending on the thickness of the graphene layer (0.34–5 nm). A stronger resonance behavior of positions in the absorption spectrum shows a strong coupling between the LSP on gold nanoparticles and the covering film. Numerical simulations indicate a significant shift of the resonance wavelength structure SiO_x/AuNPs/Graphene/SiO_x (657.90 nm) compared with experimental results obtained on SiO_x/AuNPs/SiO_x (574.71 nm) and optimized for the required parameters proposed LSPR system we achieve the highest detection sensitivity range, while the location of points of the electric field on the best corners of the gold-graphene nanoparticles.

1. Introduction

As part of our study, we analyze the evolution of the localized surface plasmon resonance (LSPR) that has been extensively studied over the last year [1,2] in a periodic nanostructure 2D metal nanoparticle. We study in this work the influence of a few thin layers of graphene on the LSPR behavior of gold nanoparticles (AuNPs).

The idea is to highlight the role of a few layers of graphene as one of the finest collections. The optical properties are significantly dependent on the chemistry surface [3,4] on which they are deposited, and on the refractive index of the dielectric environment surrounding these nanostructures [5,6]. Namely that apart from low graphene layer thicknesses (strong red shift of the resonance), the plasmon oscillation amplitude is increasing almost linearly with up to 5 nm, compared to the case where the gold nanoparticles are directly related to the detection of dielectric, the surface plasmon resonance of AuNPs deposited on a glass (SiO_x) substrate ($n_1 = 1.45$) and covered with layers of a dielectric material [3,7–12].

Numerical simulations of the structure (SiO_x/AuNPs/Graphene/SiO_x) show a high sensitivity of 59.81 (nm RIU^{-1}) for the monolayer graphene 0.34 nm [7,12], and response of plasmonic metal nanoparticles of various geometrical parameters gold nanoparticles, these findings are consistent with other reports in the literature [13] demonstrating long row detection of refractive index on plasmonic nanostructures.

Gold nanoparticles [14] are of great interest for the development of chemical and biological nanosensors and their use in the detection area based on the localized surface plasmon resonance (LSPR) [1,2].

Numerical simulations of our structure indicate that the resonance wavelength of the electric field mode is the surface plasmon, the hot spots of which (areas of high field intensities) are localized to the lower corners of the AuNPs, deferens by compared to the structure SiO_x/AuNPs/SiO_x, published in literature [13,15] and that on SiO_2 substrates [16,17].

2. Theoretical methods

2.1. Theoretical model

The optical properties of gold nanoparticles are solved numerically, in the frequency domain, using the scattered field formulation. Field analysis was performed using a commercially available finite-element-method. The simulation method has been well documented in [18–20].

A layer of gold nanoparticles of diameter (l), height (h) and inter-particle distance (a), are coated with a graphene thin-layer-thickness; and immersed in a homogeneous matrix, a transparent glass substrate

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https://doi.org/10.1016/j.photonics.2018.06.009
Received 25 February 2018; Received in revised form 11 May 2018; Accepted 20 June 2018
Available online 25 June 2018
1569-4410/

Table 1
Gold (Au) Lorentz–Drude model parameters.

Term	f_m [rad/s]	ω_p [rad/s]	ω_m [rad/s]	Γ_m [rad/s]
$m = 0$	0.760	13.72×10^{15}	0.00	0.08052×10^{15}
$m = 1$	0.024	13.72×10^{15}	0.6305×10^{15}	0.3661×10^{15}
$m = 2$	0.010	13.72×10^{15}	1.261×10^{15}	0.5241×10^{15}
$m = 3$	0.071	13.72×10^{15}	4.538×10^{15}	1.322×10^{15}
$m = 4$	0.601	13.72×10^{15}	6.538×10^{15}	3.789×10^{15}
$m = 5$	4.384	13.72×10^{15}	20.24×10^{15}	3.364×10^{15}

of SiO_x (refractive index $n_1 = 1.45$). The frequency-dependent complex permittivity of metal (gold) is described by the Lorentz–Drude model [21,22].

$$\varepsilon(\omega) = \varepsilon_{r,\infty} + \sum_{m=0}^{M} \frac{f_m \omega_p^2}{\omega_m^2 - \omega^2 + j\omega\Gamma_m} \tag{1}$$

where $\varepsilon_{r,\infty}$ are the relative permittivity at infinite frequency, ω_p the plasma frequency, and ω_m, f_m and Γ_m are the resonance frequency, strength and damping frequency, respectively, of m*th* oscillator. The Lorentz–Drude model uses M damped harmonic oscillators to describe the small resonances observed in the metal's frequency response. The values of the constants in Eq. (1) are taken from reference [21]. The value of the dielectric constant of infinite frequencies in reference [21] is $\varepsilon_\infty = 1$. The values of the other L-D parameters are given in Table 1.

2.2. Refractive index

Covering the nanoparticles with a no-absorbent and no-dispersive is not the only option to provide them with chemical protection. Thus, a material as graphene, in addition to protecting the nanoparticles, provides advantages for their sensitivity. It has indeed been shown to intercalate graphene sheets between the metal film and the medium detection delocalized surface plasmon resonance sensors generates an increased sensitivity [23,24]. This increase is not only due to the optical properties of graphene, but also to its excellent adsorption properties of biomolecules [25].

The layer of our model is monolayer graphene ($d = 0.34$ nm) and its complex refractive index (n_g) in the visible range is an absorbent and dispersing material, the refractive index of which is given by the following formula (2) [26]:

$$n_g = 3.0 + \frac{C_1}{3}\lambda \tag{2}$$

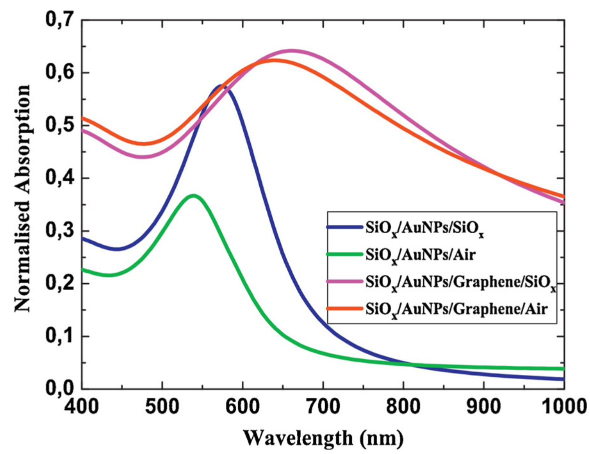

Fig. 2. Computed absorption spectra of AuNPs, in the case where $l = 25$ nm, $a = 80$ nm, $h = 20$ nm and the thickness of the graphene layer ($d = 5$ nm), for two detection Milieus, SiO_x (pink) and air (red). Or without a layer of graphene ($d = 0$ nm) for SiO_x (blue) and air (green). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

where the constant $C_1 = 5.446\,\mu m^{-1}$ [27], and is λ the wavelength of the incident light in μm.

3. Results and discussion

3.1. The effect of graphene layers deposited on the gold nanoparticles

Fig. 1 shows schematically the studied system. The network of nanoparticles is characterized by $l = 25$ nm, $h = 20$ nm and $a = 70$ nm. It is excited by a plane wave generated in the substrate refractive index $n_1 = 1.45$ (SiO_x), propagating along the *Oy*-axis and the electric field is polarized along the *Ox*-axis. Calculating is constructed as to simulate a network infinitely periodic nanoparticles and gold, constituting the nanoparticles is described by the Lorentz–Drude model [21,22].

These values of nanoparticles parameters chosen following the investigation described above, on the basis of their experience [13], show a sectional view of the overall shape of the particles. We can note the rather random shape of the particles, which made it necessary to determine statistics relating to the dimensions of the nanoparticles in the plane (inter-particle diameter and distance), l and $p = a - l$ (respectively). The results of such statistics, respectively for l and p, are

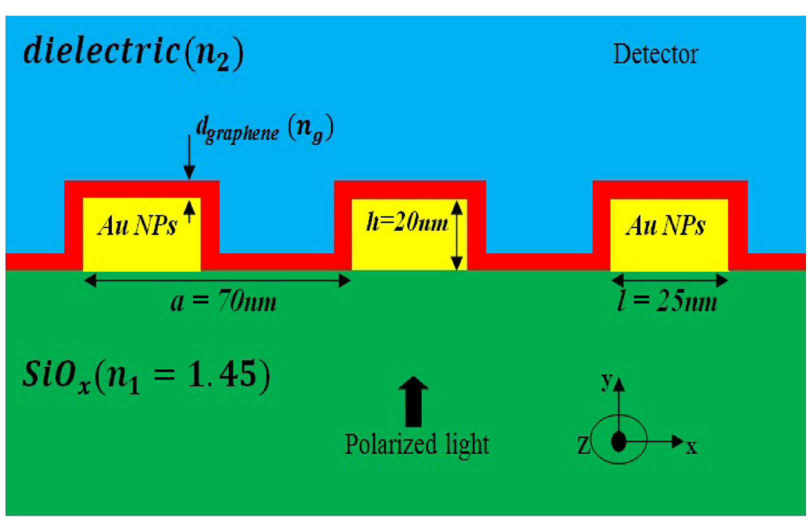

Fig. 1. Typical diagram of the modeled structure, namely gold ribbons apart and characterized by *a* length *l* and height *h*. the tapes are covered with a thin layer of graphene.