IUG Journal of Natural Studies
Peer-reviewed Journal of Islamic University-Gaza

ISSN 2409-4587

IUGNES
Vol. 25, No 2, 2017, pp 263-266

Accepted on (14-03-2017)

Dispersion Characteristics of Graphene Surface Plasmon Four Layers Waveguide

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Abstract

A four layer waveguide has been introduced. Graphene layer is separate by metamaterial layer (MTM) from a plasmonic layer The dispersion characteristics of the propagation of TM surface Plasmon through the waveguide structure containing a graphene have been derived. We numerically analyse the propagation of surface plasmon at different waveguide parameters. The obtained results presents that we can control the propagation of the plasom as we changes the thickness of the MTM layer, the MTM parameters, and the graphened conductivity.

Keywords:
Graphene,
Metamaterial,
Plasma,
Waveguide.

1. Introduction:

Graphene is considered as a single-atom thick packed into a dense 2 Dimensional honeycomb crystal lattice which has attracted dramatically consideration and attention in terms of theory and experiments due to its remarkable physical optical, electronic, mechanical and thermal properties [1-4]. These physical properties are leading to new concepts and applications in Optoelectronics technology as solar cells and integrated optical sensors. More recently, graphene has rapidly been considered a suitable alternative candidate of generating surface Plasmon to usual noble materials. This is due to the possibility of controlling and tuning generated surface Plasmon through the proposed waveguide structure. George Hanson [2] had investigated the propagation characteristics of TM waves through the parallel-plate waveguide structure composed of graphene showing that the structure can guide quasi-transverse electromagnetic modes with attenuation similar to structures composed of metals. Optimization of waveguides based on surface plasmons in double-layer graphene (DLG) has been derived and achieved taking into account the effects of both extrinsic scattering and intrinsic Landau damping [3, 4]. Coupled surface Plasmon modes of graphene bounded a plasma substrate have been investigated showing to great tunability of Plasmon characteristics by changing the surrounding substrate permittivity[3-5]. Graphene-silicon waveguide structure have been reported with some optimized physical parameters [6]. The dispersion characteristics of electromagnetic waves propagating in Graphene multilayered structures have been discussed and analyzed [7]. Other waveguide structure with graphene bounding an isotropic dielectric media and water has been analyzed and discussed to find out the effects of some physical parameters of the considered structure [8-14].

Metamaterials or Left Handed materials had initially been predicted more than fifty years ago by Veselego and have been realized experimentally about twenty years ago [15-18]. These artificial materials have unusual physical properties as having both negative permittivity and permeability leading to Negative index materials.
The recipe of the work depends on the solutions of the Maxwell's equations in each layer of the structure and then imposing the boundary condition through the proposed structure to get the dispersion characteristics equation. The roots of the dispersion characteristics are computed to find out the roots of the dispersion equation as the effective index versus the operating frequency.
This communication focuses on TM surface plasmon-Graphene Technology discussing and evaluating the dispersion characteristics of a waveguide structure composing of graphene bounded a plasma substrate and sensing, cover layer.

2. Proposed structure and Theory:

A 4-layer waveguide sensor with a graphene layer with conductivity (σ) located at a distance d_2 above a plasma surface with thickness d_1 as in Figure 1. The plasma layer has permittivity constant (ε_p) that described by

$$\varepsilon_p = \varepsilon_0\left(1-\frac{\omega^2}{\omega_p^2}\right) \quad (1)$$

Where ε_0 is the vacuum permittivity and ω_p is the plasma frequency, and ω is the angular frequency of the applied field. The space between the graphene layer and the plasma layer is filled with Metamaterials (MTM) with negative permittivity ε_2 and negative permeability μ_2. The plasma layer is laying above a dielectric with permittivity (ε) and the graphene layer is covered with dielectric with permittivity ε_3 and permeability μ_3.

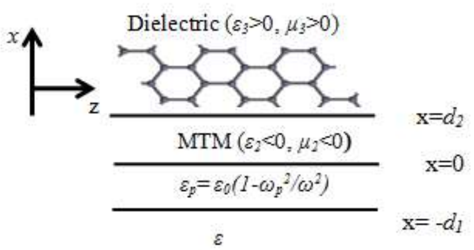

Figure 1 *The proposed structure. The field is assumed to travel a long the x-axis*

The dispersion equation (2) can be derived by solving Maxwell's equations and applying the boundary conditions.

$$\frac{\gamma_2\gamma_p\varepsilon_1+\gamma_1\gamma_2\varepsilon_p\tanh(\gamma_p d_1)}{\varepsilon_2\gamma_2\Gamma+\gamma_3\varepsilon_2\tanh(\gamma_2 d_2)}+\frac{\gamma_1\gamma_p\varepsilon_p+\gamma_p^2\varepsilon_1\tanh(\gamma_p d_1)}{\gamma_3\varepsilon_p+\Gamma\gamma_2\varepsilon_p\tanh(\gamma_2 d_2)}=0 \quad (2)$$

Where $\Gamma=\frac{\varepsilon_3}{\varepsilon_2}+i\,\frac{\sigma q}{\omega\varepsilon_2}$, $q^2-\gamma_i^2=\frac{\varepsilon_i\omega^2}{\varepsilon_0 c^2}$ (i=1,2,3,p), c is the speed of light, and σ is the optical conductivity of the graphene sheet. Here, we assumed it constant (20).
The dispersion equation can be simplified by ignoring the retardation effect as c is much larger than the Fermi velocity of the graphene. Thus, equation (2) can be rewritten as

$$\varepsilon_p\frac{\varepsilon_1+\varepsilon_p\tanh(qd_1)}{\Gamma+\tanh(qd_2)}+\varepsilon_2\frac{\varepsilon_p+\varepsilon_1\tanh(qd_1)}{1+\Gamma\tanh(qd_2)}=0 \quad (3)$$

3. Results and Discussion:

Equation (3) is solved numerically for d_1=d_2=5μm, and σ= 6.089E-6 Siemens using Maple at different values of MTM permittivity (ε_2) [19]. The parameters of the MTM are taking such that ε_2 μ_2=4. Figure 2 shows the real part of propagation constant (Re(q)) as function of frequency at for ε_2 = -1 (dash curve), ε_2= -2 (solid), and ε_2= -4 (dash-dot curve). We can see that, as absolute value of ε_2 increases the value of Re(q) decreases as expected from equation (3). Moreover, at certain frequency (around 1.43E14 Hz) the value of q obtain a maximum value. For ε_2 = -1, we obtained another maximum around 2.14E14 Hz. At low frequency, Γ become pure imaginary and we only interested in the real part. Thus, it approaches zero as ω gets smaller. At $\omega=\omega_p$, $\varepsilon p=0$ and the solution of equation (3) is zero. The previous calculation is repeated keeping all the variables the same and changing the value σ= 6.089E-5 and the results are plotted in Figure 3. We can see in Figure 3 that a third peak appear in the ε_2 = -1 curve and the values of (Re(q)) increases dramatically.

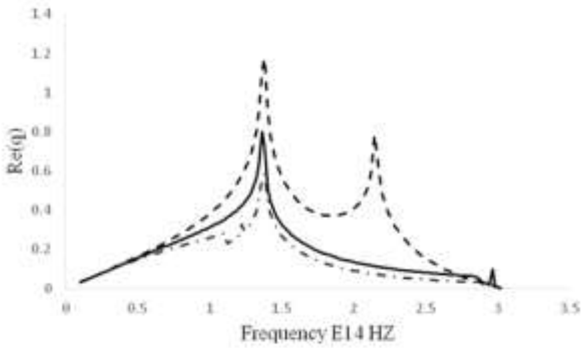

Figure 2 *The real part of the propagation constant as function of frequency at σ= 6.089E-6 at different values of ε_2. The dash curve is for $\varepsilon_2 = -1$, the solid curve is $\varepsilon_2=-2$, and the dash-dot curve is for $\varepsilon_2 = -4$*

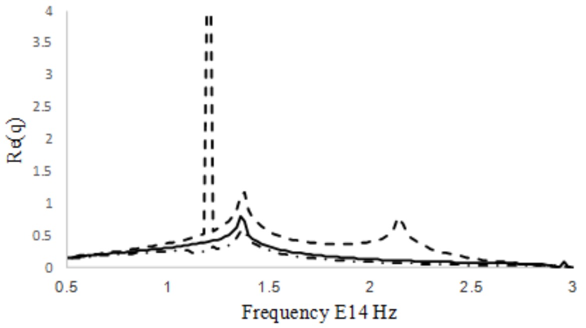

Figure 3 *The real part of the propagation constant as function of frequency at σ= 6.089E-5 at different values of ε_2. The dash curve is for $\varepsilon_2 = -1$, the solid curve is $\varepsilon_2 = -2$, and the dash-dot is for $\varepsilon_2 = -4$*

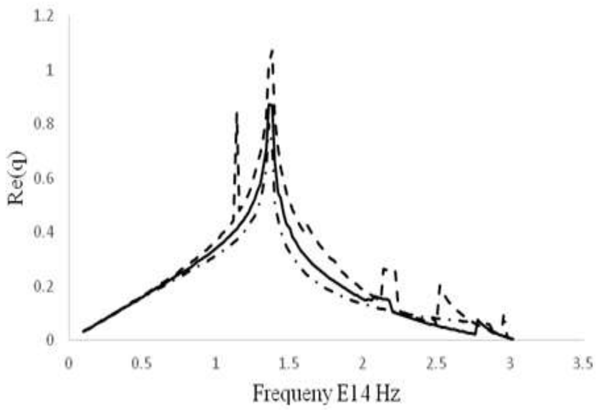

Figure 4 *The real part of the propagation constant as function of frequency at σ= 6.089E-6, $\varepsilon_2= -1$, d_1=5μm, and at different values d_2. The dash curve is for d_2=1 μm, the solid curve is for d_2=3 μm, and the dash-dot curve is for d_2=5μm*

In Figure 4, we plot the values Re(q) as function of frequency at σ= 6.089E-6, $\varepsilon_2= -1$, d_1=5μm, and at different values of thickness d_2 as follows: d_2=1 μm (dash), 3 μm (solid curve), and 5μm (dash-dot curve). Compared on Figure 1, we can see little changes as d_2 increases the value of Re(q) decreases.

Conclusion:

In conclusion, we have studied the influence of the Graphene on the sensitivity enhancement of the proposed structure containing Graphene and plasma substrate. The obtained results reveal That Graphene plasmon concepts and the considered, proposed configuration structure could be promising candidate for further improving the performance of the optical sensors.

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خصائص تشتت البالزمون السطحي للجرافين : دليل موجات رباعي الطبقات

في هذا البحث تم دراسة دليل موجي رباعي الطبقات، يتكون من طبقة جرافين يفصلها طبقه من مادة الميتا عن طبقة البالزما، وتم اشتقاق خصائص التشتت النتشار الموجات السطحية المغناطيسية المستعرضة البالزمونية خالل بنية الدليل الموجي التي تحتوي على الجرافين، ولقد حللنا عدديا انتشار البالزمون السطحي لمتغيرات مختلفة للدليل الموجي، وتشير النتائج التي تم التوصل اليها أنه يمكن التحكم بانتشار البالزمون بتغيير سمك طبقة مادة الميتا ومعامالت مادة الميتا وموصلية الجرافين.

كلمات مفتاحية:
الجرافيين
مادة الميتا
البالزما
الدليل الموجي