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تشدید پلاسمونی وابسته به شدت نور ورودی در لایه گرافن

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چکیده- در این مقاله ما به مطالعه تحریک پلاسمون پلاریتون های سطحی در حضور میدان های الکتریکی بالا بر روی سطح تک لایه گرافن با استفاده از پیکربندی کرشمان-رادر می پردازیم. ما پاشندگی را برای گرافن با کیفیت بالا در نظر می‌گیریم به طوریکه در این حالت میزان انرژی پلاسمون پلاریتون‌ها بسیار بزرگتر از انرژی تلفاتی است. نتایج نشان می‌دهند که برای موج‌های الکترومغناطیسی با شدت بالا، ثابت انتشار پلاسمون پلاریتونهای سطحی رابطه غیرخطی با زاویه تابش موج الکترومغناطیسی ورودی دارد. همچنین در شدت‌های بالا، پاشندگی پلاسمون پلاریتون‌های سطحی دارای تکینگی در بعضی فرکانس‌ها هستند که منجر به تشدیدهای پلاسمونی بیشتر می شود. از این پدیده می توان برای طراحی فیلترهای زاویه و فرکانسی استفاده کرد که قابل تنظیم با شدت نور ورودی است.

کلید واژه- گرافن ، پلاسمونیک ، کرشمان-رادر ، پاشندگی.

Intensity-dependent plasmonic resonance of graphene layer

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Abstract- In this paper, we study excitation of surface plasmon polaritons (SPPs) by Kretschmann-Raether configuration for graphene layer sandwiched between two dielectrics for enough high intensity input electromagnetic (EM) wave. We consider the dispersion of SPPs for high quality graphene layer in which scattering loss is much lower than SPPs energy. Results show that for rather high intensity EM wave, propagation constants of SPPs show nonlinear dependence to incidence angle. Also dispersion curves of surface plasmon polaritons have singularity at some frequencies which results to more plasmonic resonances. These phenomena can be used to design angle and frequency filters which are tunable by intensity of control pump.

Keywords: Graphene, Plasmonics, Kretschmann-Raether, Dispersion

1. Introduction

Graphene has shown astonishing electrical, optical and photonic properties [1]. Among them, we can mention electro-statistic tunability of charge carriers, low energy loss at terahertz frequencies, high confinement of SPPs traveling on its surface due to its 2 dimensional nature [2]. Based on above features, many structures like plasmonic filters [3], modulators [4], sensors [5] have been proposed. Significant light-matter interaction in graphene leads to very large optical susceptibilities in comparison to noble metals and conventional dielectrics [6] which motivated many researchers to utilize it in applications such as switches [7], bistable devices [8] and third harmonic generation [9]. Here, we study plasmonic resonance of graphene in Kretschmann-Raether configuration excited by high intensity input. Numerical simulation results show that at enough large intensities a second plasmonic resonance arises which can be adjusted by intensity of input optical wave. This characteristic can be used in intensity-tunable filters.

2. Materials and methods

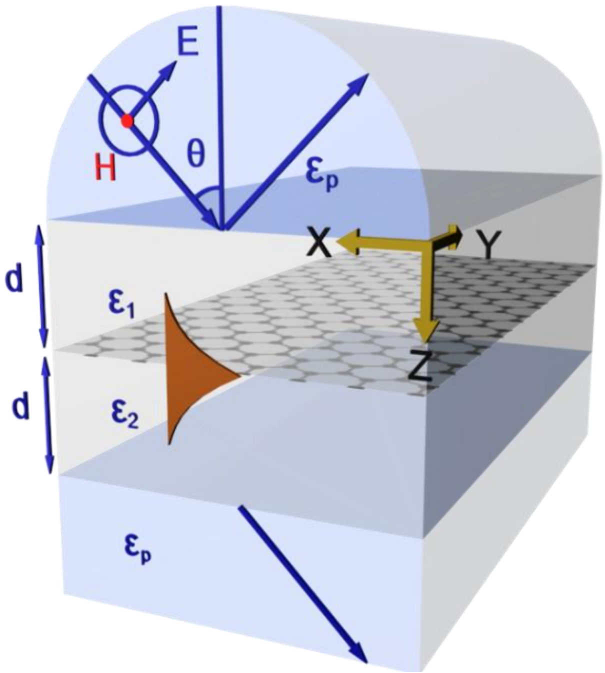

Fig. 1: Configuration of Kretschmann-Raether structure [8].

Our proposed configuration is depicted in Fig.1. A graphene sheet is sandwiched between two dielectrics with dielectric constants of ε_1 and ε_2 with thickness of d and lies parallel to XY surface.

The incident TM light propagates in the Z direction with the angle of θ respect to normal of graphene surface. The Kretschmann-Raether configuration is used to excite SPPs. Therefore a prism with dielectric constant of $\varepsilon_p > \varepsilon_1 > \varepsilon_2$ is used to satisfy conservation of momentum law. Prism is made of Ge with dielectric constant of 16. Inner dielectrics are CaF2 with dielectric constants of 1.69. The CaF2 slab thickness (d) is chosen to be 30 μm. Graphene Fermi level is set to typical value of 0.23 eV. Using Maxwell equations and boundary conditions, we can write dispersion relation for TM mode as [10]

$$\frac{\varepsilon_1}{\sqrt{k_{spp}^2 - \frac{\varepsilon_1\omega^2}{c^2}}} + \frac{\varepsilon_2}{\sqrt{k_{spp}^2 - \frac{\varepsilon_2\omega^2}{c^2}}} = -\frac{\sigma i}{\omega\varepsilon_0} \tag{1}$$

where k_{spp} the wavenumber of SPPs is, ω is the angular frequency of incident light, σ is the conductivity of graphene, ε_0 and c are the permittivity and speed of light in vacuum, respectively. By using Taylor expansion of graphene conductivity and for moderate high electric field, the graphene conductivity can be expressed as $\sigma = \sigma_1 + \sigma_3 |\mathbf{E}|^2$ where $\sigma_{(1)}$ and $\sigma_{(3)}$ are linear and third order surface conductivities of graphene and E is the electric field on graphene surface. Second order conductivity is zero due to centro-symmetric physical structure of graphene. For high quality graphene, the inequality of $\omega\tau >> 1$ is satisfied, so the conductivities can be expressed as [8,11]

$$\sigma_{\text{intra}}^{(1)} = \frac{iq^2}{\pi\hbar^2}\frac{E_F}{\omega} \tag{2}$$

$$\sigma_{\text{intra}}^{(3)} = -i\frac{9}{8}\frac{q^2}{\pi\hbar^2}\frac{(q\nu_F)^2}{\omega^3 E_F}. \qquad (3)$$

where E_F is the Fermi level of graphene, ω is the angular frequency of input wave, ν_F is the Fermi velocity of graphene electrons. The q and $\hbar$ are electrical charge of electron and reduced Planks constant, respectively. Substituting Eq. (2) and Eq. (3) into Eq. (1), we can achieve dispersion relation for SPPs on graphene surface which relates SPPs wavenumber to electric field strength. Propagation constant (Kspp) of SPPs against different angles for electric field intensities of 1 W/cm^2, 4.8 W/cm^2 and 8.5 W/cm^2 are depicted in Fig. (2). At intensity of 1 W/cm^2, plasmonic resonance occurs at incident angle of about 32 degree. However, results show that at appropriate large intensities, there are other resonances at higher incidence angles. For input intensities of 4.8 and 8.5 W/cm^2, second resonance emerges at illumination angle of 80 and 63 degrees.

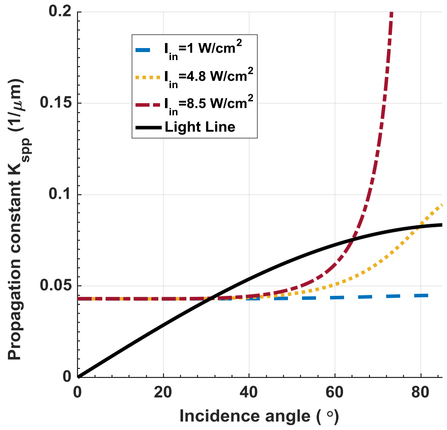

Fig. 2: Propagation constant versus input incidence angle for three different input intensities.

Transmittance versus incidence angle is shown in Fig. (3).

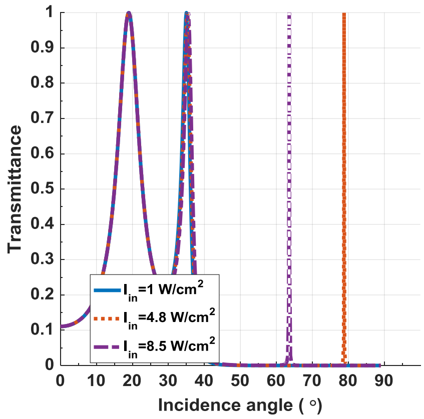

Fig. 3: Transmittance versus incidence angle.

First peak is related to Brewster angle. Second peak is the first plasmonic resonance for all intensities. Third and fourth peaks are high-intensity resonance peaks related to intensities of 8.5 W/cm^2 and 4.8 W/cm^2, respectively, which possess small full width half maximum (FWHM). This characteristic is very useful for precise intensity dependent angle filters.

Dispersion curves for three intensities of 1.9 KW/cm^2, 0.85 KW/cm^2 and 1 W/cm^2 are illustrated in Fig.4

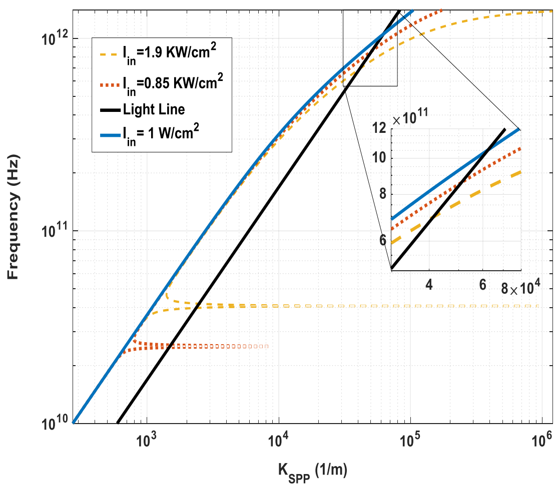

Fig. 4: Dispersion curves for three different input intensities.

It is evident that for input intensity of 1W/cm^2, the light line only crosses dispersion curve at a frequency of 1 THz, but at enough large intensities resonance frequency decreases slightly and also another plasmonic resonance becomes feasible.

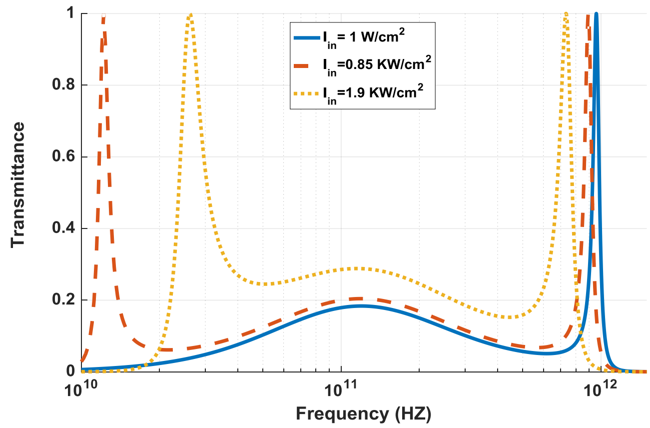

Fig. 5: Transmittance versus input light frequency.

The lower resonant frequency lies in GHz regime. For example, for input intensities of 0.85 KW/cm^2 and 1.9 KW/cm^2, resonant frequencies of 15 GHz and 28 GHz emerges respectively which is evident in Fig. (5). To explain this resonances, we investigate conductivity behaviour against variations of frequency for various input intensities. For intensities of 0.85 KW/cm^2 and 1.9 KW/cm^2, imaginary part of conductivity becomes zero at specific frequencies near resonant frequencies as shown in Fig. (6). At these frequencies, SPPs propagation constants become infinity. So there is a frequency at which light line crosses dispersion curve that is called resonant frequency. This resonant frequency lies in GHz range and can be shifted by input intensity. This phenomenon can be used to design tunable frequency filters by intensity in GHz regime.

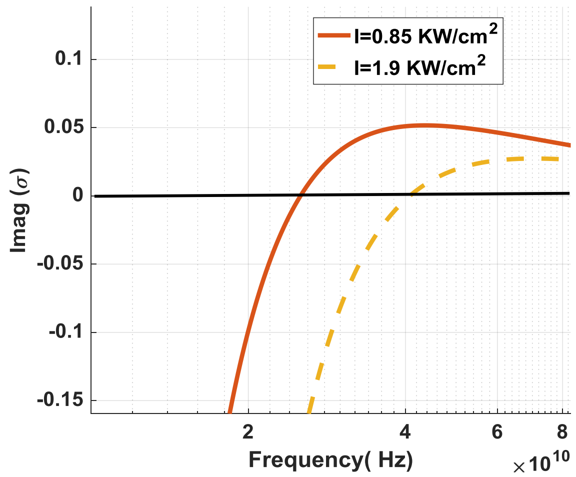

Fig. 6: Imaginary part of conductivity versus frequency.

3. Conclusions

In conclusion, we have extracted propagation constants of SPPs versus incident angle and dispersion curves related to SPPs for enough high intensities of input light excited by Kretschmann-Raether configuration. Results show that adjustable angle and frequency filters can be designed in which the controlling process can be done by means of intensity of incident wave.

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