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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

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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

![Diagram](https://example.com/diagram.png)

Fig. 1: Configuration of Kretschmann-Raether structure [8].
\[ \sigma_{\text{intra}}^{(3)} = -\frac{9}{8} \frac{q^2}{\pi \hbar^2} \left( q \nu_F \right)^2 \frac{1}{\omega^3 E_F}. \]  

(3)

where \( E_F \) is the Fermi level of graphene, \( \omega \) is the angular frequency of input wave, \( \nu_F \) 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 (Ksp) of SPPs against different angles for electric field intensities of 1 W/cm², 4.8 W/cm² and 8.5 W/cm² are depicted in Fig. (2). At intensity of 1 W/cm², 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/cm², second resonance emerges at illumination angle of 80 and 63 degrees.

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

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/cm² and 4.8 W/cm², 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/cm², 0.85 KW/cm² and 1 W/cm² are illustrated in Fig.4.
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 these 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.

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.

References