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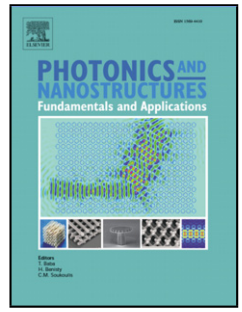

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Application of graphene second-order nonlinearity in THz plasmons excitation

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Highlights

- The nonlinear excitation of graphene surface plasmon polaritons is presented.
- The second-order nonlinearity is used for the phase matching realization.
- Different incident waves polarizations such as TE, TM, etc. are considered.
- The excited electric field is derived using the Green's function.
- The number of involved susceptibility tensor elements are extracted for all cases.
- The most efficient nonlinear effect is suggested for the plasmon excitation.

Abstract

In this paper, the phase-matching condition, the excited electric field formula, and the nonlinear susceptibility tensor elements conditions required for excitation of surface plasmon polaritons (SPPs) on flat graphene are derived. The second-order nonlinearity is utilized for compensation of the free-space and SPPs wave vectors mismatch. In order to excite SPPs on graphene, the phase matching condition is investigated for the second-order effects including the difference frequency generation (DFG), the second harmonic generation (SHG), and the sum-frequency generation (SFG). In addition, since the incident waves polarizations play an important role in the excitation of the SPPs, the realization of the susceptibility tensor elements conditions, the effect of TE, TM, not polarized and perpendicularly polarized incident waves are investigated using the Green's function theory.

Keywords: Graphene plasmonics; Nonlinear optics; Second harmonic generation; Difference frequency generation

1. Introduction

Surface plasmon polaritons (SPPs) bound to the surface of doped graphene, exhibit a number of favorable properties such as tunability, low ohmic loss in terahertz frequencies, and high confinement of plasmons, which make graphene plasmonics an attractive alternative to traditional metal plasmonics [1,2]. In particular, the confinement of graphene plasmons to volumes of many times smaller than the diffraction limit facilitates the strong light-matter interactions [3].

The dispersionless nonlinear susceptibility of graphene is much stronger than bulk semiconductors and controllable by the chemical potential which can be tuned by an external gate voltage [4-8]. Such nonlinearity of graphene can be utilized to realize the various nonlinear functional devices for telecommunications such as optical switches, wavelength converters, and signal regenerators [9].

In pristine graphene, the second-order response vanishes due to the central symmetry of graphene [10], while the symmetry can be broken using dc current [11], growing graphene on a substrate to utilize the surface effect [12], applying the oblique incidence of radiation on the 2D electron layer [13], and so on. If the incident wave has a wave vector component parallel to the plane of the 2D layer, one could observe even much stronger second-order radiation as compared to the third-order effects [6]. The intensity of the second harmonic in graphene is about two orders of magnitude larger than the typical semiconductor structures (e.g. GaAs/AlGaAs quantum wells) and in the condition of 2D plasmon resonance, the intensity of the second harmonic can be enhanced by several orders of magnitude [13]. Moreover, the second- order nonlinearity can support down/up conversion, the second harmonic generation (SHG), etc.

The magnitude of the graphene surface plasmons (GSPPs) wave vector is far more than the free-space wave vector magnitude. Therefore, in order to excite the GSPPs, the phase matching condition is required. For the compensation of this mismatch, some suggestions have been reported so far such as: Bragg grating [14], subwavelength silicon grating [15], and surface acoustic waves [16]. Nevertheless, plasmon scattering at the grating edges, the need of precise nanolithography and patterning are some of the obstacles leading to decrease in the efficiency of such approaches.

Recently, some effects such as the second- and third-order susceptibility are utilized in order to compensate the momentum mismatch between the wave vectors and consequently excite the GSPPs [17-19]. The application of the strain fields for changing the susceptibility tensor elements

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