Graphene surface magneto-plasmons excited through a magnetostatic biased graphene-strip grating : Semi analytical Approach

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Abstract

We present an accurate and simple semi analytical model for investigating the magneto-plasmonic response of a 1D subwavelength graphene strip grating under an external static magnetic field when the graphene is considered as an anisotropic layer with atomic thickness. It is based on an effective medium approach (EMA) and a rigorous phase correction. The proposed model is numerically validated and evaluated by comparing the results with those obtained from the PMM method and from methods published in the litterature.

1. Introduction

Graphene magneto-plasmonics , the research area that combine magnetic and plasmonic properties of graphene, has attracted considerable interest in recent years, thanks to the unique and unsual properties of the surface magneto-plasmons supported by graphene. These properties have been exploited to design many tunable plasmonic nonreciprocal devices in the microwave and terahertz regimes such as optical isolators and absorbers. Graphene surface magneto-plasmons have been widely studied in several theoretical and experimental works under various forms and configurations. Among these structures, periodic magnetically biased graphene ribbons arrays have attracted a great deal of research interest and became one of the most studied graphene based structures. Several and various numerical methods have been employed for modelling this structure. However, it has been shown that due to the ultra-thin nature of graphene, these numerical methods suffer from slow convergence rates and require too much computational effort. In our work, we propose to model in a simple way the magnetoplasmonic response of a 1D graphene strip grating in the presence of an external magnetic field when the graphene is considered as a bulk material through a simple semi analytical approach. This Model is useful to better understand graphene surface magnetoplasmons GSMPs and may facilitate the design of various tunable devices based on graphene magnetoplasmonics.

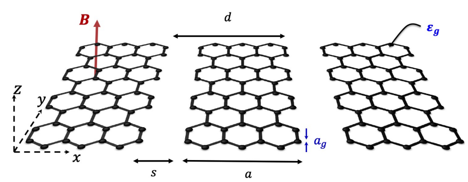

Figure 1: Sketch of the studied structure: a magnetically-biased subwavelengh graphene strip grating with width a and period $d = a + s$. The grating is surrounded by air and the magnetic field B is applied perpendicularly to the structure along the z direction.

2. Method and Results

Figure 1 depicts the structure under study which consists of a periodic array of 1D graphene ribbons under a magnetostatic bias. The width of the ribbons is a and the periodicity of the array is $d = a + s$ in the x-direction. The graphene ribbons array is suspended in free space and occupies the xy plane. It is enlightened from the lower medium $(z < 0)$ by a plane wave under normal incidence. Here, we consider the Faraday geometry where the external static magnetic field B is perpendicular to the array. Under the influence of such a magnetostatic bias, graphene will exhibit an induced anisotropy leading to asymetric surface magneto-optical conductivity and permittivity tensors.

Since, we work in the subwavelengh regime *i.e* the period d of the grating is small compared to the wavelength of the incident wave ($d \ll \lambda$), the electromagnetic response of the studied structure can be simply obtained through an effective meduim approach which consists in approximating the grating by a homogeneous anisotropic effective layer with an equivalent effective permittivity tensor. By applying this approach to the graphene permittivity tensor, we found that the latter can not reproduce the optical properties of the structure. To take into account the magnetoplasmonic resonances phenomena resulting from the coupling between the different modes living in the structure, we introduce the scattering matrix formalism. The resonance modes of the structure appear then as the zeros of the determinant of the scattring matrix applied to a cavity formed by the effective medium and graphene. A phase correction

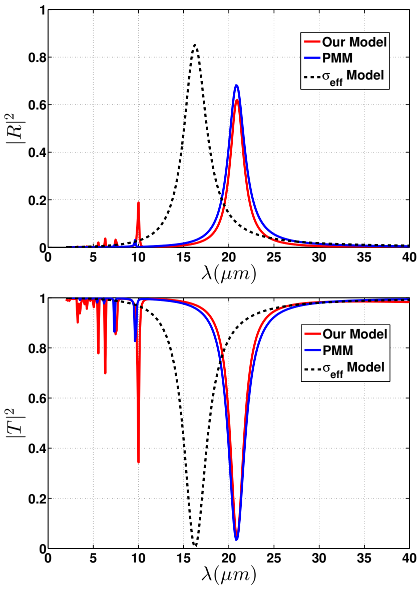

Figure 2: Comparison between the reflection and transmission spectra obtained from our Model (red solid lines) and those obtained from the PMM (blue solid lines) and from the effective medium approach [1] (dashed black lines). The results are calculated for a magnetically biased graphene strip grating with ribbon width $a = 0.9\mu$m, gap $s = 0.45\mu$m and $B = 3T$. Graphene parameters are $\mu_c = 0.6$eV, $T = 300$K and $\tau = 0.6$ps

is also required to take into account the periodicity effect, this term may be estimated thanks to a rigorous simulation. Finally, once the resonnance modes are obtained and using phenomenological approach, we can straightforwardly write the total transmission and reflection coefficients as the sum of two terms, the first term resulting from the resonnance phenomena and the second one introduces the contribution of a single strip of graphene.

Figure 2 shows the reflection and transmission spectra of a graphene strip grating when the applied magnetic field is taken to be $B = 3T$. The strip width is $a = 0.9\mu$m and the periodicity is assumed to be $d = 1.35\mu$m. The chemical potential of the graphene strips is set to $\mu_c = 0.6e$V and the relaxation time τ is 0.4ps These results are compared with the effective medium approach given in reference [1] and the PMM method. The computed spectra show several resonance peaks which correspond to the excitation of GSMP through the structure.

Figure 3 shows the reflection and transmission spectra computed through the proposed semi-analytical model, the PMM model and the effective conductivity approach proposed in [1] in the case of a graphene strip grating without an external magnetic field for: $a = 0.25\mu$m, $d = 0.35\mu$m, $\mu_c = 0.4$eV, $\tau = 0.4$p. In Both cases, we can see a good agreement between the PMM results and those obtained with our proposed model. By contrast, the comparison with the effective conductivity model shows that the latter cannot reproduce the magneto-optical properties of the stud-

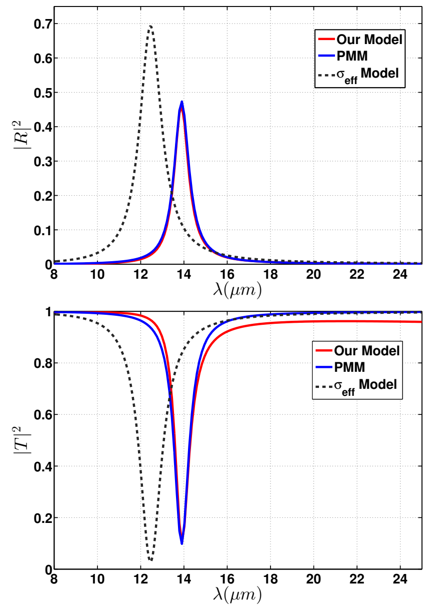

Figure 3: Comparaison between the reflection and transmission spectra obtained from our proposed Model (red solid lines) and those obtained from the PMM (blue solid lines) and from the the effective medium approach [1] (dashed black lines). The results are calculated for a graphene strip grating with ribbon width $a = 0.25\mu m$ and gap $s = 0.1\mu m$, when the magnetic bias is absent. Graphene parameters are $\mu_c = 0.4$eV, $T = 300$K and $\tau = 0. = 4$ps

ied graphene grating. We can also conclude that our semi-analytical model is a general approach that can efficiently and successfully treat both the case of a graphene strip grating biased with an external magnetic field as well as the particular case where no magnetic field is applied.

3. Conclusions

We have developped a simple and efficient semi analytical model based on an effective medium approach (EMA) and a rigorous phase correction, to decribe graphene surface magneto-plasmons excited in a magnetically-biased subwavelength graphene strip grating.

References

[1] J. S. Gomez-Diaz and A. Alù, Magnetically-biased graphene-based hyperbolic metasurfaces, *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)* (IEEE, 2016): 359–360, 2016.