Robust Multi-Layer Graphene-Based Plasmonic Cloaking

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***Abstract*—In this paper, a plasmonic cloak is designed at $1.55\ \mu m$ in an epsilon-near-zero (ENZ) comprised of alternating layers of a graphene-silica stack. Because the inclusion is covered by Au and moreover, the ENZ's boundaries are sealed by this material with optimized thicknesses, such a cloak can only work for TM incidence. This cloak is robust against the inclusion shape which is capable of working in an exceedingly large bandwidth.**

I. INTRODUCTION

A cloaking device is an fascinating application of metamaterials which attracted great attention of studies over the last few years. An epsilon-near-zero (ENZ) region is a good candidate for realizing striking applications such as a cloaking functionality because such an application requires removing both spatial and frequency dispersion from the medium enclosing a cloaked object (inclusion). Although noble metals like Au can provide an ENZ property in a very small frequency range, they exhibit a considerable loss for a propagating wave along them. In contrast, metamaterials can be manipulated to offer an ENZ region with small propagation loss [1], hence they will have promising applications for realizing a cloaking device.

Thin film materials like indium tin oxide, provide a tunable ENZ region through a chemical doping process [2] and moreover, they can only exhibit this property in a particular frequency range. In order to achieve the ENZ feature in other frequency ranges, a hybrid metamaterial structure may be used [3], however it also needs a chemical doping process. One of the promising options for achieving a ENZ property is the use of graphene which can be doped either electrically or chemically [4], [5]. Graphene is a 2D material which ideally possesses a linear band diagram, consequently it is capable of providing exceedingly large bandwidth electronic and electromagnetic devices [6], [7]. Via application of an electrostatic bias to a graphene strip, its electrical and optical properties are controlled [8], [9], but in this situation, it exhibits an anisotropic response to electromagnetic fields [9]. In [10] a cloak was designed using a monolayer graphene which a moderate bandwidth was achieved and additionally, its working frequency is tuned via an electrostatic bias gating.

Although many cloaks in the literature have been designed by employing various techniques, they can only exhibit a very good performance for particular inclusion shapes, hence, they are sensitive with respect to the inclusion shape. In this paper, a plasmonic cloaking device is designed using an ENZ region made of alternating layers the graphene-silica stack which is robust against the inclusion geometry. Moreover, Au is used to seal the cloak's boundaries with optimized thicknesses and additionally, this noble metal is employed to enclose the inclusion.

II. DESIGN AND SIMULATION

In Fig. 1 the plasmonic cloak is drawn which uses an ENZ region made of alternating layers of the graphene-silica stack. Furthermore, an inclusion with star shape is placed in the ENZ region. The ENZ region exhibits an anisotropic response [3] which its in-plane permittivity is controlled via a DC bias as shown in Fig. 1. Application of the DC bias to the graphene strips is done in an electronic solver which solves charge transport in the structure [11], [12]. Clearly, the DC bias is applied to the graphene strips symmetrically so the same chemical potential is induced in them.

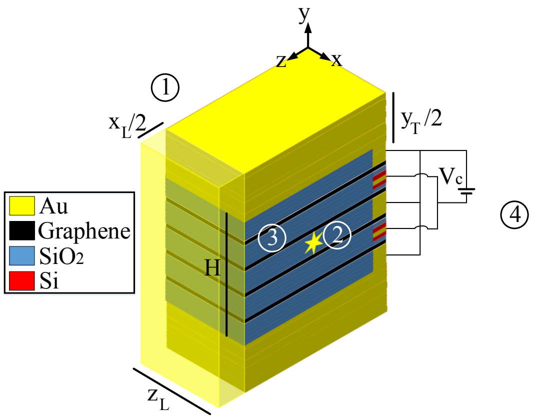

Fig. 1. Proposed plasmonic cloak using the ENZ region comprised of alternating layers of the graphene-silica stack which its boundaries are sealed by Au. In addition, an inclusion with star shaper is embedded in the ENZ region.

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The in-plane and out-of-plane components of the ENZ's permittivity are respectively given by,

$$\epsilon_{pl} = F \cdot \epsilon_{gt} + (1-F) \cdot \epsilon_s, \quad \frac{1}{\epsilon_{pd}} = \frac{F}{\epsilon_{gn}} + \frac{1-F}{\epsilon_s} \tag{1}$$

where $F = t_g/t_s$ refers to the filling factor. Additionally, t_g, ϵ_{gt}, ϵ_{gn}, t_s, and ϵ_s represent the thickness of the graphene strips, the tangential and normal components of the graphene's permittivity, the thickness and relative permittivity of silica, respectively. In this paper, the ENZ point is chosen at $1.55\ \mu m$ so the applied bias is varied so that this point is achieved. In this regard, for $\mu_c = 0.42\ eV$ this point is obtained, where μ_c is the chemical potential of the graphene strips. As a result, through application of a DC bias, the ENZ point can be tuned so a reconfigurable ENZ is designed using the graphene strips.

Here, it is assumed that a TM-polarized plane wave from the region 1 is incident on the cloak. In order to design the cloak, the reflection coefficient is computed for this polarization. To this end, the Faraday's law of induction in the region 3 is expressed as following:

$$\oint_{\partial R3} \vec{E}_3 \cdot \vec{dl} = \int_y \vec{E}_1 \cdot \vec{dl}\Big|_{x=0} + \int_x \vec{E}_3 \cdot \vec{dl}\Big|_{y=H} + \int_y \vec{E}_4 \cdot \vec{dl}\Big|_{x=W} + \int_x \vec{E}_3 \cdot \vec{dl}\Big|_{y=0} \tag{2}$$

where $\vec{E}_i$ describes the electric field in region $i = 1, 2, 3, 4$. It can be shown that the reflection coefficient is calculated as follows:

$$R^{TM} = \frac{-\frac{1}{\eta_0 H_1}(I_1 + I_2) - \frac{1}{\eta_0 H_3} I_3}{2 \cdot H + \frac{1}{\eta_0 H_3} I_3} \tag{3}$$

where H_1 and H_3 denote the complex amplitude of the magnetic field in the regions 1 and 3, respectively. Furthermore, $I_1 = \int_x \vec{E}_3 \cdot \vec{dl}\Big|_{y=H}$, $I_2 = \int_x \vec{E}_3 \cdot \vec{dl}\Big|_{y=0}$ and $I_3 = \oint_{\partial R2} \vec{E}_3 \cdot \vec{dl}$. According to (3), I_1 and I_2 become zero when the ENZ's boundaries in the y direction are sealed by a perfect electric conductor, but here we use Au instead. Varying the thickness of the Au boundaries, the transmission coefficient is computed which is maximized for $x_L = 350\ nm$ and $y_T = 100\ nm$. This performance does not change by varying the inclusion shape that in these situations, the transmission coefficient is obtained $\%87$. Fig. 2 depicts the magnetic field distribution inside the plasmonic cloak which the incident wave is transmitted through the ENZ region and then reaches the region 4 without significant distortion.

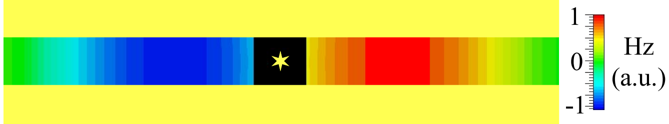

Fig. 2. The magnetic field distribution inside of the plasmonic cloak for the TM incidence.

III. CONCLUSION

In this paper, a cloaking device was designed using the ENZ region which the inclusion shape was chosen arbitrary to show that this cloak is robust with respect to the inclusion geometry. In addition, using the metal boundaries with the optimized thicknesses, a plasmon mode was excited in the ENZ region.

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