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Numerical Investigation on Graphene Based Mantle Cloaking of a PEC Cylinder

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***Abstract*—A specific coating for the achievement of the mantle cloaking of a metallic cylinder in the Terahertz frequencies is investigated. The coat is realized starting from a dielectric layer covering the cylinder, over which a certain number of modulated strips of graphene are laid. Properly set the values of the available parameters (chemical potential of graphene μ_c, dielectric constant ϵ, dielectric thickness *h*, number of modulated strips *n* and variation of width of each strip *w(z)*), a combination of the values that allows to reach the cloaking of the object is obtained. In order to quantify the cloaking at the desired frequency f_0, the Maximum Radar Cross Section is computed and compared to the various structures.**

I. Introduction

Nowadays, the elevated amount of different services provided to users located of that same area requires the use of closely positioned antennas. Even if these antennas work in different frequency bands, each one, only because of its presence, causes interference to the signals transmitted by the others. A similar effect happens if there are objects in the surroundings of the transmitting antenna [1], [2]. In order to avoid mutual blockage effects and signal interferences, the "obstacles" can be covered with complex and properly designed artificial materials (*metamaterials*), or their two dimensional counterpart, i.e., metasurfaces, to make the coated objects "invisible" (or "transparent") at the working frequency of the nearby antennas. This technique is named *cloaking*. When cloaking is obtained by a thick coating layer the technique is known as "mantle cloaking". Actually, it has also relevant applications in military and medical fields: this technique allows, for example, to make airplanes not-detectable from radars [3]or to increase the visibility of the surgeon during an operation, allowing to see behind hands and instruments [4].

II. The structure

In this work a particular structure for the mantle cloaking of a cylindrical and metallic object is presented. It is based on a series of vertical modulated strips of infinitesimal thickness laid on a dielectric substrate, as reported in Fig. 1.

The considered cylindrical object has a radius of 8.33 μm (that corresponds to $\lambda_0/12$ μm where λ_0 is the free space wavelength at the resonant frequency of $f_0 = 3$ THz) and it is made of PEC. The chosen substrate is Silicon Nitrade Si_3N_4, whose electric dispersion is fitted for the adopted frequency range 1 THz - 8 THz and its value corresponds to 3.89. Its thickness has been chosen as 10.5 μm (λ_0/9.5238 μm).

The structure is similar to that introduced in [5], but here the modulated unit cell has bee rotated and the modulation is along the longitudinal direction of the cylinder. Moreover, the modulation here is of sinusoidal type as regards the shape, and not the relative dielectric constant. Here the modulated strips are made of *graphene*, whose chemical potential μ_c is varied from 0 to 1 eV. The mean amplitude of the strips is chosen to be 1.5 μm, the maximum amplitude (that corresponds to the center of the strips) is 2.5 μm, while the minimum amplitude (that happens at the extremities of the strips) is 0.5 μm. Their thickness is infinitesimal and their number is chosen to be 14. The angular distance among two consecutive strips (taken from center to center of the strips) is 25.7 degrees. The coated cylinder has been designed with a length of 16.67 μm (λ_0/6 μm), that corresponds to the z-direction extension of the modulated line.

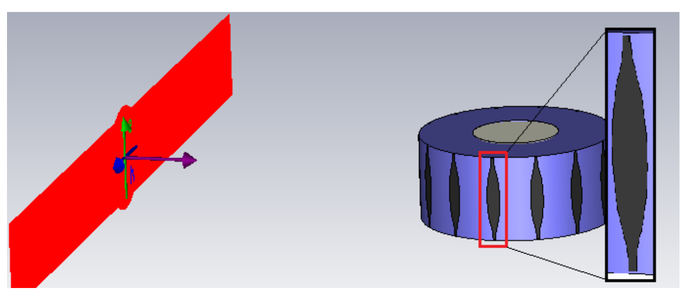

Fig. 1. Coated cylinder and plane wave orientation. The cloaking cover consists of a thick dielectric (Si_3N_4) and of 14 modulated strips of *graphene*. The propagation of the plane wave is orthogonal to the cylinder, while the electric field is parallel to its axis.

Actually, the simulated length of the object is of infinite extension and covered by a periodic pattern of the strips, since the *Boundary Condition* of the adopted simulation program, here CST [6], are set to *electric* in the z-direction, that corresponds to the one parallel to the cylinder length. This setting, however, causes a short circuit in proximity of the extremities of the strips. To avoid this effect, the strips are designed slightly shorter than the height of the metallic cylinder: in particular 0.2 μm shorter from both the extremities of the cylinder. This reduction of the length of the strips, corresponds to presence of a capacity among two consecutive strips along the z-direction.

The considered object is illuminated by a plane wave whose electric field is parallel to the cylinder axis and its propagation vector is normal to it (see Fig. 1).

III. Simulation Results

For the previously-described structure, a parametric investigation has been performed varying the chemical potential μ_c of the strips. Starting from the values of the electric field measured all around the structure, in the plane $z_0 = 0$ and at a distance $r = 60$ μm far from the center of the cylinder, the *Maximum Radar Cross Section* has been computed (1). To reduce as much as possible the numerical errors, the incident field has been computed as follows: a cylinder made of vacuum is simulated and the electric field is evaluated in the same positions as for the cloaked one. The expression of the *Maximum Radar Cross Section* is reported in Eq. (1),

$$\mathbf{MaxRCS} = \mathbf{max}_\phi \left. \frac{|\mathbf{E}_\mathrm{z} - \mathbf{E}_\mathrm{z,\ inc}|^2}{|\mathbf{E}_\mathrm{z,\ inc}|^2} \right|_\phi \quad (1)$$

where $\mathbf{E}_\mathrm{z}$ is the total (the sum of the scattered and incident) electric field at a given frequency, while $\mathbf{E}_\mathrm{z,\ inc}$ is the incident electric field at the same frequency. ϕ indicates the position (in terms of angle) at which the electric field is measured. The obtained RCS has, in this case, no measuring unit because it has no dimension. It is also possible to convert the Max RCS in eq. (1) in dB:

$$\mathbf{MaxRCS}_\mathrm{dB} = \mathbf{10\ log\ MaxRCS}. \quad (2)$$

In Fig. 2 it is possible to notice that the behaviour of the Maximum RCS changes according to the chemical potential μ_c. At μ_c= 0 the cylinder is cloaked around 3 THz. Increasing μ_c the resonant frequency f_0 is shifted towards right, i.e., toward higher frequencies.

To quantify the amount of the shift of the resonant frequency f_0 for different (increasing) values of μ_c, a table with the corresponding values to the chemical potential has been compiled and reported in Tab. I. It can be observed that f_0 increases until 3.8 THz, a value obtained for μ_c= 0.8 eV. The data in Tab. I also shows the cloaking bandwidths (BW), defined as the frequency band between the intersection points of the RCS curve of the cloaked structure and the RCS curve of the bare cylinder reduced by 3 dB, for the different values of μ_c: BW reduces when the chemical potential increases and this reduction becomes higher at high values of μ_c. At μ_c= 1 eV the Maximum RCS curve doesn't reach the -3dB curve, so at this chemical potential it is not possible to cloak the cylinder with the adopted structure.

IV. Conclusion

A structure to reach the cloaking of an infinitely long cylinder around 3 THz is presented. A particular substrate and a certain number of vertical modulated strips of graphene have been adopted to achieve the aim. The *Maximum Radar Cross Section* has been measured to understand whether the cloaking is reached and at which frequency this happens. Curves for the *Maximum RCS* have been computed for different values of the chemical potential μ_c of the *graphene* strips. They appear more and more right-shifted when the chemical potential is increased. Similar structures as the one discussed here are currently under investigation for the various applications of the *mantle cloaking* in practical cases.

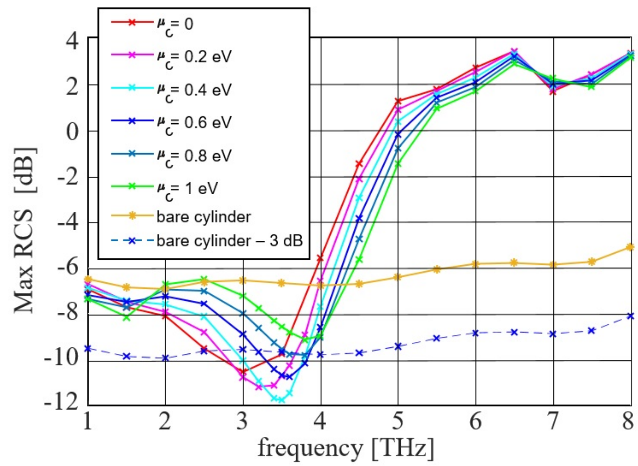

Fig. 2. Maximum Radar Cross Section wrt. frequency varying the chemical potential μ_c. The Maximum RCSs of the cloaked structures are compared to the one of the bare cylinder and to its -3dB-shifted curve.

TABLE I
Table with the values of the resonant frequency f_0 and of the cloaking bandwidth BW according to the chemical potential μ_c of the *graphene* strips.

μ_c eV	f_0 [THz]	BW [THz]
0	3	0.949
0.2	3.2	0.981
0.4	3.5	0.926
0.6	3.6	0.665
0.8	3.8	0.246
1	N.A	-

References

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