Atomically-Thin Surface Cloak Using Graphene Monolayers

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SUPPORTING INFORMATION

Tunability of the surface impedance of a graphene monolayer

The graphene surface is typically biased using either a perpendicular static electric filed or a static magnetic field via the Hall effects. In the first case, the surface impedance of graphene is isotropic and described by a scalar. In the second case, one should consider a tensor of anisotropic surface impedance. In this paper, we have limited our discussion to the scalar scenario, and we discuss here in more detail its electrically-controlled tunability properties in a non-magnetic environment. Extensions to anisotropic scenarios under the influence of magnetostatic fields may be analyzed with a similar approach.

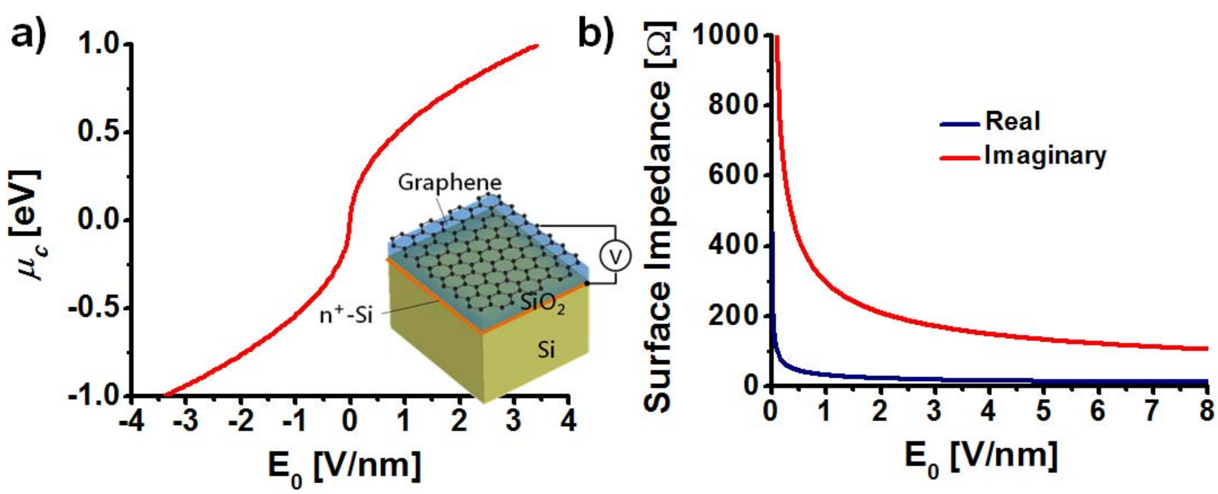

Figure S1. *(a) Dependency of the chemical potential at* $f_0 = 3\,\mathrm{THz}$ *on the electric bias field with* $\varepsilon_{ox} = 3.9$ *(this curve is obtained from equation (4) in the main text). (b) Dependency of the surface impedance at* $f_0 = 3\,\mathrm{THz}$ *on the biased electric field with* $\varepsilon_{ox} = 3.9$*. The real and imaginary parts represent the surface resistance and surface reactance, respectively.*

Figure S1a shows the relationship between the electric biasing field and the chemical potential of a graphene monolayer, obtained from equation (4) in the main text. The chemical potential may be tuned from -1 eV to 1 eV by varying the magnitude of biasing field across the structure [see inset of figure S1]. This is typically achieved by changing the bottom-gate voltage and, in general, the operation voltage may be significantly reduced by scaling the thickness of the silicon oxide insulating layer. Figure S1b shows the variation of isotropic surface impedance as a function of biasing fields. The surface reactance may be largely tuned by a moderate biasing field and the surface resistance is almost negligible as the bias increases in this frequency range. This may be explained by considering that, as the bias field increases, more charge will be induced on the graphene surface, thus forming a conducting channel that reduces the surface resistance.

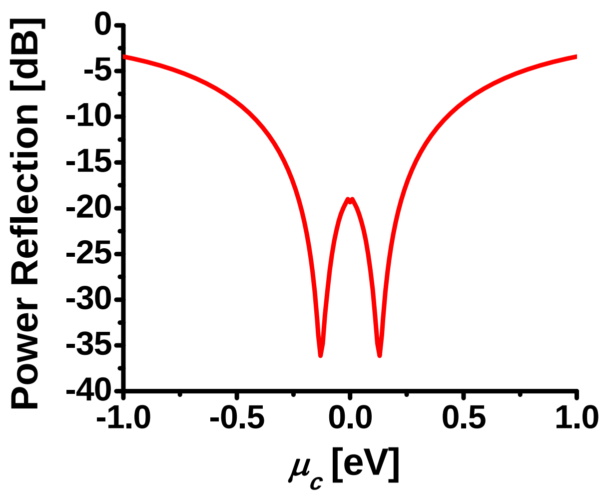

Figure S2. *Reflectance at* $f_0 = 3\,\mathrm{THz}$ *for the graphene cloak in figures 1-2 of the main text, varying the chemical potential from -1 eV to 1 eV.*

Figure S2 shows how these tunability properties are reflected into the change in reflectance at $f_0 = 3\,\mathrm{THz}$ for the graphene cloak of figure S1, realizing a tunable and switchable operation, with a reflectance varied over 30 dB in magnitude by simply controlling the chemical potential. We notice that, due to the electron-hole symmetry of the graphene's bandstructure, both negative and positive signs of chemical potential may give the same complex surface impedance, as well as cloaking performance.