INTERACTIONS OF IONS WITH GRAPHENE-SAPPHIRE-GRAPHENE COMPOSITE SYSTEM: STOPPING FORCE AND IMAGE FORCE

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Abstract. We derive general expressions for the stopping and image forces on an external charged particle moving parallel to a sandwich-like structure consisting of two doped graphene sheets separated by a layer of sapphire (Al_2O_3) in order to study the effects of plasmon-phonon hybridization on those forces.

Modeling of the system. We use a Cartesian coordinate system with coordinates $\{\vec{R}, z\}$, where $\vec{R} = \{x, y\}$ is a two-dimensional (2D) position vector in the xy-plane. Our system consists of two graphene sheets that are placed in the planes $z = a/2$ and $z = -a/2$, as depicted in Fig. 1, with the space between them being a sapphire layer of thickness a. The graphene sheets are described by 2D response functions, $\chi_1(q,\omega)$ and $\chi_2(q,\omega)$, for their non-interacting electrons and the sapphire layer is described by its local dielectric function $\varepsilon_S(\omega)$ [1]. We assume that an incident particle with charge Ze and velocity v is moving parallel to this composite structure at distance b from the top graphene surface.

In our previous publication [2] we derived an expression for the screened Coulomb interaction as:

$$W(\vec{q},\omega,z,z') = \frac{2\pi}{q}e^{-q|z-z'|} + \frac{2\pi}{q}\left[\frac{1}{\varepsilon(\vec{q},\omega)} - 1\right]e^{-q(z+z'-a)},$$

where the latter part is the induced Coulomb interaction, $W_{ind}(\vec{q},\omega,z,z')$, with $\vec{q} = \{q_x, q_y\}$ being the momentum transfer vector parallel to the xy-plane and $q = \sqrt{q_x^2 + q_y^2}$, whereas the effective 2D dielectric function $\varepsilon(\vec{q},\omega)$ is written as:

$$\varepsilon(q,\omega) = \frac{1}{2}\left[1 + \varepsilon_s(\omega)\coth(qa) + \frac{4\pi e^2}{q}\chi_2\right] - \frac{1}{2}\frac{\varepsilon_s^2(\omega)\,\mathrm{cosech}^2(qa)}{1 + \varepsilon_s(\omega)\coth(qa) + \frac{4\pi e^2}{q}\chi_1}.$$

Results. Charge density of our external point charge Ze may be written as $\rho_{ext}(\vec{R},z,t) = Ze\delta(\vec{R} - \vec{v}t)\delta[z - (a/2 + b)]$. Then, the induced potential in the region above the upper graphene sheet may be expressed as:

$$\Phi_{ind}(\vec{R},z,t) = \frac{Ze}{(2\pi)^2}\int W_{ind}(\vec{q},\vec{q}\cdot\vec{v},z,a/2+b)\,e^{i\vec{q}\cdot(\vec{R}-\vec{v}t)}d^2\vec{q}.$$

Substituting induced Coulomb interaction into previous equation and assuming that a point charge moves along the x axis, an expression for the induced potential is obtained:

$$\Phi_{ind}(x,y,z,t) = \frac{Ze}{2\pi}\int\frac{e^{-q(z-a/2+b)}}{q}\left[\frac{1}{\varepsilon(q,q_x v)} - 1\right]e^{i\left[q_x(x-vt)+q_y y\right]}\,dq_x dq_y.$$

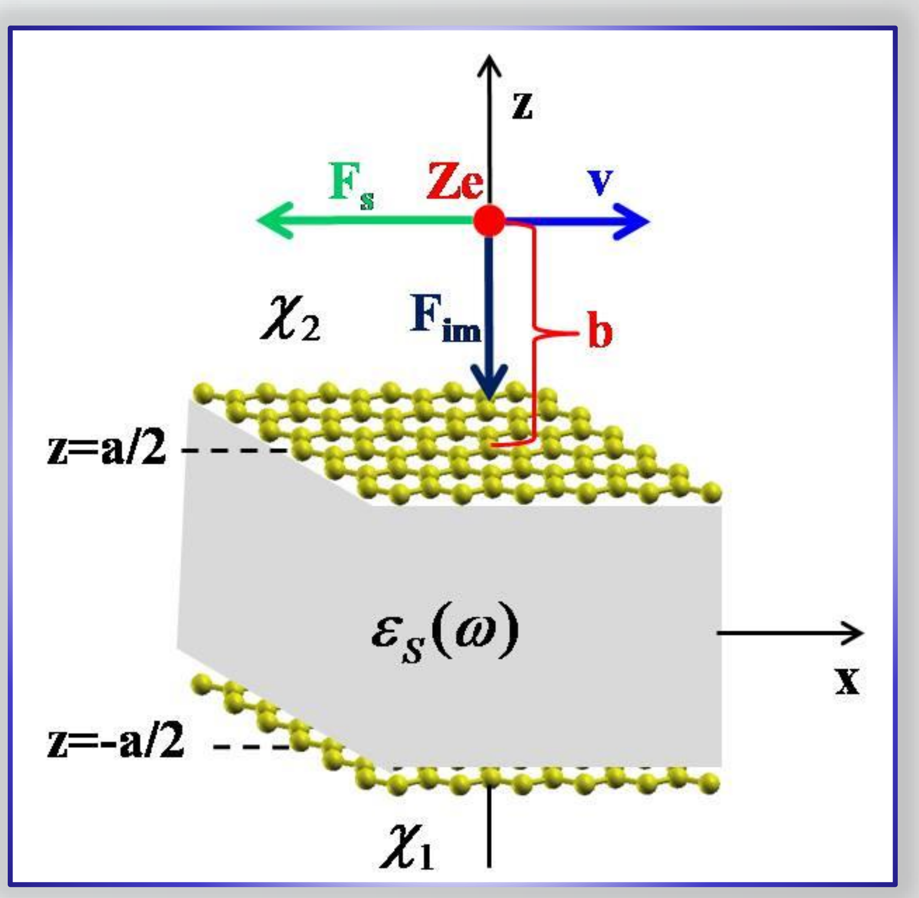

Fig. 1: Diagram of the stopping force F_s and the image force F_{im} that act on the point charge Ze moving parallel to the x axis with constant speed v at a fixed distance b above the graphene-sapphire-graphene composite system.

The stopping and image forces on the moving charge Ze are defined as partial derivatives of the induced potential [3]. By using those definitions and the symmetry properties of the real and imaginary parts of the dielectric function, the final forms of the stopping and image forces, respectively, are:

$$F_s = \frac{2(Ze)^2}{\pi}\int_0^\infty\int_0^\infty \frac{q_x e^{-2qb}}{q}\,\mathrm{Im}\left[\frac{1}{\varepsilon(q,q_x v)}\right]dq_x dq_y$$

$$F_{im} = \frac{2(Ze)^2}{\pi}\int_0^\infty\int_0^\infty e^{-2qb}\,\mathrm{Re}\left[\frac{1}{\varepsilon(q,q_x v)} - 1\right]dq_x dq_y$$

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