**Basic Motives**

- **GRAPHENE** is the first truly two-dimensional (2-D) material to be observed and isolated in nature. In essence, it is a flat monolayer of carbon atoms tightly packed into a 2-D honeycomb lattice.

- Its impressive electronic behavior is attributed to the fact that the energy-momentum relation for electrons is linear over a wide range of energies, rather than quadratic. Therefore, electrons act as massless relativistic particles, i.e., Dirac fermions.

- Graphene has already found very interesting applications in the areas of integrated circuits and optoelectronics, while it is expected to be used in several devices from transformation optics, exploiting its capability to support the propagation of surface plasmonic waves.

- Various techniques have been developed for the accurate simulation of graphene structures.

**Graphene Conductivity Model**

Our study concentrates on the isotropic local conductivity case in the absence of an external magnetic field. The graphene surface conductivity is given by the Kubo formula.

\[
\sigma(\omega, k_T) = \frac{\mu^2}{2\pi^2} \omega^2 \left[ \frac{\partial f(-\varepsilon)}{\partial \varepsilon} - \frac{\partial f(\varepsilon)}{\partial \varepsilon} \right] \frac{\omega}{\omega^2 + \mu^2}\]

The first term resembles the intraband contributions, whereas the second term resembles the interband counterparts. We are interested in the intraband \(\sigma_{\text{intra}}\) term only, which is valid for microwave frequencies:

\[
\sigma_{\text{intra}} = \frac{\mu^2}{2\pi^2} \frac{1}{\omega^2 + \mu^2} \tau
\]

- \(\mu\): chemical potential
- \(\tau\): scattering time
- \(\mu_c\): carrier mobility
- \(n_c\): carrier density
- \(v_F\): Fermi velocity
- \(e\): electron charge

**Generalized 3D FDTD Scheme**

- Direct incorporation of graphene surface conductivity. No need to split \(E_z\) and \(H_z\).
- On the surface conductivity, the surface current in the frequency domain, is given by \(J = \sigma E\).
- Also, the graphene surface current is written as \(J = J_0 + J(\omega)\).
- Only application of Ampère’s law needs to be altered:

\[
\nabla \times \mathbf{E} + \frac{1}{c^2} \frac{\partial \mathbf{B}}{\partial t} = \frac{4\pi}{c} \mathbf{J} + \frac{1}{c} \frac{\partial \mathbf{D}}{\partial t}
\]

- Auxiliary Differential Equation technique for the conductivity’s dispersive character. Setting \(\sigma = \sigma(1+j\omega)\), \(J\) fulfills:

\[
J = \sigma E = \sigma E_0 \Rightarrow J = \sigma E_0 / (1+j\omega) \Rightarrow J_{1,2} = \frac{2\Delta t}{\Delta x} \left( \frac{\sigma E_0}{\omega^2 + \mu_c^2} \right) \left( \frac{\omega}{\omega^2 + \mu_c^2} \right)
\]

**Verification of the proposed scheme**

- Simulation of structures of infinite size and validation of the simulation results via the verification of closed form results.

**Simulation Results**

**Comparison with the subcell technique [13], [16].**

- Field in space in representative time step

**REFERENCES**


