Investigating Plasmon Transport Properties in a Graphene Interface

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This project investigates surface plasmons in graphene systems. Surface plasmons are electromagnetic waves resulting from free surface charge oscillation. Graphene is a two-dimensional material with many interesting properties. It can sustain surface plasmons with frequencies in the terahertz (THz) range. The THz portion of the electro-magnetic spectrum lies between the optical and electronic portions, making it difficult to make THz sources and detectors. The goal of this project is to obtain the plasmon dispersion relation and velocity for different graphene based systems. The dispersion relation gives the plasmon's frequency as a function of its wave vector. To theoretically obtain this relation, Maxwell's equations are used, applying boundary conditions along each interface. The velocity is obtained by taking the derivative of the plasmon frequency with respect to wave vector. This work is a simplified method of the findings of E. H. Hwang, *et al*.[1] for a double interface, and also models the metal-graphene system from the experiment by Kumada, *et al*.[2]. The dispersion relation and group velocity were found for single, double, and triple layer graphene interfaces, and for the metal-graphene system. In the latter, we find that the calculated velocity obtained is significantly higher than in the experiment[2]. The triple layer graphene interface and the constant solution for the metal-graphene system are newly observed. The findings of high velocity plasmons in graphene allows for applications for signal transmission. This work demonstrates that systems with multiple graphene interfaces can be used to tune the frequency range of the plasmons.

References:

[1] E. H. Hwang, et al, PRB **80**, 205405 (2009).
[2] N.Kumada, et.al. New J. Phys., 063055 (2014).

Plasmon Properties in Graphene Interfaces

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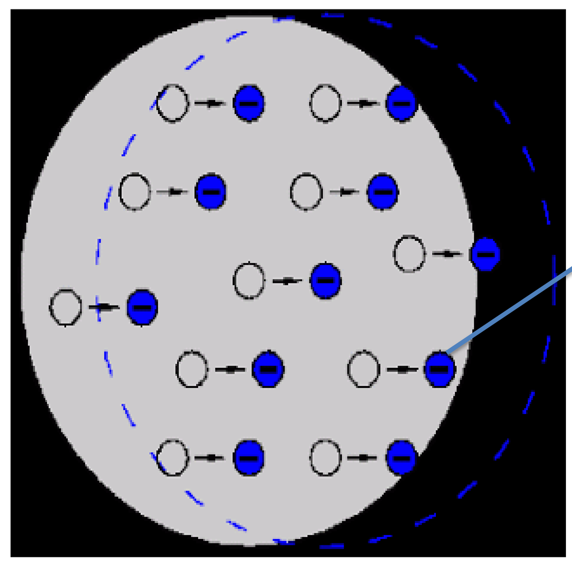
Introduction



Electrons oscillate collectively to form a plasmon

Motivation:

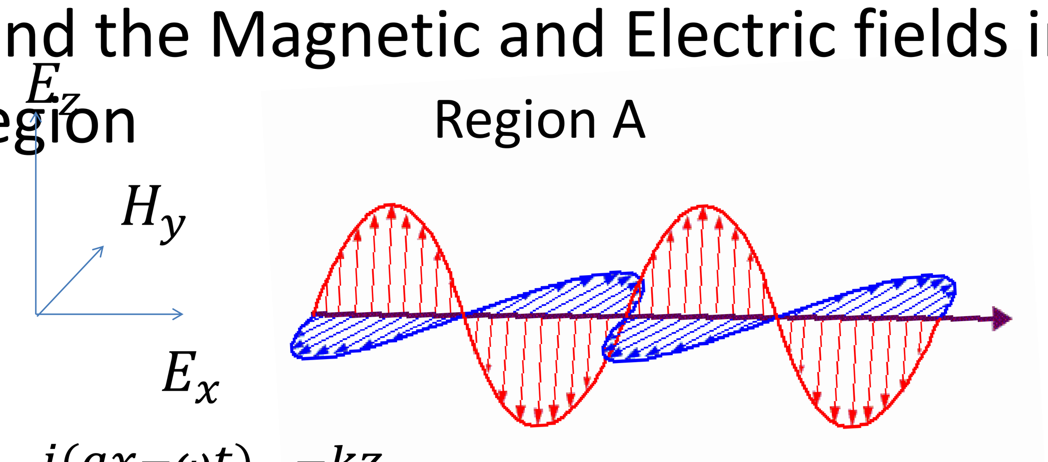
Plasmons are an useful in applications of information transfer and signal transport.

Objective:

To theoretically investigate plasmon properties in single, double, and triple interface system of graphene, as well as for a graphene-metal interface

Method

1. Maxwell's Equations in the Transverse Magnetic Mode
   - Use Faraday's Law and Ampere's Law
   - Find the Magnetic and Electric fields in each region



Current Density

$J = \sigma_D E_x$

$E, H \sim e^{i(qx-\omega t)} e^{-kz}$

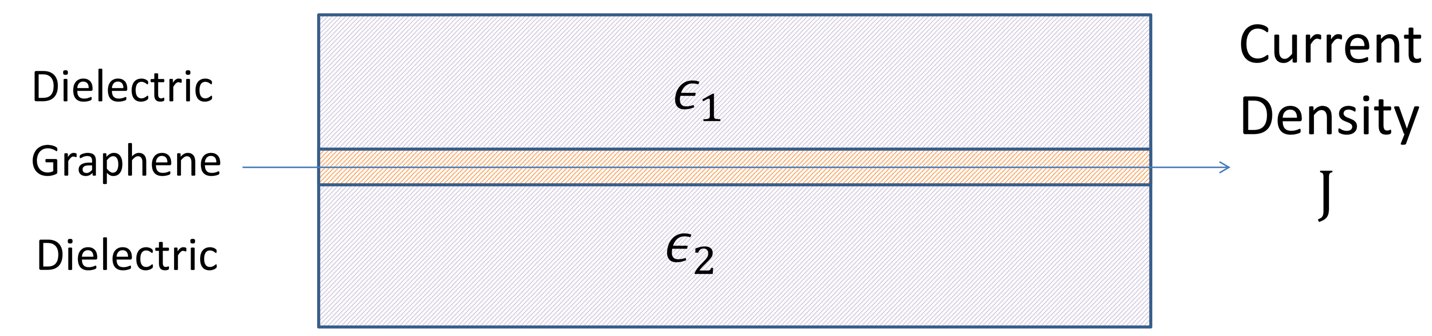
$\frac{1}{i\omega\epsilon_0\epsilon}\frac{\partial}{\partial z}H_y = E_x$

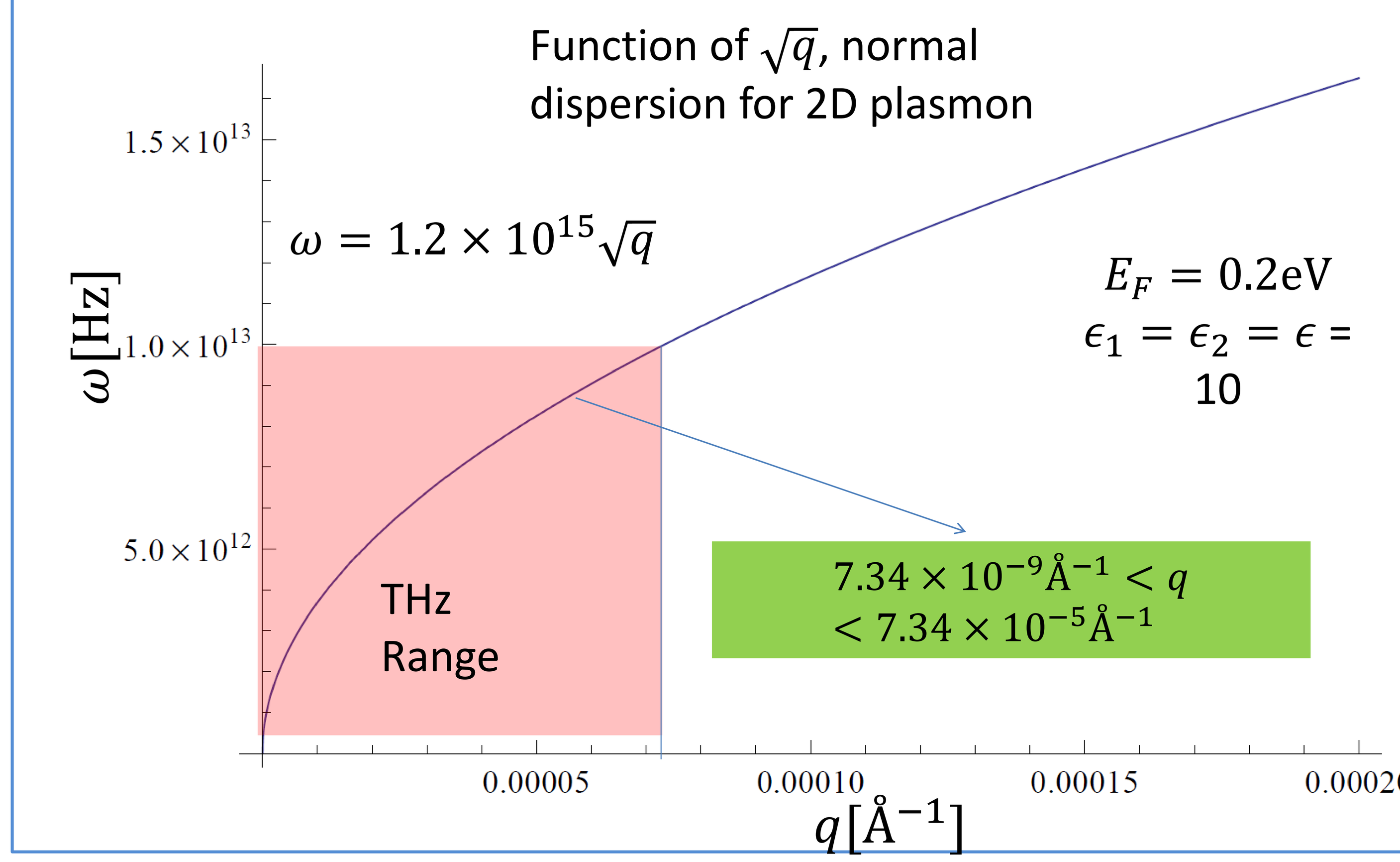
$q = \frac{2\pi}{\lambda}$

2. Use the boundary conditions at each interface to solve for $\omega(q)$, and approximate $k \approx q$ for small q
   - $E_x^{(1)} = E_x^{(2)}$,
   - $H_y^{(1)} - H_y^{(2)} = -\sigma_D E_x$
3. Take $\frac{\partial\omega}{\partial q}$ to find velocity

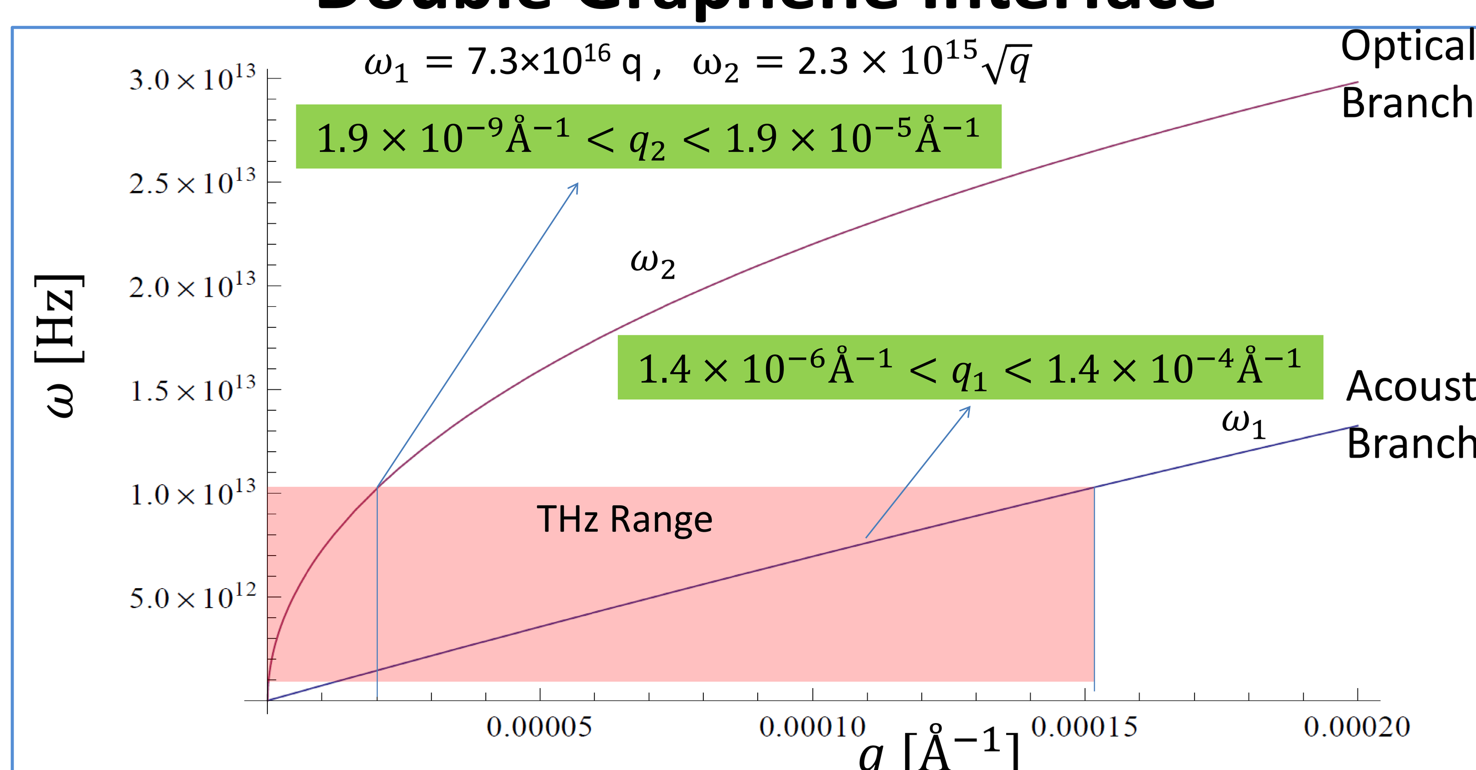
Results & Discussion

Single Graphene Interface





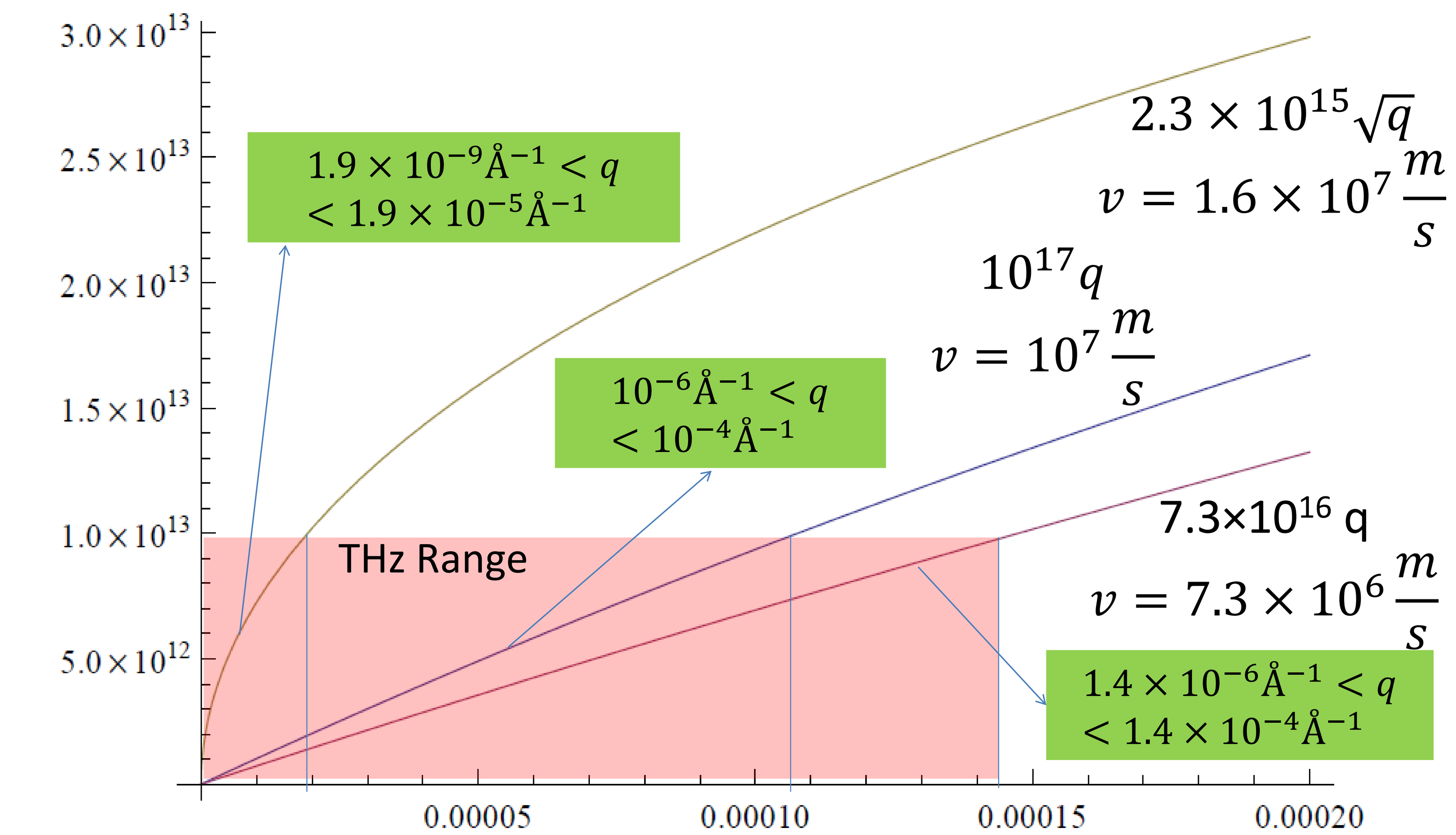
Double Graphene Interface



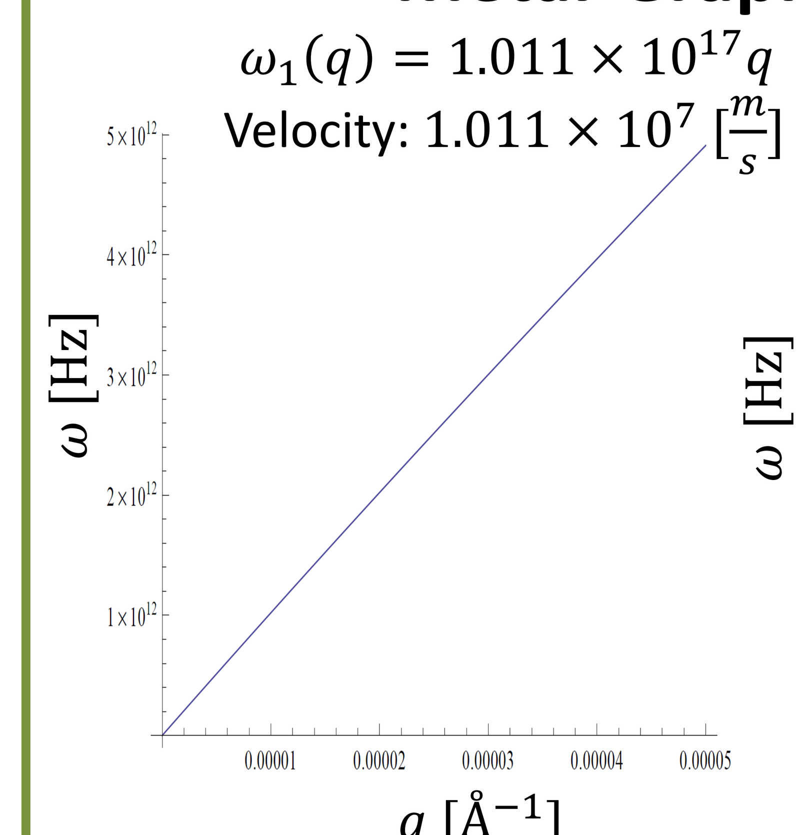
Comparison

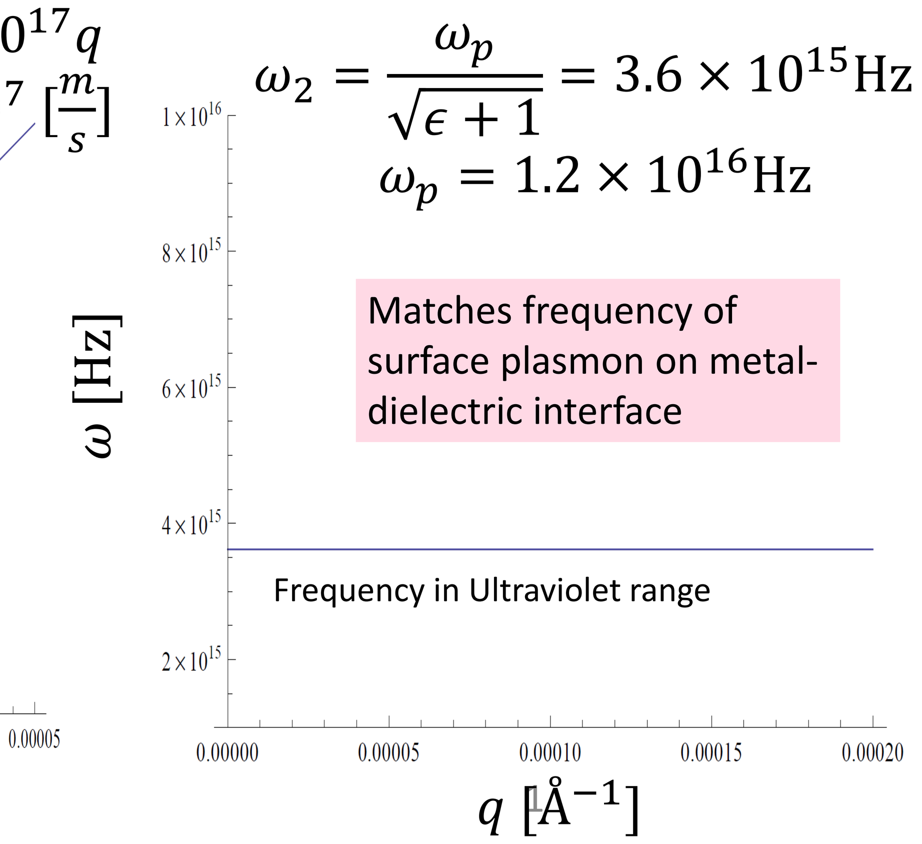
	Single Graphene Interface	Graphene-Graphene System
Dispersion Function	$\propto \sqrt{q}$	Acoustic branch: $\propto q$ Optical branch: $\propto \sqrt{q}$
THz Range q $[Å^{-1}]$	$7.34 \times 10^{-9} < q < 7.34 \times 10^{-5}$	Acoustic: $1.371 \times 10^{-6} < q_1 < 1.371 \times 10^{-4}$ Optical: $1.881 \times 10^{-9} < q_2 < 1.881 \times 10^{-5}$
V [m/s] For $q = 10^{-5}$ $[Å^{-1}]$	$v \sim 1.85 \times 10^7$	Acoustic: $v_1 \sim 7.29262 \times 10^6$ Optical: $v_2 \sim 3.6 \times 10^7$

Triple Graphene Interface



Metal-Graphene Interface





Conclusion

- Plasmons in all graphene systems were found to be able to transmit in the Terahertz range.
- The double and triple graphene interfaces offer ranges for plasmon wavevector values both above and below values for the single interface system.
- In experiments, the values for the velocity of plasmons in the metal graphene interface were lower than expected.

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