Dependency of Cylindrical Surface Interaction and Excitation on Modal Frequency

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Abstract - *Extensive research has found nano-particles, for many years subject of unanimous concern because of their anomalous electromagnetic properties originating from the resonant interaction between light and collective conduction electron oscillations so called surface Plasmons. These properties in particular local electric field enhancements enable applications such as single molecule detection using surface enhanced Raman scattering and the synthesis of composite materials exhibiting an enhanced nonlinear optical response. Since all these applications rely on the resonant behavior of localized surface Plasmons, they are restricted to a limited frequency range determined by the dielectric function of the involved media, the size and shape of the particles and the electromagnetic interaction between them. Thus those properties of the Plasmons and Polaritons on the Carbon Nanotube have been studied in different size with help of theoretical study. The surface frequency of Plasmon varies with propagation constant on the surface of Carbon Nanotube when it is placed in dielectric medium, so this new property of Carbon Nanotube have been seen in other dielectric medium. This property of surface Plasmon can be used in telecommunication, satellite media, biomedical sciences etc.*

Key Words: cnt's optical response, plasmons, polaritons.

1.INTRODUCTION

Surface plasmon and polariton i.e. the light-driven collective oscillation of electrons provide the foundation for various applications ranging from meta-materials, plasmonics, photo-catalysis to biological sensing [1]. Owing to the two dimensional (2D) feature of the excitations, plasmon polariton supported by graphene are of particular interest [2–4]. Tight mode confinement, long propagation distance, and remarkable electrostatic tunability of graphene plasmon polariton lead to new applications for waveguides, modulators and super-lenses. [5] [6] [7]. Plasmon polariton in a graphene sheet can be excited by advanced near-field scattering microscopy [3, 4], dielectric sub-wavelength grating coupler [8, 9], or nanoscale patterning [10–14], while the dispersion of graphene plasmons may be influenced by the interaction of electrons and the surface optical phonons of the polar substrate [15–17]. Using angle-resolved reflection electron-energy-loss spectroscopy, strong plasmon-phonon coupling has been confirmed in epitaxial graphene placed on the silicon carbide substrate [18].

2. Surface optical phonon frequency

An infinitely long cylindrical wire of polar semiconductor of radius R in which Z-axis coincides with the axis of the cylinder surrounded by a non-dispersive medium of dielectric constant ε_2 where the free electron concentration n_0 must satisfy the condition

$$n_0(\bar{r}) = n_0 \qquad r<R$$
$$= 0 \qquad r>R \qquad (1.1)$$

To solve the differential equation

$$\left[\nabla^2 - \alpha^2\right] n_1(\bar{r}) = 0 \qquad (1.2)$$

Let the solution be

$$n_1(r) = \sum_l n_l(\bar{r}) Y_l(\theta) e^{i(k.r-\omega t)} \qquad \text{for } k\neq 0$$

(1.3)

Eq. (1.2) can be written after putting the value of $n_l(r)$ from eq. (1.3)

Where
$$\alpha^2 = \frac{1}{\beta^2}\left[\omega_p^2 - \omega^2\right]$$

For cylindrical Harmonics

$$\nabla^2 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\left(\frac{\partial^2}{\partial \theta^2}\right) + \left(\frac{\partial^2}{\partial z^2}\right) \qquad (1.4)$$

Substituting the value of ∇^2 in equation (1.2), we get

$$\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right) + \frac{1}{r^2}\left(\frac{\partial^2}{\partial \theta^2}\right) + \left(\frac{\partial^2}{\partial z^2}\right) - \alpha^2\right] n_1(\bar{r}) = 0$$

Taking z as constant for cylindrical surface

$$\frac{\partial^2}{\partial z^2}.n_1(r) = 0$$

$$\left[\frac{1}{r}\left\{r\frac{\partial^2}{\partial r^2} + \frac{\partial}{\partial r}\right\} + \frac{1}{r^2}\left(\frac{\partial^2}{\partial \theta^2}\right) - \alpha^2\right]\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)} = 0$$

$$\left(\frac{\partial^2}{\partial r^2} + \frac{1}{r}\frac{\partial}{\partial r}\right)\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)} + \frac{1}{r^2}\left(\frac{\partial^2}{\partial \theta^2}\right)\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}$$
$$-\alpha^2\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)} = 0$$

$$\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}-\alpha^2\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}$$

$$=-\frac{1}{r^2}\left(\frac{\partial^2}{\partial\theta^2}\right)\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}$$

$$\left[\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}\right)-\alpha^2\right]\sum_l n_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}$$

$$=-\frac{1}{r^2}\left(\frac{\partial^2}{\partial\theta^2}\right)\sum_l N_l(\bar{r})Y_l(\theta)e^{i(k.r-\omega t)}$$

Further simplifying for 1 mode we have

$$\begin{bmatrix}\frac{\partial^2}{\partial r^2}N_l(r)+2ik\frac{\partial}{\partial r}N_l(r)-k^2N_l(r)\\ +\frac{1}{r}\left\{\frac{\partial}{\partial r}N_l(r)+ikN_l(r)\right\}-\left(\alpha^2+\frac{l^2}{r^2}\right)N_l(r)\end{bmatrix}e^{i(k.r-\omega t)}=0$$

a
nd also with boundary conditions

$$\frac{\varepsilon_2 l}{pR}\mathrm{I}_l(pR)=\left[\left(\frac{\omega^2}{\omega_p^2}\right)(\varepsilon_1+\varepsilon_2)-\varepsilon_1-\frac{\beta^2k^2}{\omega_p^2}(\varepsilon_1+\varepsilon_2)\right]\mathrm{I}_l^{'}(pR)$$

Which is required dispersion relation for two mode coupling for $k\neq 0$ for l mode

If we put $k=0$ in above, we get

$$\frac{\varepsilon_2 l}{\alpha R}\mathrm{I}_l(\alpha R)=\left[\left(\frac{\omega^2}{\omega_p^2}\right)(\varepsilon_1+\varepsilon_2)-\varepsilon_1\right]\mathrm{I}_l^{'}(\alpha R)$$

(1.4)

If the spatial dispersion relation is neglected, i.e. we neglect the finite speed of propagation of hydrodynamic disturbance β, the eq^n reduces to

$$(\varepsilon_1+\varepsilon_2)\left(\frac{\omega^2}{\omega_p^2}\right)-\varepsilon_1-\frac{\beta^2k^2}{\omega_p^2}(\varepsilon_1+\varepsilon_2)=0$$

Surface optical phonon frequency can take the form

$$\left(\frac{\omega_{SOP}}{\omega_t}\right)^2=\left(\frac{\varepsilon_0+\varepsilon_2}{\varepsilon_\infty+\varepsilon_2}\right) \quad (1.5)$$

Graphs between $\left(\frac{\omega_{SP}}{\omega_t}\right)$ Vs k for carbon in different medium are plotted for various values of R with

Given $\left(\frac{\omega_{SP}}{\omega_t}\right)^2$ =1.54412

$\bar{\varepsilon}$ =5.5

ε_2 =1 for Vacuum medium

$$\omega_t=25.1\times10^{13}\sec^{-1}$$

$$\beta=1.618690\times10^{14}\ \overset{0}{\mathrm{A}}\sec$$

Here $p^2=\alpha^2+k^2$

$$\alpha=\frac{\omega_p}{\beta}\left(1-\frac{\omega^2}{\omega_p^2}\right)^{1/2}=\frac{2.40011\times10^{16}}{1.61890\times10^{16}}\left[1-(0.58044)^2\right]^{1/2}$$

=1.207245

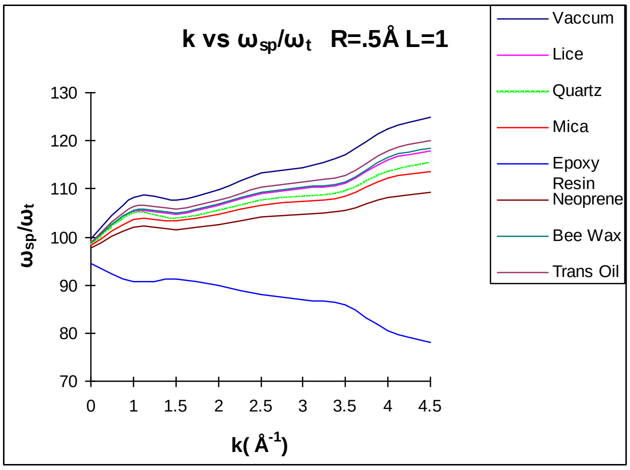
$$\alpha^2=\frac{\omega_p^2}{\beta^2}\left(1-\frac{\omega^2}{\omega_p^2}\right)$$ =1.45744

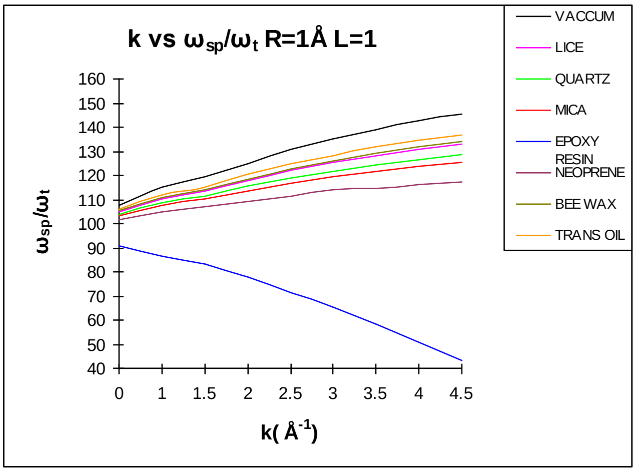
$$p^2=\frac{\omega_p^2}{\beta^2}\left(1-\frac{\omega^2}{\omega_p^2}\right)+k^2$$

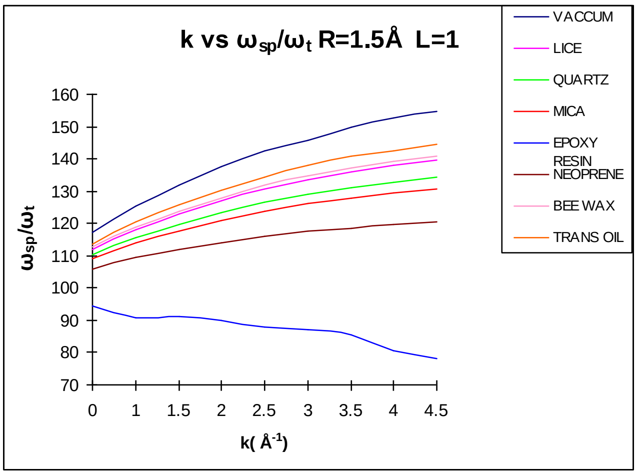
$$\omega_p=2.40011\times10^{16}\sec^{-1}$$

$$\beta=1.61890\times10^{16}\ \overset{0}{\mathrm{A}}\sec^{-1}$$

The following graphs depicts that cnts are restricted to some limited frequencies of EMWs.







3. RESULTS AND CONCLUSIONS

It shows clearly that carbon nanotubes are placed in different medium. The surface plasmon frequency varies with propagation constant k. It predicts Epoxy resin is such a medium in which surface plasmon frequency decreases less than other medium with respect to propagation constant k (Å^{-1}) because epoxy resin is insulated medium so there are no electron clouds in epoxy resin as EM wave incident on the CNT. Surface plasmon frequency increases but not so fast than other medium. It is also clear that for low value of k ω_{sp} is almost linear but as value of k increases ω_{sp} almost decreases. At very high value of k ω_p almost decreases. On the other hand for medium lice and bee wax graph is exactly similar. This shows that both medium behaves as one single medium only for ω_{sp} with respect to the propagation constant k. there are very large variation in surface plasmon frequency with respect to the variation of propagation k.
Therefore dispersion relation gives important information about surface of spherical polar semiconductor i.e. like filtering properties, a band attenuation high band gap& low band gap.

The study serves a purpose for researchers and scientists to explore the material behavior exposed to electromagnetic radiation.

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BIOGRAPHIES

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