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Excitation of SPW at the Thin Film of Nano Substances

Daya Shanker and Pradeep Kumar Sharma
Department of Physics, University of Lucknow
Lucknow, 226007, UP, India
Email: dayashanker2769@yahoo.co.in

Ashok Kumar Singh
Department of Chemistry, University of Lucknow
Lucknow, 226007, UP, India

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Abstract: Surface Plasma wave (SPW) is sensitive probe of optical properties of cylindrical surfaces of Nano substances. The purpose of these reports is to demonstrate the use of SPW to study the reflective, absorptive properties of nano size substances like Carbon, InAs, GaAS and Ge by deriving the spatial dispersion relation for three modes coupling with the help of computational methods. This study is important in electronic communication, medical sciences and computer applications.

Keyword: Surface plasma waves, nano substances and computational methods.

1. Introduction

Surface plasma waves are electromagnetic modes localized at the interface between two media with permittivity of opposite sign such as those formed by a dielectric and the other material. Phonon and SPW couple each other under certain conditions at the inter surfaces of substances. Localized Plasmon's modes are responsible for the variation of reflective and absorptive properties of substances[1, 2] and propagating surface. Plasmon's modes in the inter surfaces are the cause of strong angular dependence of the films reflectivity when measured under specific conditions[3]. Also nano material films show an enhanced optical transmission due to the excitation of surface Plasmon modes[4]. Carbon nanotubes have remarkable electrical and mechanical properties. Collective electron excitation in a carbon nano tube can provide important information about its structural and electronic properties. Using electron energy loss spectroscopy, Pichler et al[5] experimentally studied the electron excitations in single walled carbon nanotube and measured the Plasmon energy. In recent years, many experimental and theoretical works have been done to study high frequencies excitation by Fetter[6] using a simple Hydrodynamic model. Wei and Wang[7] studied the dispersion relation of acoustic wave oscillations in single walled carbon nanotube with modified hydrodynamic model, which was developed by Hassetal[8, 9].

The hydrodynamic model is used to find the spatial dispersion relation of two mode coupling between surface Plasmon and phonon on the cylindrical surfaces of carbon, Si, InAs, GaAs and Ge surfaces at Nano scale radius. This dispersion relation for two mode coupling gives most important physical properties of surface of substances and materials in dielectric surroundings. This coupling SP-SOP mode depends upon frequency and wave vector of carbon and other nano materials on the cylindrical surfaces[10]. The another derived spatial dispersion relation for three modes coupling (surface Plasmon, polariton and phonon) at cylindrical surfaces at nano size radius for carbon, Ge, SiC materials which is given as

(1)
$$
\begin{aligned}
& R X_l^{'}(\gamma k r)\left[\varepsilon_\infty(k\omega)\Omega^2 - \varepsilon_0(k\omega)\frac{\omega_t^2}{\omega_p^2}\right] \\
& \times\bar{\varepsilon}(k\omega)\left[\Omega^2 - \frac{\omega_t^2}{\omega_p^2} - \left(\varepsilon_\infty(k\omega)\Omega^2\right) - \varepsilon_0(k\omega)\frac{\omega_t^2}{\omega_p^2}\Omega^2\right] \\
& \times Y_l(\alpha k R).(R Z_l(\delta k R))^{'} + \left(\Omega^2 - \frac{\omega_t^2}{\omega_p^2}\right)\Omega^2\varepsilon_B\left[(R Y_l(\alpha k R))^{'} Z_l(\delta k R)\right] \\
& -\left(\Omega^2 - \frac{\omega_t^2}{\omega_p^2}\right) l^2\,\bar{\varepsilon}(k\omega)\varepsilon_B(k\omega) X_l(\gamma k R) Y_l(\alpha k R).Z_l(\delta k R) = 0
\end{aligned}
$$

where X_l, Y_l & Z_l are solutions of Bessel's differential equations and X_l^1, Y_l^1 & Z_l^1 are derivatives of X_l, Y_l & Z_l which is function of α, β, γ, δ and radius of cylinders ω_t & ω_p are frequencies of transverse wave (phonons) & plasmons on the surface of cylinders, Ω is frequency ratio of transverse wave and polariton waves, ε_0 ε_∞ & ε_B are the dielectric constants for lower frequency, higher frequency and Bulk dielectric medium respectively and $\varepsilon=(\varepsilon_0+\varepsilon_\infty)/2$ is average medium between interfaces. Now if radius of cylinder is taken as infinity then eq. (1) become as

(2)
$$\Omega^6\left(\frac{\omega_p}{\omega_t}\right)^2\varepsilon_\infty-\left[\varepsilon_0+\{\bar{\varepsilon}+(1+\varepsilon_\infty)k^2\}\left(\frac{\omega_p}{\omega_t}\right)^2\right]\Omega^4$$
$$+\left[\left\{(1+\varepsilon_0)+\bar{\varepsilon}\left(\frac{\omega_p}{\omega_t}\right)^2\right\}k^2+\bar{\varepsilon}\right]\Omega^2-\bar{\varepsilon}k^2=0\,.$$

Eq. (2) is cubic in Ω^2, and when omega vs. k is plotted for C, SiC, InAs, Ge and GaAs (fig 5.9-5.13), three coupled modes are obtained. The uncoupled modes are obtained. The uncoupled pure plasmon, pure optical phonon and photon modes have also been plotted. The uncoupled pure surface plasmon mode may be obtained from eq. (2) by taking the contribution due to phonons and photons to be zero, i.e. by taking ω_t =0 and $k\rightarrow 0$, so that the dispersion relation (2) reduces to:

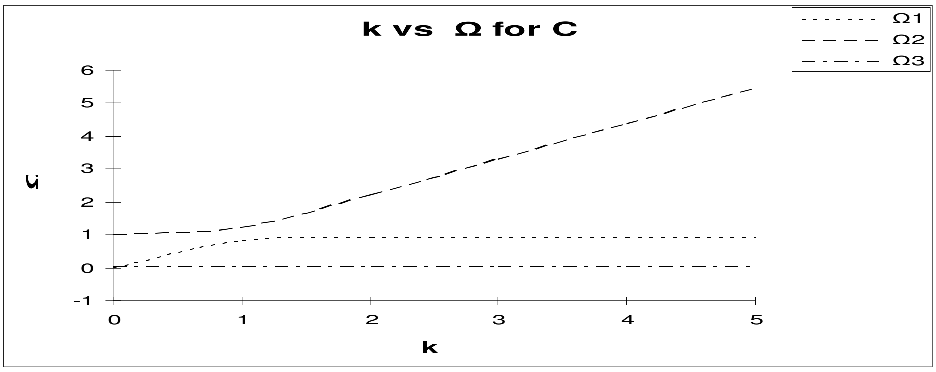
(3)
$$\Omega=\sqrt{\frac{\bar{\varepsilon}}{(1+\varepsilon_\infty)}}.$$

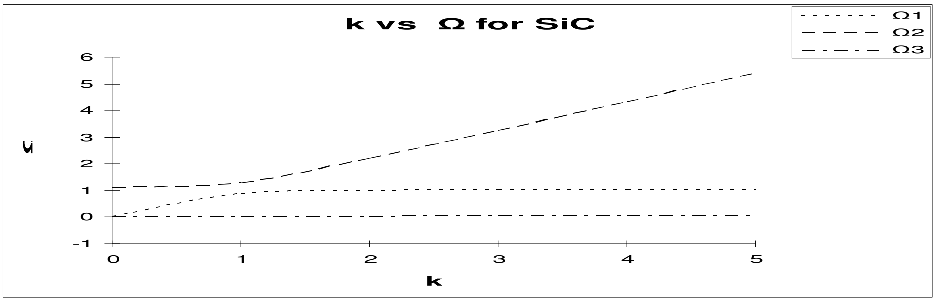
Similarly, the pure surface optical phonon mode is obtained by taking ω_P=0 and $k\rightarrow\infty$, so that eq. (2) reduces to:

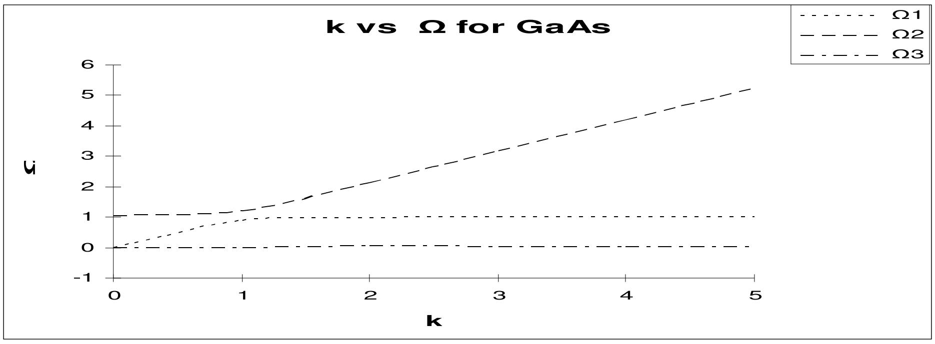
(4)
$$\Omega=\sqrt{\frac{(1+\varepsilon_0)}{(1+\varepsilon_\infty)}\left(\frac{\omega_t}{\omega_p}\right)}.$$

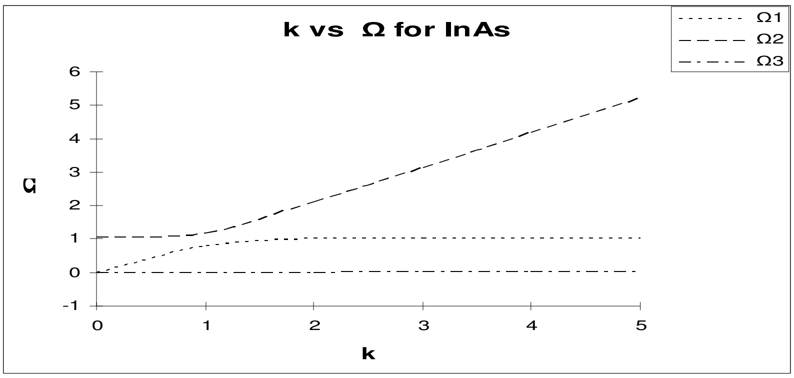
Pure photon mode is obtained by ω_P=0, as well as ω_t =0, and is given by:

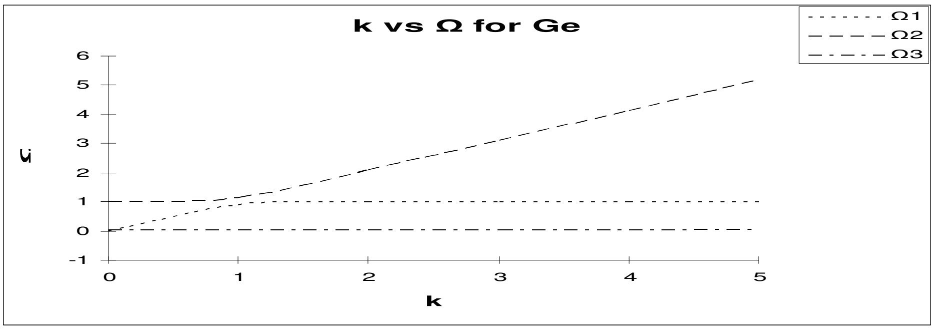
(5)
$$\Omega=\sqrt{\frac{(1+\varepsilon_\infty)}{\varepsilon_\infty}}k\,.$$


k vs Ω for C
Ω1
Ω2
Ω3
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
k


k vs Ω for SiC
Ω1
Ω2
Ω3
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
k


k vs Ω for GaAs
Ω1
Ω2
Ω3
6
5
4
3
2
1
0
-1
0
1
2
3
4
5
k


k vs Ω for InAs
Ω1
Ω2
Ω3
6
5
4
3
2
1
0
-1
Ω
0
1
2
3
4
5
k



Results for three mode coupling length on cylindrical type of semiconductor are given below:

Material	Coupling length Å	$\Delta\omega=\omega_1-\omega_2$
C	5.71948	1.02329
SiC	6.28571	.960566
InAs	6.28571	.92913
GaAs	5.802376	.734888
Ge	5.3187631	.603783

The above figures shows that for high values of wave vector, the coupled surface polariton modes tends to constant values

$$\Omega_1 = .0062 \text{ and } \Omega_2 = 1.102921,$$
$$\Omega_1 = .01544 \text{ and } \Omega_2 = .9999,$$
$$\Omega_1 = .00237 \text{ and } \Omega_2 = .9999,$$
$$\Omega_1 = .0017082 \text{ and } \Omega_2 = 1.05151,$$
$$\Omega_1 = .002125 \text{ and } \Omega_2 = 1.044866$$

for, C, SiC, InAs, GaAs and Ga respectively. At these frequency $n^2 \to \infty$, and $\varepsilon(\Omega)$. This is a condition of resonance, and at these points, the incident E.M. wave frequency matches exactly with the frequencies of coupled surface polariton mode of nano-substances. As a result, the total incident E. M. energy is propagated along the surface as surface polariton waves and no light is reflected or transmitted through the medium for above frequencies of substances. For the frequencies for which $\varepsilon(\Omega)$ lies between '-1' and '0', and hence the refractive index 'n' becomes imaginary then all the incident energy is reflected back into surrounding medium. For $\varepsilon(\Omega)$ $n^2 < 1$, the radiative Brewster mode is satisfied. This condition is satisfied for frequency region between $\Omega = .0062$ and $\Omega = .503231$, $\Omega = .01544$ and

$\Omega = .4508225$, $\Omega = .00237$ and $\Omega = .480613$, $\Omega = .0017082$ and $\Omega = .396685$, $\Omega = .002125$ and $\Omega = .4402471$ for C, SiC, InAs, GaAs and Ga respectively and $\Omega > 1.102921$, $\Omega > .9999$, $\Omega > .9999$, $\Omega > 1.05151$ and $\Omega > 1.044866$ for C, SiC, InAs, GaAs and Ga respectively. For these frequencies, the incident energy can be filtered or transmitted through the medium. Thus, it is clear that as a result of the simultaneous existence of surface plasmons and surface optical phonons, which lead to coupled surface plasmon-phonon-polariton modes, the polar semiconductor medium act as a band pass filter and as a high pass filter for incident E.M. wave. It is clear that for particular frequency, substances become active for devices and deactive for other frequencies. This is useful in medical sciences, saying important documents in electronic devices and computer components and other devices.

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