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Study Of Absorption Characteristics Of Electro Kinetic Waves In Material With High Dielectric Constant

Shivani Saxena[1], Sanjay Dixit[2], Sanjay Srivastava[3]
[1] *Depatment of Physics ,Govt. M.V.M College , 24-khanuja enclave , Bhopal, India*
[2] *Department of physics , Govt. M.V.M College Siwaji nagar , Bhopal, India*
[3]*Department of Material Science &Metallurgical Engineering , MANIT Mata mandir ,Bhopal , India*

Abstract: *The main objective of the paper is to discuss the amplitude modulation and demodulation of the electromagnetic wave in the presence of high dielectric constant. The high dielectric constant in PZT materials is developed by the substitution of suitable doping element either at A+ sites or B sites in ABO_3 crystal structure. The high dielectric constant of the material is due to the presence of stain in the existing lattice, known as strain dependent dielectric constant (SDDC). Amplitude modulation as well as demodulation of the electromagnetic wave in a transversely magnetized material taking SDDC is analyzed in different magneto-static field at the different applied electric field. For the numerical analysis, $Pb(Zr,Ti)O_3$ is selected which is irradiated by a pump wave of frequency $\Omega o=1.78*10^{14}$ sec^{-1} with dielectric constant ε =3450. It has been observed that the total absorption of the waves takes place in all the wavelength regimes when the cyclotron frequency Ωc becomes exactly equal to* $\Omega_c = \left(\Omega_0^2 + \nu^2\right)^{1/2}$

Keywords*: HDM, CMT, HDC, CO_2, plasma effects.*

I. Introduction

Modulation of the propagating electromagnetic waves has been considerable interest since the origin of physical optics with its concentration on diffraction and wave guiding. The modulation of electromagnetic wave is used in number of potential applications involving the display and processing of information onto optical pulses, mode-locking, optical beam deflection [1]. The modulation of an electromagnetic wave propagating through plasma is because of the periodic changes of the propagation parameters. The propagation of the electromagnetic wave in strain dependence of dielectric constant (SDDC) is accompanied by the appearance of a strong electromechanical coupling proportional to the square of field strength. The elastic anisotropy and piezoelectric effect are caused by electron-phonon interaction [2]. It must be converted to amplitude modulation to record phase variation. Modulated magnetic field, demodulation of power in an R.F. discharge or the propagation of an acoustic wave may cause periodic variation in the propagating parameters caused by the time varying changes in the carrier density as well as collision frequency of the plasma. The electro-optic (EO) and acousto-optic (AO) effects is a convenient methods for controlling the intensity and/or phase of the propagating waves [3]. Modulated magnetic field, demodulation of power in an R.F. discharge or the propagation of an acoustic wave may cause periodic variation in the propagating parameters caused by the time varying changes in the carrier density as well as collision frequency of the plasma. Nimje et al., [4] used hydrodynamic model of semiconductor plasma for explaining amplitude modulation as well as demodulation of an electromagnetic wave by using of hot carriers in magnetised diffusive semiconductor plasmas. The wide range of cyclotron frequency was used to optimize the basic problem of the propagation in different wave number regime. The semiconductor technology is generally based on the high mobility of excited charge carriers through diffusion processes. Hence the diffusion of carrier shows the strong influence on the nonlinearity of high mobility III-V compounds semiconductor [5]. Mishra and Jha [6] et al reported the growth analysis of modulation instability of a laser pulse propagating in a clustered gas. The growth rate of modulation instability can be changed from the front as well as at the back of the pulse which is also compared with centroid of the pulse for 80fs to 100fs pulse. The interaction of the modulational between transverse plasmons and derived ion-acoustic wave is observed due to propagation of incident laser beam through plasma. It gives the nonlinear shift in the plasma frequency in such way the modulation instability arises from the modulation of the amplitudes waves which affects the growth rate of the instability. The modulation instability is directly proportional to the finite amplitude of the pump wave. Amplitude modulation is one of the oldest forms of modulation its efficiency can either equal or better that of other modulation process if utilized to best advantage. In many complex modulation schemes amplitude modulation is commonly a preliminary step. The carrier and both side band a transmitted by AM type of system. At low power output this often gives maximum economy and simplicity. There are several reports on amplitude modulation and demodulation in gaseous and solid state plasma has been studied by a number of workers [7, 8]. The modulational instability from the propagation of a circularly polarized electromagnetic wave was investigated from Pajouh along an external constant magnetic field [9]. The solution is derived from nonlinear Schrodinger equation associated with trapped electrons and also considered the relativistic effect of electron in velocity. Cattaert et al [10] reconsidered again the amplitude modulation of circularly polarized electromagnetic (CPEM) in a magnetic aligned filed. By considering the repulsive interaction potentials, the dynamics of the modulated wave was again solved by using the nonlinear Schrödinger equation. In the above given theories of amplitude modulation effects, the dielectric constant of material is constant. But it is known fact that such an assumption is not justified for materials with high dielectric constant.

Ghosh [11-12] reported the modulation and demodulation of the acousto-optic amplitude in magnetised diffusive semiconductors materials by using hydro dynamical model. The inclusion of carriers plays the dominant role for the diffusion of the plasma waves. They reported the different wave number over wide range of cyclotron frequency. The complete absorption of the electromagnetic wave takes place when the cyclotron frequency ω_c becomes exactly equal to $(v^2+\omega_c^2)^{1/2}$. Jat [13] reported the study of the Stimulated Brillouin Scattering in n-InSb materials by applying the magnetic field. The third-order optical susceptibility is developed due to arise from the nonlinear current density and acousto-optical strain of the medium. Nimje et al.,[14] studied the modulation and demodulation in diffusive semiconductor plasmas. For numerical estimations III–V semiconductor crystal were irradiated by pump wave of frequency $1.6\text{x}10^{13}\,s^{-1}$.
Motivated from the above discussion, in the present article we have tried to present an analytical approaches on absorption of characteristics of electro kinetic waves in a strain dependent the high dielectric plasma medium in the presence of the excess charge carriers. Like other class of the of piezoelectric and ferroelectric materials, the lattice of Lead zirconate titanate (PZT) can be affected by the nature of the solvent and the concentration of the dopant materials. An anharmonicities in the interatomic potential any materials arises from the phonon scattering which result from from three phonon interactions. Tetragonal $PbTiO_3$ having large strain (c/a=1.06) exhibits ferroelectric even at high temperatures and by changing the crystals structure from a single cubic to tetragonal transition. The dopant such as La^{3+}, Nb^{5+}, Ce^{3+} and Ta^{5+} are the donor dopant which makes the PZT as a soft, and the other doapnt like such as K^+, Na^+, Sc^{3+} and Fe^{3+} behaves like as a acceptor dopant which produce the hard PZT. The domain wall easily moves in due to presence of soft dopant in PZT, and showing the better properties than the PZT [15].

Therefore it can be used to control the properties of the PZT material. In addition to this, the dopant affects the crystal lattice and also affects the optical and dielectric properties of the piezoelectric and ferroelectric materials. This is due to the development of the strain in the Perovskites lattice. The slow relaxation processes are affected by the operating temperature above at glass transition. The lattice vibration in PZT materials is due to local softening of transverse-optical phonon branch that prevents the propagation of long-wavelength (q = 0) phonons. In crystalline solid, the transport of the phonon is related with phonon mean free path and speed which is calculated by using a relaxation time, τ, i.e., $\tau = \frac{\lambda}{u}$. The relaxation time depends upon the frequency, temperature and/ or lattice parameter of the crystalline solid which affects the different scattering mechanisms (e.g., due to presence of defects, at grain boundaries, three phonon interactions). From the gas kinetic theory, the thermal conductivity k can be expressed by the following equation:

$$\kappa = \frac{1}{3}u^2 \int_0^{T_D/T} \tau(x)C(x)\,dx,$$

Where C(x) and x given by the following expression: $C(x) = \frac{3k_B}{2\pi^2 u^3}\left(\frac{k_B}{\hbar}\right)^3 T^3 \frac{x^4 e^x}{\left(e^x-1\right)^2}$ and

$x = \frac{\hbar\omega}{k_B T}$. Lattice strain is measured in terms of the crystal imperfections which arise from lattice dislocations due to different ionic radii of dopants and the matrix ions [16]. Due to presence of the mismatching in the crystal lattice and the proper development of the collective polar dipole moment of the metal ions with respect to the oxygen sublattice in the Perovskites structure, PZT material shows large ε, which develops highly nonlinear and anisotropic nature in the material.

II. Theoretical Formulation

For this calculation, we use the hydro dynamical model of homogeneous, non degenerate, PZT crystal, subjected to a transverse dc magnetic field (along x-axis) normal to the propagation vectors of the acoustic (k_s) and the pump (k_0) waves (along Z-axis). The low frequency perturbations are assumed due to presence of acoustic wave ($k_s\ \Omega_s$) in the crystal. Due to the SDDC fields associated with the acoustic wave, the electron concentration oscillates at the acoustic frequency. The transverse current density at the frequencies Ω_0 and (Ω_0

$\pm \Omega_s$), where Ω_0 is the pump wave frequency is raised from the pump wave. These sideband current densities produce sideband electric field vectors and this way the pump wave gets modulated in the direction of the applied field. In this subsequent analysis, the sideband will be represented by the suffixes ±, where + stands for the mode propagating with the frequency ($\Omega_0 + \Omega_s$) and – for ($\Omega_0 - \Omega_s$). The equation of lattice dynamics is considered in order to find the perturbed current density. The equation governing the lattice displacements, in crystals with SDDC coupling, are

$$\rho \frac{\partial^2 u}{\partial t^2} = C \frac{\partial^2 u}{\partial z^2} - (\varepsilon_0 g E_0) \frac{\partial E}{\partial z} \tag{1}$$

$$\frac{\partial \mathrm{E}}{\partial z} = \frac{en}{\varepsilon_0} - \frac{(\varepsilon_0 g E_0)}{\varepsilon_0} \frac{\partial^2 u}{\partial z^2} \tag{2}$$

Where ρ and C are the mass density and elastic stiffness constant ,respectively ε_0 is the dielectric constant when the strain is zero and g is SDDC coupling constant which can be approximated $\varepsilon_0/3$ for crystals with $\varepsilon_0 > 1$. Using (1) and (2) one obtains the perturbed carrier concentration as

$$n = [\ \varepsilon_0 \rho u \{ \Omega_s^{\ 2} - k_s^{\ 2} v_s^{\ 2} (1 + S^2)\ \}\ ]\ [e(\varepsilon_0 g E_0)]^{-1} \tag{3}$$

In which Vs is the shear acoustic speed in the crystal lattice given by

$$V_s = (C/\rho)^{1/2}\, and\ S^2 = (\varepsilon_0 g E_0)^2 / C\varepsilon_0$$

The equation is the dimensionless coupling coefficient due to SDDC. The oscillatory electron fluid velocity in the presence of the pump electric field E_0 as well as that due to the fields of the sideband modes $E_\pm$ can be obtained by using the following electron momentum transfer equation

$$\frac{\partial \vec{V}_j}{\partial t} + (\vec{V}_j.\nabla)\vec{V}_j + \nu \vec{V}_j = (\frac{e}{m})(\vec{E}_j + \vec{V}_j \times \vec{B}_0) \tag{4}$$

Where the subscript j stands for 0 , + and - modes , m is the effective mass of the electrons and ν is the phenomenological electron collision frequency. Using (4), the velocity components can be obtained as

$$V_{j_z} = [(i\Omega_j + \nu) e E_j\ ]\ [\ m\{\Omega_c^{\ 2} + (i\Omega_j + \nu)^2\}\ ]^{-1} \tag{5}$$

$$V_{j_y} = [(+\Omega_c e E_j\ ]\ [\ m\{\Omega_c^{\ 2} + (i\Omega_j + \nu)^2\}\ ]^{-1} \tag{6}$$

In which $\Omega_c = (eB_0/m)$ is the electron cyclotron frequency. Here, we have assumed an $\exp[i(\Omega_j t - k_j z)]$ dependence of the filed quantities. The total transverse current density in the medium is given by

$$\vec{J}_{total} = e\ [\sum_j\ n_0 \vec{V}_j + \sum_j\ n\vec{V}_0 \exp[i\,(\Omega_j t - k_s z)] \tag{7}$$

Where $n V_0 \exp[i(\Omega_j t - k_j z)]$ represent the current generated due to the interaction of the pump wave with the acoustic wave (6) and (7) in the wave equation given by

$$\frac{\partial^2 \vec{E}}{\partial z^2} = \mu_0 \varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} - \mu_0 \frac{\partial \vec{J}_{total}}{\partial t} = 0 \tag{8}$$

One obtains

$$\frac{\vec{E}_\pm}{E_0} = \frac{-i\Omega_0 \mu_0 e u (i\Omega_0 + \nu)\,(\varepsilon_0 g E_0)\ k_s}{m\,[\ \Omega_c^{\ 2} + (i\Omega_0 + \nu)^2\ ]\quad (k_s \pm 2k)} (1 - \exp(\mp i k_s z) \tag{9}$$

By neglecting $\exp(\mp k_s z)$ in comparison to one and then rationalizing (9), one obtain the real part of it as

$$\frac{\vec{E}_{\pm}}{E_0} = \frac{\Omega_0{}^2 \mu_0 euk_s\ (\varepsilon_0 gE_0)\ (\Omega_c{}^2 - \Omega_0{}^2 - \nu^2)}{m[\ k_s \pm 2k)[(\Omega_c{}^2 + \nu^2 - \Omega_0{}^2\ ) + 4\Omega_0{}^2\ \nu^2]} \tag{10}$$

It can be seen easily from (10) that the collision frequency only modifies the index of modulation.

III. Results And Discussion

In this subsequent section, we shall try to analyze the above said equation (10) for the discussion of the modulation and demodulation of the electromagnetic in the presence of strain dependent dielectric constant in the piezoelectric crystals with high dielectric constant. Generally PZT possess polycrystalline ferroelectric materials with the perovskite crystal structure, which arranges the atoms A as well B sites gives - a tetragonal/rhombahedral structure very close to cubic. A (A+2) sites occupied by the large divalent metal ion such as barium or lead and a tetravalent metal ion such as titanium or zirconium are occupied at B (B+3)-sites. The size and oxidation state of the atoms decides the occupancy either at A or B sites which affects the stiffness of the materials. The centrosymmetric structure in which positive and negative charge sites coinciding at the axis shows no dipoles present in the material (which is said to exhibit paraelectric behavior). By the application of an electric field, the materials built-in electric dipole by reversing the tetragonal to cubic symmetry below the Curie temperature and change the increasing polarization with filed. By using the high dielectric constant, we can modulate and demodulate the wave in strain dependent dielectric constant. By using the above equation, we can analyze the modulation index in the PZT materials with strain dependent dielectric constant by considering the two different wave number regimes viz., (a) k_s>2k and (b) k_s<2k.

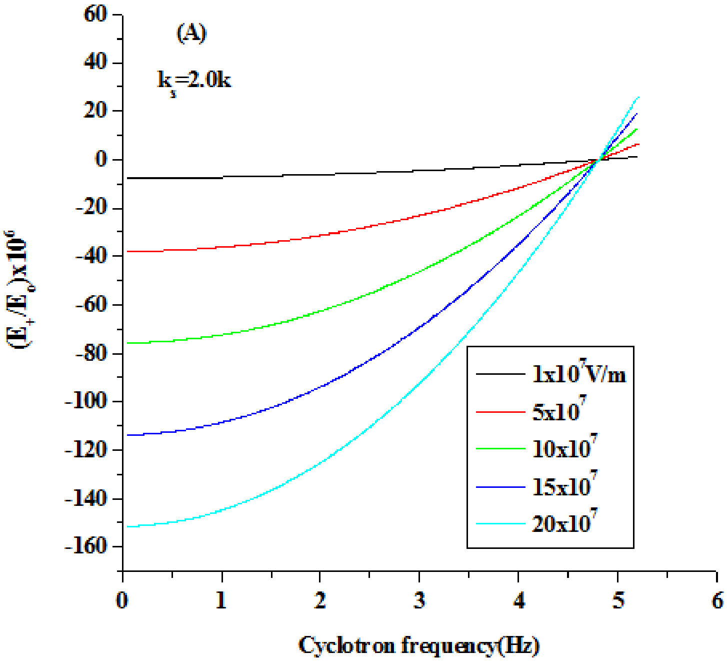
(i) The amplitude modulation and demodulation of the electromagnetic waves in SDDC such as PZT materials depends upon the variation of the cyclotron frequency. The modulation and demodulation sides and modes ($E_{\pm}$) of the electromagnetic are found in phase only under the following condition

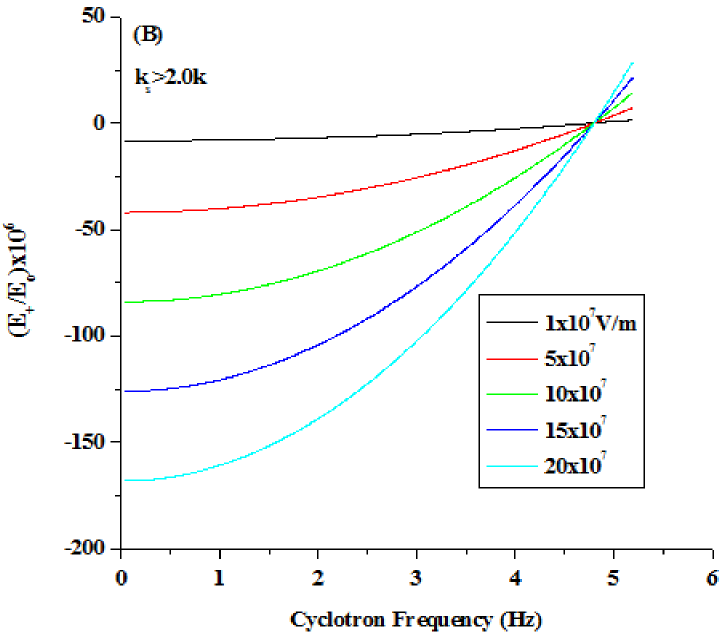
$$\Omega_c > \left(\Omega_0^2 + \nu^2\right)^{1/2}$$

By neglecting the collision frequency term from the equation (10), the complete absorption of the electromagnetic takes place in a material when the carrier frequency becomes equal to the cyclotron frequency (i.e., $\Omega_c = (eB_0 / m)$ is the electron cyclotron frequency). But when the cyclotron frequency is less than the incident frequency and the collision frequency, the amplitudes of the modulated waves and the pump wave are out of phase i.e.

$$\Omega_c < \left(\Omega_0^2 + \nu^2\right)^{1/2}$$

For the investigation of this result, numerical estimation has been carried by considering the following physical parameter: the effective mass of electron m=0.09m_o, where m_o is the free mass of the electron and theoretical density of 7.98 g/cm^3 [17] is calculated from the molar weight of the nominal composition and from the unit cell volume calculated from the refined PXRD data (obtained from conventionally sintered Pz26); the dielectric constant used in this expression [18] is ε=3540 and the refractive index taken as $\eta = \sqrt{\varepsilon} = 59.4978$; the effective carrier concentration [19] varies from lower temperature to the higher temperature, but generally taken to be 2-4 x10^{24}. For numerical calculation of the above analysis, the wave is irradiated on a specific case of Centro- symmetric crystal with 10.6μm CO_2 laser. The basic parameter is wave number k_0=5.92x10^5 m^{-1}, and the frequency Ω_0 =1.78x$10^{14}$$sec^{-1}$. The effect, phonon anharmonicity in acoustic wave propagation deals with the resonantly enhanced acousto-optical susceptibilities, refers to an operating acoustic intensity I_{ac} varies 1 – 100 kW/cm^{-2} and the acoustic frequency varies from ν_{ac}~ 0.1– 1 GHz. The Bragg diffraction of far-infrared polaritons can be used to interpret the propagation of THz field by controlling AW (acoustic wave) through pumping by AW [20]. Thus we can analyze the data in terms of the phonon anharmonicity which create an acoustically induced Bragg grating. The scattering channel is basically used to control the contrast of AW grating by the following transformation: "TO phonon ±acoustic phonon (two acoustic phonons) ↔TO phonon" for cubic (quartic) phonon anharmonicity. The TO-phonon resonance is strongly enhanced the scattering of THz light. Therefore the induced acoustic wave of frequency from the TO phonon resonance are chosen from 1 to 10 THz frequency and simultaneously gives the variation of wave number which propagate inside the centro-symmetric materials which contained the pervoskite structure. The variation of E_+/E_o and E_-/E_o with applied magneto-static field from the cyclotron with increasing electric field are shown in Figure 1 A, B and C. In Figure 1A, the modulation of the wave is studied at k_s=2.0 k with increasing Ω_c at the different electric field. From Figure 1 A, B and C, the modulation and the demodulation of the wave depends upon the applied electric field. With an increase in the magnetic field from 1x10^7 to 20x10^7 V/m, the modulation of the wave first increase 10 fold from 1x10^7 to 10 x10^7 V/m and then increases 100 fold with the increase the electric field from 10 x10^7 to 20 x10^7 V/m. However, in demodulation, the increment in the ratio is observed near about 10 times at 1x10^7 V/m and 1000 times at 20 x10^7 V/m compared to the modulation. It can be also seen from the Figure 1 a, b and c that up to $\Omega_c = \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ both the modes $E_\pm$ are observed out of phase with pump wave and for $\Omega_c > \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ gives the modulation and demodulation of both the modes. The modulation and demodulation indices for both the modes are found to be increasing with Ω_c. From the study of the results, it is found that the demodulation index is always greater than that for the modulation indices at the different electric field. The same results for the modulation and demodulation at the different electric field with the variation of magneto-static field is found in Figure 2 at k_s=2k. The demodulation index shows higher strengthening at the different electric field as compared to modulation index.





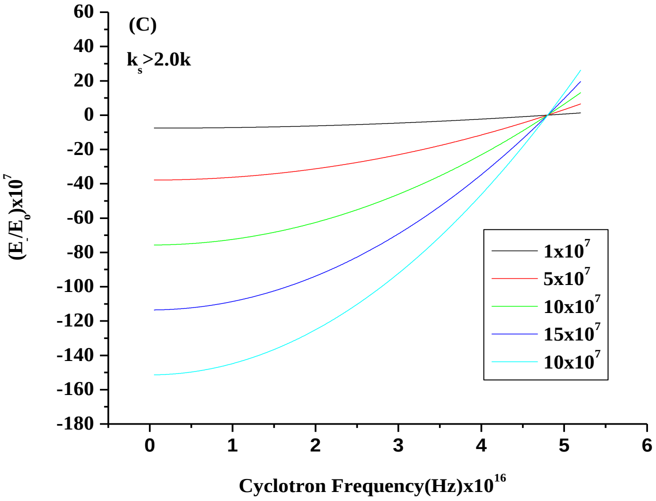
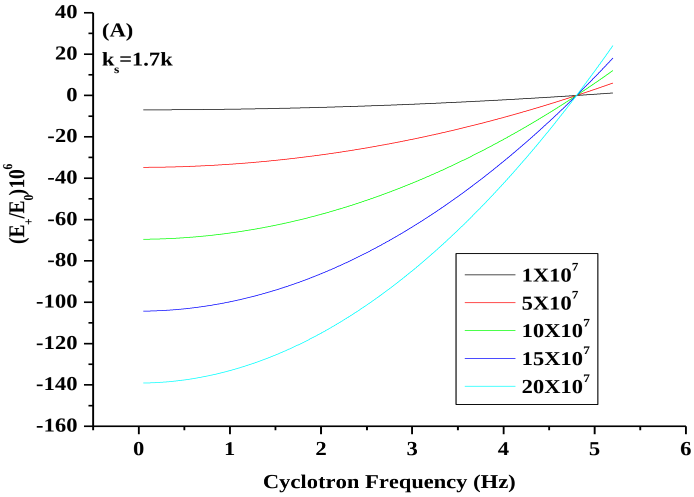


Figure.1 Variation of (A) and (B) E_+/E_o at k_s=2k and k_s>2k (C) E_-/E_0 at k_s>2k with applied magneto-static field (Ωc)



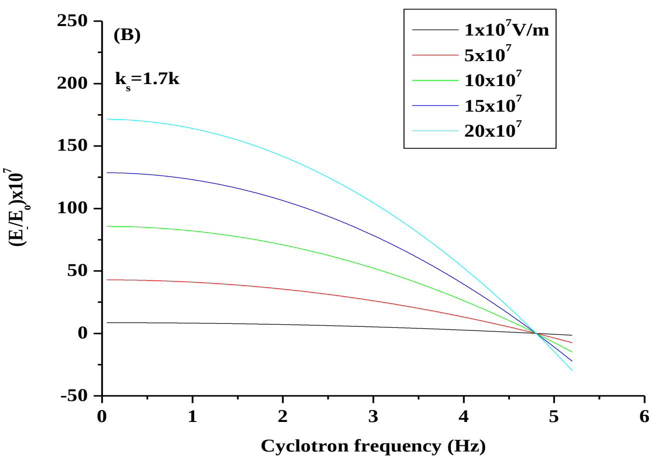
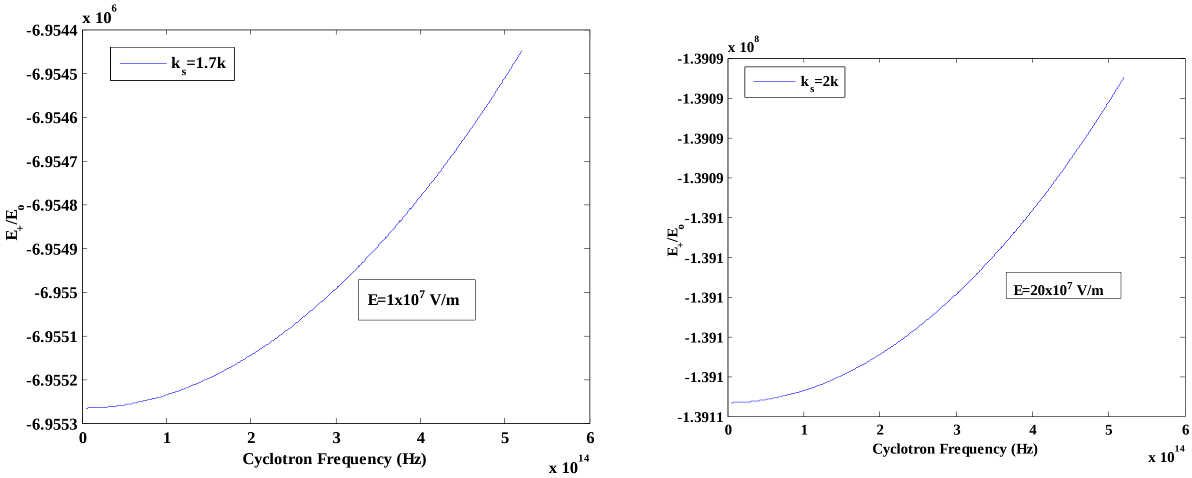
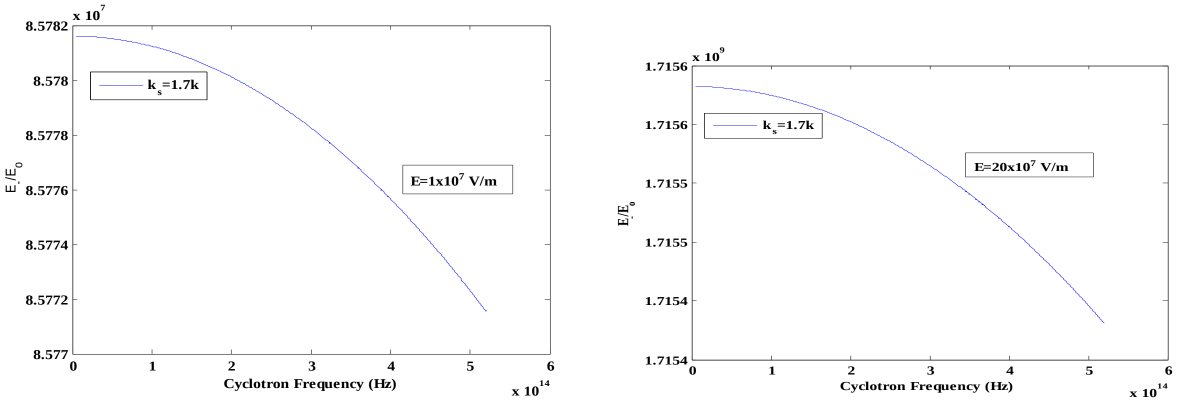


Figure.2 Variation of (A) E_+/E_o and (B) E_-/E_0 with applied magneto-static field (Ωc) at k_s<2k

(ii) The amplitudes of the E_+/E_o and E_-/E_o sides band remains in phase under the following region of $\Omega_c > \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ and $\Omega_c < \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ respectively. The complete absorption of the wave takes place when the carrier frequency becomes equal to the cyclotron frequency ($\Omega_c = \Omega_o$) by considering the absence of ν i.e., electron-electron collision frequency in this wavelength regime. The plus and minus modes are out of phase with pump frequency found in the regime $\Omega_c > \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ and $\Omega_c < \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$, respectively, raising the possibility of demodulation at the different electric field. The numerical estimation was carried out for this sequence $\Omega_c < \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$, and their results are shown in Figure 3 and 4 a & b. It can be seen from these figures that the modulation of the index for the E_+ modes increases with increase the magneto-static field as shown figure 3 a, while demodulation of the index for the E_- mode decreases with increase the magneto-static field as shown in Figure 3b at the two different magnetic fields. But this analysis is carried out k_s=2k. At the higher field, the modulation and demodulation is more, because of the more and more interaction of electron-electron interaction with electron-phonon interaction. The modulation and demodulation occur simultaneously in the opposite direction at the specific magnetic field. The same numerical analysis is carried out for k_s=2.5k which is greater than k. Their results are present in Figure 4 a and b . In Figure 4 a, the modulation of index of the E_+ mode are shown at the different electric filed while the demodulation of the index for the E_- modes are shown in Figure 4 b. It can be seen from the figure that modulation and demodulation show the same pattern for an increasing with magneto-static field. The modulation of the E+ is explained by using equation (10) and found that this occurs at the higher magnetic fields when $\Omega_c > \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ and in this region the modulation index becomes inversely proportional to the square of the cyclotron frequency, whereas E_- modes gets modulated at lower magnetic fields when $\Omega_c < \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ as shown in Figure 4 a and b.

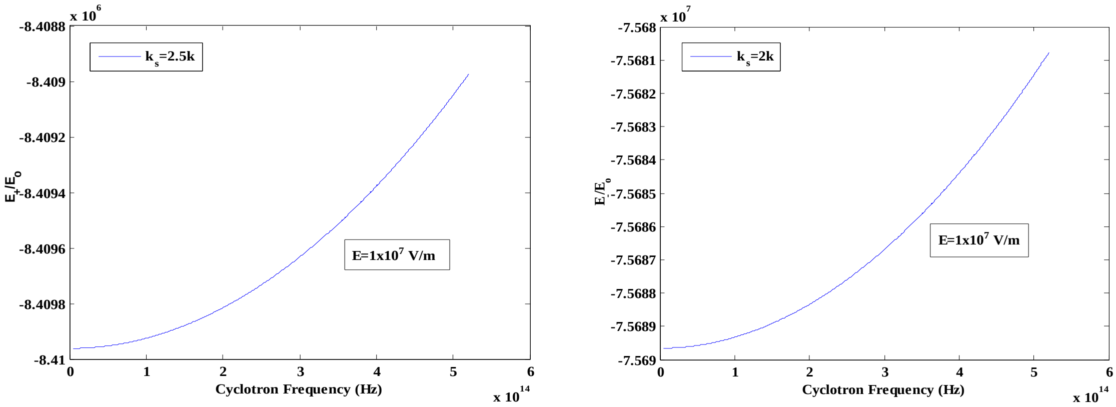


(a)

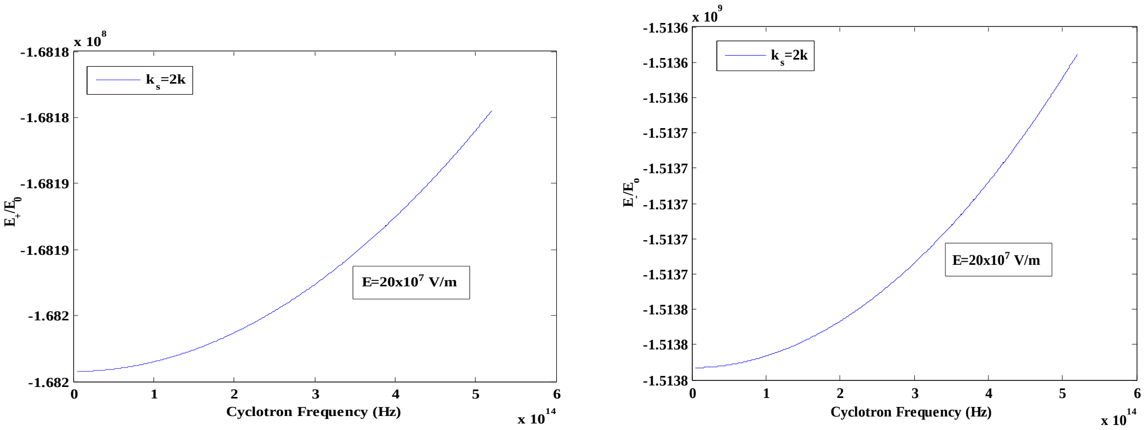


(b)

Figure.3 Variation of (a) E_+/E_o (b) E_-/E_0 with applied magneto-static field (Ωc) at k_s=1.7k



(a)



(b)

Figure.4 Variation of (a) E_+/E_o (b) E_-/E_0 with applied magneto-static field (Ωc) at k_s=2k

IV. Conclusion

1. From the above discussion, the numerical analysis for the modulation and demodulation of the plasma wave by the acoustic wave can be easily achieved by using the high dielectric material. This type of the dielectric property is found in strain dependent dielectric material which is developed by the change in crystal structure by expanding the entire lattice through doping in the parent structure.
2. This material is very useful for the modulation and demodulation of the wave at the different electric field.
3. The electric filed enhance the modulation and demodulation with an increase the magneto-static field.
4. The modulation and demodulation depend upon the variation of magneto-frequency from $\Omega_c > \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$ and $\Omega_c < \left(\Omega_o^2 + \upsilon^2\right)^{1/2}$.

5. The consideration of stain dependent dielectric constant material like Pb(Zr,Ti)O3 thus offers the suitable area of promising to peruse the modulation and demodulation interaction.
6. This interaction is a basic parameter to design the tool for the transmission of the energy and solid state diagnostics in crystals with high dielectric constant.

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Authors Bibliography

	**Author1-Shivani Saxena** She completed her M.Sc in physics in the year 2006 from Barkatullah university Bhopal. Now she is persuing Ph.D in plasma physics under the guidance of Dr sanjay Dixit from Barkatullah University.She has worked in a reputed engineering college as a Lecturer.Her field of interest is plasma physics.Email:sxn_shvn@yahoo.co.in
	**Author2-Dr Sanjay Dixit** He was born in the year 1961.He did his M.Sc in 1983 from school of studies in physics Ujjain,and then Phd in plasma physics in the year 1987 from vikram university Ujjain.Initially he worked in school of studies in physics as research fellow and then as research associate.He has been working as assistant professor in Govt MVM college Bhopal since 1987.He has been nominated as Life Fellow by the Indian Physical Society Calcutta in 1987. Email:sanjay_007dixit@rocketmail.com
	**Author3-Dr. Sanjay Srivastava** S. Srivastava was born in Banaras (U.P.), India, in 1975. He received the M. Tech. Degree in 1999 from Materials Science and Technology and the Ph.D degree in 2006, both in Metallurgical Engineering from IIT BHU, Banaras. He is currently working as an Associate Prof. (MSME), MANIT Bhopal. His research interests include composite material, Photonic of the superconducting material and Microwave engineering. He is a life time member of tribological society of India and MRSI. Email:s.srivastava.msme@gmail.com