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Original Research Article

Coherent Electromagnetic Waves' amplitude modulation and demodulation in PZT materials

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ABSTRACT
The primary goal of the work is to examine how electromagnetic waves are modulated and demodulated in materials with high dielectric constants. PZT materials get their high dielectric constant by substituting a suitable doping element at either the A+ sites or the B sites in the ABO_3 crystal structure. Because of the strain present in the current lattice, the material has a high dielectric constant, or strain dependent dielectric constant (SDDC).

1. Introduction

By changing the collision frequency of plasma carriers over time, the modulating magnetostatic field, power demodulation in the radio frequency (RF) discharge, and acoustical phonon propagation may create periodic fluctuation in the propagating parameters. Changing the amplitude and/or phase relationship among the waves as they propagate is easy with the help of the acousto-optic (AO) and electro-optic (EO) effects [1]. For the purpose of explaining the amplitude demodulation/modulation of optical radiation in magnetised $A^{III}B^{V}$ semiconductor media, the fluid model of semiconductor-plasmas has been reported by Sangwan and Singh [2].

Carrier diffusion exhibits a significant impact on the nonlinearity of semiconductors made of high mobility $A^{III}B^{V}$ materials [3]. The growth analysis of the modulational process of the coherent optical radiation that was travelling inside a clustered gas was reported by Mishra and Jha [4]. For pulses between 80 fs and 100 fs, it is possible to alter the growing rate of modulational process from back/front of the propagating pulse. According to the hydrodynamic approximation, Ghosh and Rishi [5] reported the modulation and demodulation of the acousto-optic amplitude in magnetised semiconducting materials.

For diffusion of the plasma waves, the presence of heating is crucial. Ghosh and Rishi [5] reported a variety of wave numbers over the broad regime of relevant electron-cyclotron frequency Ω_c. When $\Omega_c = (\nu^2 + \Omega_c^2)^{1/2}$, the electromagnetic wave is completely absorbed. In $A^{III}B^{V}$ semiconductor materials, Sangwan and Singh [6] investigated modulational amplification based on phonon-electron interaction. Pump waves with a frequency of 1.78×10^{14} s^{-1} were applied to III-V semiconductor crystals in order to do numerical calculations.

In the present work, we have attempted to offer an analytical method on the absorption properties of electro kinetic waves in a high dielectric semiconductor media under the appearance of the plasma carriers, which is motivated by the discussion above. Lead zirconate titanate (PZT) can be impacted by the type of solvent and the concentration of the dopant elements, similar to other classes of piezoelectric and ferroelectric materials. Due to the soft dopant in PZT and its superior qualities compared to PZT, domain wall glides in easily [7]. Lattice strain is expressed in terms of the crystal flaws brought on by lattice dislocations brought on by various ionic radii of the matrix ions and dopants [8].

2. Objectives

- To establish the potential of stain dependent dielectric constant materials like $Pb(Zr,Ti)O_3$ for the modulation and demodulation interactions.
- To create a device for solid-state diagnostics and energy transfer in crystals with high dielectric constants.

3. Theoretical formulations

We employ the homogeneous, non-degenerate PZT crystal hydrodynamic model for this computation, which is placed in the transverse magnetostatic field (along x-direction) at right angles to the propagation vectors of the pump (k_0) and acoustic (k_s) waves (along z-direction). The presence of acoustic waves (k_s, Ω_s) in the crystal is thought to be the cause of the low frequency disturbances.

The electron density is oscillating at acoustical frequency as a result of SDDC fields connected to the acoustic wave. The transverse current density is raised from the pump wave at the frequencies Ω_0 and $(\Omega_0 \pm \Omega_s)$, where Ω_0 is frequency of pump wave. By creating sideband electric field vectors, these sideband current densities influence the pump wave along the applied field direction.

The sideband will be denoted in the analysis that follows via suffixes + and -, respectively. Here + denotes the mode propagation at the frequency $(\Omega_0+\Omega_s)$ and – for $(\Omega_0-\Omega_s)$. The lattice dynamics equation is taken into account for the determination of induced current density. For crystals possessing SDDC coupling, the equation regulating the lattice displacements is as follows:

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

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

where C and ρ stand for the elastic constant and the crystal's mass density, respectively. g is SDDC coupling constant which can be approximated $\varepsilon_0/3$ for crystals with $\varepsilon_0 > 1$. Using equations (1) and (2), perturbed carrier concentration is:

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

In Eq. (3), v_s represents the speed of shear acoustic wave inside the chosen media. It may be expressed as:

$$v_s = \left(\frac{C}{\rho}\right)^{/2} \text{ and } S^2 = \frac{(\varepsilon_0 g E_0)^2}{\varepsilon_0 C}.$$

The following electron momentum transfer equation can be used to determine the velocity of oscillatory electron fluid under the influence of pump field E_0 and that caused by the optical fields associated with sidebands $E_{\pm}$:

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

where the subscript j corresponds to 0 , + and - modes, m stands for electron's effective mass and ν is the phenomenological electron's collision frequency.

The medium's net transverse current density may be determined as:

$$\vec{J}_{total} = e\left[\sum_j n_0\vec{V}_j + \sum_j n\vec{V}_0 \exp[i(\Omega_j t - k_s z)\right]. \tag{5}$$

where $n\vec{V}_0 \exp[i(\Omega_j t - k_s z)$ denotes the current produced as a result of the pump field interaction with the acoustical field. The wave formula is:

$$\frac{\partial^2 \vec{E}}{\partial z^2} = \mu_0\varepsilon\frac{\partial^2 \vec{E}}{\partial t^2} - \mu_0\frac{\partial \vec{J}_{total}}{\partial t} = 0. \tag{6}$$

From equation (6), one obtains

$$\frac{E_{\pm}}{E_0} = \frac{-i\Omega_0\mu_0 euk_s(\nu + i\Omega_0)(\varepsilon_0 g E_0)}{m[\Omega_c^2 + (\nu + i\Omega_0)^2](k_s \pm 2k)}[1 - \exp(\mp ik_s z)]. \tag{7}$$

Equation (7)'s actual portion can be obtained by ignoring $\exp(\mp ik_s z)$ comparison to one and then justifying it as follows:

$$\frac{E_{\pm}}{E_0} = \frac{\Omega_0^2\mu_0 euk_s(\varepsilon_0 g E_0)(\Omega_c^2 - \nu^2 - \Omega_0^2)}{m(k_s \pm 2k)[\Omega_c^2 + \nu^2 - \Omega_0)^2 + 4\nu^2\Omega_0^2]}. \tag{8}$$

4. Results and discussion

We may examine the modulation index in PZT materials with strain-dependent dielectric constants by utilising the aforementioned equation (8) and taking into account the two distinct regimes of wave number, namely (i) $k_s > 2k$ and (ii) $k_s < 2k$.

Numerical estimation are made for following material constants: electron's effective mass $m = 0.09\ m_0$; m_0 being the electron's rest mass and material's mass density 7.98 g/cm^3 [9] is calculated through molecular weight of significant composition and through the volume of unit cell determined via PXRD data; dielectric constant used in expression [10] is $\varepsilon = 3540$ and refractive index taken as $\eta = \sqrt{\varepsilon} = 59.4978$; the effective carrier concentration [11] varies from lower temperature to the higher temperature, but generally taken to be 2×10^{24} m^{-3} to 4×10^{24} m^{-3}.

It is possible to understand the propagation of the THz field by manipulating the acoustical field via pumping by using the Bragg diffraction of far-infrared polaritons. The variation of E_+/E_0 and E_-/E_0 with applied magneto-static field with increasing electric field are shown in Figures 1 – 3.

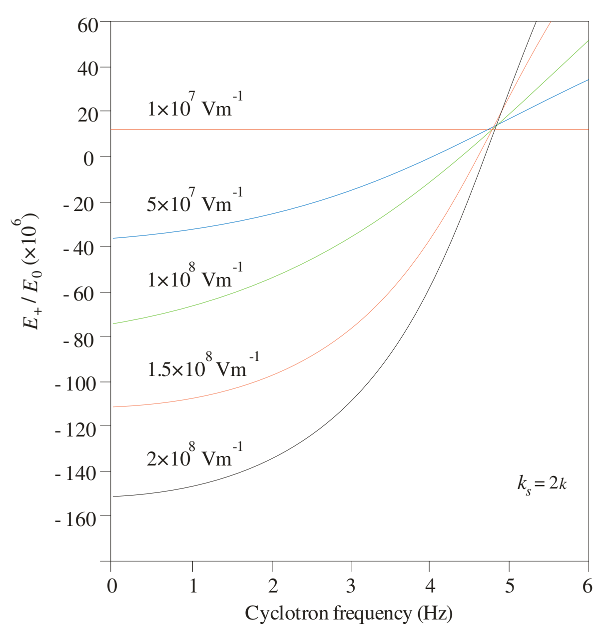

Figure 1. Variation of E_+/E_0 at $k_s = 2k$ with applied magneto-static field (Ω_c).

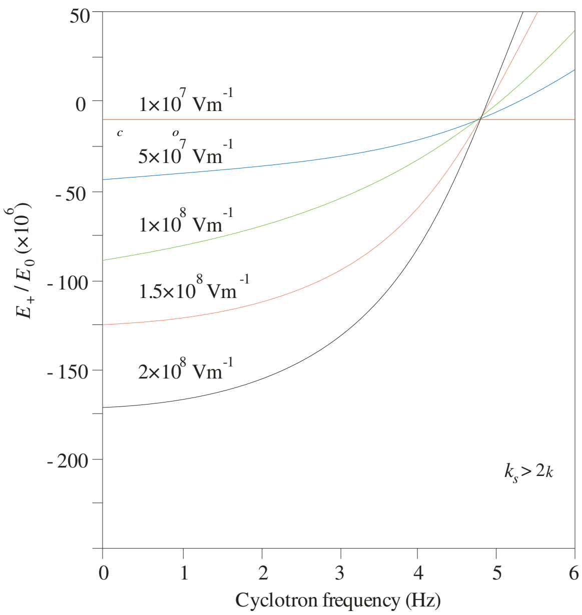

Figure 2. Variation of E_+/E_0 at $k_s > 2k$ with applied magneto-static field (Ω_c).

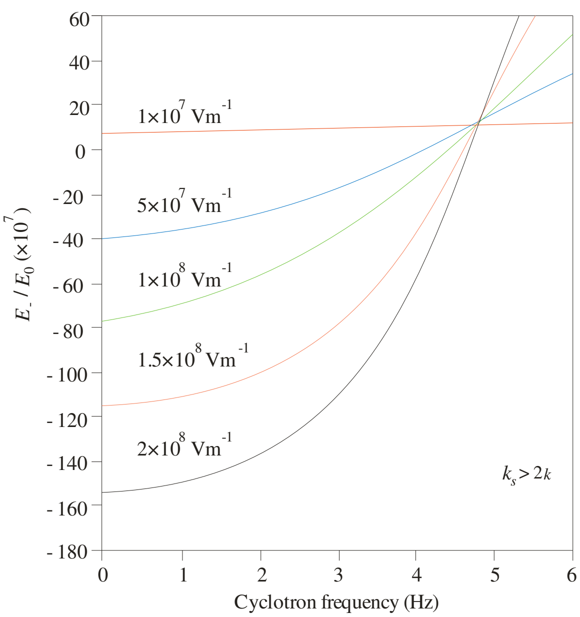

Figure 3. Variation of E_-/E_0 at $k_s > 2k$ with applied magneto-static field (Ω_c).

In Figure 1, the modulation of the wave is studied at k_s = 2.0 k with increasing Ω_c at the different electric field. From Figures 1 – 3, the demodulation/modulation of wave depends upon the applied electric field. With an increase in the electric field from 1×10^7 Vm^{-1} to 20×10^7 Vm^{-1}, the modulation of the wave first increase 10 fold from 1×10^7 Vm^{-1} to 10×10^7 Vm^{-1} and then increases 100 fold with the increase the electric field from 10×10^7 Vm^{-1} to 20×10^7 Vm^{-1}. However, in demodulation, the increment in the ratio is observed near about 10 times at 1×10^7 Vm^{-1} and 1000 times at 20×10^7 Vm^{-1} compared to the modulation. It can also seen from the Figures 1 – 3 that up to $\Omega_c = (\nu^2 + \Omega_0^2)^{1/2}$ both the modes $E_\pm$ are observed out of phase with pump wave and for $\Omega_c > (\nu^2 + \Omega_0^2)^{1/2}$ 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.

5. Conclusions

The materials having strain dependent dielectric constant are very useful for the demodulation and modulation of wave at different electric field. The electric filed enhance the modulation and demodulation with an increase the magneto-static field. The modulation and demodulation depend upon the variation of magneto-frequency from $\Omega_c > (\nu^2 + \Omega_0^2)^{1/2}$ and $\Omega_c < (\nu^2 + \Omega_0^2)^{1/2}$. The consideration of stain dependent dielectric constant material like $Pb(Zr,Ti)O_3$ thus offers the suitable area of promising to peruse the modulation and demodulation interaction. This interaction is a fundamental factor to consider when designing a tool for solid-state diagnostics and energy transfer in crystals with high dielectric constants.

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