# Amplitude modulation and demodulation of an electromagnetic wave in magnetized ion-implanted semiconductor plasmas having SDDC

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**Abstract.** In communication processes, amplitude modulation is very helpful to save power using a single band transmission. Using the hydrodynamical description of semiconductor plasma analytical investigations are made for the amplitude modulation as well as demodulation of an electromagnetic wave in magnetized ion implanted semiconductor plasmas having strain dependent dielectric constants. Analysis is made under different wave number regimes over a wide range of cyclotron frequencies without and with colloids. Numerical estimations are made for n-doped $BaTiO_3$ crystal irradiated by pump wave frequency $1.78\times10^{13}s^{-1}$. It has been found that ion implantation of negatively charged colloids modifies nearly $\approx10^5$ of magnitude of amplitude modulation and demodulation processes. Ion implantation plays a key role in development of optoelectronics.

## 1. Introduction

The problem of modulation in semiconductor plasmas has been studied in number of works [1,2]. The modulation of microwave while propagating through a piezoelectrically active semiconductor media duly irradiated by an acoustic wave was first predicted by Mathur and Sagoo [3]. The periodic variation of the propagation parameter leads to the modulation of an electromagnetic wave passing through plasma. This periodic variation in the propagation parameters, caused by the time varying change in the carrier density of the plasma, may be due to a modulated magnetic field, the modulation of power in an rf discharge or the propagation of an acoustic wave. The phenomena of modulation of an electromagnetic wave by an acoustic wave are of special interest in the problem of communication of different types. This is due to fact that the scattering of light from sound or low frequency electromagnetic waves affords a convenient means of controlling the frequency, intensity and direction of an optical beam [4].

This type of modulation makes possible a large number of applications involving the transmission, display and processing of information, the fabrication of some optoelectronic devices, such as acousto-optic modulators, these are based on the interaction of an acoustic wave or low frequency electromagnetic wave with the incident laser beam. Acousto-optic interaction in dielectrics and semiconductors is playing an increasing role in optical modulation and beam steering. However, the integrated process becomes a serious limitation due to high power requirements. The most direct approach to this problem is to tailor new material with more desirable acousto-optic properties. The study of modulation can be made with respect to amplitude, frequency and phase. Amplitude modulation is one of the oldest forms of modulation. One of the important problems in communication systems is that of developing an effective method of modulation as well as demodulation of the waves[5]. The strain dependent dielectric constant (SDDC) effect for high dielectric materials is not fully understood yet, it shows broadened peaks and considerable deviation from the Curie Weiss type law near critical strains which are attributed to complete phonon softening [6-7].

Ion implantation is the widely used doping techniques in preparation of doped semiconductors. The implanted ions in a material can modify the magnetic coercivity and nonlinear optical properties. A small quantity of ions may alter the electrical conductivity of the host material by several orders of magnitude. This process is responsible for implanted metal ions being neutralized during slowing down processes and somehow agglomerating to form colloids. The study of colloid formation of metal ions by ion implanted techniques is carried out in a number of laboratory experiments [8].

Charged grain with size range of micrometer or less are exist in many laboratory, industrial and natural plasmas. The grains are often highly negatively charged since fast-moving thermal plasma electrons easily collide inelastically with them and become attached. The grains can be useful models for studying the structural dynamics of microscopic matter. Crystal like grain structures and their physical characteristics, such as melting and fracturing have been predicted and observed in experiments and numerical simulation [9-10].

In the present paper, we investigate the effects of negatively charged colloids on the amplitude modulation and demodulation of an intense electromagnetic wave in ion implanted semiconductor crystal. The effects of charged colloids in ion implanted semiconductor plasma medium add new dimensions to the analysis presented in n-doped SDDC magnetoactive semiconductors. The intense pump beam electrostrictively generates an acoustic wave within the semiconductor medium that induces an interaction between the free carriers (through electron and colloid plasma wave) and acoustic phonons (through material vibration). This interaction induces a strong space field that modulates the pump beam. Thus, the applied optical and generated acoustic waves in an acoustooptic modulator can produce amplitude modulation and demodulation effects. It is found that ion implantation of negatively charged colloids modifies the properties of material.

## 2. Theoretical formulation

We have considered the hydrodynamic description of homogeneous, semiconductor plasma of infinite extent. The Lattice vibration equation:

$$\frac{\partial^2 u}{\partial t^2} = \frac{c}{\rho}\frac{\partial^2 u}{\partial x^2} - \frac{\varepsilon g E_0}{\rho}\frac{\partial E_1^*}{\partial x} \tag{1}$$

If $\varepsilon_s$ is dielectric constant in absence of any strain, then $g = \left( \varepsilon_s / 3 \right)$ is the coupling constant.

$$\frac{\partial E_1}{\partial x} = \frac{n_{1j} Z_j e}{\varepsilon} + g E_0 \frac{\partial^2 u^*}{\partial x^2} \tag{2}$$

where $j = e, d$ (electrons, colloids). Here $Z_d = \frac{q_d}{e}$ is the ratio of negative charges $q_d$ resided over the colloidal grains to charge $e$ on the electrons and $Z_e = -1$ is assumed for further analysis.

$$\frac{\partial v_{1j}}{\partial t} + \upsilon_j v_{1j} + \left( v_{0j} \frac{\partial}{\partial x} \right) v_{1j} = \frac{Z_j e}{m_j}\left( E_l + v_l \times B_0 \right) - \frac{k_B T}{m_j n_0} . \nabla n_1 \tag{3}$$

The subscript $l$ stands for $0, +$ and $-$ modes and $j = e, d$ ($e$- electrons and $d$-colloids). Momentum transfer equation (4) may be used to obtain the oscillatory carrier fluid velocity in presence of pump electric field ($E_0$) and field of side band modes ($E_{\pm}$).

The total transverse current density in the medium is given by

$$J_{total} = -Z_j e . \left[ \sum_l n_0 . v_l + \sum_l n_1 . v_0 . \exp\left[ i\left( k_a . x - \omega_a . t \right) \right] \right] \tag{4}$$

where $n_1 v_0 \exp[i(k_a x - \omega_l t)]$ represents the current generated due to the interaction of the pump wave with acoustic wave. In order to obtain the modulation indices of modulated sideband modes. Using equations (5), (6) and (7) in the general wave equation

$$\frac{\partial^2 E_{total}}{\partial x^2} - \mu . \varepsilon \frac{\partial^2 E_{total}}{\partial t^2} - \mu . \frac{\partial J_{total}}{\partial t^2} = 0 \tag{5}$$

and neglecting $\exp(\pm ik_a x)$ in comparison to 1, we obtain the following expression for modulation indices;

$$\frac{E_{\pm}}{E_0}=\frac{\omega_0\mu Z_j e\rho u v_a^2 A^2(\omega_0+i\upsilon_j)}{m_j\beta\left[(\omega_{cj}^2+\upsilon_j^2-\omega_0^2)-i(2.\omega_0.\upsilon_j)\right]}\cdot\frac{k_a}{(k_a\pm 2k)}\left[1+\frac{V_{Thj}^2}{2}\cdot\frac{k_a^2}{\omega_{pj}^2}\right] \quad (6)$$

in which $\beta = gE_0$. By rationalization of above equation, one can obtain the real part of modulational indices as

$$\frac{E_{\pm}}{E_0}=\frac{\omega_0^2\mu Z_j e\rho u k_a v_a^2 A^2}{m_j\beta(k_a\pm 2k)}\cdot\frac{(\omega_{cj}^2-\omega_0^2-\upsilon_j^2)}{\left[(\omega_{cj}^2+\upsilon_j^2-\omega_0^2)^2+4\omega_0^2\upsilon_j^2\right]}\cdot\left[1+\frac{V_{Thj}^2}{2}\cdot\frac{k_a^2}{\omega_{pj}^2}\right] \quad (7)$$

when $j=e$ (i.e. $e$-electrons) and $Z_e=-1$

$$\frac{E_{\pm}}{E_0}=-\frac{\omega_0^2\mu e\rho u k_a v_a^2 A^2}{m_e\beta(k_a\pm 2k)}\cdot\frac{(\omega_{ce}^2-\omega_0^2-\upsilon_e^2)}{\left[(\omega_{ce}^2+\upsilon_e^2-\omega_0^2)^2+4\omega_0^2\upsilon_e^2\right]}\cdot\left[1+\frac{V_{The}^2}{2}\cdot\frac{k_a^2}{\omega_{pe}^2}\right] \quad (8)$$

where $\omega_{ce}=e|B_0|/m_e$, $V_{The}=\left(2k_BT_e/m_e\right)^{1/2}$ and $\omega_{pe}=\left(n_0e^2/m_e\varepsilon\right)^{1/2}$ are the cyclotron frequency, the thermal speed and the plasma frequency respectively for electron.

when $j=d$ (i.e. $d$-negatively charged colloids) and $Z_d$. The colloid thermal speed is usually far smaller than the electron thermal speed:

$$V_{Thd}=\left(m_e.T_d/m_d.T_e\right)^{1/2}.V_{The} \text{ and Debye length(} j=d \text{) } \lambda_D=\left(\varepsilon.k_BT_d/n_{0d}Z_d^2e^2\right)^{1/2}$$

$$\frac{E_{\pm}}{E_0}=-\frac{\omega_0^2\mu Z_d e\rho u k_a v_a^2 A^2}{m_d\beta(k_a\pm 2k)}\cdot\frac{(\omega_{cd}^2-\omega_0^2-\upsilon_d^2)}{\left[(\omega_{cd}^2+\upsilon_d^2-\omega_0^2)^2+4\omega_0^2\upsilon_d^2\right]}\cdot\left[1+k_a^2.\lambda_D^2\right] \quad (9)$$

where $\omega_{cd}=Z_de|B_0|/m_d$, $V_{Thd}=(2k_BT_d/m_d)^{1/2}$ and $\omega_{pd}=\left(n_{0d}Z_d^2e^2/m_d\varepsilon\right)^{1/2}$ are the cyclotron frequency, the thermal speed and the plasma frequency respectively for negatively charged colloid.

## 3. Results and discussions

The numerical calculations are performed for the n-type doped semiconductor sample ($BaTiO_3$) at 77 K duly irradiated by 10.6 $\mu m$ $CO_2$ laser. The following material parameters are taken as representative values. $m_e=0.0145m_0$ ($m_0$ being the free electron rest mass), $\varepsilon_s=2000$, $m_d=1.67\times10^{-27}kg.$, $\rho=4\times10^3kg.m^{-3}$, $n_{0e}=10^{25}m^{-3}$, $T_e=T_d=77K$, $n_{0d}=2\times10^{20}m^{-3}$ $\upsilon_e=5\times10^{11}s^{-1}$ $\upsilon_d=1.405\times10^9s^{-1}$, $\omega_0=1.78\times10^{13}s^{-1}$, $\omega_a=1.6\times10^{13}s^{-1}$, $v_a=2.5\times10^3m.s^{-1}$.

Case: 1 when $k_a>2k$

The variation of $\left(E_+/E_0\right)$ and $\left(E_-/E_0\right)$ with the applied magnetic field $(\omega_c)$ are depicted in figure 1 and 2 for both without and with colloids. It may be seen from these figures that at ($\omega_c\approx\omega_0$) the modulation indices become zero. When one applies weak magnetic field so that cyclotron frequency $\omega_c$ for both case without and with colloids becomes smaller than the carrier frequency $\omega_0$, then both the modes are in phase with pump wave, which exhibits modulation process. But at a particular value of magnetic field when ($\omega_c\approx\omega_0$) modulation indices for both the modes become zero and complete absorption of wave takes place on neglecting the collision term in equations (8) and (9) for without and with colloids. On further increasing the cyclotron frequency ($\omega_c>\omega_0$) both side band go out of phase. These out of phase side bands then interact with the pump wave to produce demodulated acoustic wave. We conclude that demodulation process can be observed in the regime ($k_a>2k$ )with( $\omega_c>\omega_0$) for both without and with colloids. The variation of $\left(E_+/E_0\right)$ and $\left(E_-/E_0\right)$ with the applied magnetic field $(\omega_c)$ are depicted in figure 3 and 4 for both without and with colloids. From both the figures for same wave number regime the behavior of modulation indices for plus and minus modes are opposite in nature. In the same wave number regime the amplitude of the plus mode is positive under the condition ($\omega_c < \omega_0$) for both without and with colloids. Hence under this regime of cyclotron frequency, the amplitude of plus mode is in phase with the pump wave. This side band then interacts with the wave to produce modulated wave. However, when the carrier frequency become nearly equal to the cyclotron frequency, complete absorption of waves takes place in equations (8) and (9) separately without and with colloids. In the range defined as $\omega_c > \omega_0$, the modulation indices of plus mode is negative.

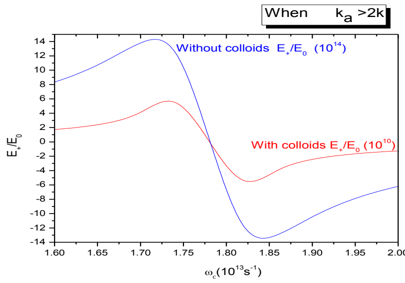


**Figure 1.** Variation of modulation index of plus mode ($k_a > 2k$) for without and with colloids respectively with magnetic field.

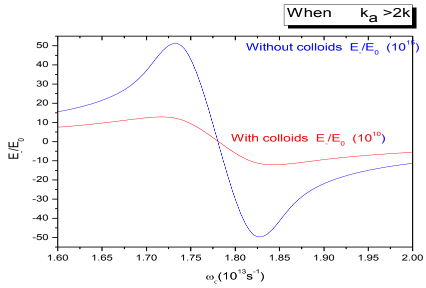


**Figure 2.** Variation of modulation index of minus mode ($k_a > 2k$) for without and with colloids respectively with magnetic field.

Case: 2 when $k_a < 2k$

This out of phase side band waves then interact with the pump to produce a demodulated wave which exhibits demodulation process. From figure 4 we may infer that in this wave number regime the amplitude of the minus mode is negative when $\omega_c < \omega_0$ and remain out of phase with the pump wave. This side band then interacts with the wave to produce demodulated acoustic wave for both without and with colloids [11]. Hence ,it can be seen easily that presence of negatively charged colloids modifies nearly $\approx 10^5$ of magnitude of amplitude modulation and demodulation processes.

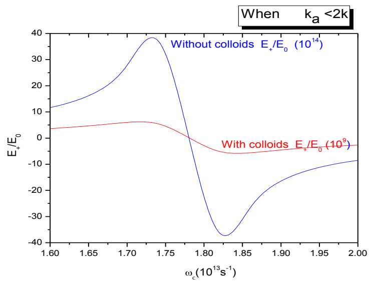


**Figure 3.** Variation of modulation index of plus mode ($k_a < 2k$) for without and with colloidsrespectively with magnetic field.

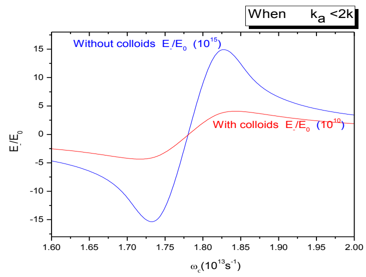


**Figure 4.** Variation of modulation index of minus mode ($k_a < 2k$) for without and with colloids respectively with magnetic field

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