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Parametric Interaction in Magnetised Diffusive Semiconductor Plasmas: Effects of Carrier Heating

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Abstract: Using Hydrodynamic model of semiconductor plasmas, incorporating influence of carrier heating (CH), the diffusion induced nonlinear current density and the consequent second-order effective susceptibility are obtained under off-resonant laser irradiation in magnetised diffusive semiconductors. The CH induced by the intense pump modifies the momentum transfer collision frequency (MTCF) which in turns refines the dispersion as well as gain profiles of the system. The results strongly suggest that the incorporation of CH by pump in the analysis leads to better understanding of parametric processes induced by diffusion in solids, which may be of great use in the generation of squeezed states.
Keywords: 52.35.Mw Parametric dispersion and amplification; **42.65.An** Optical susceptibility; **66.30.-h** Diffusive semiconductor; **72.20.Ht** Hot carrier effects; **72.30.+q** High frequency effects; plasma effects.

1. Introduction

In most of the studies of parametric interaction (PI), the diffusion of the excitation density responsible for the nonlinear (NL) refractive index change has normally been ignored. Particularly in semiconductors, the charge carriers (electrons) have generally low effective mass and high mobility, so the diffusion process in these media is a necessary and important phenomenon in presence of density gradient. It is an established fact that due to high intensity pump (which is one of the pre-requisite conditions for the onset of a parametric instability) heating of carrier becomes inevitable particularly in high mobility semiconductors. As a result, the momentum transfer collision frequency (MTCF), mobility of the carriers and conductivity of the medium become function of the pump amplitude and hence produce refinement effects. Recently, Nimje at el.[1] have studied the effects of carrier heating (CH) on diffusion induced modulational instability in magnetised semiconductor plasmas and found that the effects of CH

enhances the steady-state and transient gains of the semiconductors. Motivated by this state of art, we have decided probably for the first time to study the effects of CH on PI in diffusive magnetized semiconductors plasmas.

2. Theoretical Formulation

For analytical investigation, we use well-known hydrodynamic model of an n-type diffusive semiconductors, satisfying the condition $k_a l << 1$ (k_a and l being the acoustic wave number and electron mean free path, respectively), which simplifies the analysis without diluting any of significant informations.

On using the basic equations given in[1] and following the procedure adopted by Neogi and Ghosh [2], one may obtain diffusion induced second-order (DISO) complex susceptibility under coupled mode scheme as

$$[\chi_d^{(2)}]_{eff} = \frac{Dk^3\omega_0^2 e n_0 (\eta^2 - 1)^2}{2\rho\omega_a(\omega_a^2 - \vartheta_a^2 k^2 + 2i\gamma\omega_a)(\omega_c^2 - \omega_0^2)},$$

(2.1)

$$\times\left[1 - \frac{(\delta_1^2 + iv\omega_1)(\delta_a^2 - iv\omega_a)}{k^2 |\bar{E}|^2}\right],$$

All the symbols have their usual meanings and are well explained in Ref.[1]. The threshold pump field E_{th}, required for parametric instability is obtained by setting imaginary part of susceptibility $[\chi_d^{(2)}]_{img}$ equals to zero as

(2.2) $$E_{th} = \frac{m}{ek}\left(\frac{\omega_0}{\omega_0^2 - \omega_c^2}\right)^{-1}(\delta_1^2\delta_a^2 + v^2\omega_1\omega_a),$$

Following Yariv[3], the steady state gain coefficient of parametrically excited wave in semiconductors can be obtained by the relation

(2.3) $$\alpha_{para} = -\frac{k}{2\varepsilon_l}[\chi_d^{(2)}]_{img} E_0,$$

The parametric gain of idler wave can be achieved only if $[\chi_d^{(2)}]_{img}$ is negative.

In general, when the high intensity pump field interacts with high mobility semiconductor, carriers acquire momentum and energy from the pump and as a result electrons acquire a temperature (T_e) somewhat more than the lattice temperature (T_0). This heating modifies the MTCF that can be obtained through the relation[4]

(2.4) $$v = v_0 \left(T_e / T_0\right)^{1/2}.$$

3. Results and Discussion

We now address a detailed numerical analysis of CH effects on parametric dispersion and amplification in a III-V semiconductor at 77K duly irradiated by a nanosecond-pulsed 10.6μm CO_2 laser. The representative physical constants have been taken from Nimje at el.[1].

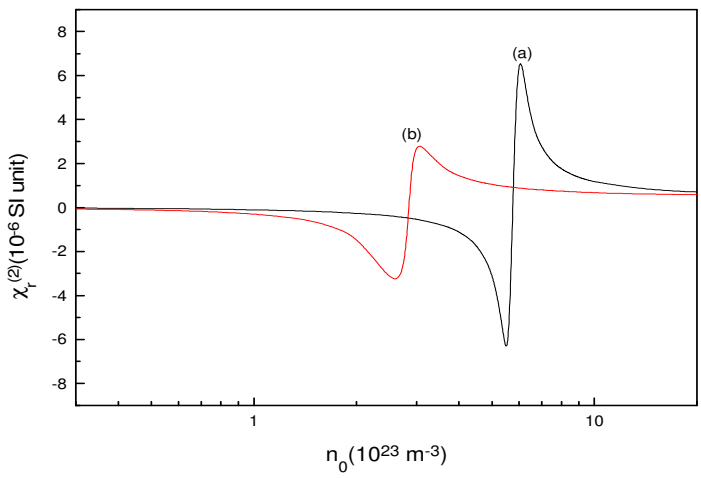

Fig. 1 Variation of real part of DISO nonlinear susceptibility $[\chi_d^{(2)}]_r$ with carrier concentration n_0.

In both the Figs. 1 and 2, curve (a) and (b) stand for with and without CH effects at $E_0 = 4.38\times10^6 Vm^{-1}$ when $\omega_c = 1.758\times10^{12} s^{-1}$ and $k = 3\times10^8 m^{-1}$.

From Fig. 1, one can infer that there exists a distinct anomalous parametric dispersion regime that varies in magnitude with n_0. It appears worth mentioning that $[\chi_d^{(2)}]_r$ can be both positive and negative under the anomalous regime. For $\omega_p < \omega_a$, $[\chi_d^{(2)}]_r$ is a negative quantity and

decreases with increase in n_0. A slight increase in tuning between ω_p and ω_a, beyond this point causes a sharp rise in $[\chi_d^{(2)}]_r$, first making it vanish when $\omega_p \approx \omega_a$. After the resonance conditions, $[\chi_d^{(2)}]_r$ increases very sharply. With further increase in the values of n_0, $[\chi_d^{(2)}]_r$ decreases rapidly and saturates at larger values of excess doping concentrations. It can also be inferred from this figure that the incorporation of CH effects enhances $[\chi_d^{(2)}]_r$ by a factor of 2 and widens the range of doping concentration at which change of sign occurs.

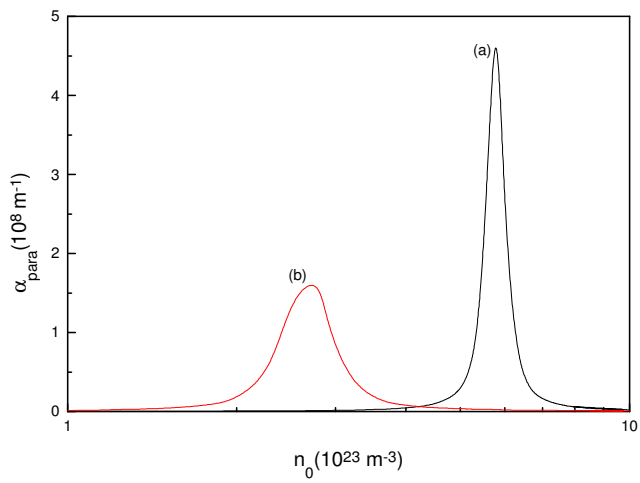

Fig. 2 Variation of gain coefficient of AW α_{para} with carrier concentration n_0

It is illustrated in Fig. 2 that for both the cases amplification increases sharply with increase in the value of excess carrier concentration n_0 and attains a peak value at n_{01} (say). If we further increase n_0, the gain coefficient starts reducing and beyond another critical value of n_{02} (say), the gain nearly disappears. The critical value n_{01} at which maximum gain is achieved, shifts towards higher magnitude in presence of carrier heating effects. In absence of heating effect $[\alpha_{para}]_{\max} \approx 1.6\times10^8 m^{-1}$ is achieved at $n_0 \approx 2.7\times10^{23} m^{-3}$ while in presence of heating effect $[\alpha_{para}]_{\max} \approx 4.6\times10^8 m^{-1}$ is obtained for $n_0 \approx 5.8\times10^{23} m^{-3}$. Thus, the incorporation of CH effects enhances the parametric gain coefficient by a

factor of 3 but for it one has to increase the doping concentration by a factor of 2. The inclusion of CH effects narrows the gain spectrum remarkably. This established that CH has an important role in deciding the gain profile characteristics.

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