Large scale magnetic field influence on trap recharging waves in InP:Fe and GaAs:Cr

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Abstract An impressive linear influence of a magnetic field on optically generated trap-recharging waves (TRW) has been observed in InP:Fe and GaAs:Cr. The phenomenon appears for the particular orientation of \( \vec{B} \) parallel to the samples’ surface and orthogonal to the direction of the electric field \( \vec{E} \) and wave vector of the TRW \( \vec{K} \). The results are qualitatively explained taking into account the Lorentz force and a pronounced inhomogeneity of the charge transport and of the TRW parameters.

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1 Introduction

Investigations of space-charge waves (SCW) in high resistive semiconductors are a powerful tool for the characterization of material properties and for the investigation of general aspects of wave processes, both linear and nonlinear, in solids [1]. SCW investigations are well known for photorefractive crystals with sillenite structure [2, 3], but there are only very few publications concerning ‘classical’ semiconductors (for instance, for InP:Fe [4] or CdTe:Ge [5]). There are also few publications concerning investigations of hologram recording at the presence of a magnetic field (see, for instance, Dam-Hansen et al. [6]), or the interaction of non-steady state photocurrents in photorefractive materials with a magnetic field [7, 8]. The latter are related to the problem of the interaction of the current excited by the interference light pattern with a magnetic field. Recently, we have addressed our attention to investigations on the interaction of SCW with magnetic fields with InP:Fe [9] and GaAs:Cr, as examples. In these samples, trap-recharging waves (TRW) appear with the eigenfrequency being inversely proportional to its wave number [11]: \( \Omega \propto 1/K \). Two kinds of interactions have been discovered, which are dominated by the presence of magnetoresistance (InP:Fe) and of a negative differential conductivity (GaAs:Cr).

In this paper, extended experimental results of our study of a magnetic field influence on TRW in InP:Fe and GaAs:Cr are presented. These data are interesting because the signal change with an application of a magnetic field strongly exceeded the observations of the previous experiments [9]. Moreover, these changes were linear as a function of the magnetic field strength. The difference in the setups used was the orientation of \( \vec{B} \), relative to the sample surface—in this manuscript, we studied the case of \( \vec{B} \) lying in the plane of the surface. For the previous studies, we used a magnetic field which was perpendicular to it. This modification to the experimental geometry was accompanied by inhomogeneities of samples’ conductivity and internal electric fields which strongly influenced the TRW propagation. It is remarkable that this influence was dependent on the direction of the magnetic field. Our findings are explained simply by taking into account the action of the Lorentz force on the carrier transport. Although our key findings can be well understood, several further interesting results were found, which require a more detailed study of these phenomena.
3 Space-charge wave background

The oscillating light interference pattern can be described by
\[
W(x, t) = W_0 \left[ 1 + m \cos(Kx + \Theta \cos \Omega t) \right]
\approx W_0 \left[ 1 + m \cos(Kx) - \frac{1}{2} m \Theta \left[ \sin(Kx + \Omega t) + \sin(Kx - \Omega t) \right] \right], \quad (1)
\]
where \( W_0 \) is the average light intensity, \( K = 2\pi / \Lambda \) with the period of the light interference pattern \( \Lambda \), and \( m = 2\sqrt{I_R - I_s} / (I_R + I_s) \) is the modulation depth of the light interference pattern generated by two coherent laser beams of intensity \( I_{R,S} \). The intensity distribution, according to (1), represents a static and two running charge gratings propagating in opposite directions. The interaction of static and running gratings is of key importance for the space-charge wave study because: (1) resonance may occur if the phase-modulation frequency \( \Omega \) and the spatial frequency \( K \) of the exciting light pattern and those of the eigenmode of TRW coincide [2]; (2) the SCW-interaction can be detected electrically via the appearing ac-current in an external electric circuit. For TRW excitation, the presence of an externally applied electric field \( E_0 \) is required [10, 12].

4 Experimental results

The experimentally determined dependencies of the TRW-current \( I_1 \) as a function of the excitation frequency \( \Omega / 2\pi \) are depicted in Fig. 2. The results are presented for both samples under study, InP:Fe (Fig. 2(a)) and GaAs:Cr (Fig. 2(b)), and the following experimental conditions: \( E_0 = 5 \text{ kV/cm, } K = 1.8 \times 10^3 \text{ cm}^{-1} \), and \( m = 0.48 \) (InP:Fe); and \( E_0 = 0.5 \text{ kV/cm, } K = 1.8 \times 10^3 \text{ cm}^{-1} \), and \( m = 0.46 \) (GaAs:Cr). We note that the data points are normalized to the maximum value of the ac current, i.e., to the ac current detected at resonance \( I_1(\Omega_R) \) for \( B = 0 \text{ mT} \). The results without the application of a magnetic field \( (B = 0 \text{ mT}; \text{triangles in Fig. 2}) \) are in full accordance with our previous findings [9]: Resonant excitation of the TRW is found at frequencies of \( \sim 2 \text{ kHz} \) (InP:Fe) and \( \sim 200 \text{ Hz} \) (GaAs:Cr), both with maximum amplitudes in the order of \( 10 \text{ nA} \) and a quality factor in the range \( 0.15 \leq Q \leq 0.5 \).

The application of a magnetic field dramatically changes the amplitude of the resonance and all changes are strongly dependent on the direction of \( \vec{B} \). For InP:Fe, an application of a “positive” \( \vec{B} \) of strength \( B = +471 \text{ mT} \) reduces the current by more than 40%, while the application of a “negative” \( \vec{B} \) of the same amount increases it by approximately the same amount. For GaAs:Cr, these reductions/increases in presence of magnetic fields are even more pronounced: changes of about 100% are found.