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EXPERIMENTAL STUDIES OF LIGHT DIFFRACTION ON DYNAMIC GRATINGS IN NONUNIFORM ELECTRIC FIELDS

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Nonuniform external microwave electric field and internal space-charge electric field are found responsible for transient grating diffraction efficiency enhancement in nanosecond and picosecond time scale in bulk crystals of Si, GaAs, and CdTe.

1. Introduction

The different problems of carrier transport can be solved by using light diffraction on dynamic gratings technique. Measurements of kinetic coefficients at high carrier concentrations, influence of doping or radiation defects, mapping of growth defects have been carried out in numerous works [1,2]. Generation of grating-like distribution of free carriers and their heating by external electric field allowed us to measure hot carrier ambipolar diffusion coefficient and field dependences in uniform electric fields, i.e. when grating vector K_g was perpendicular to field orientation [3]. The case when K_g is along direction of field has revealed unexpected features of enhanced diffraction efficiency, and the analysis of time-integrated signals in nanosecond time scale was quite complicated. In photorefractive semiconductors, creation of periodic space-charge electric field takes place due to diffusive decay of initially generated free carrier grating [4], and the direction of this field is always along K_g. Thus, carrier transport peculiarities in nonuniform electric field can be studied in a simple way.

2. Experimental set-ups

In this work we present experimental studies of carrier dynamics by using two different ways for installation the nonuniform electric field in the samples. In the first case, 10 ns duration pulse of YAG-laser ($\lambda = 1.06$ µm) was applied simultaneously with a 200 ns microwave electric field pulse to a sample, and the time-integrated self-diffracted beam intensity on thin grating (with period $\Lambda = 30...40$ µm) was measured. The sample of high-resistivity Si or GaAs was inserted into waveguide, and the field effect was studied in geometry $K_g \parallel E$ (Fig. 1a). In the second case, 30 ps pulse of YAG-laser recorded free carrier (FC) and photorefractive (PR) dynamic gratings in bulk CdTe or GaAs crystals ($\rho = 10...50$ MOm·cm) and time-resolved Bragg diffraction of s- or p-polarized probe beams on grating with $\Lambda = 1.8$ µm was studied. In Fig.1b the configuration of incident intensity, space-charge and electric field are shown. The more details description of these experiments are given in [3,5].

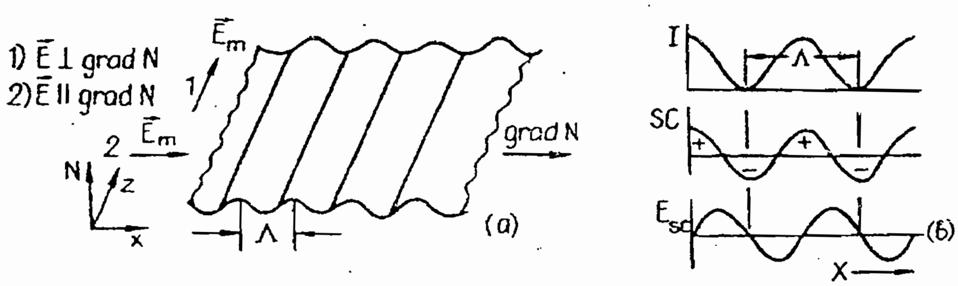

Fig.1. Geometry of external (a) and space-charge (b) electric fields with respect to dynamic grating vector.

3.Results and discussions

Self-diffracted beam efficiency η_E in strong longitudinal external electric fields exceeded one η_0 (without field) essentially (see Fig.2). The smaller was value of Λ, the larger was field effect (in case of Si, for Λ of 42 and 34 µm the ratio of enhancement increased from 1.3 to 1.8). These observations cannot be explained by the model of purely diffusive erasure of a grating, since the corresponding field dependences in transverse electric fields gave evidence of grating erasure time decrease due to hot carrier diffusion (Fig.2). We assume that nonuniform field distribution in the sample due to carrier gradient leads to nonuniform carrier heating and subsequent complex diffusion-drift processes.

Time resolved studies of FC and PR grating dynamics have shown that grating decay constants varies with excitation power and time. The fastest average decay time of electron-like FC gratings in CdTe:V was equal to 80...100 ps at the lowest fluences, when N>>P. With increasing the incident power, decay speed reached its ambipolar value (N=P) with constant of 230 ps. The build-up of π-shifted hole grating due to space-charge electric field and the decay of the latter grating with time constant of ≈400 ps (corresponding to hole mobility 80...90 cm²/V·s) was observed at longer delay times. Thus, diffusion and drift related processes governs FC grating decay (Fig.3a).

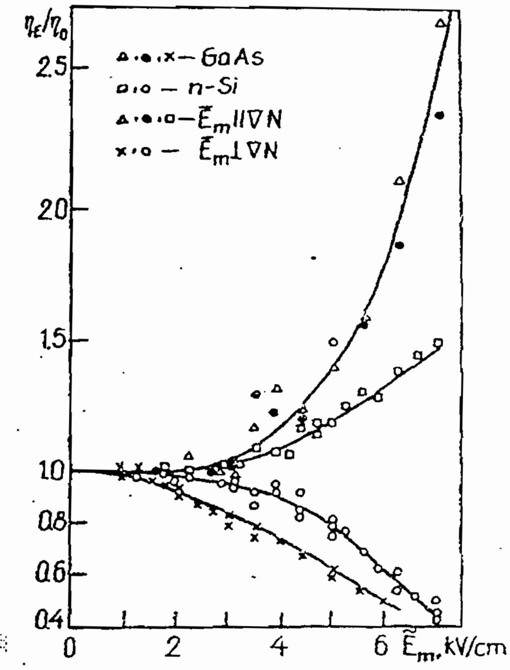

Fig.2. The dependence of self-diffraction efficiency vs. applied external mw electric field in Si and GaAs at T_0=300K.

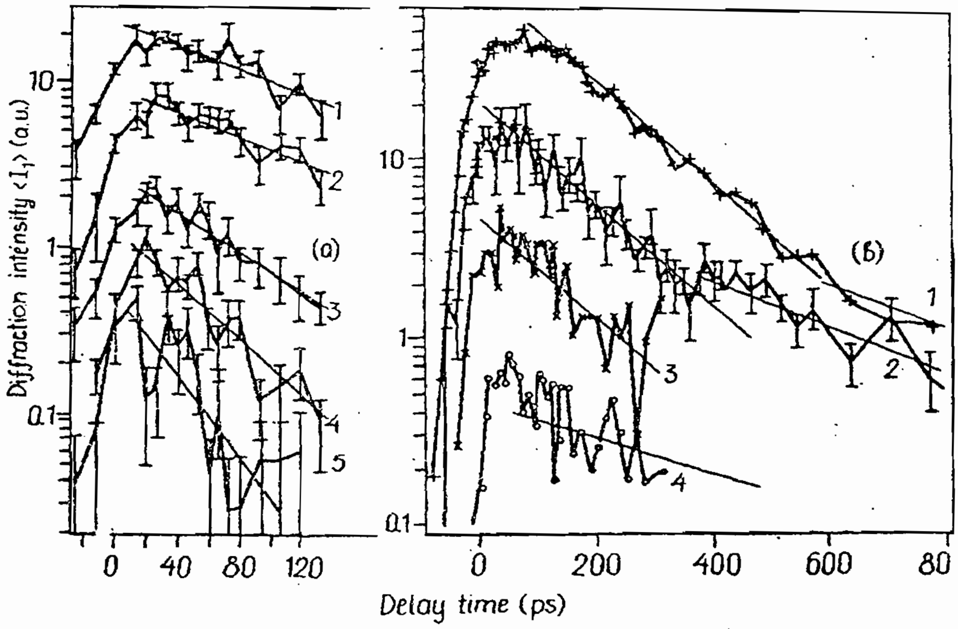

Fig.3. Free carrier (a) and photorefractive (b) grating decay in CdTe at different incident powers (in mJ cm^{-2}):
a) 1-3.3, 2-2.8, 3-2.3, 4-2.0, 5-1.9; b) 1-6.5, 2-4.8, 3-2.9, 4-1.9.

The same processes have been observed in PR grating decay, where Dember field related modulation of refractive index and ambipolar diffusion with the same constant of 230 ps dominated at high excitations. At lower excitations, PR grating build-up was delayed by diffusion time (in order to create SC field between ionized donors and electrons), and this grating relaxed by dielectric relaxation time modified by periodic charge distribution, i.e. with time of 600 ps (Fig.3b). The similar processes have been observed in semi-insulating GaAs: fast diffusion of electrons, generated from EL2 traps, created SC field in 6 ps, and processes of hole drift and ambipolar diffusion were revealed via FC and PR grating decay.

The interaction of two refractive index modulation mechanisms lead to step-like increase of diffracted beam intensity during grating build-up, and to a saw-like modulation of it (i.e. a very fast decay and recovery of diffracted signal) during the grating decay. We attribute this to a strong feed-back between SC field and grating modulation: electron diffusion has created SC field, and the latter redistributes the electron concentration. In addition to impeding their diffusion, the field will enforce carriers to move back to grating peaks and, in this way, will increase grating efficiency. This fine structure exists on both FC and PR grating decay curves (Fig.3a,b).

The observed peculiarities may be explained by existence of nonuniform electric fields in which grating modulation and SC field temporal value do not equilibrate linearly. A time and space varying feed-back strength may create trapezoidal carrier distribution with steep edge at positions $\Lambda/4$, $3\Lambda/4$. A similar behaviour in grating decay was observed in type-II QW heterostructures [6] where carrier confinement to the different layers also create nonhomogeneous electric fields. The alternative model of hot carrier enhanced diffusivity [7] is less reliable because ultrafast oscillations of η we have observed at delay time much longer than the duration of the laser pulse.

In conclusion, the effect of nonuniform external mw and internal SC electric fields leads to carrier redistribution and to increased modulation depth of the dynamic grating. The diffraction of light may serve as sensitive instrument to reveal carrier temporal or integrated redistribution. The modelisation of carrier dynamics in nonuniform electric fields should reveal and predict more features of carrier transport.

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