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Interactions of light with nonequilibrium current carriers generated by laser radiation in gallium selenide crystals

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Abstract

The effect of laser light on nonequilibrium current carriers in GaSe crystals was experimentally studied. A nanosecond Nd:YAG laser with a power of $\sim 10^{26}$ kW/cm^{2}sec was used as a radiation source. It was shown that during two-photon excitation of GaSe crystals, an EMF was observed that reached a value of ~ 1 V at a pump power of $\sim 10^{25}$ kW/cm^{2}sec.

Keywords: laser light, GaSe crystals, nonequilibrium current carriers.
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1. Introduction

When electrons interact with photons, in addition to energy, the electron also receives the photon's momentum, which, in principle, should lead to the emergence of an ordered motion of current carriers relative to the lattice in the direction of light propagation. The magnitude of the resulting flow should depend significantly on both the specific energy band scheme and the mechanism of interaction of light with current carriers. The effect of electron drag by photons is possible, basically, in two variants. In one of them, the process occurs with the simultaneous participation of a third body (for example, a phonon or an impurity center) in addition to electrons and a photon. In the case of such indirect absorption of light, the

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photon's momentum is transferred to the lattice in the interaction act itself. The other variant provides for the participation in the primary interaction act of only two particles: a photon and an electron. An example of such a process is the appearance of recoil electrons in Compton scattering. In a solid, such a possibility is also realized during a direct transition between energy bands. Since in the case of direct interband transitions the observation of the drag effect is difficult due to strong absorption of light, it is convenient from the experimental point of view to choose a system of subbands in the valence band, where due to relatively small absorption coefficients a uniform distribution of light along the length of the sample is easily realized. Of great interest is the study of the phenomenon of dragging of free current carriers by photons in semiconductors in the optical and infrared spectral regions. However, in semiconductors during interband single-photon transitions due to a very high absorption coefficient ($10^4 – 10^5$ cm^{-1}) light is absorbed at very short lengths of the sample, which creates great difficulties in conducting the experiment. Therefore, it is reasonable to study the interband drag effect in two-photon absorption, when the absorption coefficients are small ($\sim 10^{-2} – 10^{-3}$ cm^{-1}) and the entire volume of the sample works effectively. Detection of the phenomenon of carrier drag by photons in semiconductors can be used to create ultra-fast, subnanosecond uncooled receivers of pulsed laser radiation in the visible and infrared spectral regions. Such detectors are of particular importance at present in connection with the advent of powerful pulsed lasers capable of generating extremely short light pulses.

It should be noted that layered GaSe crystals are a convenient object for studying the drag effect under two-photon excitation. GaSe crystals, due to their layered structure (covalent bonding along the layers and weak van der Waals bonding between the layers), high nonlinear polarizability, optical homogeneity, high exciton binding energy ($\sim$20 meV), the presence of a fast recombination channel and a natural mirror surface, have become one of the main elements of optoelectronics [1-4].

This work is devoted to an experimental study of the drag effect in GaSe crystals under interband two-photon transitions.

2. Experimental technique

Layered GaSe crystals grown by the Bridgman method were used as the initial material. Since these crystals have a layered structure, it was possible to obtain very thin single-crystal plates by mechanically splitting them off from thick samples. For the experiment, p-GaSe was chosen with a dark conductivity of $\sim 10^{-5}$ Ohm^{-1}cm^{-1} and dimensions of ($10\times5\times5$) mm. The experiments were carried out with a pulsed Nd:YAG laser with built-in 2nd and 3rd harmonic generators designed to generate radiation with a wavelength of 1064, 532 and 335 nm. The laser pulse duration was

10 ns with a maximum power of $\sim$12 MW/cm^2. The radiation intensity was varied using calibrated neutral light filters. The laser beam was directed along the layers, i.e. perpendicular to the "c" axis. To prevent light from getting on the contacts, they had the shape shown in Fig. 1. The amplitude value of the potential difference arising in the direction of light propagation and the shape of the voltage pulse were recorded on an oscilloscope with memory (Tektronix TDS – 2012C) [5]. In the EMF mode at 300 K, a voltage pulse was observed that very accurately repeated all the details of the laser pulse shape, and the direction of the current corresponded to the direction of light propagation. When the sample was illuminated from the opposite side, the voltage pulse changed its polarity without changing in amplitude.

3. Experimental results and their discussion

The experimental dependence of the drag EMF on the laser radiation intensity I_0 is shown in Fig. 2. As can be seen from the figure, within the range of intensity variation $(1 \cdot 10^{24} - 2 \cdot 10^{25})$ kv/sm^2, the dependence of the EMF on I_0 is close to quadratic.

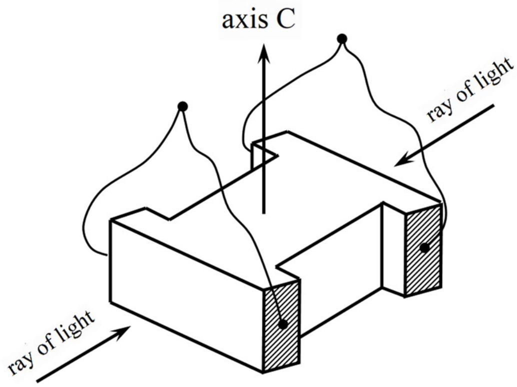

Fig. 1. Mutual position of the GaSe sample and the laser beam. The drag EMF can be written in general as follows [6].

$$E = \int_0^l \frac{A[I(x)]^2 \cdot S_{l.} dx}{S_T[(S_{l.}/S_T) \cdot \sigma_l(x) + \sigma_T]} \quad (1)$$

where x is the current coordinate along the length of the sample, $S_{l.}$ is the area of the light channel, S_T is the area of the dark part of the sample, σ_T is the dark conductivity of the sample, $\sigma_{l.}(x) = \sigma_T + \sigma_{in.}(x)$ is the light conductivity of the sample, $\sigma_{in.(x)}$ is the “introduced” conductivity of the sample, A is a constant coefficient, l is the length of the sample,

$$I(x) = \frac{I_0\, exp(-\alpha x)}{1 + (\beta/\alpha) I_0 (1 - exp(-\alpha x))} \quad (2)$$

where I_0 is the intensity of light falling on the sample, α is the coefficient of one-photon absorption, β is the two-photon absorption constant.

In this case, when the change in the resistance of the sample can be neglected ($R(x) = const$), that is, when $\sigma_{in.}(S_{l.}/S_T) \ll \sigma_T$ (relatively small intensities), it is easy to show that the drag EMF $E \sim I_0^2$ at $\alpha l \gg 1$ and $(\beta/\alpha) I_0 < 1$.

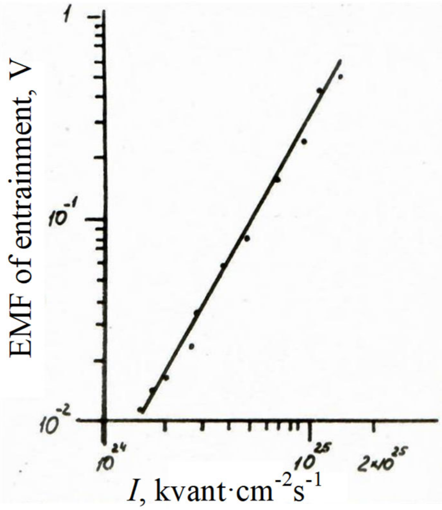

Fig.2. Dependence of the drag EMF on the intensity of the incident radiation in GaSe crystals.

At high intensities, when $\alpha_{in.}(S_{l.}/S_T) \geq \sigma_T$, it is necessary to take into account the change in the resistance of the sample due to the entrainment of the carrier concentration in the light channel, which will lead to the dependence of the EMF on I_0 being obviously less than quadratic. If we are dealing with single-photon entrainment, then the dependence of the EMF on the intensity of the incident radiation should be linear (if the resistance of the sample does not change) and weaker than linear if the resistance of the sample decreases with increasing intensity.

All these facts convincingly indicate that the obtained effect, firstly, is associated with the directed action of light and, secondly, that the cause of its occurrence is two-photon interband transitions. The volumetric nature of the effect was also indicated by the dependence of the amplitude value of the signal on the length of the sample. For this purpose, samples of a large cross section of 5×5 mm^2 were cut out (in this case, the propagation of the light beam along the length of the sample occurred without contact with the side walls) and the dependence of the arising EMF on the length of the sample was recorded on them. The dependence turned out to be linear, which indicates that the effect is volumetric.

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