SPECTRAL OSCILLATIONS OF PHOTOCURRENT IN INDIUM ANTIMONIDE, DUE TO ABSOLUTE NEGATIVE CONDUCTIVITY IN A QUANTIZING MAGNETIC FIELD

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1. One of the authors has shown earlier [1] that the effect of absolute negative conductivity (ANC) is possible in a semiconductor illuminated by monochromatic light in the presence of a quantizing electric field.

It was noted that the conditions for realizing ANC

$$\tau_e < \tau_{ak},\ \tau_{ee},\ \tau_{eh} \tag{1}$$

are satisfied in pure p-type indium antimonide (here τ_e is the lifetime of the electron in the conduction band; τ_{ee}, τ_{eh}, and τ_{ak} are the energy relaxation times in collisions with electrons, holes, and acoustic phonons). Under these conditions, the photoelectrons are localized in energy near the energy ω with which they were produced in the conduction band. The value of the ANC varies periodically with ω, and reaches a maximum whenever the energy of the photoelectrons coincides with the Landau level. If the photoelectron energy becomes larger than the energy ω_0 of the optical photon, then a rapid discharge of the photoelectron takes place, with emission of an optical phonon, after which the process is repeated. The number of maxima in each series is

$$N_s = \begin{cases} \left[\dfrac{\omega_o}{\Omega}\right] + \left[\dfrac{\omega_o}{\Omega} - \dfrac{g}{2}\dfrac{m}{m_o}\right] + 2, & \omega_o > \dfrac{g}{2}\dfrac{m}{m_o}\Omega \\ 1, \quad \omega_o \leqslant \dfrac{g}{2}\dfrac{m}{m_o}\Omega \end{cases} . \tag{2}$$

The condition for the maximum ANC, with allowance for the spin splitting of the Landau levels, is

$$\omega - \left[\frac{\omega - (1/2 - gm/4m_o)\,\Omega}{\omega_o}\right]\omega_o = \Omega\left(N + \frac{1}{2} \pm \frac{g}{4}\frac{m}{m_o}\right), \tag{3}$$

$$0 \leqslant N \leqslant [\omega_o/\Omega],$$

where g is the spin splitting factor, m_0 the mass of the free electron, [x] the integer part of the number, and $\Omega = eH/mc$.

2. We have investigated experimentally the spectrum of the photocurrent in a strong magnetic field, at helium temperatures in pure p-InSb, where the ANC conditions (1) are satisfied for electrons. Samples with hole densities 8×10^{12} cm^{-3} (No. 1), 1.7×10^{12} cm^{-3} (No. 2), and 9.2×10^{12} cm^{-3} (No. 3) and with dimensions 10×0.5×2 mm were etched in CP-4 and placed directly in the liquid helium. The magnetic field, produced by a superconducting magnet, was applied perpendicular to the current and to the incident radiation. The source of the monochromatic radiation was an IKS-21 instrument. The measurements were made in a constant electric field of intensity 0.1 V/cm. The photoconductivity signal was measured with a narrow-band tuned amplifier and a synchronous detector, and was plotted with an automatic recorder.

Figure 1 shows the spectral dependence of the transverse photocurrent for sample No. 1 in a magnetic field H = 15 kOe. (A similar dependence was obtained for sample No. 2.) A

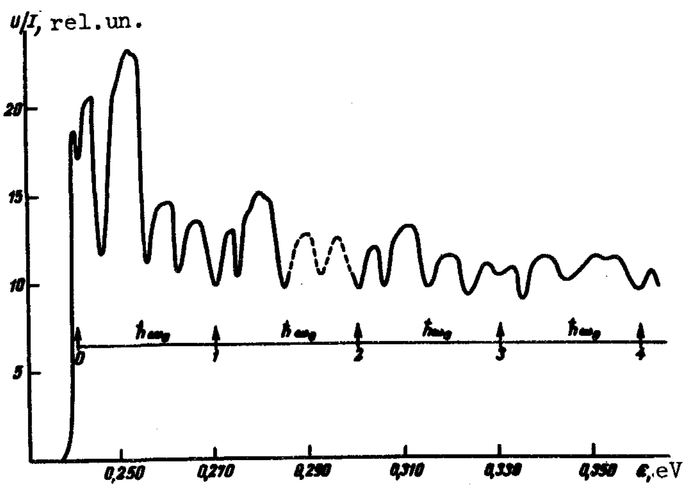

Fig. 1

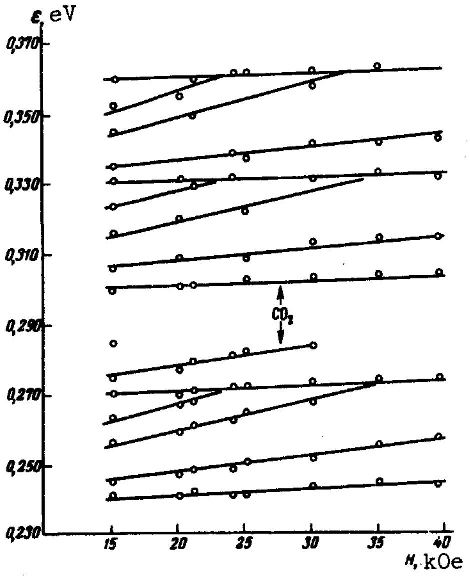

Fig. 2

Fig. 1. Spectral dependence of the photocurrent for sample No. 1 (T = 4.2°K, H = 15 kOe). Ordinates - photoconductivity signal per unit photon flux, abscissas - photon energy in electron volts.

Fig. 2. Positions of photocurrent minima vs. magnetic field for sample No. 1.

characteristic feature is the oscillating character of the spectral dependence, which reveals series with periods equal to ω_0.

The positions of the minima in the first series coincide with the maxima of the absorption coefficient [2]. Figure 2 shows the dependence of the positions of the minima of the photocurrent on the magnetic field. The minima of the series have different rates of displacement with the magnetic field. The distance between the minima of different series is close to the energy of the optical phonon.

No photocurrent oscillations were observed for sample No. 3. It should also be noted that the measurements were made on thick samples, whose thickness greatly exceeded the diffusion length and the absorption length. Special measurements have shown that the spectral photoconductivity peak due to surface recombination [3] is missing. It can therefore be assumed that the photocurrent oscillations are not connected with oscillations of the absorption coefficient.

3. The arguments presented below show that the observed photocurrent oscillations are apparently due to ANC of the electrons in the conduction band.

It must first be taken into account that the total photocurrent consists of an electron component and a hole component

$$I(\omega) = I_e(\omega) + I_h.$$

In p-InSb, the non-equilibrium holes have time to become thermalized, so that their current is positive and is independent of ω. Recognizing that the hole lifetime in p-InSb greatly exceeds τ_e [4], it is clear that $I_h > |I_e(\omega)|$, and the total photocurrent is positive. Under these conditions the maxima of the ANC of the electrons become manifest as minima of the total photocurrent. We assume that this is exactly the reason for the oscillating character of the spectral dependence of the photocurrent (see Fig. 1), which agrees fully with the theoretical notions advanced in Sec. 1. A comparison of the number of minima in the period in accordance with formula (2), and also of the rate of displacement of the minima in accord with (3), with the experimental values show good agreement.

The absence of oscillations in more highly doped samples is apparently due to the violation of the condition (1) and confirms our point of view.

4. The results enable us to point to a method of attaining complete ANC. To this end, it is necessary to use the impurity photoconductivity in p-InSb, so as to get rid of the thermalized non-equilibrium holes.

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LINE STRUCTURE OF GENERATION SPECTRA OF LASERS WITH INHOMOGENEOUS BROADENING OF THE AMPLIFICATION LINE

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It is known that the generation spectrum of an Nd^{3+} glass laser has a line structure. Various hypotheses have been advanced to explain this structure, such as the analytic properties of the gain function [1] or the fluctuating character of the emission [2]. In our opinion, the line structure of the generation spectrum of a laser with an inhomogeneously broadened line is due to the high sensitivity of the generation spectrum to the presence of frequency-dependent losses in the resonator. It can be shown that introduction of frequency-dependent losses of the type

$$\frac{1}{T(\omega)} = \frac{1}{T_0} - \Delta\left(\frac{1}{T}\right)\cos\frac{r\pi\omega}{\Delta\omega} \tag{1}$$

into the resonator leads to the appearance in the laser spectrum of dips with relative intensity

$$\frac{\Delta I}{I_0} = \frac{\Delta(1/T)}{1/T_0}\left(\frac{ST_0}{I_0} + \frac{I_0}{PT_0}\,e^{-\frac{2\pi\gamma}{\Delta\omega}}\right)^{-1} \tag{2}$$

where ST_0, I_0, and P are respectively the spontaneous-noise power, the generation power averaged over the frequency, and the pump power in a unit frequency interval. Formula (2) is based on the assumption that the inhomogeneous width is infinite, and that the homogeneous broadening is characterized by a dispersion contour with width γ.

Frequency-dependent losses of type (1) can be produced by placing in the resonator a plane-parallel layer of matter of optical thickness ℓ. The interference of the light reflected from its surfaces causes its transmission to depend on the frequency in accordance with formula (1), where $\Delta\omega = 1/2\ell$.

A cell made up of two wedge-like glass plates with strictly parallel internal surfaces was placed inside a confocal resonator with spherical mirrors (R = 1 m).

It follows from (2) that the sensitivity of the generation spectrum to the presence of losses depends on the ratio $2\pi\gamma/\Delta\omega$.

We used two cells of different thickness, $\ell_1 = 0.45$ cm ($\Delta\omega = 1.1$ cm$^{-1} \ll \gamma$) and $\ell_2 = 0.025$ cm ($\Delta\omega = 20$ cm$^{-1} \sim \gamma$). The loss modulation depth $\Delta(T^{-1})/T_0^{-1}$ depended on the coefficient of reflection from the interface between the glass and the layer of matter in the cell. The matter employed was a mixture of benzene and chlorobenzene, chosen such as to have a minimum reflection coefficient.