Oscillations of polarization of recombination radiation of a variable gap semiconductor in a magnetic field

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An oscillatory character of the variation of the degree of polarization is observed and is due to recombination of spin-polarized electrons in a variable-gap semiconductor in a magnetic field, as a function of the energy of the emitted quanta at a fixed magnetic field, and as a function of the magnetic field at a fixed quantum energy.

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1. Optical orientation of the electron spins in semiconductors has been under intensive study in recent years. Spin-polarized electrons are excited by circularly polarized light, and the degree of their orientation is determined directly from the degree of polarization of the recombination radiation. A magnetic field *H* perpendicular to the exciting light beam causes precession of the spins around the field direction. The recombination radiation consists of photons produced upon recombination of electrons whose spins are in different rotation phases. As a result, in an ordinary semiconductor, where the optical transitions that occur at different points of the crystals are energywise equivalent, the magnetic field causes depolarization of the radiation. The polarization preserves the sign in this case, since the number of electrons with initial spin orientation is always maximal as a result of the recombination and relaxation processes.[1]

2. The polarization of the recombination radiation should have a qualitatively

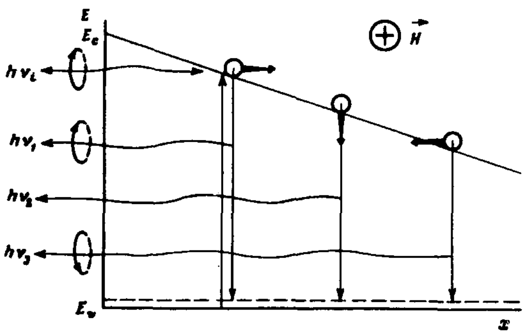

FIG. 1. Energy program of variable-gap semiconductor of *p*-type. The magnetic field (*H*) is perpendicular to the plane of the figure.

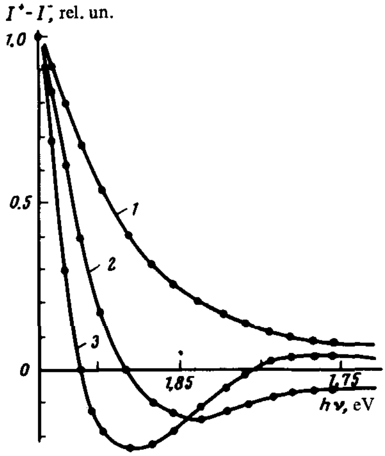

FIG. 2. Plot of $(I^+ - I^-)$ against the quantum energy $h\nu$ at different values of the magnetic field H, kOe: 1—0; 2—1; 3—2.7. The ordinates of curves 2 and 3 are shown with magnification 3 and 14 times, respectively.

different character in the case of a variable-gap semiconductor—a semiconductor with a continuously variable forbidden-band width inside the crystal. In such a semiconductor, the optical transitions that occur at different points of the crystal turn out to be energywise not equivalent, and therefore the emission spectrum should carry information concerning the motion of the carriers and their spins.

Figure 1 shows the energy diagram of a variable-gap semiconductor of p-type, exposed to stationary illumination from the side of the wide-band surface, by circularly polarized light with photon energy $h\nu_i$. This light excites electrons with spins oriented along the x axis. The electrons drift under the influence of the quasi-electric field of the variable-gap semiconductor in the direction of the decreased width of the forbidden band and diffuse, gradually vanishing as a result of recombination. The electron spins behave in similar fashion, the only difference being that the average spin per electron can vanish also as a result of relaxation processes. In a transverse magnetic field, the spins will also precess as they move. As a result, the spins arrive at different points of the semiconductors with different phases, determined by the time of motion and by the precession rate (by the magnitude of the magnetic field). Since different points of the crystal differ in the energy of the emitted quanta, this leads to the appearance of oscillations of the degree of polarization in the spectral emission band of the variable-gap semiconductor. The degree of polarization of the radiation emitted in a direction opposite to the exciting beam is proportional to the x-component of the average spin per electron. If the spin executes one complete revolution in the course of its drift-diffusion motion, then the degree of polarization of the radiation reverses sign twice as a function of the energy of the emitted photons ($h\nu$), and executes one complete oscillation. For example, according to Fig. 1, where the spins of the electrons are arbitrarily designated at different points of the semiconductor, the recombination radiation emitted in a direction opposite to exciting beam will have right-hand circular polarization for the photon energy $h\nu_1$, no polarization at $h\nu_2$, and left-hand polarization at $h\nu_3$.

Thus, the degree of polarization of the radiation of the variable-gap semiconductor in a magnetic field should have an alternating-sign oscillatory character as a function of the energies of the emitted photons. With increasing magnetic field, the period of the oscillations should decrease because of the increase in the precession frequency of the spin, and the damping of the oscillations should increase, reflecting the dephasing of the spins as a result of diffusion.

At a fixed emission-photon energy ($h\nu < h\nu_i$), the degree of polarization should also oscillate with increasing magnetic fields, since the direction of the spin with which the electron arrives at a given point of the crystal (with $E_g = h\nu$) changes with increasing H as a result of the increased precession frequency.

3. For an experimental observation of the oscillations of the recombination-radiation polarization we used variable-band crystals p-(GaAl)As, in which the width of the forbidden band decreases with a gradient of 160 eV/cm, from a value 1.98 eV on the illuminated surface. The crystals were grown by liquid epitaxy and were doped with zinc to a hole density $(3-5)\times 10^{17}$ cm^{-3}. We registered the recombination radiation emitted in a direction opposite to that of the exciting beam. The crystal temperature was 77 K. The stationary excitation of the nonequilibrium carriers was effected by circularly polarized light of an He—Ne laser ($h\nu_i = 1.959$ eV).

Figure 2 shows plots of the intensity difference between the right- and left-hand polarizations $(I^+ - I^-)$ against $h\nu$ without a magnetic field and at different values of the transverse magnetic field. At $H = 0$, the difference $(I^+ - I^-) = f(h\nu)$ decreases exponentially with decreasing $h\nu$, remaining positive. In a magnetic field, the difference $(I^+ - I^-) = f(h\nu)$ is of alternating sign, decreasing in amplitude with increasing magnetic field. The energy period of the oscillations of the difference $(I^+ - I^-)$ decreases with increasing H.

As follows from Fig. 2, at a fixed value of $h\nu$ the difference $(I^+ - I^-) = f(H)$ has also an oscillatory character as a function of the magnetic field.

4. The experimentally observed effect of the oscillations of the polarization of recombination radiation of a variable-band semiconductor in a magnetic field is theoretically treated by us elsewhere.[2] The formulas given there make it possible, using the experimental data, to determine the parameters that characterize electron transport in a variable-gap semiconductor, namely the lifetime of the nonequilibrium electrons $\tau = 1.1\times 10^{-9}$ sec, the spin-relaxation time $\tau = 4.0\times 10^{-10}$ sec, and the nonequilibrium electron mobility $\mu_c = 8\times 10^3$ cm^2/V sec. We used in the calculation the values of the g factor as given by Hermann *et al.*[3]

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