Rise of hot-hole luminescence in a transverse magnetic field

Yu. L. Ivanov

A. F. Ioffe Physicotechnical Institute, Academy of Sciences of the USSR, Leningrad

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The hot-hole luminescence integrated over the far-IR spectrum has been studied in p-type germanium in a strong transverse magnetic field. The luminescence rises sharply when traps appear in the light-hole band.

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The accumulation of hot holes in a light-mass band in germanium in strong, crossed electric and magnetic fields has been the subject of several theoretical papers.[1-3] The effect was recently confirmed experimentally by Valov *et al.*,[4] who studied the galvanomagnetic behavior. Vorob'ev *et al.*[5] worked from a study of the near-IR absorption to calculate the light-hole disbribution in crossed fields and concluded that the hole population becomes inverted. It has been mentioned in several places (Ref. 1, for example) that an increase in the concentration of light holes to a value above the equilibrium value could intensify the far-IR emission and lead to stimulated emission in that part of the spectrum.

In this letter we are reporting some preliminary results on the spontaneous emission over a broad spectral interval which arises in p-type germanium upon the application of strong, crossed electric and magnetic fields.

The dimension of the p-type germanium samples along the direction of the applied electric field was far shorter than that along the Hall drift direction. This configuration satisfies the "short-sample" conditions (see Ref. 6, for example), so that the current through the sample in a strong, transverse magnetic field can be assumed dissipative, and the electric field can be assumed equal to the applied field. The sample was positioned in a superconducting solenoid. The emission was detected with a germanium photoresistance doped with gallium to a concentration $\sim 6\times 10^{14}$ cm^{-3}. This type of detector is most sensitive in the far-IR part of the spectrum, in the wavelength interval $\sim$50–120 μm (see Ref. 7, for example). Special experiments showed that there was no emission in the intrinsic absorption region. The photoresistance was positioned $\sim$13 cm from the edge of the solenoid and shielded from the solenoid field by a lead cup. Optical coupling with the sample was provided by a copper tube, used as waveguide. The sample and the photoresistance were directly immersed in liquid helium. Voltage pulses 10 μs long were applied to the sample. The current pulses through the sample and the output pulses from the photoresistance, converted by a synchronous detector, were recorded on an x-y chart recorder. The horizontal deflection on the chart corresponded to the strength of the magnetic field.

We studied two groups of samples, with carrier density of 5×10^{13} and 4×10^{11} cm^{-3}, for various orientations of the fields E and H with respect to the crystallographic axes. The intensity of the emission, which occurred in the absence of a magnetic field in the saturation region of the drift velocity, was found to be proportional to the current through the sample and to the carrier density. When a magnetic field was applied, the luminescence signal intensified, but the behavior of the intensification was different for the two groups of samples. For the carrier density of 5×10^{13} cm^{-3} the signal intensified only comparatively slightly, rising gradually from zero with increasing magnetic field.

With a further increase in the magnetic field, the signal fell off, reaching a level in strong magnetic fields lower than that in the absence of a magnetic field. At its maximum, the signal increased by only 30%, and it shifted toward stronger magnetic fields as the electric field was intensified.

Figure 1a shows some luminescence curves for the carrier density of 4×10^{11} cm^{-3}. The curves are normalized to a unit value in the absence of a magnetic field. Shown for comparison in Fig. 1b are the curves of the current against the magnetic field. At this carrier density the luminescence signal initially remains constant as the magnetic field is increased, but at a certain point, it increases sharply (by a factor of 3), reaches a maximum, and then falls off to values lower than in the absence of a magnetic field.

These results are completely consistent with Vosilyus and Levinson's interpretation[8] of the carrier behavior in crossed E and H fields, if the emission is assumed to result from direct optical transitions of holes from a light-mass band to a heavy-mass band. In weak magnetic fields all the carriers reach the active region, where they emit an optical phonon and return to the vicinity of $p = 0$ in momentum space. The light-hole density remains constant, and the emission intensity does not change.

When the magnetic field reaches a certain value $H_{c_1} = Ec\sqrt{m_l^*/2\epsilon_0}$, where m_l^* is the mass of a light hole, a trap for light holes appears. In momentum space, the light holes occupy a spindle-shaped region[1)] (Ref. 9). Arrows A_1–A_3 in Fig. 1 show the calculated values of H_c, at which the traps appear in the light-hole band, for three

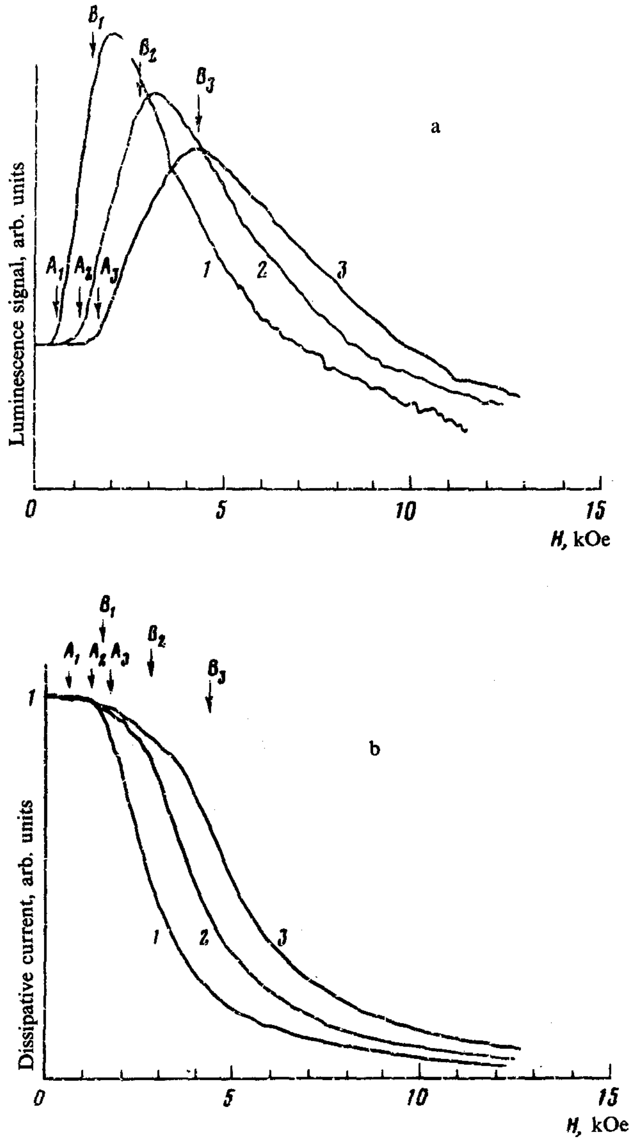

FIG. 1. Dependence of the luminescence signal (a) and of the dissipative current (b) on the magnetic field. 1—$E = 360$ V/cm; 2—$E = 670$ V/cm; 3—$E = 1100$ V/cm.

values of the electric field. The occupation of a spindle-shaped region by the light holes leads to an increase in their density and to an intensification of the emission.

Later, when the magnetic field reaches the value $H_{c_h} = Ec\sqrt{m_h^*/2\epsilon_0}$, where m_h^* is the mass of a heavy hole, a trap appears in the heavy-hole band, and these holes begin to occupy a spindle-shaped region. The curves in Fig. 1 correspond to the case in which the fields E and H and the Hall drift are all in the [100] direction. For this case, we used the value $m_h^* = 0.21\ m_0$ to calculate the values of H_{c_h}, which are shown by arrows B_1–B_3. The filling of the spindle-shaped region by the heavy holes is a process which competes with the accumulation of light holes, so that the density of light holes decreases, and the emission fades. The curves of the current against the magnetic field in Fig. 1b are also in qualitative accordance with this interpretation of the hole behavior. It can be seen (particularly clearly for curve 3) that at the magnetic field shown by arrow A the dissipative current begins to decrease, because holes go from the heavy band to the trap in the light band; at the magnetic field shown by arrow B there is a sharper decrease in the dissipative current, because of the appearance of traps in the heavy band.

A change in the magnetic field evidently changes the emission spectrum. Since the spectral sensitivity of the detector is not flat, the spectral change caused by the magnetic field may distort the dependence of the output signal from the photoresistance on the magnetic field. This distortion may explain the decrease in the signal to a value below the initial value in strong magnetic fields.

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[1)] See also Refs. 2–5 for a detailed discussion of the accumulation mechanism.

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