Electron-hole liquid in indium antimonide in a strong magnetic field

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A new emission band, which is related to decomposition of the electron-hole liquid (EHL) stabilized by a magnetic field, is observed in the magnetophotoluminescence spectra of pure indium antimonide crystals at high levels of excitation.

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The effective electron mass in indium antimonide and therefore the exciton binding energy are extremely small. For this reason, exciton lines are generally observed in absorption[1] and reflection[2] spectra only as a result of application of a comparatively strong magnetic field, which increases the exciton ionization energy. It was shown in Refs. 3 and 4 that in sufficiently strong magnetic fields, the dense electron-hole plasma self-compresses under the action of Coulomb forces, i.e., the energy per pair of plasma particles as a function of the density of electron-hole pairs has a minimum. In this case, the energy per particle pair may turn out to greater in absolute magnitude than the exciton binding energy and the formation of EHL in a magnetic field will be energetically more favorable. In this paper, we report the observation of recombination radiation from EHL stabilized by a magnetic field.

The experiments were performed on n-InSb specimens with dimensions 5×5 mm and thickness 100–250 μm with electron density at nitrogen temperature $(1-2)\times10^{14}$ cm^{-3}. After mechanical polishing, the specimens were etched in SR-4A. A Nd^{3+}YAG laser ($\lambda = 1.06\ \mu$m, power ~1 W) served as a quasistationary photoexcitation source. The luminescence spectrum was analyzed by a MDR-2 monochromator with a grating of 100 lines/mm and was recorded with a Ge:Au photoresistance, cooled to ~100 K. A magnetic field up to 60 kOe was produced with the help of a superconducting solenoid. All measurements were performed at a temperature of 2 K in a Faraday geometry. The magnetic field was oriented perpendicular to the wide face of the specimen.

At low levels of excitation in magnetic fields exceeding ~7 kOe, the recombination-radiation spectrum consists of two well-resolved lines (insert in Fig. 1). The long-wavelength component of the spectrum is apparently related to radiative decay of electron impurity complexes (EIC).[1)] The EIC luminescence intensity first increases linearly with increasing excitation level and then its growth slows down considerably. Moreover, the EIC luminescence intensity increased primarily due to regions in the crystal far from the center of the region in which nonequilibrium carriers were generated. At the same time, the line broadened toward the long-wavelength side and a tail appeared in it, extending into the low-energy range of photons (spectrum 1 in Fig. 1).

The broadening of the line with increasing pumping level is attributable to the appearance of a new emission band in the spectrum on the long-wavelength edge of the

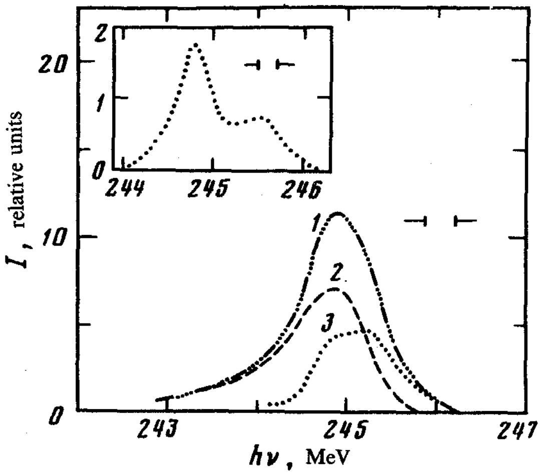

FIG. 1. Emission spectra for high levels (500 W/cm^2) and low (insert) levels of excitation in a 46-kOe magnetic field. The labels on the spectra are explained in the text.

EIC luminescence line. This band can be separated by making use of the fact that the intensity of EIC luminescence depends weakly on the excitation level. The luminescence spectrum recorded with a 20% depth of modulation of the exciting light intensity is represented by curve 2 in Fig. 1. This spectrum was constructed from the spectrum obtained experimentally in this manner, so that the intensity of the line would correspond to a modulation depth of 100%. Spectrum 3 was obtained as a difference of spectra 1 and 2. To reduce the contribution of EIC radiation to the integral luminescence intensity, we recorded spectra 1 and 2 by observing a finite 0.3×0.4 mm region of the crystal with the highest excitation density.

The long-wavelength radiation band produced by strong pumping can also be separated by applying a weak electric field in a direction perpendicular to the magnetic field. For this purpose indium contacts were deposited on the narrow faces of the specimen. For a voltage of 5 V on the specimen, the radiation lines shown in the insert in Fig. 1 decreased considerably, while at a voltage of 10 V they disappeared completely. At the same time, the intensity of the long-wavelength band increased. The effect of the electric field is illustrated in Fig. 2. Spectrum 2 (dashed line) was recorded with

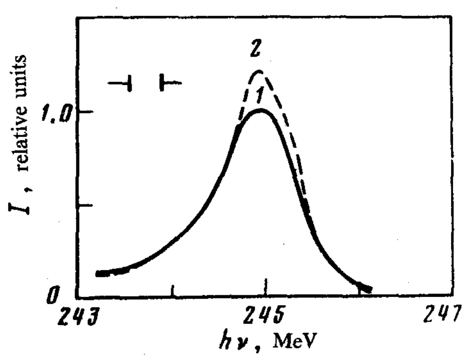

FIG. 2. Effect of an electric field on the luminescence spectrum. Spectrum 2 is for zero electric field. The intensity of the magnetic field is 46 kOe.

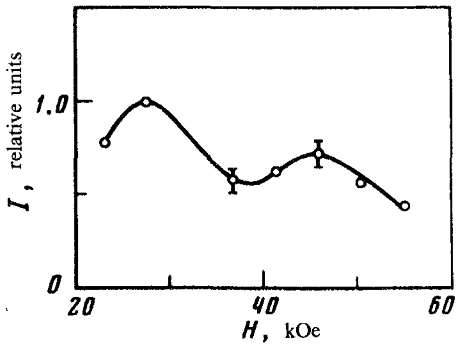

FIG. 3. Dependence of the EHL emission intensity on the magnetic field.

20% modulation of the excitation radiation intensity. In addition, the excitation intensity was not too high, so that the EIC radiation still gives an appreciable contribution to the total radiation intensity. When the electric field is switched on, the spectrum changes due to breakdown of EIC (continuous line), but the shape of the long-wavelength edge of both spectra is the same.

The constancy of the shape and increase in the intensity of the long-wavelength band when the electric field is switched on show that this band is related to the recombination of the electron–hole plasma (EHP).

Figure 3 shows the dependence of the intensity of the EHP radiation on the magnetic field intensity. The oscillatory nature of the dependence is apparently related to the passage of the Landau level of heavy holes (due to the small effective mass and high electronic g factor, all electrons are located in the lower spin sublevel of the zero Landau band) through the hole Fermi level. The oscillations observed indicate convincingly the Fermi degeneracy in EHP.

The short-wavelength boundary of the EHP radiation spectrum is shifted by $\phi \cong 0, 5$ from the red boundary of the spectrum of excitonic magnetoreflection (in a field of 46 kOe). Thus, the spectral position of the long-wavelength-radiation band and its behavior in magnetic and electric fields leads to the conclusion that this radiation is related to recombination of EHL stabilized by a magnetic field.

In conclusion we note that the rough estimate of the EHL density from the width of the emission line $n_0 \sim 10^{16}$ cm^{-3} agrees well with the estimate from the equations in Ref. 3, although under our experimental conditions, these equations are at the limit of applicability.

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[1)]The results of investigations of the magnetophotoluminescence for low levels of excitation will be published separately.

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