Polarization of low temperature photoluminescence induced in germanium by deformation

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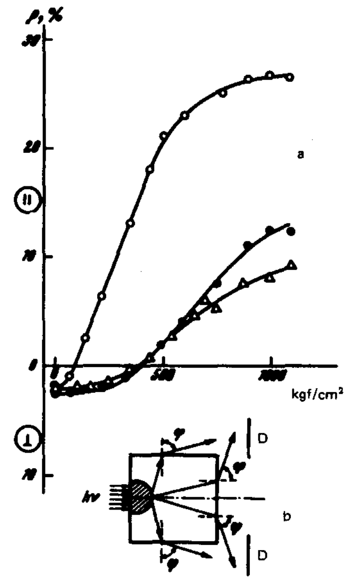
The polarization of recombination radiation of free excitons and electron-hole drops (EHD) in germanium at 1.8–5 °K under conditions of uniaxial compression is investigated. It is observed that the degree of polarization of the radiation of the free excitons and of the condensed phase of the excitons have different pressure dependences.

Polarization effects in the study of optical properties of semiconductors are a powerful means of investigating the structure of the energy bands, of the symmetry of local states, and of a large number of questions connected with the spin-lattice relaxation of the carriers. A determination of the dependence of the recombination-radiation polarization following application of uniaxial compression, as noted in[1], can also help identify the nature of the radiative transitions in semiconductors.



a) Dependence of the degree of polarization ρ of the radiation of free excitons and of the condensed phase of electrons and holes on the uniaxial pressure: ○—free excitons, $T=5$°K, Δ, •—condensate, $T=1.8$°K (the samples were etched in H_2O_2 + NaOH and in CP-4A, respectively). b) Emergence of photoluminescence from Ge sample in the direction of the monochromator slit. View from the top along the compression axis. Shaded part—excitation region; ϕ—Brewster angle for Ge, (≈ 76°); D—diaphragm.

An investigation of the polarization induced by elastic deformation in the emission line of low-temperature photoluminescence of germanium with a quantum energy 708.5 meV (*K* line), was reported in[2]. This photoluminescence was attribed by various authors either to radiation of the condensed phase of electrons and holes,[3–5] or to radiative annihilation of the biexciton.[6] Attainment of a high degree of polarization (~50%) in the *K* line even at low pressures (100–150 kgf/cm²) has led the authors of[2] to the conclusion that this line belongs to biexciton emission.

It is known[4,5] that the behavior of the *K* line in deformed germanium varies significantly with the homogeneity of the applied pressure. It is not indicated in[2] whether the homogeneity of the deformation was monitored. The absence of such a control might have led to uncertainties in the measurement of the degree of the polarization.

We have investigated the polarization of the radiation of pure germanium at temperatures 1.8–5 °K, with the carriers excited with helium-neon laser light of 40 mW power. The polarization was measured with a film polaroid by the usual method.[7] We took into account the distortions introduced by the optical system, by the monochromater, and by the photoreceiver. Samples measuring 2×2×3 mm were cut in such a way that the ⟨111⟩ axis coincided with the compression direction. Prior to the measurements, the samples were polished and etched either in the CP-4A etchant, or in a boiling mixture of hydrogen peroxide with lye.

The homogeneity of the pressure was monitored by measuring first the emission spectra as functions of the pressure for both the *K* line and for the free-exciton line.[4,5]

We found that a noticeable polarization (polarization plane parallel to the compression axis) of the *K* line is observed at pressures exceeding 300–400 kgf/cm², reaching 15–20% at pressures near 1000 kgf/cm². When

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the etchant H_2O_2+NaOH was used, we obtained the same $\rho(P)$ dependence, except that the degree of polarization ρ reached at 1000 kgf/cm^2 was somewhat lower (~10–12%), this being connected with the depolarizing influence of the germanium surface in the case when no polishing etchant is used (the depth of the relief is commensurate with the radiation wavelength $\lambda = 1.7\ \mu$).

It is seen from the figure that the tendency of $\rho(P)$ to saturate appears only at pressures ~1000 kgf/cm^2, when the gap $\delta E_{1,2}$ between the subbands of the light and heavy holes reaches ~3.2 meV[8] and becomes comparable with the Fermi energy of the holes in the condensed phase.[4]. At low pressures (up to 300 kgf/cm^2), the degree of polarization ρ was negligibly small, as expected for the radiation of the condensed phase.[2]

At the same time, the polarization for the free-exciton line increases practically at the lowest pressures ($\Delta\rho/\Delta P = 5\%$ at 100 kgf/cm^2) and saturates at 500–600 kgf/cm^2, when the splitting of the ground state (more accurately, of the components α_1 and α_2 in the absorption lines of the free exciton[8]) greatly exceed kT and the population of the lower state becomes predominant.

It is interesting that a weak temperature dependence of the degree of polarization is observed at 500–600 kgf/cm^2 only when helium goes through the λ point, when the resultant boiling of the helium depolarized the emerging radiation.

We have also noted that the large value of the initial degree of polarization (polarization plane perpendicular to the compression axis) was connected with "edge" effects that occur when the recombination radiation emerges from the lateral surfaces of the sample at the small angle $90° - \phi$, where ϕ is the Brewster angle (76° for germanium). At the customarily used apertures of the focusing system and at the small sample dimensions, this strongly polarized "edge" radiation is incident on the entrance slit of the monochromator. At small shifts of the sample relative to the optical axis of the system, the degree of polarization without compression reached 40–50%. The use of diaphragms, or the use of samples in the form of Weierstrass spheres, when the rays were normally incident on the sample and no polarization occurred upon refraction by the interface between the semiconductor and the vacuum, has made it possible to decrease the initial degree of polarization to values equal to the the experimental error, 2–3%.

This may be the reason for the discrepancy between our results and those of[2]. We note also that the different character of the $\rho(P)$ dependences of the two lines (of the excitons and of the condensed phase) excludes the possibility of explaining the results with the aid of photoelasticity theory.

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