Manifestation of domain instability and the Franz-Keldysh effect in the recombination radiation of CdS single crystals

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It is observed that the formation of domains leads to quenching of the photoluminescence of CdS and to the appearance of low-frequency oscillations of the radiation and of the photocurrent. A long-wave shift of the spectrum, due to the Franz-Keldysh effect, is observed in the domain region.

It is well known that application of an electric field can lead, under certain conditions, to the formation of strong-field regions (electric domains) in a homogeneous semiconductor sample. To investigate the domain instability it is customary to use various probe methods as well as electro-optical measurements.[1] Of considerable interest, in our opinion, may be the investigation of radiative recombination of a sample with domains. Such investigations can yield additional information on the nature of the domain and on the processes that occur in a crystal in the presence of a domain. In addition, measurement of the luminescence in the visible region of the spectrum permits a direct visual observation of the formation and motion of the domain in the crystal. On the other hand, the domain is a macroscopic formation with linear dimensions that are large in comparison with the characteristic mean free path of the carriers. This makes it possible to use it as a "specimen" with high field intensity, and thus investigate the influence of a strong electric field on the luminescence spectra.

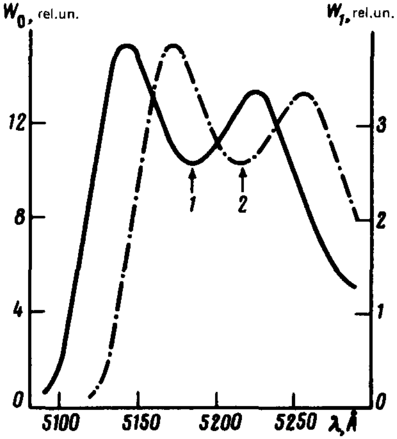
We have investigated the green edge luminescence of high-resistance CdS single crystals. The electric field was applied to the sample through Ohmic contacts. Simultaneously with the field dependence of the radiation intensity $W(E)$, we measured the current-voltage characteristic (CVC) of the sample. The investigated samples were placed directly in liquid nitrogen. The crystal was excited with light uniformly over its volume. The following distinguishing features were observed:

1. The voltage corresponding to the linear section of the CVC produces no noticeable change in the luminescence intensity. At a certain threshold value of the field (5×10^2–10^3 V/cm), corresponding to current saturation in the CVC, a sharply outlined region of width 1–1.5 mm is produced in the uniformly glowing crystal, and the radiation intensity in this region is several times lower than in the remaining part of the sample (the sample lengths were 6–10 mm). The appearance of such a region can be naturally related with the formation of a domain. Indeed, as shown by probe measurements, the voltage decreases mainly in this part of the crystal.

2. An increase of the field leads to a further extinction of the luminescence in the domain, accompanied by low-frequency oscillations of the radiation intensity and of the current in the circuit of the sample. Such photocurrent oscillations were first observed by one of the authors in CdS and CdSe single crystals.[2] The oscillation frequency depends on the excitation intensity.

3. The domain was formed either near the contact or in the central part of the sample. As a rule, reversal of the voltage polarity did not influence the point where the domain was formed.

4. The domain motion (when it was observed) was from the anode to the cathode.



Spectral dependence of the luminescence intensity in the domain region: 1 (W_0)—without an electric field, 2 (W_1)—in a field.

Since the green luminescence of CdS has a strong temperature dependence and is practically completely quenched when the temperature is increased from 77 to 100 °K, it is natural to relate the luminescence quenching in the field with the mechanism of temperature-electric inhomogeneity. Indeed, if the luminescence quenching $\Delta W(E)$ in the domain is measured at the (doubled) frequency of the applied alternating field, then a large inertia is observed in the quenching, and ΔW cannot be registered at a frequency higher than 100 Hz. A comparison of the temperature dependence of the radiation in the range 77—100 °K with the $W(E)$ dependence has made it possible to determine the sample temperature in the region of the domain, which reached 85—90 °K.

It should be stated that in piezoelectric semiconductors such as CdS, there can occur in addition to the temperature-electric inhomogeneity, at the same values of the threshold field, also an acoustoelectric inhomogeneity due to phonon generation. Since both these processes cause inhomogeneities of the electric field and of the temperature, one process stimulates the other, and a coupled inhomogeneity can be observed in experiment. Thus, the domain motion observed by us, from the anode to the cathode, is obviously due to the temperature gradients produced along the crystal as the result of phonon generation.[3]

It was of interest to investigate the influence of the field in the domain on the spectral distribution of the radiation. In the figure we compare the luminescence spectra obtained without a field (curve 1) and in the presence of a field (curve 2) in the domain region. We see that the electric field of the domain shifts the spectrum towards the long-wave side, and this shift reaches 30 Å in an approximate field 10^4 V/cm. On the other hand, an increase of the sample temperature from 78 to 100 °K does not cause a noticeable shift of the spectrum, in accord with the available published data on the very weak temperature shift of the spectrum of the green luminescence of CdS.[4] Thus, the shift of the spectrum in the domain is due to the Franz-Keldysh effect. Insofar as we know, the Franz-Keldysh effect was never observed in the luminescence of CdS, although attempts to observe it were made.[5]

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