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Abstract

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PHYSICS

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RECOMBINATION RADIATION IN LEAD SELENIDE LAYERS

(Presented by Academician A. A. Lebedev, July 27, 1964)

The photoelectric properties of layers of lead chalcogenides have been studied over the last two decades in connection with their use as detectors of infrared radiation. Their optical properties have been less investigated; thus, for example, recombination radiation has been observed only in layers of lead sulfide ⁽¹⁾.

In the present work the spectrum of recombination radiation of a lead selenide layer is described, the spectra of photoconductivity and photoluminescence of layers of lead selenide and lead sulfide are compared, and a unified interpretation is proposed for the observed parallelism in the spectral shift of both effects, based on the heterogeneity of the composition of the layers.

Measurements of the luminescence spectra were carried out on an apparatus consisting of a Pfund-type mirror monochromator with a diffraction grating of 200 lines/mm, a detector-cooled lead telluride photoresistor, an alternating-current amplifier V6-2, and an EPP-09 recorder. Excitation was produced by the radiation of a DRSh-250 mercury lamp, whose thermal radiation was removed by a cell with water. Modulation of the exciting light was performed with a perforated disk. A germanium light filter was used to filter the luminescent radiation. The spectral curves were corrected for the selectivity of the detector and the nonuniformity of the energy distribution in the echelette. The photoconductivity spectrum was recorded on an IKS-12 spectrometer; the magnitude of the photoresponse was calculated per unit of incident radiation measured by means of a thermoelement.

Fig. 1. Spectra of photoconductivity (1) and luminescence (2): *a* —activated lead selenide layer at 20°; *b* —chemical lead sulfide layer at 20°; *c* —chemical lead sulfide layer obtained with a different bath composition.

Lead selenide layers exhibit weak luminescence at room temperature. The spectrum of recombination radiation lies in the region from 3 to 4 μ , with a maximum

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Fig. 2

Figure 2: Fig. 2

near 3.4 μ (see Fig. 1a). The maximum of the photoconductivity* is located near 2 μ ; the characteristic wavelength $\lambda_{1/2}$ (pho-

* The principal photoelectric properties of the investigated lead selenide samples were reported by P. V. Izvozchikov and I. A. Taksami at the Second All-Union Conference on Photoelectric and Optical Phenomena in Semiconductors (2). The author expresses sincere gratitude to them for the samples provided.

corresponding to which is 1/2 of the maximum) is 3.6 μ , which indicates significant reactivation of the layers (cf. (3)). In standard layers $\lambda_{1/2}$ is about 4.7–5.0 μ , which approximately corresponds to the energy gap for the forbidden-band width at 290°K ($E_g = 0.25$ eV).

Figures 1b and c show the luminescence and photoconductivity spectra of two lead sulfide layers obtained under somewhat different deposition conditions. It is characteristic that in both cases the position of the luminescence maximum approximately corresponds to the value of $\lambda_{1/2}$ for the photoconductivity. At the same time, the energy of the emitted quantum considerably exceeds the forbidden-band width determined in single crystals of lead sulfide ($E_g = 0.4$ eV).

Fig. 2. Band diagram for a crystallite of a layer of thickness d . E_g is the forbidden-band width near the substrate, E'_g is the forbidden-band width near the outer surface, E_l is the level of the luminescence center, μ is the Fermi level, $h\nu$ is the quantum whose absorption leads to the appearance of photoluminescence.

This displacement of the luminescence and photoconductivity spectra in the samples is most likely due to the specific composition of the layers, which constitute a complex heterogeneous system. The existing concepts of energy bands in lead chalcogenides are insufficient for explaining the facts under discussion. New considerations must be introduced. First of all, let us determine the nature of the “self-activated” emission. From the totality of various experimental data, not presented here, it may be assumed that the act of emission is associated with recombination of a hole at a center that has previously captured a photoelectron. The level of the center is assumed to be located near the bot-

tom of the conduction band. It is further assumed that the structure of the centers of “self-activated” emission is one and the same in samples of different origin and that they are situated, most probably, in the bulk substance of the layer, closer to the edge of the crystallite, somewhere at the boundary with oxygen-containing compounds. It follows from this that the energy terms of the emission center are determined, on the one hand, by the properties of the lead chalcogenide and, on the other, by the properties of the closely adjoining environment of oxygen-containing compounds. A change in the method of preparing and activating the layers affects both the number of emission centers and their environment. The band diagram for such a system will to some extent resemble the diagram for heterojunctions; i.e., the forbidden-band width becomes a function of coordinate for a given crystallite of the layer (see Fig. 2). The intensity of conductivity in the layers near the outer surface leads to the concentration in them of thermalized holes.

At present it has been established that the high photoconductivity of lead sulfide layers is connected with a process of multiple capture of photoelectrons. This process probably takes place in the inversion region. At the same time, only hot photoelectrons will possess energy sufficient to become localized at capture and recombination centers in the region of maximum hole concentration. The conditions of recombination and capture for thermalized electrons located in places where the forbidden-band width approaches E_g will in the general case be different and, most likely, close to the conditions for unactivated layers. The photoconductivity of the latter is negligible. It follows from this that the “red” limit of the photoeffect in the present case will approach the value $E'_g > E_g$. The energy of the quantum of recombination radiation $h\nu_l$ will also be determined by the value E'_g . This follows from the single nature of the mechanism of displace-

of the position of the center level relative to the bottom of the valence band and of the forbidden-band width at the given point of the crystal. Further, since the gap between the center level and the bottom of the valence band does not exceed kT , an electron that has settled on this level may be regarded as “quasi-free”⁽⁴⁾. In this case the lifetime for radiative recombination will be comparable with the lifetime calculated for band-to-band transitions. The total recombination lifetime (neglecting capture) in the given specimen will be determined by the theoretical value for band-to-band recombination, multiplied by the quantum efficiency of the observed luminescence.

In conclusion, the author expresses deep gratitude to Acad. A. A. Lebedev and L. N. Kurbatov, and also to I. V. Abarenkov and M. M. Petrashchuk, for their interest in the work and valuable comments during its discussion. G. N. Ikonnikova and O. A. Kurzina provided great assistance in the measurements.

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