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Figure 1: Fig. 2. Dependence of brightness on voltage

Abstract

Full Text

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VOLUME ELECTROLUMINESCENCE AND EMISSION OF HOT ELECTRONS FROM SUBLIMATED ZINC SULFIDE FILMS

1. J. Destriau and D. Curie considered the Destriau open luminescence effect in zinc sulfide powder in an electric field as a volume effect ([1,2]). Further investigations showed the special importance, for these phenomena, of processes at the boundaries of two phases ([3]) and of the associated increase in field strength, for example in the so-called Mott-Schottky layer ([4]). The assumption of volume electroluminescence in the Destriau effect was abandoned.

On the other hand, volume electroluminescence was found in certain single crystals (CdS, ZnS) ([5,6]), i.e., luminescence from one electrode all the way to the other; some later works on the electroluminescence of single crystals also point to the same conclusion ([7,8]).

We have observed volume luminescence from one electrode to the other in sublimated zinc sulfide films with a slot-like arrangement of the electrodes.

Fig. 2. Dependence of brightness on voltage

2. The starting material was zinc sulfide activated with copper, available as an industrial product under the grade FK-106. Copper chloride was added to it; the mixture was poured into an alundum crucible and placed, under high vacuum, in a high-temperature zone (1000—1200°), while a glass substrate was placed in a zone with a temperature of 300—350°. A polycrystalline, dense film, firmly fixed to the glass, 3—10μ thick, transparent but somewhat scattering light, was obtained.

A slot cell was prepared from the film, i.e., two electrodes were placed on top of the film, separated from one another by a distance from several tenths of a millimeter to 1.5—2 mm. The electrodes were deposited by vacuum evaporation, mainly from aluminum; other metals (Cu, In, Au) were also tested.

A constant voltage was applied to the electrodes. The film began to glow at a voltage of the order of 10^4 V/cm. The film glows from the cathode to the anode; in some cases the glow consists of regions of greater and lesser brightness extending from one electrode to the other (Fig. 1a), while in other cases it breaks up into brighter bands standing out against a generally more weakly glowing background (Fig. 1b). Separate brighter or less bright spots may be observed, chaotically distributed throughout the entire space between the electrodes (Fig. 1c).

3. Our slot electroluminescent cells possess an extraordinarily high exponent in the dependence of brightness on the voltage across the cell. Fig. 2 gives the dependence of the brightness B (measured with an FEU-35 photomultiplier and a galvanometer) on the voltage across the cell V (V is given in volts, B in arbitrary units). For cell No. 16 the quantities B and V are related by

$$B = 1.59 \cdot 10^7 V^{13} \quad (V \text{ in kV}).$$

In this example B varied from 3 at 0.3 kV to 43,000 at 0.64 kV, i.e., almost 15,000-fold. The proportionality of brightness to the 13th power of the voltage ...

···is extremely steep, if it is compared with the analogous dependence for electroluminescent cells of another type.

For the formula $B = AV^k$, the following exponents were obtained by us for different specimens of slit cells:

Cell No.	10	12	15	16	17	19
k	12	13.2	15.1	13	13.4	13

For cell No. 12 the slope of the graph became still somewhat steeper, beginning at a voltage of 3 kV.

The greatest brightnesses attained in these experiments were, in order of magnitude, close to the brightness of powder electroluminescent cells.

Table 1

V, kV	0.3	0.4	0.5	0.6
i_{exp}, μA	0.13	0.4	1.35	4.7
i_{calc}, μA	0.143	0.447	1.38	4.37

The dependence usually used for electroluminescent cells, of brightness on voltage, of the form $B = Ae^{-b/\sqrt{V}}$, differed strongly from the actual form of this dependence in our cells.

Fig. 3. Brightness and voltage waves: a–100 Hz, b–1000 Hz

Figure 2: Fig. 3. Brightness and voltage waves: a–100 Hz, b–1000 Hz

The dependence of the current through the cell on voltage was approximately exponential. For cell No. 16 it corresponded to the expression $i = 0.00479 \cdot 10^{4.93V}$ (i in μA; V in kV). The current values calculated from this formula are compared in Table 1 with those measured in the experiment.

4. Measurements were also made with alternating voltage, and oscillograms of the brightness waves at different audio frequencies were recorded (Fig. 3). The cell had a slit width of 0.3 mm. The oscillograms were obtained at voltages of 450 V rms and frequencies of 100 Hz (Fig. 3a) and 1000 Hz (Fig. 3b). In the first case, complete coincidence of the phases of brightness and voltage is observed; in the second, a small lag of the brightness-wave peak. If the alternating voltage is applied after the preceding action of a constant voltage, a certain fraction of unipolarity appears in the brightness waves.

Fig. 3. Brightness and voltage waves: a–100 Hz, b–1000 Hz

5. During the first measurements at high direct voltages, attention was drawn to breakdowns that occurred in some cases. Their peculiarity was that the film remained undamaged, while the electrodes were destroyed. It was assumed that the breakdowns were caused by the appearance of electrons in the air near the surface of the electroluminescent film. To check this, a film with slit electrodes (slit 2 mm) was mounted in a vacuum tube, in which a collector was placed at a distance of 3 mm from the film. Emission of electrons from the electroluminescent layer into vacuum was detected.

A galvanometer and a collecting voltage of 400 V, producing a saturation current, were connected between the anode of the cell and the collector. At the same time the current flowing through the cell was also measured. Figure 4 presents the dependence for the current through the cell (I) and for the emission saturation current (II) (the currents are presented on different scales). At voltages from 800 to 2800 V on the cell, graphs I and II practically merge. This indicates that the emission current is directly proportional to the through current across the cell; in the given interval it was 2.5% of the latter. Above a voltage of 2800 V, the growth of the emission current slowed, while the through current continued to increase with increasing steepness.

Several cases have been described in the literature of the observation of electroluminescence in semiconductor crystals that were placed under voltage

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Fig. 1. Photographs of the glow of slit cells. Distance between the electrodes: a –0.4 mm, b –0.3 mm, c –0.5 mm

Figure 1: Photographs of the glow of slit cells.

Figure 3: Figure 1: Photographs of the glow of slit cells.

Figure 1a: signal from the piezoelectric sensor and voltage on the p–n junction.

Figure 4: Figure 1a: signal from the piezoelectric sensor and voltage on the p–n junction.

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Fig. 1. *a* —signal from the piezoelectric sensor, $f_{\text{res}} = 500$ kHz, *b* —voltage on the *p*–*n* junction; the bias voltage V is applied in the form of a pulse of duration 120 μsec

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for obtaining emission (9–11). External emission was also observed from the surface of a ZnS crystal (12).

Emission from the surface of sublimated electroluminescent films is described for the first time.

The sublimated electroluminescent films described are reproducible without particular difficulty and constitute a promising material for applications in radio electronics.

Fig. 4. Dependence of the through current (I) and emission current (II) on voltage

Conclusions. 1. Through (bulk) electroluminescence has been observed in sublimated films of zinc sulfide activated with copper in slot cells.

2. A very steep dependence of this electroluminescence B on the voltage across the cell V, of the type $B = AV^k$, where $k > 10$, has been obtained.
3. It has been established that electroluminescent cells of this type possess considerable "cold" emission of hot electrons.

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Fig. 4. Dependence of the through current (I) and emission current (II) on voltage

Figure 5: Fig. 4. Dependence of the through current (I) and emission current (II) on voltage

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REFERENCES

1. G. Destriau, Phil. Mag., **38**, No. 285, 700 (1947).
2. D. Curie, J. Phys., Radium, **14**, No. 10, 510 (1953).
3. P. Zalm, J. Phys., Radium, **17**, No. 8–9, 777 (1956).
4. W. W. Piper, F. E. Williams, Phys. Rev., **87**, 151 (1953).
5. R. W. Smith, Phys. Rev., **105**, No. 1, 900 (1957).
6. J. Woods, J. Electron. Control, **3**, No. 5, 531 (1957).
7. K. W. Böer, H. J. Hänsch, H. Obernik, Physica Status Solidi, **1**, No. 4, 352 (1961).
8. J. L. Gillson, P. J. Darnell, Phys. Rev., **125**, No. 1, 149 (1962).
9. M. I. Elinson, G. F. Vasil' ev, A. G. Zhdan, Radio Engineering and Electronics, **4**, No. 10, 1718 (1959).
10. V. F. Bibik, P. G. Borzyak, O. G. Sorbei, Solid State Physics, **4**, No. 11, 3003 (1962).
11. G. D. Fedorovich, Ukrainian Physical Journal, **9**, No. 3, 345 (1964).

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