# OSCILLOGRAPHIC INVESTIGATION OF A NEW TYPE OF ELECTROLUMINESCENCE OF BLACK CARBORUNDUM

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## Abstract

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# OSCILLOGRAPHIC INVESTIGATION OF A NEW TYPE OF ELECTROLUMINESCENCE OF BLACK CARBORUNDUM

## (LUMINESCENCE III)

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### PHYSICS

1. When rectangular field pulses act on crystals of black carborundum with an electron-hole junction (Losev’ s “sensitive” layer), luminescence of the region of the electron-hole junction arises for both directions of the pulse. These two types of luminescence differ substantially both in appearance and in nature. With a pulse that produces current in the forward direction, luminescence II arises, which is regarded as recombination luminescence due to injection of carriers through the electron-hole junction. With the reverse direction of the pulse, luminescence I is observed—individual luminous points or chains of luminous points along the periphery of the region in which luminescence II was observed. At large pulse amplitudes, beginning with a certain repetition rate, in addition to luminescence I there becomes noticeable the luminescence of the whole figure that was visible under luminescence II, but with a different color of luminescence (ˆ1). The existence of this special type of luminescence was established with the aid of three groups of facts: the appearance of the luminescence in microscopic observations, the superlinear increase of the average brightness with pulse frequency, and the presence of an increase in brightness in the interval between voltage pulses. It was proposed to call this luminescence luminescence III. To reveal the main features of luminescence III, an oscillographic investigation was carried out, the results of which are given below.

When photographing oscillograms, the number of sweeps of the recording beam was in individual cases limited to a single sweep. In this case the photograph was taken with an exposure of $\frac{1}{500}$ sec, with a Jupiter-3 lens of aperture ratio 1:1.5 on photographic films with a light sensitivity of 130 GOST. Such photographs reveal details not detectable by direct observation. The oscilloscope was a two-beam instrument with a commutated beam, of the “Solartron”type manufactured by “The Solartron Electronic Group Lim.” A voltage from an I-26 rectangular-pulse generator was applied to one input, and the readings of an FEU-19M photomultiplier to the other input. All oscillograms were obtained under the action of pulses on crystal No. 20 of black carborundum, which was also used in

Oscillograms

Figure 1: Oscillograms

the preceding work (ˆ1). Completely analogous results were also obtained with other crystals of black carborundum.

The sign of the pulse voltage in all examples given below corresponded to the excitation of luminescence I, i.e., to the reverse direction on the electron-hole junction. In all figures an increase in luminescence corresponds to an upward deflection; the beam runs from left to right.

2. Luminescence III arises if the time interval between voltage pulses is sufficiently small, for example less than 250 $\mu$sec, i.e., if the pulse repetition rate is greater than 4 kHz; it develops after the voltage pulse has ceased and is extinguished when the next pulse appears.

Figure 1 presents the characteristic course of the change of the oscillogram as the pulse repetition rate is changed from 4 to 10 kHz (pulse duration 10 $\mu$sec, pulse amplitude 50 V). Each photograph was obtained as a result of 4 sweeps of the beam.

In Fig. 1, 1 (4 kHz) the brightness rapidly increases during the action of the pulse; the maximum is reached after the end of the pulse; this is followed by an approximately monotonic decrease of the brightness to zero; the process is repeated with the next pulse. For brevity we shall call such a course normal; it corresponds to luminescence I. In Fig. 1, 2 (5 kHz), disturbances of monotonicity are noticeable in the second part of the decay curve. In Fig. 1, 3 (7 kHz), the rate of decrease of the brightness changes in jumps: a slowing down is visible, then an acceleration of the decay;

Fig. 1. 1 –4 kHz, 2 –5 kHz, 3 –7 kHz, 4 –8 kHz, 5 –9 kHz

Fig. 2. 1 –1 kHz, 2 –7 kHz, 3 –8 kHz, 4 –9 kHz, 5 –10 kHz

Fig. 3. 1 –2 kHz, 2 –4 kHz, 3 –6 kHz, 4 –8 kHz

at the end of the period a flash is visible, preceding the increase of the luminescence produced by the second pulse. In the three brightness waves recorded on the oscillogram, the deviations from the normal course are similar, but they differ substantially in details. In Fig. 1, 4 (8 kHz), in each of the brightness waves in the second part of the period there predominates an increase in brightness, which occurs as separate flashes distributed at random. In Fig. 1, 5 (9 kHz), the minimum of luminescence is reached almost in the middle of the interval between two voltage pulses; then the luminescence increases and by the moment the next pulse appears reaches an almost maximal value. The voltage pulse extinguishes this luminescence, and it flares up again after the termination of the voltage pulse.

Thus, the appearance of luminescence III is associated with a radical change

Fig. 4

Figure 2: Fig. 4

in the brightness wave: the brightness increases in the interval between pulses, the luminescence becomes incoherent, the flashes have a random distribution, a scatter of brightness waves is obtained upon periodic repetition of the process, and the visually perceived brightness wave broadens into a band.

The general picture corresponding to visual observation of the oscillograms is given in Fig. 2. The photographs were taken with an exposure of $\frac{1}{60}$ sec., which corresponded to about 30 sweeps of the beam superposed in the image (pulse duration 10 $\mu$sec, amplitude 50 V). At a repetition rate of 1 kc/s (Fig. 2, 1) an almost normal course of the brightness wave was obtained. At 7 kc/s (Fig. 2, 2) an increase in brightness immediately following the pulse is still visible. At 8 kc/s (Fig. 2, 3) the pulse-associated rise in brightness is almost imperceptible. At 9 kc/s (Fig. 2, 4) a decrease in brightness after the pulse and an increase in it in the interval between pulses clearly appear; this is still more distinct at 10 kc/s (Fig. 2, 5).

**Fig. 4**

Similar results were obtained by changing the pulse duration while keeping the pulse amplitude and repetition rate unchanged. Thus, with a pulse duration of 7 $\mu$sec (amplitude 60 V; repetition rate 10 kc/s), the luminescence died out immediately after the pulse and began to flare up approximately 20 $\mu$sec after the end of the pulse.

3. Luminescence III exists during the interval between voltage pulses and therefore creates a large constant component in the luminescence.

Figure 3 shows oscillograms obtained with a single sweep of the beam across the screen. The beam alternately reveals either the voltage pulse or the brightness wave. The zero axes of the brightness wave and of the pulse oscillogram were brought together at a repetition rate of 2 kc/s. As the repetition rate increases, a constant component appears in the luminescence, owing to which the zero axis of the brightness wave is shifted upward by a distance the greater, the larger the constant component of the luminescence. The photograph shows a gradual increase of the constant component on going to repetition rates of 4 and 6 kc/s, and a sharp increase of the constant component on going from a repetition rate of 6 kc/s to a repetition rate of 8 kc/s. At 8 kc/s the constant component of the brightness wave was approximately four times greater than the amplitude of the alternating component, whereas the latter decreased by approximately 20% between 6 and 8 kc/s. The occurrence of a large constant component explains the superlinear increase, with increasing repetition rate, of the mean luminescence values determined by means of a galvanometer, which was indicated at the beginning of the article.

Figure 4 shows a photograph obtained with a single sweep of the beam (exposure $\frac{1}{500}$ sec, pulse 10 $\mu$sec, 50 V, 10 kc/s). The oscillogram is highly enlarged. The zero axis of the pulse is located approximately in the middle of the vertical deflection of the brightness wave. Two periods of the brightness wave were clearly obtained. In the first, immediately after the end of the pulse, quenching of the luminescence $AB$ is observed; this is followed by a flash $BC$; a brighter flash $CD$; not less than two flashes on $DE$; a decrease in brightness $EF$, a flash $FG$, and the following pulse quenches the luminescence. After a period, the recording begins with quenching $HJ$; there follow flashes $JK$, $KL$, a small decrease in brightness $LM$, not less than two strong flashes on $MN$, after which a new pulse again quenches the luminescence. Individual moments in the development

brightness waves are not reproduced and occur each time in a different way; they have the character of random events.

4. It is natural to compare the phenomena described here with the previously described visible luminescence of the electron-hole junction in silicon when a voltage is applied in the reverse direction (^2). In silicon two kinds of luminescence were obtained: one in the form of point luminescence, which was regarded by the authors as luminescence resulting from avalanche breakdown, and another, which had the appearance of a glow over the surface of the electron-hole junction and was regarded as internal emission under the action of the field. The brightness waves of these luminescences are not given, and therefore it is difficult to make a comparison. However, both mechanisms proposed by the authors (^2) should excite luminescence in phase with the pulse and therefore with a normal form of the oscillogram. Meanwhile, luminescence III is the afterglow of electroluminescence. It indicates another—recombination—mechanism. Luminescence III arises as a result of repeated actions of sufficiently long pulses with a sufficient voltage amplitude on the electron-hole junction in the reverse direction. The field of the pulse drives free electrons in the electron-conducting part and free holes in the hole-conducting part away from the internal boundary of the junction, forming there a double layer with a considerable electric moment. After the pulse ceases, relaxation processes must take place in the double layer, and if, before the appearance of the next pulse, complete restoration of the initial state does not occur, then the charges at the boundaries of the double layer and the strength of the internal field in it will increase with each subsequent pulse up to some stationary limit. Under these conditions luminescence III arises; it consists of separate, randomly distributed flashes not directly controlled by the pulse voltage; the latter, when it appears, quenches luminescence III by accelerating the carriers that create it, and at the same time sustains it by replenishing the supply of these carriers. The energy source of luminescence III is the field of the preceding pulses; its energy is drawn from the electrostatic energy of the formed double layer, and it is determined by the local conditions in the electron-hole junction.

The increase of luminescence I and the quenching of luminescence III during the action of the pulse are superposed. By selecting the required conditions and expanding the oscillogram as much as possible, I was able to observe an approximate equality of these two actions of the pulse, which have opposite effects on the brightness: in this case, in the first microseconds of the action of the pulse a decrease in brightness was observed, which in the last microseconds was replaced by its increase; by increasing the frequency or duration of the pulse, or by slightly changing the amplitude, I obtained a decrease in brightness throughout the entire duration of the pulse; the opposite action also produced the opposite effect, i.e., the brightness wave approached the normal form—luminescence I predominated.

In studying luminescence III of carborundum crystals, the recombination mechanism of luminescence appeared especially clearly, and its details are recorded in our photographs. A similar mechanism has been proposed by many investigators to explain the component of the brightness wave of electroluminescent zinc sulfide that is shifted in phase with respect to the voltage by approximately 90°. The question of the relation between recombination processes in the electroluminescence of zinc sulfide and in the electroluminescence of carborundum, usually observed under very different conditions, should become the subject of a special investigation.

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*Note: Figure translations are in progress. See original paper for figures.*