LUMINESCEENCE OF ROCK SALT IN VERY STRONG ELECTRIC FIELDS

N. S. Nesmelov and I. S. Pikalova

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The luminescence of thin single-crystal layers of NaCl in very strong electric fields was observed. Oscillograms of the brightness waves were obtained. The light flux and luminescence delay were measured as functions of the applied field strength amplitude. The reasons for the delay phenomenon and the drop in the electric strength of samples when electrodes with electron conductivity (metal or graphite) are used are discussed.

Electroluminescence is difficult to observe in ionic crystals because breakdown of the crystal occurs before the field becomes strong enough to produce luminescence. The electric strengthening that occurs in solid dielectrics when the thickness of the layer is reduced has enabled field strengths of $10^5$–$10^6$ V/cm to be achieved in single-crystal layers of NaCl of sub-micron thickness [1]. It was shown earlier in [2] that the possibility of producing strong electric fields without breakdown can be used for the experimental study of new phenomena occurring in such fields, including luminescence. Technologically, however, the preparation of uniform single-crystal layers of micron thickness is fairly complex and difficult. This is why the first communication on the observation of luminescence in rock salt only appeared recently [3].

Studies of electroluminescence in single crystals of alkali halides will obviously give a much better insight into the mechanism of this phenomenon. Ionic crystals with a cubic lattice have the simplest structure. Many physical properties of alkali halides are much better known than those of other solids. On the one hand, this can facilitate an interpretation of the results, and on the other, it can yield supplementary data on the structural features of these solids. From this point of view the phenomenon of luminescence in ionic crystals subject to strong electric fields is of considerable scientific interest.

Samples with a layer thickness of up to three microns can be prepared by the method described in [4].

We used the new method of preparation described in [5], by which a thickness of 1 micron or less can be achieved in single crystals. A substantial area of constant thickness can be obtained by this method; this is very important for producing a uniform field in the layer. No mechanical stresses, cracks, or other microdefects are produced in the layers when the electrode surfaces are formed by using a solvent. The electric strength of the layer is thus determined by the thickness and properties of the dielectric.

Samples made by the method described in [5] withstood field strengths of up to $10^8$ V/cm without breakdown. Luminescence of the salt layer occurred regularly at field strengths of $0.5 \cdot 10^7$–$1.2 \cdot 10^7$ V/cm.

The circuit shown schematically in Fig. 1 was used to study the brightness waves, where 1 is the holder for the NaCl sample, 2 the exciting field generator, 3 an FEU-18A photomultiplier, 4 the multiplier supply unit, 5 an USh-10 wideband amplifier, 6 an OK-17M two-beam oscilloscope, and 7 an opaque box for the photomultiplier.

The luminescence produced in the salt layer by a strong field was recorded by the photomultiplier and the resulting voltage applied after amplification to the plates of the oscilloscope. Part of the voltage applied to the sample was applied to the second pair of plates via a voltage divider. The phenomena seen on the screen were recorded on film.

For visual observation of the luminescence and study of the brightness waves, liquid electrodes of saturated NaCl solution in butyl alcohol were employed. It was shown earlier [1] that this solution does not destroy the surface adjacent to the electrode. It should be mentioned that luminescence of the layer also occurs when liquid electrodes made from solutions of NaBr, KBr, KCl, and AgNO$_3$ in butyl alcohol are used. The form of the brightness waves and the color of the luminescence remain the same. The same result is also obtained when crystals occurring naturally or cultivated from a solution are used as samples.
The luminescence of thin single-crystal layers of NaCl was observed visually in an alternating field (an AF generator with step-up transformer was used for excitation). The layer was not more than 1.5 \mu m thick. The area of equal thickness varied between 0.0025 mm² and 0.1 mm² according to the sample. A microscope with no significant bottom light was used for the observations.

When the field in the salt layer is increased slowly, the following stages of luminescence may be observed: 1) weak blue luminescence occurs in the central part of the layer at a field strength of $0.5 \cdot 10^7 - 1.2 \cdot 10^7$ V/cm; 2) after a further rise of a few percent the region of luminescence rapidly widens and covers the entire layer; 3) on further increase, the luminescence becomes so bright that it can be seen in a dark room by the naked eye; 4) if the field is maintained at this level or increased still further the luminescence ceases, followed by breakdown of the sample and the appearance of puncture channels roughly one micron in diameter.

The extinction of the luminescence after sustained exposure to a strong field is obviously connected with the intense heating produced by the currents flowing in the layer.

Microphotographs of the stages of luminescence in a single crystal layer of natural rock salt 1.2 \mu m thick may be seen in Fig. 2, where the applied voltages are 1) 700 V, 2) 800 V, 3) 900 V, 4) 1200 V, 5) 1500 V, and the voltage frequency is $f = 4000$ cps.

The brightness waves were observed with a variety of excitation voltages, namely alternating, half-wave alternating, and single-polarity pulses. Oscillograms of the brightness waves produced by the alternating (I) and pulse (II) voltages are given in Fig. 3. It can be seen that luminescence only occurs when the applied voltage amplitude exceeds some critical value.

In the case of alternating excitation (Fig. 3a), the brightness waves have twice the frequency of the applied voltage, while in the case of half-wave or pulsed excitation (Fig. 3b) the waves roughly follow the shape of the excitation. It is clear from both oscillograms that the luminescence is very unstable and that the brightness wave consists of separate extremely short "bursts" with a duration of a few microseconds (Figs. 3b and 4). When the excitation amplitude is considerable the "bursts" follow one another so rapidly that a constant background of luminescence is produced. At low applied voltages the individual "bursts" are more sparse, so that the level of the constant brightness background is greatly reduced relative to the maximum amplitude of the "bursts" and the brightness wave envelope becomes more broken (Fig. 4). In Fig. 4, I is the shape of the luminescence pulse and II the shape of the excitation pulse. The peak seen on the luminescence curve at the leading edge of the excitation pulse is explained by pick-up at the photomultiplier when the voltage on the sample changes sharply. This pick-up only becomes significant when the multiplier output voltage is highly amplified, i.e., when the luminescence is extremely weak.