ANTI-STOKES ENERGY TRANSFER BETWEEN Cu AND Mn CENTERS IN ELECTROLUMINESCENE OF ZnS-Cu, Mn SINGLE CRYSTALS

V. E. Oranovskii and M. P. Golovei
P. N. Lebedev Physics Institute, USSR Academy of Sciences
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It has been observed that in photoluminescence of zinc-sulfide luminors activated simultaneously with copper and manganese the excitation energy is transferred from the copper to the manganese [1]. The interaction of these centers in electroluminescence was investigated under the influence of an electric field of 10^5 - 10^6 V/cm. In this case examination under a microscope has revealed that the light is produced by individual isolated regions, in the form of parallel hatchures, inside the crystal. The copper centers produce a green-yellow light, the manganese ones a red light, and the light from the complex copper-manganese center contains both components and is yellow in color. The "brightness waves" of individual hatchures, i.e., plots of the variation of the brightness during the time when the voltage is applied, were registered with an oscilloscope with the aid of a microscope, photomultiplier, and amplification and storage circuits.

Earlier investigations [2], made on crystals activated with copper only, have shown that if the excitation is produced by symmetrical alternating voltage, each hatchure glows for one half cycle only. This glow character and also the form and phase of the brightness waves remained unchanged on going from contactless excitation of the crystal to excitation via indium-gallium contacts deposited on the ends of the crystal. We have shown that the glowing hatchure is connected with the presence of a p-n junction in the crystal. During the half cycle when the exciting voltage is applied to the p-n junction in the inverse direction, a space-charge region is produced around the junction and the field becomes concentrated to values 10^5 - 10^6 V/cm. This results in impact or tunnel ionization of the glow centers in the given region, with separation of the charges. During the next half cycle, when the voltage is applied to this p-n junction in the forward direction, the carriers of both polarities are returned towards each other and recombine, producing radiation. Thus, during the inverse half cycle there is no luminescence from the copper centers, since the charges are separated and recombination is impossible.

We have investigated in the present work crystals activated not only with copper but also with manganese. It is known that manganese, unlike copper, does not become ionized during the luminescence process, and merely goes over to an excited state. The return to the initial state is accompanied by radiation. Consequently, we can expect radiation from manganese just during the time of the inverse voltage, i.e., during the excitation half cycle. During the next half cycle, the manganese cannot be excited and consequently should not glow. This was qualitatively confirmed by the experiment.

Light filters were used to study separately the brightness waves of the blue (copper)

and red (manganese) components of the luminescence of the yellow hatchures, i.e., the hatchures containing both copper and manganese.

The investigations have shown that the blue component of the yellow hatchure, unlike the blue luminescence of a pure "copper" crystal, has not one but two maxima during the cycle of exciting voltage. The distance between the maxima is ~180°. Let the positive half cycle of the voltage be denoted by the letter A and the negative by the letter B. In pure copper crystals, there was no change in the brightness waves when contactless excitation was replaced by excitation via sputtered electrodes. In the case of the blue component of the yellow hatchure, such a change in the method of excitation affects the ratio of the amplitudes. Whereas the brightness waves in the half cycles A and B were close in magnitude in the case of contact excitation, the brightness wave in half-cycle B was approximately half that of A in the contactless method.

The red component of the yellow hatchure also has two brightness waves per cycle. On going from the contactless to the contact excitation, the ratio of their amplitudes changes in the same manner as for the blue component.

Comparison of the brightness waves of the pure copper hatchures and of the blue component of the copper-manganese hatchures shows that the brightness wave of the copper center is produced in the copper-manganese hatchure by a different mechanism than in the pure copper hatchure. The very presence of two waves per cycle (as against one in the pure copper hatchure) indicates this fact.

On changing from contactless to contact excitation, the increase in the intensity of the red component is accompanied by an increase in the brightness of the blue "copper" luminescence, which was not observed at all during this half cycle in the absence of manganese.

Starting from the present notions concerning the electroluminescence mechanism, we can propose the following scheme for the formation of the brightness waves of the blue and red components of the yellow hatchure. The brightness wave is produced during the half-cycle A when the electrons and holes, separated during the preceding half-cycle B, return and recombine on the copper centers. This wave is similar in mechanism to the brightness wave of the pure copper hatchure. The brightness wave of the red component produced during half-cycle A is also due to the return of electrons and holes to the observable region, either directly or via energy transfer from the copper to the manganese. This may be, for example, resonance transfer [1].

The red wave B is likewise easy to interpret. According to the presently accepted point of view, the manganese in zinc-sulfide luminors does not go over into an ionized state and emits directly upon excitation. The red wave, which appears in the ionization half-cycle B, is produced in precisely this manner.

The appearance of the blue wave in the half-cycle B can be explained only by admitting the possibility of energy transfer not only from the copper center to the manganese one, but conversely from the manganese to the copper centers.

Observation of such a transfer is of interest, since the energy of the excited manganese center is lower than the energy radiated by the copper center. Consequently, this transfer violates Stokes rule.

It is impossible for the time being to describe in greater detail the mechanism of such a transfer. We can only point out that the energy necessary to cover the difference between the orange and the blue quantum is most likely to be provided by the field.

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[2]   V. E. Oranovskii and V. V. Samoteikin, Optika i spektroskopiya 13, 474 (1965).

LIGHT-REACTION ACCELERATION OF MACROPARTICLES OF MATTER

G. A. Askar'yan, M. S. Rabinovich, M. M. Savchenko, V. K. Stepanov, and V. B. Studenov
P. N. Lebedev Physics Institute, USSR Academy of Sciences
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We describe in this communication the first experiments on the acceleration of macroparticles of matter by the action of laser radiation. As shown in [1] the recoil pressure during evaporation can exceed the direct light pressure by a factor of thousands or tens of thousands, and therefore the "light-reaction" method of particle acceleration, proposed in [1], is more effective than acceleration with light pressure, especially when the path is small or the acceleration time is short.

We used for the acceleration the radiation from a Q-switched ruby laser. The radiation was focused on a thin transparent film (or thin foil), on which were sprinkled (with the beam acting from below) or glued particles with dimension on the order of a fraction of a millimeter. Metal filings and corundum powder were used.

A piezoelectric micrometeorite recorder was placed at a distance of 15 cm along the direction of particle motion. The particle velocities, as estimated from the delay time of the piezoelectric recorder pulse, were of the order of 10^6 cm/sec. Such velocities correspond to a not very high ratio of the initial mass to the final mass, $v_{fin} \simeq u_{esc} \ln(M_0/M_{fin}) \sim u_{esc}$, since the particle dimensions were larger than the dimensions of the craters left after single flashes on the target.

To investigate the action of the accelerated particles on matter, glass or metal plates were placed in their path, and a metallographic microscope was used to investigate the craters produced by impacts of particles with different masses.

Figure 1 shows a crater on a glass plate, magnified 600 times, and Fig. 2 shows, with magnification 120x, the opening pierced by another particle in a copper foil 20 μ thick.