SOLIDS

ROLE OF THE THERMOACTIVATED AND TUNNEL ELECTRON RELAXATIONS OF RADIATION DEFECTS IN INITIATION OF ISOTHERMAL EXOEMISSION CURRENT

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The paper presents the results of investigations of the isothermal exoelectron emission (EEE) in alkaline-halide crystals (AHC), which occurs in the process of crystal irradiation and immediately after its cessation, accompanying the relaxation of the excited surface. The work is aimed at understanding the role of the thermoactivated and tunnel electron relaxations of the complementary pairs of radiation defects in the EEE phenomenon. Values of the isothermal EEE current components, both the temperature-dependent and temperature-independent ones, and the characteristic decay times are evaluated. The contributions of thermoactivated and tunnel recombinations to the resulting current of the isothermal EEE are compared. It is shown that, for the decay times comparable with the characteristic ones, the temperature-dependent component of the current, which originates from the thermoactivated relaxations of the complementary pairs of radiation defects, is predominant.

The phenomenon of isothermal EEE, which accompanies the relaxation of an excited surface, provides one of the ways to lose the information about a radiation dose recorded by ionizing radiation on the color centers (CC) of wideband-gap insulating crystals [1—3]. That's why, a study of the nature of this phenomenon as well as features of the EEE relaxation kinetics is of great practical interest from a viewpoint of the exoemission radiation dosimetry of a surface layer (skin-dosimetry) [1, 2].

In the process of irradiation of some AHC, as well as immediately after its cessation, accompanying the relaxation of the excited surface, the exoemission of low-energy electrons occurs. Upon the energy relaxation of the non-equilibrium excited surface and

the stabilization of its properties, the isothermal EEE decays to a background level. This decay is governed by a duration of the relaxation processes in a near-surface layer, namely by the tunnel and thermoactivated electron recombinations of radiation defects, and depends on a kind of AHC and experiment conditions (a dose of the preliminary irradiation, temperature, etc.). In this paper aimed at the determination of the role of thermoactivated and tunnel electron-hole recombinations of radiation defects in the appearance of the isothermal EEE current, we carry out the calculation of a value of the isothermal EEE current and make its comparison with the experimental curves of the EEE decay, at various doses of the ultraviolet irradiation [3] of the CsBr AHC.

1. Results and Discussion

1.1. Experimental procedure

The isothermal EEE at room and somewhat elevated temperatures was experimentally observed after the irradiation, with certain doses, of CsBr either by ultraviolet light from an LDD 400-W deuterium lamp (a mean photon energy $\langle h\nu \rangle \approx 6.5 \div 6.6$ eV, a flux density $j \sim 10^{13}$ photons/(cm^2·s) [8]), or by electrons with the electron energy $E = 2.5 \div 3$ keV and $j \sim 10^{13} \div 10^{15}$ electrons/(cm^2·s) [9]. To avoid a surface charging, the above experiments were carried out with a quenchering of the output of photo- or secondary electrons,
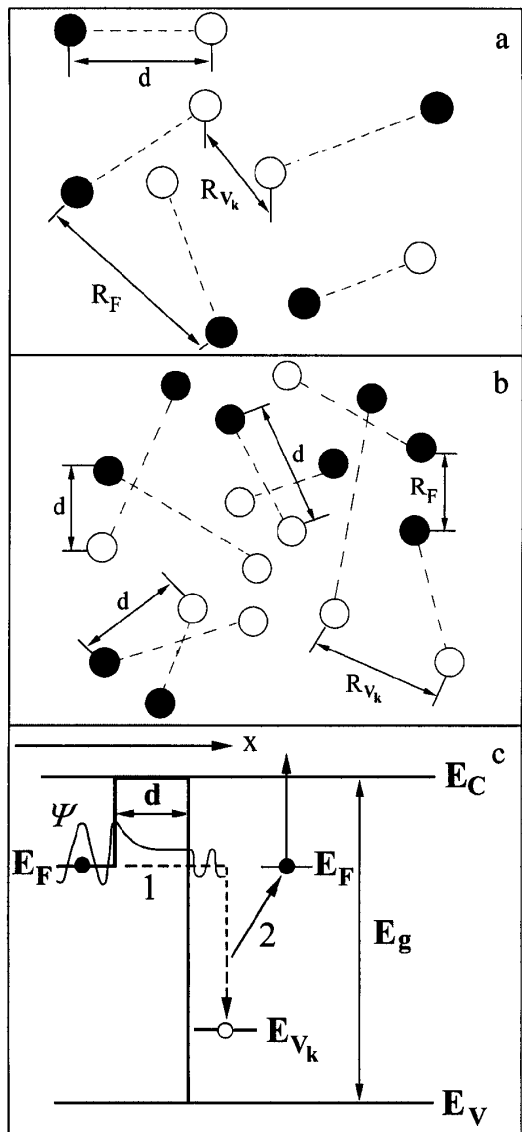
Fig. 1. "Genetically coupled" complementary pairs of radiation defects induced by the irradiation of various ((a) — low, (b) — high) doses (d — distance between the complementary (electron-hole) components of pairs; R_F and R_{Vk} — distances between the electron and hole CC, respectively). (c) — Energy scheme of the tunnel $[V_k, F]$ electron recombinations of the complementary pairs of radiation defects (E_g — energy gap; E_C — bottom of the conduction band; E_V — top of the crystal valence band): 1 — the tunneling of the electron of an F center through a potential barrier and its subsequent recombination with the hole of a V_k center; 2 — ionization of a neighboring electron F center (the Auger-like birth of an exoelectron)

respectively. A VEU-6 secondary-emission multiplier with a channel of the spiral kind, working in the electron (electron impulse) counting mode, was used as an exoelectron detector. The amplification factor of the multiplier achieves 7×10^8 at a 3.5-kV supply voltage, which allows a registration of the emission current $\simeq 10^{-19}$ A accounting for a low level of the inherent noises (≈ 0.1 imp./s). The registration of exoelectrons is more advantageous in the impulse counting mode than that in the current probing one, since the utilization of the former mode with the use of a discriminator in the channel of registration and amplification provides an opportunity to reach the optimal signal-to-noise ratio. A multiplier connection scheme with the so-called open terminal, which forms electron impulses of the positive polarity, was employed. A discrimination level was chosen $\simeq 10$ pulse/s. The experiments were carried out in a vacuum of 10^{-7} Torr. Crystalline specimens had the form of polished plates of $0.5 \times 6 \times 8$ mm in size. After placing in a vacuum camera, the specimens were first annealed at 630—650 K for 5 h, then cooled down to a necessary/room temperature, and finally, they were subjected to irradiation. The registration of the isothermal EEE was performed in 1.5—2 min after the cessation of irradiation. The delay time of 1.5—2 min is conditioned by peculiarities of the experiment geometry and is necessary for positioning the system "specimen — radiation source — exoelectron detector".

1.2. Isothermal recombinational EEE

Ionizing irradiation of CsBr crystals gives rise to the generation and accumulation of the complementary pairs of radiation defects $F(v_a^+ e^-) - H(i_a^0)$ and $F(v_a^+ e^-) - V_k(e_s^+)$, which are formed simultaneously. Depending on the irradiation conditions, particularly on the radiation flux density and temperature, the complementary pairs of radiation defects can either recombine instantly through the tunneling of closely located pairs (Fig. 1), or be stabilized by the lattice and accumulated in a crystal, with the subsequent thermoactivated recombination. The probability of the latter process depends on the crystal temperature T and recombination activation energy E_a: $p \sim p_0 \exp(-E_a/kT)$.

As an example, in the AHC irradiated with moderate doses of ionizing radiation at 295 K, the distances between the interstitial $H(i_a^0)$ and electron $F(v_a^+ e^-)$ CC can be $(1 \div 2)a$ (for CsI) or $10a$ (for KCl, KBr) [4], where a is the crystal lattice parameter. In these cases, a weak stabilization of the interstitials (i_a^0) with the lattice can lead to a smaller or greater recombination output and thus to the isothermal recombinational EEE after the irradiation cessation [4, 5].

At $T \geq 295$ K, the initially formed $H(i_a^0)$ and $V_k(e_s^+)$ point defects are mobile, especially the interstitial halogen atoms. A mobility of the point CC is determined by a migration activation energy E_a: the smaller E_a, the lower is the temperature, at which the CC mobility and the thermoactivated recombination of complementary pairs are possible. If the radiation-induced generation of defect pairs occurs more intensively than their recombination, then, in the case where the mobility of the $H(i_a^0)$ and $V_k(e_s^+)$ point CC is high, i.e. the E_a value is small, the complex composite defects can be formed, for example, the $V_2(v_c^- e^+ i_a^0)$ hole centers, which include the $H(i_a^0)$ and $V_k(e_s^+)$ CC. These centers are the basic radiation-induced hole CC, which are complementary to the F centers. They are accumulated in the crystal irradiated with moderate doses at room temperature.

In general, the isothermal EEE current is proportional to the rate of electron trap release and can be written [3] as

$$I(t) \sim -\frac{dN_e(t)}{dt} = f^l(N_e)\nu_0 \exp(-E_a/kT), \qquad (1)$$

where N_e is the number of occupied electron traps; ν_0 is the frequency factor of the EEE process [6], and $f^l(N_e)$ is a function that is determined by an order l of the kinetics of the EEE process, i.e. by an ionization mechanism of exoemission-active centers (EAC). Each of the thermoactivated processes, in particular a migration, diffusion, or recombination of the centers, is characterized by its own activation energy and makes a contribution to the total activation energy E_a of the EEE process.

One of the reasonable ways to determine the order of the isothermal EEE kinetics is based on the method of formal analysis of the emission decay curves, which is widely used in the study of the thermal emissivity of radiation-excited crystals [7]. The formal analysis of the EEE decay curves, which was performed in [3], made it possible to state that the isothermal EEE is initiated by the recombination processes of the complementary pairs of radiation defects and has the order $l = 2$ (bimolecular process). The authors of work [3] also presented the data which provide evidence for a slower decay of the isothermal EEE in the case where the irradiation dose, which determines a state of the complementary pairs of radiation defects (point defect → complex → aggregate), is greater. Basing on these results, the authors of [3,6] made a conclusion about the recombinational Auger-like relaxation nature of the EEE after irradiation of CsBr.

1.3. Temperature-independent component of the isothermal EEE current

The isothermal EEE, occurring immediately after the CsBr irradiation cessation, is observed in a wide temperature range and even at temperatures, where the migration and diffusion of the $H(i_a^0)$ and $V_k(e_s^+)$ centers initiating EEE are "frozen". In this case, it is necessary to consider the tunnel recombinations of the hole and electron CC, for example the $[V_k, F]$ recombinations, and take account of their contribution independent of temperature to the isothermal EEE current. A realization of the $[V_k, F]$ tunnel electron recombinations, which can occur at any temperature, is likely at high concentrations of the complementary electron-hole defect pairs ($n_{es} = n_{hs} \approx 10^{11} \div 10^{12}$ cm^{-2}) on the surface and in the near-surface layer of the irradiated crystal, or at small distances between the complementary pairs. A manifestation of the recombination processes is strongest immediately after the irradiation cessation, since the concentrations of radiation defects are the greatest at this moment and the distances between the complementary components of recombinating pairs are the smallest. It can be seen from a consideration of the electron band structure of the irradiated CsBr crystal [6] that the energy released in $[V_k, F]$ recombinations is enough for the Auger-like ionization of a neighboring F center ($[V_k, F] \rightarrow F$ process).

A similar kinetics of tunnel recombinations in the AHC was considered in [10]. It was assumed that electrons are emitted only from a thin near-surface layer, whose thickness doesn't exceed a mean distance between the CC ($R_e \leq (N_F)^{-1/3}$, where $N_F \simeq N_{V_k}$, with N_F and N_{V_k} being the bulk concentrations of electron and hole CC, respectively), i.e the process is limited to a two-dimensional tunnel recombination with the rate

$$v(r) = \nu_0 \exp(-r/r_0), \qquad (2)$$

where ν_0 is the recombination frequency factor; r_0 — a half of the Bohr radius for the electron of an F center, and r is the distance between the recombination centers.

The kinetics of the surface/near-surface recombinations was studied by analogy with that of the bulk one [11]. The density of the temperature-independent component of the isothermal EEE current $J_1(t)$ equals

$$J_1(t) = \pi^2 \sigma_i \, r_0^2 R_a^2 \, n_{hs} \, n_{es}^2 \, e \, (\ln \nu_0 t)/t, \qquad (3)$$

where σ_i is the probability of ionization of a near-surface electron F center (the birth of an exoelectron with the energy exceeding the crystal electron affinity and the momentum directed towards the surface); R_a is the radius for the Auger-like ionization; n_{hs} and n_{es} are the surface concentrations of hole and electron centers; and n_{hs} approximately equals n_{es}, since the centers are complementary Frenkel defect pairs and their concentrations can be estimated as $n_{es} = (N_F)^{2/3}$. For CsBr, $\sigma_i = 0.2$ [3]; $r_0 = 2$ Å; $\nu_0 = 10^6$ s^{-1} [6]; $R_a = 10$ Å; $n_{hs} = n_{es} \approx 10^{11}$cm^{-2} [3].

It is worth noting that the tunnel electron-hole recombinations occur with a sufficiently high probability only in the slightly spaced ("genetically coupled") pairs of $F(v_a^+ e^-) - V_k(e_s^+)$ centers (see Fig. 1a,b). In the case where the potential barrier, through which the electron of the F center tunnels, has a height $E_F = 1.86$ eV [6] and a width d (see Fig. 1c), the estimation of its transparency D ($D = D_0 \exp(-\frac{2d}{k}\sqrt{2mE_F})$) shows that acceptable values of the tunnel recombination probability ($10^{-3} - 10^{-6}$) can only be obtained, when the barrier thickness d (a distance between the $F - V_k$ centers in CsBr) does not exceed 5—10 Å.

At first sight, this result is not in compliance with the values of the concentrations of complementary F and V_k CC, which were used in calculations of the isothermal EEE current density, because the average distance between the centers of the same kind (R_F and R_{Vk}) is $(n_{es})^{-1/2} \approx 100$ Å at such concentrations (10^{11} cm^{-2}). However, it should be noted that the surface concentrations of the centers, which were used at calculations, were obtained from the bulk concentration values N_F under assumption of a homogeneous distribution of the centers. In reality, this distribution is far from homogeneous, the gradients of concentrations are sufficiently high, and this is especially pertinent to the surface and near-surface regions, where the center concentration can considerably exceed the calculated values. In addition, the distance between the complementary centers, the components of a "genetically coupled" pair, can be by a few orders smaller than the calculated distance between the centers of the same kind in the near-surface layer [11].
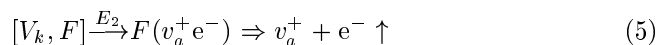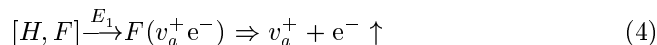
Therefore, accounting for a spatial inhomogeneity of the distribution of near-surface defects in the irradiated CsBr crystal, the distances between CC can take the values, at which the tunnel electron relaxations of radiation defects are likely (see Fig. 1,c), and, consequently, the consideration of a contribution of the latter to the isothermal EEE current is well-grounded.

1.4. Temperature-dependent component of the isothermal EEE current

Consider a decay of the isothermal EEE current in the temperature region 140—300 K. It is obvious that the presence of the concentration gradients of radiation CC within a near-surface layer gives rise to the appearance of the diffusion-controlled flows of such centers which are aimed at the reduction of these gradients. The recombination of the complementary pairs of defects initiates the Auger-like recombinational EEE, which occurs in the process of irradiation and the accompanying formation of CC, as well as after its cessation, and decays in the course of time, as the concentration gradients are reduced. Since the motion of the centers which initiate the recombinations is governed by the concentration gradients and thermoactivated diffusion, a flow of electrons from the F centers (emitted owing to the energy released during the recombinations) constitutes a temperature-dependent component of the isothermal EEE current.

1.4.1. Thermoactivated recombinations of radiation defects

The $H(i_a^0)$ centers, which are formed under irradiation of a crystal and are weakly localized in the lattice, can efficiently move in CsBr and initiate the $[H, F]$ recombinations already at $T > 100$ K. The $V_k(e_s^+)$ hole centers are mobile at $T > 140$ K and realize a hopping motion within the valence band with the autolocalization at lattice sites during $\tau = 10^{-10} \div 10^{-9}$ s and with the creation of energy levels in the energy gap region of the crystal [12]. Thus, in the process of irradiation and after its cessation, the H and V_k centers are able to initiate both the thermoactivated recombinations with the electron F CC in the region $T > 140$ K and Auger-like ionizations of neighboring F centers according to the schemes

$$[H, F] \xrightarrow{E_1} F(v_a^+ e^-) \Rightarrow v_a^+ + e^- \uparrow \qquad (4)$$

$$[V_k, F] \xrightarrow{E_2} F(v_a^+ e^-) \Rightarrow v_a^+ + e^- \uparrow \qquad (5)$$

These exoreactions, which occur in the relaxing non-equilibrium solid phase (irradiated CsBr crystal) and are accompanied by a release of energies E_1 and E_2, are the main schemes of the exoelectron birth. The concentrations of radiation-induced $[H, F]$ and $[V_k, F]$ complementary pairs can be described by a single distribution function $n(r, t)$. Consider their

recombinations in a way similar to that proposed in [13 − 15]. At $T > 140$ K, the thermoactivated diffusion and recombinations of H or V_k centers with the electron F CC, which occur on the surface and within the near-surface layer, can be described by an equation, in which the recombination rate is determined by the diffusion flux of mobile recombination initiators to a chosen recombination center complementary to them, i.e. to the electron F center. Since, the complementary CC pairs annihilate simultaneously in the process of recombination, their distribution is described by the single function $n(r,t)$:

$$\frac{dn(r,t)}{dt} = \frac{D_X}{r}\frac{d}{dr}\left(r\frac{\partial n(r,t)}{\partial r}\right) - P(t)n(r,t), \qquad (6)$$

where $D_X(T)$ is the diffusion coefficient of a recombination initiator (an interstitial halogen atom or a hole), depending on temperature; $P(t)$ - a recombination rate defined by the diffusion flux of H or V_k to a chosen recombination F center with the effective recombination radius R:

$$P(t) = 2\pi R D_X\left(\frac{\partial n(r,t)}{\partial r}\right)_R. \qquad (7)$$

The effective recombination radius R is equal to a distance between the nearest haloids in the lattice (for CsBr — 4.29 Å). The mean concentration $n(t)$ of the recombinating particles at a chosen point of the near-surface layer satisfies the equation

$$\frac{dn(t)}{dt} = -P(t)n(t) \qquad (8)$$

with the initial conditions $n(0) = (N_H)^{2/3} = (N_F)^{2/3} \simeq n_0$ and the boundary conditions $n(R,t) = 0$ and $n(\infty,t) = n(t)$. Here, N_H and N_F are the bulk concentrations of the H and F centers, respectively, at a moment of the irradiation cessation.

1.4.2. Calculation of the temperature-dependent component of the isothermal EEE current

The density of a temperature-dependent component of the isothermal EEE current, $J_2(t,T)$, is proportional to the recombination rate per surface area unit, $F(t)$, and the emission quantum yield, Y, of each recombination act, i.e. $J_2(t,T) \sim e \times Y \times F(t)$. The detailed solution of a task of the type of Eq. (6) was presented in [13,15]. Here, we write the final result for the density of a temperature-dependent component of the isothermal EEE current in the approximation of "small" decay times t:

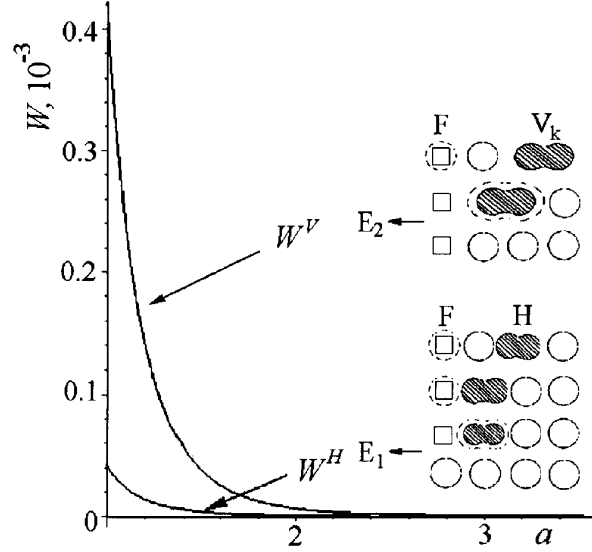$$J_2^X(t,T) = 2eY^X R(\pi D_X(T)/t)^{1/2} \times$$

Fig. 2. Dependence of the probability of the F center ionization, W, on a distance between the recombinating pair and the emission center in units of the CsBr lattice parameter a. The W^H and W^V curves correspond to the $[H,F] \xrightarrow{E_1} F(v_a^+ e^-)$ and $W^V - [V_k,F] \xrightarrow{E_2} F(v_a^+ e^-)$ processes, respectively. Inset shows the schemes of the $[H,F]$ and $[V_k,F]$ recombinations: E_1 and E_2 are the energies released at the corresponding recombinations

$$\times \frac{n_0^2}{\left(1 + 4Rn_0(\pi D_X(T)t)^{1/2}\right)^2} \qquad (9)$$

Here, Y^X is the quantum yield of the electron emission of each recombination act (see expressions (4) and (5)), which includes the probabilities of the pair recombination, F center ionization, and electron emission. The formula for the calculation of the quantum yield obtained within the frames of perturbation theory [13] is

$$Y^X = W^X(r)\pi r^2 n_e, \qquad (10)$$

where $W^X(r)$ is the probability of the F center ionization in the process of recombination of the $[H,F]$ pairs ($[V_k,F]$ pairs) located at a distance r from the emission center (F center); n_e is the mean concentration of surface electron centers (10^{11} cm^{-2}).

At the same time, the probability of the $F(v_a^+ e^-)$ center ionization in the process of recombination of a complementary pair of defects located at a distance r from the emission center ($F(v_a^+ e^-)$ center) is

$$W^X(r) = \frac{1}{\pi\hbar}\left(\frac{e^2}{r}\right)^6 \frac{m}{M_{X,F}} \frac{E_e^{3/2}(E_{X,F} - E_e)^{1/2}\tau_0^X}{E_{X,F}^5 \times E_0^2}. \quad (11)$$

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$$[V_k, F] \longrightarrow F(v_a^+ e^-) \Rightarrow v_a^+ + e^- \uparrow$$

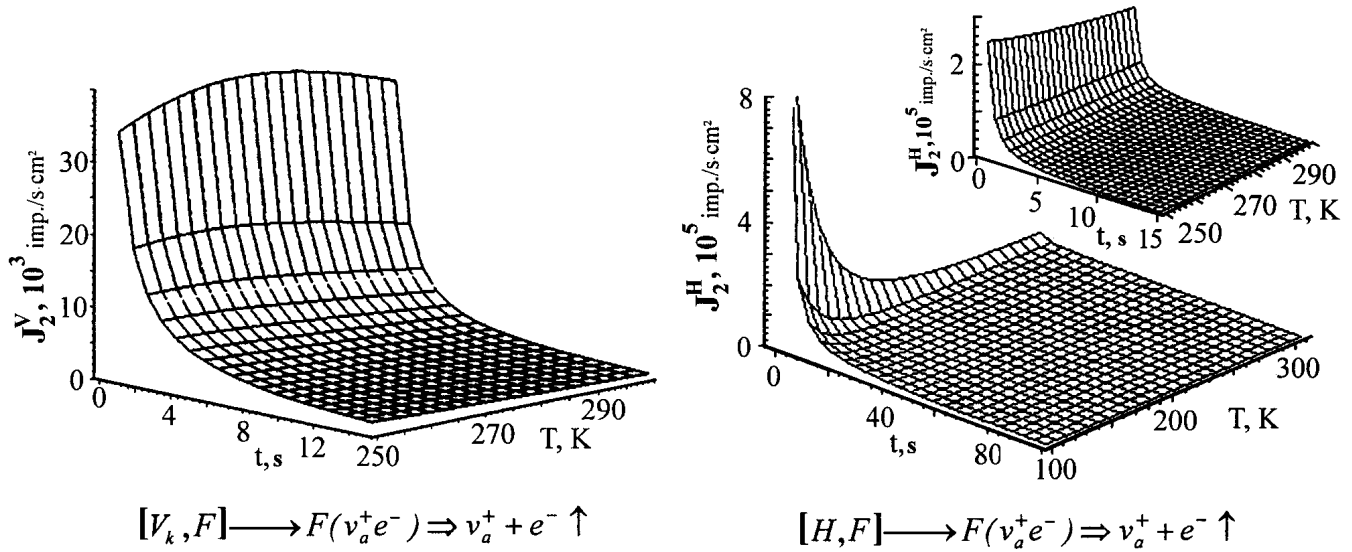$$[H, F] \longrightarrow F(v_a^+ e^-) \Rightarrow v_a^+ + e^- \uparrow$$

Fig. 3. Temperature-dependent components of the isothermal EEE current of a CsBr crystal originated from different kinds of recombinations: J_2^H — from the $[H, F]$ recombinations; J_2^V — from the $[V_k, F]$ ones

Here, e is the electron charge; m — the free electron mass; M_X — the mass of a recombinating pair (132.6×10^{-24} g for a $[H, F]$ pair and 265.2×10^{-24} g for a $[V_k, F]$ one); E_e - the ionization energy of an F center (for CsBr, $E_e = 1.85$ eV); $E_{X,F}$ - the energy, which is released at the recombination of a complementary pair ($E_{H,F} \approx 6$ eV, $E_{V,F} \approx 5.1$ eV); $E_0 = me^4/\hbar^2 = 27.21$ eV; and τ_0^X - the mean lifetime of an $[X, F]$ pair (the time of the autolocalization at the site of a recombination initiator: $\sim 10^{-11}$ s for a $H(i_a^0)$ center and $\sim 10^{-10}$ s for a $V_k(e_s^+)$ center).

Since the probabilities of the F center ionization, $W^X(r)$, are considerably greater than zero only at distances of the order of the lattice constant a (Fig. 2), the quantum yield of exoelectrons from ionized F centers (see Eq. (10)) can be rewritten as

$$Y^X = W^X(a) \pi a^2 n_e. \tag{12}$$

It is worth noting that both the quantum yield and the relaxation EEE current density derived from it substantially depend on the concentration of emission centers which, in turn, depends on the observation time elapsed after the irradiation cessation. Within the temperature region under consideration, the diffusion of electron F centers from a crystal bulk to the exoemission active layer is impossible. For an $H(i_a^0)$ center, the temperature dependence of the diffusion coefficient can be expressed [16] as

$$D_H = 10^{-2} \exp(-0.1/kT), \tag{13}$$

and, at $T = 295$ K, $D_H = 1.96 \times 10^{-4}$ cm$^2 \cdot$s^{-1}. Since, for hole $V_k(e_s^+)$ centers, the activation energy of the hopping migration is sufficiently higher and equals 0.37 eV [17], the coefficient of thermoactivated diffusion of holes equals [17]

$$D_V = 10^{-2} \exp(-0.37/kT), \tag{14}$$

and, at $T = 295$ K, $D_V = 4.83 \times 10^{-9}$ cm$^2 \cdot$s^{-1}, i.e. it is far smaller than D_H.

The results, obtained upon the model calculations of the components $J_2^H(t, T)$ and $J_2^V(t, T)$ (see Eq. (9)) of the density of the isothermal EEE current emitted from a CsBr crystal (Fig. 3), with each component originating from the $[H, F]$ and $[V_k, F]$ recombinations, respectively (see Eqs. (4) and (5)), are conditionally supplementary to each other. Actually, within the near-surface layer, two competing relaxation-recombination processes occur in parallel, and they change the contributions of each other to the general picture of the relaxation decay of the isothermal EEE current. In Fig. 3, we present the results of calculations of the currents for the crystals with the emitting surface area of 1 cm^2.

It is seen from the dependences presented in Fig. 3 that the decay rate of the temperature-dependent component of the isothermal EEE current increases with the temperature of an irradiated CsBr crystal. This agrees with what should be expected, since both the probability and the rate of thermoactivated electron relaxations of the complementary pairs of radiation defects increase with temperature. It should be noted
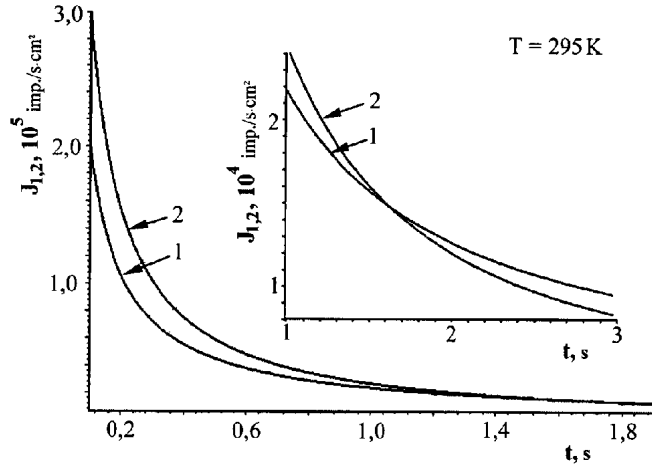
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Fig. 4. Temperature-independent (1) and temperature-dependent (2) components of the isothermal EEE current at small decay times

that the density of the temperature-dependent component of the isothermal EEE current $J_2(t,T)$ should be calculated with regard for the contributions from both types of thermoactivated recombinations, namely $[H,F]$ and $[V_k,F]$.

According to (9), the characteristic decay time of the kinetics of the recombinational isothermal EEE is calculated as

$$t^X = (16\pi n_0^2 R^2 D_X)^{-1}. \qquad (15)$$

For the current components resulted from the thermoactivated $[H,F]$ and $[V_k,F]$ recombinations, the characteristic decay times at $T = 295$ K are $\approx 5 \times 10^{-6}$ s and ≈ 0.2 s, respectively.

1.4.3. Role of the thermoactivated and tunnel electron recombinations of radiation defects in the initiation and quenchering of the EEE current

Consider the contributions of the above types of recombinations for the times comparable with the characteristic decay times. Let us clarify how the value of the temperature-dependent component J_2 correlates with that of the temperature-independent one J_1 at $T = 295$ K in the case where relation (9) is valid, i.e. at small decay times (Fig. 4). As follows from the analysis of the ratio between the values of the components J_2 and J_1 of the isothermal EEE current, the contribution of thermoactivated recombinations is determinative at small decay times ($t \sim 1$ s).
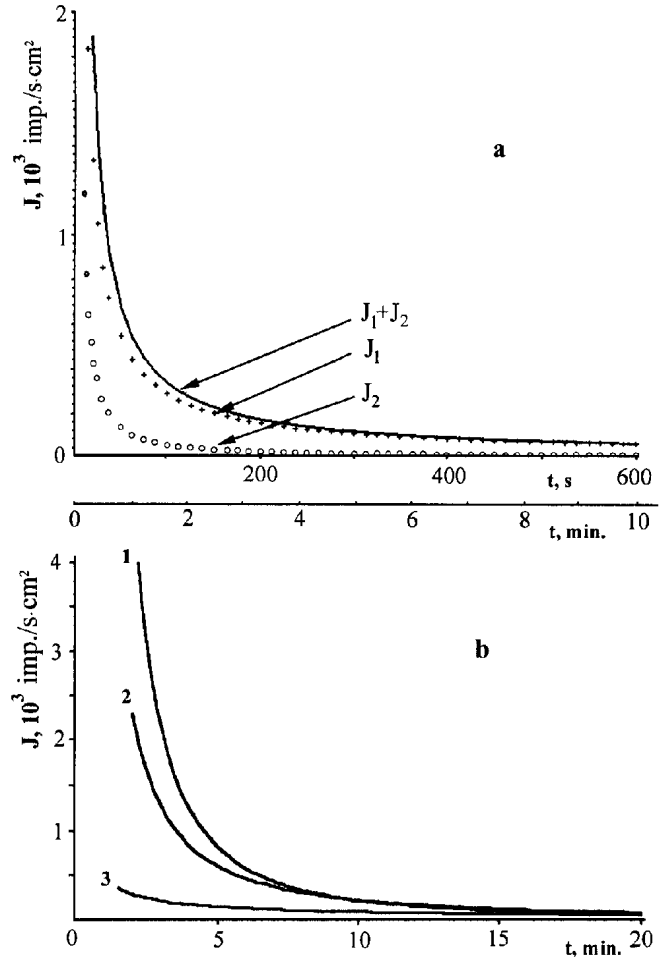

Fig. 5. (a) — Calculated curves of the decay kinetics of the current densities for the isothermal EEE (J), and its components caused by the tunnel (J_1) and thermoactivated (J_2) recombinations of the radiation CC. (b) — Isothermal EEE for a CsBr crystal irradiated at 295 K with various doses of ultraviolet: $1 - 10^3$ Gy; $2 - 1.5 \cdot 10^3$ Gy; $3 - 2 \cdot 10^3$ Gy

By comparing the kinetics of the isothermal EEE decay, calculated theoretically (Fig. 5,a, curves $J_1(t)$, $J_2(t)$, and $J(t) = J_1(t) + J_2(t)$) with that obtained in experiment (Fig. 5,b, curves 1, 2, and 3), it can be concluded that the former and the latter sets of curves are in compliance with each other, both by the order of magnitude and the decay times.

The experimentally obtained curves of the EEE current decay $J(t)$ as a function of the preceding irradiation dose can easily be explained within the frames of the Auger-like recombinational mechanism of the isothermal EEE [6]. In addition to a growth of the concentrations of the recombinating complementary hole and electron CC, and change of their "aggregative state"

in a near-surface layer, an increase in the irradiation dose leads also to a rise in the thickness of the colored layer of the crystal, as a result of a longer radiation-induced shaking of the lattice and the radiation-induced diffusion of CC into the crystal depth. As the dose of the preceding irradiation of the crystal surface increases, the effective activation energy E_a^{eff} of the EEE relaxation processes grows due to the thermal destruction of complex centers, and this reduces the probability of the thermoactivated recombination processes. At the same time, the diffusion depth for interstitials and holes also rises and can reach the value which is greater than the yield depth of exoelectrons. Diffusing from the deeper layers, the recombination initiators e_s^+ and i_a^0 can reach the near-surface layer, and this flow occurring until the gradients of their concentrations disappear will support the intensity of electron-hole recombinations, i.e. the exoemission current, by reducing its velocity and delaying its decay. If the irradiation doses are high enough to form the aggregates and clusters of radiation defects with a radiolysis of the near-surface emitting layer of a crystal and a possible segregation of the metallic component phase [5], the EEE gets suppressed (see Fig. 5b), due to a lack of the elementary recombination partners.

2. Conclusions

We have considered the decay of the isothermal EEE current in the irradiated CsBr crystals by basing on the analysis of contributions from the thermoactivated and tunnel electron relaxations of the complementary pairs of radiation defects. The values of both the temperature-dependent and temperature-independent EEE current components originating from the former and the latter kinds of relaxations, respectively, as well as the characteristic decay times have been calculated. The comparison of the corresponding contributions to the resulting current of the isothermal EEE has been performed. It is shown that, for the decay times comparable with the characteristic ones, the temperature-dependent component of the current is dominant.

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РОЛЬ ТЕРМОАКТИВОВАНИХ ТА ТУНЕЛЬНИХ ЕЛЕКТРОННИХ РЕЛАКСАЦІЙ РАДІАЦІЙНИХ ДЕФЕКТІВ У ВИНИКНЕННІ СТРУМУ ІЗОТЕРМІЧНОЇ ЕКЗОЕМІСІЇ

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Р е з ю м е

Наведено результати дослідження ізотермічної екзоелектрон-ної емісії (ЕЕЕ), зумовленої термоактивованими та тунельними електронними релаксаціями комплементарних пар радіаційних дефектів, утворюваних іонізуючим радіаційним опроміненням, і яка відбувається в процесі опромінення лужно-галоїдних кри-сталів (ЛГК), а також відразу після його припинення, супрово-джуючи релаксацію збудженої поверхні. Розраховано величи-ни температурно-залежної та температурно-незалежної компо-нент струму ізотермічної ЕЕЕ та характеристичні часи їх зага-сання. Проведено порівняння внесків термоактивованих та ту-нельних рекомбінацій у результуючий струм ізотермічної ЕЕЕ та встановлено, що для часів загасання, сумірних з характери-стичними, температурно-залежна компонента струму, зумов-лена термоактивованими релаксаціями комплементарних пар радіаційних дефектів, є переважаючою.