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Kinetic Analysis of Relaxation Electron Emission: Exotic Cases of the Energy Transfer

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The kinetic theories of non-stationary and non-equilibrium Auger-emission, ion-recombination electron emission, emission stimulated by surface electric fields, radical-recombination electron emission and their influence on stationary electron emission that have been developed are capable of explaining most of the important features of the relaxation electron emission. Thus, it is shown, that both Auger luminescence and exoemission have a similar dependence on time and temperature. The rate of emission decay is defined by the depth of the trapping centers, responsible for recombination. Ion-Recombination emission from the opposite side of the sample has time delay and lower maximum intensity, in comparison with that from the side exposed to radiation, as predicted by the theory developed in this study. Tunnel electron ejection is expected for thin insulator films during emission stimulated by the surface electric field. Different types of energy transfer from recombined radicals to electron trapping centers and the role of relaxation process in stationary emission are also discussed.

Keywords: Exoelectron emission, Auger-recombination, radical-recombination, surface electric field, solids.

1. Introduction

The modern definition of Relaxation Electron Emission (REE) or Exoelectron Emission (EE) is the non-equilibrium, non-stationary emission of low energy electrons from the surface of solid during relaxation, after excitation/irradiation of the sample. Some part of the excitation energy is stored inside the solid in the form of ion defects, plasmons, surface level electrons, adsorption layer rearrangements, etc. In dielectrics and semiconductors, energy is stored in the form of electrons/holes trapped in the energy gap. During the process of relaxation, this stored energy can be released not only in the form of EE but also in the form of luminescence, exo-ion emission, etc., while part of the energy is transformed into heat.

In our previous papers [1 – 3], the phenomenological models of classic thermo and photostimulated EE have been developed. These models are capable of explaining all important features of the REE, while electron ejection from the trap and electron emission from the conduction band induced mainly by photons or by thermal energy. Another possible mechanism of electron exit into vacuum is due to Auger-recombination [4, 5].

This mechanism allows us to describe the hole-induced EE. The holes released by optical or thermal stimulation can recombine with electrons trapped in the trapping centers. The energy, released during the recombination, partially emits as thermoluminescence (TL) and partially transfers to the populated electron traps, inducing electron emission into vacuum [6]. Subsequently, electrons emit as a result of Auger recombination. Released electrons can get energy during the Auger process, including ion-vacancy recombination [7].

One of the varieties of this mechanism is the EE process, based on the surface recombination of ions or radicals with the energy transfer to exoelectrons [8].

One other exotic mechanism, in which electrons receive energy, is due to the surface electric field.

There are two cases in this model: (i) the electron escapes the trap and goes to the conduction band due to thermal energy, and electron acceleration from surface electric fields compensates for the energy loss on the penetration depth and on the overcoming electron affinity [9, 10]; (ii) the total energy, beginning with the delocalization of electrons, comes from the surface electric field [11, 12].

In this paper, we provide a mathematical description of the above-mentioned “exotic” mechanisms of REE. This proposed mathematical model is capable of yielding good fits to the experimental data and explain the basic experimental evidence.

2. Auger – Emission

The possible participation of Auger – recombination processes in REE occurs at low temperatures if the electron affinity is high [13]. In this case, the recombination energy of electrons and holes can be transferred (with probability α) to the localized electrons, thus causing electron emission if the following condition is fulfilled (Fig. 1):

$$\left.\begin{array}{ll}\text{for case (a):} & E_G-\varepsilon_m-\varepsilon_1\ge\chi\\ \text{for case (b):} & E_G-\varepsilon_m-\varepsilon_2\ge\chi\end{array}\right\}\qquad(2.1)$$

where: E_G – band gap; ε_m – energy depth of the hole trap (eV); ε_1, ε_2 – energy depths of different electron traps (eV); χ – electron affinity (eV); CB – conduction band; FB – forbidden band; VB – valence band; P_1 – probability of electron ejection from the trapping center (s^{-1}); ν – the hole concentration in the hole traps (cm^{-3}); α – the transfer probability of the recombination energy of electrons and holes to the localized electrons; A_{RE}, A_{RQ}, A_R – the recombination probabilities for the cases of recombination with emission of electron or photon, with quenching and complete recombination correspondingly (s^{-1}). Both

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electron and hole (as in Fig. 1) can be charge carriers. The recombination energy can be transferred to the adjacent trap of the same depth as n_1 (diagram a) or to the deeper trap n_2 (diagram b). The system of equations for this case is:

$$\left.\begin{aligned} &\frac{dn_1}{dt} = -P_1 n_1 \ ; \quad P_1 = P_{10}\, exp(-\varepsilon_1 / kT) \ ; \\ &\frac{dN}{dt} = P_1 n_1 - A_R N \ ; \quad A_R = A_{RQ} + A_{RE} \ ; \\ &\frac{d\nu}{dt} = -A_{RE} N \ ; \end{aligned}\right\} \tag{2.2}$$

Here: t – time (s); T – temperature (K); n_1 – electron concentration in traps (cm^{-3}); N – electron concentration in CB (cm^{-3}) .

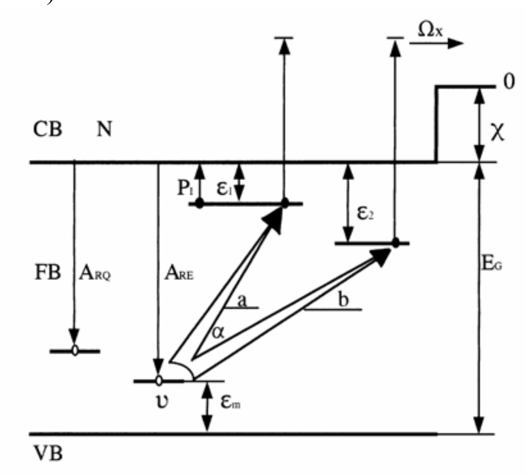

Fig. 1. Energy level diagram for Auger-emission mechanism

If we solve (2.2) using quasi-stationary approximation (QSA, that means: $\frac{dN}{dt} = 0$, i.e., electron concentration in the CB is constant), assuming that T is independent of time, we get:

$$\left.\begin{aligned} &n_1 = n_{10}\, exp(-P_1 t) \ ; \quad N = \frac{P_1 n_1}{A_R} \ ; \\ &-\frac{d\nu}{dt} = \frac{A_{RE} P_1 n_1}{A_R} = \frac{A_{RE}}{A_R} P_1 n_{10}\, exp(-P_1 t) ; \end{aligned}\right\} \tag{2.3}$$

From this, the luminescence intensity (I_L) and the exoemission intensity (I) can be derived, assuming $\alpha =$ constant:

$$\begin{aligned} I_L &= -B_q (1-\alpha)\frac{d\nu}{dt} = B_q (1-\alpha)\frac{A_{RE}}{A_R} P_1 n_{10}\, exp(-P_1 t) = \\ &= I_{LO}\, exp(-P_1 t) \end{aligned} \tag{2.4}$$

where B_q is the quantum yield regarding losses in the luminescence center. For exoemission, the number of electrons emitted from cm^2 per sec from a layer at a depth (x, $x + dx$) i.e. the emission intensity from this layer is:

$$\begin{aligned} I_x &= -\alpha \frac{d\nu}{dt} \Omega_x dx = \\ &= \alpha P_1 n_{10}\, exp(-P_1 t) \Omega_0 dx D \frac{A_{RE}}{A_R} \ , \end{aligned} \tag{2.5a}$$

where $\Omega_x = \Omega_0 D g_x$ – probability of hot electron emission which depends on the distance between the electron and the surface (x); Ω_0 – dimension coefficient (s^{-1}); D – average transparency of the surface barrier for hot electrons.

By integrating this equation, while assuming that $\Omega_0 = 1$ [3], the afteremission intensity is given by:

$$\begin{aligned} I &= f(\lambda) D \alpha P_1 n_{10}\, exp(-P_1 t) \frac{A_{RE}}{A_R} = \\ &= I_0\, exp(-P_1 t) \end{aligned} \tag{2.5b}$$

where: $f(\lambda) = [1 - exp(-l/\lambda)]$; l – the entire excited layer; λ – the effective depth of emission layer [3].

For the constant heating rate β, in analogy with TL and TSEE [1], we get:

$$\begin{aligned} I_L &= (1-\alpha) P_{10} n_{10}\, exp\left\{ -\frac{\varepsilon_1}{kT_1} - \right. \\ &\left. - \frac{P_{10}}{\beta} \int_{T_0}^{T} exp(-\varepsilon_1 / kT) dT \right\} \frac{A_{RE}}{A_R} B_q \ ; \end{aligned} \tag{2.6}$$

$$\begin{aligned} I &= f(\lambda) D \alpha P_{10} n_{10} \cdot \\ &\cdot exp\left\{ -\frac{\varepsilon_1}{kT_1} - \frac{P_{10}}{\beta} \int exp(-\varepsilon_1 / kT) dT \right\} \frac{A_{RE}}{A_R} \ . \end{aligned} \tag{2.7}$$

Thus, both luminescence and exoemission have a similar dependence on time and temperature [14]. The rate of emission decay is defined by the depth of the traps, the emptying of which leads to recombination.

Emission of electrons in Auger-emission can also be caused by hole release, that is why such REE is sometimes called “hole-induced”. It was, for example, observed in alkali halide crystals at liquid nitrogen temperature [15].

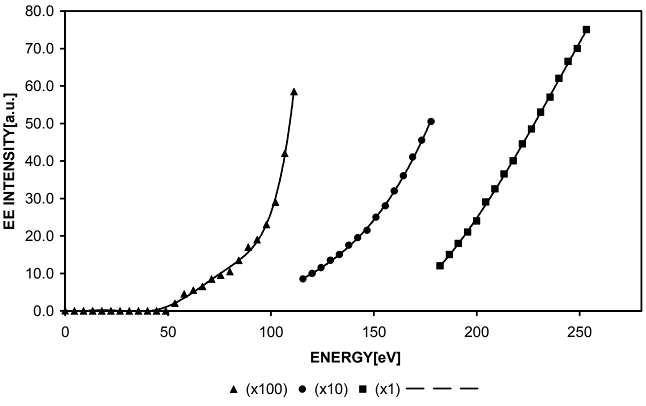

Fig. 2. The TSEE intensity dependence (sum for two peaks at 353 and 443 K) of MgO on exciting electron energy

According to formulae (2.4 – 2.7) the emission intensity is proportional to α and A_{RE}. A_{RE} is proportional to the recombination cross-section which increases as the energy depth of the recombination center (ε_m) decreases. Contrary to the above, α increases with the increase in the depth of the trap to which energy is transmitted. Thus, the highest probability of Auger-emission is caused by “shallow” recombination centers and “deep” transmission centers, as is shown in Fig. 1b. According to [16], it can be estimated that the Auger-emission intensity is:

$$I \sim \left(\frac{R_0}{R} \right)^6 \ . \tag{2.8}$$

As it is in dipole-dipole transmission, where: R_0 – const. and R is the distance between centers.

Such dependence on R can serve as a criterion for the Auger-mechanism of emission. R can be changed by changing the concentration of the activator, which creates centers, by changing the excitation density or the energy of exciting particles. The example of such supralinear dependence of TSEE in MgO on exciting electron energy is shown in Fig. 2. The TSEE at 353 and 443 K, being due to the Auger-type mechanism [6], shows a sharp supralinear (expected for Auger mechanism) increase, as exciting electron energy is changed from 50 to 300 eV. The TSEE of MgO is not found at all at electron energies less than 50 eV.

The effective transmission distance is larger than in the case of resonance transmission ($R \approx 3 - 4$ nm). For wide-band dielectrics, however, Auger-emission can be observed only for small R, i.e. in the case of the creation of associated pairs of shallow and deep traps, and, of course, at low temperatures, when shallow traps are not thermally ionized.

3. Ion-Recombination REE

This type of emission includes cases of electron release from the trap with energy sufficient for emission in the course of ion defect annihilation.

a) Annihilation of complementary defects, one of which is an electron trap [7]. Since the emission repeats itself after each excitation, annihilating defects must be in an equilibrium state at the experimental temperature, or regenerated under excitation. Therefore, these are Frenkel defects. These are usually considered to be F-centers and interstitial anions. The reaction can be described in the following way:

$$V_A e^- + I_A \rightarrow L + e^- , \qquad (3.1)$$

where V_A, I_A – anion vacancy and interstitial anion, $V_A\ e^-$ – anion vacancy, captured electron, L – undisturbed lattice, e^- – electron. Formally, we can use the same system of equations as we used for non-stationary thermostimulated exoemission [1], only now P will stand for the probability of defect pair annihilation:

$$P = P_0\, exp\left(-\omega / kT\right) , \qquad (3.2)$$

where ω is diffusion activation energy, and P depends on the diffusion coefficient and on the complementary defect concentration. The energy (g) released by annihilation is equal to the energy spent on pair creation. A necessary condition for emission is that:

$$g \geq \varepsilon + \chi . \qquad (3.3)$$

Conditions (3.2) and (3.3) are not easily met. Thus, for NaCl $\omega \approx 1.7$ eV and $g_F \approx 2.9$ eV (activation energy for anion diffusion and Frenkel pair creation). So this mechanism of REE can occur only at quite a high experimental temperature, or with additional photo-stimulation.

b) Annihilation of defects which trap electrons on the surface [17, 18]. These are usually vacancies, which trap electrons (i.e. F-centers) and were created at depth l by neutron radiation. If the annihilation energy is not enough for emission, photo-stimulation is used. The emission intensity is given by $I = \gamma i(0,\ t)$, where γ is a coefficient which takes into account the probability of electron exit into the vacuum in the cases of annihilation, diffusion and photo-stimulation (if any) while $I(0,\ t)$ represents the density of the defect flux through the surface. If we solve the diffusion equation:

$$\frac{dm}{dt} = D\frac{d^2 m}{dx^2} \qquad (3.4)$$

under the initial condition:

$$m(x,0) = \begin{cases} m_0, \text{ at } l-h \leq x \leq l+h \\ 0, \text{ at } x<l-h \text{ and } x>l+h \end{cases} \qquad (3.5)$$

i.e. at “rectangular” depth distribution of defects; $m(0,t) = 0$, we obtain:

$$I = \gamma m_0 \sqrt{\frac{D}{\pi t}} \left\{ exp\left[-\frac{(l-h)^2}{4Dt} \right] - exp\left[-\frac{(l+h)^2}{4Dt} \right] \right\} \qquad (3.6)$$

where m_0 is the initial defect concentration at depth l; l – the depth of defects from the emitter surface (cm); D – defects diffusion coefficient (cm^2 s^{-1}).

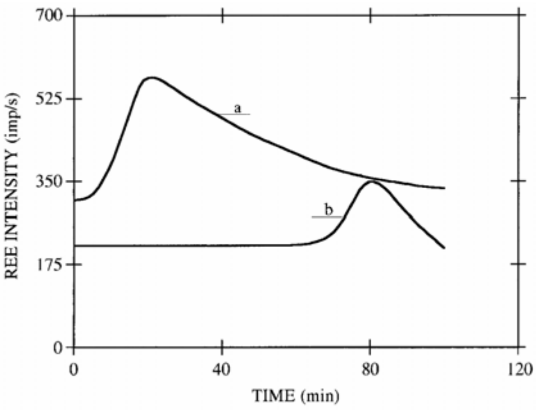

Fig. 3. Typical time dependence of ion-recombination REE for annihilation of surface defects which trap electrons: (a) from the side exposed to radiation; (b) from the opposite side of the sample (after Akselrod et al.[18])

The emission intensity reaches a maximum very quickly for small l and high T, because defects diffusion increases with the temperature. Emission can be observed from both sides of the sample, i.e., side exposed to radiation and from opposite side of the sample. A typical dependence of $I(t)$, is presented in Fig. 3 [18]. As it may be predicted from (3.6), the emission intensity from the opposite side of the sample reaches its maximum later than that from the side exposed to radiation, because of longer diffusion length. This maximum intensity (from the opposite side) is lower than that from the exposed side, due to the energy dissipation during the diffusion.

4. Emission Stimulated by the Surface Barrier Electric Field

It is known that excitation causes surface charging [10, 19]. The maximum surface potential, (V_s), is defined by the emitted electron energy and is usually not higher than (5 – 15) V. Electrons which are situated at depth x and move without collisions, can get the following energy within the field:

$$\omega_x = eV_s \frac{x}{d} = eEx \tag{4.1}$$

where d is the emitter thickness; e is the charge of electron and E is the magnitude of the electric field. Emitters will have "electron acceleration" during cathode excitation if the secondary emission coefficient is $\sigma > 1$. But in this case, due to the uneven depth distribution of the volume charge (primary electrons are captured mostly at the depth of l while secondary electrons are ejected from a depth of the order of magnitude λ) an additional pulling electric field is created in layer l. Such a complicated pattern can be calculated only by using numerical simulation and only in certain cases [20]. But if we assume that the electric field is constant in the course of REE, the emission intensity can be estimated. In this case, the system of kinetic equations is:

$$\begin{cases} \dfrac{dn}{dt} = -Pn \\ \dfrac{dN}{dt} = Pn - (A_R + \Omega)N \end{cases} ; \tag{4.2}$$

$$I_x = N\Omega_x dx = N\Omega_E D g_x dx , \tag{4.3}$$

where:

$$\Omega_E = S\, exp\left(-\frac{\lambda'_\chi}{\lambda'}\right) = \frac{\sqrt{2}}{\sqrt{m\chi}} eE\, exp\left(-\frac{\chi}{eE\lambda'}\right) \tag{4.4}$$

n – electron concentration in traps (cm^{-3}); N – electron concentration in CB (cm^{-3}); Ω_E – the probability for an electron in the conduction band to get energy χ; λ'_χ is the path, on which the electron gets energy χ in field E; V – velocity of such an electron; $S = V/\lambda'_\chi$ is the inverse time of electron path traversal; m – effective electron mass.

1) If electron ejection from the trap is thermal, then: $P \to P_T = P_0\, exp(-\varepsilon/kT)$, and from (4.2 – 4.3) in analogy with [3], we get:

$$I = f(\lambda) D n_0 \frac{P_0 \Omega_E}{A_R} exp(-P_T t) = I_0\, exp(-P_T t) \tag{4.5}$$

– for the afteremission intensity, and:

$$I = f(\lambda) D n_0 \frac{P_0 \Omega_E}{A_R} exp\left\{-\frac{\varepsilon}{kt} - \frac{P_0}{\beta}\int_{T_0}^{T} exp(-\varepsilon/kT)dT\right\} \tag{4.6}$$

– for the TSEE intensity.

2) The probability of tunnel electron ejection from the trap is given by:

$$P_E \approx \frac{eEr}{2\pi\hbar} exp\left\{-\frac{\pi\varepsilon^{3/2}\sqrt{2m}}{4eE\hbar}\right\} , \tag{4.7}$$

where r is the trap radius.

Introducing P_E into (4.5) instead of P_T, we will get the intensity of afteremission. Estimation (at ε = 1 eV, T = 300 K) shows that tunnel ejection can compete with thermal ejection at $E \approx 10^6$ V/cm. We can, therefore, expect tunnel ejection for thin insulator films (oxides on metals), where it is possible to get high E together with small ε at low temperature. Interaction between traps and lattice oscillations introduces a thermal dependence of the type $P_0\, exp(-a/kT)$ into the probability of tunneling, which leads to TSEE in the course of heating. The estimation of the coefficients P_0 and a requires numerical simulation for particular systems.

5. Radical-Recombination REE

If a metal or a dielectric has an adsorbed layer, excitation can initiate radical creation (in the course of molecular dissociation) or unstable molecule creation (in the course of the association of atoms and simple molecules). After excitation, both at constant temperature and under heating, the onset of relaxation is accompanied by the release of the stored energy. Part of this energy can be spent on EE. Molecular dissociation is a monomolecular process, so formally REE kinetics will not differ from the description of non-stationary thermostimulated EE from the surface centers [1]. Let us now consider REE initiated by radical recombination. We will use the model of an ideal adsorbed layer (lattice gas without interaction between the particles outside the recombination radius; the diffusion coefficient is taken into account in the reaction rate). This model works well when the surface density of radicals is low [21]:

$$\theta << 1 ; \tag{5.1}$$

$$\frac{d\theta}{dt} = -a\theta^2 . \tag{5.2}$$

From this we derive:

$$\theta = \frac{\theta_0}{1 + a\theta_0 t} \quad \text{(at } T = \text{const.)} \tag{5.3}$$

and

$$i = -\frac{d\theta}{dt} = a\theta^2 = \frac{a\theta_0^2}{(1 + a\theta_0 t)^2} \tag{5.4}$$

is the number of recombinations (s^{-1}cm^{-2}). Here θ_0 is initial surface density of complementary radicals (A and B).

$$\theta_{A0} = \theta_{B0} = \theta_0 \text{ and } a = a_0\, exp(-q/kT) \tag{5.5}$$

– is the reaction rate.

For an exothermal reaction, the thermal dependence can be connected to the diffusion coefficient. In the case of a constant heating rate, introducing (5.5) into (5.2) and integrating between T_0 and T, we get:

$$\theta = \theta_0 \left[1 + \frac{a_0\theta_0}{\beta}\int_{T_0}^{T} exp(-q/kT)dT\right] \tag{5.6}$$

and

$$i = -\frac{d\theta}{dt} = a\theta^2 = \frac{\theta_0 a_0\, exp(-q/kT)}{\left[1 + \dfrac{a_0\theta_0}{\beta}\displaystyle\int_{T_0}^{T} exp(-q/kT)dT\right]^2} . \tag{5.7}$$

The amount of energy released in the course of radical recombination can be quite large. For example, H –H, OH, O – O and N – N recombination yields 4.48, 4.77, 5.12 and 9.76 eV respectively.

a) If this energy is transferred to electrons inside the adsorbed layer [8, 22, 23] theobserved REE depends slightly on the type of basic material. The emission intensity will be:

$$I = \eta i; \quad 0 < \eta < 1 \tag{5.8}$$

where η is the emission coefficient.

b) The recombination energy can be transferred to electrons trapped in the subsurface layer of the basic materiel [8, 24]. Then;

$$I = D\gamma i \tag{5.9}$$

where γ is the transmission coefficient; $\gamma \sim r^{-k}$, where $k = 6 - 10$, depending on the type of interaction between the centers. If one of the radicals is associated with the trap in the basic material, then γ = const. Otherwise, γ is a function of the trap and radical concentration.

If the adsorbed layer is removed in high vacuum, i.e., both the radicals and electron trapping centers are removed; emission of type (a) vanishes. Type (b) emission can vanish at a given temperature by removing of adsorbed layer and leaving subsurface layer, i.e., radicals removing only, but will renew itself under photo-stimulation or at a higher temperature, sufficient for direct thermal electron emission from the trap**,** because electron trapping centers are situated in the subsurface layer.

c) If some of the adsorbed particles create spots with low χ (singular points) [1 – 3], radical recombination can cause singular points "poisoning", i.e., radical recombination leads to increasing of χ in singular point, and REE weakening. The opposite is also possible, i.e., radical recombination can cause the creation of singular points and REE intensification. The removal of the adsorption layer will lead to the same consequences as in case (b), i.e., on the one hand, to disappearance of radical recombination emission, but, on the other hand, to the creation of thermo or photostimulated emission from subsurface electron trapping centers.

6. Discussion. Relaxation Processes: Their Influence on Stationary Emission

Relaxation processes influence stationary emission not only in the form of emission decay, but cause an initial increase of emission, temperature dependence of emission intensity, etc. Usually, these effects are not substantial, since the relative concentration of electron traps is not large. However, they can become quite noticeable, for example, if the probability of electron emission from the traps is a great deal higher than that from the valence band of the dielectric (or semiconductor). This can be observed in secondary electron emission. It is possible to create conditions in photoemission when these two probabilities are equal. Electrons move from the valence band into the conduction band by photon illumination:

$$E_G < h\nu < E_G + \chi \tag{6.1}$$

and from there are emitted thermally (Ω_T), or by long wavelength illumination (Ω_ν), or by an accelerating electric field (Ω_E). This process can be described:

$$\begin{cases} \dfrac{dN}{dt} = KJ + Pn - \left(A_C + A_R + \Omega\right)N \\ \dfrac{dn}{dt} = -Pn + A_C N \end{cases}; \tag{6.2}$$

$$I_x = N\Omega_x dx; \quad I = f(\lambda) D N \Omega . \tag{6.3}$$

Here A_c is the probability of electron capture by the second centers [2]; J is the excitation intensity and K is the absorption coefficient. The solution of (6.2), using QSA is:

$$N = \frac{KJ}{A_c + A_R + \Omega}\left\{1 + \frac{A_c}{A_R + \Omega}\left[1 - \exp\left(-\frac{A_R + \Omega}{A_c + A_R + \Omega} Pt\right)\right]\right\} \tag{6.4}$$

$$N = \frac{KJ\Omega}{A_c + A_R + \Omega}\left\{1 + \frac{A_c}{A_R + \Omega}\left[1 - \exp\left(-\frac{A_R + \Omega}{A_c + A_R + \Omega} Pt\right)\right]\right\} f(\lambda) D \tag{6.5}$$

For extreme cases:

a) $Pt = 0 \rightarrow I_0 = \Omega f(\lambda) D \dfrac{KJ}{A_c + A_R + \Omega}$ (6.5a)

At low temperature and weak excitation the emission intensity and the trapped electron concentration will increase linearly with time. However, this intensity will seem constant during the time of measurement. Such a state can be called "quasi-stationary emission":

b) $Pt \rightarrow \infty \quad \rightarrow I_\infty = \Omega f(\lambda) D \dfrac{KJ}{A_R + \Omega}$ (6.5b)

and

$$\frac{I_\infty}{I_0} \equiv \frac{A_c + A_R + \Omega}{A_R + \Omega} = 1 + \frac{A_c}{A_R + \Omega} \tag{6.6}$$

This means that the stationary emission intensity increases with time (initial emission increase) and with temperature (since $P = P_0 \exp(-\varepsilon/kT)$). The temperature dependence of the emission intensity reaches a maximum if the mean free path of the electron depends on temperature (electron-phonon scattering). If the electron emission from the conduction band is thermal, Ω also depends on temperature ($\Omega = \Omega_0 \exp(-\chi/kT)$), and $I(T)$ acquires a complicated form.

At low temperature, it is convenient to use illumination ($\chi < h\nu < \varepsilon$) or an electric field for electron ejection from the conduction band into the vacuum.

This effect is greater for materials which have the following characteristics: $A_c >> A_R$, high absorption coefficient (thin excited layer) and long electron mean free path (thick layer of electrons stored in traps). All these will enhance the ratio A_c/Ω; while Ω can be reduced, using (at low temperature) weak illumination or an electric field. Similar considerations are useful for other types of emitter irradiation.

7. Conclusions

The theories developed in this work allow the mathematical formalism and physical concepts to explain:

i) the dependence of luminescence and exoelectron emission intensity on time and temperature, as well as influence of the depth of the trapping centers on the rate of emission decay during Auger-recombination.

ii) the dependence of emission, excited by ion-recombination processes, on the defect depths from the emitter surface and diffusion coefficient.

iii) the competition between tunnel and thermal electron ejection during exoemission.

iv) the influence of the removal of the adsorption layer on exoelectron emission, stimulated by recombination of radicals, in three different cases: electron trapping centers are situated in adsorbed layer, electron trapping centers are situated in the subsurface layer; and in the case of creation of spots with low electron affinity in the adsorbed layer.

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