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DYNAMICS OF STREAMER DISCHARGE DEVELOPMENT IN SEMICONDUCTORS

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Space-time dynamics of streamer discharges in semiconductors in view of processes of shock (tunnel and photo-) ionization, radiating spontaneous and stimulated recombination as well as electron-photon interaction in a strong electric field has been modeled. The possibility of formation in these conditions of space-nonuniform dissipative structures, self-oscillatory regular and other modes were shown; their laws and interrelation with dynamics of streamer laser discharge were established. Nonmonotonic dependence of system characteristics on key parameters – excitation rate, life time of nonequilibrium carriers and photons, quantum efficiency of active environment as well as strengthening of structure interaction in conditions of stimulated recombination causing variety of own system dynamics were revealed. Radiating processes provide high speed of structure distribution compared with phase speed of light, and they are the basic generation mechanism of nonequilibrium carriers generation in self-oscillatory mode respective to optimum conditions of streamer occurrence and development.

1. Introduction

Electric («streamer») discharges in semiconductors – is comparatively new phenomenon and it is not studied yet being of great scientific and practical interest [1–4], in particular, for developing new generation of semiconductor lasers and modern elemental base of optoacoustic-electronics and informatics on the basis of using direct bandgap materials with large width of forbidden zone.

Earlier [2, 3] the idea of streamer self-organization was suggested and qualitatively substantiated. According to this idea the process of discharge development supposes variety of phenomena of interaction between nonequilibrium discharge carriers, photons, phonons, electric field etc. including formation of spatially inhomogeneous dissipative structures (DS) and assignment of self-oscillations (SO) in such complex system. These modes, as it is known, are the most important behavioral terms (self-organization) of nonlinear system [5]. Taking into account the complexity of the studied phenomena the numerical simulation of proper processes becomes actual.

SO mode possibility follows from the data of our preliminary investigations [4, 6] and was observed as well in independent researches of other authors [7] in respect to the conditions of tunnel generation mechanism of nonequilibrium carriers and nonradiative spontaneous recombination. However, space-time picture of streamer development and a part of radiative recombination including stimulated one are not studied in this process. These questions represent significant interest as an accepted point of view to laser medium as to nonlinear dissipative system capable of showing complex proper dynamic from various regular (self-oscillations) to chaotic regimes and make a subject of investigations of the given paper. Hopefully, detection of various dynamic modes allows expanding regions of applying streamer lasers as well as using them as model experimental and theoretical object for studying dynamics of other nonlinear systems including optical ones.

2. Physical premises of constructing model

According to the said above the interaction in crystal of electrons, photons and strong electric field forming three-component system to a first approximation is taken as a principle of the studied model. In this case the equation system describing the generation process of charge carriers at leading edge of discharge channel and motion of strong field region in space has the following form [1]:

$$\partial n/\partial t=(1/e)\mathrm{div}\,\boldsymbol{j}_e+\alpha_e\upsilon_e n+\alpha_p\upsilon_p p+W-n/\tau_e, \quad (1)$$

$$\partial p/\partial t=-(1/e)\mathrm{div}\,\boldsymbol{j}_p+\alpha_e\upsilon_e n+\alpha_p\upsilon_p p+W-p/\tau_p, \quad (2)$$

$$\mathrm{div}\mathbf{E}=4\pi e(p-n)/\varepsilon, \quad (3)$$

$$\boldsymbol{j}_e=en\mu_e\mathbf{E}+e\nabla(nD_e),\ \boldsymbol{j}_p=ep\mu_p\mathbf{E}-e\nabla(pD_p). \quad (4)$$

Here (1), (2) are the kinetic equations (t – time) for concentration of nonequilibrium carriers of charge n and p (respectively electrons and holes) taking into account the generation process of electron-hole pairs, field drift and spontaneous radiative recombination; (3) is the Poisson equation for electric field voltage $\mathbf{E}$ in a crystal; W is the rate of electron-hole pair formation due to tunnel effect and (or) photoionization; α_e, α_p are the coefficients (probability) of impact ionization, υ_e, υ_p are the absolute values of drift rates, $\alpha_i=a/E\exp(-b/E^2)$ is the probability of proper process for electrons (holes), $a\approx3{,}55\hbar\omega_0/e\ell^2$ and $b\approx2{,}4E_i\hbar\omega_0/(e\ell)^2$ are the material constants, ℓ is the length of carrier free path, $\hbar\omega_0$ is the energy of optical phonons, E_i is the ionization energy; $j_e(j_p)$ is the current density, $\mu_e(\mu_p)$ and $D_e(D_p)$ are the mobility and coefficients of carrier diffusion; $\tau_e(\tau_p)$ and τ_f are the lifetime of conduction electrons (holes) and photons respectively.

In the studied high energy-gap semiconductors, for example, CdS, current density of holes is rather lower than for electrons ($\mu_e/\mu_p\sim10$ at 77 and 300 K) therefore, hole current in existing models of streamer discharge as a fast phenomenon is neglected [1, 4, 7]. Besides, let us assume a series of approximations used, in particular, for describing the process of nonequilibrium carrier propagation in avalanche diodes in balance equations for electrons and holes and the Poisson equation exami-

ned at electric breakdown. So, in crystal small region (inside of streamer channel with radius of $r=r_0$) single-axis approximation is possible in respect to distribution of nonequilibrium carriers of current and electric field, the carrier diffusion is neglected and their drift rate saturation is taken into account that is it is supposed $\upsilon_d=\upsilon_0=$const. The original system of equations (1)–(4) for the case of impact ionization subject to stimulated radiative recombination may be written down as

$$\partial n/\partial t=\alpha_e\upsilon_e n+\upsilon_0\partial n/\partial x-n/\tau-\eta(n-n_{\text{inv}})n_f, \quad (5)$$

$$\partial n_f/\partial t=-n_f/\tau_f+\eta(n-n_{\text{inv}})n_f, \quad (6)$$

$$\partial/\partial t\ \text{div}\mathbf{E}=\partial/\partial t\ \text{div}\mathbf{E}'-1/\tau_{\text{м}}\ \text{div}\mathbf{E}, \quad (7)$$

in which photon density is denoted by n_f and density of volume charge plasma is understood by concentration of nonequilibrium electrons n as current is mainly of electron character. So (5) is the kinetic equation for concentration of nonequilibrium electrons n (virtually plasma density), (6) is the kinetic equation for photon density n_f [8]. The second plasma component p (positive charges) or the condition of crystal electrical neutrality is taken into account in the equation (7) for voltage of total electric field in crystal $\mathbf{E}$ [9] used instead of (3). In this case $\mathbf{E}'$ is the component of voltage of the applied «external» field, τ and τ_f are the lifetimes of conduction electrons and photons respectively, η is the specific gain coefficient, n_{inv} is the concentration at inversion threshold, $\tau_{\text{м}}$ is the Maxwell relaxation time. Radiation intensity is supposed to be proportional to photon density, $I=c\hbar\omega n_f/N$ (N is the index of medium refraction).

Coefficient $k=\eta(n-n_{\text{inv}})$ describes in linear approximation the rate of photon emission [8]. Concentration at inversion threshold corresponds to absence of absorption (amplification). Increasing excitation level and transferring from absorption to amplification that is through the inversion threshold the sign of a last member in the equation for carrier concentration (5) changes from negative to positive one. As a result, the sign of nonlinear component of refraction index stipulated, in particular, by cubic susceptibility changes and self-defocusing is changed by self-focusing [8].

In conditions $\mu_p<<\mu_n$ «Maxwell» relaxation time is presented in the following way:

$$\tau_{\text{м}}=\varepsilon_0\varepsilon_2/e(\mu_e n+\mu_p p)\approx\varepsilon_0\varepsilon_2/e\mu_e n=C_0/n, \quad (8)$$

where $C_0=\varepsilon_0\varepsilon_2/e\mu_e$, ε_0 is the electric constant, ε_2 is the inductive capacity of a crystal. To simplify the calculations the ratio (7) may be used in the form

$$\partial E/\partial t=A\text{-}En/C_1+C_1,\ A=\partial E'/\partial t,\ C_1=E_0\,n_0/C_0-A_0. \quad (9)$$

Electron drift velocity $\upsilon_e\approx\mu_e E/(1+\mu_e E/\upsilon_0)\to\upsilon_0\approx10^7$ cm/s is saturated at $E\sim10^4$ V/cm and in the region of strong fields interesting for us (impact ionization threshold corresponds to $E\geq10^5$ V/cm) is supposed to be constant, $\upsilon_e=\upsilon_0$, similarly to existing ideas [1].

3. Self-oscillations in conditions of spontaneous recombination

Let us firstly study the conditions of appearing self-oscillation modes in the simplest case – for «two-component» system of electrons and field in conditions of spontaneous recombination (equation system (5) and (7)). Let the external field $\mathbf{E}'$ be supplied to the crystal by needle electrode with rounded radius $R=r_0$ (electrode touches the crystal, origin of coordinates x is on its surface) and be approximated for simplicity by linear dependence on time in one-dimensional case [4]:

$$\mathbf{E}'=Bt/(R+x)^2, \quad (10)$$

where $B=2RU_0/(\varepsilon\tau_1)$; U_0 is the amplitude, τ_1 is the duration of excitation pulse front or the constant of continuous voltage build-up; $\varepsilon=(\varepsilon_1+\varepsilon_2)/\varepsilon_1$, ε_1 is the environment inductive capacity, ε_2 is the crystal inductive capacity. This implies

$$A=\partial E'/\partial t=B/(R+x)^2,\ A_0=A|_{x=0}=B/R^2=2U_0/(\varepsilon\tau_1 R). \quad (11)$$

Parameter A represents a velocity of external field voltage growth or rate of excitation pulse rise. The used approximation is conformed to the data [4] according to which form of voltage pulse i. e. electric field plays a sidetrack in comparison with steepness (growth rate) of leading edge of a pulse at streamer charge excitation. Besides, optimal discharge gap electrode -crystal in dielectric environment supporting intensification of excitation pulse edge is required for streamer appearance. Therefore, optimal steepness of this front is required. The results of the examined system analysis for the cases of spontaneous and induced recombination given below result in the same conclusion. It follows from the expression (10) that value A depends to a certain extent on the form (characteristics) of discharge gap through the parameter R (at condition $x<R$) however in our case it is supposed to be constant.

For different tasks original and boundary conditions: $t=0$, $n=n_0$, $n_f=n_{f0}$, $E=E_0$, $x=0$, $\partial\text{E}/\partial t=0$, $A=\partial E'/\partial t=A_0$; non-dimensional quantities: n/n_1, n_f/n_1, n_{inv}/n_1, E/E_1, t/t_1, T/τ_0, τ/τ_0, τ_f/τ_0, x/x_1, R/x_1, υ_e/υ_0, A_0/A_1, C_1/A_1; initial data $n_0=0...10^2$, $n_{f0}=10^{-18}...10^2$, $E_0=10^{-6}...10^2$; normalization parameters $n_1=10^{18}$ cm^{-3}, $E_1=10^6$ V/cm, $t_1=10^{-13}$ s, $\tau_0=10^{-12}$ s, $x_1=10^{-4}$ cm, $A_1=10^{18}$ V/(cm·s) and typical values of physical magnitudes for high energy-gap semiconductors: $\varepsilon_1=2$, $\varepsilon_2=10$, $\upsilon_e=10^5...10^7$ cm/s, $\mu_e=300$ cm^2/(V·s), $\mu_p=50$ cm^2/(V·s), $\tau=10^{-9}...10^{-11}$ s, $\tau_f=10^{-12}$ s, $R=10^{-4}$ cm, $U_0=10^4...10^5$ B, $\tau_1=10^{-8}...10^{-10}$ s, $\eta=10^{-5}...10^{-8}$ cm^3/s, $E_i=3$ eV, $\hbar\omega_0=30$ meV, $\ell=5\cdot10^{-7}$ cm (CdS, 300 K) were used in this paper. Here T is the period of self-oscillations (pulsations) of the studied system.

The system of equations (5), (7) was numerically analyzed by the program «Mathematics 4» (by Runge-Kutta method etc.) at $B=1$ (1...5), $C_0=1.84$, $C_1=1$ (0,1...2) ranges of parameter variation are given in brackets. The solution of proper task is obtained in parametric form $E(n)$ in wide time range – up to several nanoseconds (Fig. 1, *a*). The influence of lifetime of nonequilibrium carriers and external field growth rate on solutions was studied.

Increasing the rate in the range $A=0{,}001...0{,}6$ at $\tau=10$, or lifetime in the range $\tau=10...500$ at $A=0{,}5$ the transfer from periodic mode or the mode of weak decaying oscillations (pulsations) of field and carrier concentration to periodic mode accompanied at first by growth

of concentration stationary value to $n \approx 2$ (A=0,5, τ=10) and then its slump is observed. This fact may be explained by assignment of general synchronous frequency in self-oscillation system that is typical for two-component system [5]. Then it is shown that for three-component system (the case of induced recombination) the situation is a bit more complex and there is nonmonotonic dependence of solutions on steepness of external field edge that coordinates as well with known ideas. Increasing lifetime τ from 10 to 500 and A=0,001 the oscillation period T grows in the range 73...280 K, at growth of edge steepness to A=0,1 decreases (T=7,5) and in the process of damped oscillations changes continuously. In the range A<0,001, τ<10 there are no solutions.

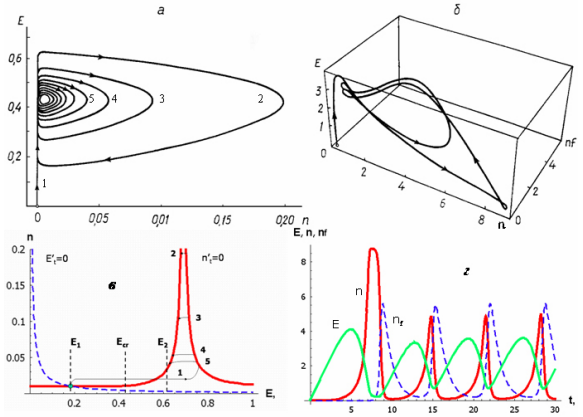

Fig. 1. *Self-oscillations of electron-photon system in conditions of spontaneous (а, в) and simulated (б, г) recombination. Characteristics of the system (в) and time dependence of the field, plasma density and photons (г). $A=10^{23}$ (а, в), B=1 (б); τ=10 (а, в), $n_{inv}=10^{22}$; $t \to 3 \cdot 10^4$ (а), $2 \cdot 10^3$ (б); C_1= 0; τ_f=1 (б); η=1; $n_0=10^{210}$ (а, в), 10^{23} (б); $n_{f0}=10^{23}$ (б); $E_0=10^{26}$ (а, в), 10^{22} (б). It is presented in dimensionless form.*

For qualitative description of mechanism of occurrence of self-oscillations in this system its characteristics (zero isoclines E and n) and assumed scheme of solutions (cycles) implementation are given in Fig. 1, *в*. It is seen that at the initial stage at each next cycle the characteristics are restructured (dashed curve) owing to the change of original conditions and then their position sets and periodic oscillations occur in the system. Self-oscillation mechanism in such «two-component» system is analytically studied in the work [7] in respect to tunnel effect conditions. According to these data self-oscillations are connected to occurrence of negative dynamic differential conductivity (NDDC) in multiplication region (on frequency ~10^{12} Hz) stipulated by delay of tunnel process at saturation of charge carrier drift velocity. As the similar phenomenon of breakdown delay or weak transit-time effects accompanying by NDDC occurrence and self-oscillation (self-excitation) at avalanche frequency is known in conditions of impact ionization [13] then it may be considered as one of the reasons of examined phenomenon in our case.

4. Self-oscillation processes with stimulated recombination and dissipative structure formation

The analysis of solutions of equation system (5)–(7) for the case of stimulated recombination depending on parameters of task A, n_{inv}, η, τ_f etc. is given in parametric form $E(n,n_f)$ (Fig. 1, *б*), as a time function $E(t,0)$, $n(t,0)$, $n_f(t,0)$ (Fig. 1, *г*) and in the form of space-time dependences $E(t,x)$, $n(t,x)$, $n_f(t,x)$ at different conditions (Fig. 2–4). In particular, the picture of development of electron-photon interaction in strong electric field in small region of strong crystal field near electrode ($x \sim r_0 = R$) or at rising edge of this process (discharge) is shown in Fig. 2, therefore the formed field region is as an electrode continuation in a crystal.

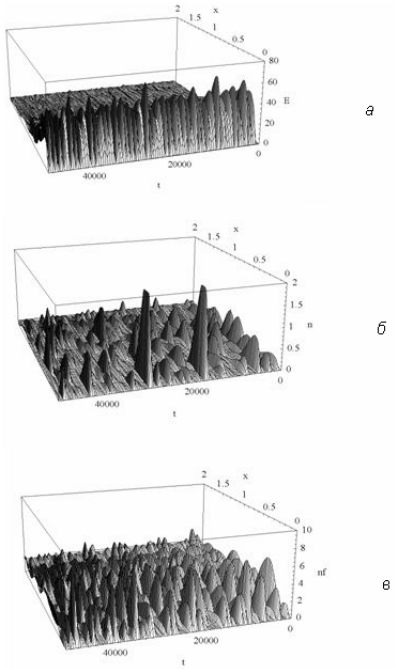

Fig. 2. *Space-time dynamics of: а) electric field, б) plasma density, в) photons and formation of regular modes and dissipative structures in the range of strong field front. =2, $n_{inv}=10^{-2}$, $t \to 50000$, $x \to 2$, τ_f=0.08, η=1; n_0=0, $n_{f0}=10^{-5}$, $E_0=10^{-2}$, C_1=0, $C_0 \equiv C_0/2$, υ_0=−0,001*

Similar processes in larger scale of changing spatial value up to crystal size ~1 cm (in this case small-scale coordinate structure is not spatially resolved except closely spaced descending part) are shown in Fig. 3.

It follows from the given time dependences $E(t,0)$, $n(t,0)$, $n_f(t,0)$ (Fig. 1, *г*) that plasma and photon density in the mode of regular or quasi-periodical oscillations in conditions of saturation of charge carrier drift velocity lag in time from electric field development (impact ionization process) almost by a half of period. It indicates, by analogy with two-component system, NDDC occurrence as one of possible reasons of self-oscillation formation. Stationary periodical oscillations (the mode of regular pulsations) of electric field, nonequilibrium carrier concentra-

tion and photon density in the examined system occur at $nn_{inv} \cong 0{,}01$, $\eta \cong 1$, $A=1...10$, $\tau_f \cong 1$ (Fig. 1, *б*). In this case carrier concentration and photon density achieve maximal values $n=5...30$, $n_f=3...10$ (Fig. 1, *г*) and system sensitivity to the value of specific gain coefficient η correlates with one of the main conditions of streamer excitation – the necessity of a certain quantum efficiency of the medium [2, 3]. The analysis of solutions indicates the existence of optimum depending on photon lifetime.

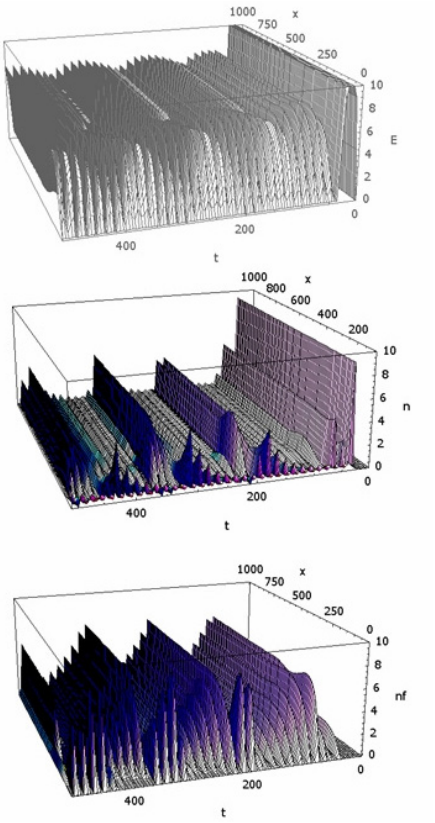

Fig. 3. *Formation of self-oscillation modes of electron-photon system at significant distances from excitation region (of electrode): а) E(t,x), б) n(t,x), в) $n_f(t,x)$. B=1, $n_{inv}=10^{-2}$, $t \to 500$, $x \to 10000$, $\tau_f=0.08$, $\eta=1$; $n_0=0$, $n_{f0}=10^{-5}$, $E_0=10^{-2}$, $C_1=0{,}95$, $\upsilon_0=0{,}3$*

Variation of initial conditions in wide range does not influence the parameters of steady oscillations (except the initial phase). Presence of spatial inhomogeneity of solutions (Fig. 2–4) indicates the formation of dissipative structures, for example in the form of future pulse or edge [5]. Domain formation in analogy with generating structures on the basis of Gunn effect should be noted among the other possible reasons of self-oscillation occurrence [3].

Dependence of solutions on the rate of rise of external field is of nonmonotonic character and rate oscillations (V) of DS move take place. Typical size of inhomogeneity region of about 1 mkm is close to parameters of streamer channel (longitudinal size is kept in mind as the charge channel is strongly inhomogeneous along the axis and represents quasi-periodical sequence of flashing dots and dashes with the length of 1...30 mkm and longer [1]) and duration of light pulse of 3...5 ps meets its radiative properties. Estimation of maximal values of rate of motion results in values $V_{max} \geq 5 \cdot 10^9$ cm/s (Fig. 4, *г*) in accordance with data for discharges, pulsations of streamer propagation rate are experimentally revealed as well [10]. At a first approximation the specified size of channel longitudinal inhomogeneity (~30 mkm) divided into average rate of structure propagation (~10^9 cm/s) corresponds to light pulse duration of some picoseconds.

The rate of dissipative structure motion may be estimated as well by analogy with the idea of streamer rising edge motion [1]. In this case the rate of transfer of density profile (gradient) of nonequilibrium carrier concentration is understood under DS rate:

$$V=(\partial n/\partial t)/(\partial n/\partial x), \qquad (12)$$

which exceeds significantly electron drift rate. Really, substituting into (5) the value of time derivative estimation in the region of electric field maximal strength (firstly without recombination members) and using estimation of spatial derivative in this region by the data of cited literature in the form of $\partial n/\partial x \approx n_s/r_0$, we have

$$V \approx \upsilon_0 + \upsilon_0 \alpha_0 r_0 = \upsilon_0 (1 + \alpha_0 r_0). \qquad (13)$$

In conditions of intensive multiplication of nonequilibrium carriers at impact ionization the condition $\alpha_0 r_0 \sim 10$ is fulfilled whence $V >> \upsilon_0$. Taking into account the stimulated processes ($n > n_{inv}$) maximal value of rate V increases additionally in comparison with $\upsilon_0 \sim 10^7$ cm/s by an order of magnitude (it is supposed $n_f^s \sim 10^{19}$ cm^{-3}, $\eta \sim 10^{-6}$ cm^3/s):

$$V \approx \upsilon_0 + \eta n_f^s r_0 = \upsilon_0 (1 + \eta n_f^s r_0 / \upsilon_0) \sim 10^2 \upsilon_0. \qquad (14)$$

The analysis of experimental data by the conditions of streamer discharge excitation [1, 4] and comparison with the data of calculation given above show that optimal conditions of streamer occurrence are developed in periodical oscillation mode in nonlinear system. In this case self-oscillations may be examined as one of sources of intensive microwave radiation contributing significantly into charge development by the data of [11]. Self-oscillation mode or the mode of regular pulsations stipulates short duration of generated current pulses (~10^{-11} s and shorter) and so decreases (excludes) the part of crystal lattice heating in streamer formation. This mode explains as well the intermittent structure of discharge channel [1].

In case of induced recombination (light generation) structure interaction is amplified. Their development characterized by transfer from chaos to SO and DS (Fig. 2–4) recalls a streamer formation process. In the range of ideas of external action influence on DS behavior [5] the effect of streamer optical quenching is explained [2–4, 6]. In this case illumination weak influence at the final stage of discharge formation with dissipative structure properties is forecasted.

The analysis of experimental laws of streamer discharge interaction in semiconductors in various conditions [1–4, 6] allows concluding that at high levels of excitation streamers behave as dissipative structures and at average levels – like structures in nonlinear conservative medium (solitons) that is combine the properties of both structures. In this regard one can say about higher degree of self-organization of streamer discharges in comparison with the examined structures.

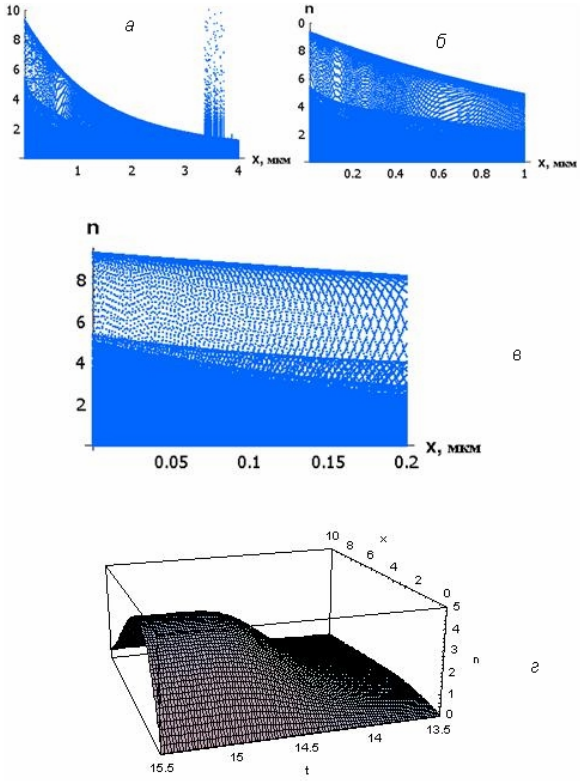

Fig. 4. *Chaos and structures in electron-photon system (а–в). Estimation of structure development rate (г). B=5, $n_{inv}=10^{-2}$, $t\to200$, $x\to50$, $\tau_f=1$, $\eta=1$; $n_0=0$, $n_{f0}=10^{-5}$, $E_0=10^{-2}$, $C_1=0$, $C_0\equiv C_0/2$, $\upsilon_0=0{,}001$; $V\approx\Delta x/\Delta t=5\cdot10^{-4}/10^{-13}=5\cdot10^{9}$ см/с, $\Delta n=5\cdot10^{18}$ см$^{-3}$ (г)*

Really, the main difference of these structures is in the fact that solitons recover their shape and propagation velocity after collision while structures of traveling edge (pulse) type cancel out when meeting or one of them absorbs another one and becomes stronger. The rate and shape of traveling edge do not depend on initial conditions in wide range of changing while in the case of soliton these edge characteristics are determined by initial perturbations. Streamer discharge velocity may be varied approximately in the range of two orders changing amplitude of field excitation pulses (~10^7...10^9 cm/s) that stresses, on the one side, their soliton nature and, on the other side, the traveling wave mode inherent to dissipative structures may be set at achievement of phase velocity of light. Streamers behave like DS meeting in conditions of average excitation levels. It should be noted that continuation of streamer propagation during some time after stress removal interpreted as display of discharge soliton properties is revealed in gaseous medium [12]. A similar phenomenon has not observed before in solids but it may be predicted in the range of the developed idea.

5. Efficiency of different generation mechanisms of nonequilibrium carriers in self-oscillation mode

To compare contribution of different multiplication mechanisms of nonequilibrium carriers into formation of self-oscillation modes the solution of electron-photon system in the conditions of tunnel effect, impact- and photoionization were studied.

The analysis of solutions subject to spontaneous and induced recombination in the case of tunnel effect ($W_i=A_{\nu}N_{\nu}E^{10/3}\exp(-E_c/E)$, where $A_{\nu}\approx10^{-7}$ s^{-1}(V/см)$^{-10/3}$, $E_c=7{,}4\cdot10^7$ V/cm, $N_{\nu}=2\cdot10^{22}$ cm^{-3} (CdS, 80 K) show that in equal conditions steepness of edge of excitation pulse, recombination rate etc. – the achieved concentration of nonequilibrium carriers in self-oscillation mode is about an order lower than at impact ionization and fields required for obtaining equal concentration are rather higher. To be sure in the fact that different approximations for probability of impact ionization result in the same result the calculations are performed as well for another approximation often used in literature $\alpha(z)=\alpha_0\exp\{-(E_i/E_0)/[(z-r_0)/r_0]\}$, where $\alpha_0=a_1/\ell\exp[-(E_i/E_0)]$, $E_i=a_2\in_i/e\ell$, $a_1=0{,}6$, $a_2=0{,}3$. The main laws of the process of electron-photon interaction in strong electric fields revealed by the example of impact ionization such as self-oscillating character, existence of optimum in a number of parameters etc. are retained as well in the case of tunnel effect.

If photoionization is the mechanism of generation of nonequilibrium carriers ($W_f(z)=(kI_0/\hbar\omega)\exp(-kz)$, $k\sim10^2$ cm^{-1} – the efficient absorption coefficient of charge carrier bremsstrahlung quantum in hot electron-hole plasma $I_0\sim10^9$ W/cm^2 – its intensity) then calculation gives at optimal alternative the values of carrier concentration and photon density close to corresponding data for impact ionization and slightly exceeding them in 1,5...2,0 times. Therefore, in self-oscillating mode the efficiency of radiative processes as a generation mechanism of nonequilibrium charge carriers dominates over the tunnel effect efficiency in comparison with stationary model for which the invert correlation is typical [1].

6. Conclusion

In the system simulating the dynamics of streamer charge development in semiconductors with nonequilibrium charge carriers, photons and strong electric field the wide range of dynamic modes – from chaos to different self-oscillation modes and spatial-inhomogeneous dissipative structures as elements of self-organization display are formed. The comparison of efficiency of probable generation mechanisms of nonequilibrium carriers indicates the dominant contribution of radiative process in these conditions. This process is responsible for the rate of formation and propagation of dissipative structures compared with phase light speed in the medium. Self-oscillation and DS modes beside high rate of propagation explain a number of other important physical properties of streamer discharge in semiconductors – space-time structure, initiation conditions, external action influence and nondestructive character of discharge being one of its important practical properties.

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RELAXATION PARAMETERS OF ABSORPTION LINES OF VIBRATIONALLY EXCITED HF MOLECULE

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The design model allowing obtaining authentic values of half-width and shift of line centers of HF molecule of hot and cold strips to dissociation limit has been developed. Calculation results of rotary and oscillatory dependences of relaxation parameters of lines HF-HF were obtained.

1. Introduction

One of the main problems of modern theoretical spectroscopy is the investigation of high molecule vibration state. Reliable values of parameters of molecule absorption lines in gaseous phase are necessary for applications in photochemistry of atmosphere, laser physics developing data bases of spectroscopic information. Here the new model founded on the variant of Korf-Levit-Cherkasov impact broadening theory, energy levels and wave functions of Morse oscillator, computed *ab initio* or semi-empirical functions of multipole moments and polarization of diatomic molecule is given. The proposed model allows studying the influence of intramolecular dynamics of diatomic molecules in conditions of strong vibration excitation on half-width and shift of absorption lines. To check model reliability the half-widths and shifts of line centers of high hot and cold bands of HF molecule were calculated in the article.

Half-widths and shifts of line centers of HF molecule were measured before up to v=2 [1–4]. At the present there are no experimental values of half-width and shifts of line centers formed by transition to higher vibration states of HF molecule. Good fit of half-width and shift of line centers of HF-HF calculated in the paper with measuring results [1–4] confirms as well the reliability of proposed model.

In [5, 6] the results of analysis of dependence of relaxation parameters of line R_0 of diatomic molecules on various factors of intramolecular dynamics are given: change of rotational constant, dipole, quadrupole moments, polarizability. It is shown that significant changes of broadening and shift coefficients depending on intramolecular dynamics are observed for lines of high vibration-rotational (VR) bands of molecules CO HF and. At strong vibration excitation the adiabatic effect connected with energy level shift at collisions should appear as well in half-widths. As it is shown in [7] this effect increases half-widths of H_2O lines in bands conditioned by valence vibration excitation. On the contrary, in H_2O molecule the decrease of half-width of lines in the bands of nv_2 type conditioned by significant rise of rotational constant and anomalous centrifugal effect at excitation of bending vibration is observed [8].