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NONLINEAR-OPTICAL PROPERTIES OF SEMICONDUCTORS IN TERMS OF STREAMER DISCHARGE

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Nonlinear optical phenomena at streamer discharge in hexagonal and cubic semiconductors have been simulated. The possibility of light self-trapping in these conditions was shown.

Discovery of streamer discharge in semiconductors accompanied by intensive laser effect (1973. [1]), has stimulated, on the one hand, further development of breakdown and pre-breakdown physics of solids in strong fields and, on the other hand, contributed to appearance of new scientific branches – physics of semiconductors streamer discharge and streamer laser physics. At present one of the trends in semiconductor physics and engineering is design of future-technology transistors, integrated microcircuits (optoelectronic systems IC) and new elemental base of opto-acousto-electronics on the basis of direct-zone materials with wide range of band gap. The role of emissive, including nonlinear, optical processes is great, therefore, the questions on phenomena in strong electric fields and interaction of optical and electric fields are actual. In this connection it seems to be necessary to investigate the corresponding processes at streamer discharge in wide-gap semiconductors, which is explained by original properties and sophistication of the phenomenon, possibility to obtain new information on substance structure and prospects for wide practical application.

Peak value of light field intensity in the channel of streamer discharge amounts ~10^9...10^{11} W/sm^2 and is sufficient for different nonlinear optical effects in semiconductors, radiation self-trapping mode, in particular [2]. However, under these conditions, including media with cubic (n_2) and of the fifth order (n_4) nonlinearities, n_2, n_4 coefficients and other parameters of the problem involved – wavefront radius, size and character of initial beam (two- or three-dimensional case), are not known in details, therefore, numerical simulation of the process is required. Threshold, energy and spatial properties of the effect are analysed below depending on nonlinearities and other parameters for hexagonal and cubic semiconductors, the conditions of optimal autochannelling are considered.

In wide-gap compounds of A_2B_6 type (hexagonal CdS, CdSe and cubic CdTe) the effects of self-influence have complex nature depending on pulse duration, method of excitation (one-photon, two-photon) and other factors, appearing in process concurrence of self-focusing and self-defocusing [3, 4]. In this case n_2+n_4 ($n_2>0$, $n_4<0$) nonlinearity combined effect is realised. For the mentioned media the theory of self-channelling of intensive light beams has been developed [2], its results are used in the present work.

Analysis of existent data on light self-influence indicates the necessity of numerical simulation for self-channelling radiation effect in discharge conditions at varying nonlinearity coefficients in the range $n_2\sim10^{-9}...10^{-8}$ units CGSE, $n_4\sim-(10^{-14}...10^{-12})$ units CGSE. The effect criteria including diffraction, self-focusing and self-defocusing of light can be written in the following way:

$$(2|n_2E^2+n_4E^4|/n_o)^{1/2}=1{,}22\lambda/(Dn_o), \qquad (1)$$

where D is the initial beam diameter, λ is the wavelength in vacuum, E is the amplitude of electric field intensity of light wave, n_o is the linear factor of medium refraction. The relevant (1) radiation power is equal to

$$P_{cr1-4}=|cD/(64n_4)\{[(n_on_2D)^2\pm2\cdot1{,}22^2n_on_4\lambda^2]^{1/2}\pm n_on_2D\}|. \qquad (2)$$

Analysis of possible values of P_{cr} according to (2) shows that minimal effect threshold P_{cr1} corresponds to the «–» sign in both dyads of the last expression. Similarly, denote the power corresponding to the sign «+» in dyads by P_{cr2}, P_{cr3} is denoted by the signs «+,–» and P_{cr4} is denoted by the signs «–, +». In particular, for cadmium sulphide monocrystals in the edge region of band-gap absorption ($n_2=1{,}2\cdot10^{-9}$ un. CGSE, $n_4=-1{,}4\cdot10^{-12}$ un. CGSE [3]) at $D=1$ mm we have $P_{cr1}\approx150$, $P_{cr2}\approx1830$, $P_{cr3}\approx180$ and $P_{cr4}\approx2160$ W. Luminescence intensity of the streamer doing along the channel is $P\sim10$ kW [5], therefore, at streamer discharge the condition of light self-channelling by the effect threshold $P_s>P_{cr}$ is met with significant reserve.

According to theoretical [6, 7] and experimental data [8] the process of radiation self-trapping results in plasma displacement of nonequilibrium carrier out of the light channel, i. e. the region of strong electric field, hence – in decrease of current value to lower than the destruction threshold. It is consistent with the absence of destructions in the channel of semiconductor streamer discharge [1] and could be one of the reasons for its non-destructive character.

Let us estimate the sizes of self-constricted beam in the medium under study, where the channel radius R oscillates and depends on beam size [2]. Analysis of dependence $R(P_{cr})$ taking into account the criterion (1) and experimental data for nonlinearity coefficient at light excitation [3] indicates the presence of two characteristic minimums (branches) of this dependence (Fig. 1), moreover, for P_{cr1} criterion the branches are lower than for P_{cr2}.

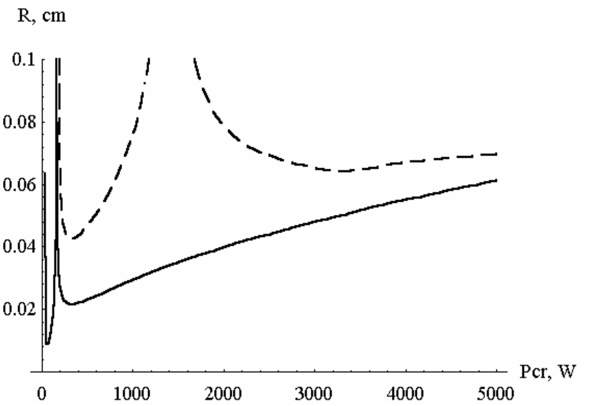

Fig. 1. *Spatial-energetic characteristics of light self-channelling effect for the criteria: 1)* P_{cr1} *and 2)* P_{cr2}. $n_2=1,2\cdot10^{-9}$ *un. CGSE,* $n_4=-1,4\cdot10^{-12}$ *un. CGSE, b=1*

The branch in the region P_{cr}=200...300 W for the case P_{cr1} is least influences by parameters of wave surface (b), in this connection it is of great interest from the point of view of numerical modeling. Here b is the proportional coefficient depending on $R_f^2=bR_0^2/|Q|$, where $Q=n_2E^2/n_0-(kR_0)^{-2}$, R_f is the curvature radius of wave surface, k is the wavenumber, $R_0=D/2$ is the radius of initial beam. The increase in factor of nonlinearity n_2 within the limits of the order in comparison with the known data for crystals CdS results in reduction of threshold power and the cross-section sizes of the light channel up to the values corresponding to parameters of streamer $P_{cr}\leq$10...30 W, $R\leq$10 microns (Fig. 2). Similar changes take place with decrease in n_4 coefficient from ~10^{-12} to 10^{-14} un. CGSE.

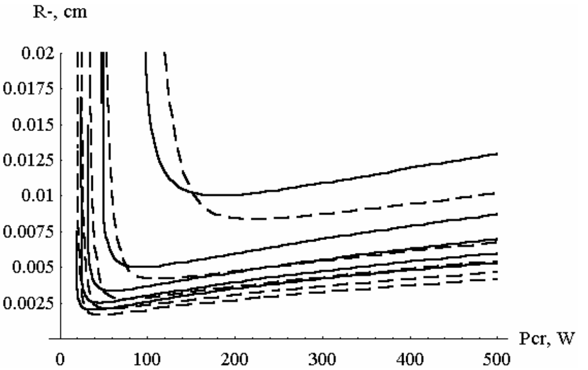

Fig. 2. *Dependence of light channel radius on threshold intensity at varying nonlinearity coefficients for spherical (full line curve) and cylindrical (dash line curve) beams: 1)* $n_2=2\cdot10^{-9}$, *2)* $4\cdot10^{-9}$, *3)* $6\cdot10^{-9}$, *4)* $8\cdot10^{-9}$, *5)* 10^{-8} *un. CGSE;* $n_4=?10^{-12}$ *un. CGSE*

By the example of cadmium sulphide crystals we calculate anisotropy of nonlinear susceptibility of the fifth order $\chi^{(5)}$, defining threshold and spatial properties of light self-channelling. Behaviour of the system in strong electric field can be simulated by using incompletely symmetrical sixth-rank tensor of $[[\mathbf{V}^2]^3]$ type [9] or $[\mathbf{V}^2][[\mathbf{V}^2]^2]$ [10] – by analogy with tensor of electrooptic effect (this tensor is known to be asymmetrical). Let us study the former case; the results of simulation taking into account the second tensor are similar. Spatial distribution $\chi^{(5)}$, corresponding to convolution of the given tensor in the plane of crystal () type is determined by the relation

$$\chi^{(5)}{}_{(1\bar{0}10)}=\chi_{111}\sin^6\Theta+\chi_{333}\cos^6\Theta+3(\chi_{113}+4\chi_{155})\sin^4\Theta\cos^2\Theta+$$
$$+3(\chi_{133}+4\chi_{355})\sin^2\Theta\cos^4\Theta. \qquad (3)$$

In approximation $\chi_{133}\approx\chi_{355}\approx\chi_{333}$; $\chi_{133}\approx\chi_{155}$~$0,1\chi_{333}$ the relation (3) gives three directions, symmetrical relative to 210> ($\theta=\pi/2$), which are different from the discharge directions on the average by ±(2...5)°. In the basal plane (0001) angular distribution $\chi^{(5)}$ has the view

$$\chi^{(5)}{}_{(0001)}=16(\chi_{111}-\chi_{222})\cos^6\varphi+24(\chi_{222}-\chi_{111})\cos^4\varphi+$$
$$9(\chi_{111}-\chi_{222})\cos^2\varphi+\chi_{222} \qquad (4)$$

And gives the local maximums in the direction of $1\bar{0}10$> type in rather a wide range $+\infty>\chi_{111}>\chi_{222}$. Analysis of both relations (3) and (4) shows that spatial anisotropy of nonlinear susceptibility under consideration, and hence, self-channeling effect corresponds approximately to streamer orientation (with the pointed out accuracy). This indicates that given effect conditions not only crystallographic orientation, but also threadlike form of streamer discharge.

Similar calculations for cubic semiconductors (of $\bar{4}3m$ symmetry) using the forth-rank tensors, for example $[\mathbf{V}^2]^2$ or $\mathbf{V}[\mathbf{V}^3]$, result in localization of distribution maximums of nonlinear susceptibility in <110> directions, corresponding to streamer orientation in CdTe, GaAs and InP crystals with accuracy of some degrees.

It should be noted that in experimentally stated spatial picture (direction system) of streamer discharges, in hexagonal semiconductors, in particular [1, 11, 12] there are no basic symmetry elements of 6*mm* type, except for prismatic planes, where they are localized; asymmetry of the picture observed is apparent (in the range 0,5...1°) relatively to the axis of the sixth order. This indicates the changes (distortions) in crystal symmetry as well as the fact that in the given conditions there appear the two families of discharges simultaneously – positively and negatively directed ones (of heteropoles) according to the statements [13]. In cubic semiconductors there are also distortions of lattice symmetry appearing in incomplete coincidence of discharge path with the directions [110]. In this connection spatial orientation of streamers reflects point group of not only initial, i. e. undisturbed crystal (the familiar Neumann principle and Hermann theorem) but also the result of field interaction with the medium and corresponds to the general principle of the Curie's symmetry superposition – dissymmetry addition principle. Therefore, application of «non-destructive» streamer discharges is a sophisticated and in some cases unique tool for investigation of electric, nonlinear-optic, crystallographic and a number of other properties of solids in strong fields.

Thus, the effect of light self-influence in self-trapping condition (wave-guide mode) at streamer discharge in media with cubic and the fifth order of nonlinearities has been considered. In the course of self-consistent problem the threshold and spatial properties of light self-channelling for hexagonal and cubic semiconductors have been estimated. These data are close to corresponding characteristics of streamer tracks. Nonlinear interaction of discharge radiation with semiconductor in waveguide mode results in threadlike form of streamer and decreases (removes) fractures of crystal lattice. Symmetry for crystallographic direction system of streamer discharges in wide-gap semiconductors corresponds to the general principle of symmetry superposition.

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INFLUENCE OF GENERATION MECHANISMS ON PULSE PROFILE OF MECHANICAL STRESS IN METAL TAGET UNDER THE ACTION OF POWER ION BEAMS

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The system model «High power ion beam – metal» is suggested. Regularities of impulse formation of mechanical load in the volume of metal target subjected to the action of ion beams of different component composition in the range of power density $10^7...10^{10}$ W/sm² have been considered. The influence of generation mechanisms on the profile and amplitude-to-time parameters of shock-wave excitation is studied.

Introduction

Modern systems of pulse beam generation of charged particles permit of production of concentrated energy flux in the wide range of intensities $W=10^5...10^{13}$ W/sm^2, at pulse duration $10^{-8}...10^{-6}$ sec. Such a wide range of energy impact defines the excitation within the target volume of different physical phenomena and, consequently, the variety of resultant effects developed both at separate processes and their superposition. These processes could be used for solution of a great number of scientific and theoretical problems.

Intermediate power density range $10^7...10^{10}$ W/sm^2 is characterised by large quantity of excited processes (high-velocity heating, phase transitions, plasma formation, ablation, generation of acoustic and shock waves and others), parallel occurrence of which determines technological possibilities for application of high power ion beams (HPIB). Micro- and nanosecond duration of action and nonlinearity relative to the radiation conditions makes hard-to-reach for investigation of fast phase transformation experimentally. Existing experimental studies [1] give integral picture of «HPIB – metal» system and, consequently, are directed at final result of action. In general, detailed research in dynamics of real physical system is possible only in the course of numerical experiment.

A number of investigations [1–5] are devoted to the questions of shock-wave excitement generation in metals under the HPIB influence [1–5]. In the range of intensities $10^7...10^{10}$ W/sm^2 in «HPIB – metal» system the thermoelastic and shot loading mechanisms occur simultan-